Aziridine used as a vinylidene unit in palladium-catalyzed [2+2+1] domino annulation

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Electronic Supplementary Information

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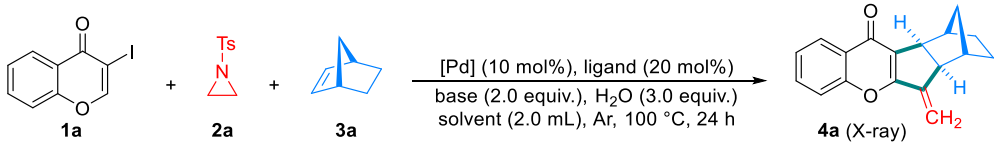
1. General experimental information

Unless otherwise noted, all commercially available reagents were used without further purification. All of the solvents were treated according to known methods. Column chromatography was performed on silica gel (200-400 mesh). ^{1}H NMR (400 MHz) chemical shifts were reported in ppm (δ) relative to tetramethylsilane (TMS) with the solvent resonance employed as the internal standard. ^{13}C NMR (100 MHz) chemical shifts were reported in ppm (δ) from tetramethylsilane (TMS) with the solvent resonance as the internal standard. ^{19}F NMR (376 MHz) chemical shifts were reported in ppm (δ) ($CFCl_3$ as an outside standard and low field is positive). Data were reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, td = triplet of doublets, tt = triplet of triplets, ddd = doublet of doublet of doublets, dt = doublet of triplets, dq = doublet of quartets, brs = broad singlet, sext = sextet, m = multiplet), coupling constants (Hz) and integration. HRMS measurements were obtained on a TOF analyzer. Melting points were uncorrected.

3-Iodochromones (**1**) was prepared according to the reported procedures.[1] *N*-Ts-aziridine (**2a**) was purchased from commercial suppliers. **2b**−**2h** were prepared according to the reported procedures.[2] Bridged olefins **3a**−**3c** were purchased from commercial suppliers. Bridged olefins **3d**−**3f** were prepared according to the reported procedures.[3,4]

2. Optimization of the reaction conditions for the construction of 4a[a]



Entry	[Pd]	Ligand	Base	Solvent	Yield (%)[b]
1	$Pd(OAc)_2$	**L1**	Cs_2CO_3	PhMe	24
2	$Pd(TFA)_2$	**L1**	Cs_2CO_3	PhMe	13
3	$Pd(OPiv)_2$	**L1**	Cs_2CO_3	PhMe	6
4	$PdCl_2$	**L1**	Cs_2CO_3	PhMe	trace
5	$PdBr_2$	**L1**	Cs_2CO_3	PhMe	14
6	PdI_2	**L1**	Cs_2CO_3	PhMe	10
7	$PdCl_2(nbd)$	**L1**	Cs_2CO_3	PhMe	16
8	$PdCl_2(PPh_3)_2$	**L1**	Cs_2CO_3	PhMe	trace
9	$PdCl_2(dppb)$	**L1**	Cs_2CO_3	PhMe	trace
10	$PdCl_2(dppe)$	**L1**	Cs_2CO_3	PhMe	trace
11	$PdCl_2(dippp)$	**L1**	Cs_2CO_3	PhMe	trace
12	$Pd(dppf)Cl_2$	**L1**	Cs_2CO_3	PhMe	trace
13	$Pd(dppf)Cl_2 \cdot DCM$	**L1**	Cs_2CO_3	PhMe	trace
14	$[(cinnamyl)PdCl]_2$	**L1**	Cs_2CO_3	PhMe	31
15	$Pd(Phos)Cl_2$	**L1**	Cs_2CO_3	PhMe	14
16	$[(SIPr)PdCl_2]_2$	**L1**	Cs_2CO_3	PhMe	7

17	$PdCl_2(CH_3CN)_2$	**L1**	Cs_2CO_3	PhMe	13
18	$PdCl_2(CH_3CN)_4(BF_4)_2$	**L1**	Cs_2CO_3	PhMe	11
19	$(PCy_3)_2PdCl_2$	**L1**	Cs_2CO_3	PhMe	trace
20	[(NHC)Pd(allyl)Cl]	**L1**	Cs_2CO_3	PhMe	trace
21	$Pd(OTf)_2$(dippp)	**L1**	Cs_2CO_3	PhMe	8
22	$[(C_4H_7)PdCl]_2$	**L1**	Cs_2CO_3	PhMe	28
23	$[Pd(allyl)Cl]_2$	**L1**	Cs_2CO_3	PhMe	45
24	$[Pd(\mu\text{-}Br)^tBu_3P]_2$	**L1**	Cs_2CO_3	PhMe	10
25	dichlorobis(1-methylallyl)dipalladium	**L1**	Cs_2CO_3	PhMe	28
26	di-mu-chlorobis{2-[(dimethylamino)methyl]phenyl}dipalladium	**L1**	Cs_2CO_3	PhMe	17
27	dichlorobis(triethylphosphine)palladium	**L1**	Cs_2CO_3	PhMe	13
28	$Pd(dba)_3$	**L1**	Cs_2CO_3	PhMe	trace
29	$Pd(PPh_3)_4$	**L1**	Cs_2CO_3	PhMe	trace
30	$[Pd(allyl)Cl]_2$	**L2**	Cs_2CO_3	PhMe	23
31	$[Pd(allyl)Cl]_2$	**L3**	Cs_2CO_3	PhMe	27
32	$[Pd(allyl)Cl]_2$	**L4**	Cs_2CO_3	PhMe	42
33	$[Pd(allyl)Cl]_2$	**L5**	Cs_2CO_3	PhMe	37
34	$[Pd(allyl)Cl]_2$	**L6**	Cs_2CO_3	PhMe	45
35	$[Pd(allyl)Cl]_2$	**L7**	Cs_2CO_3	PhMe	45
36	$[Pd(allyl)Cl]_2$	**L8**	Cs_2CO_3	PhMe	43
37	$[Pd(allyl)Cl]_2$	**L9**	Cs_2CO_3	PhMe	36

38	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	PhMe	55
39	$[Pd(allyl)Cl]_2$	**L11**	Cs_2CO_3	PhMe	10
40	$[Pd(allyl)Cl]_2$	**L12**	Cs_2CO_3	PhMe	17
41	$[Pd(allyl)Cl]_2$	**L13**	Cs_2CO_3	PhMe	trace
42	$[Pd(allyl)Cl]_2$	**L14**	Cs_2CO_3	PhMe	48
43	$[Pd(allyl)Cl]_2$	**L15**	Cs_2CO_3	PhMe	18
44	$[Pd(allyl)Cl]_2$	**L16**	Cs_2CO_3	PhMe	32
45	$[Pd(allyl)Cl]_2$	**L17**	Cs_2CO_3	PhMe	13
46	$[Pd(allyl)Cl]_2$	**L18**	Cs_2CO_3	PhMe	35
47	$[Pd(allyl)Cl]_2$	**L19**	Cs_2CO_3	PhMe	31
48	$[Pd(allyl)Cl]_2$	**L20**	Cs_2CO_3	PhMe	28
49	$[Pd(allyl)Cl]_2$	**L21**	Cs_2CO_3	PhMe	45
50	$[Pd(allyl)Cl]_2$	**L22**	Cs_2CO_3	PhMe	21
51	$[Pd(allyl)Cl]_2$	**L23**	Cs_2CO_3	PhMe	25
52	$[Pd(allyl)Cl]_2$	**L24**	Cs_2CO_3	PhMe	35
53	$[Pd(allyl)Cl]_2$	**L25**	Cs_2CO_3	PhMe	13
54	$[Pd(allyl)Cl]_2$	**L26**	Cs_2CO_3	PhMe	25
55	$[Pd(allyl)Cl]_2$	**L27**	Cs_2CO_3	PhMe	35
56	$[Pd(allyl)Cl]_2$	**L28**	Cs_2CO_3	PhMe	40
57	$[Pd(allyl)Cl]_2$	**L29**	Cs_2CO_3	PhMe	20
58	$[Pd(allyl)Cl]_2$	**L30**	Cs_2CO_3	PhMe	trace
59	$[Pd(allyl)Cl]_2$	**L31**	Cs_2CO_3	PhMe	27

60	$[Pd(allyl)Cl]_2$	**L32**	Cs_2CO_3	PhMe	9
61	$[Pd(allyl)Cl]_2$	**L33**	Cs_2CO_3	PhMe	24
62	$[Pd(allyl)Cl]_2$	**L34**	Cs_2CO_3	PhMe	trace
63	$[Pd(allyl)Cl]_2$	**L35**	Cs_2CO_3	PhMe	trace
64	$[Pd(allyl)Cl]_2$	**L36**	Cs_2CO_3	PhMe	11
65	$[Pd(allyl)Cl]_2$	**L37**	Cs_2CO_3	PhMe	22
66	$[Pd(allyl)Cl]_2$	**L38**	Cs_2CO_3	PhMe	trace
67	$[Pd(allyl)Cl]_2$	**L39**	Cs_2CO_3	PhMe	trace
68	$[Pd(allyl)Cl]_2$	**L40**	Cs_2CO_3	PhMe	10
69	$[Pd(allyl)Cl]_2$	**L41**	Cs_2CO_3	PhMe	trace
70	$[Pd(allyl)Cl]_2$	**L42**	Cs_2CO_3	PhMe	9
71	$[Pd(allyl)Cl]_2$	**L43**	Cs_2CO_3	PhMe	trace
72	$[Pd(allyl)Cl]_2$	**L44**	Cs_2CO_3	PhMe	13
73	$[Pd(allyl)Cl]_2$	**L45**	Cs_2CO_3	PhMe	trace
74	$[Pd(allyl)Cl]_2$	**L46**	Cs_2CO_3	PhMe	trace
75	$[Pd(allyl)Cl]_2$	**L47**	Cs_2CO_3	PhMe	trace
76	$[Pd(allyl)Cl]_2$	**L48**	Cs_2CO_3	PhMe	trace
77	$[Pd(allyl)Cl]_2$	**L49**	Cs_2CO_3	PhMe	trace
78	$[Pd(allyl)Cl]_2$	**L50**	Cs_2CO_3	PhMe	trace
79	$[Pd(allyl)Cl]_2$	**L51**	Cs_2CO_3	PhMe	trace
80	$[Pd(allyl)Cl]_2$	**L52**	Cs_2CO_3	PhMe	11
81	$[Pd(allyl)Cl]_2$	**L10**	K_2CO_3	PhMe	10

82	$[Pd(allyl)Cl]_2$	**L10**	Na_2CO_3	PhMe	trace
83	$[Pd(allyl)Cl]_2$	**L10**	$NaHCO_3$	PhMe	trace
84	$[Pd(allyl)Cl]_2$	**L10**	KOH	PhMe	19
85	$[Pd(allyl)Cl]_2$	**L10**	NaOH	PhMe	6
86	$[Pd(allyl)Cl]_2$	**L10**	LiOH	PhMe	11
87	$[Pd(allyl)Cl]_2$	**L10**	$CsOH·H_2O$	PhMe	42
88	$[Pd(allyl)Cl]_2$	**L10**	NaOPiv	PhMe	trace
89	$[Pd(allyl)Cl]_2$	**L10**	NaOAc	PhMe	trace
90	$[Pd(allyl)Cl]_2$	**L10**	KOAc	PhMe	10
91	$[Pd(allyl)Cl]_2$	**L10**	K_3PO_4	PhMe	7
92	$[Pd(allyl)Cl]_2$	**L10**	KH_2PO_4	PhMe	trace
93	$[Pd(allyl)Cl]_2$	**L10**	C_6H_5ONa	PhMe	32
94	$[Pd(allyl)Cl]_2$	**L10**	CsF	PhMe	9
95	$[Pd(allyl)Cl]_2$	**L10**	KF	PhMe	trace
96	$[Pd(allyl)Cl]_2$	**L10**	Et_3N	PhMe	14
97	$[Pd(allyl)Cl]_2$	**L10**	NaOMe	PhMe	trace
98	$[Pd(allyl)Cl]_2$	**L10**	^{t}BuONa	PhMe	14
99	$[Pd(allyl)Cl]_2$	**L10**	^{t}BuOK	PhMe	16
100	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	mesitylene	25
101	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	*o*-xylene	48
102	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	*m*-xylene	26
103	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	*p*-xylene	41

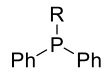
104	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	PhF	38
105	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	PhCl	51
106	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	$PhNO_2$	55
107	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	$PhCF_3$	52
108	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	1,4-dioxane	39
109	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	DCE	54
110	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	DMSO	trace
111	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	DMF	trace
112	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	NMP	17
113	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	HMPA	14
114	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	CPME	31
115	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	MTBE	15
116	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	glyme	51
117	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	anisole	49
118	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	THF	43
119	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	*t*-AmOH	48
120[c]	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	PhMe	42
121[d]	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	PhMe	46
122[e]	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	PhMe	54
123[f]	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	PhMe	57
124[g]	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	PhMe	62
125[h]	$[Pd(allyl)Cl]_2$	**L10**	Cs_2CO_3	PhMe	65

126[i]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	71
127[j]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	64
128[k]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	66
129[i,l]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	45
130[i,m]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	63
131[i,n]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	60
132[i,o]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	56
133[i,p]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	59
134[i,q]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	64
135[i,r]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	42
136[i,s]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	59
137[i,t]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	60
138[i,u]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	62
139[i,v]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	38
140[i,w]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	70
141[i,x]	[Pd(allyl)Cl]$_2$	**L10**	Cs_2CO_3	PhMe	39

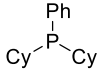
[a] Unless otherwise noted, all reactions were performed with **1a** (0.2 mmol, 1.0 equiv.), **2a** (0.2 mmol, 1.0 equiv.), **3a** (0.8 mmol, 4.0 equiv.), Pd-catalyst (10 mol%), ligand (20 mol%), base (0.4 mmol, 2.0 equiv.), H_2O (0.6 mmol, 3.0 equiv.) in 2.0 mL of solvent under Ar atmosphere at 100 ˚C for 24 h. [b] Isolated yields based on **1a**. [c] H_2O (0 equiv.) was added. [d] H_2O (1.0 equiv.) was added. [e] H_2O (5.0 equiv.) was added. [f] 1.1 equiv. of **2a** was used. [g] 1.2 equiv. of **2a** was used. [h] 1.3 equiv. of **2a** was used. [i] 1.4 equiv. of **2a** was used. [j] 1.5 equiv. of **2a** was used. [k] 1.6 equiv. of **2a** was used. [l] 1.5 equiv. of Cs_2CO_3 was used. [m] 2.5 equiv. of Cs_2CO_3 was used. [n] 3.0 equiv. of Cs_2CO_3 was used. [o] 1.0 mL of PhMe was used. [p] 1.5 mL of PhMe was used. [q] 2.5 mL of PhMe was used. [r] 3.0 mL of PhMe was used. [s] Carried out at 80 ˚C. [t] Carried out at 90 ˚C. [u] Carried out at 110 ˚C. [v] Carried out at 120 ˚C. [w] Carried out with 20 mol% [Pd(allyl)Cl]$_2$ and 40 mol% P(4-$CF_3C_6H_4$)$_3$. [x] Carried out in the absence of water.

Ligands examined in this work:

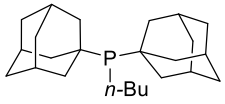
L1: R = Ph;
L2: R = 2-MeC_6H_4;
L3: R = 2-OMeC_6H_4;
L4: R = 3-MeC_6H_4;
L5: R = 3-OMeC_6H_4;
L6: R = 3-FC_6H_4;
L7: R = 4-MeC_6H_4;
L8: R = 4-OMeC_6H_4;
L9: R = 4-FC_6H_4;
L10: R = 4-$CF_3C_6H_4$;
L11: R = C_6F_5;
L12: R = 3,5-$(CF_3)_2C_6H_3$;
L13: R = 2,4,6-$(Me)_3C_6H_2$;
L14: R = 2-furyl;
L15: R = Cy, PCy_3;



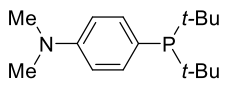
L16: R = Me;
L17: R = C_6F_5;



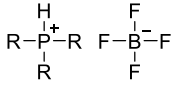
L18



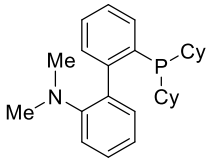
L19



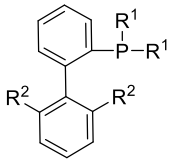
L20



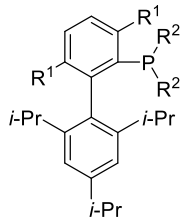
L21: R = *t*-Bu;
L22: R = Cy;



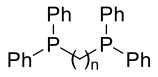
L23: DavePhos



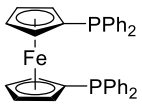
L24: R^1 = Ph, R^2 = H;
L25: R^1 = *t*-Bu, R^2 = H, JohnPhos;
L26: R^1 = Cy, R^2 = H, CyJohnPhos;
L27: R^1 = Cy, R^2 = OMe, Sphos;
L28: R^1 = Cy, R^2 = isopropoxy, RuPhos;



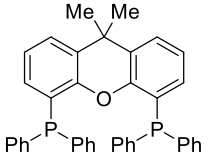
L29: R^1 = H, R^2 = Cy, Xphos;
L30: R^1 = H, R^2 = *t*-Bu, ^{t}BuXphos;
L31: R^1 = OMe, R^2 = Cy, BrettPhos;



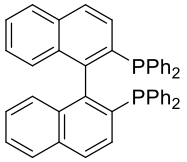
L32: n = 1, DPPM;
L33: n = 2, DPPE;
L34: n = 3, DPPP;
L35: n = 4, DPPB;
L36: n = 5, DPPPE;
L37: n = 6, DPPH;



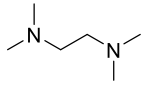
L38: DPPF



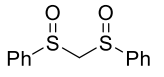
L39: Xantphos



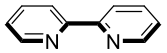
L40: *rac*-BINAP



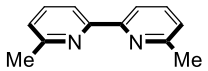
L41: TMEDA



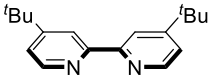
L42



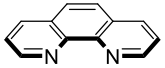
L43



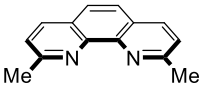
L44



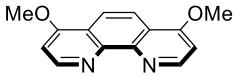
L45



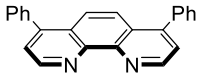
L46



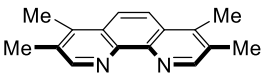
L47



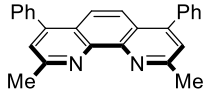
L48



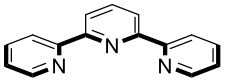
L49



L50

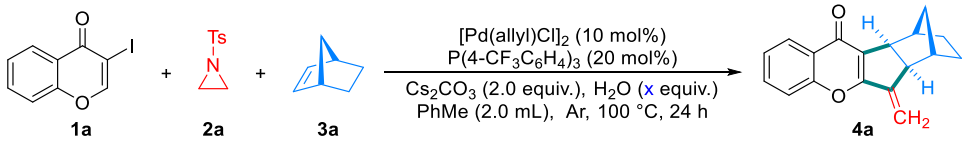


L51



L52

3. The water effect on the yield of 4a



Reaction conditions: The reaction was performed with **1a** (0.2 mmol, 1.0 equiv.), **2a** (0.28 mmol, 1.4 equiv.), **3a** (0.8 mmol, 4.0 equiv.), $[Pd(allyl)Cl]_2$ (10 mol%), $P(4\text{-}CF_3C_6H_4)_3$ (20 mol%), Cs_2CO_3 (0.4 mmol, 2.0 equiv.), H_2O (0.2x mmol, x equiv.) in 2.0 mL of PhMe under an Ar atmosphere at 100 °C for 24 h. Isolated yields of **4a** based on **1a**.

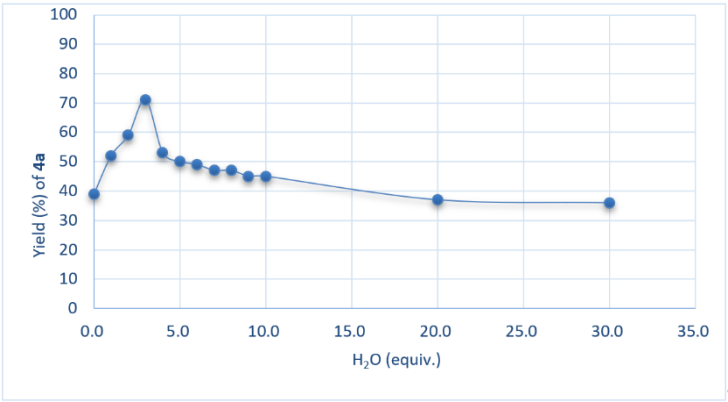
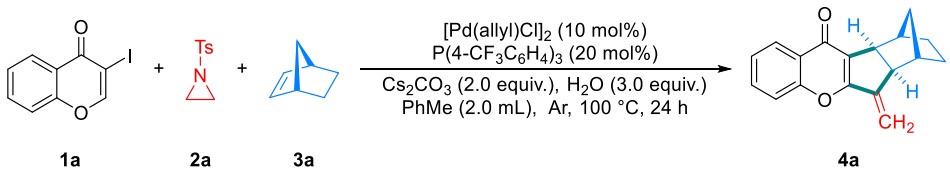


Fig. E1 The water effect on the yield of **4a**

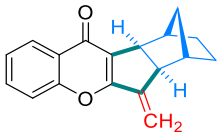
4. Representative procedure for the synthesis of compound 4a



To a 4.0 mL flame-dried vial with a stir bar, **1a** (54.5mg, 0.2 mmol), **2a** (55.2 mg, 0.28 mmol), **3a** (75.3 mg, 0.8 mmol), $[Pd(allyl)Cl]_2$ (7.3 mg, 0.02 mmol), $P(4\text{-}CF_3C_6H_4)_3$ (18.7 mg, 0.04 mmol), Cs_2CO_3 (130.3mg, 0.4 mmol), H_2O (10.8 μL, 0.6 mmol) and PhMe (2.0 mL) were added. Then, the reaction vial was evacuated and backfilled with argon three times, and the mixture was stirred at 100 ˚C for 24 h. After completed of the reaction, it was concentrated to remove solvent and purified by flash column chromatography on silica gel (petroleum ether/ethyl acetate = 50:1 – 30:1) to afford the product **4a** (37.5mg, 71% yield).

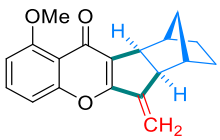
5. Characterization data of compounds 4a-ab

Scheme 2, 4a



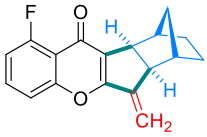
Compound **4a**: white solid, 37.5 mg, 71% yield, mp 124.6 – 125.3 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.22 (dd, J = 8.0, 1.6 Hz, 1H), 7.62 (td, J = 8.6, 1.6 Hz, 1H), 7.47 (d, J = 8.4 Hz, 1H), 7.37 (t, J = 7.6 Hz, 1H), 5.77 (d, J = 2.4 Hz, 1H), 5.32 (d, J = 1.8 Hz, 1H), 3.06 (d, J = 6.4 Hz, 1H), 2.75 (d, J = 6.0 Hz, 1H), 2.57 (d, J = 3.6 Hz, 1H), 2.20 (d, J = 3.6 Hz, 1H), 1.71 – 1.62 (m, 1H), 1.62 – 1.53 (m, 1H), 1.50 – 1.40 (m, 1H), 1.37 – 1.29 (m, 1H), 1.17 (d, J = 10.4 Hz, 1H), 1.05 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.0, 164.7, 156.4, 148.5, 133.3, 126.5, 125.9, 124.9, 118.2, 110.5, 110.1, 48.0, 46.8, 43.7, 38.5, 32.3, 29.4, 28.5; HRMS (ESI-TOF): calcd. for $C_{18}H_{17}O_2$ $[M + H]^+$ 265.1223; found 265.1232.

Scheme 2, 4b



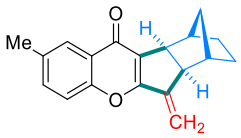
Compound **4b**: white solid, 37.9 mg, 64% yield, mp 119.5 – 120.8 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49 (t, J = 8.4 Hz, 1H), 7.03 (d, J = 8.4 Hz, 1H), 6.77 (d, J = 8.4 Hz, 1H), 5.68 (d, J = 2.4 Hz, 1H), 5.26 (d, J = 1.8 Hz, 1H), 3.95 (s, 3H), 3.00 (d, J = 6.4 Hz, 1H), 2.71 (d, J = 5.8 Hz, 1H), 2.59 (d, J = 3.6 Hz, 1H), 2.16 (d, J = 3.4 Hz, 1H), 1.68 – 1.59 (m, 1H), 1.59 – 1.50 (m, 1H), 1.47 – 1.37 (m, 1H), 1.35 – 1.26 (m, 1H), 1.15 (d, J = 10.4 Hz, 1H), 1.02 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.2, 162.6, 160.3, 158.7, 148.5, 133.3, 127.7, 115.5, 110.5, 109.7, 106.4, 56.5, 48.1, 47.0, 43.6, 38.3, 32.3, 29.4, 28.6; HRMS (ESI-TOF): calcd. for $C_{19}H_{19}O_3$ $[M + H]^+$ 295.1329; found 295.1335.

Scheme 2, 4c



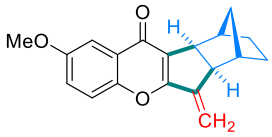
Compound **4c**: white solid, 33.0 mg, 58% yield, mp 146.1 – 147.4 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54 (td, J = 8.4, 5.6 Hz, 1H), 7.26 (d, J = 8.4, 1H), 7.00 (dd, J = 10.8, 8.4 Hz, 1H), 5.74 (d, J = 2.4 Hz, 1H), 5.32 (d, J = 2.0 Hz, 1H), 3.03 (d, J = 6.4 Hz, 1H), 2.73 (d, J = 6.2 Hz, 1H), 2.57 (d, J = 3.8 Hz, 1H), 2.18 (d, J = 3.6 Hz, 1H), 1.70 – 1.61 (m, 1H), 1.60 – 1.52 (m, 1H), 1.47 – 1.39 (m, 1H), 1.35 – 1.28 (m, 1H), 1.15 (d, J = 10.4 Hz, 1H), 1.05 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.5, 163.6, 161.2 (d, J = 263.0 Hz), 157.6 (d, J = 3.8 Hz), 148.1, 133.2 (d, J = 10.8 Hz), 127.3, 115.2 (d, J = 10.0 Hz), 114.2 (d, J = 4.4 Hz), 112.0 (d, J = 21.2 Hz), 110.8, 48.0, 46.8, 43.6, 38.3, 32.3, 29.3, 28.5; ^{19}F NMR (376 MHz, $CDCl_3$) δ -112.9 – -113.0 (m, 1F); HRMS (ESI-TOF): calcd. for $C_{18}H_{16}FO_2$ $[M + H]^+$ 283.1129; found 283.1131.

Scheme 2, 4d



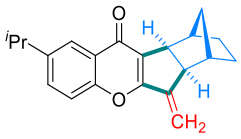
Compound **4d**: white solid, 34.0 mg, 61% yield, mp 161.8 – 162.9 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.01 (dd, J = 1.6, 0.4 Hz, 1H), 7.43 (dd, J = 8.4, 2.2 Hz, 1H), 7.36 (d, J = 8.4 Hz, 1H), 5.76 (d, J = 2.4 Hz, 1H), 5.31 (d, J = 2.0 Hz, 1H), 3.06 (d, J = 6.4 Hz, 1H), 2.75 (d, J = 6.4 Hz, 1H), 2.57 (d, J = 4.0 Hz, 1H), 2.44 (s, 3H), 2.19 (d, J = 3.8 Hz, 1H), 1.71 – 1.62 (m, 1H), 1.61 – 1.53 (m, 1H), 1.50 – 1.41 (m, 1H), 1.37 – 1.29 (m, 1H), 1.16 (dt, J = 10.4, 1.6 Hz, 1H), 1.04 (dt, J = 10.4, 1.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.2, 164.7, 154.7, 148.7, 134.9, 134.5, 126.5, 125.4, 124.5, 118.0, 110.3, 48.1, 46.9, 43.8, 38.5, 32.3, 29.5, 28.6, 21.0; HRMS (ESI-TOF): calcd. for $C_{19}H_{19}O_2$ $[M + H]^+$ 279.1380; found 279.1381.

Scheme 2, 4e



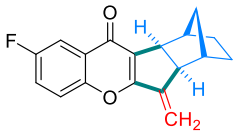
Compound **4e**: yellow solid, 36.6 mg, 62% yield, mp 125.8 – 126.9 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.57 (d, J = 2.6 Hz, 1H), 7.37 (d, J = 9.2 Hz, 1H), 7.19 (dd, J = 8.8, 2.4 Hz, 1H), 5.73 (s, 1H), 5.28 (s, 1H), 3.86 (s, 3H), 3.04 (d, J = 6.4 Hz, 1H), 2.72 (d, J = 6.2 Hz, 1H), 2.55 (d, J = 2.6 Hz, 1H), 2.17 (d, J = 2.6 Hz, 1H), 1.64 (tt, J = 11.8, 4.2 Hz, 1H), 1.55 (tt, J = 11.6, 3.6 Hz, 1H), 1.48 – 1.37 (m, 1H), 1.35 – 1.26 (m, 1H), 1.14 (d, J = 10.4 Hz, 1H), 1.02 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.8, 164.6, 156.8, 151.1, 148.5, 125.8, 125.4, 123.1, 119.5, 110.3, 105.3, 56.0, 48.1, 46.8, 43.7, 38.4, 32.2, 29.4, 28.5; HRMS (ESI-TOF): calcd. for $C_{19}H_{19}O_3$ $[M + H]^+$ 295.1329; found 295.1332.

Scheme 2, 4f



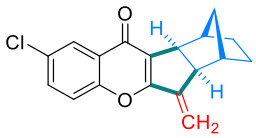
Compound **4f**: white solid, 37.0 mg, 60% yield, mp 113.9 – 115.4 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (d, J = 2.4 Hz, 1H), 7.48 (dd, J = 8.6, 2.4 Hz, 1H), 7.37 (d, J = 8.6 Hz, 1H), 5.73 (d, J = 2.4 Hz, 1H), 5.28 (d, J = 1.8 Hz, 1H), 3.04 (d, J = 6.4 Hz, 1H), 2.99 (dd, J = 13.8, 6.8 Hz, 1H), 2.71 (d, J = 6.4 Hz, 1H), 2.55 (d, J = 3.8 Hz, 1H), 2.16 (d, J = 3.8 Hz, 1H), 1.64 (tt, J = 11.4, 4.2 Hz, 1H), 1.54 (tt, J = 11.6, 3.6 Hz, 1H), 1.48 – 1.39 (m, 1H), 1.35 – 1.28 (m, 1H), 1.26 (d, J = 6.8 Hz, 6H), 1.13 (d, J = 10.4 Hz, 1H), 1.01 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.2, 164.5, 154.8, 148.6, 145.7, 132.1, 126.3, 124.5, 122.6, 118.0, 110.2, 48.0, 46.8, 43.7, 38.4, 33.8, 32.2, 29.4, 28.5, 24.1, 24.0; HRMS (ESI-TOF): calcd. for $C_{21}H_{23}O_2$ $[M + H]^+$ 307.1693; found 307.1703.

Scheme 2, 4g



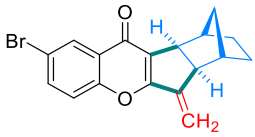
Compound **4g**: white solid, 30.0 mg, 53% yield, mp 138.1 – 139.0 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86 (dd, *J* = 8.4, 3.2 Hz, 1H), 7.48 (dd, *J* = 9.2, 4.2 Hz, 1H), 7.35 (ddd, *J* = 9.2, 7.6, 3.2 Hz, 1H), 5.78 (d, *J* = 2.4 Hz, 1H), 5.35 (d, *J* = 2.0 Hz, 1H), 3.06 (d, *J* = 6.6 Hz, 1H), 2.77 (d, *J* = 6.2 Hz, 1H), 2.56 (d, *J* = 3.8 Hz, 1H), 2.21 (d, *J* = 3.8 Hz, 1H), 1.66 (tt, *J* = 11.4, 3.8 Hz, 1H), 1.58 (tt, *J* = 11.6, 3.8 Hz, 1H), 1.50 – 1.41 (m, 1H), 1.38 – 1.30 (m, 1H), 1.16 (d, *J* = 10.4 Hz, 1H), 1.06 (d, *J* = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.2, 165.1, 159.6 (d, *J* = 246.2 Hz), 152.6, 148.4, 126.1 (d, *J* = 8.6 Hz), 126.0, 121.3 (d, *J* = 25.4 Hz), 120.2 (d, *J* = 8.0 Hz), 111.0 (d, *J* = 2.4 Hz), 110.8 , 48.1, 46.8, 43.8, 38.5, 32.3, 29.4, 28.6; ^{19}F NMR (376 MHz, $CDCl_3$) δ -117.0 – -117.1 (m, 1F); HRMS (ESI-TOF): calcd. for $C_{18}H_{16}FO_2$ $[M + H]^+$ 283.1129; found 283.1134.

Scheme 2, 4h



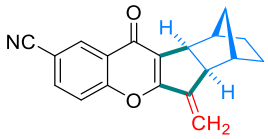
Compound **4h**: white solid, 36.0 mg, 60% yield, mp 141.7 – 142.6 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.17 (d, *J* = 2.4 Hz, 1H), 7.57 (dd, *J* = 8.8, 2.6 Hz, 1H), 7.43 (d, *J* = 8.8 Hz, 1H), 5.78 (d, *J* = 2.4 Hz, 1H), 5.35 (d, *J* = 1.4 Hz, 1H), 3.06 (d, *J* = 6.6 Hz, 1H), 2.76 (d, *J* = 6.4 Hz, 1H), 2.56 (d, *J* = 3.6 Hz, 1H), 2.20 (d, *J* = 3.6 Hz, 1H), 1.66 (tt, *J* = 11.4, 3.8 Hz, 1H), 1.58 (tt, *J* = 11.8, 3.8 Hz, 1H), 1.50 – 1.41 (m, 1H), 1.38 – 1.29 (m, 1H), 1.15 (d, *J* = 10.4 Hz, 1H), 1.06 (d, *J* = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.8, 165.0, 154.8, 148.3, 133.5, 130.9, 126.6, 125.9, 125.4, 119.9, 111.1, 48.1, 46.8, 43.8, 38.5, 32.3, 29.4, 28.5; HRMS (ESI-TOF): calcd. for $C_{18}H_{16}ClO_2$ $[M + H]^+$ 299.0833; found 299.0843.

Scheme 2, 4i



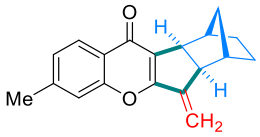
Compound **4i**: white solid, 27.6 mg, 40% yield, mp 155.2 – 156.2 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.34 (d, J = 2.4 Hz, 1H), 7.71 (dd, J = 8.8, 2.4 Hz, 1H), 7.37 (d, J = 8.8 Hz, 1H), 5.78 (d, J = 2.4 Hz, 1H), 5.35 (d, J = 2.0 Hz, 1H), 3.06 (d, J = 6.6 Hz, 1H), 2.77 (d, J = 6.4 Hz, 1H), 2.56 (d, J = 4.0 Hz, 1H), 2.21 (d, J = 3.8 Hz, 1H), 1.67 (tt, J = 11.4, 4.2 Hz, 1H), 1.58 (tt, J = 11.6, 3.2 Hz, 1H), 1.50 – 1.41 (m, 1H), 1.38 – 1.30 (m, 1H), 1.15 (dt, J = 10.4, 1.6 Hz, 1H), 1.06 (dt, J = 10.4, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.7, 165.0, 155.2, 148.3, 136.2, 128.6, 126.7, 126.3, 120.2, 118.4, 111.1, 48.1, 46.9, 43.8, 38.5, 32.3, 29.4, 28.6; HRMS (ESI-TOF): calcd. for $C_{18}H_{16}BrO_2$ $[M + H]^+$ 343.0328; found 343.0338.

Scheme 2, 4j



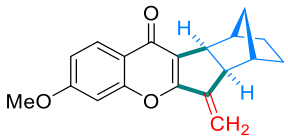
Compound **4j**: white solid, 25.2 mg, 44% yield, mp 166.0 – 167.2 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.55 (d, J = 2.0 Hz, 1H), 7.86 (dd, J = 8.6, 2.2 Hz, 1H), 7.59 (d, J = 8.8 Hz, 1H), 5.82 (d, J = 2.4 Hz, 1H), 5.40 (d, J = 1.8 Hz, 1H), 3.07 (d, J = 6.4 Hz, 1H), 2.79 (d, J = 6.0 Hz, 1H), 2.55 (s, 1H), 2.22 (s, 1H), 1.68 (tt, J = 11.4, 4.2 Hz, 1H), 1.59 (tt, J = 11.8, 3.6 Hz, 1H), 1.50 – 1.40 (m, 1H), 1.39 – 1.29 (m, 1H), 1.16 (dd, J = 10.6 Hz, 1.4 Hz, 1H), 1.08 (dd, J = 10.4 Hz, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.1, 165.2, 158.2, 147.9, 135.7, 131.6, 127.3, 125.3, 119.9, 117.8, 112.0, 109.2, 48.0, 46.8, 43.7, 38.5, 32.4, 29.4, 28.5; HRMS (ESI-TOF): calcd. for $C_{19}H_{16}NO_2$ $[M + H]^+$ 290.1176; found 290.1184.

Scheme 2, 4k



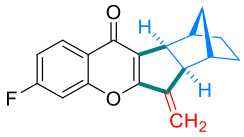
Compound **4k**: white solid, 30.0 mg, 54% yield, mp 106.6 – 107.7 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11 (d, J = 8.0 Hz, 1H), 7.28 (s, 1H), 7.19 (d, J = 8.2 Hz, 1H), 5.75 (d, J = 2.4 Hz, 1H), 5.31 (d, J = 1.6 Hz, 1H), 3.06 (d, J = 6.4 Hz, 1H), 2.75 (d, J = 5.8 Hz, 1H), 2.57 (s, 1H), 2.48 (s, 3H), 2.20 (s, 1H), 1.72 – 1.63 (m, 1H), 1.62 – 1.52 (m, 1H), 1.50 – 1.41 (m, 1H), 1.38 – 1.30 (m, 1H), 1.17 (dd, J = 10.6, 1.0 Hz, 1H), 1.05 (dd, J = 10.4, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.2, 164.5, 156.6, 148.7, 144.7, 126.5, 126.4, 125.7, 122.6, 118.1, 110.2, 48.1, 46.9, 43.8, 38.5, 32.3, 29.5, 28.6, 21.9; HRMS (ESI-TOF): calcd. for $C_{19}H_{19}O_2$ $[M + H]^+$ 279.1380; found 279.1391.

Scheme 2, 4l



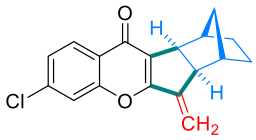
Compound **4l**: yellow solid, 36.9 mg, 63% yield, mp 138.9 – 140.2 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11 (d, J = 8.8 Hz, 1H), 6.93 (dd, J = 8.8, 2.4 Hz, 1H), 6.87 (d, J = 2.4 Hz, 1H), 5.71 (d, J = 2.4 Hz, 1H), 5.28 (d, J = 1.8 Hz, 1H), 3.89 (s, 3H), 3.03 (d, J = 6.4 Hz, 1H), 2.73 (d, J = 6.2 Hz, 1H), 2.56 (d, J = 3.8 Hz, 1H), 2.18 (d, J = 3.8 Hz, 1H), 1.65 (tt, J = 11.4, 4.2 Hz, 1H), 1.56 (tt, J = 11.8, 3.8 Hz, 1H), 1.49 – 1.39 (m, 1H), 1.36 – 1.28 (m, 1H), 1.17 (dt, J = 10.4 Hz, 1.6 Hz, 1H), 1.04 (dt, J = 10.4 Hz, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.6, 164.3, 163.9, 158.2, 148.6, 127.2, 126.5, 118.8, 114.0, 109.8, 100.7, 55.9, 48.1, 46.8, 43.7, 38.5, 32.3, 29.5, 28.6; HRMS (ESI-TOF): calcd. for $C_{19}H_{19}O_3$ $[M + H]^+$ 295.1329; found 295.1333.

Scheme 2, 4m



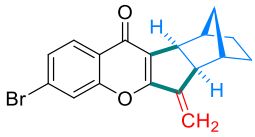
Compound **4m**: white solid, 32.2 mg, 57% yield, mp 90.8 – 92.4 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.23 (dd, J = 8.8, 6.4 Hz, 1H), 7.15 (dd, J = 9.2, 2.2 Hz, 1H), 7.10 (td, J = 8.6, 2.2 Hz, 1H), 5.75 (d, J = 2.4 Hz, 1H), 5.33 (d, J = 1.6 Hz, 1H), 3.05 (d, J = 6.4 Hz, 1H), 2.76 (d, J = 5.8 Hz, 1H), 2.56 (d, J = 3.2 Hz, 1H), 2.20 (d, J = 3.0 Hz, 1H), 1.66 (tt, J = 11.6, 4.2 Hz, 1H), 1.57 (tt, J = 11.8, 3.8 Hz, 1H), 1.50 – 1.40 (m, 1H), 1.37 – 1.29 (m, 1H), 1.16 (d, J = 10.4 Hz, 1H), 1.06 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.2, 165.5 (d, J = 253.0 Hz), 164.9, 157.4 (d, J = 13.2 Hz), 148.3, 128.3 (d, J = 10.6 Hz), 126.7, 121.7 (d, J = 2.4 Hz), 113.6 (d, J = 22.6 Hz), 110.8, 105.0 (d, J = 25.4 Hz), 48.1, 46.8, 43.7, 38.5, 32.3, 29.4, 28.5; ^{19}F NMR (376 MHz, $CDCl_3$) δ -103.9 – -104.0 (m, 1F); HRMS (ESI-TOF): calcd. for $C_{18}H_{16}FO_2$ $[M + H]^+$ 283.1129; found 283.1136.

Scheme 2, 4n



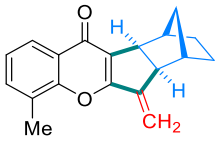
Compound **4n**: white solid, 31.6 mg, 53% yield, mp 149.4 – 150.1 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.16 (d, J = 8.4 Hz, 1H), 7.51 (d, J = 1.8 Hz, 1H), 7.34 (dd, J = 8.4, 1.8 Hz, 1H), 5.76 (d, J = 2.4 Hz, 1H), 5.34 (d, J = 1.8 Hz, 1H), 3.05 (d, J = 6.4 Hz, 1H), 2.76 (d, J = 6.2 Hz, 1H), 2.56 (d, J = 3.8 Hz, 1H), 2.21 (d, J = 3.8 Hz, 1H), 1.67 (tt, J = 10.8, 4.0 Hz, 1H), 1.58 (tt, J = 11.6, 4.2 Hz, 1H), 1.50 – 1.41 (m, 1H), 1.38 – 1.30 (m, 1H), 1.16 (dt, J = 10.4 Hz, 2.0 Hz, 1H), 1.07 (dt, J = 10.4 Hz, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.2, 164.8, 156.6, 148.3, 139.3, 127.3, 126.9, 125.8, 123.5, 118.4, 110.9, 48.1, 46.9, 43.8, 38.5, 32.3, 29.5, 28.6; HRMS (ESI-TOF): calcd. for $C_{18}H_{16}ClO_2$ $[M + H]^+$ 299.0833; found 299.0842.

Scheme 2, 4o



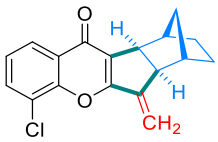
Compound **4o**: white solid, 28.3 mg, 41% yield, mp 143.6 – 144.7 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08 (dd, J = 8.4, 3.2 Hz, 1H), 7.68 (s, 1H), 7.54 – 7.46 (m, 1H), 5.76 (s, 1H), 5.34 (s, 1H), 3.05 (d, J = 6.4 Hz, 1H), 2.76 (d, J = 4.6 Hz, 1H), 2.56 (s, 1H), 2.21 (s, 1H), 1.67 (tt, J = 11.8, 3.8 Hz, 1H), 1.58 (tt, J = 11.8, 3.8 Hz, 1H), 1.50 – 1.40 (m, 1H), 1.38 – 1.30 (m, 1H), 1.16 (d, J = 10.4 Hz, 1H), 1.07 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.3, 164.7, 156.5, 148.3, 128.6, 127.5, 127.4, 126.9, 123.8, 121.4, 111.0, 48.1, 46.8, 43.7, 38.5, 32.3, 29.4, 28.5; HRMS (ESI-TOF): calcd. for $C_{18}H_{16}BrO_2$ $[M + H]^+$ 343.0328; found 343.0338.

Scheme 2, 4p



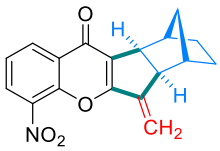
Compound **4p**: white solid, 34.5 mg, 62% yield, mp 110.0 – 111.1 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.07 (d, J = 8.0 Hz, 1H), 7.46 (d, J = 8.0 Hz, 1H), 7.26 (t, J = 7.6 Hz, 1H), 5.77 (d, J = 2.4 Hz, 1H), 5.33 (d, J = 1.8 Hz, 1H), 3.07 (d, J = 6.4 Hz, 1H), 2.76 (d, J = 5.8 Hz, 1H), 2.58 (d, J = 3.2 Hz, 1H), 2.51 (s, 3H), 2.20 (d, J = 3.2 Hz, 1H), 1.67 (tt, J = 11.4, 4.2 Hz, 1H), 1.58 (tt, J = 11.8, 4.0 Hz, 1H), 1.50 – 1.41 (m, 1H), 1.38 – 1.30 (m, 1H), 1.18 (d, J = 10.4 Hz, 1H), 1.05 (dd, J = 10.4, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.4, 164.4, 154.8, 148.8, 134.4, 127.6, 126.3, 124.7, 124.5, 123.6, 110.2, 48.1, 46.9, 43.7, 38.5, 32.3, 29.4, 28.6, 15.7; HRMS (ESI-TOF): calcd. for $C_{19}H_{19}O_2$ $[M + H]^+$ 279.1380; found 279.1386.

Scheme 2, 4q



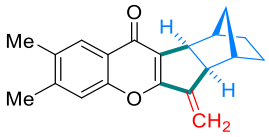
Compound **4q**: white solid, 30.2 mg, 51% yield, mp 99.9 – 101.1 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.12 (dd, *J* = 8.0, 1.6 Hz, 1H), 7.68 (dd, *J* = 7.6, 1.6 Hz, 1H), 7.30 (t, *J* = 7.8 Hz, 1H), 5.87 (d, *J* = 2.4 Hz, 1H), 5.37 (d, *J* = 1.8 Hz, 1H), 3.06 (d, *J* = 6.4 Hz, 1H), 2.77 (d, *J* = 6.2 Hz, 1H), 2.56 (d, *J* = 3.8 Hz, 1H), 2.21 (d, *J* = 3.8 Hz, 1H), 1.67 (tt, *J* = 11.4, 4.2 Hz, 1H), 1.58 (tt, *J* = 11.8, 4.2 Hz, 1H), 1.49 – 1.40 (m, 1H), 1.37 – 1.29 (m, 1H), 1.17 (d, *J* = 10.4 Hz, 1H), 1.06 (d, *J* = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.3, 164.7, 152.0, 148.0, 133.7, 126.5, 126.3, 125.0, 124.6, 123.4, 111.5, 48.0, 46.9, 43.7, 38.4, 32.3, 29.4, 28.5; HRMS (ESI-TOF): calcd. for $C_{18}H_{16}ClO_2$ $[M + H]^+$ 299.0833; found 299.0834.

Scheme 2, 4r



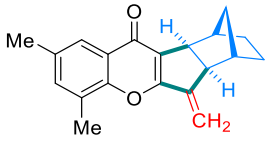
Compound **4r**: yellow solid, 25.6 mg, 41% yield, mp 139.6 – 140.9 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.51 (dd, *J* = 8.0, 1.8 Hz, 1H), 8.29 (dd, *J* = 8.0, 1.8 Hz, 1H), 7.49 (t, *J* = 8.0 Hz, 1H), 5.90 (d, *J* = 2.4 Hz, 1H), 5.42 (d, *J* = 2.0 Hz, 1H), 3.09 (d, *J* = 6.6 Hz, 1H), 2.81 (d, *J* = 6.4 Hz, 1H), 2.57 (d, *J* = 3.8 Hz, 1H), 2.24 (d, *J* = 3.8 Hz, 1H), 1.69 (tt, *J* = 11.6, 4.2 Hz, 1H), 1.60 (tt, *J* = 12.0, 4.2 Hz, 1H), 1.50 – 1.42 (m, 1H), 1.39 – 1.32 (m, 1H), 1.20 (d, *J* = 10.6 Hz, 1H), 1.10 (d, *J* = 10.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.9, 165.0, 148.7, 147.4, 139.2, 131.9, 129.5, 126.9, 126.8, 124.2, 112.8, 48.0, 47.0, 43.7, 38.5, 32.4, 29.4, 28.5; HRMS (ESI-TOF): calcd. for $C_{18}H_{16}NO_4$ $[M + H]^+$ 310.1074; found 310.1085.

Scheme 2, 4s



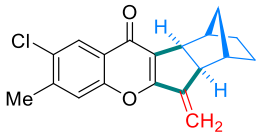
Compound **4s**: white solid, 42.0 mg, 72% yield, mp 110.1 – 110.8 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90 (s, 1H), 7.20 (s, 1H), 5.69 (d, J = 2.4 Hz, 1H), 5.25 (d, J = 1.8 Hz, 1H), 3.02 (d, J = 6.4 Hz, 1H), 2.70 (d, J = 6.0 Hz, 1H), 2.54 (d, J = 3.6 Hz, 1H), 2.33 (s, 3H), 2.30 (s, 3H), 2.16 (d, J = 3.6 Hz, 1H), 1.63 (tt, J = 11.4, 3.8 Hz, 1H), 1.54 (tt, J = 11.6, 4.2 Hz, 1H), 1.47 – 1.39 (m, 1H), 1.34 – 1.26 (m, 1H), 1.13 (d, J = 10.4 Hz, 1H), 1.01 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.0, 164.2, 154.9, 148.7, 143.6, 134.0, 126.3, 125.5, 122.6, 118.3, 109.9, 48.0, 46.8, 43.7, 38.4, 32.2, 29.4, 28.5, 20.4, 19.3; HRMS (ESI-TOF): calcd. for $C_{20}H_{21}O_2$ $[M + H]^+$ 293.1536; found 293.1545.

Scheme 2, 4t



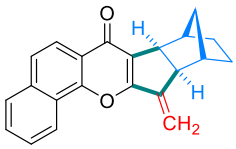
Compound **4t**: white solid, 35.8 mg, 61% yield, mp 142.6 – 143.8 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 (s, 1H), 7.29 (s, 1H), 5.75 (d, J = 2.4 Hz, 1H), 5.31 (d, J = 2.0 Hz, 1H), 3.07 (d, J = 6.6 Hz, 1H), 2.76 (d, J = 6.2 Hz, 1H), 2.58 (d, J = 3.6 Hz, 1H), 2.47 (s, 3H), 2.40 (s, 3H), 2.20 (d, J = 3.6 Hz, 1H), 1.69 – 1.62 (m, 1H), 1.58 (tt, J = 11.4, 4.2 Hz, 1H), 1.49 – 1.42 (m, 1H), 1.37 – 1.30 (m, 1H), 1.17 (d, J = 10.4 Hz, 1H), 1.05 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.5, 164.3, 153.1, 149.0, 135.7, 134.3, 127.3, 126.2, 124.4, 123.0, 109.9, 48.1, 46.9, 43.8, 38.5, 32.3, 29.5, 28.6, 21.0, 15.6; HRMS (ESI-TOF): calcd. for $C_{20}H_{21}O_2$ $[M + H]^+$ 293.1536; found 293.1540.

Scheme 2, 4u



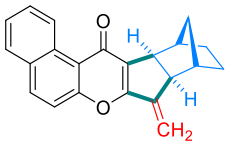
Compound **4u**: white solid, 37.2 mg, 60% yield, mp 132.8 – 133.4 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.17 (s, 1H), 7.37 (s, 1H), 5.75 (d, J = 2.4 Hz, 1H), 5.33 (d, J = 1.8 Hz, 1H), 3.05 (d, J = 6.4 Hz, 1H), 2.76 (d, J = 6.0 Hz, 1H), 2.56 (d, J = 3.2 Hz, 1H), 2.49 (s, 3H), 2.20 (d, J = 3.2 Hz, 1H), 1.67 (tt, J = 11.8, 4.4 Hz, 1H), 1.59 – 1.54 (m, 1H), 1.49 – 1.42 (m, 1H), 1.38 – 1.30 (m, 1H), 1.16 (d, J = 10.4 Hz, 1H), 1.06 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.9, 164.8, 154.7, 148.5, 142.4, 131.6, 126.5, 125.7, 124.0, 120.1, 110.7, 48.1, 46.9, 43.8, 38.5, 32.3, 29.5, 28.6, 20.9; HRMS (ESI-TOF): calcd. for $C_{19}H_{18}ClO_2$ $[M + H]^+$ 313.0990; found 313.0989.

Scheme 2, 4v



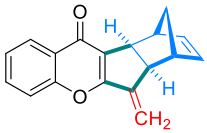
Compound **4v**: yellow solid, 33.5 mg, 53% yield, mp 135.4 – 136.5 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.53 (d, J = 8.0 Hz, 1H), 8.19 (d, J = 8.8 Hz, 1H), 7.91 (d, J = 7.2 Hz, 1H), 7.75 (d, J = 8.8 Hz, 1H), 7.72 – 7.62 (m, 2H), 5.92 (s, 1H), 5.39 (s, 1H), 3.14 (d, J = 6.4 Hz, 1H), 2.82 (d, J = 5.8 Hz, 1H), 2.64 (d, J = 2.4 Hz, 1H), 2.24 (d, J = 2.0 Hz, 1H), 1.72 – 1.66 (m, 1H), 1.61 (tt, J = 11.4, 3.8 Hz, 1H), 1.53 – 1.46 (m, 1H), 1.40 – 1.33 (m, 1H), 1.23 (d, J = 15.8 Hz, 1H), 1.09 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.0, 164.0, 153.6, 148.7, 136.0, 129.1, 128.2, 127.9, 127.1, 125.1, 124.4, 122.4, 121.2, 121.1, 110.0, 48.3, 47.0, 43.8, 38.5, 32.4, 29.5, 28.6; HRMS (ESI-TOF): calcd. for $C_{22}H_{19}O_2$ $[M + H]^+$ 315.1380; found 315.1387.

Scheme 2, 4w



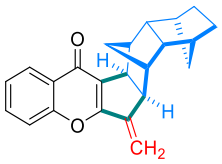
Compound **4w**: white solid, 26.6 mg, 42% yield, mp 161.7 – 162.4 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.15 (d, J = 7.8 Hz, 1H), 8.06 (d, J = 8.6 Hz, 1H), 7.89 (d, J = 6.6 Hz, 1H), 7.80 – 7.69 (m, 1H), 7.65 – 7.51 (m, 2H), 5.79 (s, 1H), 5.34 (s, 1H), 3.16 (s, 1H), 2.82 (s, 1H), 2.68 (s, 1H), 2.24 (s, 1H), 1.75 – 1.66 (m, 1H), 1.66 – 1.58 (m, 1H), 1.55 – 1.46 (m, 1H), 1.41 – 1.33 (m, 1H), 1.22 (d, J = 10.2 Hz, 1H), 1.09 (d, J = 10.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 179.4, 162.4, 157.7, 148.4, 135.2, 131.2, 130.8, 129.2, 129.1, 128.2, 127.2, 126.5, 118.0, 109.8, 48.4, 47.2, 43.7, 38.5, 32.4, 29.5, 28.6; HRMS (ESI-TOF): calcd. for $C_{22}H_{19}O_2$ $[M + H]^+$ 315.1380; found 315.1388.

Fig. 2, 4x



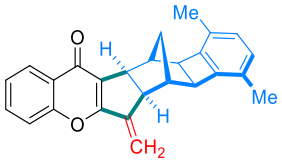
Compound **4x**: yellow solid, 12.9 mg, 25% yield, mp 148.2 – 149.4 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.25 (dd, J = 8.0, 1.6 Hz, 1H), 7.65 (ddd, J = 8.6, 7.2, 1.6 Hz, 1H), 7.49 (dd, J = 8.4, 1.0 Hz, 1H), 7.39 (ddd, J = 8.0, 7.2, 1.0 Hz, 1H), 6.33 (dd, J = 5.8, 3.2 Hz, 1H), 6.18 (dd, J = 5.8, 3.0 Hz, 1H), 5.84 (d, J = 2.4 Hz, 1H), 5.42 (d, J = 2.0 Hz, 1H), 3.25 – 3.05 (m, 2H), 2.85 – 2.71 (m, 2H), 1.42 – 1.37 (m, 1H), 1.27 (dd, J = 11.2, 3.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.9, 165.0, 156.5, 146.8, 139.1, 136.3, 133.4, 126.6, 126.0, 125.1, 125.0, 118.3, 111.1, 48.4, 45.7, 44.6, 43.6, 42.0; HRMS (ESI-TOF): calcd. for $C_{18}H_{15}O_2$ $[M + H]^+$ 263.1067; found 263.1075.

Fig. 2, 4y



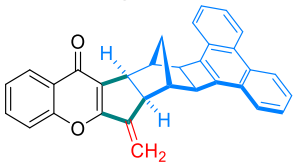
Compound **4y**: white solid, 35.0 mg, 53% yield, mp 142.9 – 144.5 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.23 (dd, J = 8.0, 1.6 Hz, 1H), 7.66 – 7.61 (m, 1H), 7.47 (d, J = 8.4 Hz, 1H), 7.41 – 7.35 (m, 1H), 5.77 (d, J = 2.4 Hz, 1H), 5.30 (d, J = 2.0 Hz, 1H), 3.45 (d, J = 6.2 Hz, 1H), 3.09 (d, J = 5.6 Hz, 1H), 2.64 (d, J = 4.6 Hz, 1H), 2.42 (s, 1H), 2.27 (s, 1H), 2.22 (d, J = 4.4 Hz, 1H), 1.87 (dd, J = 10.0, 4.8 Hz, 1H), 1.76 (dd, J = 10.0, 4.6 Hz, 1H), 1.65 (d, J = 11.0 Hz, 1H), 1.52 (d, J = 7.2 Hz, 2H), 1.19 (d, J = 10.4 Hz, 1H), 1.09 – 0.99 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.9, 164.5, 156.4, 149.1, 133.3, 126.5, 125.9, 125.0, 124.9, 118.2, 110.2, 50.7, 50.0, 48.8, 43.3, 43.1, 42.1, 36.6, 36.5, 35.5, 35.3, 31.4, 31.3; HRMS (ESI-TOF): calcd. for $C_{23}H_{23}O_2$ $[M + H]^+$ 331.1693; found 331.1706.

Fig. 2, 4z



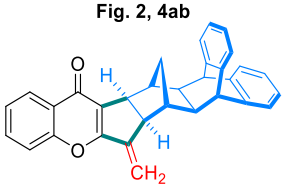
Compound **4z**: white solid, 51.2 mg, 70% yield, mp 189.9 – 190.8 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.26 (dd, J = 8.0, 1.6 Hz, 1H), 7.65 (td, J = 7.0, 1.6 Hz, 1H), 7.49 (dd, J = 8.4, 0.4 Hz, 1H), 7.40 (td, J = 7.6, 1.0 Hz, 1H), 6.90 (s, 2H), 5.86 (d, J = 2.4 Hz, 1H), 5.44 (d, J = 2.0 Hz, 1H), 3.46 (d, J = 3.6 Hz, 1H), 3.31 (d, J = 3.6 Hz, 1H), 3.13 (d, J = 6.4 Hz, 1H), 2.82 (d, J = 5.4 Hz, 1H), 2.71 (s, 1H), 2.31 (s, 1H), 2.18 (s, 3H), 2.17 (s, 3H), 0.96 (d, J = 11.2 Hz, 1H), 0.77 (d, J = 11.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.0, 164.4, 156.4, 147.9, 143.8, 143.1, 133.4, 129.7, 129.2, 128.8, 128.6, 126.2, 125.9, 125.0, 124.8, 118.2, 111.1, 49.2, 47.8, 46.6, 45.6, 42.9, 38.0, 26.5, 16.4, 16.3; HRMS (ESI-TOF): calcd. for $C_{26}H_{23}O_2$ $[M + H]^+$ 367.1693; found 367.1700.

Fig. 2, 4aa



Compound **4aa**: white solid, 44.5 mg, 51% yield, mp 224.6 – 225.8 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.76 – 8.69 (m, 2H), 8.28 (d, J = 7.8 Hz, 1H), 7.91 – 7.81 (m, 2H), 7.64 – 7.57 (m, 5H), 7.49 (d, J = 8.4 Hz, 1H), 7.40 (t, J = 7.2 Hz, 1H), 5.88 (s, 1H), 5.49 (s, 1H), 3.84 (s, 1H), 3.70 (s, 1H), 3.30 (d, J = 3.6 Hz, 1H), 2.98 (s, 1H), 2.89 (s, 1H), 2.50 (s, 1H), 0.98 (d, J = 11.0 Hz, 1H), 0.77 (d, J = 11.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.5, 156.5, 147.9, 140.1, 139.1, 133.5, 131.1, 131.0, 128.3, 128.2, 126.9, 126.7, 126.0, 125.9, 125.8, 125.1, 124.0, 123.8, 123.4, 122.9, 118.3, 111.3, 49.5, 48.1, 47.0, 46.0, 42.4, 37.7, 26.5; HRMS (ESI-TOF): calcd. for $C_{32}H_{23}O_2$ $[M + H]^+$ 439.1693; found 439.1703.

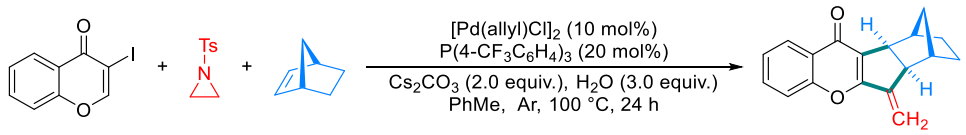
Fig. 2, 4ab



Compound **4ab**: white solid, 72.1 mg, 82% yield, mp 238.5 – 239.3 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.20 (d, J = 8.0 Hz, 1H), 7.61 (t, J = 7.8 Hz, 1H), 7.43 (d, J = 8.4 Hz, 1H), 7.36 (t, J = 7.6 Hz, 1H), 7.29 (dd, J = 8.8, 4.2 Hz, 2H), 7.20 – 7.13 (m, 2H), 7.10 (t, J = 4.2 Hz, 2H), 7.05 (t, J = 3.8 Hz, 2H), 5.73 (d, J = 2.0 Hz, 1H), 5.31 (d, J = 1.2 Hz, 1H), 4.38 (d, J = 2.4 Hz, 1H), 4.31 (d, J = 2.6 Hz, 1H), 2.97 (d, J = 6.4 Hz, 1H), 2.65 (d, J = 5.6 Hz, 1H), 2.43 (s, 1H), 2.21 (dd, J = 8.4 Hz, 2.4 Hz, 1H), 2.07 (dd, J = 8.6 Hz, 2.2 Hz, 1H), 2.03 (s, 1H), 0.36 (d, J = 11.6 Hz, 1H), -0.53 (d, J = 11.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.0, 165.0, 156.3, 147.5, 144.7, 144.5, 142.3, 142.0, 133.4, 126.2, 126.1, 125.9, 125.8, 125.7, 125.4, 125.0, 124.7, 124.5, 124.3, 123.5, 123.3, 118.2, 110.9, 49.8, 49.1, 48.5, 48.4, 48.3, 48.1, 46.8, 41.7, 27.0; HRMS (ESI-TOF): calcd. for $C_{32}H_{25}O_2$ $[M + H]^+$ 441.1849; found 441.1851.

6. Preparative-scale experiments

6.1 Synthesis of **4a** on a gram-scale **(Scheme 3a)**



1a
2.18 g

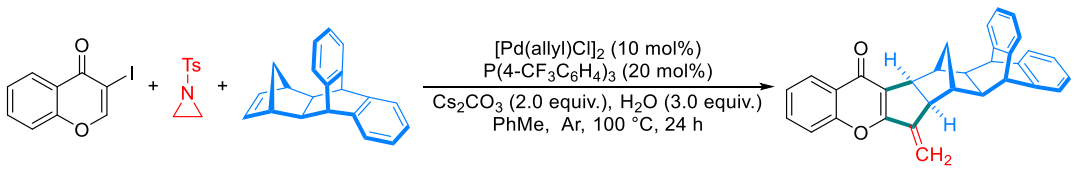
2a

3a

4a
53% yield, 1.12g

To a 350 mL flame-dried pressure tube with a stir bar, **1a** (2.18 g, 8.0 mmol), **2a** (2.21 g, 11.2 mmol), **3a** (3.01 g, 32.0 mmol), $[Pd(allyl)Cl]_2$ (292.7 mg, 0.8 mmol), $P(4\text{-}CF_3C_6H_4)_3$ (746.1 mg, 1.6 mmol), Cs_2CO_3 (5.21 g, 16.0 mmol), H_2O (432.0 μL, 24.0 mmol) and PhMe (80 mL) were added. The reaction tube was evacuated and backfilled with argon three times, and the mixture was stirred at 100 ˚C for 24 h. After completed of the reaction, it was concentrated to remove solvent and purified by flash column chromatography on silica gel (petroleum ether/ethyl acetate = 50:1 – 30:1) to afford the product **4a** (1.12 g, 53% yield).

6.2 Synthesis of **4ab** on a gram-scale (**Scheme 3b**)



1a
1.36 g

2a

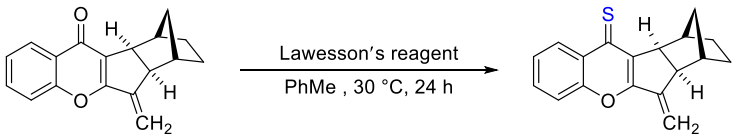
3f

4ab
57% yield, 1.25g

To a 350 mL flame-dried pressure tube with a stir bar, **1a** (1.36 g, 5.0 mmol), **2a** (1.38 g, 7.0 mmol), **3f** (5.41 g, 20.0 mmol), $[Pd(allyl)Cl]_2$ (183.0 mg, 0.5 mmol), $P(4\text{-}CF_3C_6H_4)_3$ (466.3 mg, 1.0 mmol), Cs_2CO_3 (3.26 g, 10.0 mmol), H_2O (270.0 μL, 15.0 mmol) and PhMe (50 mL) were added. The reaction tube was evacuated and backfilled with argon three times, and the mixture was stirred at 100 ˚C for 24 h. After completed of the reaction, it was concentrated to remove solvent and purified by flash column chromatography on silica gel (petroleum ether/ethyl acetate = 50:1 – 20:1) to afford the product **4ab** (1.25 g, 57% yield).

7. Transformations of 4a into 5-12

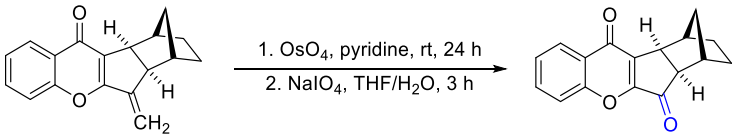
7.1 Synthesis of **5** from **4a** (**Scheme 4**)



4a **5**

To a solution of **4a** (52.8 mg, 0.2 mmol) in extra dry PhMe (2.0 mL) was added Lawesson's reagent (45.2 mg, 0.1 mmol), and the mixture was stirred at 30 ˚C for 24 h. After completion, the reaction mixture was directly purified by flash chromatography on silica gel (petroleum ether/ethyl acetate = 30:1 – 10:1) to afford the product **5** (47.7 mg, 85% yield).[5] Brown solid, mp 182.8 – 184.1 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.62 (dd, J = 8.2, 1.2 Hz, 1H), 7.66 (td, J = 6.8, 1.6 Hz, 1H), 7.49 (dd, J = 8.4, 0.8 Hz, 1H), 7.39 (td, J = 7.6, 1.0 Hz, 1H), 5.95 (d, J = 2.4 Hz, 1H), 5.50 (d, J = 2.0 Hz, 1H), 3.20 (d, J = 6.8 Hz, 1H), 2.84 (d, J = 3.6 Hz, 1H), 2.80 (d, J = 6.4 Hz, 1H), 2.25 (d, J = 3.6 Hz, 1H), 1.67 (tt, J = 12.0, 4.2 Hz, 1H), 1.60 (tt, J = 11.8, 3.8 Hz, 1H), 1.52 – 1.44 (m, 1H), 1.40 – 1.33 (m, 1H), 1.13 (d, J = 10.4 Hz, 1H), 1.05 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 200.2, 155.9, 151.4, 148.5, 137.7, 133.4, 130.8, 128.3, 126.0, 118.6, 112.9, 49.8, 47.9, 43.8, 37.7, 32.7, 29.4, 28.5; HRMS (ESI-TOF): calcd. for $C_{18}H_{17}SO$ $[M + H]^+$ 281.0995; found 281.1008.

7.2 Synthesis of **6** from **4a** (**Scheme 4**)

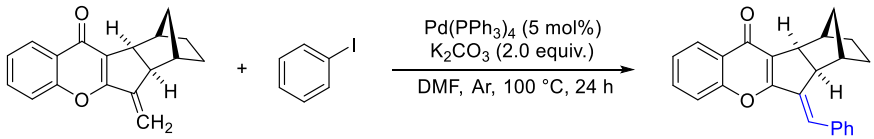


4a **6**

To a solution of **4a** (52.8 mg, 0.2 mmol) in dry pyridine (2.0 mL) was added a solution of OsO_4 in PhMe (0.2 M, 4.4 mL, 0.22 mmol), and the dark reaction mixture was stirred at room temperature for 24 h. Aqueous $NaHSO_3$ solution was added. After further reaction for 90 min, the mixture was diluted with water and extracted with DCM (3 × 10 mL) and ethyl acetate (3 × 10 mL). Drying over anhydrous Na_2SO_4 and evaporation of the solvent from the organic phase gave residue that can be

used directly for the next step. To a solution of the above crude product in THF/H_2O (1:1, 3.0 mL) was added $NaIO_4$ (47.06 mg, 0.22 mmol) at 0 ˚C. The solution was warmed to room temperature and stirred for additional 3 h. Then diluted with ethyl acetate before it was quenched with aqueous $Na_2S_2O_3$ solution. The organic layer was separated, washed with water and brine, dried over anhydrous Na_2SO_4, filtered and concentrated. The residue was purified by flash column chromatography on silica gel (petroleum ether/ethyl acetate = 50:1 – 30:1) to afford the product **6** (33.2 mg, 62% yield).[6] White solid, mp 171.5 – 172.6 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.27 (d, *J* = 7.8 Hz, 1H), 7.75 (t, *J* = 7.8 Hz, 1H), 7.62 (d, *J* = 8.6 Hz, 1H), 7.47 (t, *J* = 7.6 Hz, 1H), 3.14 (d, *J* = 5.4 Hz, 1H), 2.69 (d, *J* = 2.4 Hz, 1H), 2.59 (d, *J* = 2.0 Hz, 1H), 2.49 (d, *J* = 5.0 Hz, 1H), 1.77 (tt, *J* = 12.0, 4.0 Hz, 1H), 1.66 (tt, *J* = 11.8, 4.2 Hz, 1H), 1.56 – 1.47 (m, 1H), 1.43 – 1.35 (m, 1H), 1.09 (d, *J* = 11.0 Hz, 1H), 1.01 (d, *J* = 10.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 202.7, 178.1, 159.6, 156.2, 141.5, 135.2, 126.3, 126.0, 125.2, 119.3, 53.3, 42.3, 40.0, 37.5, 32.2, 29.1, 28.8; HRMS (ESI-TOF): calcd. for $C_{17}H_{15}O_3$ $[M + H]^+$ 267.1016; found 267.1022.

7.3 Synthesis of **7** from **4a** (**Scheme 4**)

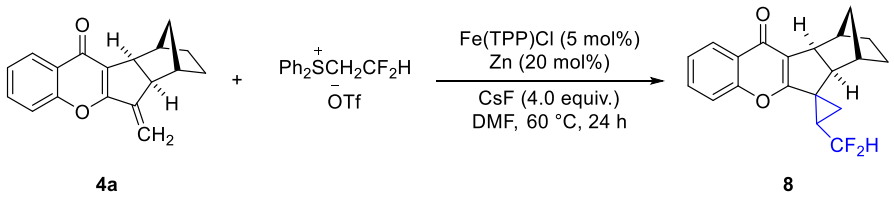


4a **7**

To a 4.0 mL flame-dried vial with a stir bar, **4a** (52.8 mg, 0.2 mmol), iodobenzene (81.6 mg, 0.4 mmol), $Pd(PPh_3)_4$ (11.6 mg, 0.01 mmol), K_2CO_3 (55.3 mg, 0.4 mmol), and DMF (2.0 mL) were added. The reaction vial was evacuated and backfilled with argon three times, and the mixture was stirred at 100 ˚C for 24 h. After completed of the reaction, the reaction solution was extracted with ethyl acetate. The organic phase was separated, washed with water (3 × 10 mL), and dried over anhydrous Na_2SO_4. After filtration, the solvent was removed by concentration. The residue was subjected to flash column chromatography on silica gel (petroleum ether/ethyl acetate = 70:1 – 40:1) to afford the product **7** (60.7 mg, 89% yield).[7] White solid, mp 189.0 – 189.6 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.25 (d, *J* = 7.8 Hz, 1H), 7.68 – 7.59 (m, 3H), 7.53 (d, *J* = 8.4 Hz, 1H), 7.43 (t, *J* = 7.6 Hz, 2H), 7.37 (d, *J* = 7.6 Hz, 1H), 7.32 (t, *J* = 7.2 Hz, 1H), 7.12 (s, 1H), 3.25 (s, 2H), 2.69 (s,

1H), 2.44 (s, 1H), 1.76 – 1.66 (m, 1H), 1.65 – 1.56 (m, 1H), 1.55 – 1.41 (m, 2H), 1.22 (d, *J* = 10.4 Hz, 1H), 1.02 (d, *J* = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.6, 165.8, 156.4, 139.9, 135.7, 133.3, 129.7, 128.9, 128.3, 125.9, 125.8, 125.5, 125.0, 124.9, 118.1, 48.0, 47.7, 39.4, 39.3, 32.6, 29.0, 28.8; HRMS (ESI-TOF): calcd. for $C_{24}H_{21}O_2$ $[M + H]^+$341.1536; found 341.1546.

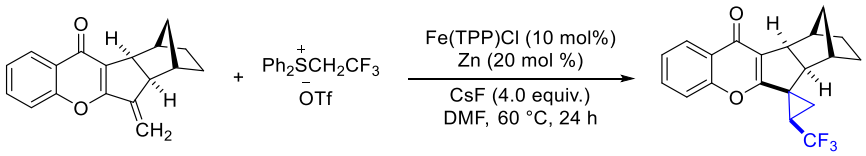
7.4 Synthesis of **8** from **4a** (**Scheme 4**)



Into a mixture of Fe(TPP)Cl (7.04 mg, 0.01 mmol) and zinc powder (2.6 mg, 0.04 mmol) was added DMF (0.5 mL) under Ar atmosphere, and the mixture was stirred at 60 ˚C for 10 min. Substrate **4a** (52.8 mg, 0.2 mmol), sulfonium salt $Ph_2S^+CH_2CF_2H{\cdot}TfO^-$ (160.0 mg, 0.4 mmol), CsF (121.5 mg, 0.8 mmol) and DMF (2.0 mL) were then added. The resulting mixture was stirred at 60 ˚C for another 24 h, then diluted with DCM (10.0 mL) and water (10.0 mL). The organic phase was separated and washed with water (3 × 10 mL), and then dried over anhydrous Na_2SO_4. After filtration, the solvent was removed by concentration. The residue was subjected to flash column chromatography on silica gel (petroleum ether/ethyl acetate = 40:1 – 20:1) to afford the product **8** (59.1 mg, 90% yield).[8] White solid, mp 115.0 – 116.3 ˚C; 55:45 dr; ^{1}H NMR (400 MHz, $CDCl_3$) δ (major + minor) 8.22 (d, *J* = 8.0 Hz, 1H), 7.60 (q, *J* = 7.2 Hz, 1H), 7.41 – 7.30 (m, 2H), 5.94 (td, *J* = 55.6, 7.6 Hz, 0.55H), 5.71 (td, *J* = 55.8, 5.4 Hz, 0.45H), 3.29 (d, *J* = 7.6 Hz, 0.55H), 3.25 (d, *J* = 7.6 Hz, 0.45H), 2.64 (s, 1H), 2.31 (d, *J* = 7.6 Hz, 0.45H), 2.17 (d, *J* = 7.6 Hz, 0.55H), 2.11 – 2.04 (m, 0.45H), 1.99 (dd, *J* = 11.2, 3.6 Hz, 1H), 1.83 (sext, *J* = 8.0 Hz, 0.55H), 1.64 – 1.39 (m, 4.45H), 1.39 – 1.27 (m, 1.55H), 1.22 – 1.06 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (major + minor) 175.4, 175.3, 169.0, 168.1, 156.4, 156.2, 133.1, 132.9, 126.1, 126.0, 125.3, 125.1, 124.7, 124.6, 123.3, 121.3, 117.8, 117.7, 116.4 (t, *J* = 238.0 Hz), 116.3 (t, *J* = 235.0 Hz), 48.9, 48.3, 47.9, 43.6, 39.7, 39.4, 39.3, 39.0, 33.9, 33.6, 32.9, 32.8, 32.3 (t, *J* = 30.0 Hz), 29.0, 28.9, 27.9, 27.7, 26.2 (t, *J* = 28.0 Hz), 14.4, 13.0; ^{19}F NMR (376 MHz, $CDCl_3$) δ (major + minor) -107.01 (ABdd, *J* = 289.6, 56.0 Hz, major), -110.24 (ABddd, *J* = 289.6, 55.4, 9.6 Hz, major), -112.60 (ABddd, *J* = 287.0, 55.8, 10.4 Hz,

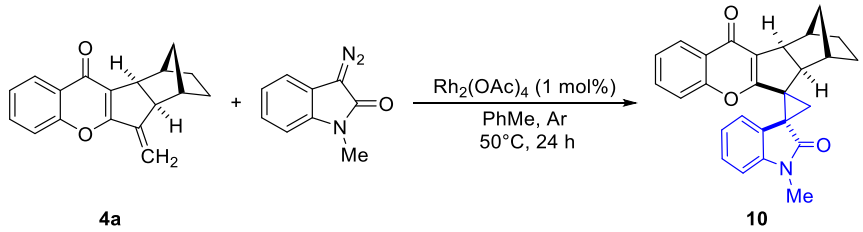
minor), -116.02 (ABddd, J = 287.0, 55.8, 9.6 Hz, minor); HRMS (ESI-TOF): calcd. for $C_{20}H_{19}F_2O_2$ $[M + H]^+$ 329.1348; found 329.1356.

7.5 Synthesis of **9** from **4a** (**Scheme 4**)



Into a mixture of Fe(TPP)Cl (14.1 mg, 0.02 mmol) and zinc powder (2.6 mg, 0.04 mmol) was added DMF (0.5 mL) under Ar atmosphere, and the mixture was stirred at 60 ˚C for 10 min. Substrate **4a** (52.8 mg, 0.2 mmol), sulfonium salt $Ph_2S^+CH_2CF_3{\cdot}TfO^-$ (167.4 mg, 0.4 mmol), CsF (121.5 mg, 0.8 mmol) and DMF (2.0 mL) were then added. The resulting mixture was stirred at 60 ˚C for another 24 h, then diluted with DCM (10.0 mL) and water (10.0 mL). The organic phase was separated and washed with water (3 × 10 mL), and then dried over anhydrous Na_2SO_4. After filtration, the solvent was removed by concentration. The residue was subjected to flash column chromatography on silica gel (petroleum ether/ethyl acetate = 40:1 – 20:1) to afford the product **9** (55.4 mg, 80% yield).[8] White solid, mp 134.8 – 135.9 ˚C; 99:1 dr; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.22 (d, J = 7.8 Hz, 1H), 7.60 (t, J = 7.8 Hz, 1H), 7.41 – 7.33 (m, 2H), 3.30 (d, J = 7.4 Hz, 1H), 2.66 (d, J = 3.8 Hz, 1H), 2.16 (d, J = 7.4 Hz, 1H), 2.02 – 1.91 (m, 2H), 1.86 (t, J = 6.8 Hz, 1H), 1.66 – 1.50 (m, 3H), 1.50 – 1.40 (m, 1H), 1.30 (d, J = 10.6 Hz, 1H), 1.17 – 1.06 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.7, 166.8, 156.4, 133.1, 125.9, 125.2, 125.1 (q, J = 273.2 Hz), 124.5, 123.8, 118.1, 49.7, 47.6, 39.1, 38.9, 34.9 (q, J = 2.0 Hz), 32.8, 31.7 (q, J = 38.8 Hz), 28.8, 28.0, 14.31 (q, J = 3.2 Hz); ^{19}F NMR (376 MHz, $CDCl_3$) δ -59.6 (s, 3F); HRMS (ESI-TOF): calcd. for $C_{20}H_{18}F_3O_2$ $[M + H]^+$ 347.1253; found 347.1261.

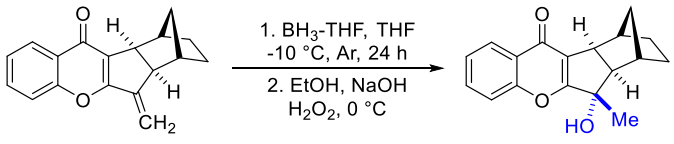
7.6 Synthesis of **10** from **4a** (**Scheme 4**)



4a **10**

To a solution of **4a** (52.8 mg, 0.2 mmol) and $Rh_2(OAc)_4$ (0.89 mg, 0.002 mmol) in extra dry PhMe (1.0 mL) was added a solution of 3-diazooxindole (57.7 mg, 0.4 mmol) in extra dry DCM (1.0 mL) under Ar atmosphere. The mixture was stirred at 50 ˚C for 24 h. After completion, the reaction mixture was directly purified by flash chromatography on silica gel (petroleum ether/ethyl acetate = 5:1 – 3:1) to afford the product **10** (74.8 mg, 91% yield).[9] White solid, mp 186.5 – 187.7 ˚C; 99:1 dr; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.21 (d, J = 7.8 Hz, 1H), 7.76 – 7.64 (m, 2H), 7.57 (d, J = 8.4 Hz, 1H), 7.39 (t, J = 7.6 Hz, 1H), 7.23 (t, J = 7.6 Hz, 1H), 7.00 (t, J = 7.6 Hz, 1H), 6.87 (d, J = 7.8 Hz, 1H), 3.28 (s, 3H), 3.11 (d, J = 7.4 Hz, 1H), 2.64 (s, 1H), 2.52 (t, J = 7.2 Hz, 2H), 2.39 (s, 1H), 2.33 (d, J = 5.6 Hz, 1H), 1.68 – 1.57 (m, 2H), 1.47 – 1.27 (m, 3H), 1.11 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.7, 167.4, 156.1, 144.5, 133.3, 127.6, 126.5, 126.3, 125.4, 123.3, 121.6, 117.6, 108.2, 49.3, 46.8, 44.9, 41.8, 40.3, 39.3, 32.7, 28.8, 28.2, 26.8, 23.4; HRMS (ESI-TOF): calcd. for $C_{27}H_{24}NO_3$ $[M + H]^+$ 410.1751; found 410.1759.

7.7 Synthesis of **11** from **4a** (**Scheme 4**)

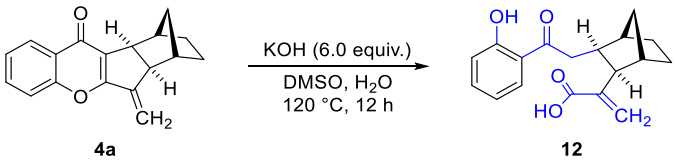


4a **11**

To a THF (1.0 mL) solution of **4a** (52.8 mg, 0.2 mmol) was added 1M borane tetrahydrofuran (BH_3-THF, 0.35 mL, 0.35 mmol) under Ar atmosphere, and the mixture was stirred at -10 ˚C for 24 h. The reaction was quenched by careful addition of ethanol (0.50 mL), 3N NaOH (0.30 mL) and 30% aqueous H_2O_2 solution (0.40 mL) at 0 ˚C. The resulting solution was extracted with DCM (3 × 5 mL) and washed with brine (2.0 mL). The organic layers were combined, dried over anhydrous

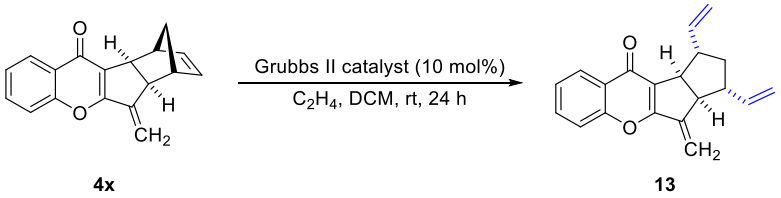
Na_2SO_4, concentrated under reduced pressure, and purified by flash chromatography on silica gel (petroleum ether/ethyl acetate = 5:1 – 3:1) to afford the product **11** (29.6 mg, 52% yield).[10] White solid, mp 258.1 – 259.4 ˚C, 99:1 dr; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.17 (dd, J = 8.0, 1.4 Hz, 1H), 7.59 (td, J = 7.8, 1.6, 1H), 7.42 – 7.30 (m, 2H), 3.11 (d, J = 7.0 Hz, 1H), 3.01 (brs, 1H), 2.55 (s, 1H), 2.31 (s, 1H), 2.11 (d, J = 7.0 Hz, 1H), 1.64 – 1.51 (m, 5H), 1.36 – 1.12 (m, 2H), 1.01 (d, J = 10.4 Hz, 1H), 0.93 (d, J = 10.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.7, 169.5, 157.0, 133.5, 125.8, 125.1, 124.4, 121.5, 118.4, 80.9, 55.9, 47.5, 37.8, 37.6, 33.2, 29.1, 28.6, 20.2; HRMS (ESI-TOF): calcd. for $C_{18}H_{19}O_3$ $[M + H]^+$ 283.1329; found 283.1334.

7.8 Synthesis of **12** from **4a** (**Scheme 4**)



To a 10.0 mL pressure tube with a stir bar, **4a** (52.8 mg, 0.2 mmol), KOH (67.3 mg, 1.2 mmol), H_2O (1.0 mL) and DMSO (2.0 mL) were added. The mixture was stirred at 120 ˚C for 12 h. After completed of the reaction, it was concentrated to remove solvent and purified by flash column chromatography on silica gel (DCM/MeOH = 40:1 – 20:1) to afford the product **12** (28.8 mg, 48% yield). White solid, mp 204.3 – 205.3 ˚C; ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.59 (s, 1H), 11.96 (s, 1H), 7.77 (d, J = 7.6 Hz, 1H), 7.51 (t, J = 7.6 Hz, 1H), 6.93 (t, J = 7.8 Hz, 2H), 6.19 (s, 1H), 5.69 (s, 1H), 2.74 (d, J = 9.2 Hz, 1H), 2.67 (d, J = 15.4 Hz, 1H), 2.40 – 2.31 (m, 1H), 2.22 (s, 1H), 1.96 (s, 1H), 1.65 (d, J = 9.6 Hz, 1H), 1.50 (s, 2H), 1.23 (t, J = 9.4 Hz, 3H), 1.13 (d, J = 10.0 Hz, 1H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 206.4, 169.2, 160.9, 141.9, 136.2, 130.6, 123.7, 120.3, 119.3, 117.9, 109.7, 45.5, 43.4, 40.8, 40.7, 34.0, 30.2, 28.5; HRMS (ESI-TOF): calcd. for $C_{18}H_{21}O_4$ $[M + H]^+$301.1434; found 301.1432.

8. Transformation of 4x into 13



4x **13**

Ethylene gas was gently bubbled through a solution of **4x** (52.5 mg, 0.2 mmol) in extra dry DCM (40 mL) over 10 min followed by addition of the Grubbs II catalyst (17.0 mg, 0.02 mmol). The mixture was stirred at room temperature for 24 h. After completion, the reaction mixture was directly purified by flash chromatography on silica gel (petroleum ether/ethyl acetate = 90:1 – 60:1) afford the product **13** (21.8 mg, 44% yield).[11] White solid, mp 71.2 – 72.3 ˚C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.24 (dd, J = 7.8, 1.6 Hz, 1H), 7.64 (td, J = 7.8, 1.6 Hz, 1H), 7.49 (d, J = 8.4 Hz, 1H), 7.39 (td, J = 7.6, 0.8 Hz, 1H), 6.45 (ddd, J = 16.8, 10.4, 6.0 Hz, 1H), 5.89 (ddd, J = 17.2, 10.2, 8.2 Hz, 1H), 5.77 (d, J = 2.2 Hz, 1H), 5.38 (d, J = 1.6 Hz, 1H), 5.18 – 5.05 (m, 4H), 3.41 (t, J = 8.4 Hz, 1H), 3.03 (t, J = 9.0 Hz, 1H), 2.60 – 2.50 (m, 1H), 2.35 (dq, J = 8.4, 4.0 Hz, 1H), 2.02 (dt, J = 8.2, 5.6 Hz, 1H), 1.65 (q, J = 12.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.1, 161.5, 156.5, 146.8, 141.6, 140.6, 133.4, 127.5, 126.0, 125.1, 125.0, 118.2, 115.4, 113.4, 110.6, 51.6, 49.7, 49.6, 49.2, 41.2; HRMS (ESI-TOF): calcd. for $C_{20}H_{19}O_2$ $[M + H]^+$291.1380; found 291.1385.

9. References

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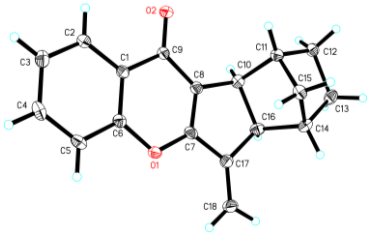
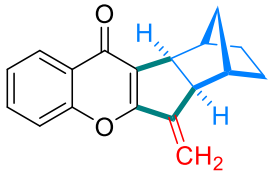
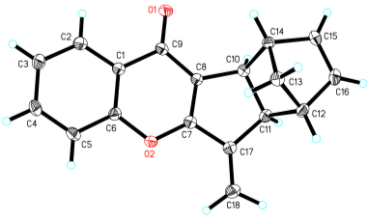
10. X-ray crystal data for 4a, 4x, 4y, 4z, 4aa, 4ab, 7, 9, 10, 11, 12, 4a' and 4a''

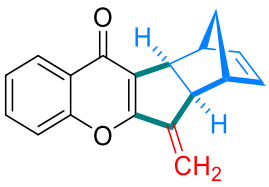




4a (CCDC: 2058527)

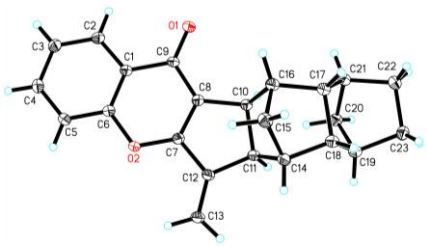
Identification code	**4a**
Empirical formula	$C_{18}H_{16}O_2$
Formula weight	264.31
Temperature/K	100.00(10)
Crystal system	orthorhombic
Space group	$P2_12_12_1$
a/Å	7.2944(5)
b/Å	11.3560(9)
c/Å	15.9573(12)
α/°	90
β/°	90
γ/°	90
Volume/Å^3	1321.83(17)
Z	4
ρ_{calc}g/cm^3	1.328
μ/mm^{-1}	0.085
F(000)	560.0
Crystal size/mm^3	0.12 × 0.1 × 0.08
Radiation	Mo Kα (λ = 0.71073)
2θ range for data collection/°	4.402 to 49.996
Index ranges	-6 ≤ h ≤ 8, -13 ≤ k ≤ 10, -16 ≤ l ≤ 18
Reflections collected	4093
Independent reflections	2252 [R_{int} = 0.0261, R_{sigma} = 0.0395]
Data/restraints/parameters	2252/0/189
Goodness-of-fit on F^2	1.048
Final R indexes [I>=2σ (I)]	R_1 = 0.0434, wR_2 = 0.0958
Final R indexes [all data]	R_1 = 0.0479, wR_2 = 0.0991
Largest diff. peak/hole / e Å^{-3}	0.17/-0.19
Flack parameter	0.8(10)

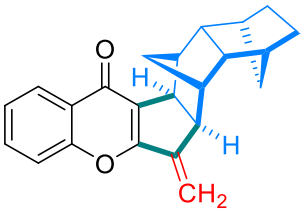




4x (CCDC: 2058528)

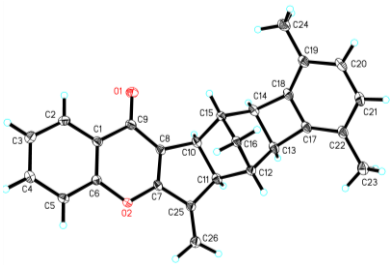
Identification code	**4x**
Empirical formula	$C_{18}H_{14}O_2$
Formula weight	262.29
Temperature/K	150.00(10)
Crystal system	monoclinic
Space group	$P2_1$
a/Å	5.3438(6)
b/Å	14.9294(15)
c/Å	8.1896(9)
α/°	90
β/°	98.718(11)
γ/°	90
Volume/Å^3	645.82(13)
Z	2
ρ_{calc}g/cm^3	1.349
μ/mm^{-1}	0.087
F(000)	276.0
Crystal size/mm^3	0.14 × 0.13 × 0.12
Radiation	Mo Kα (λ = 0.71073)
2θ range for data collection/°	5.032 to 58.898
Index ranges	-6 ≤ h ≤ 7, -20 ≤ k ≤ 15, -6 ≤ l ≤ 10
Reflections collected	3087
Independent reflections	2260 [R_{int} = 0.0200, R_{sigma} = 0.0380]
Data/restraints/parameters	2260/1/190
Goodness-of-fit on F^2	1.044
Final R indexes [I>=2σ (I)]	R_1 = 0.0377, wR_2 = 0.0815
Final R indexes [all data]	R_1 = 0.0416, wR_2 = 0.0846
Largest diff. peak/hole / e Å^{-3}	0.14/-0.24
Flack parameter	0.6(15)

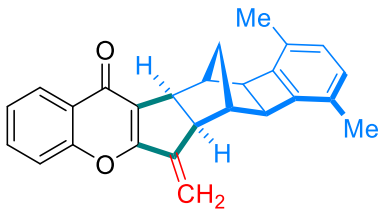




4y (CCDC: 2058529)

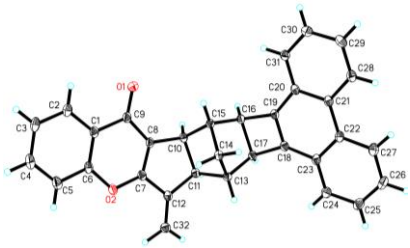
Identification code	**4y**
Empirical formula	$C_{23}H_{22}O_2$
Formula weight	330.40
Temperature/K	149.99(10)
Crystal system	triclinic
Space group	P-1
a/Å	12.0554(6)
b/Å	13.0086(9)
c/Å	13.4818(8)
α/°	116.323(7)
β/°	91.642(4)
γ/°	114.330(6)
Volume/Å^3	1667.9(2)
Z	4
ρ_{calc}g/cm^3	1.316
μ/mm^{-1}	0.645
F(000)	704.0
Crystal size/mm^3	0.13 × 0.12 × 0.1
Radiation	Cu Kα (λ = 1.54184)
2θ range for data collection/°	7.574 to 147.742
Index ranges	-15 ≤ h ≤ 11, -16 ≤ k ≤ 14, -15 ≤ l ≤ 16
Reflections collected	11435
Independent reflections	6532 [R_{int} = 0.0379, R_{sigma} = 0.0485]
Data/restraints/parameters	6532/0/451
Goodness-of-fit on F^2	1.078
Final R indexes [I>=2σ (I)]	R_1 = 0.0860, wR_2 = 0.2346
Final R indexes [all data]	R_1 = 0.0990, wR_2 = 0.2522
Largest diff. peak/hole / e Å^{-3}	0.41/-0.39

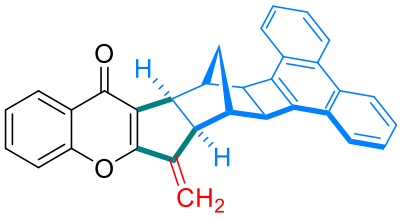




4z (CCDC: 2058530)

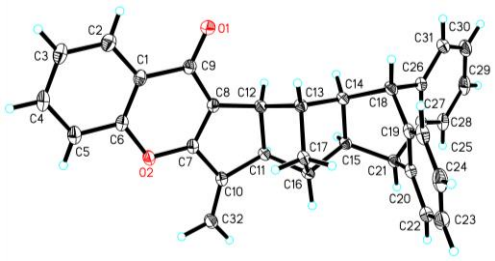
Identification code	**4z**
Empirical formula	$C_{26}H_{22}O_2$
Formula weight	366.43
Temperature/K	150.00(10)
Crystal system	monoclinic
Space group	$P2_1/c$
a/Å	11.0214(6)
b/Å	15.4607(9)
c/Å	11.2885(7)
α/°	90
β/°	98.746(5)
γ/°	90
Volume/Å^3	1901.18(19)
Z	4
ρ_{calc}g/cm^3	1.280
μ/mm^{-1}	0.079
F(000)	776.0
Crystal size/mm^3	0.14 × 0.13 × 0.12
Radiation	Mo Kα (λ = 0.71073)
2θ range for data collection/°	4.502 to 49.988
Index ranges	$-13 \le h \le 12$, $-18 \le k \le 17$, $-11 \le l \le 13$
Reflections collected	8636
Independent reflections	3347 [R_{int} = 0.0265, R_{sigma} = 0.0347]
Data/restraints/parameters	3347/0/263
Goodness-of-fit on F^2	1.055
Final R indexes [I>=2σ (I)]	R_1 = 0.0439, wR_2 = 0.0966
Final R indexes [all data]	R_1 = 0.0563, wR_2 = 0.1038
Largest diff. peak/hole / e Å^{-3}	0.20/-0.23

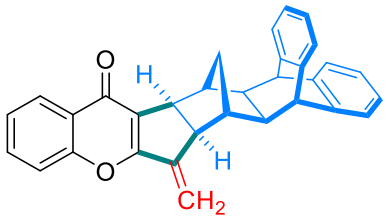




4aa (CCDC: 2058531)

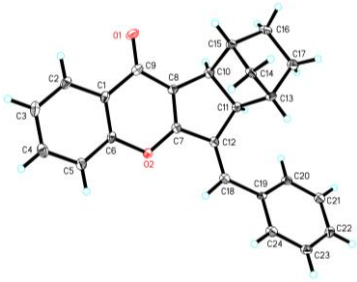
Identification code	**4aa**
Empirical formula	$C_{32}H_{22}O_2$
Formula weight	438.49
Temperature/K	149.99(10)
Crystal system	orthorhombic
Space group	$Pca2_1$
a/Å	13.7006(6)
b/Å	5.4053(2)
c/Å	28.9327(13)
α/°	90
β/°	90
γ/°	90
Volume/Å^3	2142.64(16)
Z	4
ρ_{calc}g/cm^3	1.359
μ/mm^{-1}	0.653
F(000)	920.0
Crystal size/mm^3	0.12 × 0.1 × 0.09
Radiation	Cu Kα (λ = 1.54184)
2θ range for data collection/°	6.11 to 147.726
Index ranges	-15 ≤ h ≤ 16, -6 ≤ k ≤ 6, -35 ≤ l ≤ 22
Reflections collected	5047
Independent reflections	2774 [R_{int} = 0.0284, R_{sigma} = 0.0343]
Data/restraints/parameters	2774/1/316
Goodness-of-fit on F^2	1.080
Final R indexes [I>=2σ (I)]	R_1 = 0.0364, wR_2 = 0.0899
Final R indexes [all data]	R_1 = 0.0382, wR_2 = 0.0919
Largest diff. peak/hole / e Å^{-3}	0.17/-0.17
Flack parameter	1.6(4)

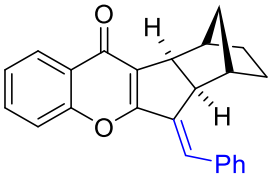




4ab (CCDC: 2058532)

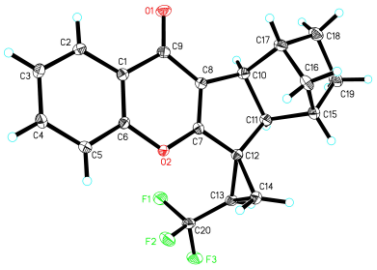
Identification code	**4ab**
Empirical formula	$C_{32}H_{24}O_2$
Formula weight	440.51
Temperature/K	149.99(10)
Crystal system	monoclinic
Space group	$P2_1/c$
a/Å	11.4782(7)
b/Å	17.1767(9)
c/Å	12.0834(8)
α/°	90
β/°	112.707(7)
γ/°	90
Volume/Å^3	2197.7(3)
Z	4
ρ_{calc}g/cm^3	1.331
μ/mm^{-1}	0.637
F(000)	928.0
Crystal size/mm^3	0.12 × 0.11 × 0.1
Radiation	Cu Kα (λ = 1.54184)
2θ range for data collection/°	8.35 to 147.622
Index ranges	-12 ≤ h ≤ 14, -14 ≤ k ≤ 21, -15 ≤ l ≤ 10
Reflections collected	8701
Independent reflections	4314 [R_{int} = 0.0565, R_{sigma} = 0.0682]
Data/restraints/parameters	4314/0/315
Goodness-of-fit on F^2	1.068
Final R indexes [I>=2σ (I)]	R_1 = 0.0699, wR_2 = 0.1888
Final R indexes [all data]	R_1 = 0.0876, wR_2 = 0.2088
Largest diff. peak/hole / e Å^{-3}	0.32/-0.35

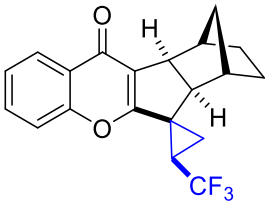




7 (CCDC: 2058534)

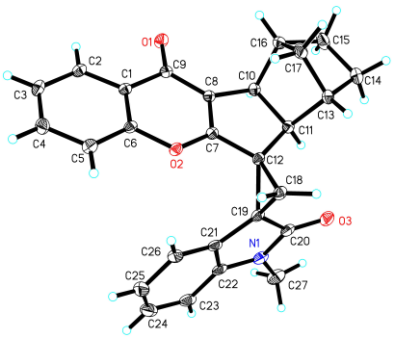
Identification code	**7**
Empirical formula	$C_{24}H_{20}O_2$
Formula weight	340.40
Temperature/K	150.00(10)
Crystal system	monoclinic
Space group	$P2_1$
a/Å	5.9952(5)
b/Å	16.7750(15)
c/Å	8.7581(8)
α/°	90
β/°	106.597(10)
γ/°	90
Volume/Å^3	844.10(14)
Z	2
ρ_{calc}g/cm^3	1.339
μ/mm^{-1}	0.084
F(000)	360.0
Crystal size/mm^3	0.12 × 0.11 × 0.1
Radiation	Mo Kα (λ = 0.71073)
2θ range for data collection/°	4.854 to 49.984
Index ranges	$-7 \le h \le 5$, $-19 \le k \le 19$, $-10 \le l \le 9$
Reflections collected	3430
Independent reflections	2523 [R_{int} = 0.0264, R_{sigma} = 0.0639]
Data/restraints/parameters	2523/1/235
Goodness-of-fit on F^2	1.038
Final R indexes [I>=2σ (I)]	R_1 = 0.0487, wR_2 = 0.1001
Final R indexes [all data]	R_1 = 0.0590, wR_2 = 0.1063
Largest diff. peak/hole / e Å^{-3}	0.18/-0.24
Flack parameter	-0.6(10)

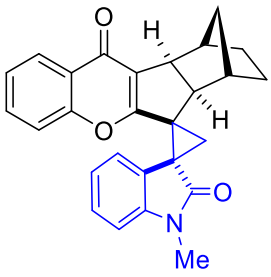




9 (CCDC: 2058536)

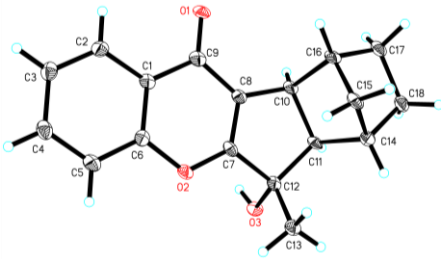
Identification code	**9**
Empirical formula	$C_{20}H_{17}F_3O_2$
Formula weight	346.33
Temperature/K	149.99(10)
Crystal system	monoclinic
Space group	$P2_1/c$
a/Å	9.7519(7)
b/Å	15.4163(10)
c/Å	10.9175(8)
α/°	90
β/°	105.715(8)
γ/°	90
Volume/Å^3	1580.0(2)
Z	4
ρ_{calc}g/cm^3	1.456
μ/mm^{-1}	0.116
F(000)	720.0
Crystal size/mm^3	0.14 × 0.12 × 0.11
Radiation	Mo Kα (λ = 0.71073)
2θ range for data collection/°	4.338 to 49.994
Index ranges	$-11 \le h \le 8$, $-18 \le k \le 15$, $-12 \le l \le 12$
Reflections collected	7021
Independent reflections	2790 [R_{int} = 0.0252, R_{sigma} = 0.0319]
Data/restraints/parameters	2790/0/226
Goodness-of-fit on F^2	1.050
Final R indexes [I>=2σ (I)]	R_1 = 0.0391, wR_2 = 0.0845
Final R indexes [all data]	R_1 = 0.0471, wR_2 = 0.0895
Largest diff. peak/hole / e Å^{-3}	0.21/-0.24

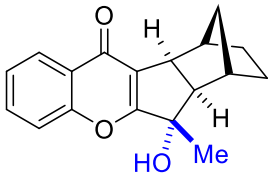




10 (CCDC: 2058537)

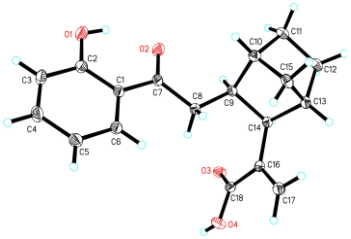
Identification code	**10**
Empirical formula	$C_{27}H_{23}NO_3$
Formula weight	409.46
Temperature/K	149.99(10)
Crystal system	monoclinic
Space group	Ia
a/Å	12.9830(7)
b/Å	10.0352(4)
c/Å	16.4235(8)
α/°	90
β/°	109.296(5)
γ/°	90
Volume/Å^3	2019.56(18)
Z	4
ρ_{calc}g/cm^3	1.347
μ/mm^{-1}	0.699
F(000)	864.0
Crystal size/mm^3	0.13 × 0.12 × 0.11
Radiation	Cu Kα (λ = 1.54184)
2θ range for data collection/°	10.502 to 147.51
Index ranges	-16 ≤ h ≤ 16, -12 ≤ k ≤ 8, -20 ≤ l ≤ 19
Reflections collected	3985
Independent reflections	2967 [R_{int} = 0.0270, R_{sigma} = 0.0304]
Data/restraints/parameters	2967/2/282
Goodness-of-fit on F^2	1.077
Final R indexes [I>=2σ (I)]	R_1 = 0.0392, wR_2 = 0.1034
Final R indexes [all data]	R_1 = 0.0400, wR_2 = 0.1043
Largest diff. peak/hole / e Å^{-3}	0.24/-0.38
Flack parameter	1.0(3)

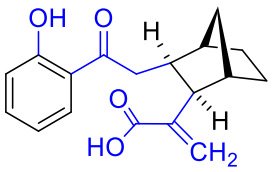




11 (CCDC: 2058538)

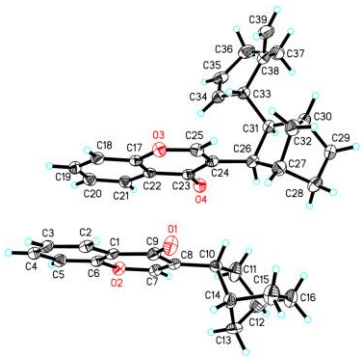
Identification code	**11**
Empirical formula	$C_{18}H_{18}O_3$
Formula weight	282.32
Temperature/K	149.99(10)
Crystal system	triclinic
Space group	P-1
a/Å	7.9260(13)
b/Å	8.5308(15)
c/Å	11.3433(18)
α/°	74.736(15)
β/°	89.146(13)
γ/°	64.955(16)
Volume/Å^3	666.2(2)
Z	2
ρ_{calc}g/cm^3	1.407
μ/mm^{-1}	0.095
F(000)	300.0
Crystal size/mm^3	0.13 × 0.1 × 0.08
Radiation	Mo Kα (λ = 0.71073)
2θ range for data collection/°	5.496 to 49.998
Index ranges	-6 ≤ h ≤ 9, -10 ≤ k ≤ 9, -13 ≤ l ≤ 13
Reflections collected	4305
Independent reflections	2349 [R_{int} = 0.0402, R_{sigma} = 0.0749]
Data/restraints/parameters	2349/0/192
Goodness-of-fit on F^2	1.055
Final R indexes [I>=2σ (I)]	R_1 = 0.0835, wR_2 = 0.2078
Final R indexes [all data]	R_1 = 0.1087, wR_2 = 0.2349
Largest diff. peak/hole / e Å^{-3}	0.46/-0.38

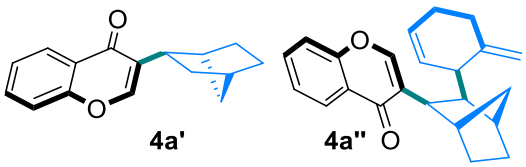




12 (CCDC: 2058540)

Identification code	**12**
Empirical formula	$C_{18}H_{20}O_4$
Formula weight	300.34
Temperature/K	149.99(10)
Crystal system	orthorhombic
Space group	Pbca
a/Å	8.2978(4)
b/Å	11.1917(5)
c/Å	32.354(2)
α/°	90
β/°	90
γ/°	90
Volume/Å^3	3004.6(3)
Z	8
ρ_{calc}g/cm^3	1.328
μ/mm^{-1}	0.758
F(000)	1280.0
Crystal size/mm^3	0.15 × 0.11 × 0.08
Radiation	Cu Kα (λ = 1.54184)
2θ range for data collection/°	5.462 to 133.158
Index ranges	-9 ≤ h ≤ 9, -12 ≤ k ≤ 13, -37 ≤ l ≤ 38
Reflections collected	6145
Independent reflections	2641 [R_{int} = 0.0365, R_{sigma} = 0.0420]
Data/restraints/parameters	2641/0/209
Goodness-of-fit on F^2	1.066
Final R indexes [I>=2σ (I)]	R_1 = 0.0511, wR_2 = 0.1183
Final R indexes [all data]	R_1 = 0.0629, wR_2 = 0.1253
Largest diff. peak/hole / e Å^{-3}	0.18/-0.21



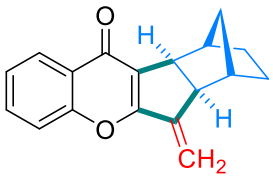


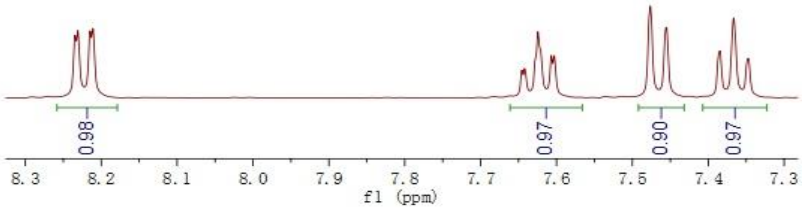
4a' and **4a''** (CCDC: 2077701)

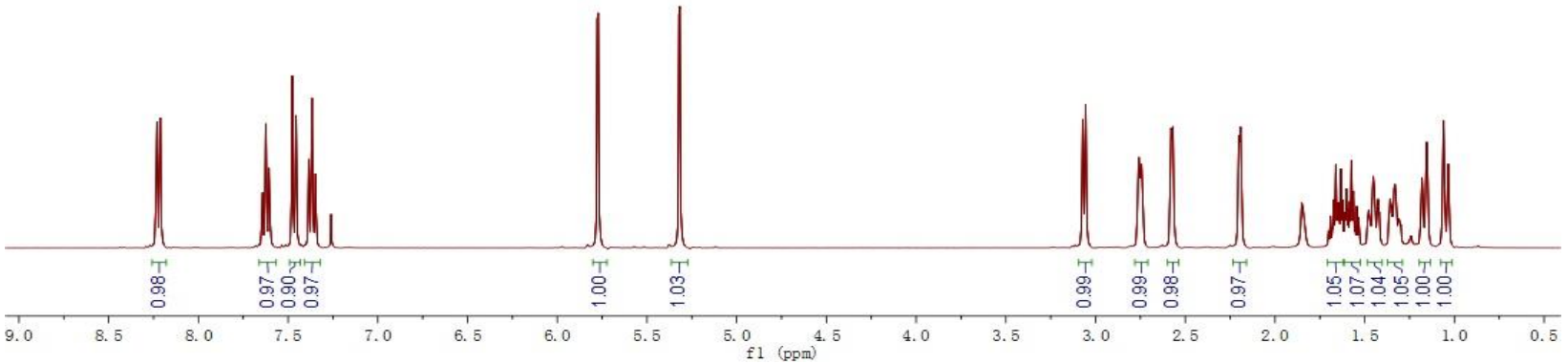
Identification code	**4a'** and **4a''**
Empirical formula	$C_{39}H_{40}O_4$
Formula weight	572.71
Temperature/K	149.99(10)
Crystal system	monoclinic
Space group	$P2_1/n$
a/Å	19.8900(14)
b/Å	6.5408(4)
c/Å	23.4265(19)
α/°	90
β/°	102.826(7)
γ/°	90
Volume/Å^3	2971.7(4)
Z	4
ρ_{calc}g/cm^3	1.280
μ/mm^{-1}	0.639
F(000)	1224.0
Crystal size/mm^3	0.14 × 0.11 × 0.09
Radiation	Cu Kα (λ = 1.54184)
2θ range for data collection/°	5.282 to 133.196
Index ranges	-23 ≤ h ≤ 23, -7 ≤ k ≤ 4, -26 ≤ l ≤ 27
Reflections collected	10226
Independent reflections	5241 [R_{int} = 0.0395, R_{sigma} = 0.0488]
Data/restraints/parameters	5241/0/388
Goodness-of-fit on F^2	1.024
Final R indexes [I>=2σ (I)]	R_1 = 0.0750, wR_2 = 0.2001
Final R indexes [all data]	R_1 = 0.0975, wR_2 = 0.2243
Largest diff. peak/hole / e Å^{-3}	0.31/-0.31

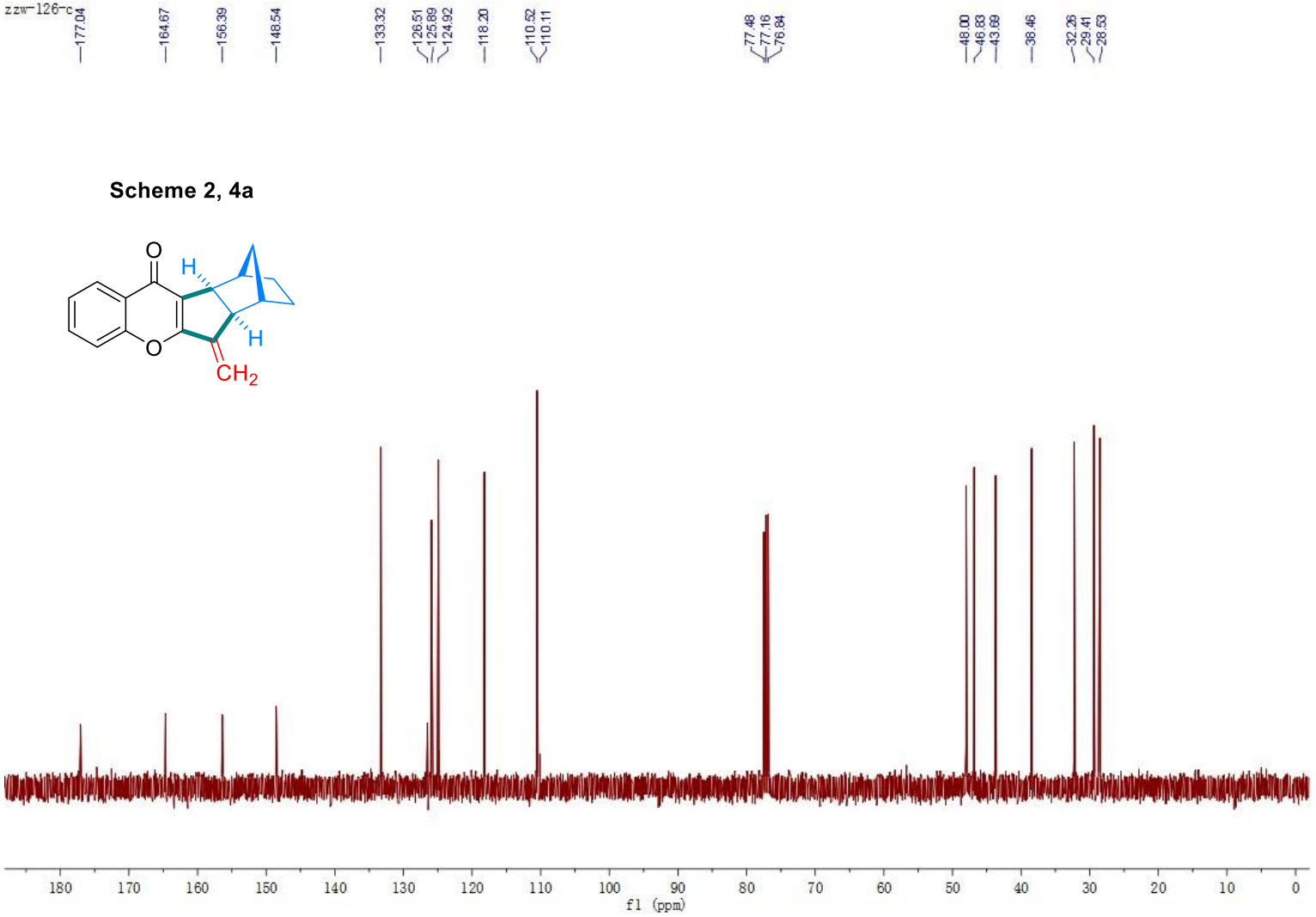
11. ^{1}H and ^{13}C NMR spectra of 4a-ab and 5-13

Scheme 2, 4a





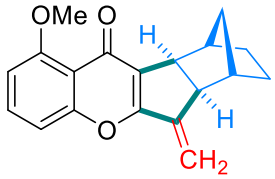


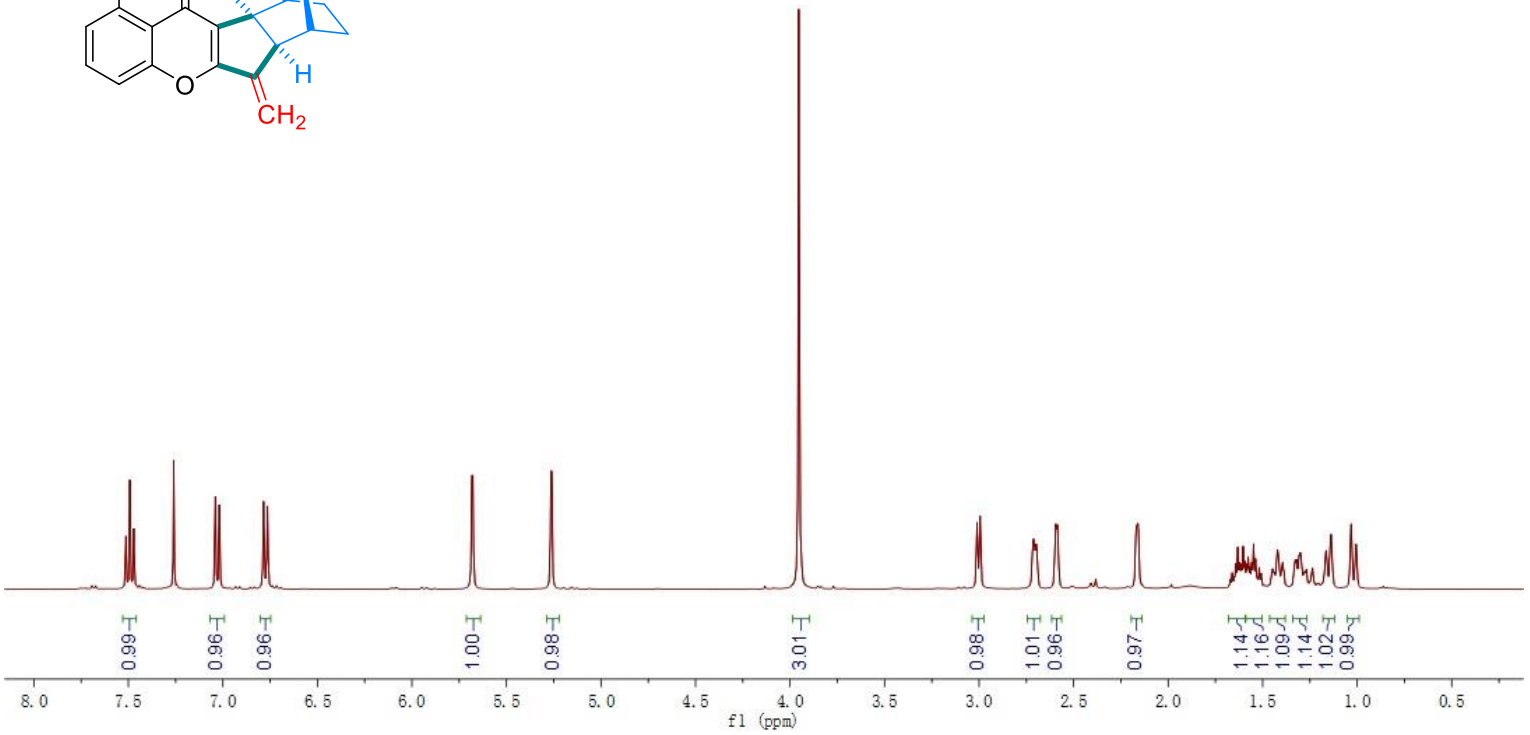

zzw-126-c
177.04
164.67
156.39
148.54
133.32
126.51
125.89
124.92
118.20
110.52
110.11
77.48
77.16
76.84
48.00
46.83
43.69
38.46
32.26
29.41
28.53
O
H
H
O
CH2
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

Scheme 2, 4a


zzw-140-H
7.5130
7.4921
7.4712
7.2698
7.0395
7.0185
6.7848
6.7641
5.6834
5.6776
5.2646
5.2603
3.9539
3.0106
2.9944
2.7127
2.6880
2.5943
2.5855
2.1680
2.1594
1.6318
1.6035
1.5766
1.5480
1.5377
1.4212
1.3064
1.3012
1.1646
1.1386
1.0319
1.0059

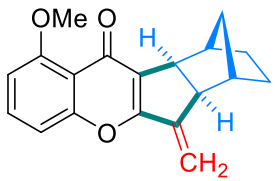
Scheme 2, 4b

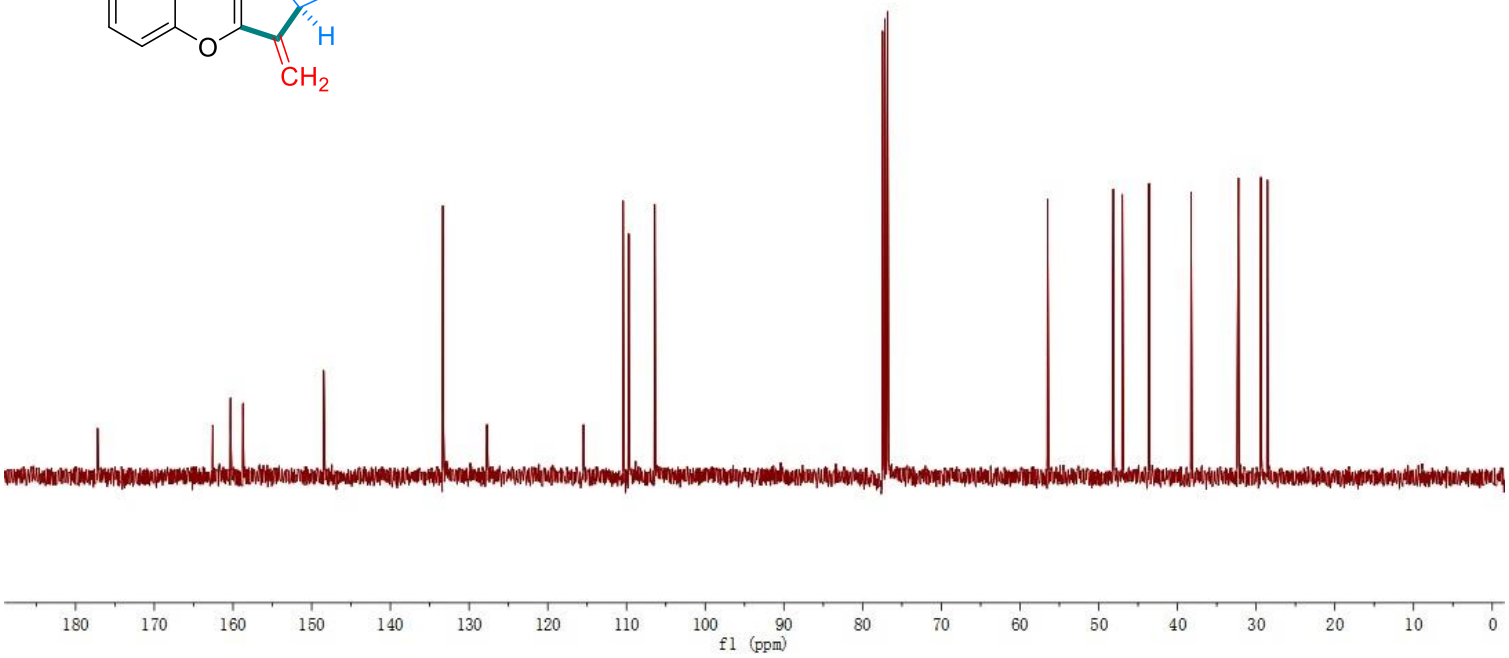

OMe
O
H
H
O
CH2


0.99
0.96
0.96
1.00
0.98
3.01
0.98
1.01
0.96
0.97
1.14
1.16
1.09
1.14
1.02
0.99
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

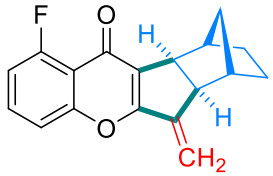

zzw-140-C
177.22
162.56
160.30
158.72
148.49
133.32
127.72
115.46
110.45
109.72
106.42
77.48
77.16
76.84
56.50
48.13
47.00
43.60
38.27
32.25
29.38
28.58

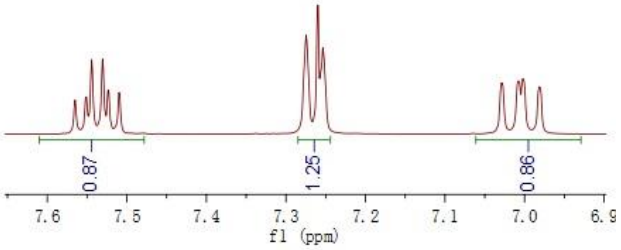
Scheme 2, 4b

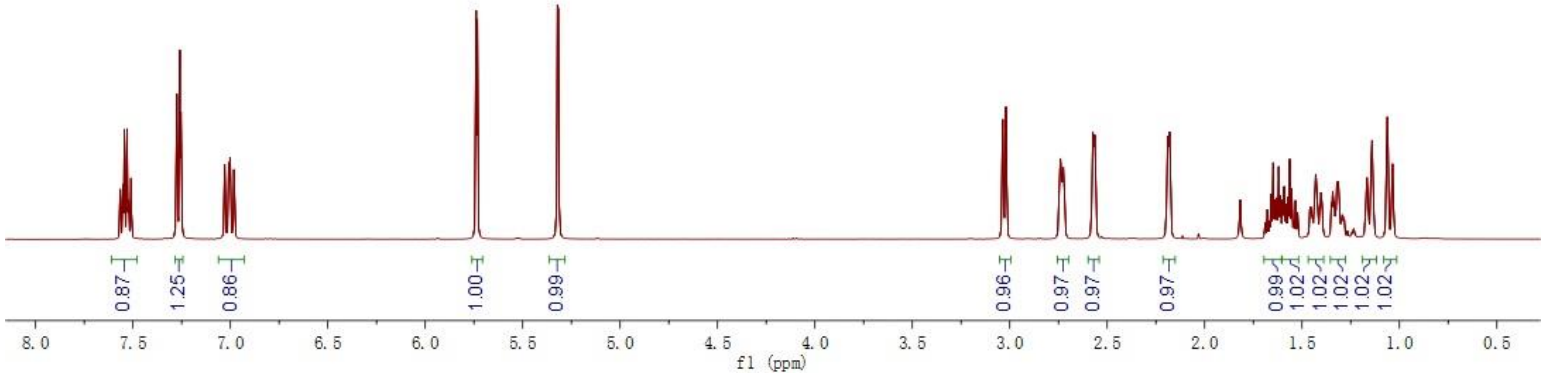

OMe
O
H
H
O
CH2

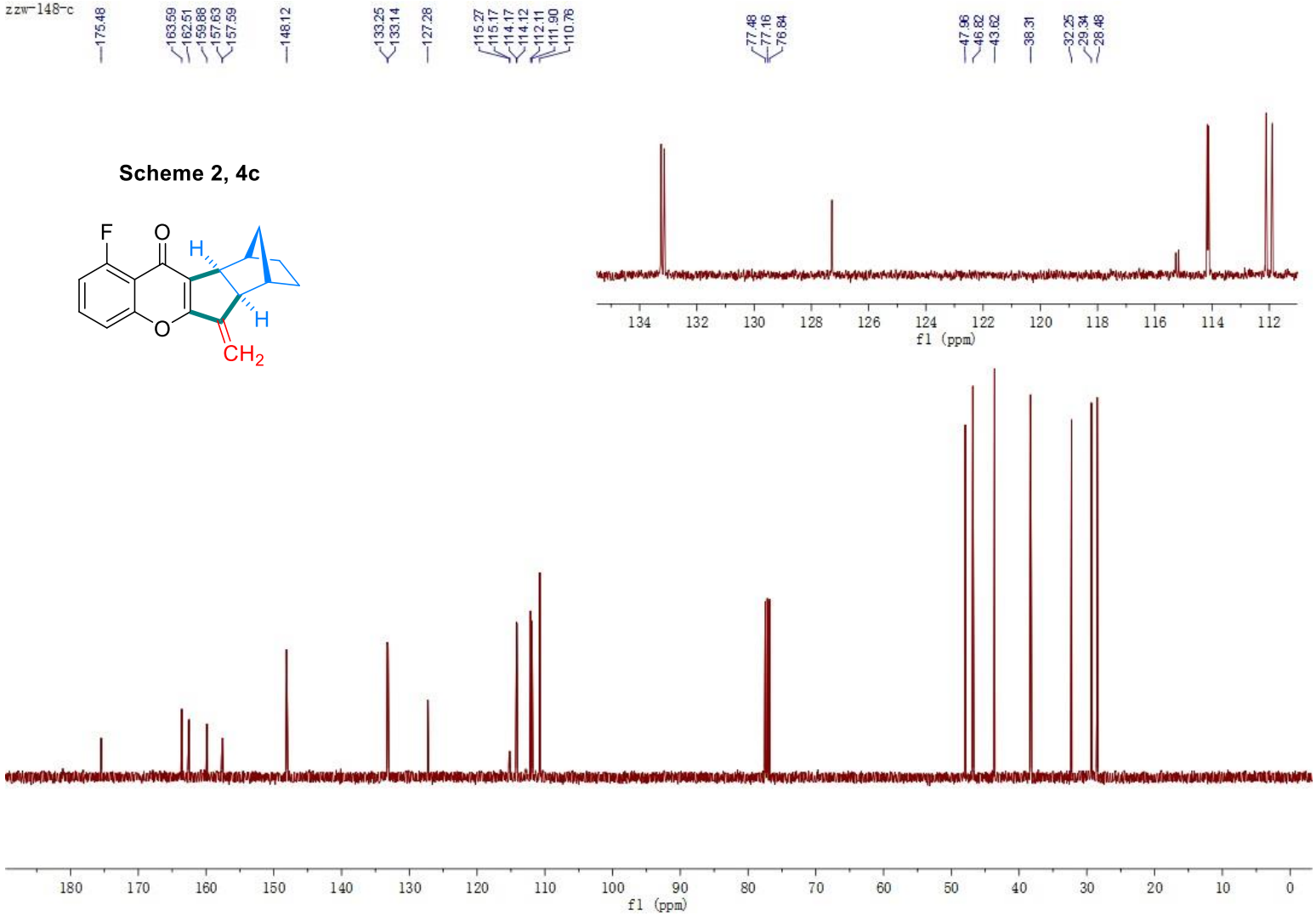

180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

Scheme 2, 4c


F
O
H
H
O
CH2


0.87
1.25
0.86
7.6
7.5
7.4
7.3
7.2
7.1
7.0
f1 (ppm)

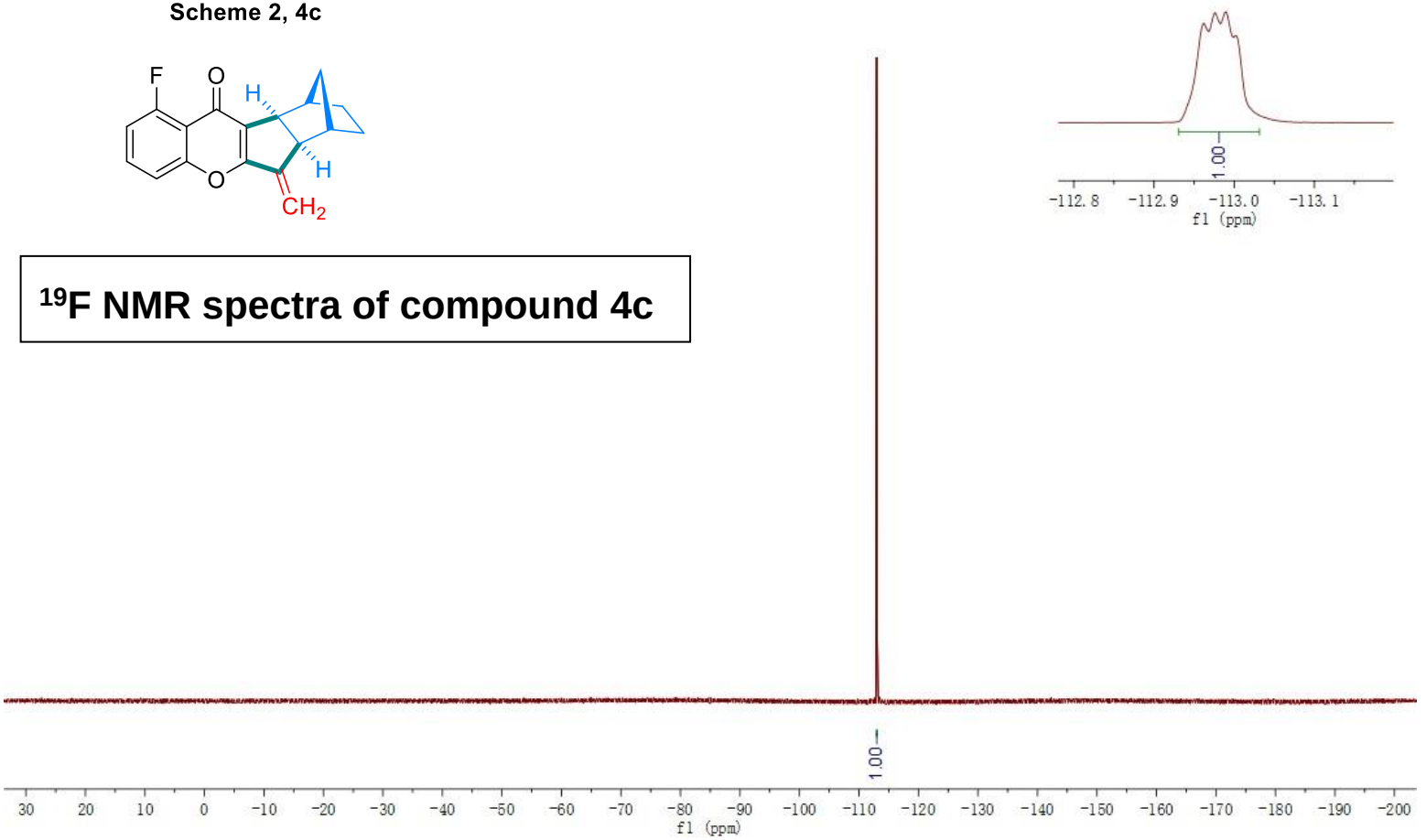

0.87
1.25
0.86
1.00
0.99
0.96
0.97
0.97
0.97
0.99
1.02
1.02
1.02
1.02
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

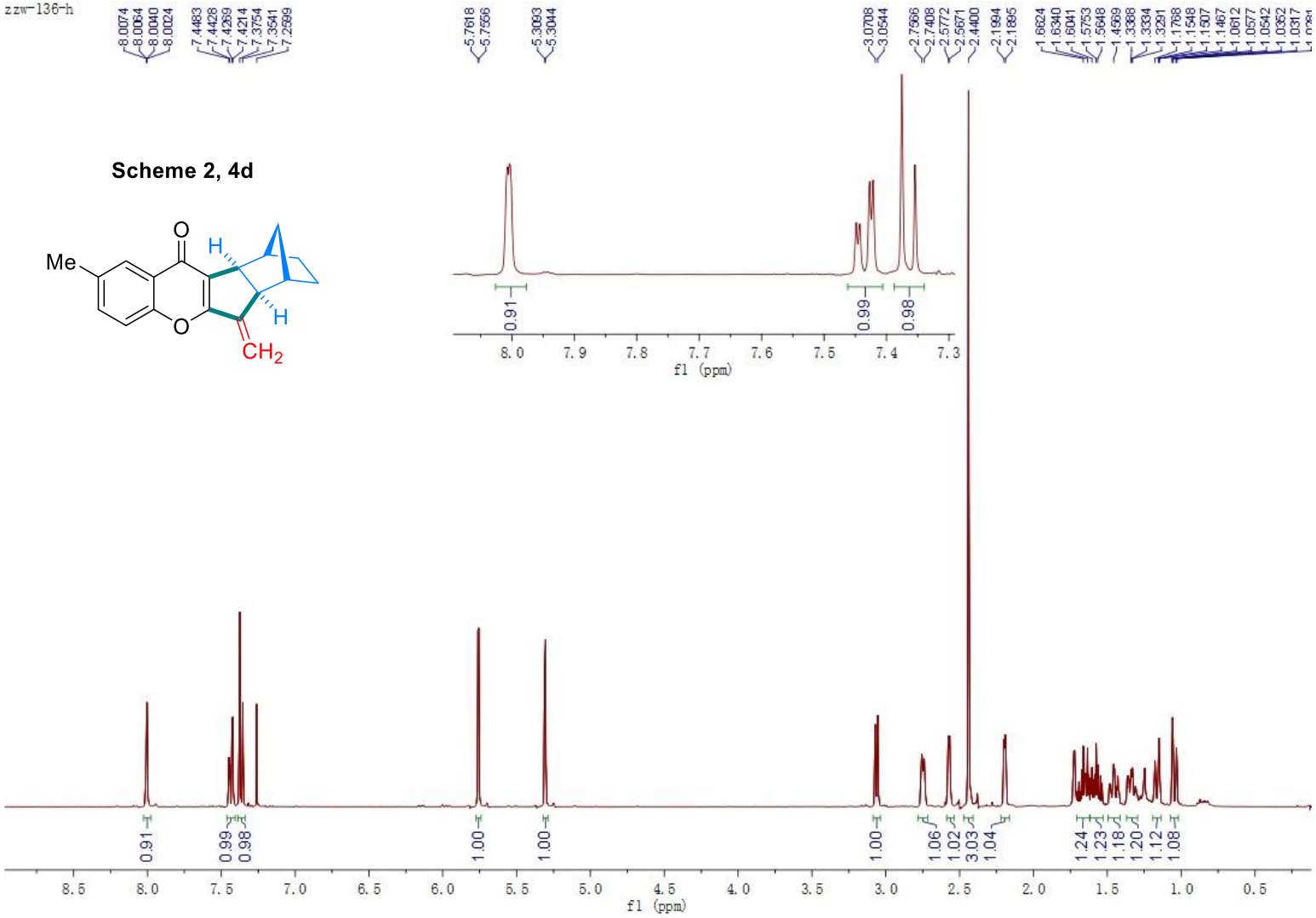

zzw-148-c
175.48
163.59
162.51
159.88
157.63
157.59
148.12
133.25
133.14
127.28
115.27
115.17
114.17
114.12
112.11
111.90
110.78
77.48
77.16
76.84
47.96
46.82
43.62
38.31
32.25
29.34
28.48
Scheme 2, 4c
F
O
H
H
O
CH2
134
132
130
128
126
124
122
120
118
116
114
112
f1 (ppm)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

zzw-148-F

Scheme 2, 4c

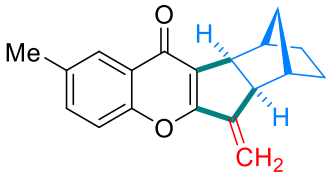
^{19}F NMR spectra of compound 4c

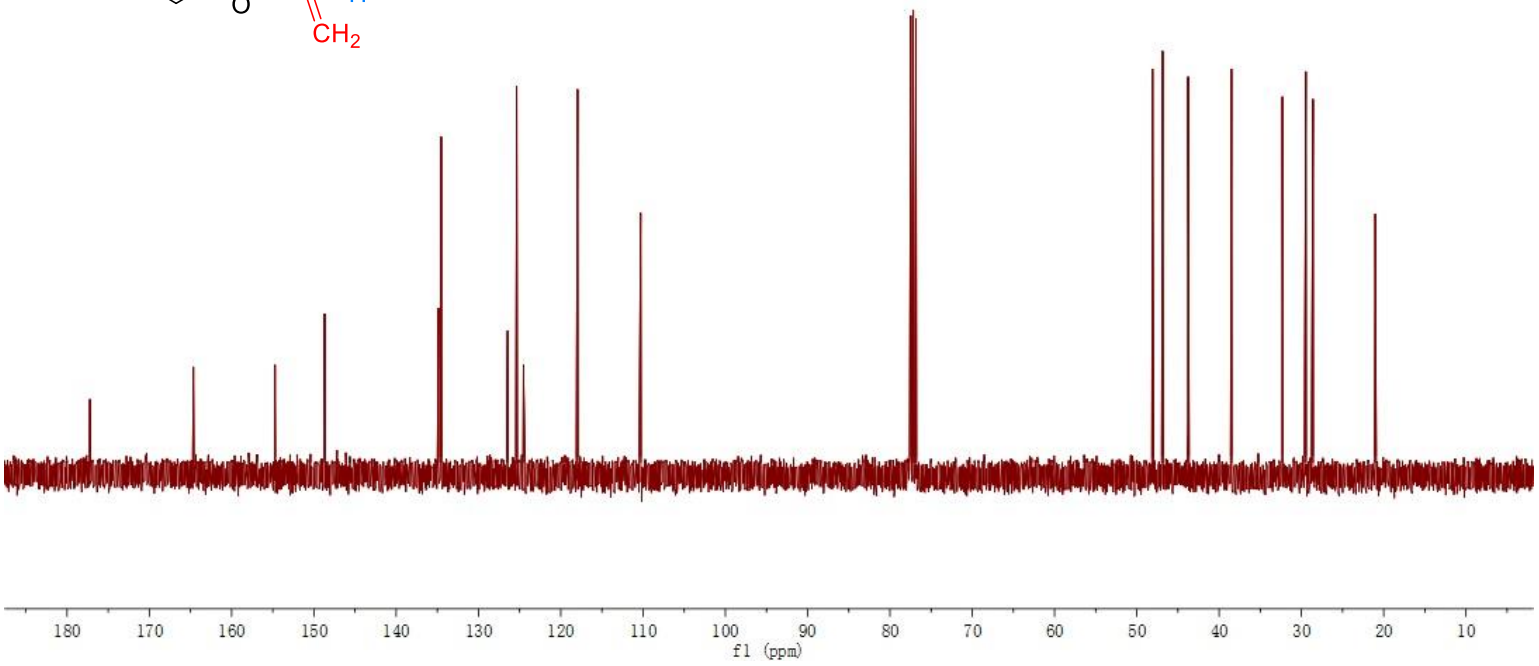


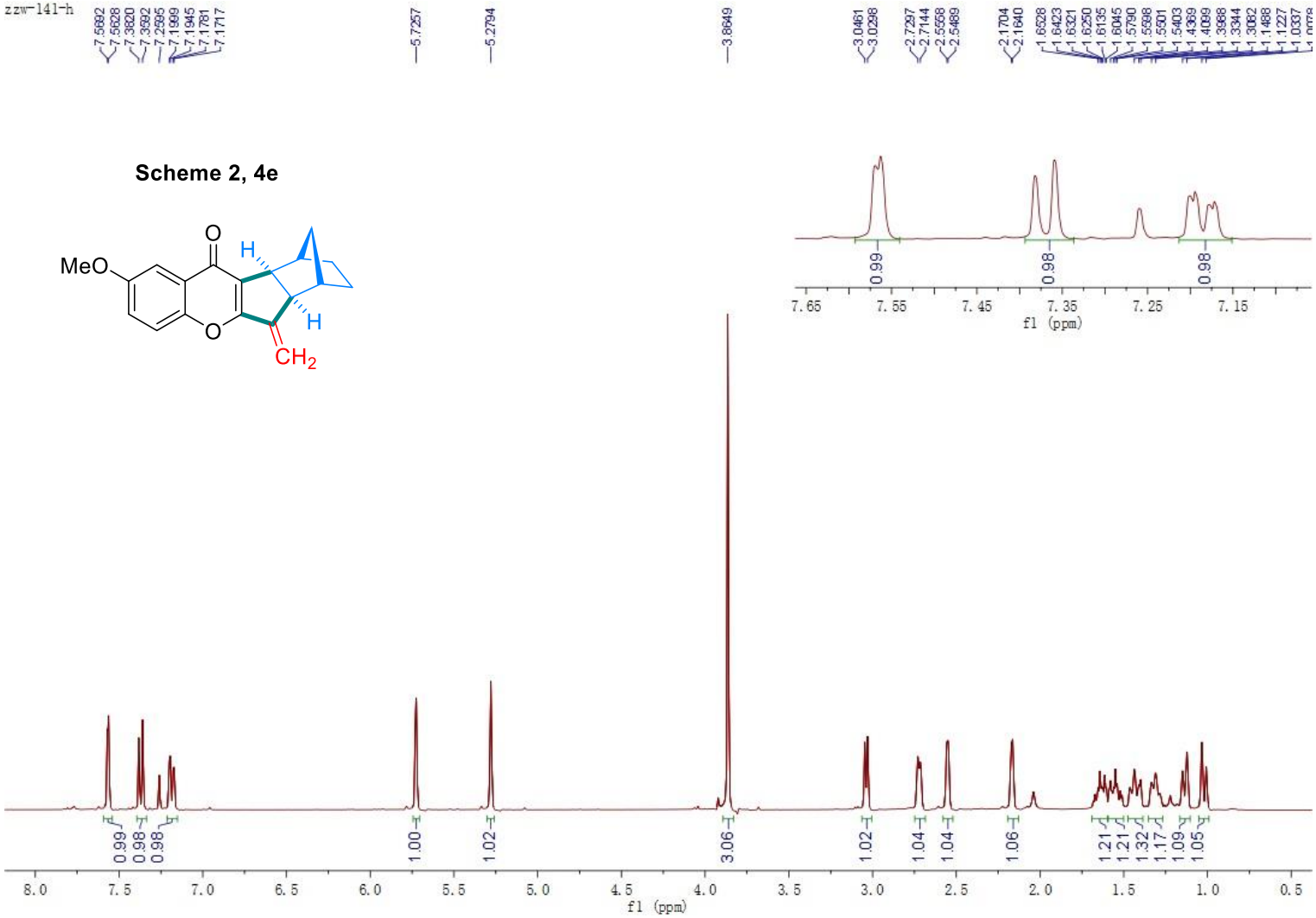

zzw-136-h
Scheme 2, 4d
Me
O
H
H
O
CH2
f1 (ppm)


zzw-136-c
177.21
164.65
154.73
148.71
134.87
134.54
126.45
125.35
124.53
117.97
110.30
77.48
77.16
76.84
48.09
46.87
43.76
38.51
32.30
29.46
28.60
21.01

Scheme 2, 4d

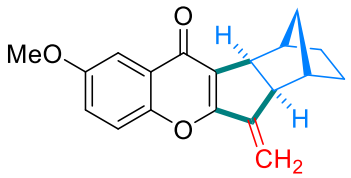

O
Me
H
H
O
CH2

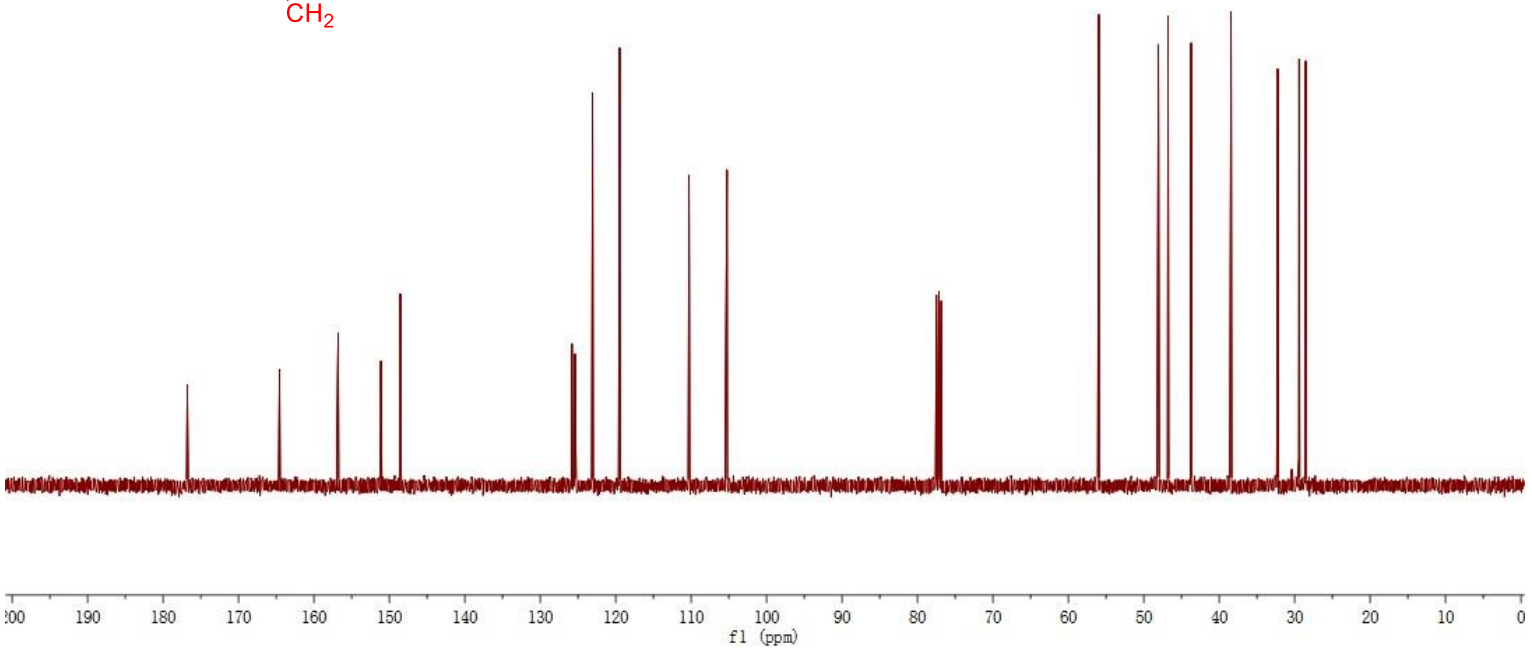

180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)


zzw-141-h
Scheme 2, 4e
MeO
O
H
H
O
CH2
f1 (ppm)


zzw-141-c
176.78
164.56
156.78
151.12
148.53
125.80
125.40
123.06
119.48
110.28
105.25
77.48
77.16
76.84
55.96
48.06
46.78
43.71
38.43
32.24
29.40
28.53

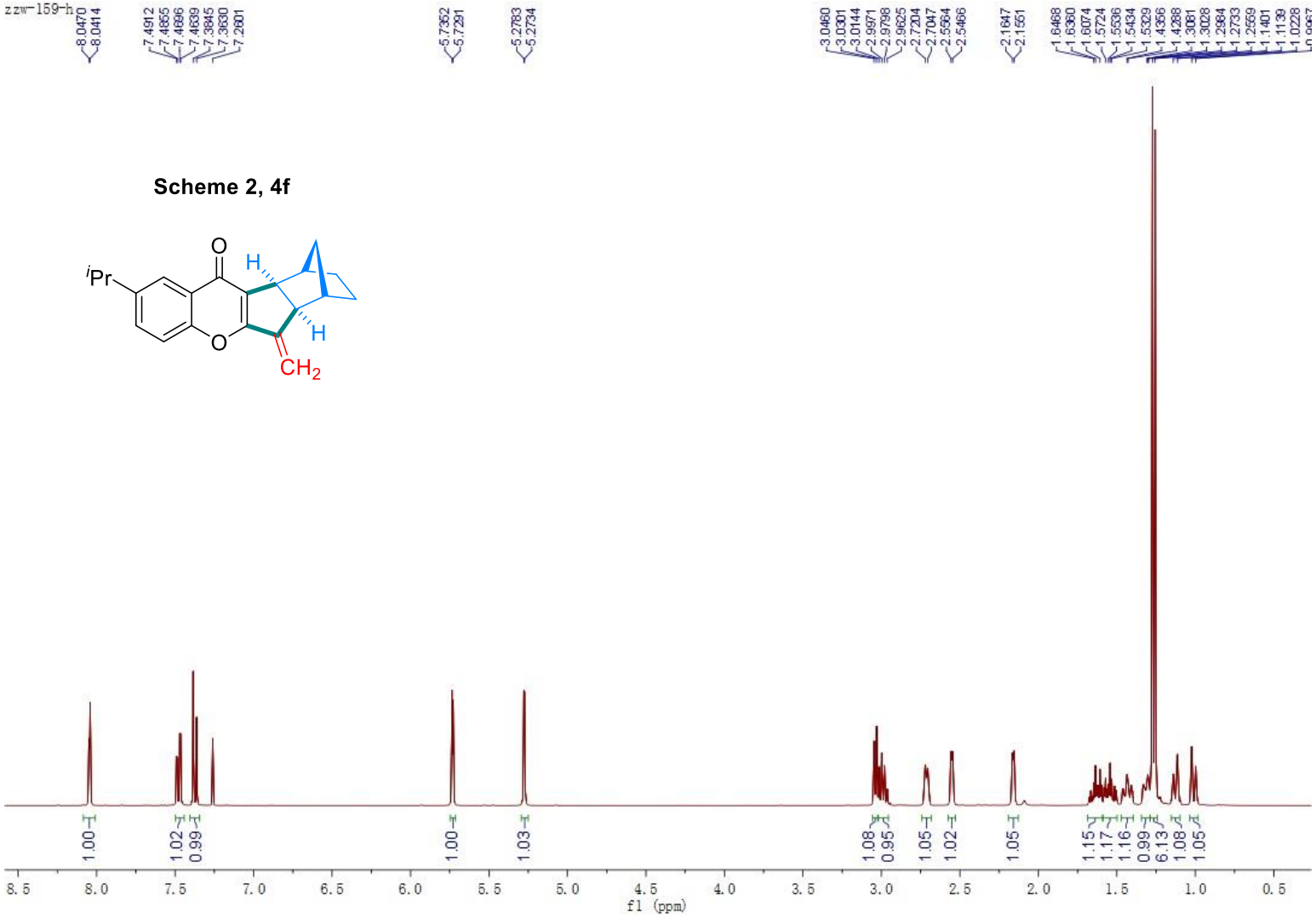
Scheme 2, 4e


MeO
O
H
H
O
CH2


200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

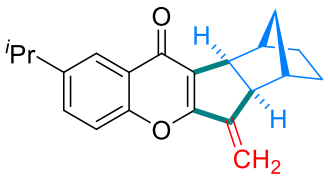
Scheme 2, 4f

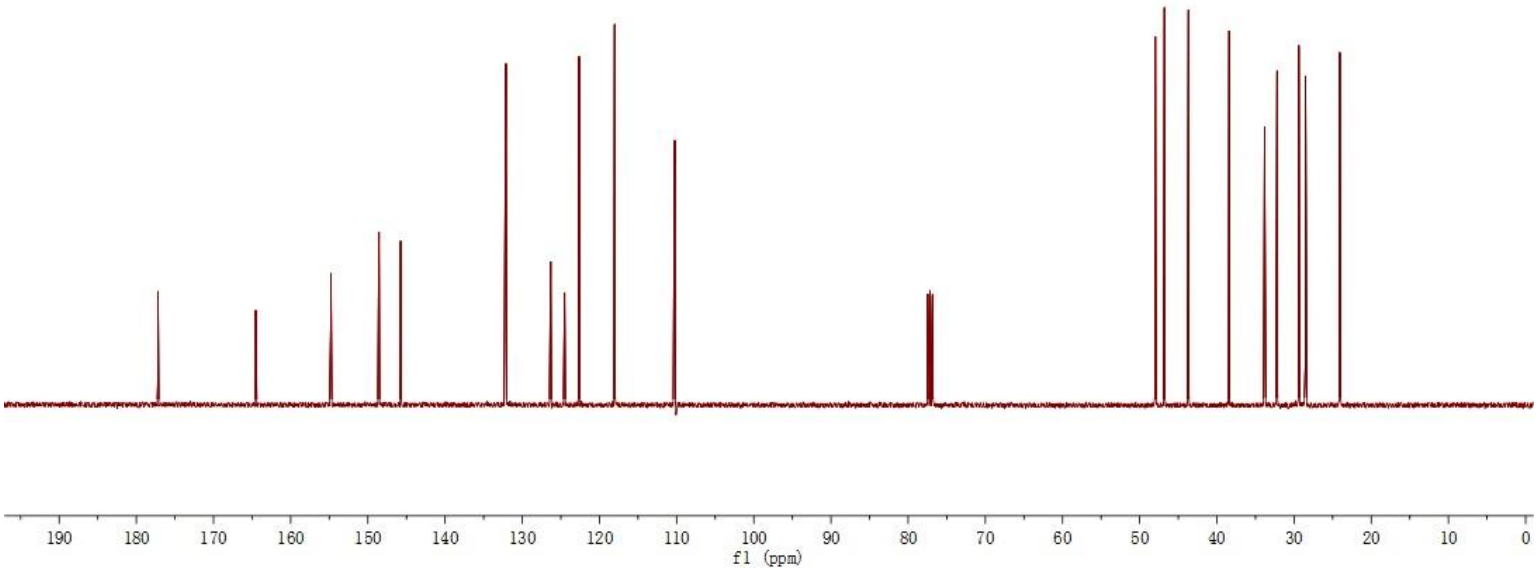
O
H
iPr
H
O
CH2


zzw-159-h
8.0470
8.0414
7.4912
7.4855
7.4696
7.4639
7.3845
7.3630
7.2601
5.7352
5.7291
5.2783
5.2734
3.0460
3.0301
3.0144
2.9971
2.9798
2.9625
2.7304
2.7047
2.5564
2.5466
2.1647
2.1551
1.6468
1.6360
1.6074
1.5724
1.5536
1.5434
1.5329
1.4356
1.4288
1.3061
1.3028
1.2984
1.2733
1.2559
1.1401
1.1139
1.0228
1.00
1.02
0.99
1.00
1.03
1.08
0.95
1.05
1.02
1.05
1.15
1.17
1.16
0.99
6.13
1.08
1.05
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-159-c
177.20
164.53
154.79
148.56
145.74
132.12
126.32
124.52
122.64
118.02
110.24
77.48
77.16
76.84
47.98
46.79
43.68
38.40
33.81
32.20
29.39
28.52
24.08
24.01

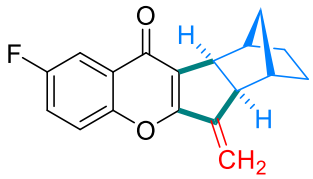
Scheme 2, 4f

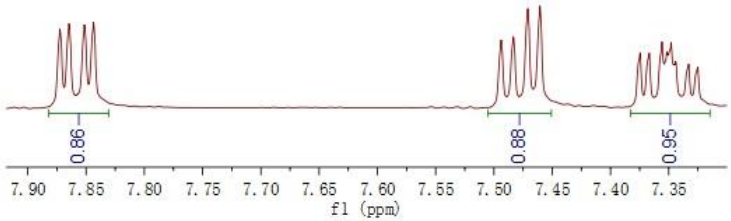

O
H
iPr
H
O
CH2

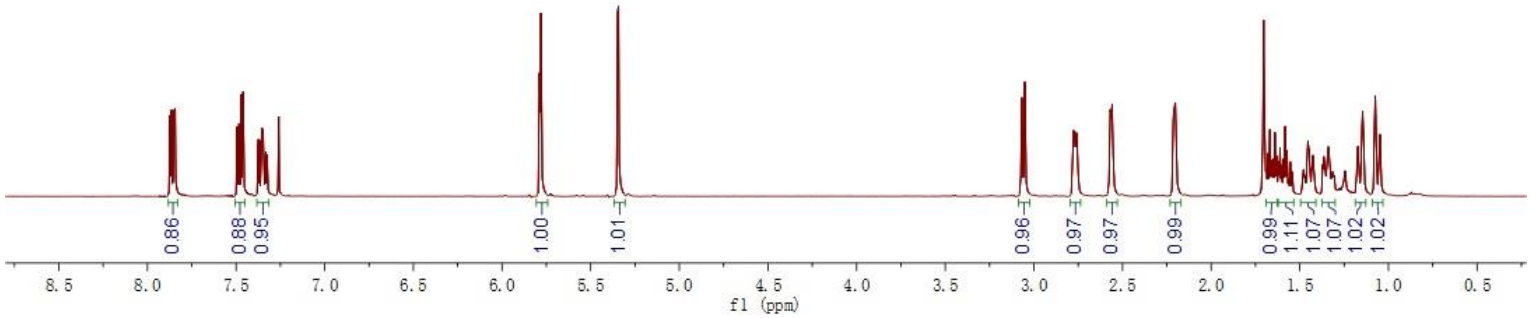

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

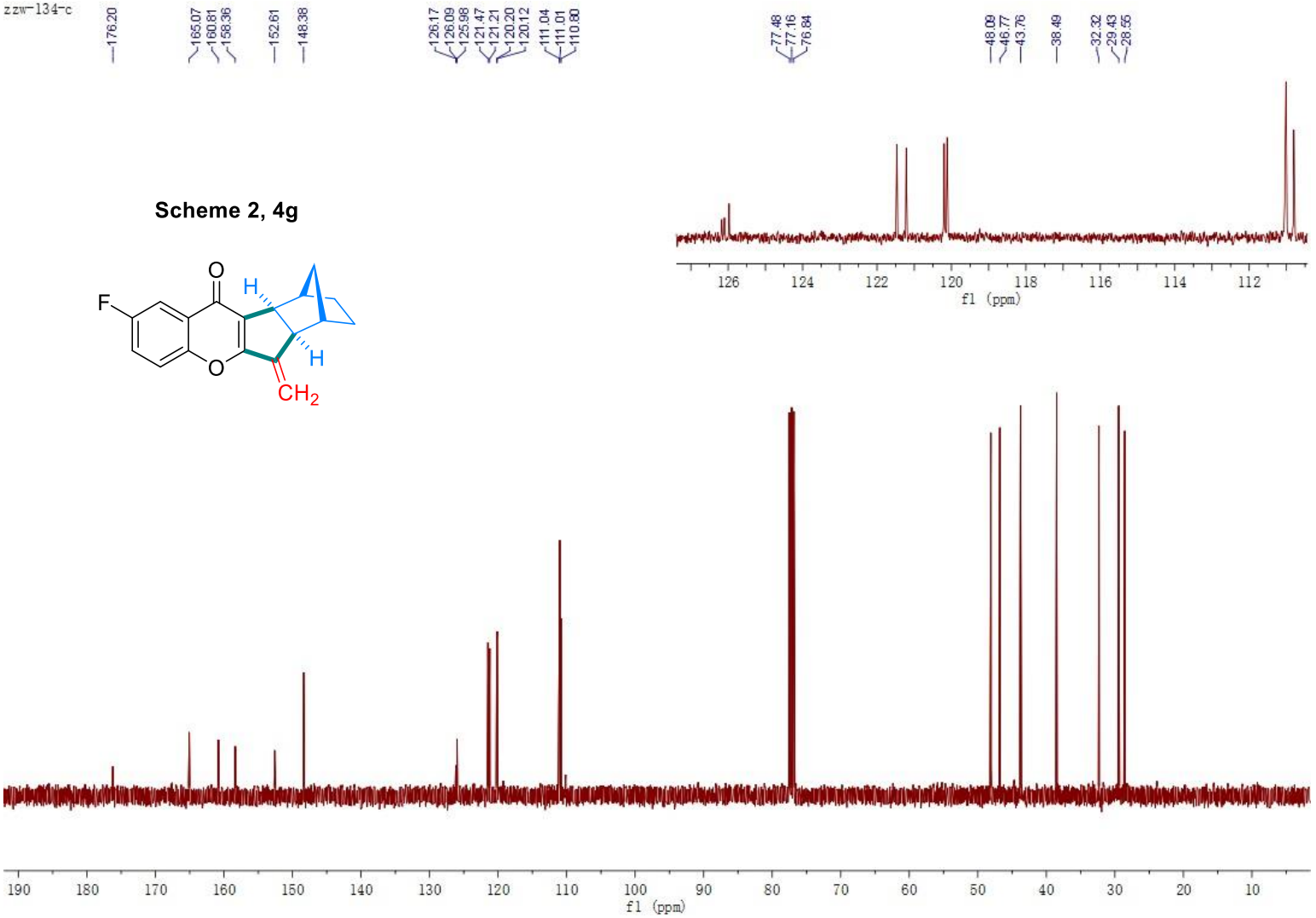

zzw-134-h
7.8724
7.8646
7.8514
7.8436
7.4938
7.4833
7.4710
7.4605
7.3746
7.3668
7.3558
7.3516
7.3480
7.3440
7.3330
7.3252
7.2595
5.7867
5.7805
5.3478
5.3428
3.0681
3.0517
2.7752
2.7600
2.5882
2.5686
2.2113
2.2019
1.6791
1.6685
1.6499
1.6399
1.6305
1.6115
1.5927
1.5828
1.5723
1.4540
1.4478
1.4261
1.3646
1.3434
1.3379
1.1718
1.1456
1.0739

Scheme 2, 4g


O
H
F
O
H
CH2

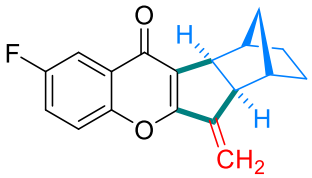

0.86
0.88
0.95
7.90
7.85
7.80
7.75
7.70
7.65
7.60
7.55
7.50
7.45
7.40
7.35
f1 (ppm)

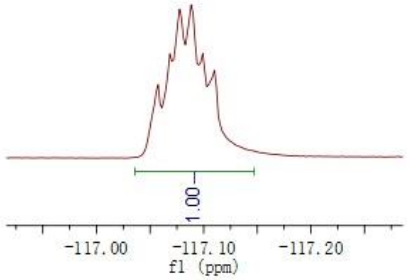

0.86
0.88
0.95
1.00
1.01
0.96
0.97
0.97
0.99
0.99
1.11
1.07
1.07
1.02
1.02
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-134-c
176.20
165.07
160.81
158.36
152.61
148.38
126.17
126.09
125.98
121.47
121.21
120.20
120.12
111.04
111.01
110.80
77.48
77.16
76.84
48.09
46.77
43.76
38.49
32.32
29.43
28.55
Scheme 2, 4g
F
O
H
H
O
CH2
126
124
122
120
118
116
114
112
f1 (ppm)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

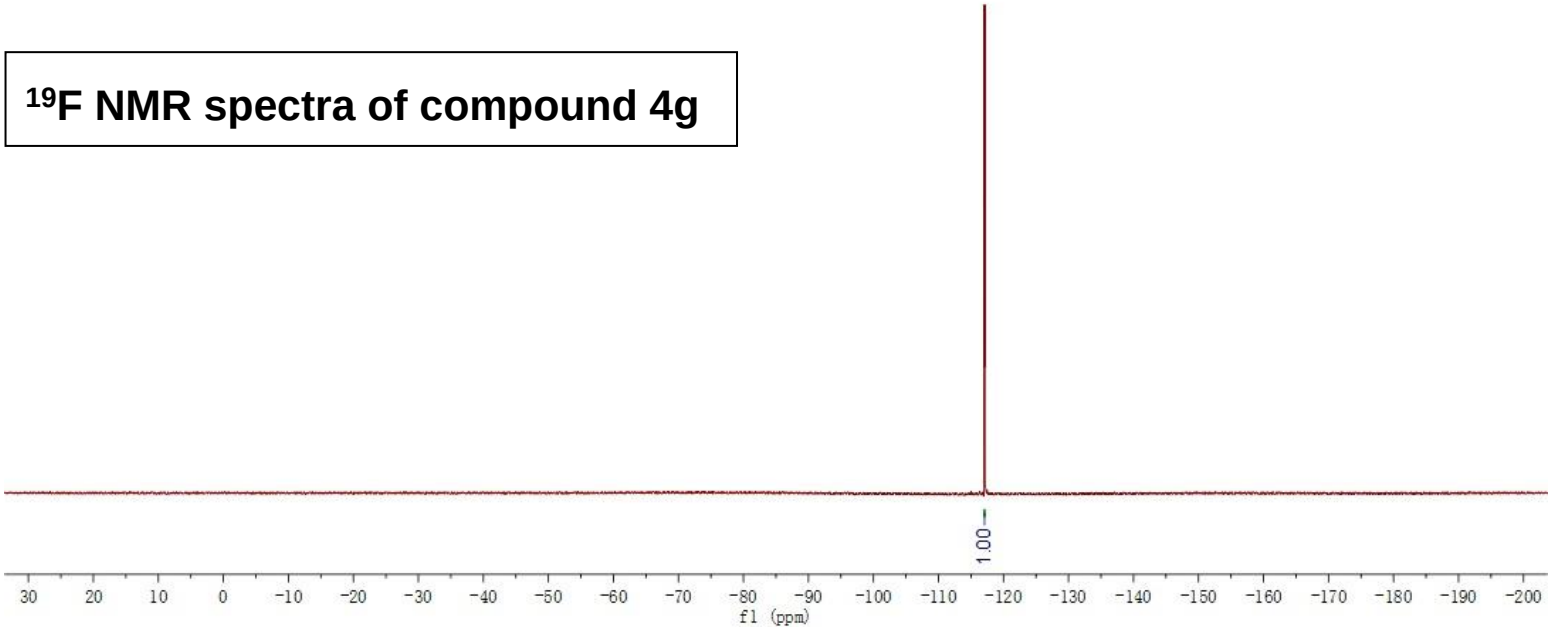
zzw-134-F

Scheme 2, 4g



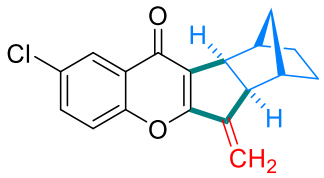


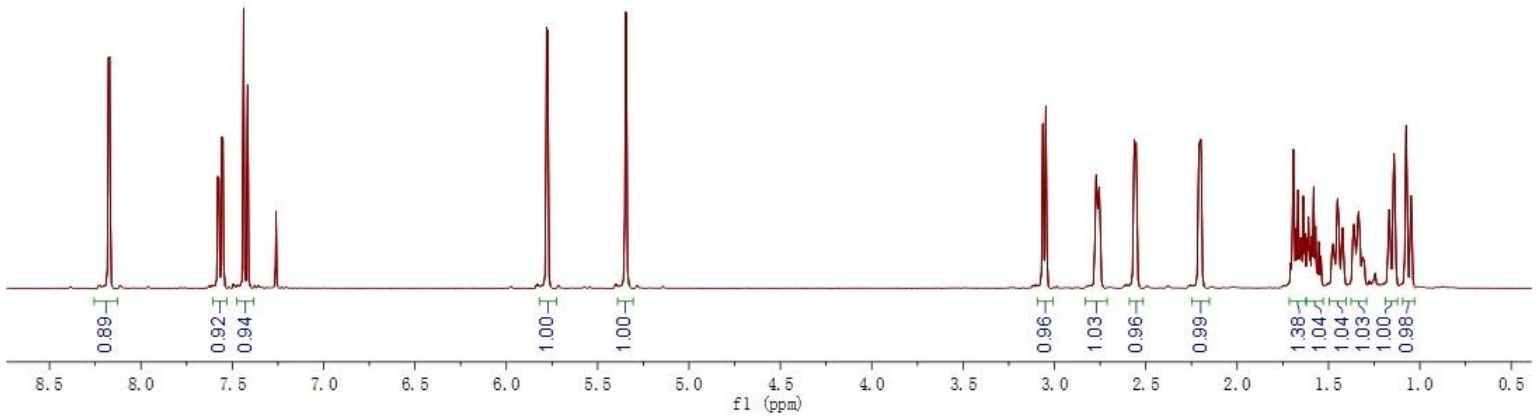
^{19}F NMR spectra of compound 4g




zzw-131-h
8.1779
8.1716
7.5797
7.5732
7.5574
7.5510
7.4379
7.4156
7.2604
5.7795
5.7736
5.3472
5.3436
3.0632
3.0468
2.7707
2.7548
2.5621
2.5531
2.2079
2.1991
1.6923
1.6770
1.6664
1.6377
1.6284
1.6094
1.5809
1.5706
1.4505
1.4230
1.3613
1.3391
1.3347
1.1674
1.1412
1.0743

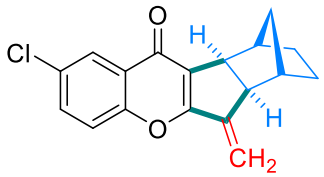
Scheme 2, 4h

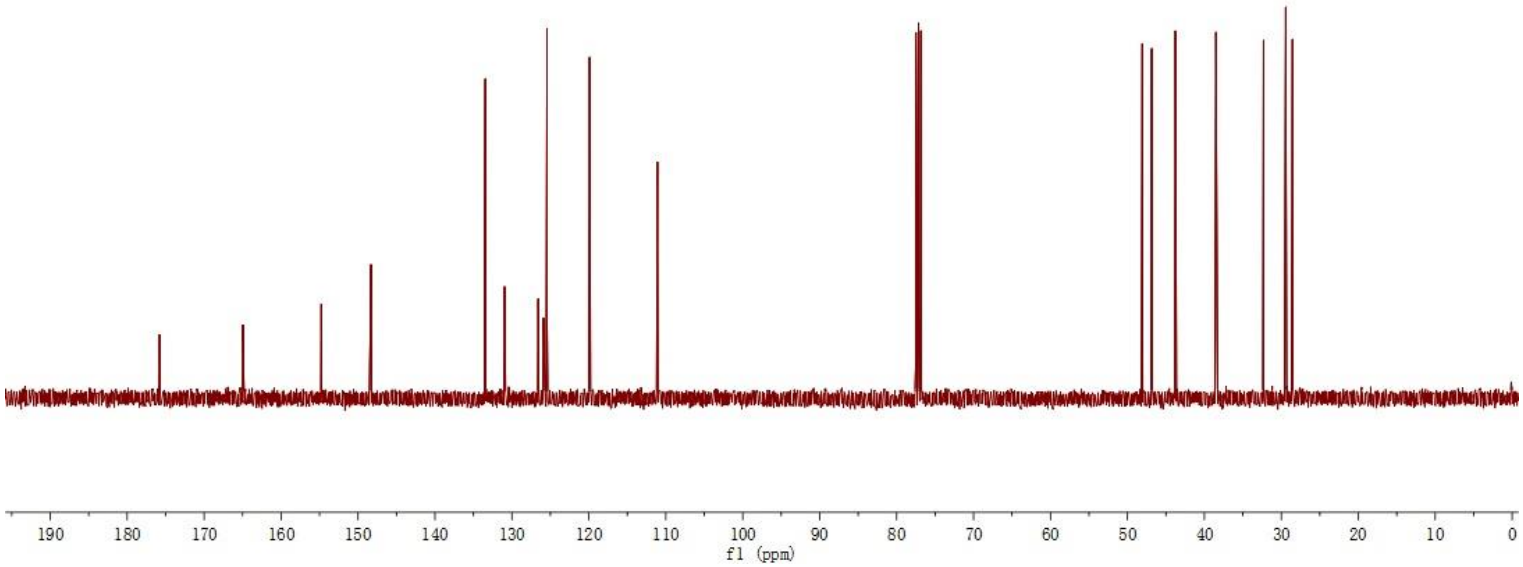

O
Cl
H
H
O
CH2


0.89
0.92
0.94
1.00
1.00
0.96
1.03
0.96
0.99
1.38
1.04
1.04
1.03
1.00
0.98
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-131-c
175.78
164.96
154.77
148.31
133.45
130.94
126.58
125.90
125.44
119.89
111.09
77.48
77.16
76.84
48.07
46.83
43.76
38.49
32.32
29.43
28.54

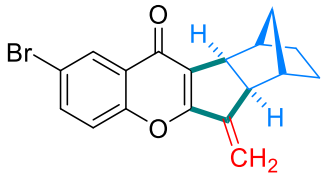
Scheme 2, 4h

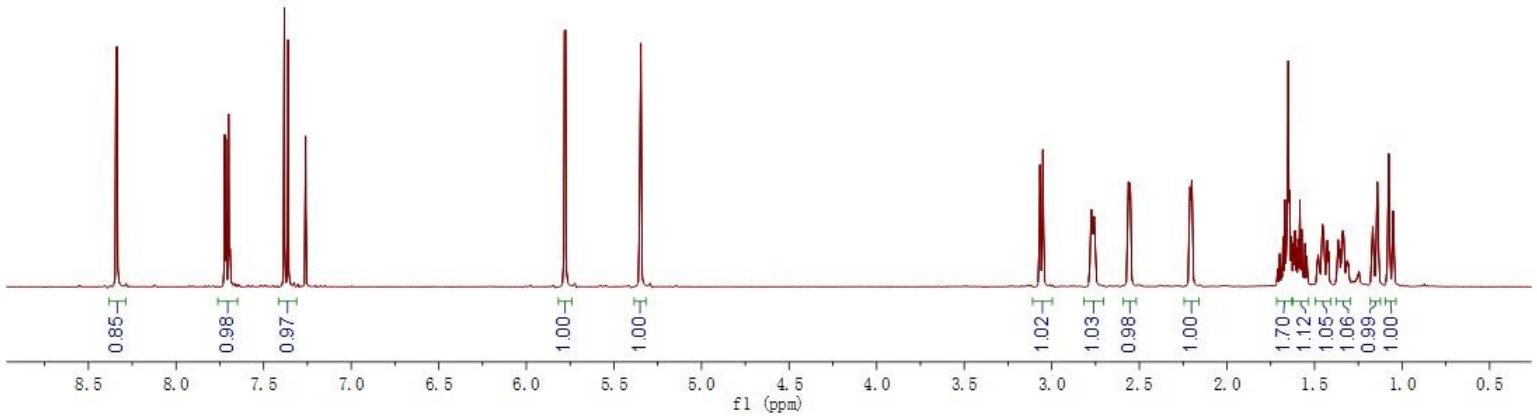

O
Cl
H
H
O
CH2


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-128-h
8.3424
8.3362
7.7218
7.7155
7.6997
7.6934
7.3819
7.3598
7.2599
5.7822
5.7760
5.3512
5.3463
3.0673
3.0509
2.7738
2.7578
2.5626
2.5527
2.2108
2.2010
1.6688
1.6577
1.6501
1.6405
1.6125
1.5836
1.5731
1.4541
1.3381
1.1675
1.1453
1.1413
1.1374
1.0799
1.0765
1.0731
1.0538

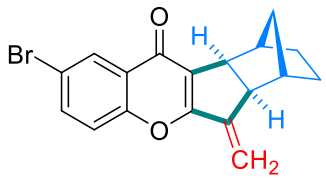
Scheme 2, 4i

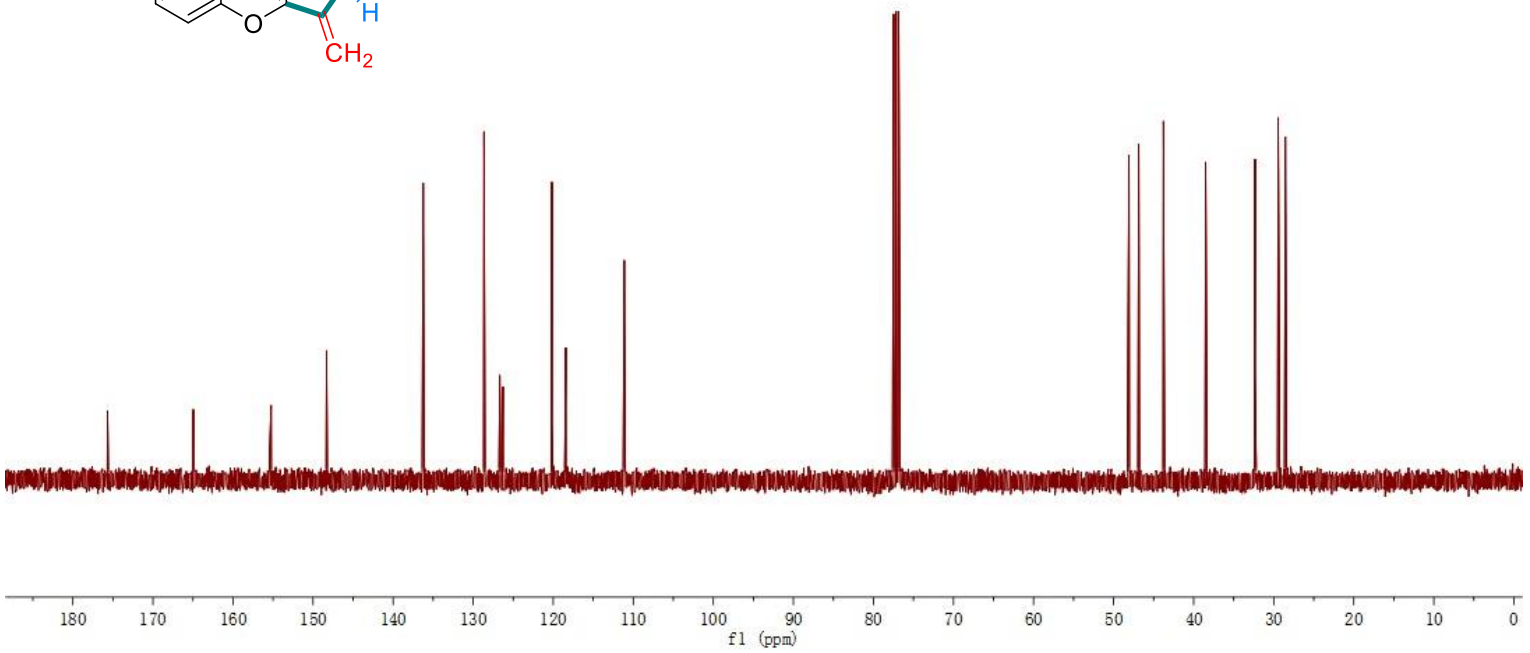

O
Br
H
H
O
CH2


0.85
0.98
0.97
1.00
1.00
1.02
1.03
0.98
1.00
1.70
1.12
1.05
1.06
0.99
1.00
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-128-c
175.67
164.95
155.24
148.31
136.24
128.64
126.67
126.28
120.17
118.43
111.13
77.48
77.16
76.84
48.07
46.86
43.77
38.50
32.33
29.44
28.55

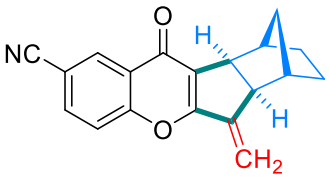
Scheme 2, 4i

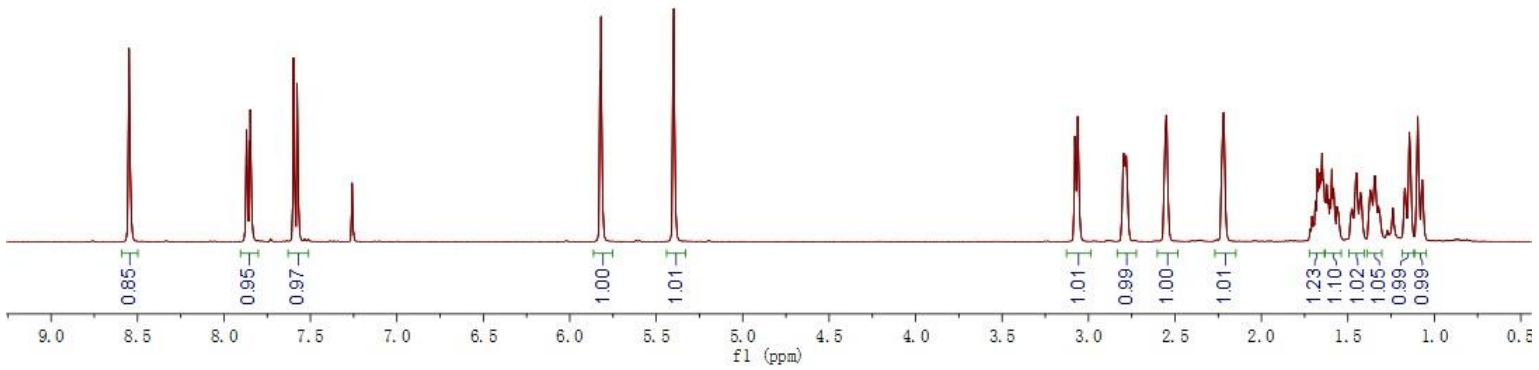

O
H
Br
H
O
CH2


180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-150-h
8.5542
8.5491
7.8742
7.8690
7.8524
7.8473
7.5965
7.5768
7.2596
5.8255
5.8196
5.4029
5.3962
3.0783
3.0620
2.7968
2.7819
2.5499
2.2187
1.6776
1.6673
1.6595
1.6493
1.6408
1.6214
1.5929
1.5832
1.4493
1.4272
1.3705
1.3652
1.3430
1.1708
1.1442
1.0956

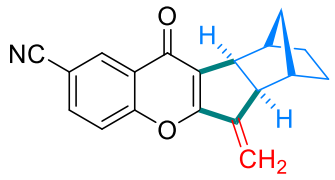
Scheme 2, 4j

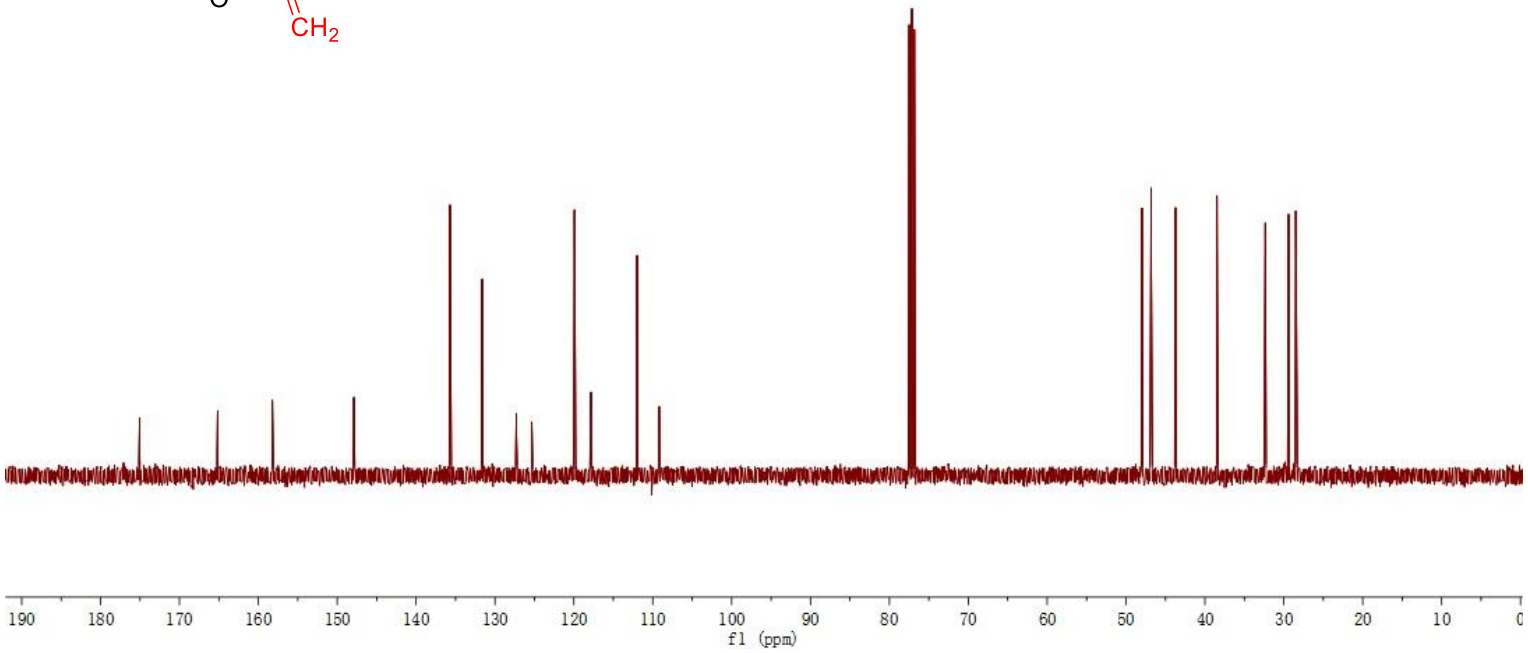

NC
O
H
H
O
CH2

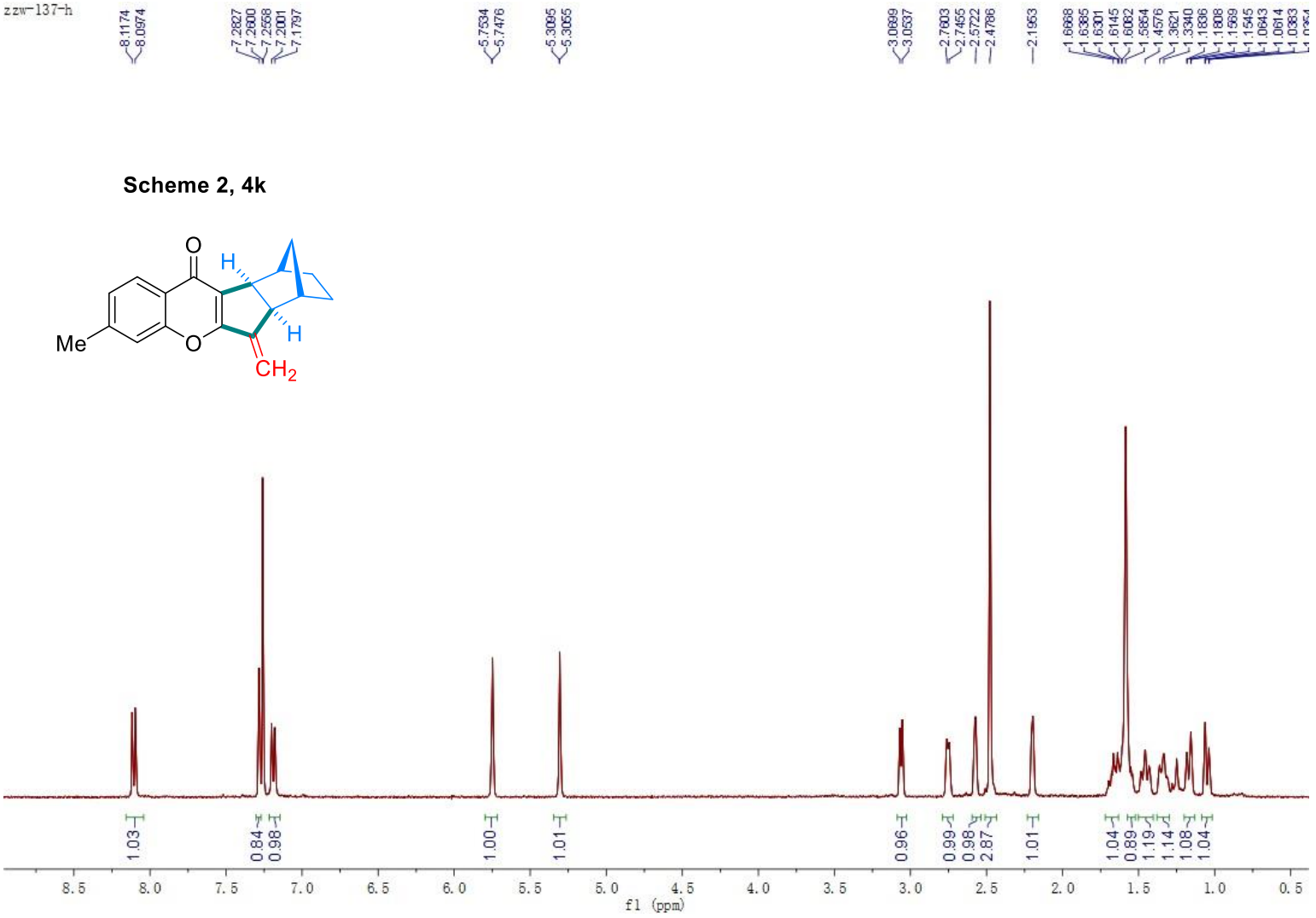

0.85
0.95
0.97
1.00
1.01
1.01
0.99
1.00
1.01
1.23
1.10
1.02
1.05
0.99
0.99
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)


zzw-150-c
175.05
165.16
158.22
147.88
135.71
131.63
127.29
125.33
119.91
117.83
111.98
109.19
77.48
77.16
76.84
47.99
46.81
43.74
38.48
32.35
29.40
28.48

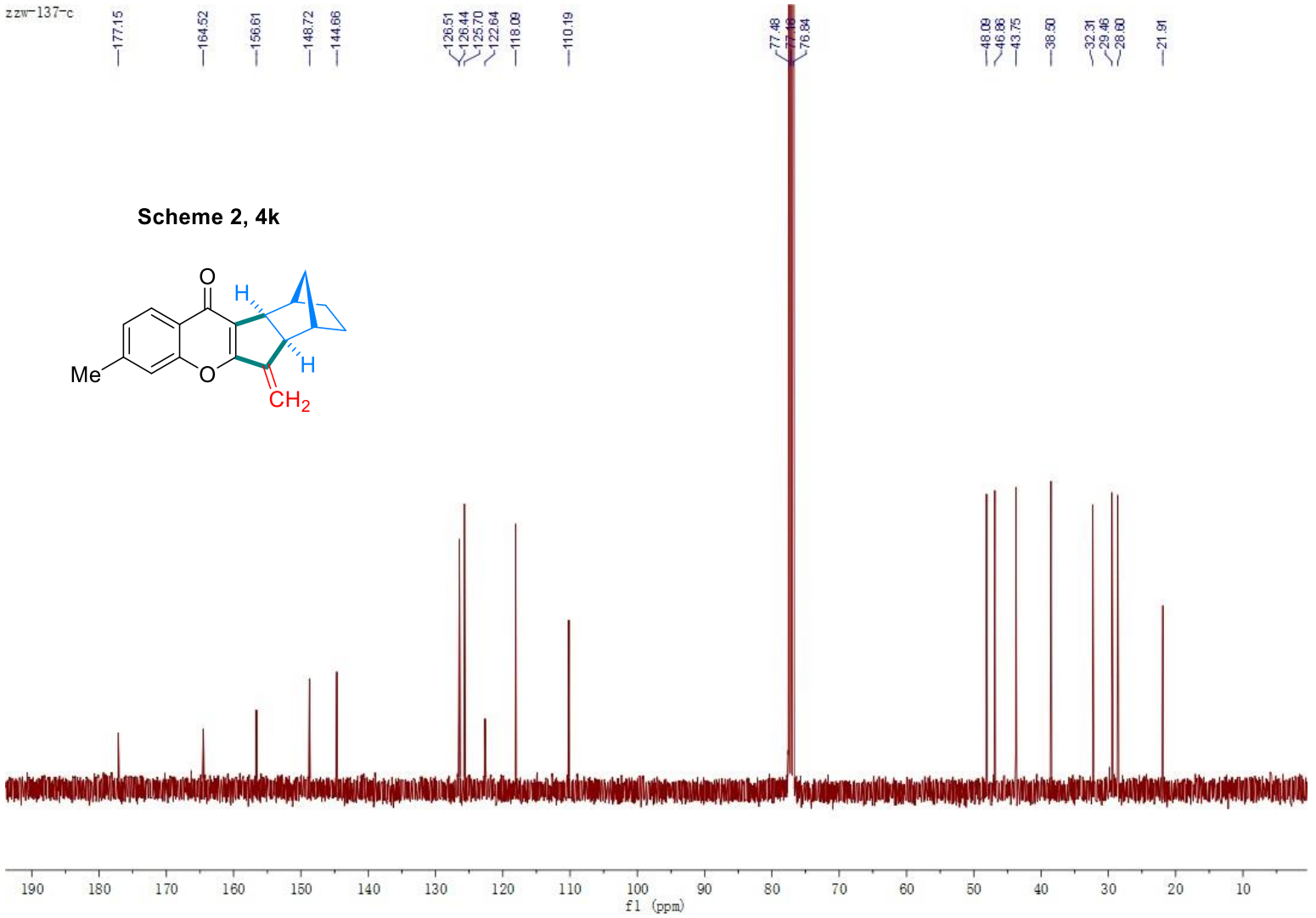
Scheme 2, 4j

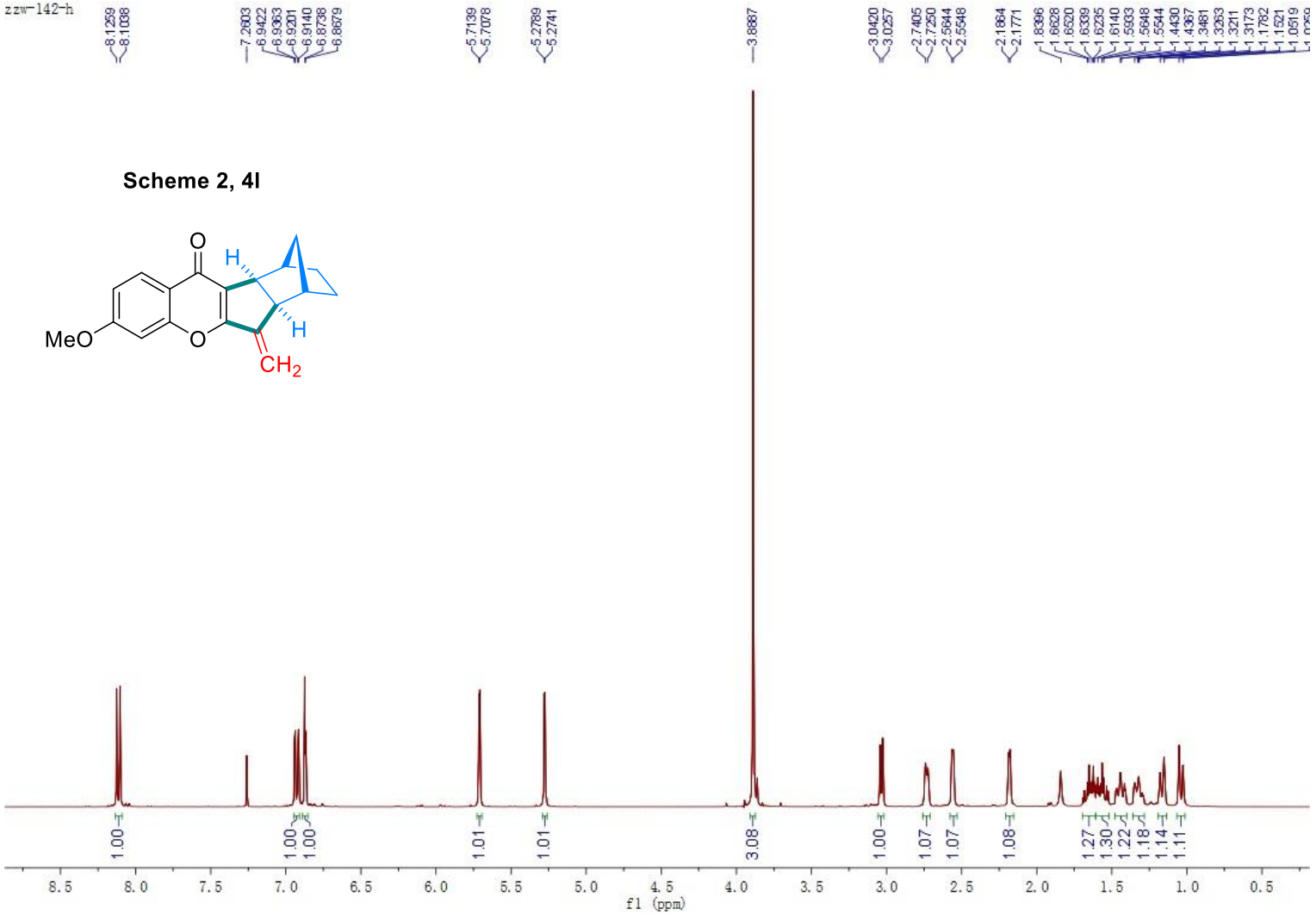

NC
O
H
H
O
CH2


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-137-h
8.1174
8.0974
7.2827
7.2600
7.2558
7.2001
7.1797
5.7534
5.7476
5.3095
5.3055
3.0899
3.0537
2.7603
2.7455
2.5722
2.4786
2.1953
1.6668
1.6385
1.6301
1.6145
1.6082
1.5854
1.4576
1.3621
1.3340
1.1836
1.1808
1.1569
1.1545
1.0643
1.0614
1.0383
O
H
H
Me
O
CH2
1.03
0.84
0.98
1.00
1.01
0.96
0.99
0.98
2.87
1.01
1.04
0.89
1.19
1.14
1.08
1.04
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

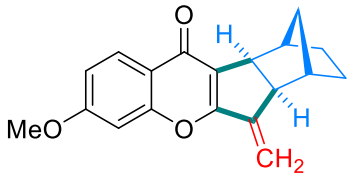
Scheme 2, 4k

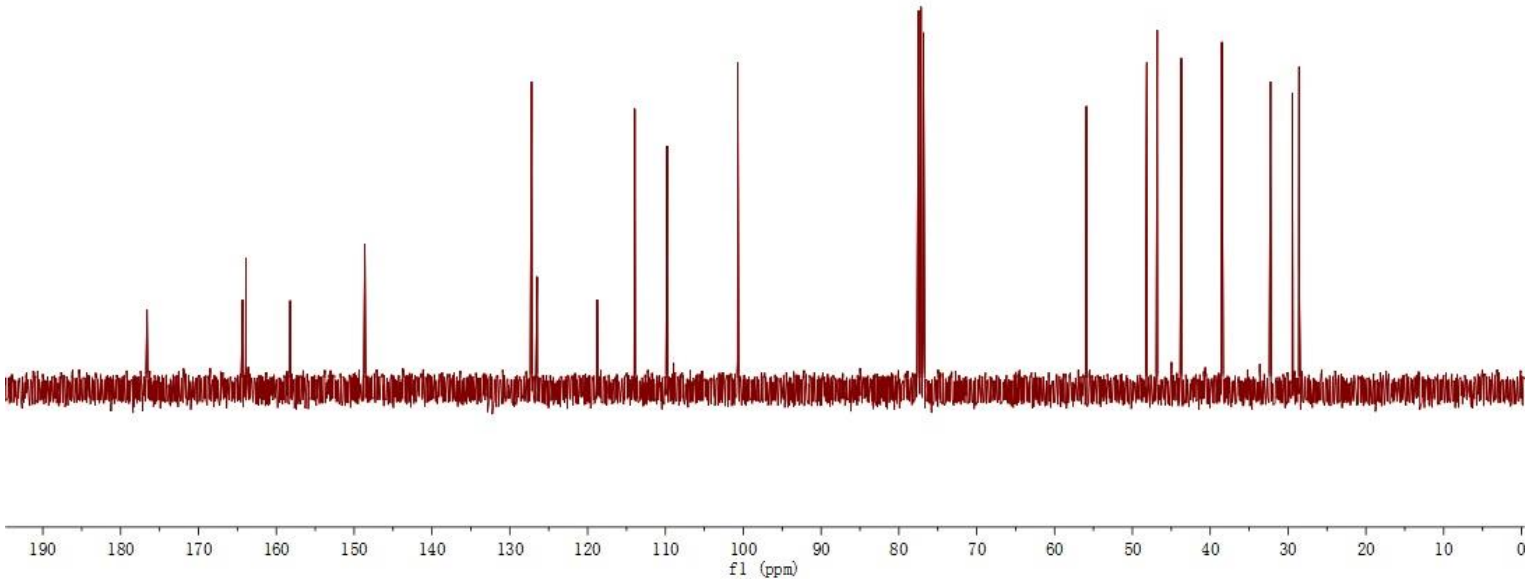

zzw-137-c
177.15
164.52
156.61
148.72
144.66
126.51
126.44
125.70
122.64
118.09
110.19
77.48
77.16
76.84
48.09
46.86
43.75
38.50
32.31
29.46
28.60
21.91
Scheme 2, 4k
O
H
Me
O
H
CH2
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)


zzw-142-h
8.1259
8.1038
7.2803
6.9422
6.9363
6.9201
6.9140
6.8738
6.8679
5.7139
5.7078
5.2789
5.2741
3.8887
3.0420
3.0257
2.7405
2.7250
2.5644
2.5548
2.1864
2.1771
1.8396
1.6628
1.6520
1.6339
1.6235
1.6140
1.5933
1.5648
1.5544
1.4430
1.4367
1.3481
1.3263
1.3211
1.3173
1.1782
1.1521
1.0519
Scheme 2, 4l
O
H
H
MeO
O
CH2
1.00
1.00
1.00
1.01
1.01
3.08
1.00
1.07
1.07
1.08
1.27
1.30
1.22
1.18
1.14
1.11
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-142-c
176.62
164.34
163.91
158.21
148.62
127.22
126.49
118.77
113.95
109.77
100.71
77.48
77.16
76.84
55.90
48.14
46.82
43.70
38.50
32.27
29.45
28.58

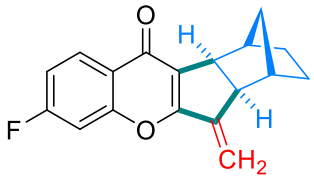
Scheme 2, 4l

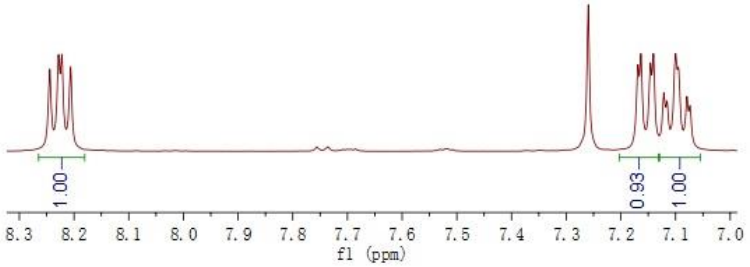

O
H
H
MeO
O
CH2

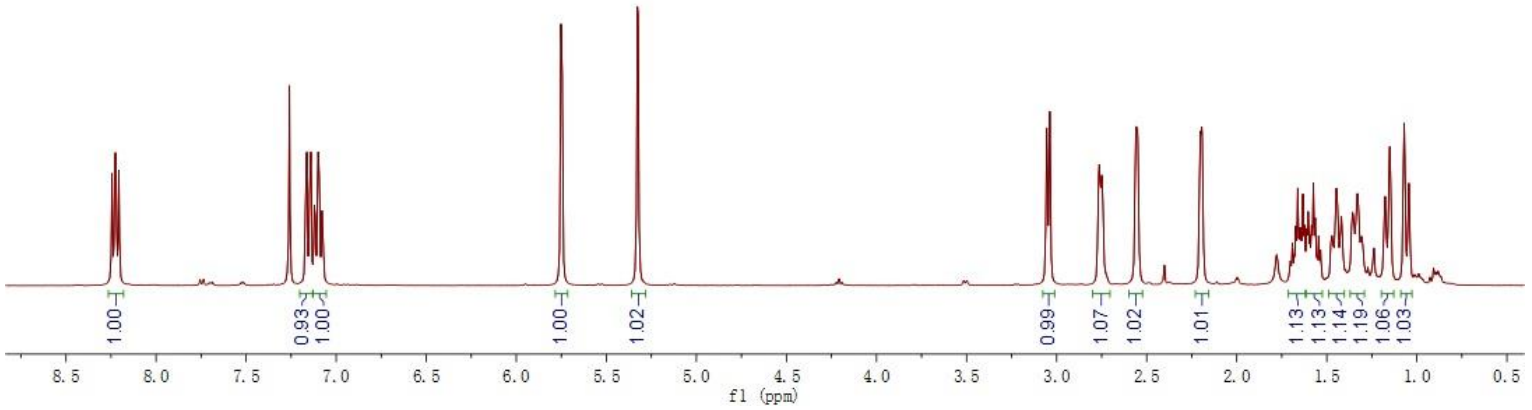

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

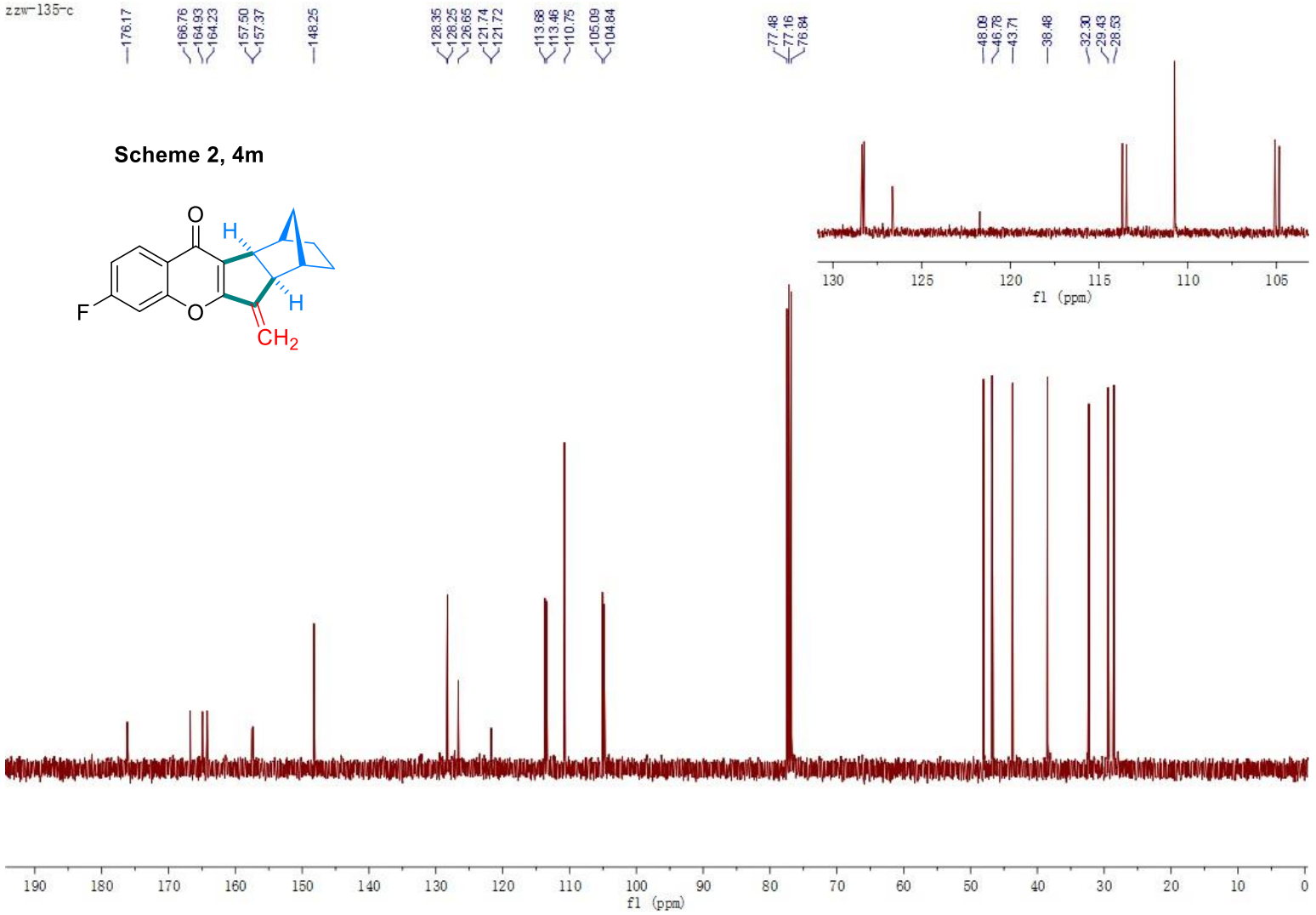

zzw-135-h
8.2445
8.2282
8.2225
8.2064
7.2596
7.1687
7.1633
7.1459
7.1405
7.1214
7.1157
7.1001
7.0962
7.0791
7.0735
5.7518
5.7461
5.3276
5.3237
3.0546
3.0384
2.7632
2.7484
2.5594
2.5514
2.2015
2.1939
1.6717
1.6612
1.6428
1.6326
1.6234
1.6035
1.5845
1.5747
1.5645
1.4466
1.4190
1.3563
1.3297
1.1763
1.1502
1.0703

Scheme 2, 4m


O
H
F
O
H
CH2


1.00
0.93
1.00
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
f1 (ppm)

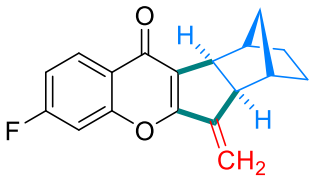

1.00
0.93
1.00
1.00
1.02
0.99
1.07
1.02
1.01
1.13
1.13
1.14
1.19
1.06
1.03
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

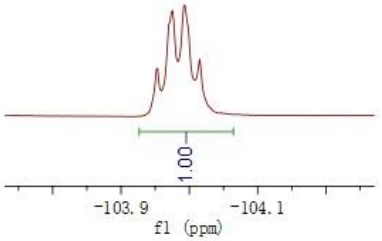

zzw-135-c
176.17
166.76
164.93
164.23
157.50
157.37
148.25
128.35
128.25
126.65
121.74
121.72
113.88
113.46
110.75
105.09
104.84
77.48
77.16
76.84
48.09
46.78
43.71
38.48
32.30
29.43
28.53
Scheme 2, 4m
O
H
F
O
H
CH2
130
125
120
115
110
105
f1 (ppm)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

zzw-135-F

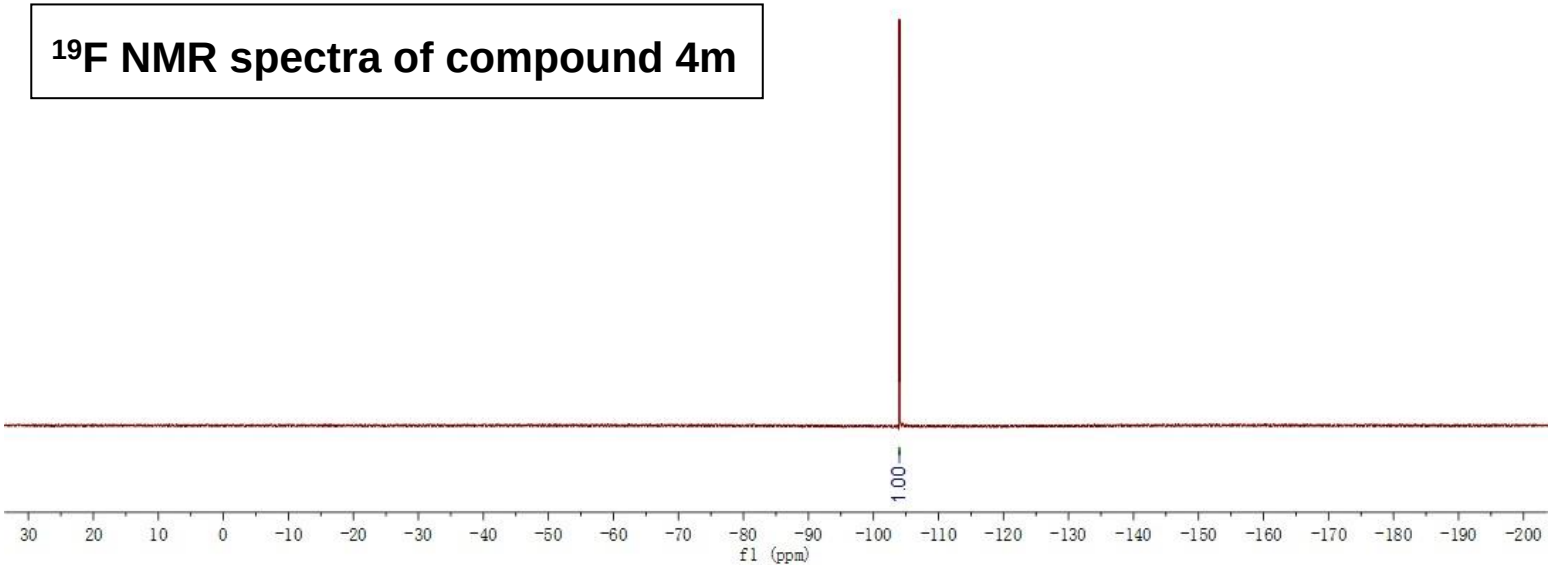
-103.95
-103.97
-103.99
-104.02

Scheme 2, 4m



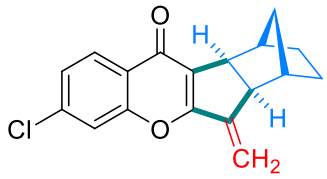


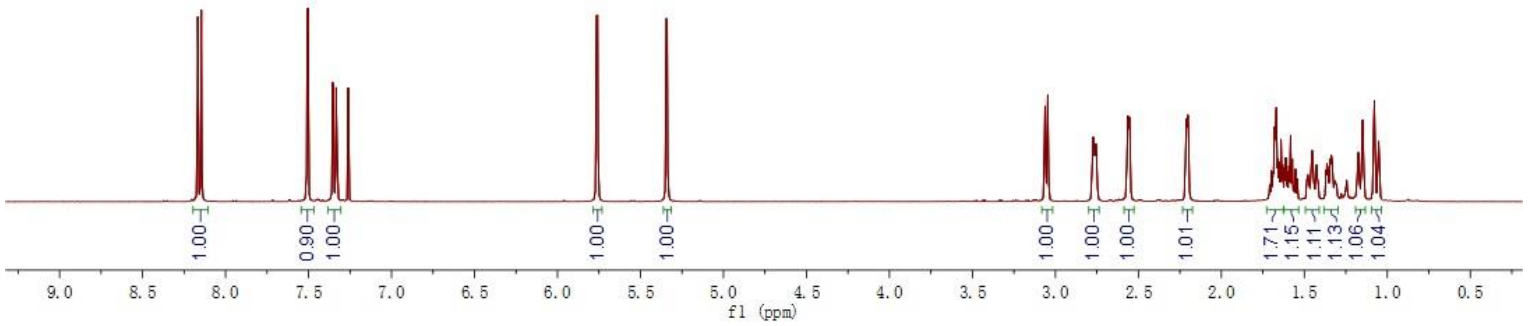
^{19}F NMR spectra of compound 4m

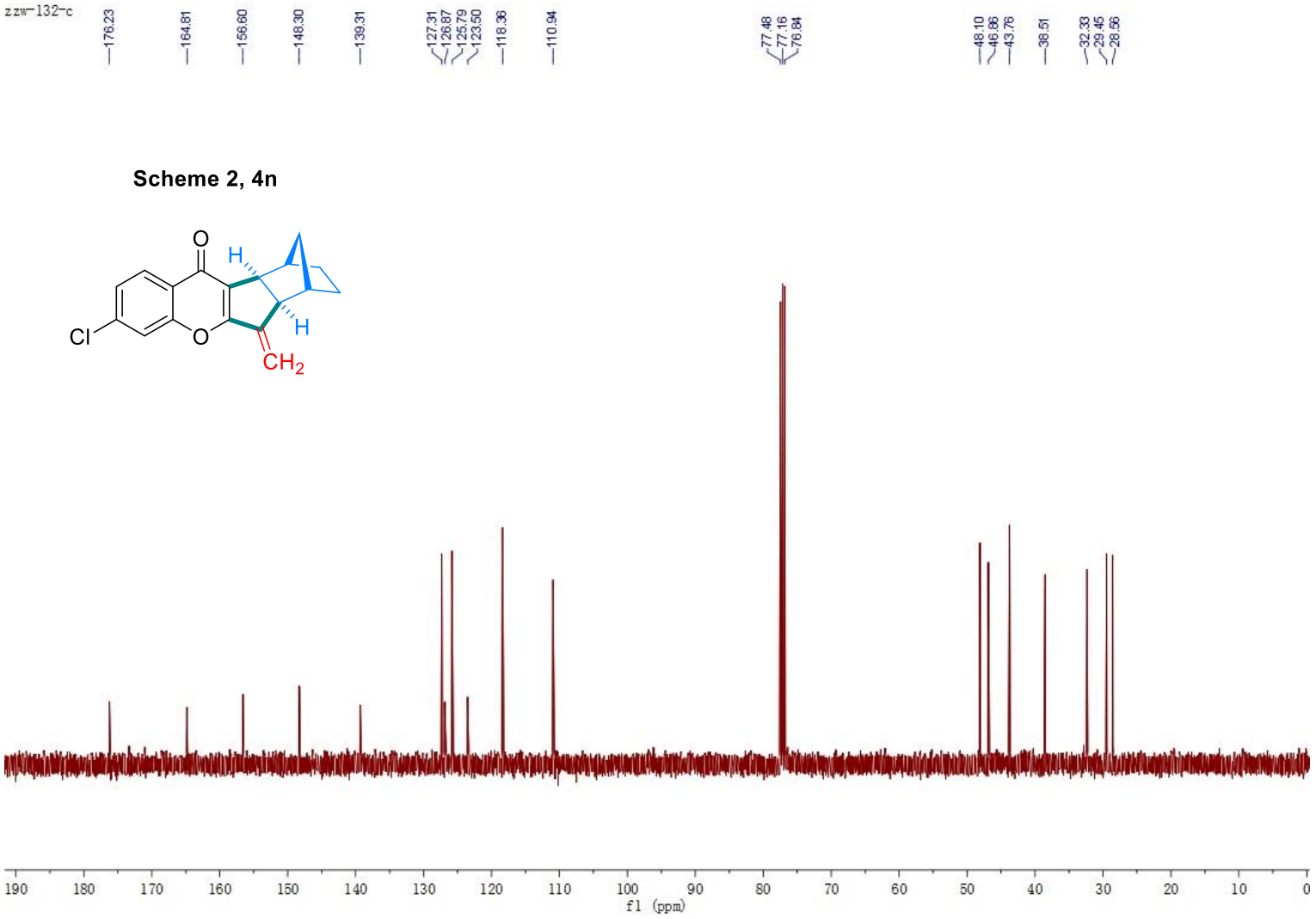



zzw-132-h
8.1672
8.1459
7.5063
7.5036
7.3551
7.3503
7.3337
7.3290
7.2603
5.7644
5.7583
5.3441
5.3393
3.0624
3.0461
2.7719
2.7564
2.5635
2.5539
2.2109
2.2014
1.6789
1.6688
1.6580
1.6400
1.6117
1.5829
1.5724
1.4532
1.3427
1.3372
1.1749
1.1487
1.0813
1.0782
1.0750
1.0552
1.0520

Scheme 2, 4n

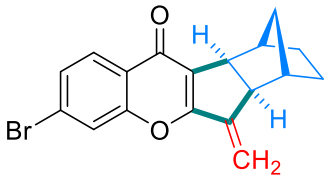

O
H
Cl
O
H
CH2

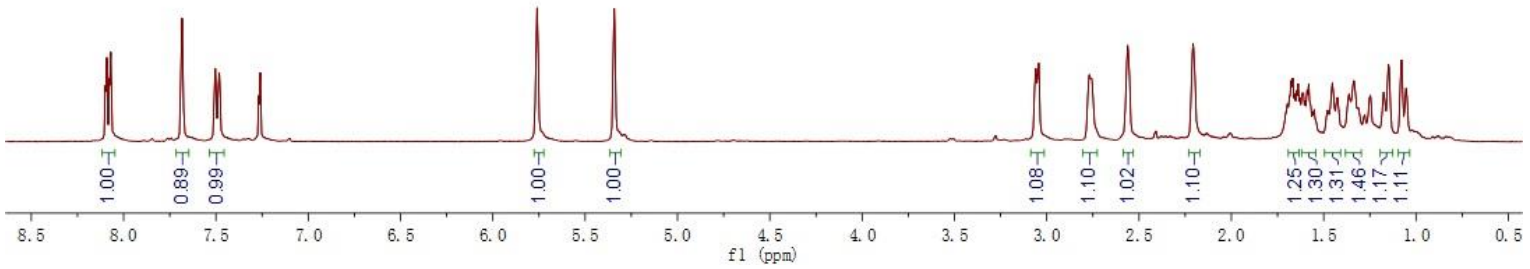

1.00
0.90
1.00
1.00
1.00
1.00
1.00
1.01
1.71
1.15
1.11
1.13
1.06
1.04
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

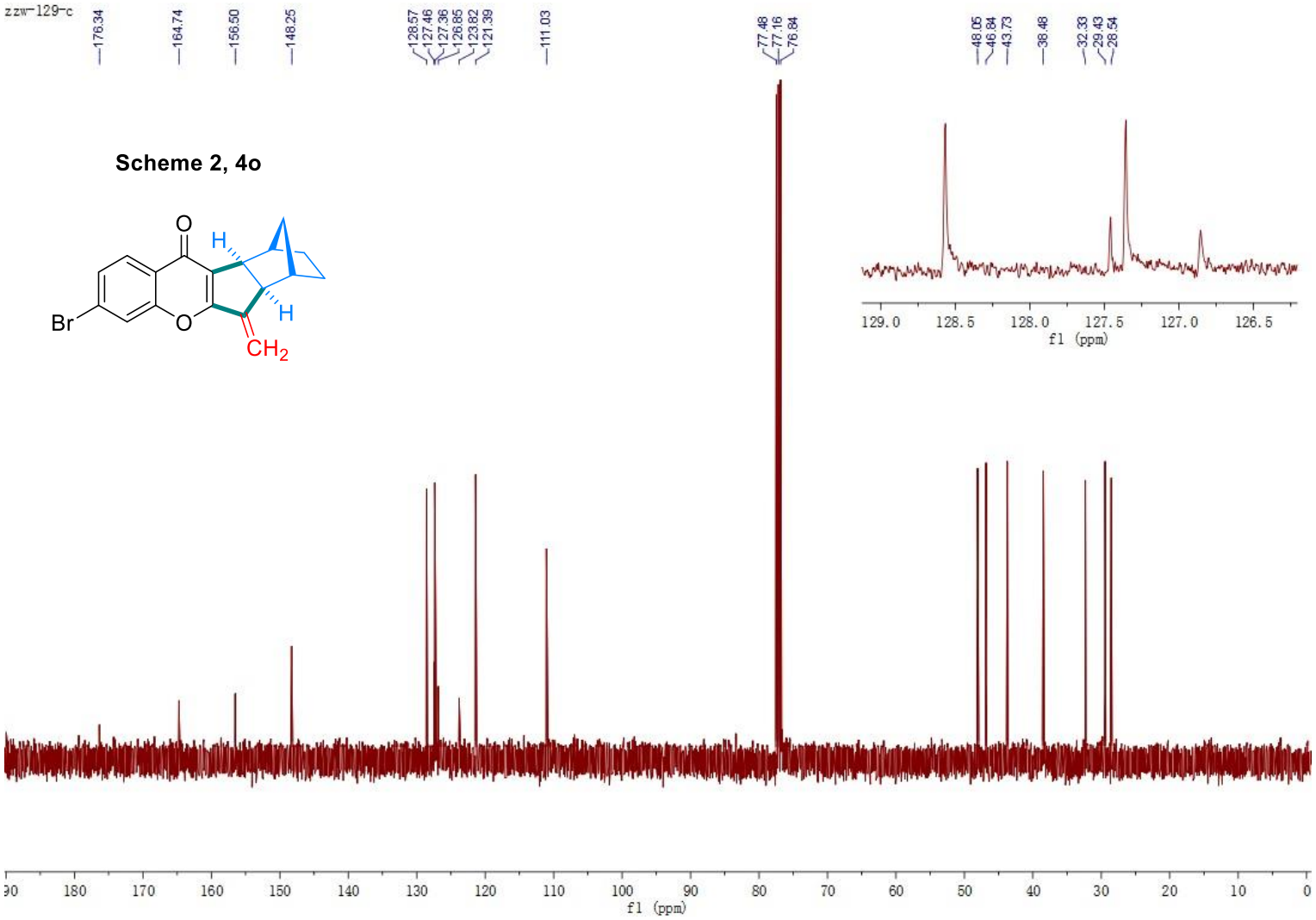

zzw-132-c
176.23
164.81
156.60
148.30
139.31
127.31
126.87
125.79
123.50
118.36
110.94
77.48
77.16
76.84
48.10
46.88
43.76
38.51
32.33
29.45
28.56
Scheme 2, 4n
O
H
Cl
O
H
CH2
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-129-1
8.0990
8.0908
8.0777
8.0695
7.6833
7.5031
7.4904
7.4818
7.2682
7.2596
5.7606
5.3425
3.0592
3.0435
2.7692
2.7578
2.5615
2.2074
1.6856
1.6762
1.6672
1.6573
1.6475
1.6385
1.6180
1.6096
1.5899
1.5810
1.4528
1.4258
1.3630
1.3361
1.1749
1.1488
1.0791

Scheme 2, 4o


O
H
Br
O
H
CH2

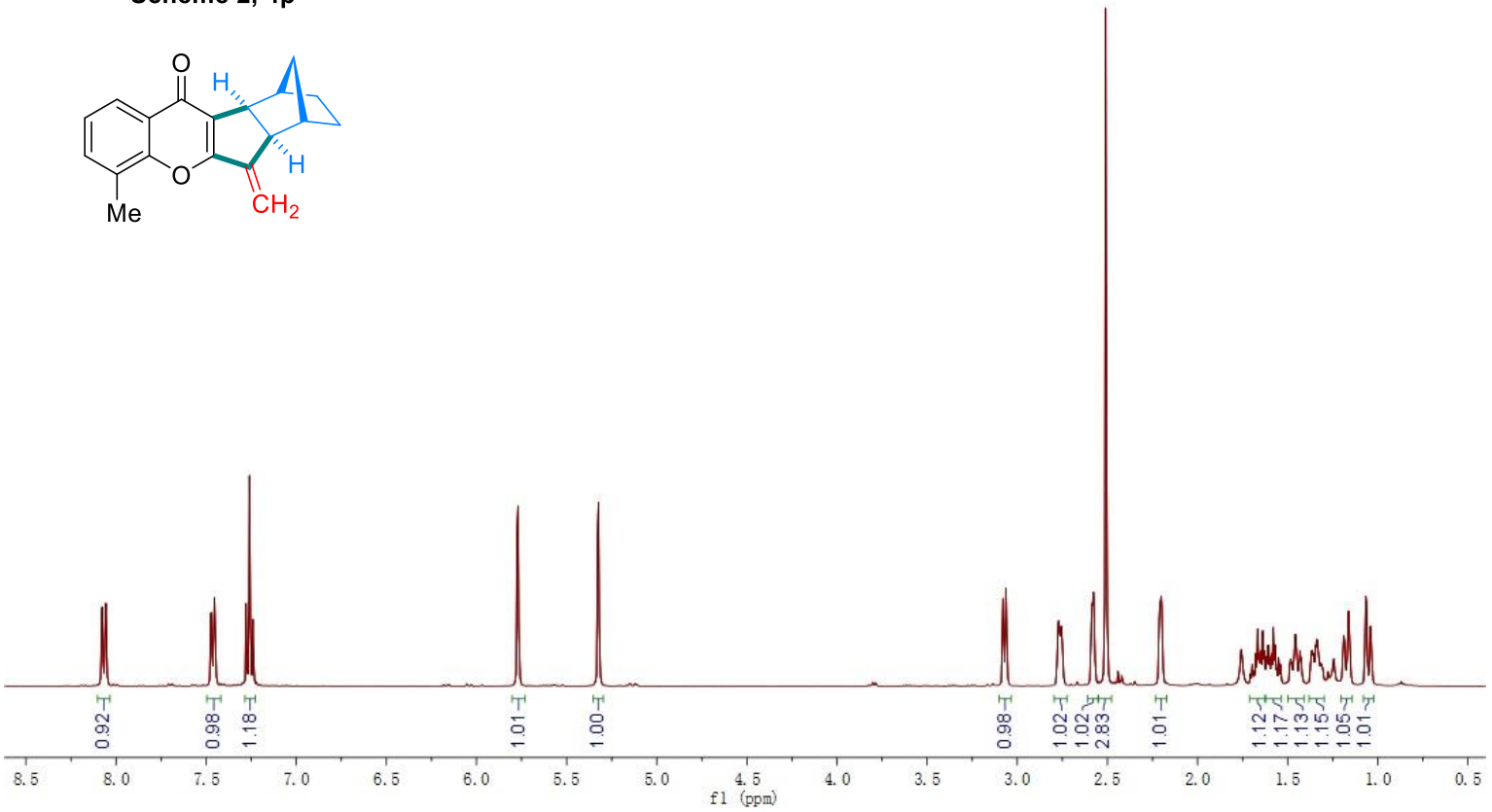

1.00
0.89
0.99
1.00
1.00
1.08
1.10
1.02
1.10
1.25
1.30
1.31
1.46
1.17
1.11
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-129-c
176.34
164.74
156.50
148.25
128.57
127.46
127.36
126.85
123.82
121.39
111.03
77.48
77.16
76.84
48.05
46.84
43.73
38.48
32.33
29.43
28.54
Scheme 2, 4o
O
H
Br
O
H
CH2
129.0
128.5
128.0
127.5
127.0
126.5
f1 (ppm)
90
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-149-h
8.0765
8.0566
7.4740
7.4723
7.4704
7.4559
7.4542
7.4524
7.2791
7.2596
7.2410
5.7756
5.7696
5.3280
5.3232
3.0793
3.0630
2.7701
2.7553
2.5864
2.5771
2.5100
2.2068
2.2008
1.6663
1.6484
1.6379
1.6085
1.5803
1.5701
1.4578
1.4527
1.3665
1.3449
1.3395
1.3369
1.1883
1.1622
1.0865
1.0634
1.0404

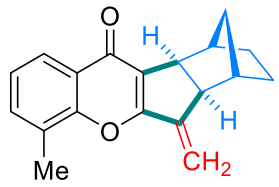
Scheme 2, 4p

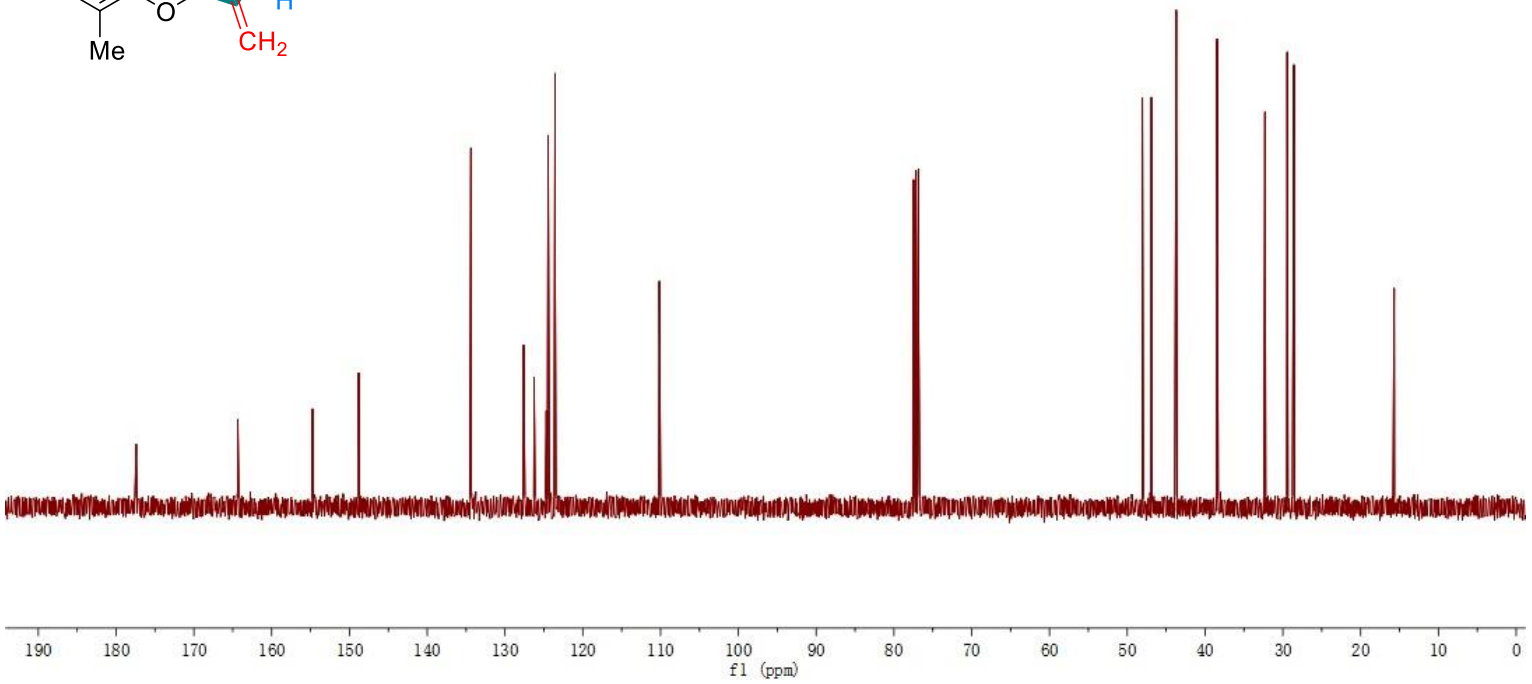
O
H
H
O
Me
CH2


0.92
0.98
1.18
1.01
1.00
0.98
1.02
1.02
2.83
1.01
1.12
1.17
1.13
1.15
1.05
1.01
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-149-c
177.42
164.35
154.75
148.81
134.38
127.60
126.26
124.68
124.46
123.56
110.15
77.48
77.16
76.84
48.06
46.88
43.71
38.45
32.29
29.43
28.88
15.89

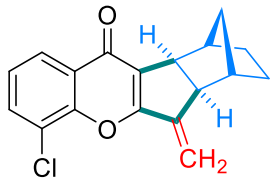
Scheme 2, 4p

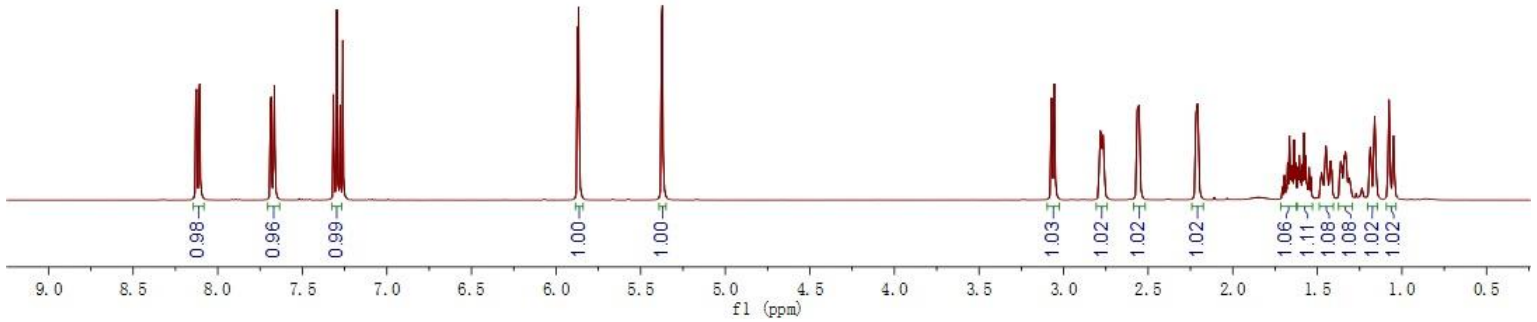

O
H
H
O
Me
CH2

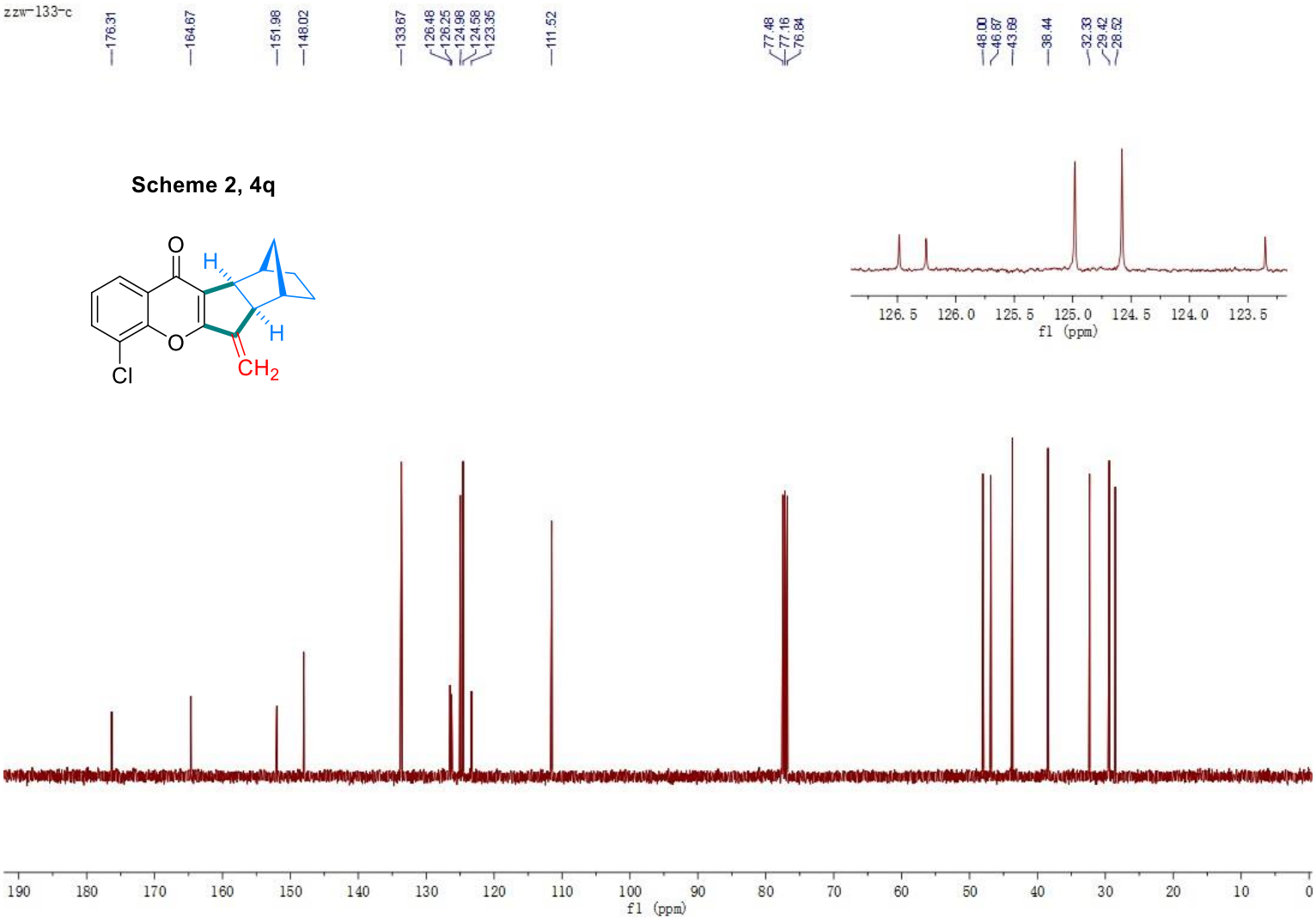

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-133-h
8.1298
8.1261
8.1098
8.1061
7.6876
7.6839
7.6683
7.6645
7.3159
7.2962
7.2765
7.2602
5.8726
5.8665
5.3761
5.3712
3.0712
3.0549
2.7823
2.7669
2.5639
2.5543
2.2164
2.2071
1.6758
1.6652
1.6306
1.6273
1.6070
1.5883
1.5784
1.5660
1.4498
1.4439
1.4222
1.3624
1.3408
1.3355
1.1872
1.1610
1.0765

Scheme 2, 4q

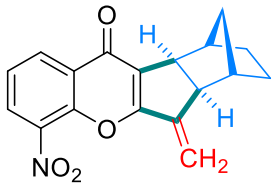

O
H
H
O
Cl
CH2

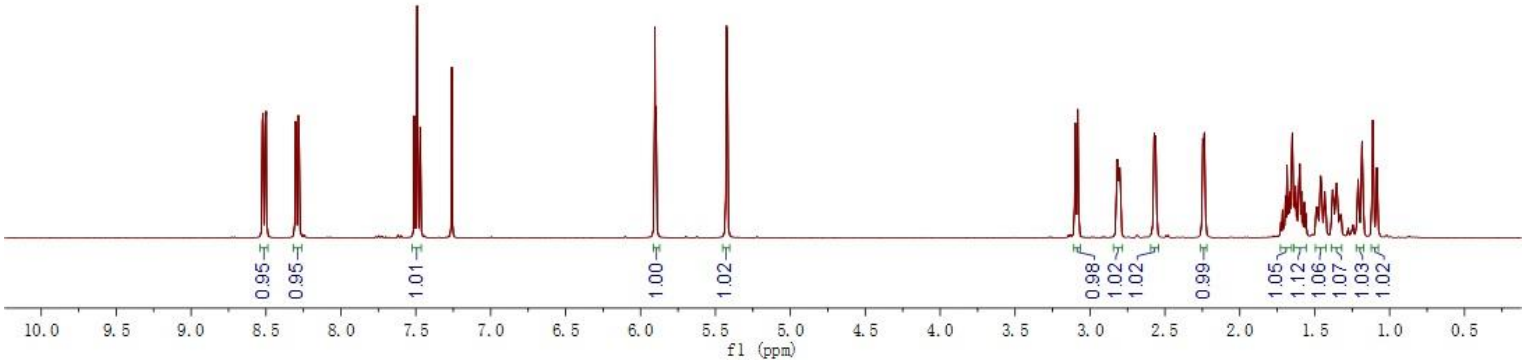

0.98
0.96
0.99
1.00
1.00
1.03
1.02
1.02
1.02
1.06
1.11
1.08
1.08
1.02
1.02
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

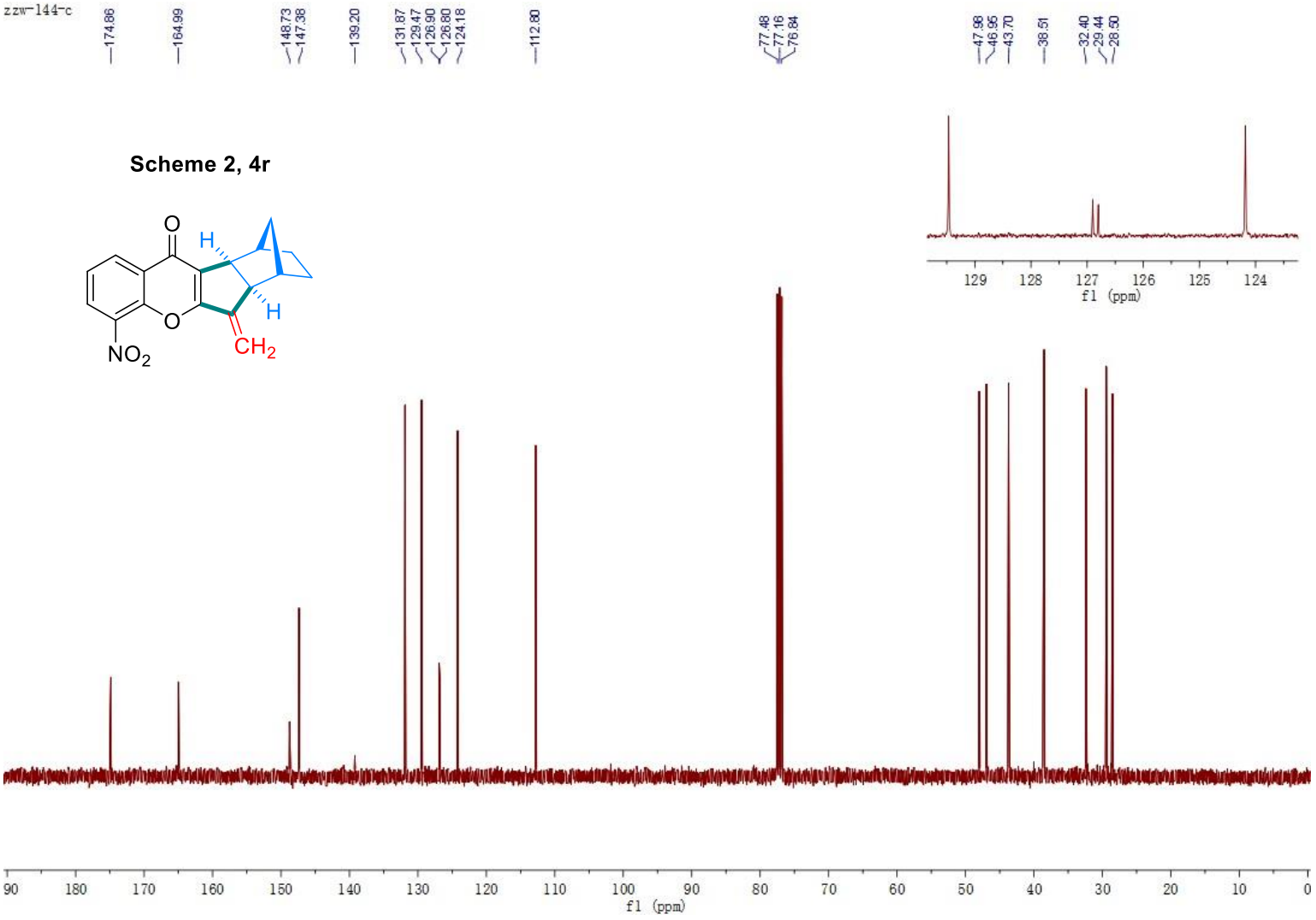

zzw-133-c
176.31
164.67
151.98
148.02
133.67
126.48
126.25
124.98
124.58
123.35
111.52
77.48
77.16
76.84
48.00
46.87
43.89
38.44
32.33
29.42
28.52
Scheme 2, 4q
O
H
H
O
Cl
CH2
126.5
126.0
125.5
125.0
124.5
124.0
123.5
f1 (ppm)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

zzw-144-h

Scheme 2, 4r

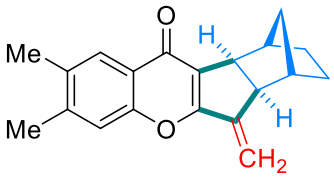


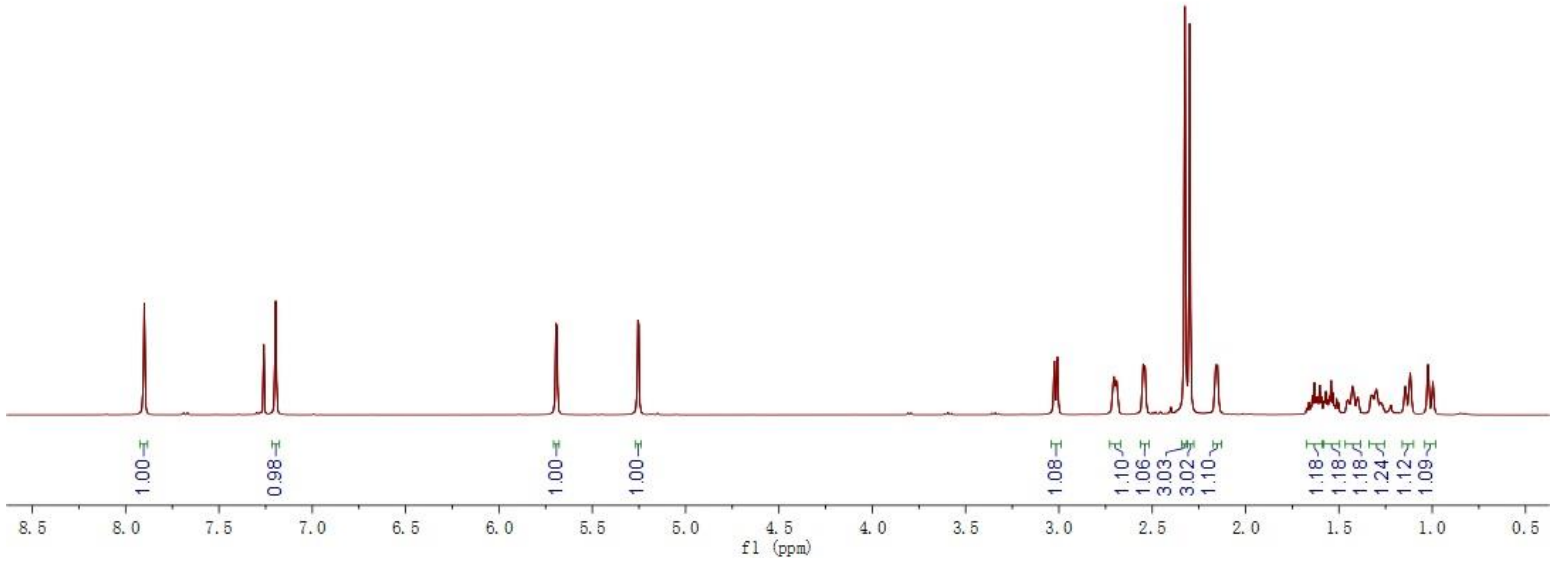



zzw-144-c
174.86
164.99
148.73
147.38
139.20
131.87
129.47
126.90
126.80
124.18
112.80
77.48
77.16
76.84
47.98
46.95
43.70
38.51
32.40
29.44
28.50
Scheme 2, 4r
O
H
H
O
NO2
CH2
129
128
127
126
125
124
f1 (ppm)
90
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-138-H
7.9003
7.2597
7.1959
5.6946
5.6886
5.2554
5.2509
3.0243
3.0080
2.7062
2.6910
2.5484
2.5383
2.3253
2.2992
2.1599
2.1508
1.6416
1.6310
1.6024
1.5704
1.5515
1.5416
1.5311
1.4273
1.3995
1.3262
1.3166
1.3043
1.2991
1.1439
1.1179
1.0223

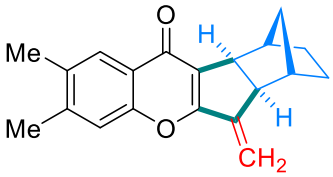
Scheme 2, 4s

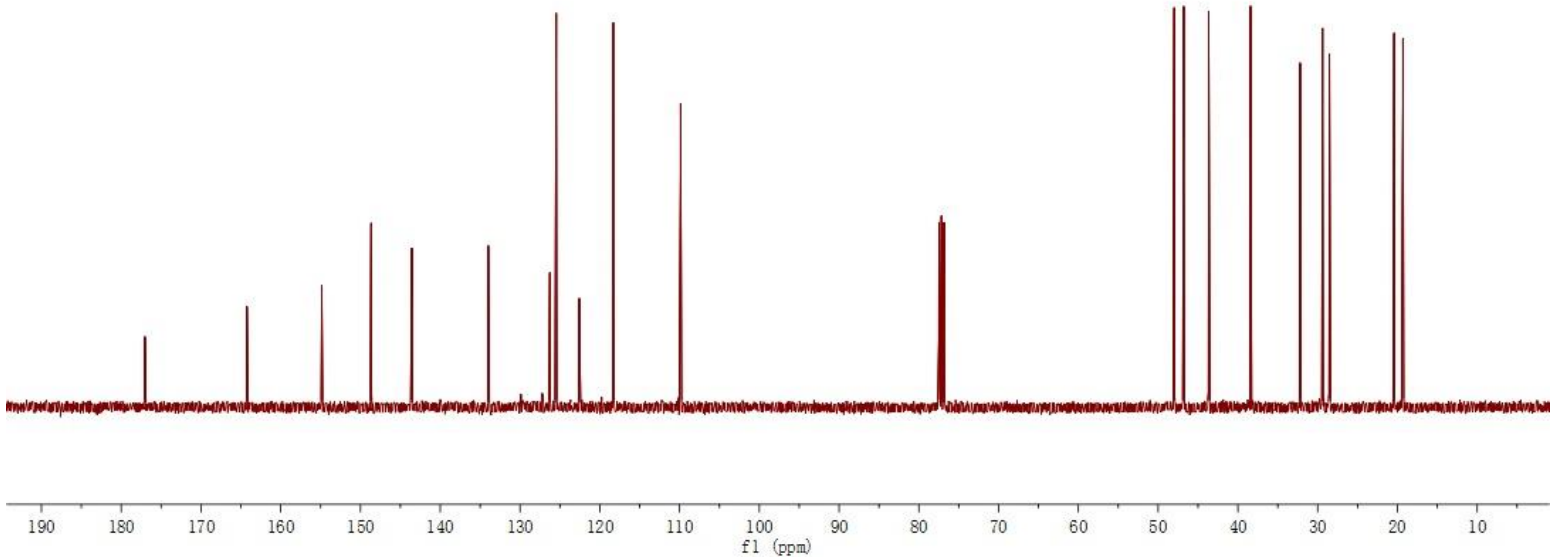

O
H
Me
Me
O
H
CH2

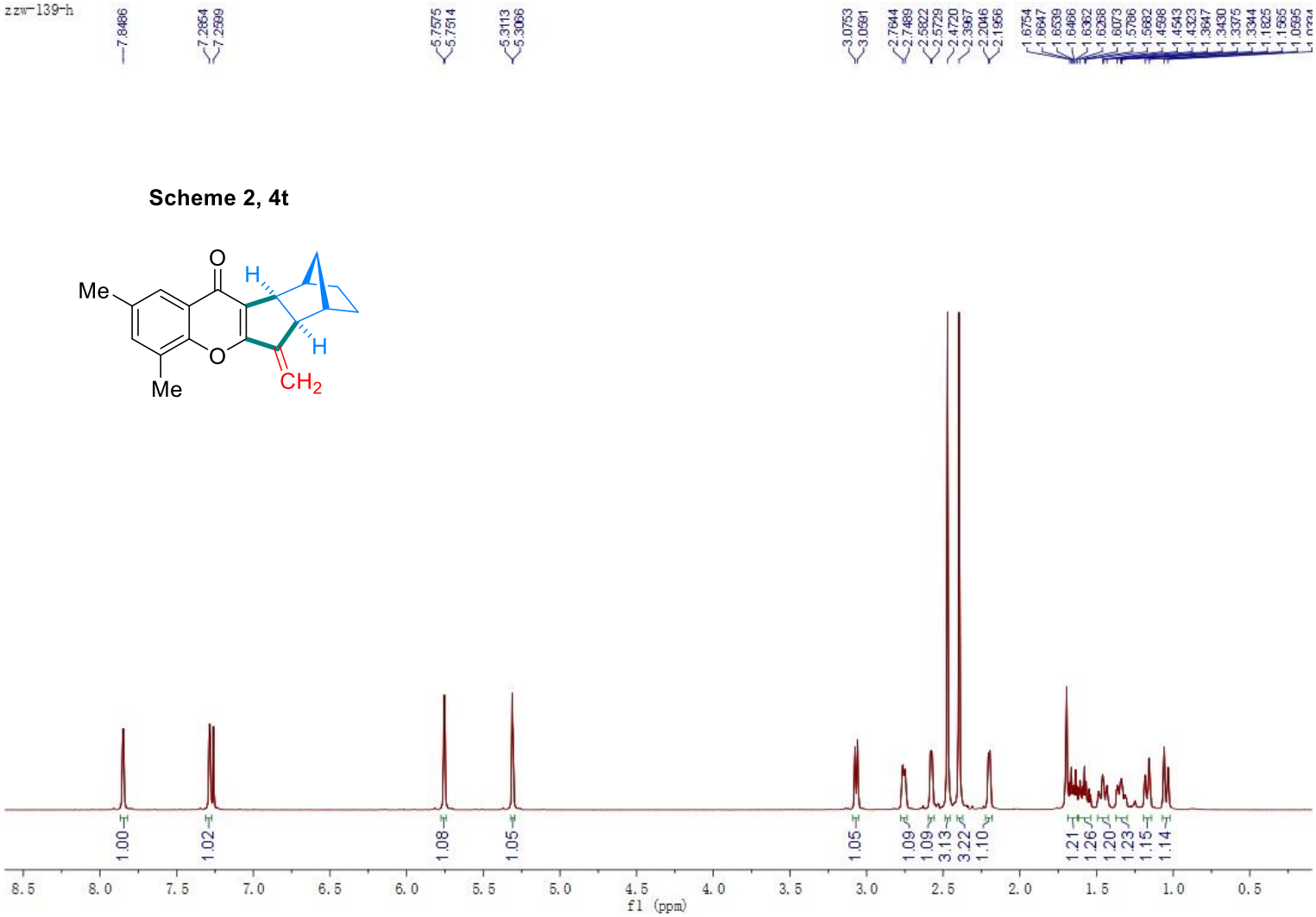

1.00
0.98
1.00
1.00
1.08
1.10
1.06
3.03
3.02
1.10
1.18
1.18
1.18
1.24
1.12
1.09
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-138-C
177.03
164.24
154.85
148.67
143.56
133.98
126.26
125.46
122.58
118.32
109.87
77.48
77.16
76.84
47.98
46.80
43.65
38.41
32.20
29.39
28.52
20.41
19.31

Scheme 2, 4s

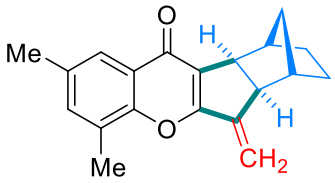

O
H
Me
Me
O
H
CH2

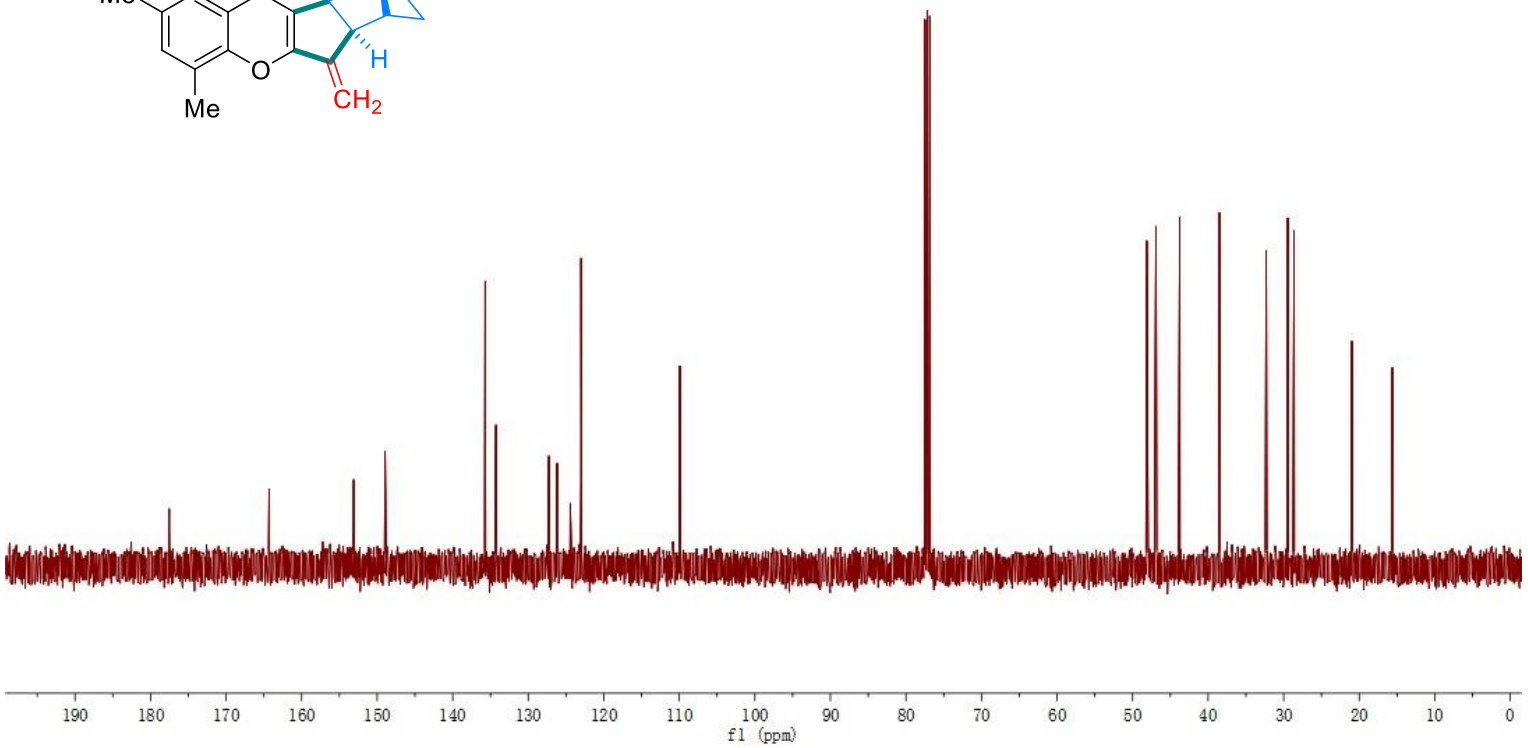

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)


zzw-139-h
7.8486
7.2854
7.2599
5.7575
5.7514
5.3113
5.3066
3.0753
3.0591
2.7644
2.7489
2.5822
2.5729
2.4720
2.3967
2.2046
2.1956
1.6754
1.6647
1.6539
1.6466
1.6362
1.6268
1.6073
1.5786
1.5682
1.4598
1.4543
1.4323
1.3647
1.3430
1.3375
1.3344
1.1825
1.1665
1.0595
Scheme 2, 4t
O
H
Me
H
O
CH2
Me
1.00
1.02
1.08
1.05
1.05
1.09
1.09
3.13
3.22
1.10
1.21
1.26
1.20
1.23
1.15
1.14
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-139-c
177.53
164.30
153.10
148.95
135.71
134.27
127.27
126.18
124.44
123.00
109.92
77.48
77.16
76.84
48.13
46.90
43.75
38.49
32.31
29.46
28.62
20.97
15.61

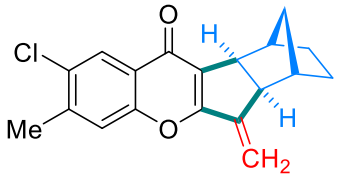
Scheme 2, 4t

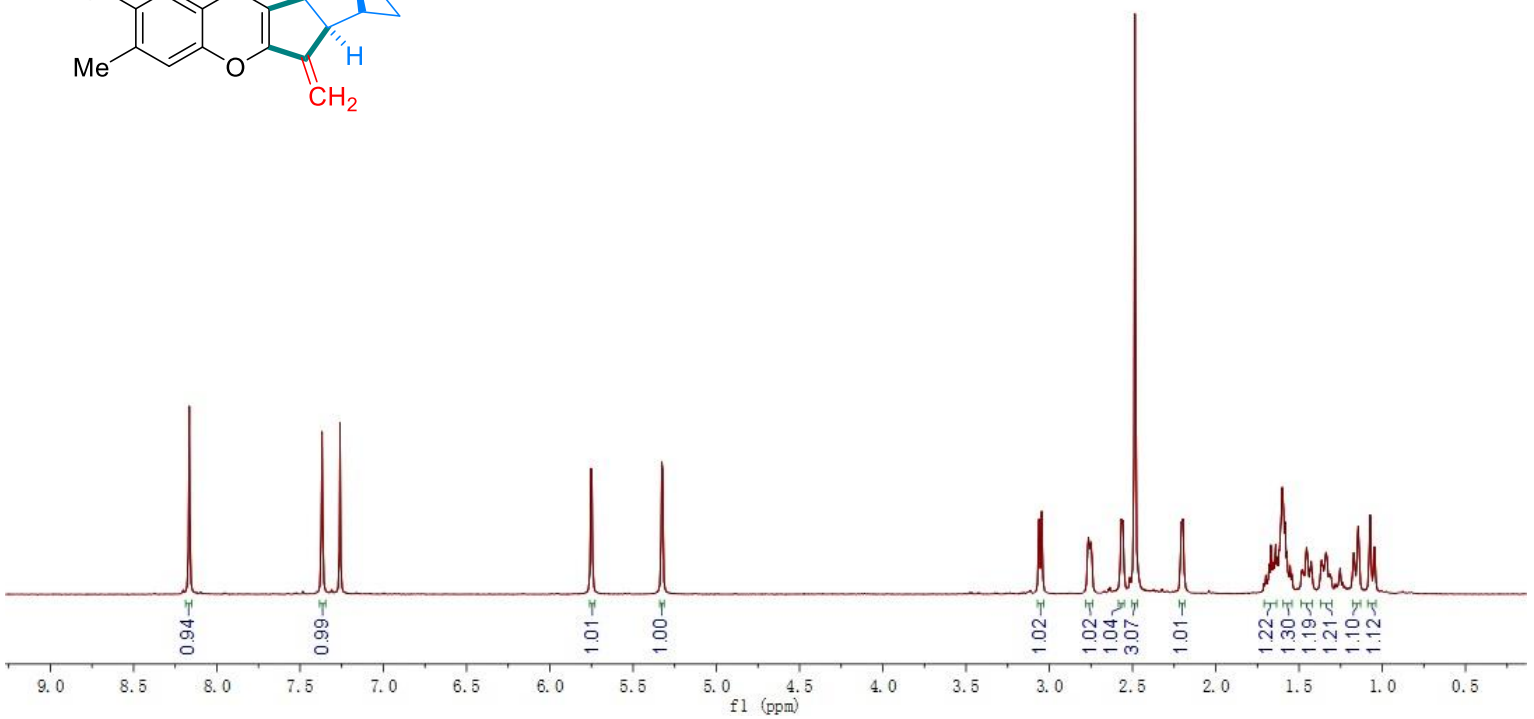

O
H
Me
O
H
CH2
Me

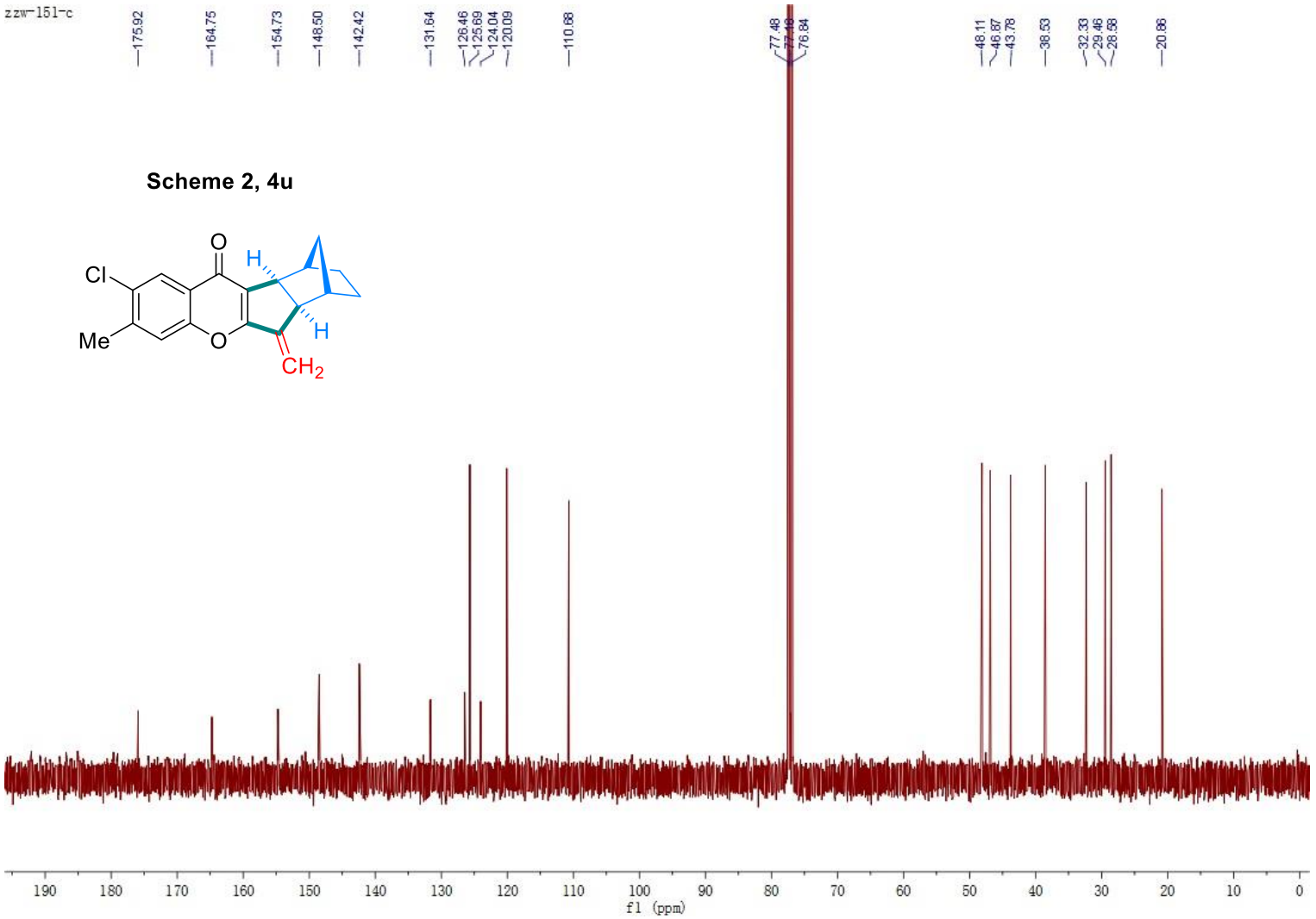

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-151-h
8.1658
7.3882
7.2599
5.7531
5.7473
5.3278
5.3235
3.0615
3.0452
2.7645
2.7493
2.5670
2.5587
2.4868
2.2059
2.1979
1.6692
1.6510
1.6404
1.6310
1.6199
1.6106
1.6009
1.5838
1.5733
1.4547
1.3644
1.3427
1.3377
1.3364
1.1709
1.1447
1.0728

Scheme 2, 4u

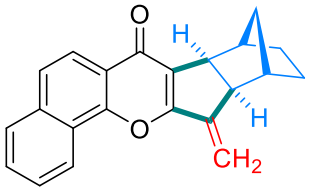

O
Cl
H
Me
O
H
CH2

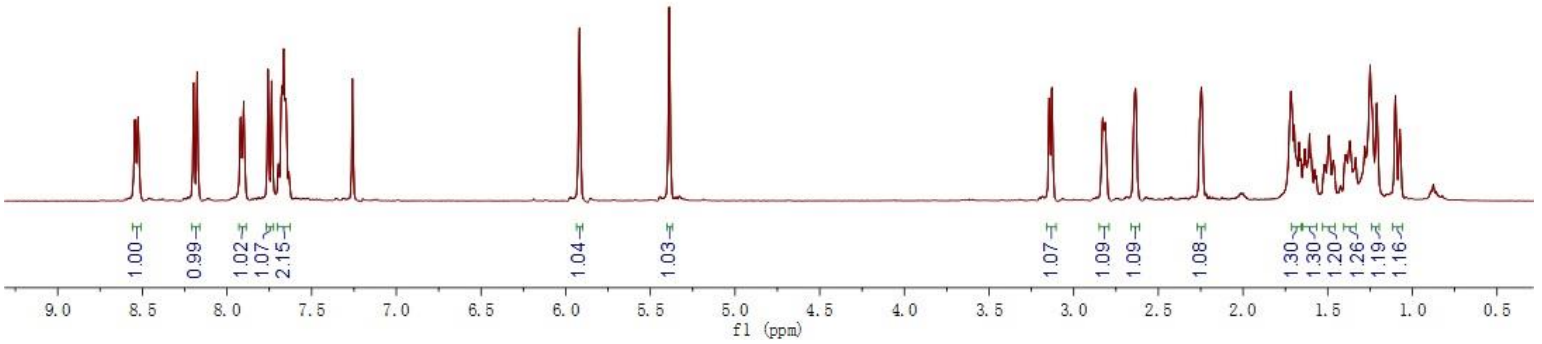

0.94
0.99
1.01
1.00
1.02
1.02
1.04
3.07
1.01
1.22
1.30
1.19
1.21
1.10
1.12
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

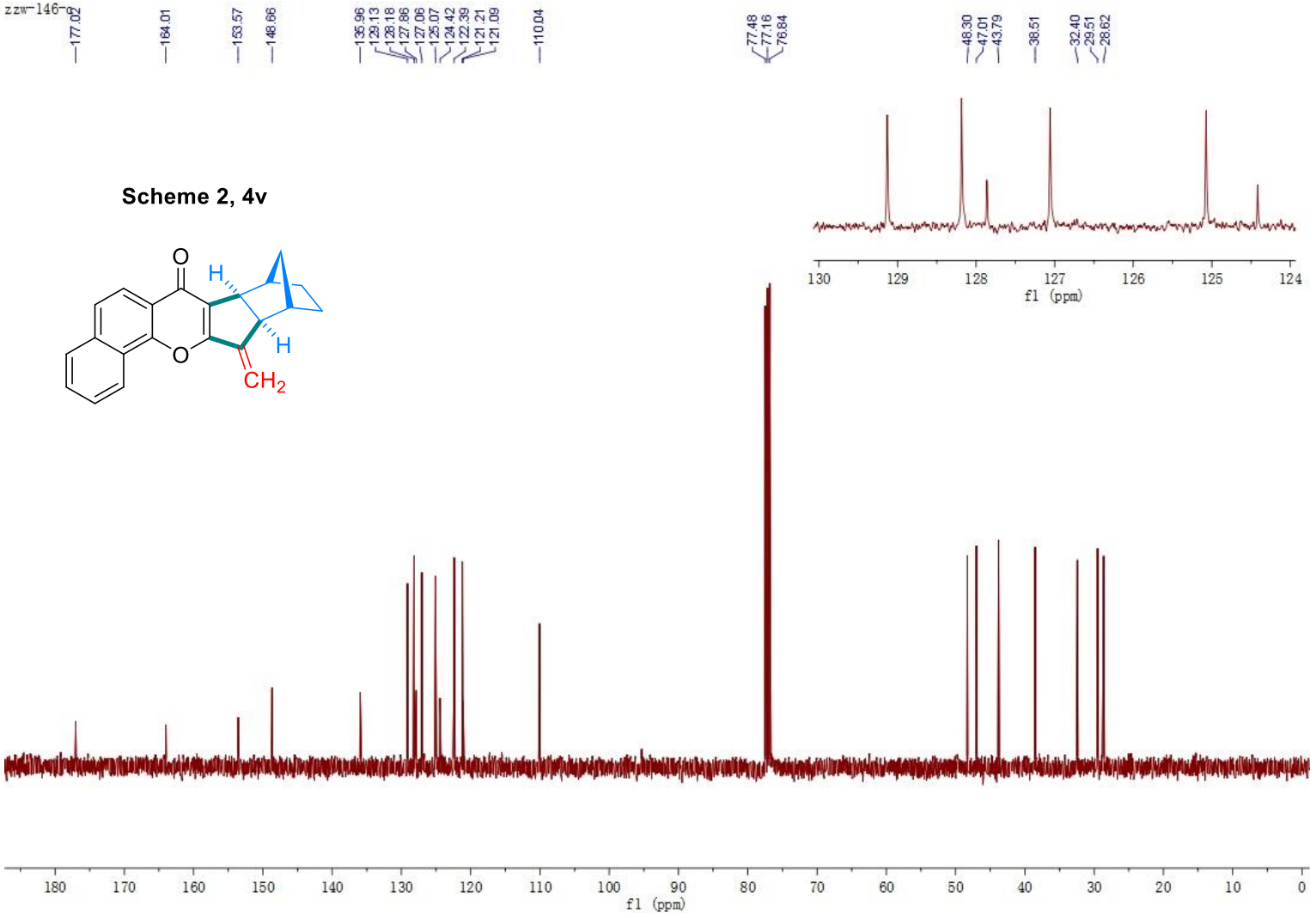

zzw-151-c
175.92
164.75
154.73
148.50
142.42
131.64
126.46
125.69
124.04
120.09
110.88
77.48
77.16
76.84
48.11
46.67
43.78
38.53
32.33
29.46
28.68
20.86
Scheme 2, 4u
O
H
Cl
H
Me
O
CH2
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-146-h
8.5449
8.5248
8.1960
8.1763
7.9196
7.9013
7.7681
7.7363
7.6749
7.6660
5.9179
5.3882
3.1443
3.1282
2.8278
2.8134
2.6407
2.6347
2.2452
1.7167
1.6975
1.6879
1.6798
1.6685
1.6595
1.6354
1.6165
1.6067
1.5971
1.4933
1.3945
1.3679
1.3342
1.2492
1.2100
1.0997

Scheme 2, 4v

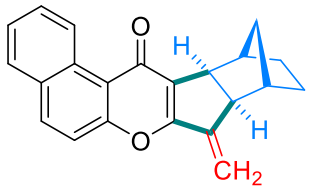

O
H
H
O
CH2

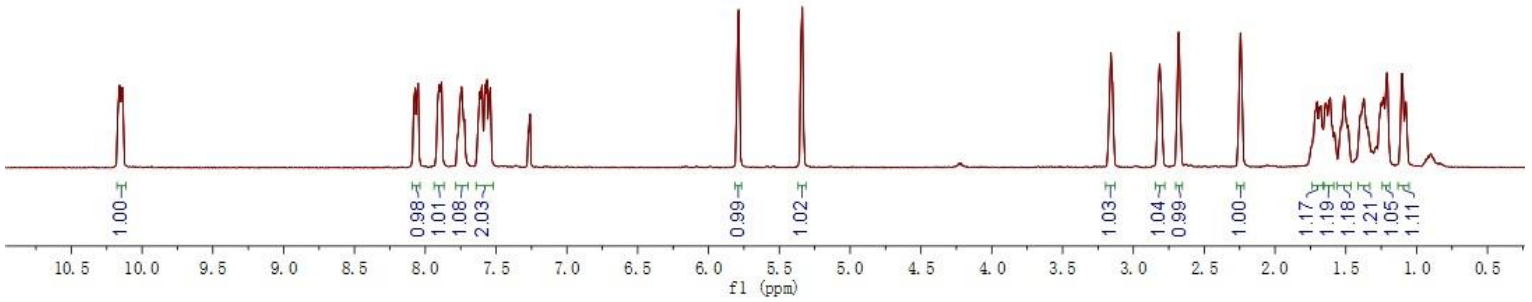

1.00
0.99
1.02
1.07
2.15
1.04
1.03
1.07
1.09
1.09
1.08
1.30
1.30
1.20
1.26
1.19
1.16
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-146-2
177.02
164.01
153.57
148.66
135.96
129.13
128.18
127.86
127.06
125.07
124.42
122.39
121.21
121.09
110.04
77.48
77.16
76.84
48.30
47.01
43.79
38.51
32.40
29.51
28.62
Scheme 2, 4v
O
H
H
O
CH2
130
129
128
127
126
125
124
f1 (ppm)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-147-h
10.1582
10.1386
8.0715
8.0498
7.9023
7.8857
7.7435
7.7234
7.6149
7.5997
7.5788
7.5632
7.5409
7.2598
5.7873
5.3380
3.1588
2.8152
2.6806
2.2438
1.7029
1.6906
1.6764
1.6435
1.6098
1.5797
1.5124
1.4852
1.3731
1.3476
1.2493
1.2355
1.2096
1.1024

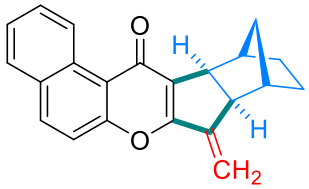
Scheme 2, 4w

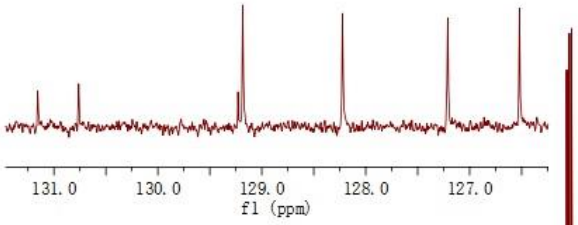

O
H
H
O
CH2

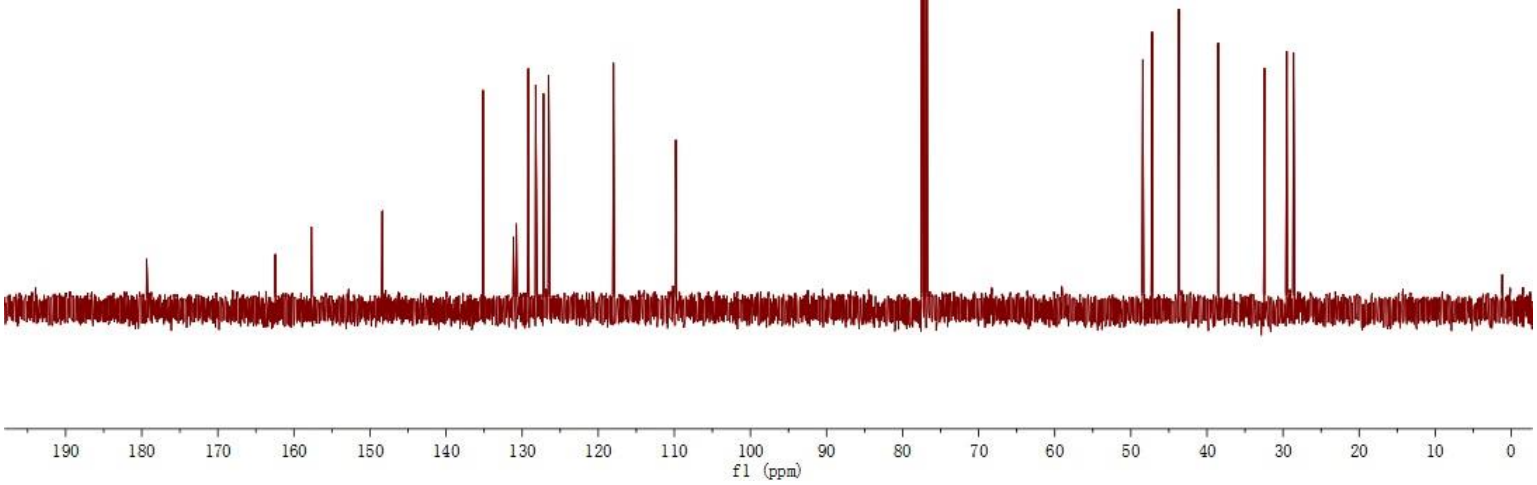

1.00
0.98
1.01
1.08
2.03
0.99
1.02
1.03
1.04
0.99
1.00
1.17
1.19
1.18
1.21
1.05
1.11
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-147-c
179.35
162.44
157.71
148.37
135.15
131.16
130.76
129.23
129.18
128.22
127.21
126.52
118.00
109.80
77.48
77.16
76.84
48.43
47.21
43.70
38.50
32.44
29.52
28.61

Scheme 2, 4w

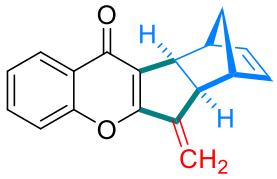

O
H
H
O
CH2

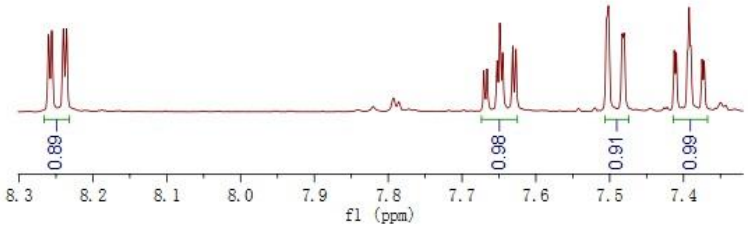

131.0
130.0
129.0
128.0
127.0
f1 (ppm)

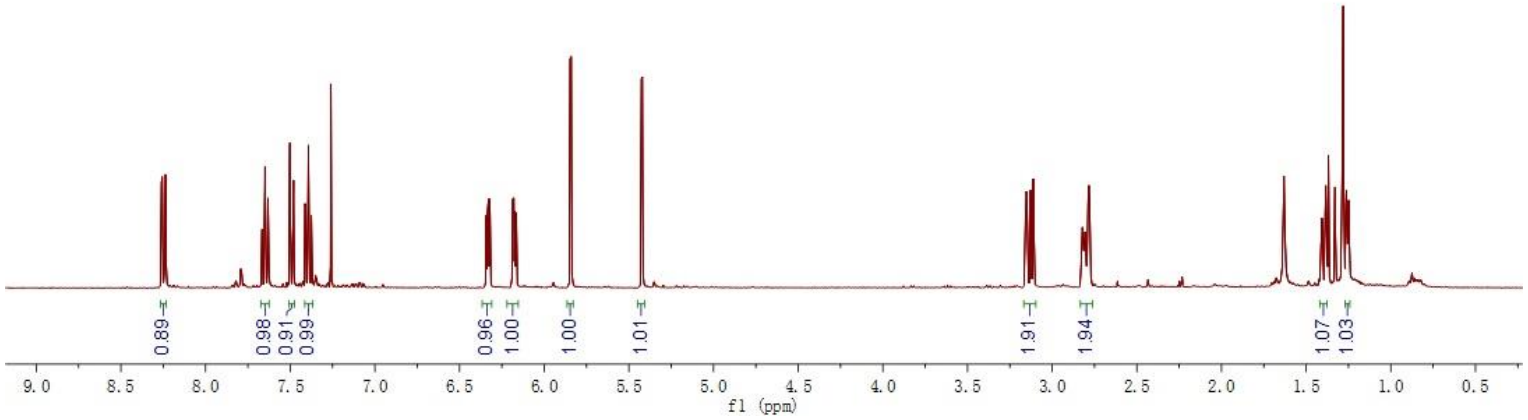

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-160-h
8.2599
8.2557
8.2400
8.2368
7.6488
7.6314
7.6271
7.5039
7.5018
7.4829
7.4807
7.4124
7.3944
7.3923
7.3901
6.3351
6.3286
6.3209
6.1865
6.1792
6.1723
6.1650
5.8467
5.8405
5.4254
5.4204
3.1521
3.1278
3.1117
2.8216
2.8120
2.8058
2.7964
2.7832
1.4109
1.4070
1.4031
1.3877
1.3838
1.3799
1.3756
1.2856
1.2812
1.2625
1.2468

Fig. 2, 4x


O
H
H
O
CH2


0.89
0.98
0.91
0.99
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
f1 (ppm)


0.89
0.98
0.91
0.99
0.96
1.00
1.00
1.01
1.91
1.94
1.07
1.03
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

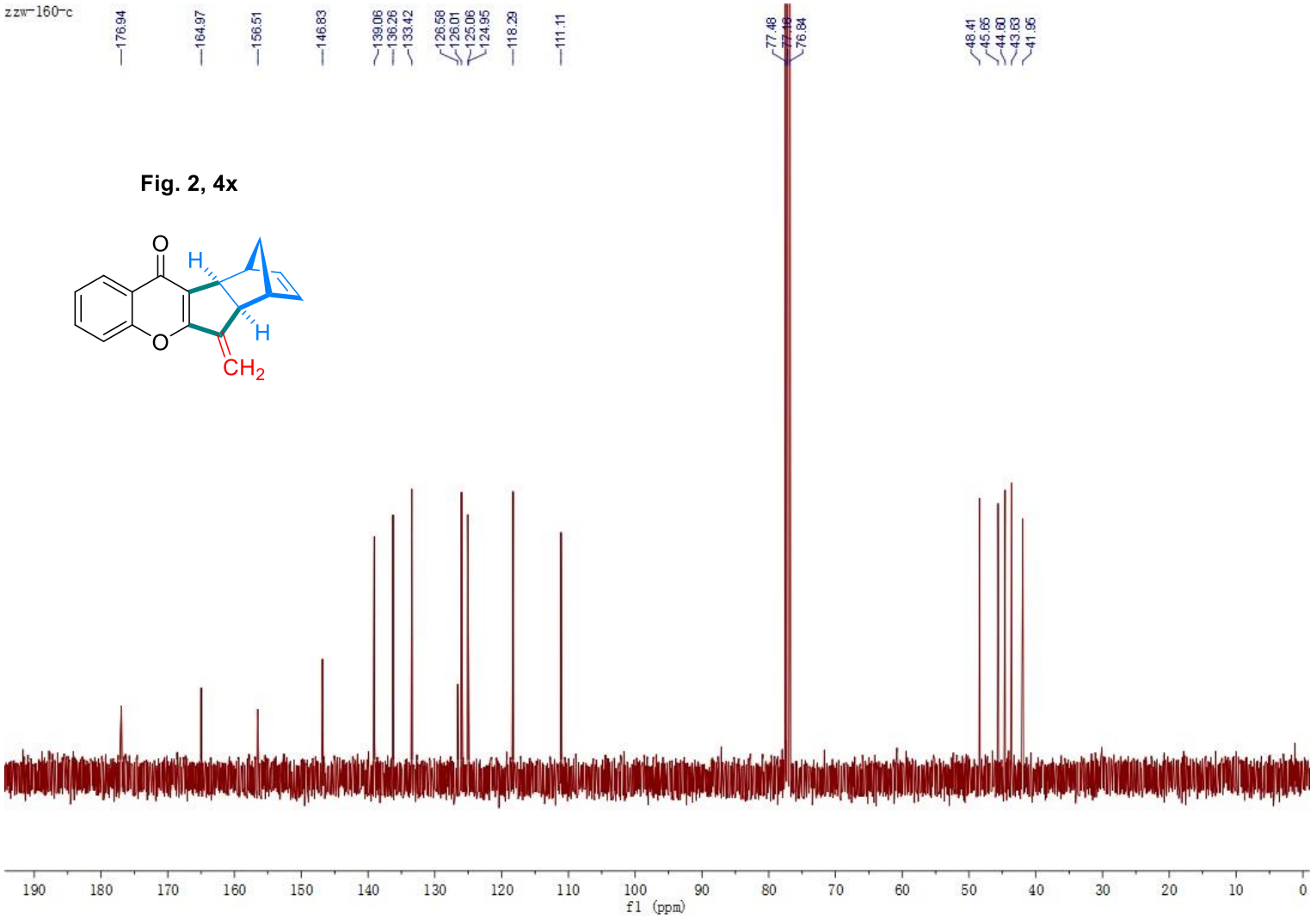
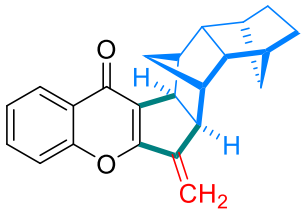
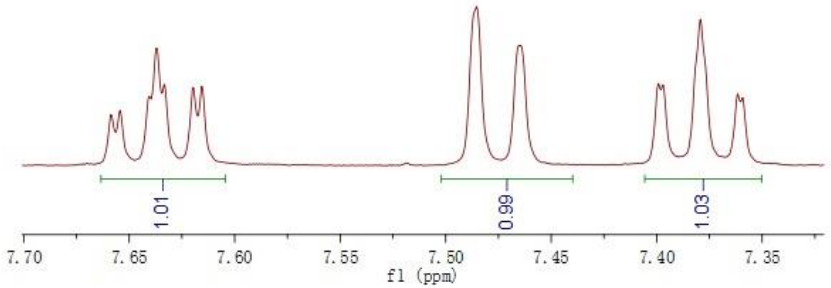

zzw-160-c
176.94
164.97
156.51
146.83
139.06
136.26
133.42
126.58
126.01
125.06
124.95
118.29
111.11
77.48
77.16
76.84
48.41
45.85
44.60
43.63
41.95
O
H
H
O
CH2
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

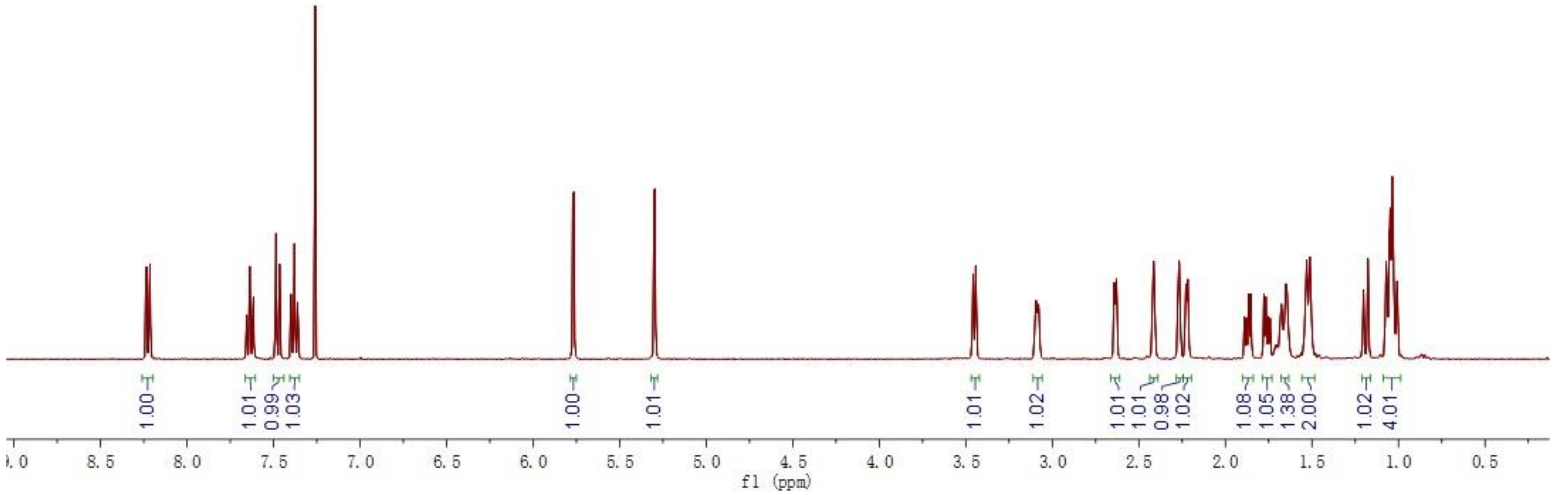
Fig. 2, 4x


zzw-163-H
8.2374
8.2333
8.2174
8.2134
7.6585
7.6543
7.6404
7.6370
7.6334
7.6197
7.6155
7.4864
7.4645
7.3992
7.3970
7.3793
7.3616
7.3393
7.2595
5.7708
5.7648
5.3007
5.2961
3.4581
3.4425
3.0948
3.0811
2.6416
2.6300
2.4152
2.2680
2.2384
2.2175
1.8653
1.8536
1.7776
1.7662
1.6492
1.5301
1.1765
1.0711
1.0535
1.0478
1.0360
1.0080

Fig. 2, 4y


O
H
H
O
CH2


1.01
0.99
1.03
7.70
7.65
7.60
7.55
7.50
7.45
7.40
7.35
f1 (ppm)


1.00
1.01
0.99
1.03
1.00
1.01
1.01
1.02
1.01
1.01
0.98
1.02
1.08
1.05
1.38
2.00
1.02
4.01
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

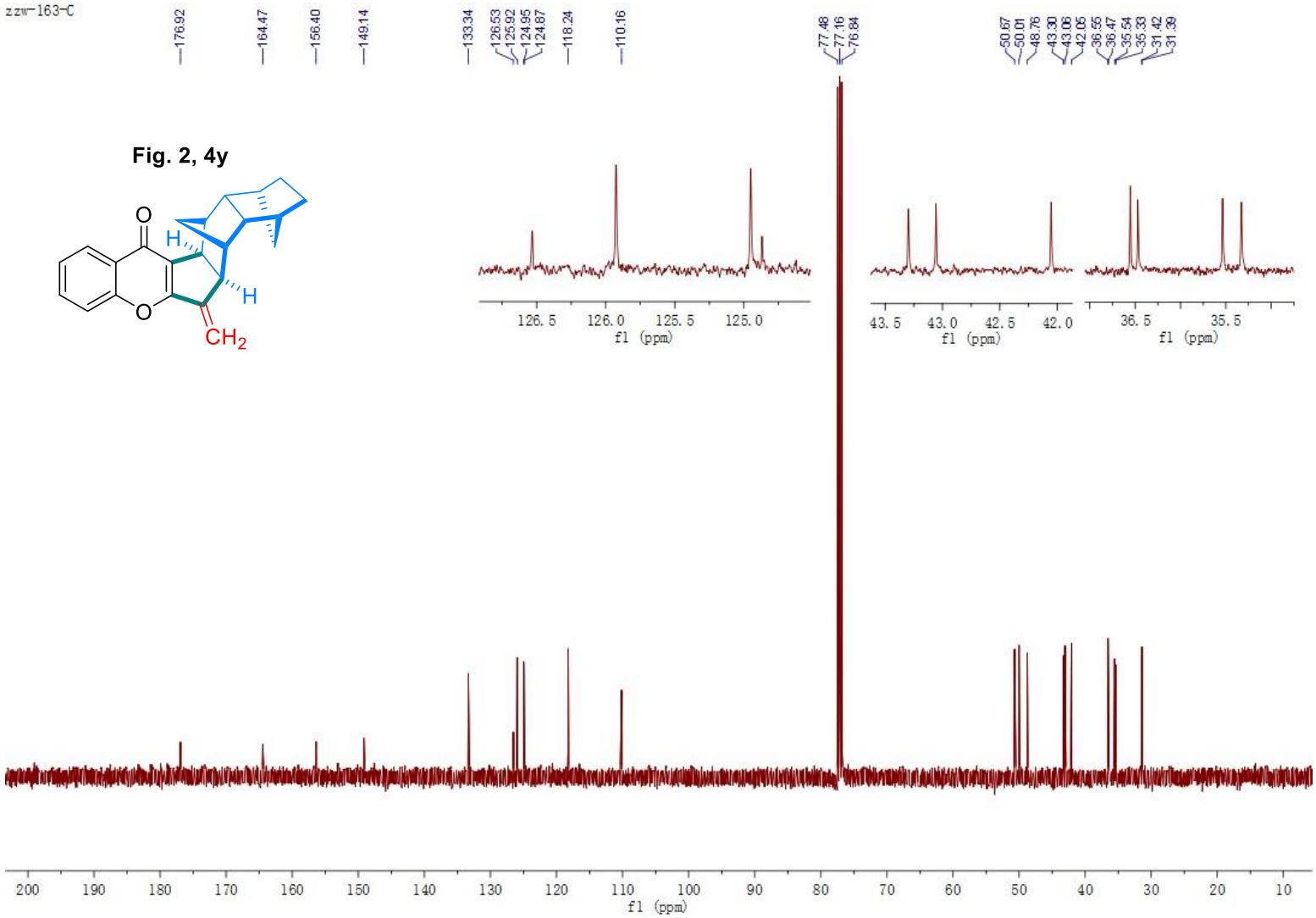
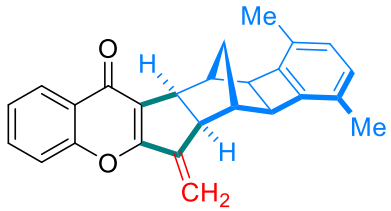

zzw-163-C
176.92
164.47
156.40
149.14
133.34
126.53
125.92
124.95
124.87
118.24
110.16
77.48
77.16
76.84
50.67
50.01
48.76
43.30
43.06
42.05
36.55
36.47
35.54
35.33
31.42
31.39
126.5
126.0
125.5
125.0
f1 (ppm)
43.5
43.0
42.5
42.0
f1 (ppm)
36.5
35.5
f1 (ppm)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

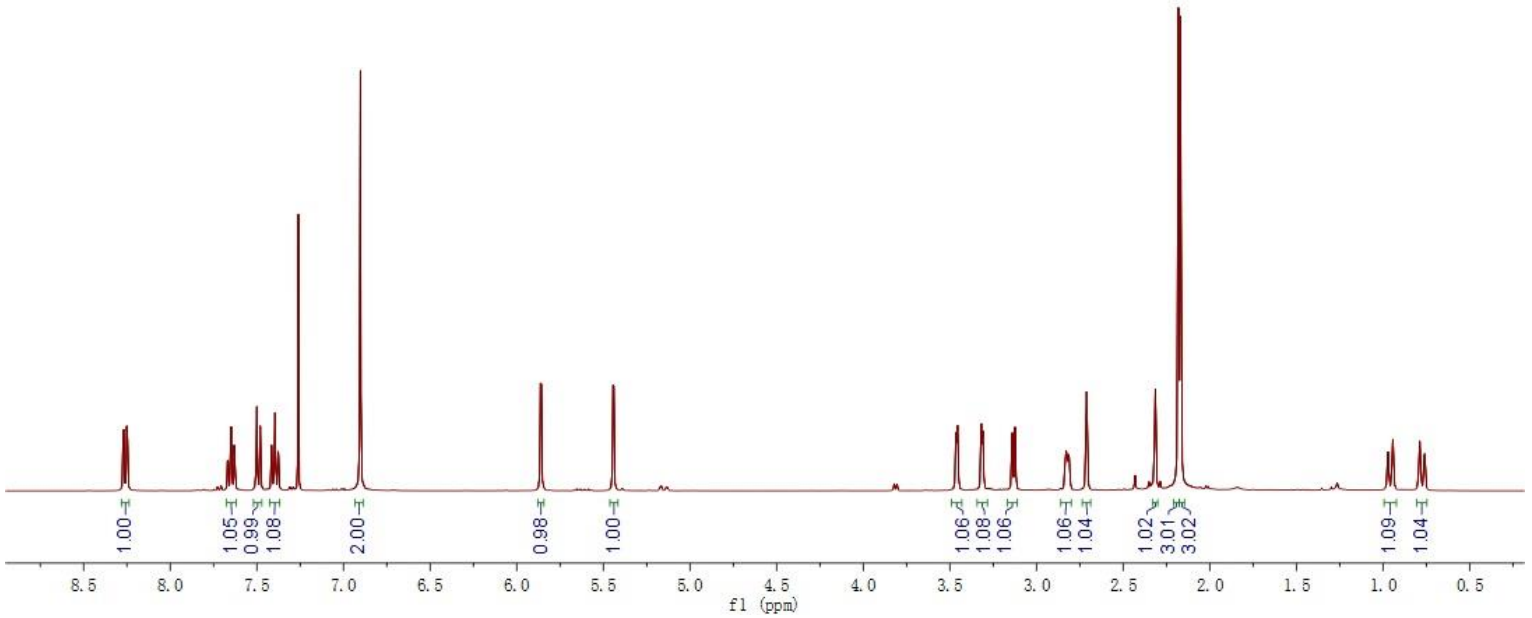
Fig. 2, 4y

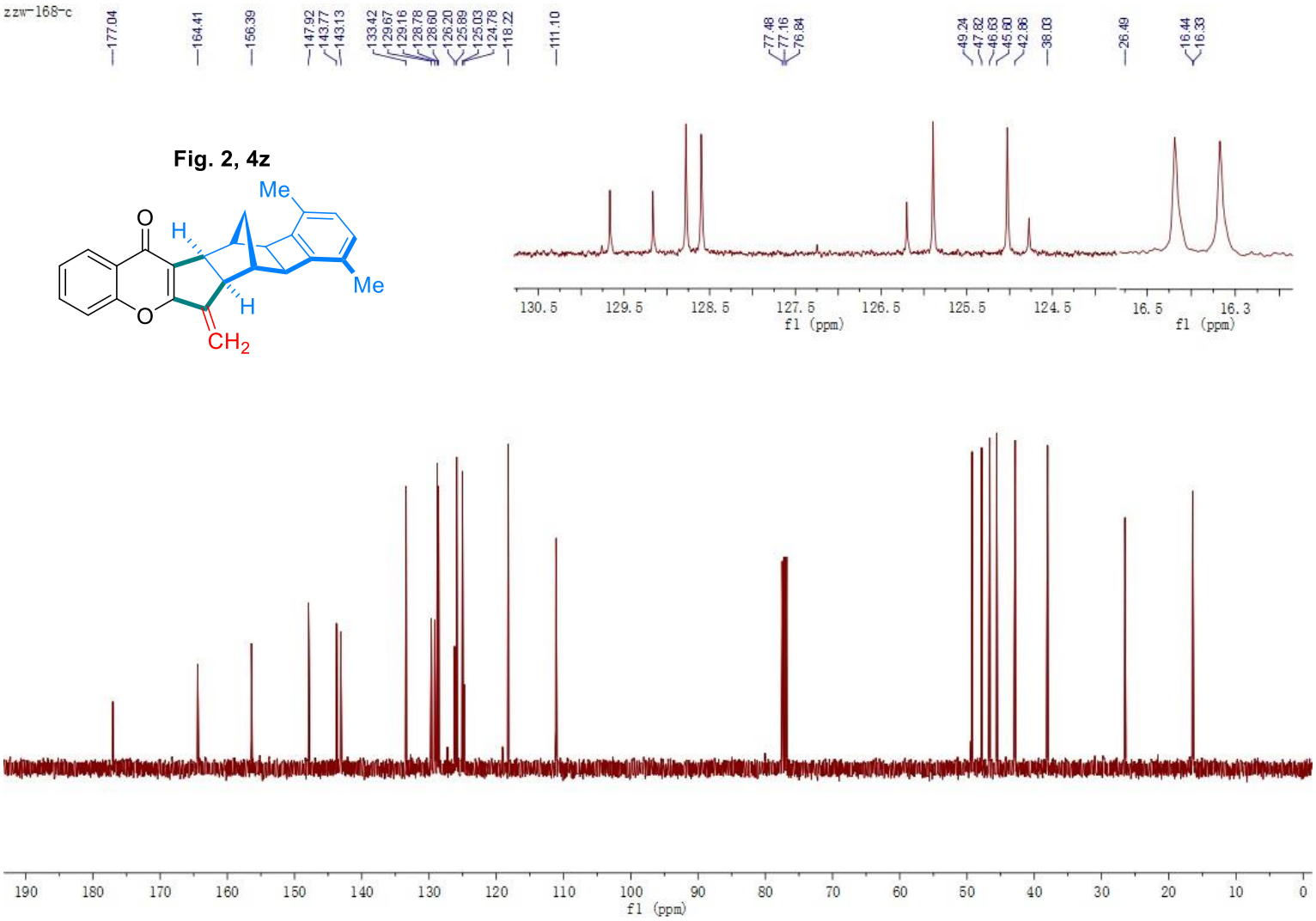
O
H
H
O
CH2


zzw-168-h
8.2709
8.2669
8.2510
8.2470
7.6481
7.6444
7.6307
7.4997
7.4800
7.4788
7.4150
7.4127
7.3950
6.9023
5.8630
5.8570
5.4439
5.4392
3.4642
3.4553
3.3183
3.3094
3.1396
3.1235
2.8287
2.8154
2.7103
2.3139
2.1807
2.1686
0.9709
0.9429
0.7877
0.7596

Fig. 2, 4z

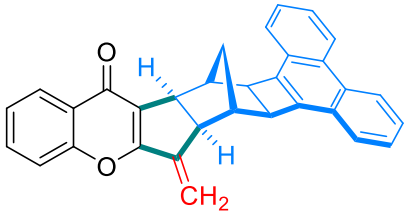

Me
O
H
Me
H
O
CH2

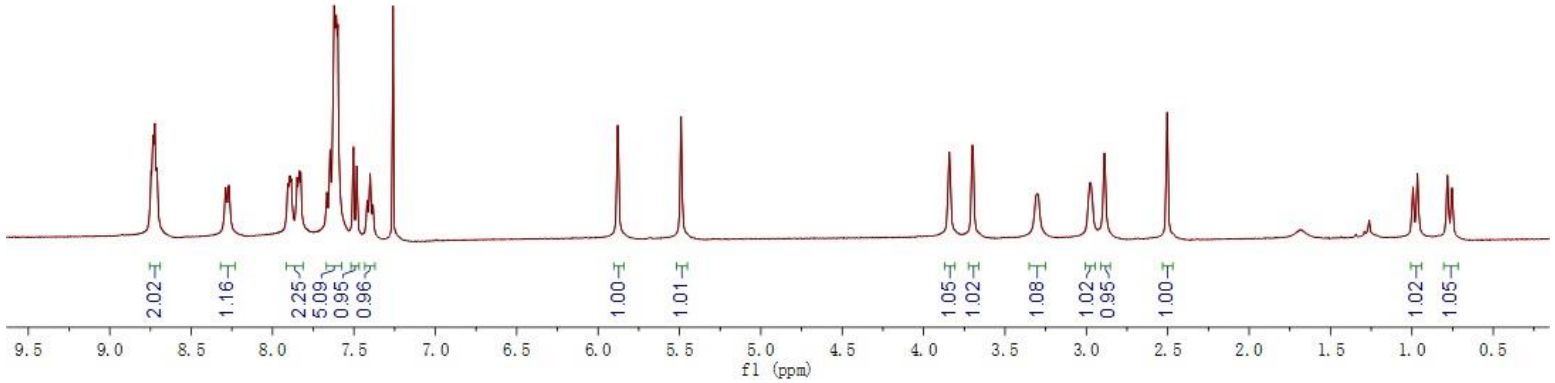

1.00
1.05
0.99
1.08
2.00
0.98
1.00
1.06
1.08
1.06
1.06
1.04
1.02
3.01
3.02
1.09
1.04
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-168-c
177.04
164.41
156.39
147.92
143.77
143.13
133.42
129.67
129.16
128.78
128.60
126.20
125.89
125.03
124.78
118.22
111.10
77.48
77.16
76.84
49.24
47.82
46.63
45.60
42.86
38.03
26.49
16.44
16.33
Fig. 2, 4z
Me
O
H
Me
H
O
CH2
130.5
129.5
128.5
127.5
126.5
125.5
124.5
f1 (ppm)
16.5
16.3
f1 (ppm)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-170-H
8.7461
8.7336
8.7235
8.7144
8.7101
8.2679
8.2683
7.9064
7.8931
7.8847
7.8487
7.8426
7.8378
7.8345
7.8264
7.8215
7.6122
7.6086
7.6057
7.5988
7.5029
7.4821
7.4184
7.4002
7.3823
7.2596
5.8795
5.4888
3.8417
3.6997
3.3081
3.2993
2.9760
2.8888
2.5036
0.9934
0.9658
0.7813
0.7534

Fig. 2, 4aa


O
H
H
O
CH2


2.02
1.16
2.25
5.09
0.95
0.96
1.00
1.01
1.05
1.02
1.08
1.02
0.95
1.00
1.02
1.05
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

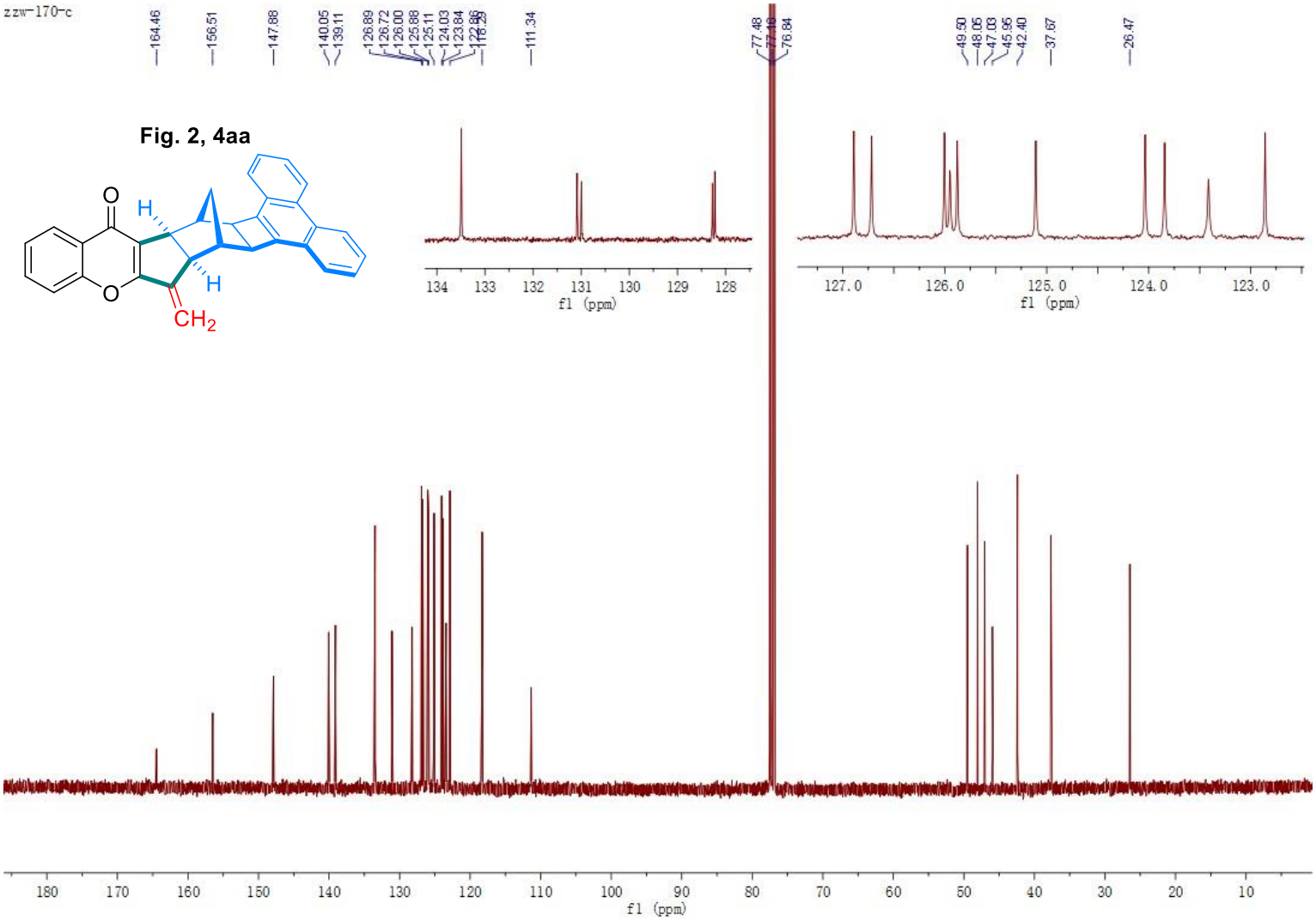
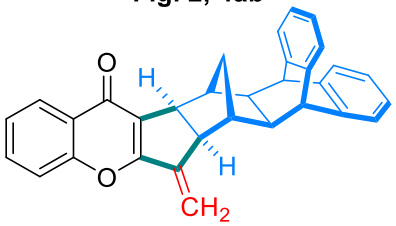
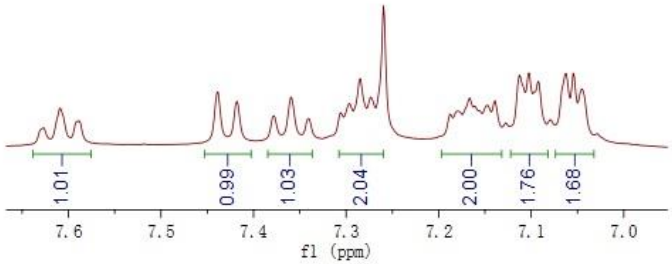

zzw-170-c
164.46
156.51
147.88
140.05
139.11
126.89
126.72
126.00
125.88
125.11
124.03
123.84
122.86
111.34
77.48
77.16
76.84
49.50
48.05
47.03
45.96
42.40
37.67
26.47
f1 (ppm)
f1 (ppm)
f1 (ppm)

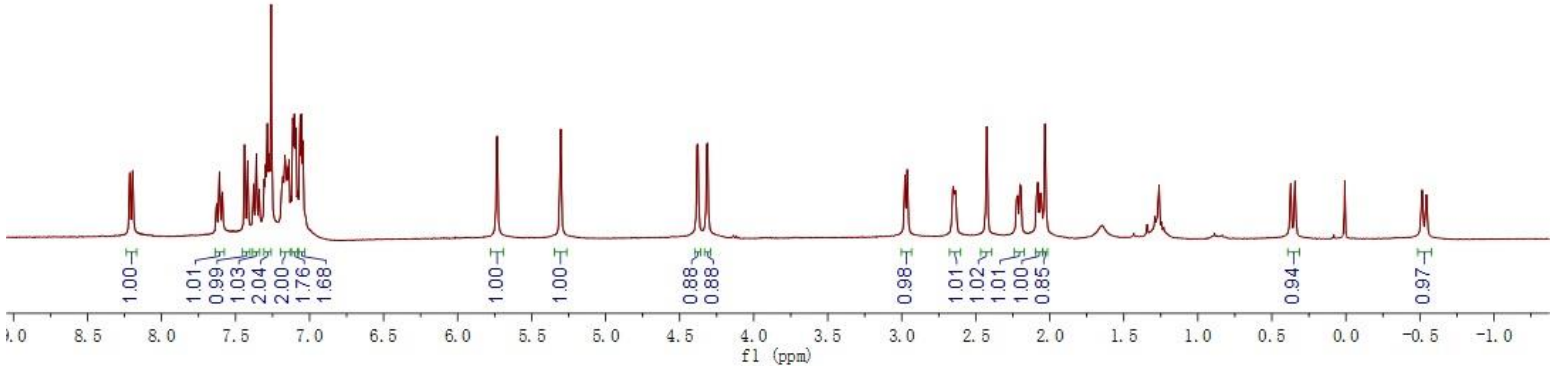
Fig. 2, 4aa


zzw-169-h
8.2139
8.1941
7.6089
7.4388
7.4179
7.3595
7.2965
7.2849
7.2731
7.2596
7.1665
7.1610
7.1473
7.1393
7.1125
7.1025
7.0922
7.0627
7.0543
7.0452
5.7371
5.7317
5.3067
5.3035
4.3828
4.3765
4.3173
4.3109
2.9781
2.9621
2.6523
2.6383
2.4256
2.2229
2.2166
2.2014
2.1958
2.0867
2.0810
2.0648
2.0594
2.0320
0.3723
0.3435
-0.5148
-0.5439

Fig. 2, 4ab


O
H
H
O
CH2


1.01
0.99
1.03
2.04
2.00
1.76
1.68
7.6
7.5
7.4
7.3
7.2
7.1
7.0
f1 (ppm)


1.00
1.01
0.99
1.03
2.04
2.00
1.76
1.68
1.00
1.00
0.88
0.88
0.98
1.01
1.02
1.01
1.00
0.85
0.94
0.97
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
f1 (ppm)

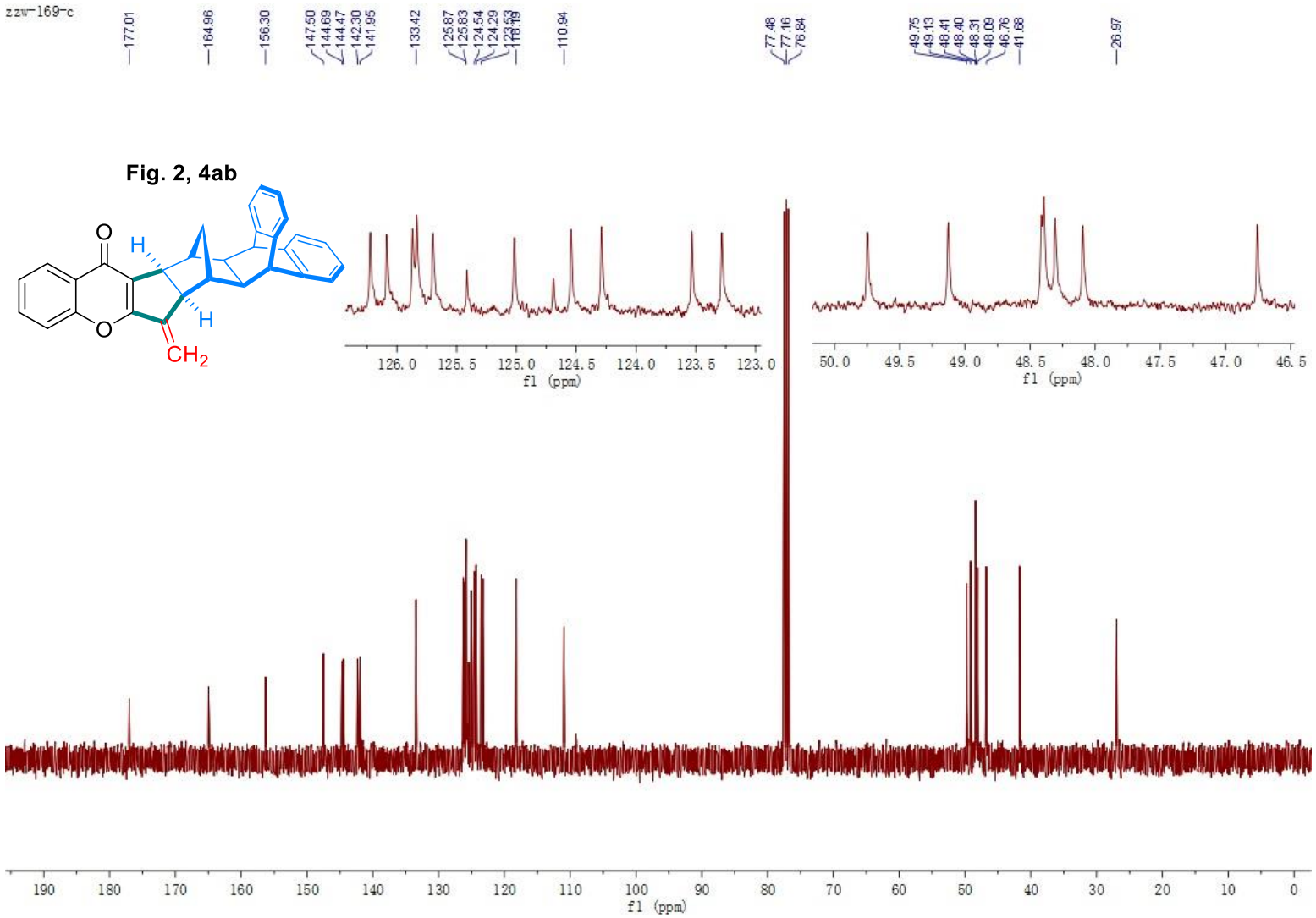
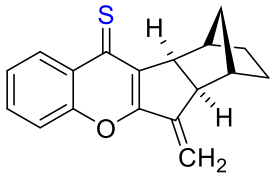
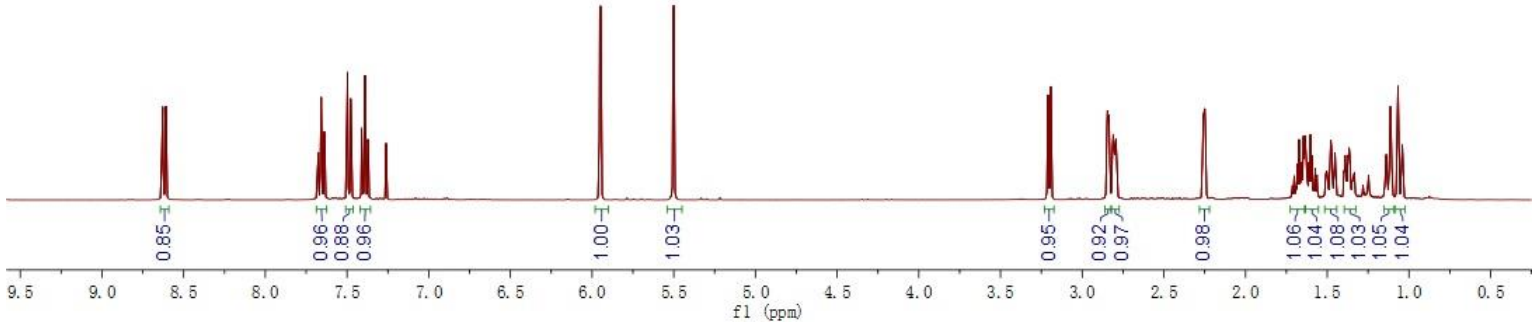

zzw-169-c
177.01
164.96
156.30
147.50
144.69
144.47
142.30
141.95
133.42
125.87
125.83
124.54
124.29
123.53
118.19
110.94
77.48
77.16
76.84
49.75
49.13
48.41
48.40
48.31
48.09
46.76
41.68
26.97
O
H
H
O
CH2
126.0 125.5 125.0 124.5 124.0 123.5 123.0
f1 (ppm)
50.0 49.5 49.0 48.5 48.0 47.5 47.0 46.5
f1 (ppm)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

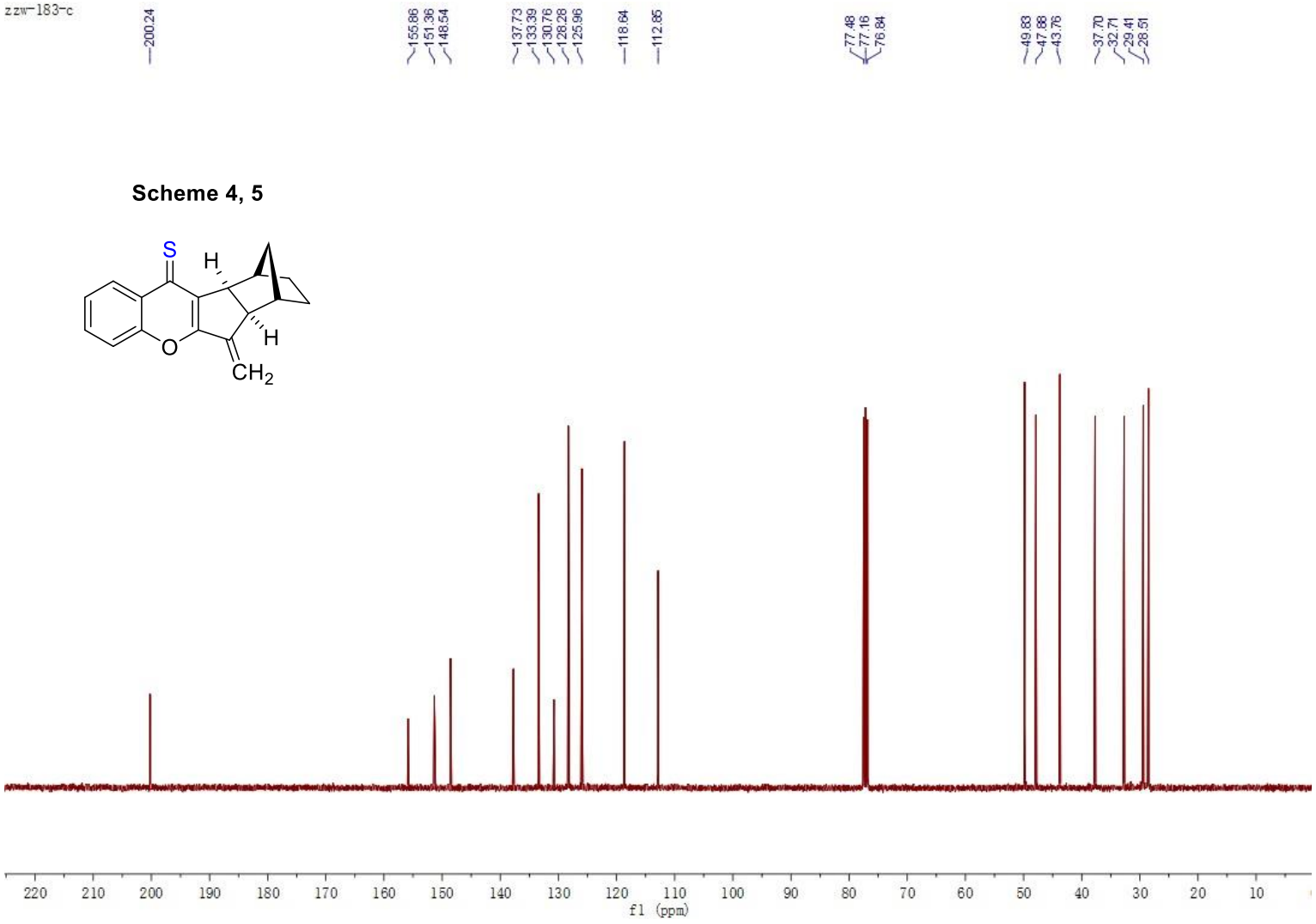
Fig. 2, 4ab


zzw-183-h
8.6315
8.6281
8.6110
8.6077
7.6796
7.6755
7.6616
7.6583
7.6546
7.6410
7.6368
7.4966
7.4909
7.4776
7.4760
7.4103
7.4077
7.3899
7.3873
7.3722
7.3695
7.2604
5.9525
5.9462
5.5009
5.4968
3.2092
3.1925
2.8453
2.8362
2.8098
2.7936
2.2383
2.2493
1.6833
1.6725
1.6549
1.6450
1.6360
1.6122
1.6027
1.5925
1.4780
1.4523
1.3905
1.3710
1.3659
1.1387
1.1124
1.0696

Scheme 4, 5


S
H
H
O
CH2

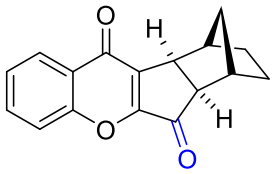

0.85
0.96
0.88
0.96
1.00
1.03
0.95
0.92
0.97
0.98
1.06
1.04
1.08
1.03
1.05
1.04
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

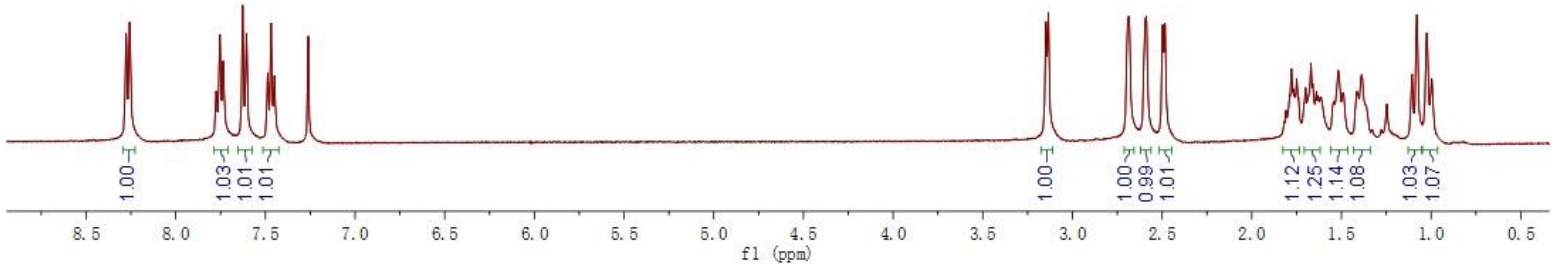

zzw-183-c
200.24
155.86
151.36
148.54
137.73
133.39
130.76
128.28
125.96
118.64
112.85
77.48
77.16
76.84
49.83
47.88
43.76
37.70
32.71
29.41
28.51
S
H
H
O
CH2
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

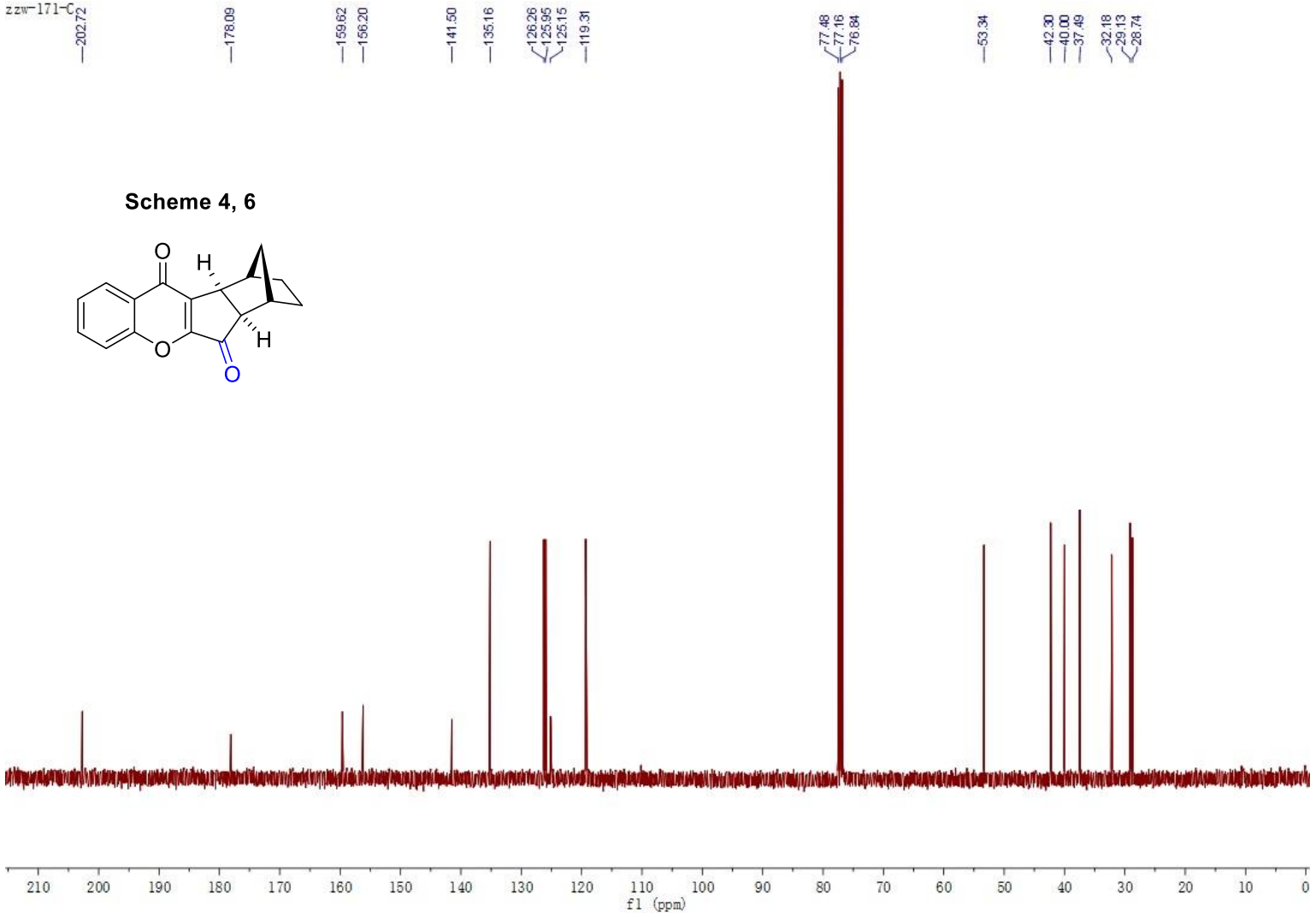
Scheme 4, 5


zzw-171-H
8.2767
8.2569
7.7742
7.7537
7.7358
7.6267
7.6053
7.4872
7.4681
7.4494
3.1479
3.1344
2.6911
2.6848
2.5939
2.5880
2.4968
2.4842
1.7787
1.7688
1.7494
1.6995
1.6805
1.6701
1.6596
1.6398
1.5181
1.0794
1.0241
0.9972

Scheme 4, 6

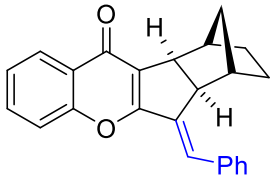

O
H
O
H
O

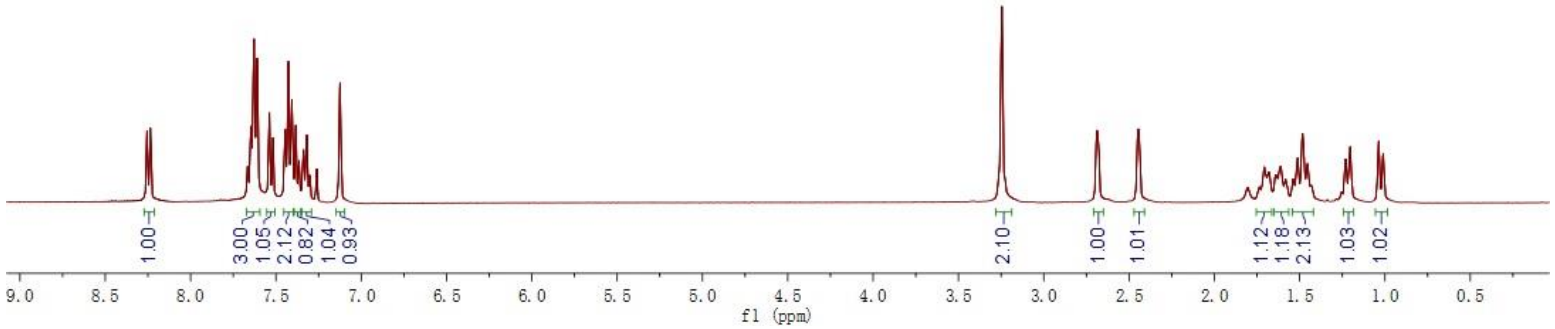

1.00
1.03
1.01
1.01
1.00
1.00
0.99
1.01
1.12
1.25
1.14
1.08
1.03
1.07
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-171-C
202.72
178.09
159.62
156.20
141.50
135.16
126.26
125.95
125.15
119.31
77.48
77.16
76.84
53.34
42.30
40.00
37.49
32.18
29.13
28.74
Scheme 4, 6
O
H
O
H
O
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-173-h
8.2566
8.2358
7.6662
7.6628
7.6452
7.6282
7.6105
7.5378
7.5169
7.4449
7.4265
7.4065
7.3832
7.3644
7.3376
7.3189
7.3017
7.2800
7.1243
3.2454
2.6883
2.4429
1.7358
1.7065
1.6948
1.6871
1.6814
1.6392
1.6334
1.6189
1.6139
1.6092
1.5820
1.5727
1.5373
1.5117
1.4820
1.4542
1.4346
1.4297
1.2301
1.2040
1.0363
1.0101

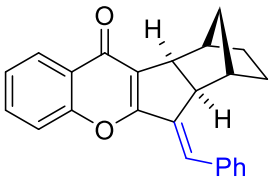
Scheme 4, 7

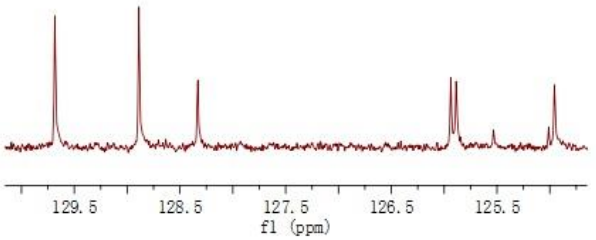

O
H
H
O
Ph

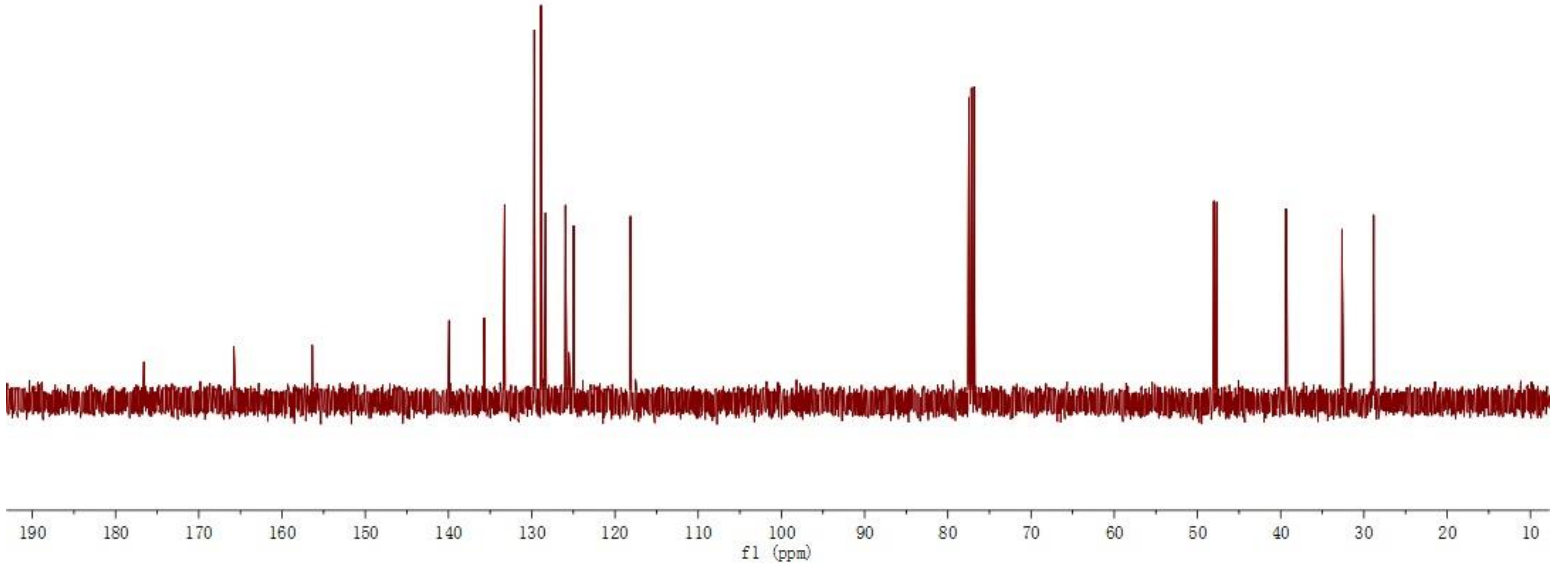

1.00
3.00
1.05
2.12
0.82
1.04
0.93
2.10
1.00
1.01
1.12
1.18
2.13
1.03
1.02
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-173-c
176.59
165.78
156.39
139.91
135.71
133.25
129.68
128.89
128.33
125.94
125.89
125.53
125.01
124.96
118.12
77.48
77.16
76.84
48.03
47.67
39.38
39.28
32.64
28.95
28.84

Scheme 4, 7

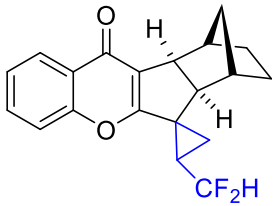

O
H
H
O
Ph

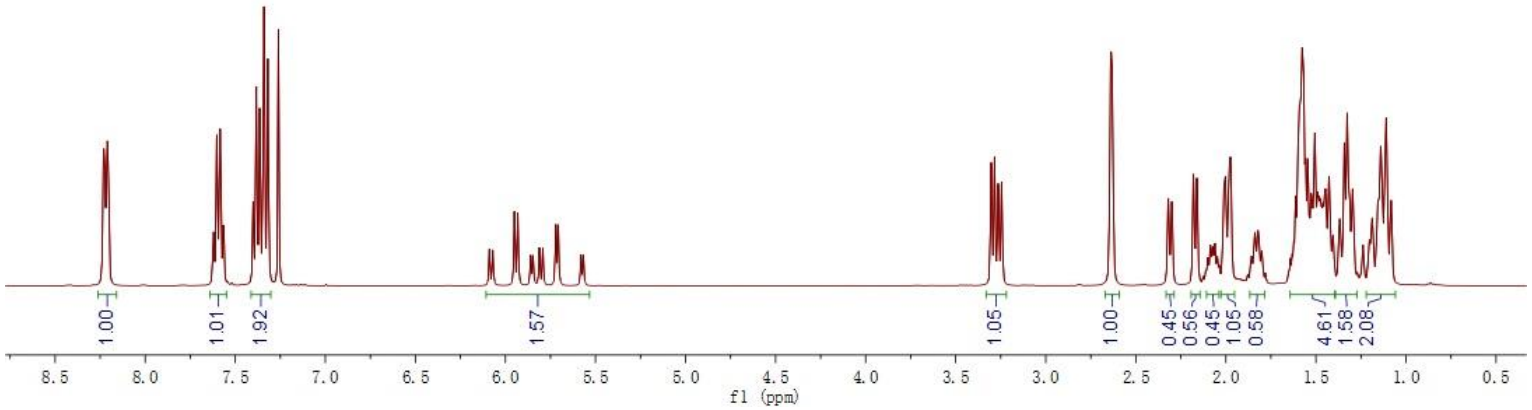

129.5
128.5
127.5
126.5
125.5
f1 (ppm)

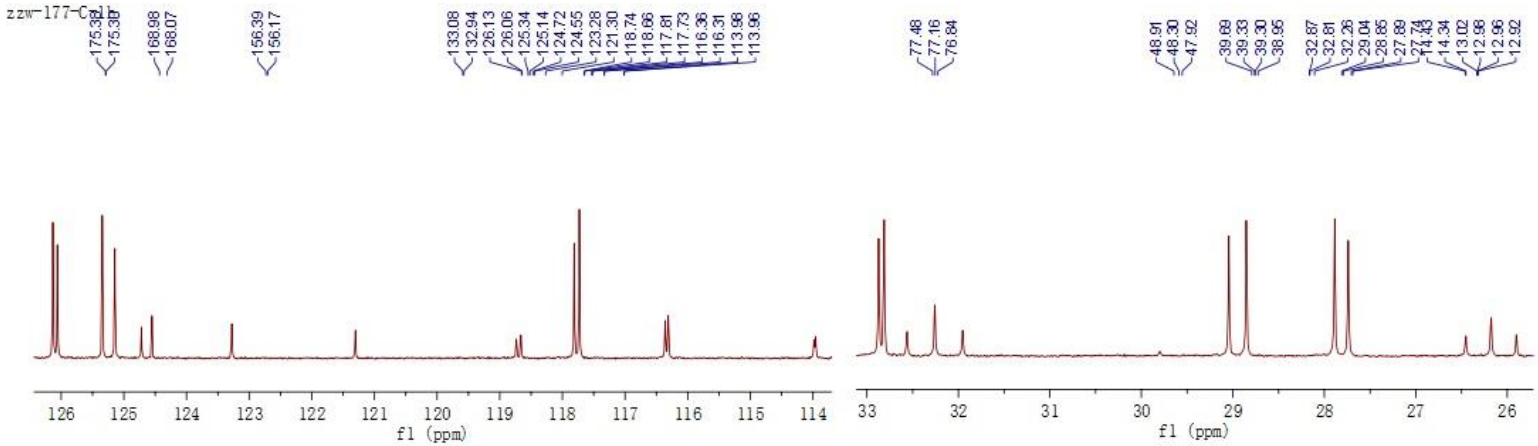

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)


zzw-177-H
8.2291
8.2090
7.6200
7.6022
7.5842
7.5666
7.4011
7.3828
7.3643
7.3405
7.3193
7.2602
6.0892
6.0701
5.9503
5.9312
5.8597
5.8465
5.8113
5.7922
5.7200
5.7067
5.5803
5.5671
3.3028
3.2840
3.2641
3.2448
2.6396
2.3195
2.3003
2.1797
2.1608
2.0109
2.0017
1.9829
1.9735
1.8368
1.8202
1.6126
1.5820
1.5455
1.5064
1.3677
1.3420
1.3262
1.3261
1.2961
1.1874
1.1307
1.1092

Scheme 4, 8

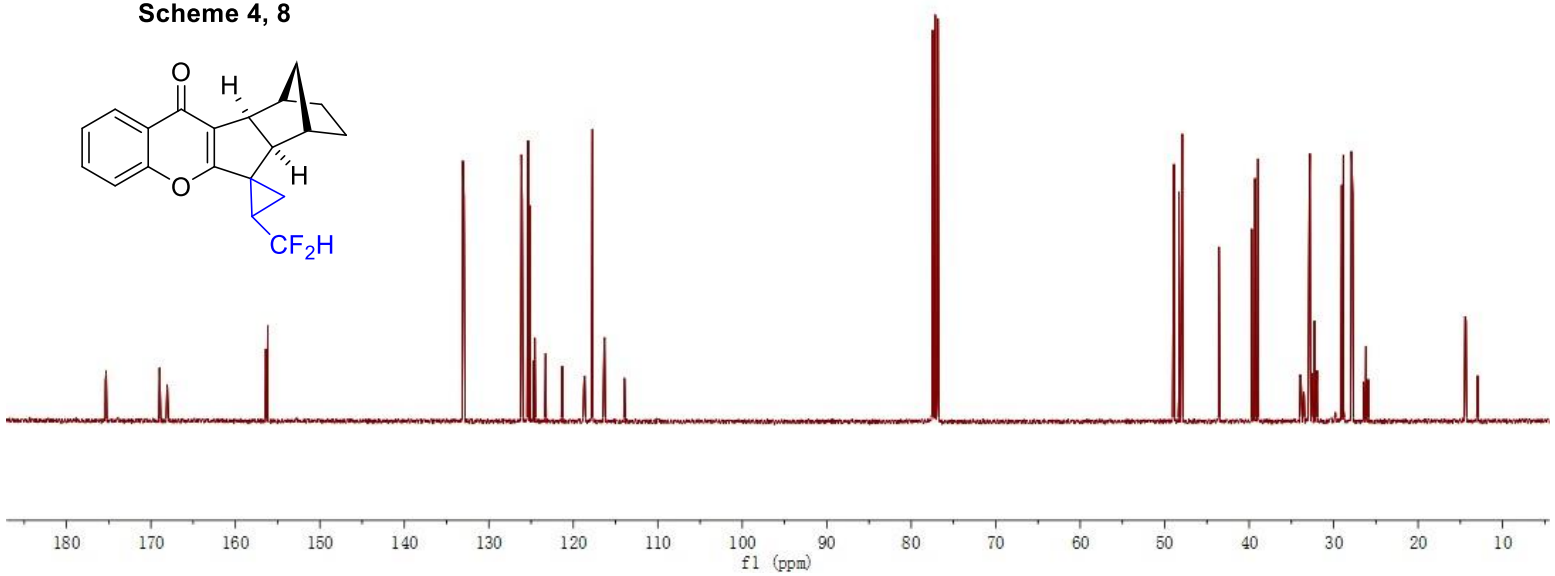

O
H
H
O
CF2H


1.00
1.01
1.92
1.57
1.05
1.00
0.45
0.56
0.45
1.05
0.58
4.61
1.58
2.08
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-177-C
175.38
175.30
168.98
168.07
156.39
156.17
133.08
132.94
126.13
126.06
125.34
125.14
124.72
124.55
123.28
121.30
118.74
118.66
117.81
117.73
116.36
116.31
113.98
113.96
77.48
77.16
76.84
48.91
48.30
47.92
39.69
39.33
39.30
38.95
32.87
32.81
32.26
29.04
28.85
27.89
27.74
14.34
13.02
12.98
12.96
12.92
126 125 124 123 122 121 120 119 118 117 116 115 114
f1 (ppm)
33 32 31 30 29 28 27 26
f1 (ppm)

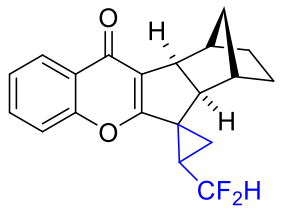
Scheme 4, 8

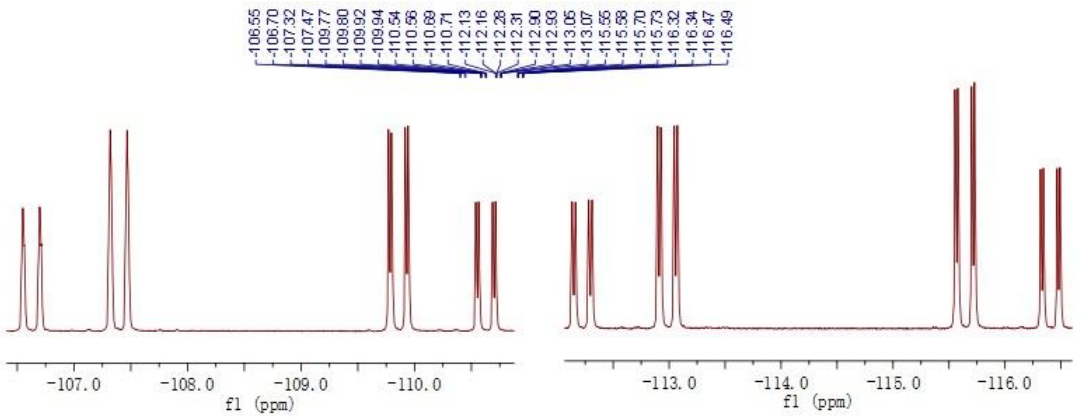
O
H
H
O
CF2H


180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)

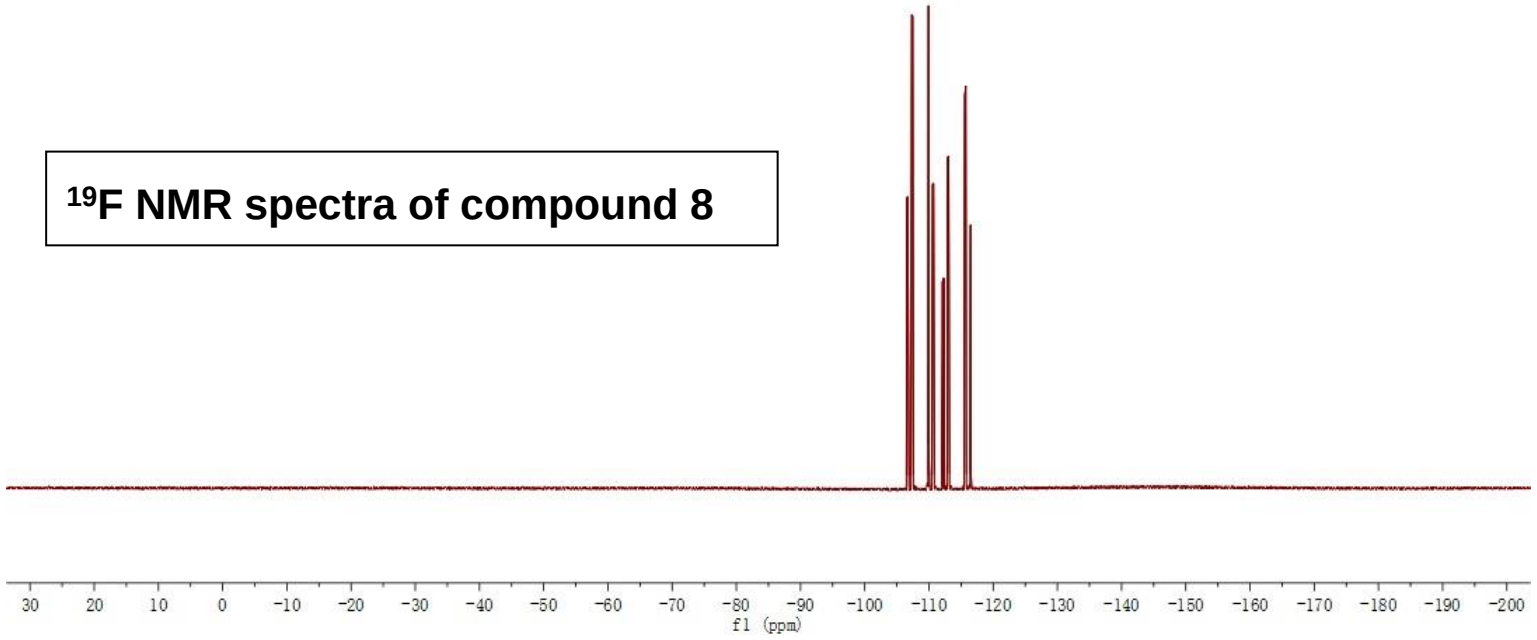
zzw-177-F

Scheme 4, 8



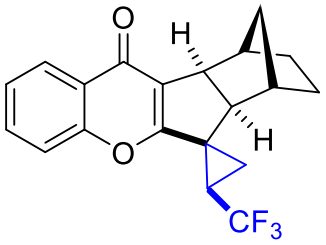


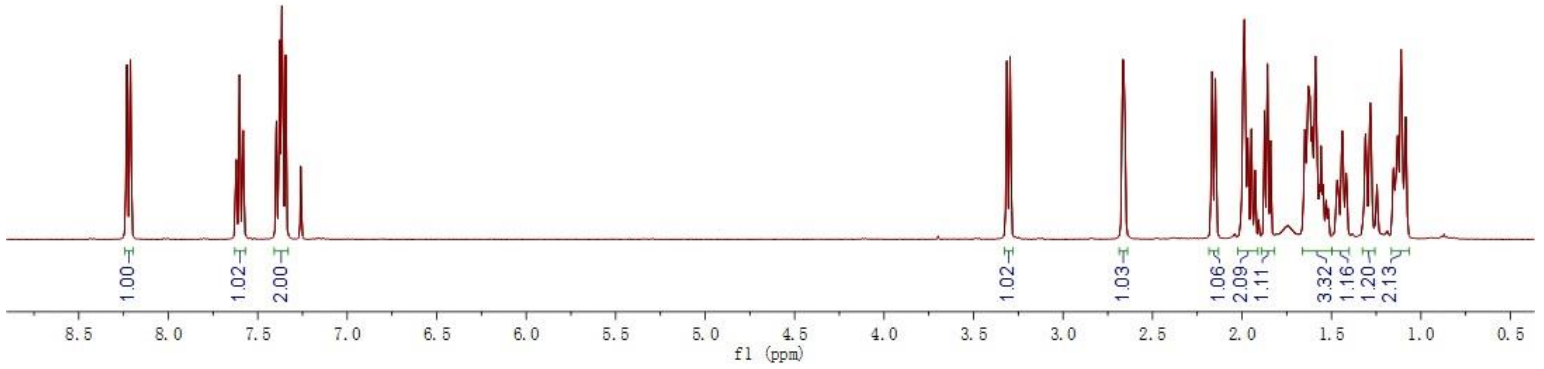
^{19}F NMR spectra of compound 8

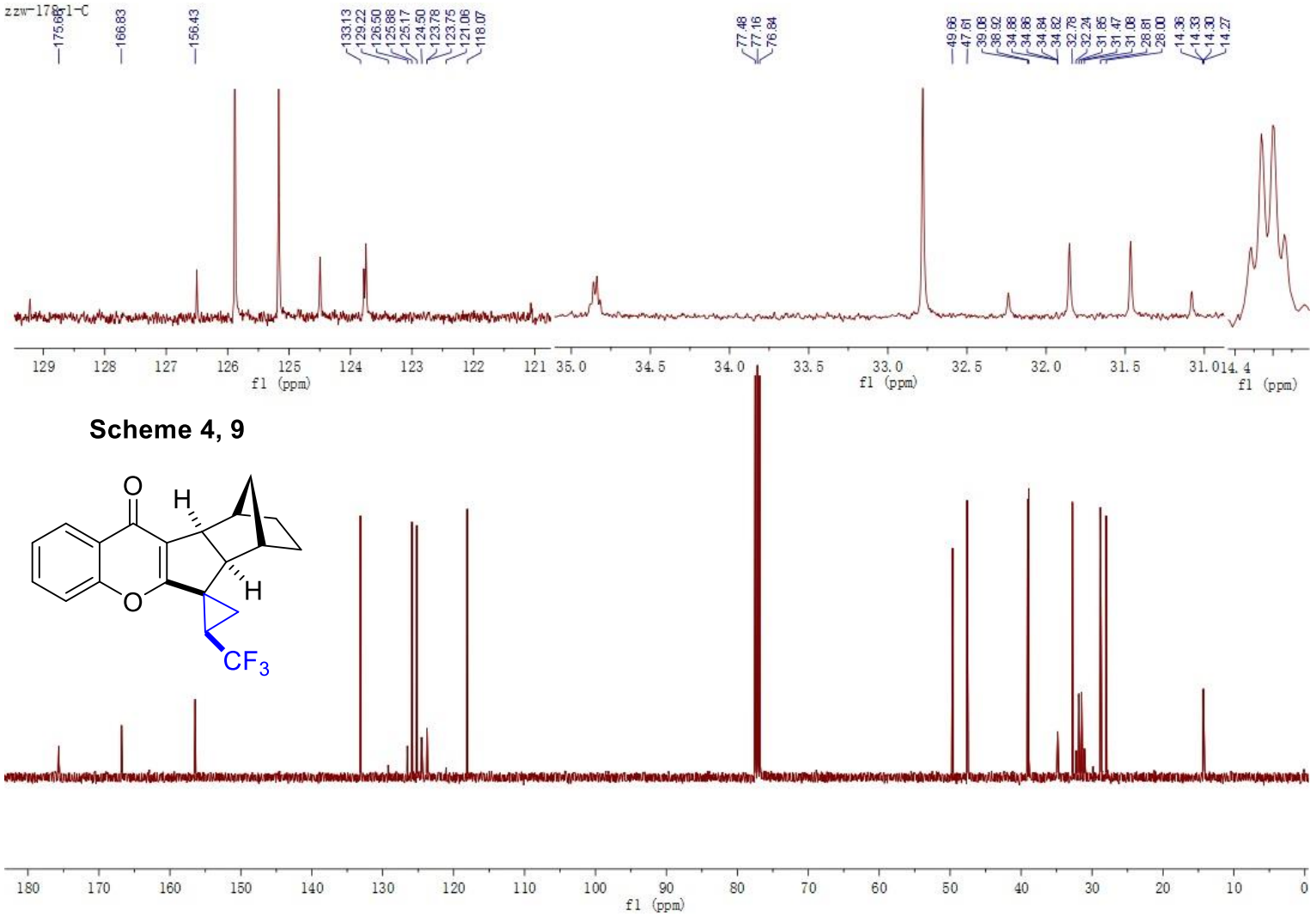



zzw-178-1-H
8.2312
8.2115
7.6204
7.6016
7.5815
7.3961
7.3772
7.3648
7.3444
7.2595
3.3141
3.2956
2.6659
2.6665
2.1673
2.1488
1.9997
1.9853
1.9676
1.9468
1.9266
1.8737
1.8576
1.8404
1.6487
1.6299
1.6196
1.5898
1.5684
1.4421
1.4370
1.3095
1.2829
1.1314
1.1106

Scheme 4, 9


O
H
H
O
CF3

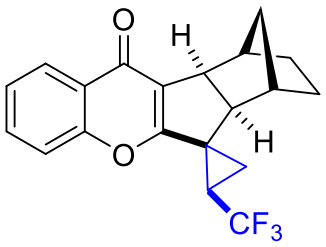

1.00
1.02
2.00
1.02
1.03
1.06
2.09
1.11
3.32
1.16
1.20
2.13
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-178-1-C
175.68
166.83
156.43
133.13
129.22
126.50
125.88
125.17
124.50
123.78
123.75
121.06
118.07
77.48
77.16
76.84
49.66
47.61
39.08
38.92
34.88
34.86
34.84
34.82
32.78
32.24
31.85
31.47
31.08
28.81
28.00
14.36
14.33
14.30
14.27
f1 (ppm)
Scheme 4, 9
O
H
H
O
CF3

zzw-178-0-F

-59.63

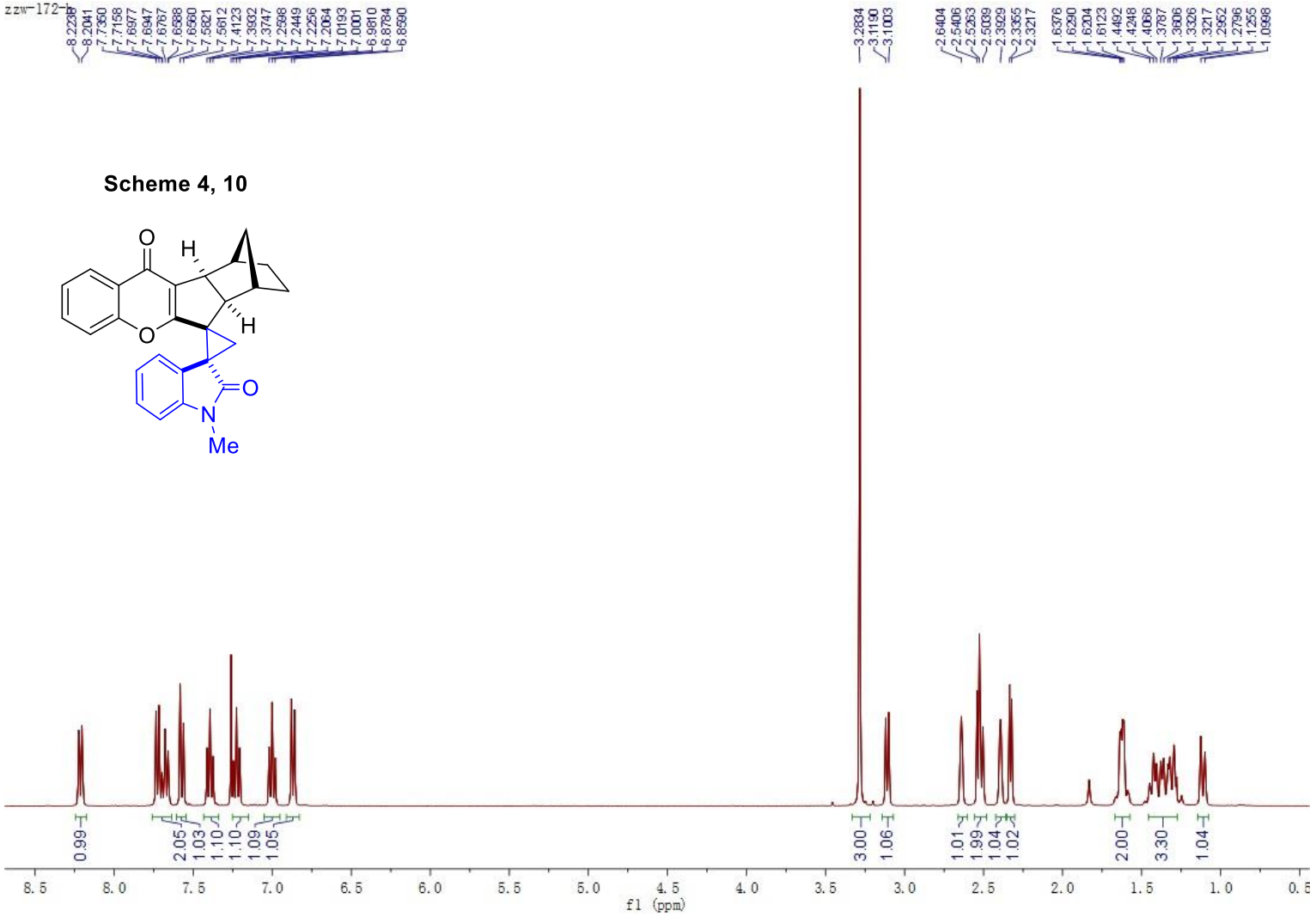
Scheme 4, 9

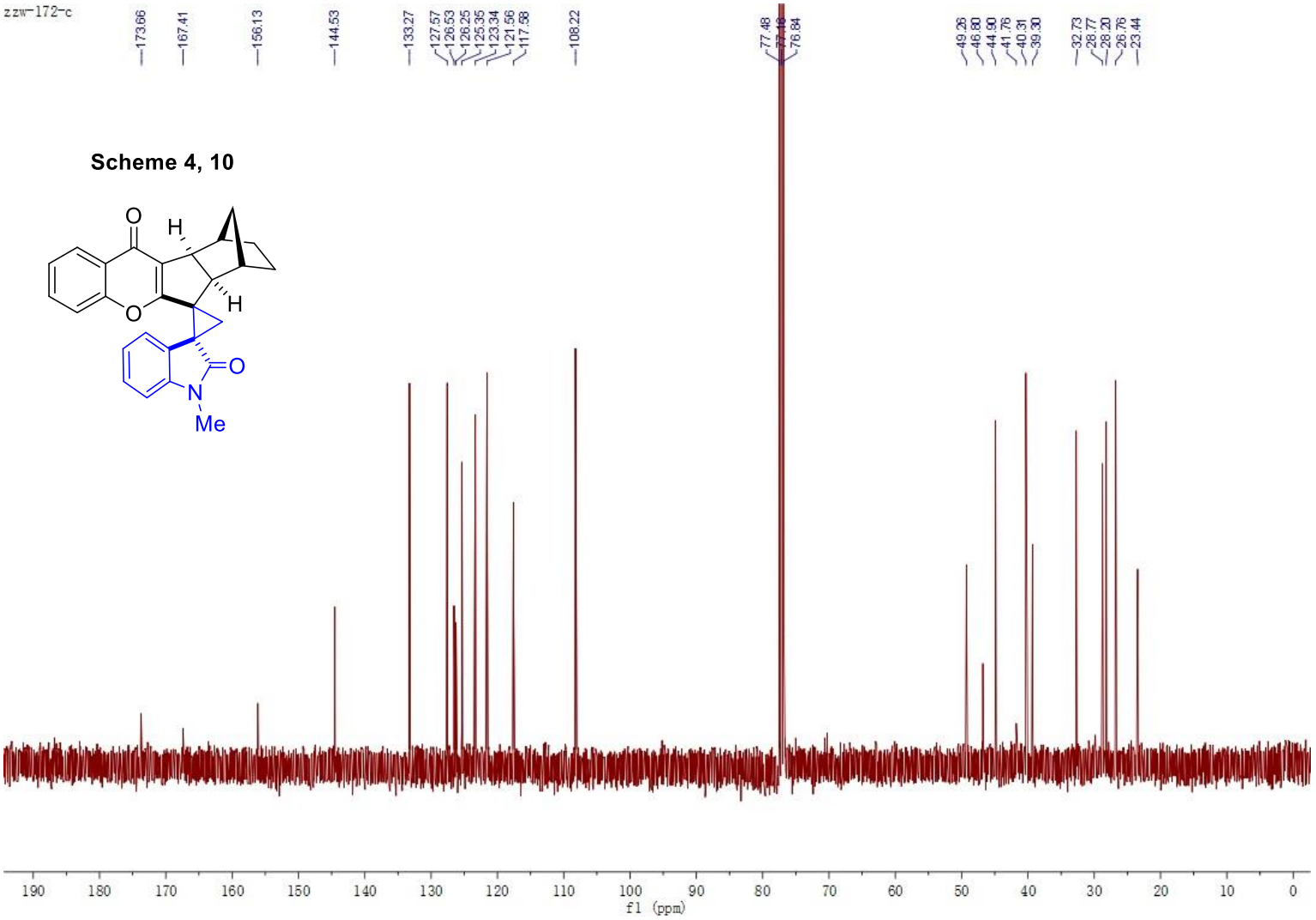


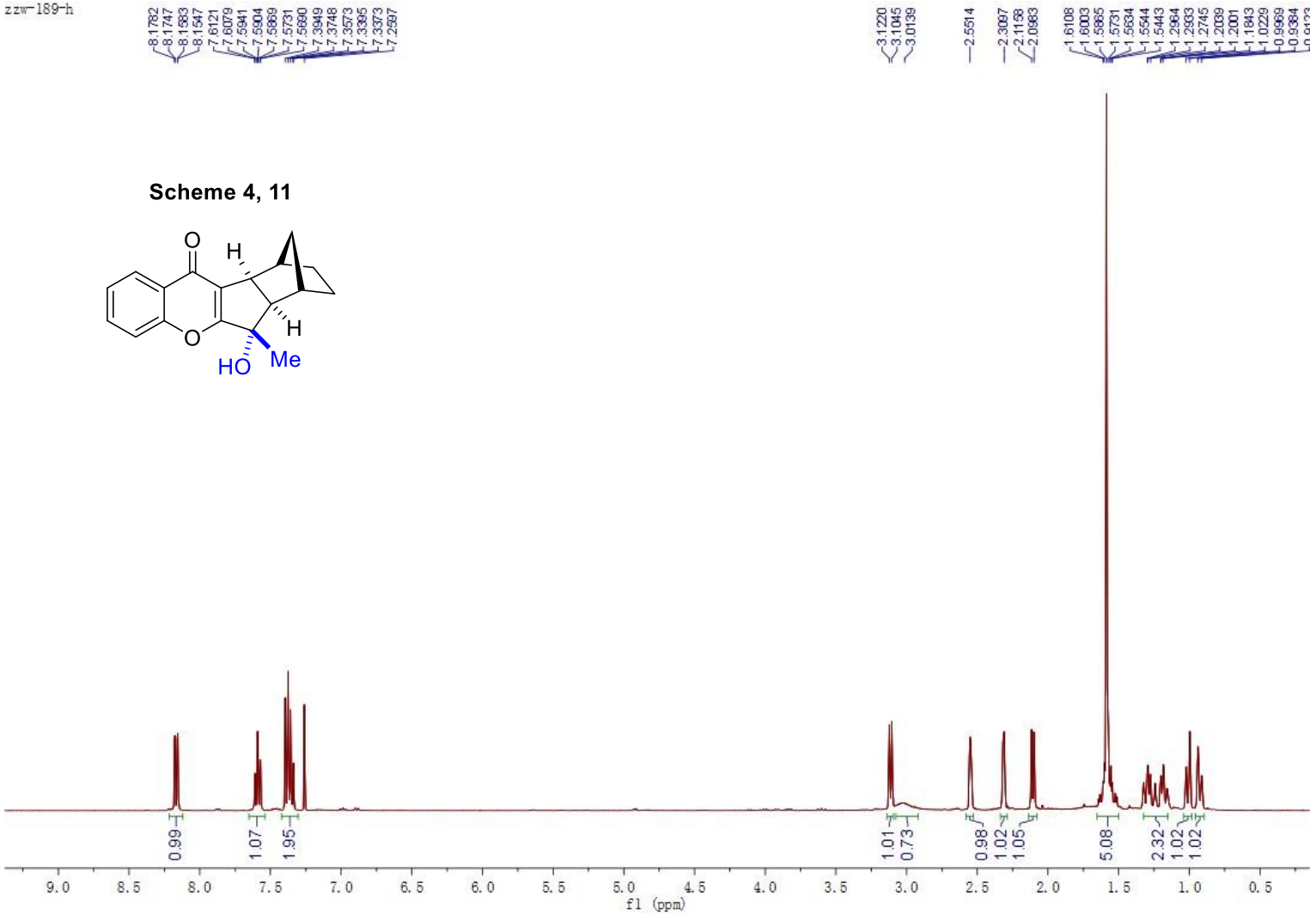
^{19}F NMR spectra of compound 9

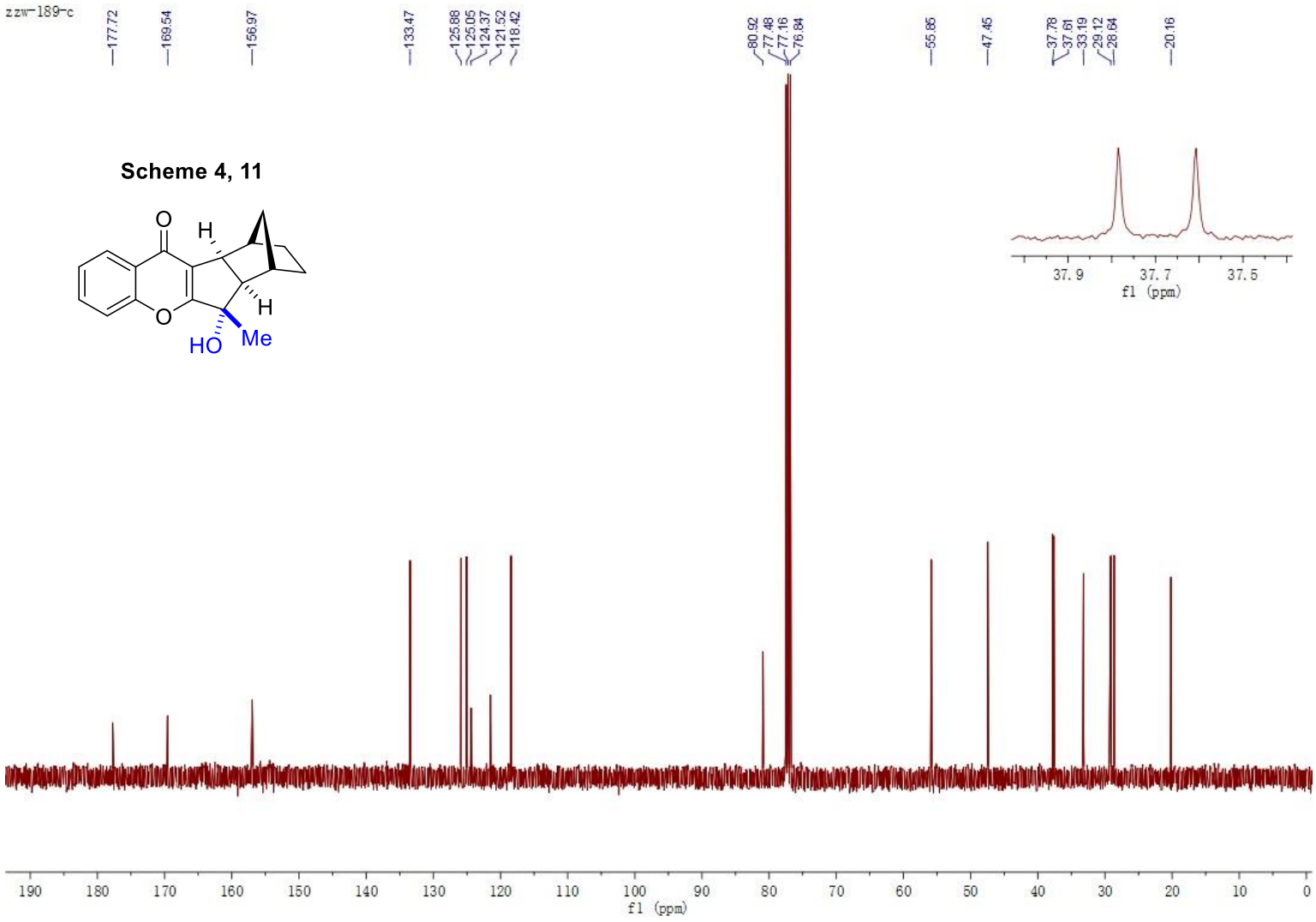
30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200

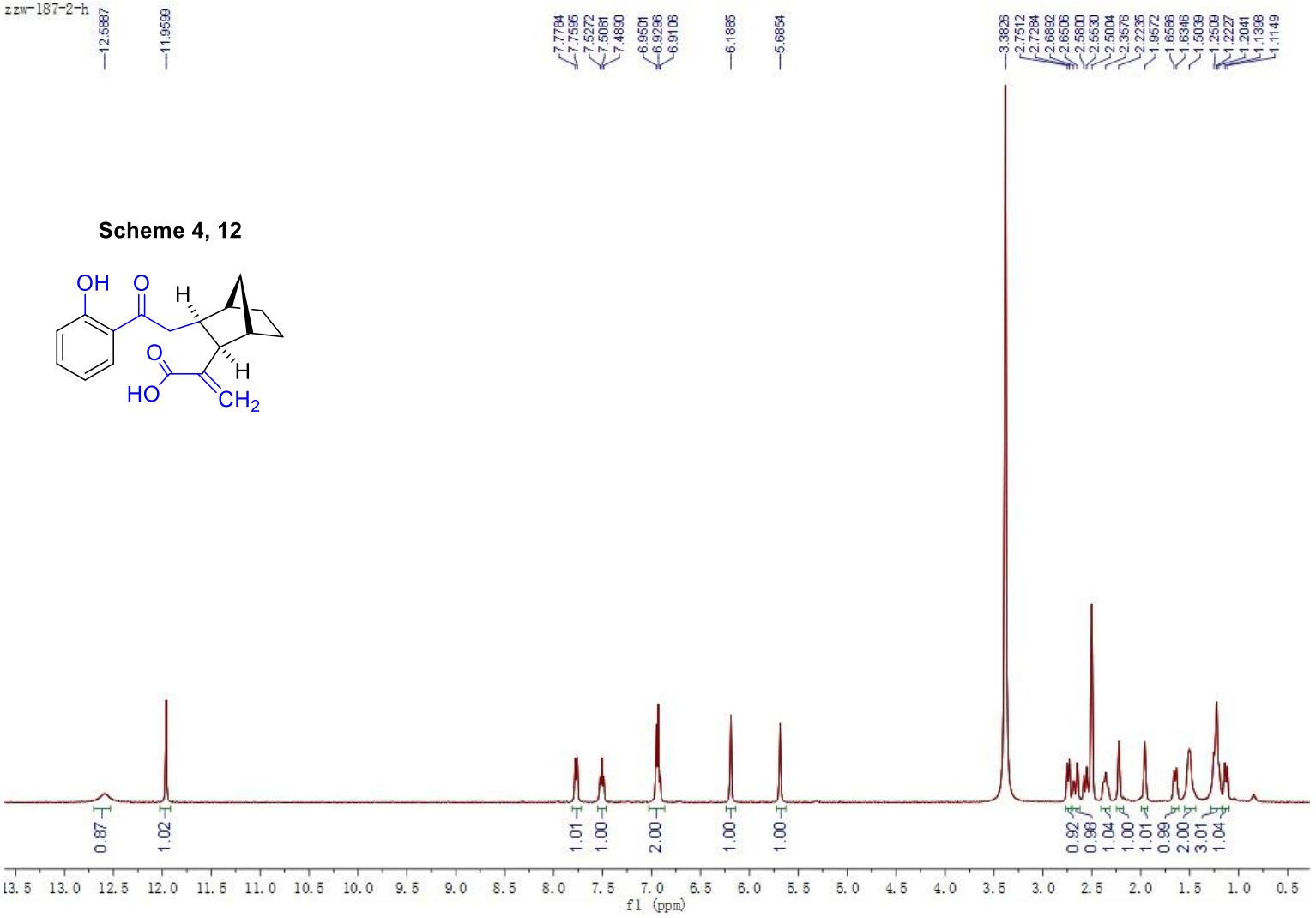
f1 (ppm)


zzw-172-1
Scheme 4, 10
O
H
H
O
O
N
Me
f1 (ppm)


zzw-172-c
173.66
167.41
156.13
144.53
133.27
127.57
126.53
126.25
125.35
123.34
121.56
117.58
108.22
77.48
77.16
76.84
49.26
46.80
44.90
41.76
40.31
39.30
32.73
28.77
28.20
26.76
23.44
Scheme 4, 10
O
H
H
O
O
N
Me
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

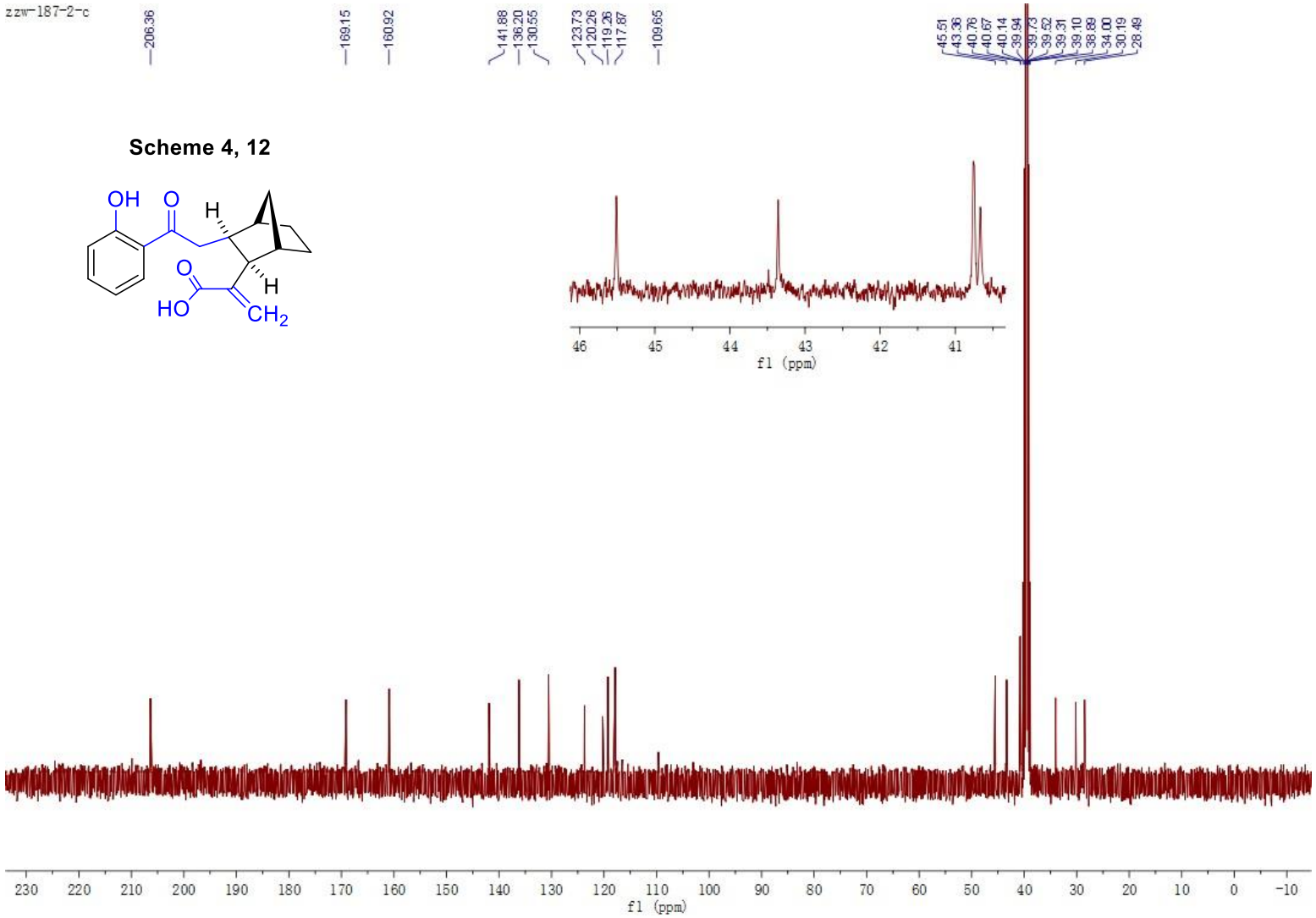

zzw-189-h
8.1782
8.1747
8.1583
8.1547
7.6121
7.6079
7.5941
7.5904
7.5869
7.5731
7.5690
7.3949
7.3748
7.3573
7.3395
7.3373
7.2997
3.1220
3.1045
3.0139
2.5514
2.3097
2.1158
2.0983
1.6108
1.6003
1.5865
1.5731
1.5634
1.5544
1.5443
1.2964
1.2933
1.2745
1.2039
1.2001
1.1843
1.0229
0.9969
0.9384
Scheme 4, 11
O
H
H
O
HO
Me
0.99
1.07
1.95
1.01
0.73
0.98
1.02
1.05
5.08
2.32
1.02
1.02
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-189-c
177.72
169.54
156.97
133.47
125.88
125.05
124.37
121.52
118.42
80.92
77.48
77.16
76.84
55.85
47.45
37.78
37.61
33.19
29.12
28.64
20.16
Scheme 4, 11
O
H
H
O
HO
Me
37.9
37.7
37.5
f1 (ppm)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


zzw-187-2-h
12.5887
11.9599
7.7784
7.7595
7.5272
7.5081
7.4890
6.9501
6.9296
6.9106
6.1885
5.6854
3.3826
2.7512
2.7284
2.6892
2.6506
2.5800
2.5530
2.5004
2.3576
2.2235
1.9572
1.6586
1.6346
1.5039
1.2509
1.2227
1.2041
1.1398
1.1149
0.87
1.02
1.01
1.00
2.00
1.00
1.00
0.92
0.98
1.04
1.00
1.01
0.99
2.00
3.01
1.04
f1 (ppm)

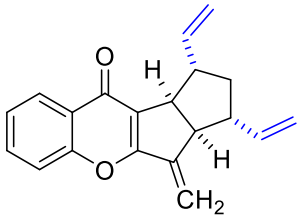
Scheme 4, 12

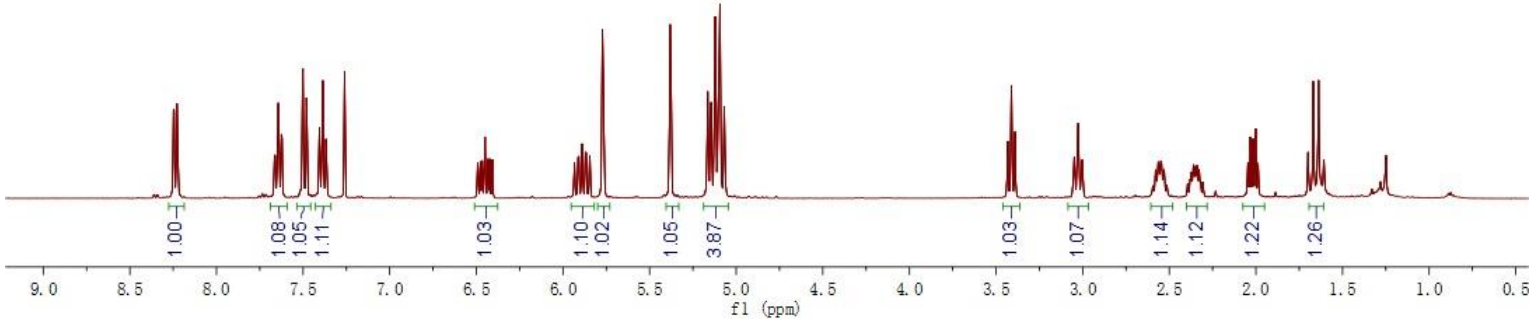
OH
O
H
O
HO
H
CH2

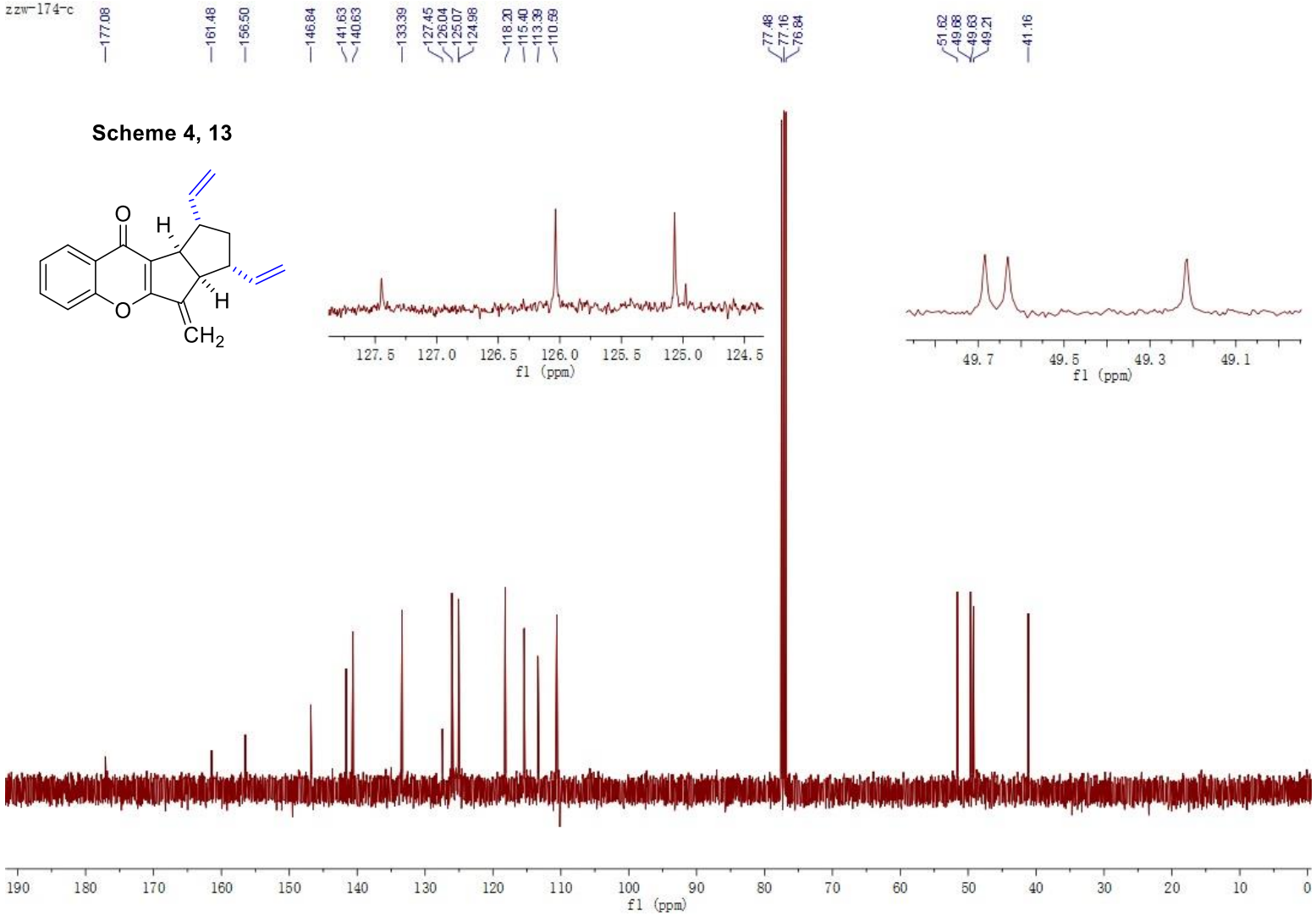

zzw-187-2-c
206.36
169.15
160.92
141.88
136.20
130.55
123.73
120.26
119.26
117.87
109.65
45.51
43.36
40.76
40.67
40.14
39.94
39.73
39.52
39.31
39.10
38.89
34.00
30.19
28.49
Scheme 4, 12
OH
O
H
O
HO
H
CH2
46
45
44
43
42
41
f1 (ppm)
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)


zzw-174-h

Scheme 4, 13


O
H
O
H
CH2


1.00
1.08
1.05
1.11
1.03
1.10
1.02
1.05
3.87
1.03
1.07
1.14
1.12
1.22
1.26
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


zzw-174-c
177.08
161.48
156.50
146.84
141.63
140.63
133.39
127.45
126.04
125.07
124.98
118.20
115.40
113.39
110.59
77.48
77.16
76.84
51.62
49.68
49.63
49.21
41.16
Scheme 4, 13
O
H
H
O
CH2
127.5 127.0 126.5 126.0 125.5 125.0 124.5
f1 (ppm)
49.7 49.5 49.3 49.1
f1 (ppm)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)