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Interaction studies between photochromic spiropyrans and transition metal cations: the curious case of copper

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General methods

Chemicals were purchased from Acros Organics or Aldrich and were used as received. Chloroform was distilled over CaH_2. Otherwise stated, all chemicals were obtained from commercial sources and used as received. All melting points were determined with a Stuart SMP3 instrument. Infrared spectra were obtained on a Perkin Elmer Paragon 1000 Fourier Transform spectrometer. Flash chromatography was carried out using silica gel, particle size 0.04-0.063 mm. TLC analysis was performed on precoated $60F_{254}$ slides, and visualised by either UV irradiation or $KMnO_4$ staining.

^{1}H-NMR studies

Proton Nuclear Magnetic Resonance spectra were recorded on a Bruker DPX 400 MHz spectrometer in $CDCl_3$, CD_3CN and d-DMSO. All the solvents were standardised with respect to TMS. Chemical shifts are reported in ppm and coupling constants in Hertz. Carbon NMR spectra were recorded Bruker DPX 100 MHz with total proton decoupling. Standard solutions of zinc chloride (2 M) were prepared in D_2O. An aliquot of this solution (10 ml) was added to 800 ml of spiropyran solution $2x10^{-2}$ M in CD_3CN. The samples were stored in the dark for 24 h and the spectra were collected.

Analogously to compound **SP1-SP1**, the *gem* methyl groups are not magnetically equivalent and they can be identified as two singlets at 1.27 and 1.33 ppm that integrate for six protons each (*a* in figure S1a). The triplet at 1.19 ppm was assigned to the CH_3 protons *n* of the ethyl ester while the corresponding CH_2 *m* were identified in the quadruplet at 4.07 ppm. The aliphatic protons attached to the indolic nitrogen gives three groups of signals: a multiplet in the range 1.84-1.89 ppm for protons *k*, a triplet at 2.35 ppm assigned to protons *l*, and another multiplet between 3.21 and 3.29 ppm corresponding to protons *j* which are directly attached to the nitrogen. The vinylic protons *b* and *c* are identified by two doublets at 6.01 ppm for *b* and 8.81 ppm respectively and their coupling constant of 10.4 Hz confirms their *cis* configuration. Long range coupling was observed for the two aromatic protons on the benzopyran ring *d* and *e* that are identified as a doublet and a double doublet at 8.13 and 8.02 ppm. The doublet at 6.75 ppm integrates for four protons and it corresponds to the overlapping of two distinct doublets that identify protons *f* and *g*. The signals at 7.42 ppm integrate for four protons and correspond to protons *h* and *i*. The correlation between protons *e-f*, *g-i*, and *h-i* can be clearly seen in the aromatic region ^{1}H-^{1}H COSY NMR spectra of **SP3-SP3** reported in figure S1b. Here, the doublet at 6.75 ppm is interrelated with signals at 7.42 ppm because of the interaction between protons *g* and *h*. The same doublet at 6.75 ppm interrelates with the shifts of protons at 8.02 ppm because of the interactions between protons *f* at 6.75 ppm and *e* at 8.02 ppm.

In th spectra of compound **SP2-SP2** the four *gem* methyl groups *a* are magnetically equivalent and they are identified by two singlets integrating for six protons each at 1.25 and 1.30 ppm. The two tethers functionalized with a terminal OH group pending from each indolic nitrogen, give very characteristic signals. The multiplet in the region from 3.26 ppm to 3.40 ppm was attributed to the four protons *j* while the multiplet shifted to a lower field, in the range of 3.59-3.82 ppm corresponds to methylene protons *k* Those of the two OH groups, namely protons *l*, are two triplets located at 3.69 ppm and 3.82 ppm. The aromatic region was studied also by ^{1}H-^{1}H COSY NMR and it is shown in figure 7b. The two doublets corresponding to the vinylic protons are localized at

6.03 for proton *b*, and 7.08 ppm for proton *c*. Their coupling constant value is equal to 10.4 Hz and is typical for a *cis* configuration. This confirms the fact that both units are in their closed forms and not in the merocyanine ones. Two overlapped doublets are observable at 6.76 and 6.78 ppm and the whole integration is four protons. The first signal at 6.76 ppm corresponds to proton *g* as it correlates with the multiplet at 7.40-7.42 ppm. The latter integrates for four protons which correspond to *h* and *i*. The second doublet at 6.78 ppm corresponds to proton *f* in the benzopyran part of the molecule and its correlation with the double doublet at 8.02 ppm, assigned to proton *e*, can be clearly seen in the spectrum. Long range coupling was observed between the doublet 8.12 ppm, assigned to proton *d*, and the double doublet corresponding to *e*, as confirmed by their coupling constant of 2.8 Hz.

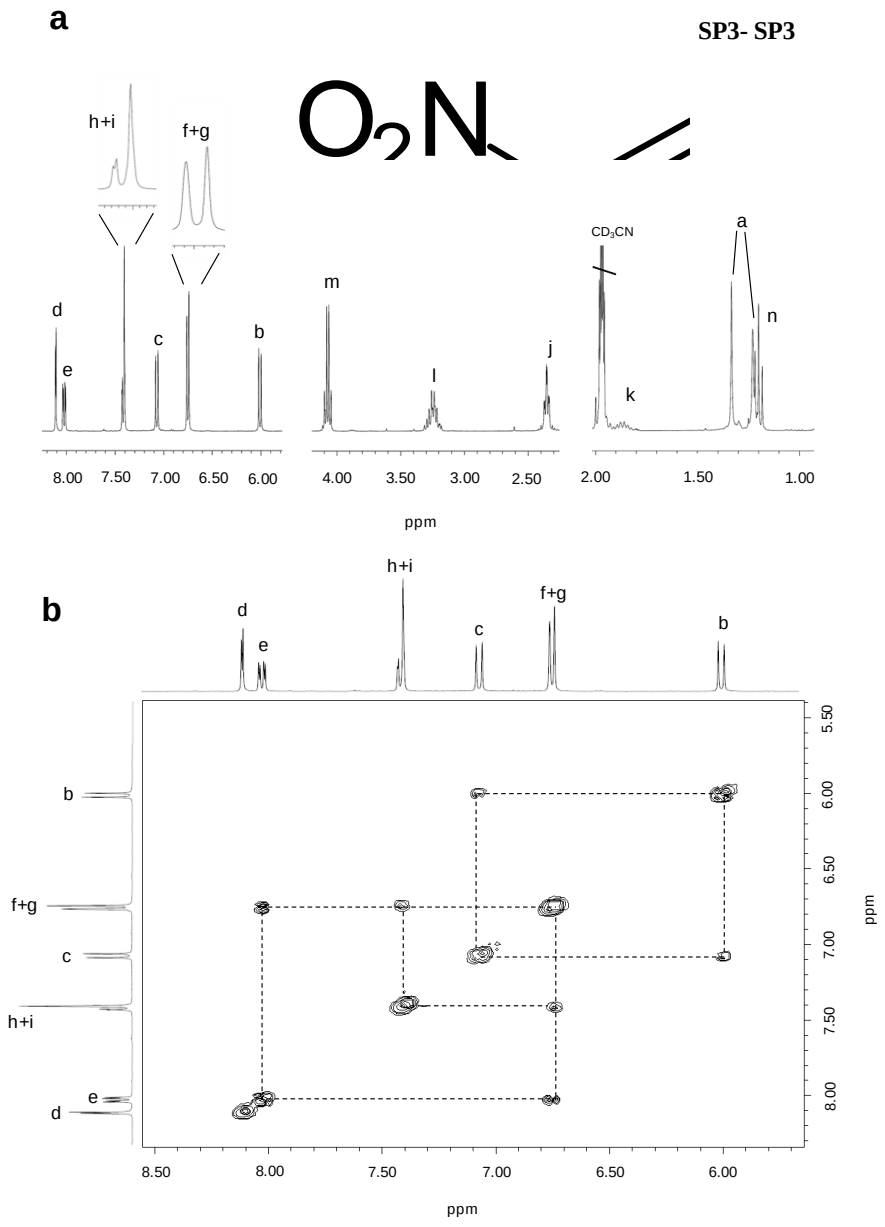

Fig.S1 (**a**) ^{1}H-NMR and (**b**) ^{1}H-^{1}H COSY NMR partial spectra of **SP3-SP3** ($1x10^{-2}$ M in acetonitrile, 293K).

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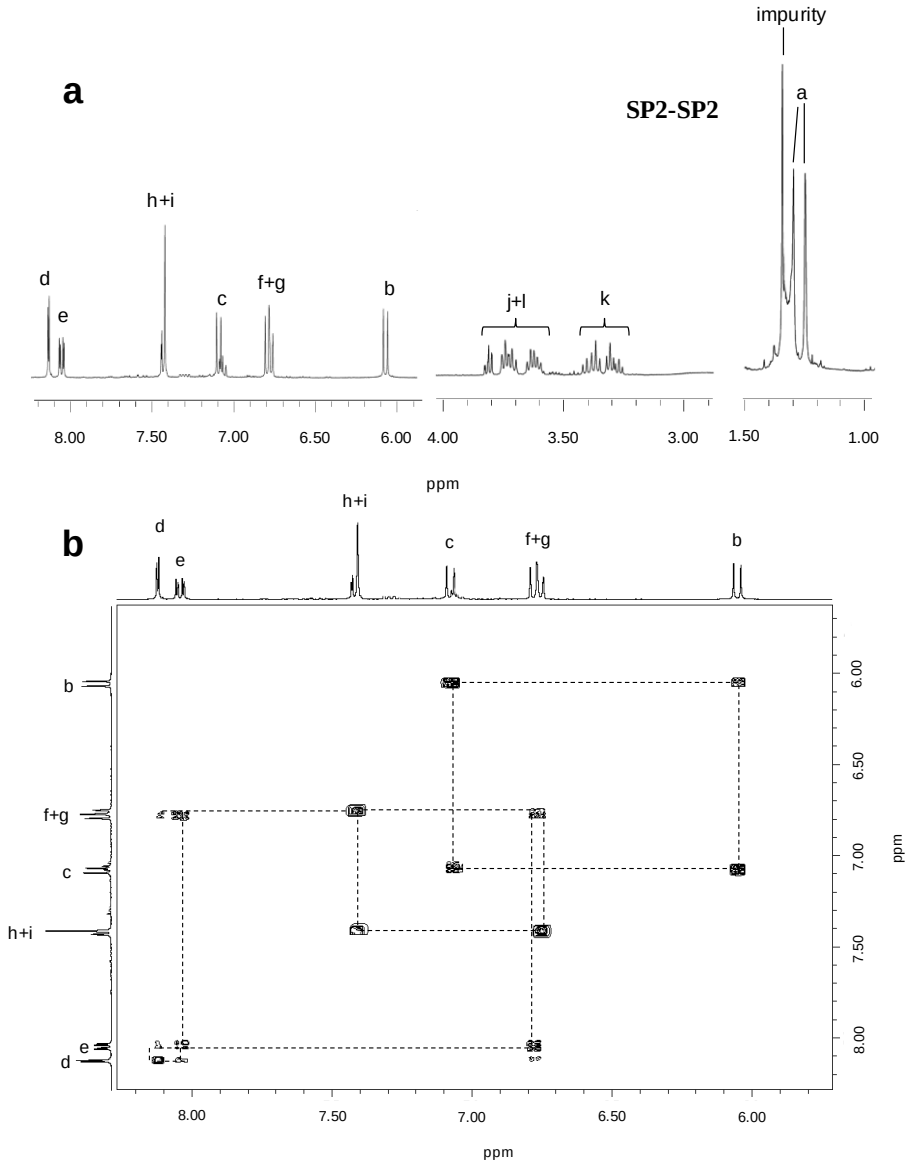

Fig.S2 (**a**) ^{1}H-NMR and (**b**) ^{1}H-^{1}H COSY NMR partial spectra of **SP2-SP2** ($1x10^{-2}$ M in acetonitrile, 293K).

UV-Vis absorption

UV-Vis absorption measurement were carried out with a Perkin Elmer Lambda 35 UV-Vis Spectrometer. The spiropyrans solutions of concentration $1x10^{-4}$ M were prepared by dilution starting from mother solutions of spiropyrans $1x10^{-3}$ M in spectroscopic grade methanol and acetonitrile. The metal perchlorates solutions were prepared in distilled water and they had a concentration of $1x10^{-2}$ M. Quartz cuvettes of 1 cm path length were used. The solutions were irradiated in custom built cabinet by means of a UVGL-58 Handheld UV Lamp at 254 nm and a Schott KL 1500 LCD visible lamp. In the UV-vis absorption studies on the complexation, 1 ml of spiropyran solutions were placed in a quartz cuvette of 1 cm path length and 1 ml (1 eq) of the metal solutions was added by means of a micropipette.

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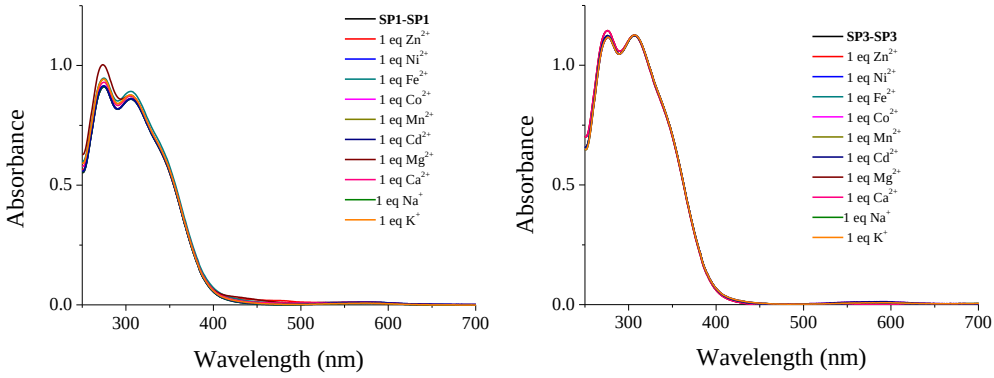


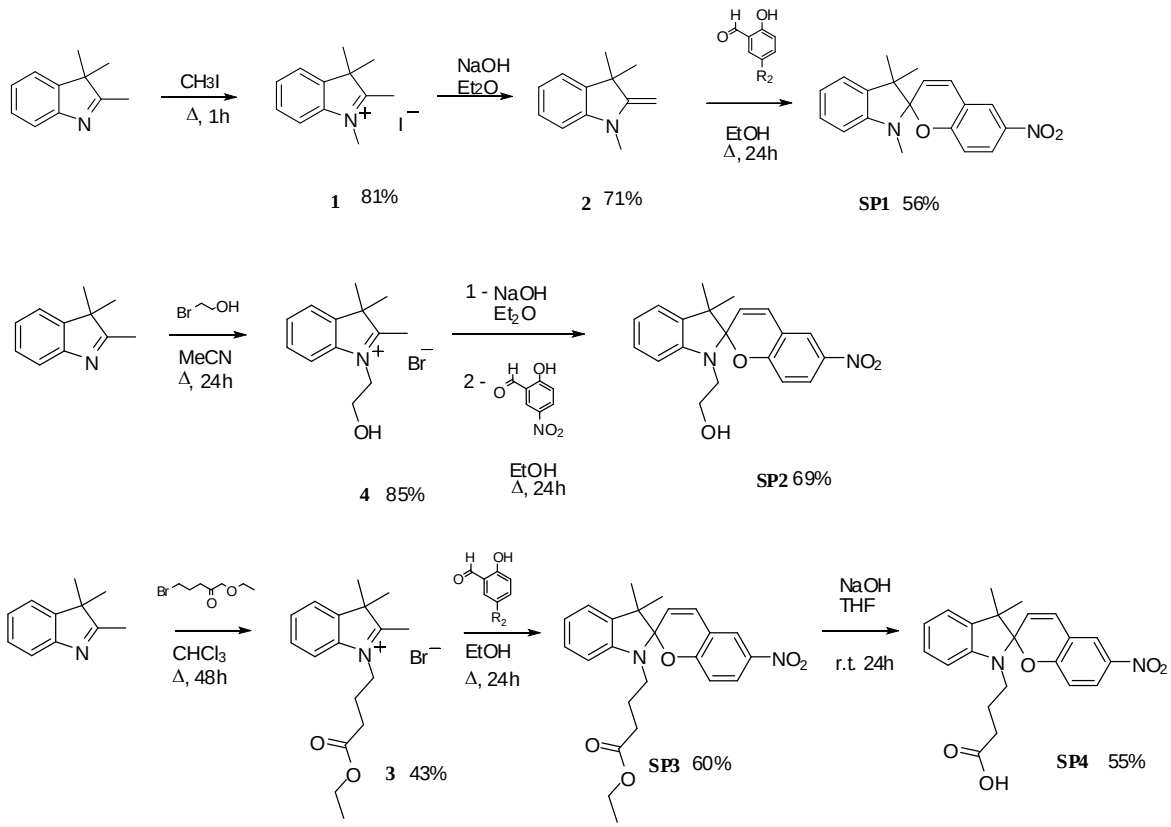
Fig.S3 Absorption spectra of **SP1-SP1** and **SP3-SP3**before and after the addition of one equivalent of different metal perchlorates and chlorides ($2.5x10^{-6}$ M and $2.5x10^{-5}$ M in acetonitrile, 293K).

Mass Spectrometry

MALDI-TOF MS spectra were acquired with a Waters MALDI-Q TOF Premier spectrometer. The instrument was operated in positive reflectron mode. The matrix used in the experiments was *trans*-2[3(4-*tert*-Butylphenyl)-2-methyl-2-propenylidene]malononitrile dissolved in DCM (2 mg/ml). Acetonitrile solution of the complexes were prepared by adding 10 ml of a $1x10^{-1}$ M solution of the desired metal chloride or perchlorate to a $1x10^{-3}$M solution of spiropyrans. The resulting mixtures were equilibrated overnight at 20^{o}C in the dark. Matrix solutions were mixed with complex solutions with ratio 1:1 and 1 ml of the resulting mixture was spotted on the MALDI plate. The compound [Glu^{1}] Fibrinopeptide B, 1570.6774 m/z $(M+H)^{+}$ was used as reference.

Synthesis

Compounds **SP1**, **SP2**, **SP3**, and **SP4** were synthesized following the route depicted in scheme **S1**.



Scheme S1 Synthesis of compounds **SP1-SP4**.

1,2,3,3-Tetramethyl-3H-indolium iodide[1] (1)

A solution of 2,3,3-trimethylindolenine (1.6ml, 10 mmol) in 20 ml of CH_3I was stirred at 60ºC under N_2 for 1h. The solution was then cooled to r.t. and a white precipitate was filtered off and washed with Et_2O to afford 2.45 gr of the product as a pink powder, yield = 81%. **^{1}H-NMR** (400 MHz, DMSO): δ = 1.52 (s, 6H, $(CH_3)_2$), 2.76 (s, 3H, CH_3), 3.91 (s, 3H, CH_3N), 7.58-7.66 (m, 2H, arom.), 7.82-7.86 (s, 1H, arom.), 7.88-7.94 (s, 1H, arom.). **^{13}C-NMR** (100 MHz, DMSO): δ = 14.0 (CH_3), 21.7 (CH_3), 34.6 (CH_3 salt), 53.9 ($C(CH_3)_2$), 115.7, 123.2, 128.8, 129.3, 141.6, 142.1, (arom.), 195.9 (*C*=N). **HRMS (*m/z* -ES) :** Found: 300.0261 ($(M+H)^+$, Requires: 300.0249). **υ (cm^{-1}) :** 3025, 1695, 1510, 1465, 1202, 991. **mp :** 258 ºC.

1,3,3-Trimethyl-2-methyleneindoline[1] (2)

Compound **100** (729 mg, 2.12 mmol) was stirred in 40 ml of a 1:3 mixture of Et_2O/NaOH aq 2M for 30 minutes. The organic phase was collected, dried over Na_2SO_4 and the solvent was evaporated to afford 368 mg of a pink oil, yield = 71%. **^{1}H-NMR** (400 MHz, DMSO): δ = 1.37 (s, 6H, $(CH_3)_2$), 3.06 (s, 3H, CH_3N), 3.861 (s, 2H, ethylene), 6.56 (d, 1H, *J*=7.8 Hz, arom.), 6.78 (t, 1H, *J*=7.4 Hz, arom.), 7.12 (d, 1H, *J*=7.2 Hz, arom.), 7.15 (t, 1H, *J*=8.00 Hz, arom.), 7.28 (s, 1H, arom.). **^{13}C-NMR** (100 MHz, DMSO): δ = 28.3 (CH_3N), 29.5 (2 x CH_3), 43.6 ($C(CH_3)_2$), 72.5 (C ethylene), 104.4, 117.8, 121.3, 127.1, 137.1, 145.9 (arom.), 162.4 (C=CH_2). **HRMS (*m/z* -ES) :** Found: 174.1290 ($(M+H)^+$, Requires: 174.1283).

1-(4-Ethoxy-4-oxobutyl)-2,3,3-trimethyl-3H-indolium bromide (3)

A solution of 2,3,3-trimethylindolenine (8.49 mmol, 1.36 ml) and 4-bromobutyrate (12.7 mmol, 1.81 ml) in 20 ml of chloroform was stirred under reflux for 24h. The solution was cooled to room temperature and the solvent was then evaporated. To the purple residue 1 ml of methanol was added and the product was crystallized from 20-30 ml of diethyl ether affording 1.22 g of a pink powder, yield 43%. **^{1}H-NMR** (400 MHz, $CDCl_3$): δ = 1.19 (t, 3H, *J*=7.0 Hz, CH_3), 1.62 (s, 6H, $(CH_3)_2$), 2.21-2.27 (m, 2H, CH_2), 2.70 (t, 2H, *J*=5.8 Hz, CH_2), 3.17 (s, 3H, CH_3), 4.02 (q, 2H, J_1=7.6 Hz, J_2=14.6 Hz, CH_2), 4.86 (t, 2H, *J*=8.0 Hz, CH_2), 7.53-7.60 (m, 3H, arom.), 8.01-8.10 (m, 1H, arom.). **^{13}C-NMR** (100 MHz, $CDCl_3$): δ =13.6 (CH_3), 15.7 (CH_3), 22.2 (CH_2), 22.4, 22.6 ($(CH_3)_2$), 29.9 (CH_2), 48.0 ($C(CH_3)_2$), 54.1 (NCH_2), 60.5 (OCH_2CH_3),, 115.4, 122.6, 129.1, 129.5, 140.7, 141.1 (arom.), 172.3 (COOEt), 195.9 ($NCCH_3$). **HRMS (*m/z* -ES) :** Found: ($(M^+$-Br) 274.1810, $C_{17}H_{24}NO_2$ Requires: 274.1807). **υ (cm^{-1}) :** 2999, 1722, 1468, 1371, 1206, 768. **mp :** 187ºC.

1-(2-Hydroxyethyl)-2,3,3-trimethyl-3H-indolium bromide[2] (4)

A solution of 2,3,3-trimethyl-3H-indole (1.40 g, 8.8 mmol) and 2-bromoethanol (1.37 g, 10.9 mmol) in MeCN (20 ml) was heated for 24 h under reflux and N_2. After cooling down to ambient temperature, the solvent was distilled off under reduced pressure. The residue was suspended in hexane (25 ml) and the mixture was sonicated and filtered. The resulting solid was crystallized from $CHCl_3$ (35 ml) to afford **1** (1.14 g, 46%) as a pink solid. **^{1}H-NMR** (400 MHz, CD_3CN): δ = 1.61 (6H, s, $(CH_3)_2$), 2.81 (3H, s, CH_3), 4.02–3.94 (2H, m, CH_2OH), 4.54 (2H, t, *J*=5.0 Hz, CH_2N), 4.82 (1H, t, *J*=6.0 Hz, OH), 7.65–7.54 (2H, m, arom.), 7.74–7.72 (1H, m, arom.), 7.83–7.75 (1H, m, arom.); **^{13}C-NMR** (100 MHz, CD_3CN): δ = 14.61 (CH_3), 21.93 (CH_3+CH_3), 50.86 ($C(CH_3)_2$), 54.67 (CH_2N), 57.80 (CH_2OH), 115.54, 123.33, 129.03, 129.71, 141.42, 141.99, 198.84 (arom.); **HRMS (*m/z* -ES)**: Found: ($(M^+$-Br) 204.1381, $C_{13}H_{18}NO$ Requires: 204.1388). **υ (cm^{-1}) :** 3251, 1611, 1606, 1465, 1093, 1058. **mp :** 195ºC.

1',3',3'-Trimethyl-6-nitrospiro[chromene-2,2'-indoline] (SP1)[1]

A solution containing 0.3 g (1 mmol) of **2** and 0.167 g (1 mmol) of 5-nitrosalicylaldehyde in 20 ml of ethanol was stirred at reflux for 24h. The solution was then concentrated and kept in the freezer for 24h. A yellow powder was filtered off from the chilled solution and washed with cold ethanol. It was then dissolved in 30 ml of dichloromethane, washed with a 10 % aqueous solution of Na_2CO_3, dried over Na_2SO_4. The solvent was then distilled at reduced pressure affording 200 mg of a grey solid, yield 62%. **^{1}H-NMR** (400 MHz, CD_3CN): δ = 1.22 (s, 3H, CH_3), 1.32 (s, 3H, CH_3), 2.77 (s, 3H, NCH_3), 5.90 (d, 1H, *J*=10.4 Hz, CH ethylene), 6.60 (d, 1H, *J*=7.7 Hz, arom.), 6.79 (d, 1H, *J*=8.4 Hz, arom), 6.90 (d, 1H, *J*=7.3 Hz, arom), 6.97 (d, 1H, *J*=10.4 Hz, H ethylene), 7.13 (d, 1H, *J*=7.2 Hz, arom.), 7.19 (t, 1H, *J*=7.7 Hz, arom.), 8.03 (s, 1H, arom.), 8.11 (d, 1H, *J*=2.8 Hz, arom.). **^{13}C-NMR** (100 MHz, CD_3CN): δ = 19.9 (CH_3), 25.9 (NCH_3), 28.8 (CH_3), 52.2 ($C(CH_3)_2$), 106.3 (C spiro.), 107.1, 115.5, 118.7, 119.7, 121.5, 121.6, 122.6, 125.8, 127.8,128.3 (arom.), 136.1 (arom.), 140.9 (CNO_2), 147.7, 159.8 (arom.). **HRMS (*m/z* -ES) :** Found: 323.1395 ($(M+H)^+$, $C_{19}H_{18}N_2O_3$ Requires: 323.1396). **υ (cm^{-1}) :** 1609, 1487, 1330, 1269. **mp :** 179ºC.

2-(3',3'-Dimethyl-6-nitrospiro[chromene-2,2'-indoline]-1'-yl)ethanol (SP2)[2]

A solution of **4** (0.5 g, 1.8 mmol) in KOH (aq 5%) (20 ml) was stirred at ambient temperature for 30 min. Then, it was extracted with Et_2O (3x20 ml). The organic phase was dried over Na_2SO_4, filtered, and concentrated under reduced pressure to afford a yellow oil. The oil was then dissolved in 20 ml of EtOH and 2-hydroxy-5-nitrobenzaldehyde (0.35 g, 2.1 mmol) was added to the solution which was heated for 6 h under reflux and N_2. After cooling down to ambient temperature, the mixture was filtered. The resulting solid was dissolved in DCM , washed with a Na_2CO_3 solution in water (10%) and the organic phase was dried over Na_2SO_4. After evaporation of solvent 520 mg, 83% of product were obtained as a purple solid. **^{1}H-NMR** (400 MHz, CD_3CN): δ = 1.19 (3H, s, CH_3), 1.28 (3H, s, CH_3), 3.86 (1H, t, *J*=6.0, OH), 3.39-3.23 (2H, m, CH_2N), 3.69-3.58 (2H, m, CH_2OH), 6.03 (1H, d, *J*=10.4, ethylene), 6.71 (1H, d, *J*=8.0, arom.), 6.76 (1H, d, *J*=9.2, arom.), 6.88 (1H, t, *J*=7.6, arom.), 7.07 (1H, d, *J*=10.4, ethylene), 7.15 (2H, d, *J*=7.2, arom.), 7.19 (1H, t, *J*=7.6, arom.), 8.04 (1H, dd, J_1=9.2 Hz, J_2=2.8 Hz, arom.), 8.11 (1H, d, *J*=2.4 Hz, arom.); **^{13}C-NMR** (100 MHz, CD_3CN): δ = 19.10 (CH_3), 25.17 (CH_3), 45.93 ($C(CH_3)_2$), 52.52 (CH_2N), 59.90 (CH_2OH), 106.80, 107.06, 115.27, 119.39, 121.73, 122.28, 122.73, 125.59, 127.69, 127.82, 133.94, 135.99, 147.37, 159.46 (arom.). **HRMS (*m/z* -ES)**: Found: 353.1512 $(M+H)^+$, $C_{20}H_{21}N_2O_4$ Requires: 353.1501). **υ (cm^{-1}) :** 3363, 1608, 1577, 1508, 1478, 1331, 1270, 948, 745. **mp :** 170ºC.

Ethyl 4-(3',3'-dimethyl-6-nitrospiro[chromene-2,2'-indoline]-1'-yl)butanoate (SP3)

A solution containing 0.6 g (1.69 mmol) of the indolium bromide salt **3** and 0.34 g (2.03 mmol) of 5-nitrosalicylaldehyde were added in 20 ml of absolute ethanol and refluxed for 24h. The solution was then cooled to r.t. and the dark purple mixture was further cooled in an ice bath and filtered. The filter cake was washed with cold ethanol yielding an orange solid which was dissolved in dichloromethane and washed with an aqueous solution of Na_2CO_3. The organic layer was dried over Na_2SO_4 and the solvent was distilled at reduced pressure. Recrystallization from ethanol afforded 170 mg of a pale yellow powder, yield 23%. **^{1}H-NMR** (400 MHz, $CDCl_3$): δ = 1.21 (s, 3H, CH_3), 1.25, (t, 3H, *J*=7.3 Hz, CH_3), 1.31 (s, 3H, CH_3), 1.90-2.02 (m, 2H, CH_2), 2.35-2.40 (m, 2H, CH_2), 3.21-3.26 (m, 2H, CH_2), 4.11-4.14 (m, 2H, CH_2), 5.89 (d, 1H, *J*=10.5 Hz, CH), 6.67 (d, 1H, *J*=7.8 Hz, arom.), 6.76 (d, 1H, *J*=8.7 Hz, arom.), 6.92 (d, 1H, *J*=10.5 Hz, CH), 6.93 (m, 1H, arom.) 7.12 (d, 1H, *J*=6.8 Hz, arom.), 7.20-7.25 (m, 1H, arom.), 8.01-8.05 (m, 2H, arom.). **^{13}C-NMR** (100 MHz, $CDCl_3$): δ=14.2 (CH_3), 19.9 (CH_3), 24.1 (CH_3), 25.9 (CH_2), 31.7 (CH_2), 43.1 (NCH_2), 52.6 ($C(CH_3)_2$), 60.5 (OCH_2CH_3), 106.7, 106.8 (arom.), 115.6 (C spiro.), 118.4, 119.6, 121.7, 121.8, 122.7, 125.9, 127.8, 128.2, 135.9 (arom.), 140.9 (CNO_2), 147.0 (arom.), 159.5 (CO), 173.1 (COOEt). **HRMS (*m/z* -ES) :** Found: 423.1919 ($(M+H)^+$, $C_{24}H_{26}N_2O_5$ Requires: 422.1920). **υ (cm^{-1}) :** 2962, 1732, 1510, 1479, 1332,1274, 1089, 952. **mp :** 116ºC.

4-(3',3'-Dimethyl-6-nitrospiro[chromene-2,2'-indoline]-1'-yl)butanoic acid (SP4)

A solution containing 151.1 mg (3.58 mmol) of **SP3** were stirred in a solution 2:1 of THF and aqueous NaOH 10% for 48h. The reaction was quenched with 40 ml of an aqueous solution of citric acid 10%, the product was then extracted with chloroform and dried over $MgSO_4$. The solvent was finally evaporated affording 129.4 mg of a wine red solid, yield 91%. **^{1}H-NMR** (400 MHz, CD_3CN): δ = 1.21 (s, 3H, CH_3), 1.30 (s, 3H, CH_3), 1.93-2.02 (m, 2H, CH_2), 2.41-2.45 (m, 2H, CH_2), 3.21-3.26 (m, 2H, CH_2), 5.88 (d, 1H, *J*=10.4 Hz, CH), 6.67 (d, 1H, *J*=7.8 Hz, arom.), 6.76 (d, 1H, *J*=8.7 Hz), 6.90 (d, 2H, *J*=10.4 Hz, CH), 6.93 (m, 1H, arom.), 7.10-7.22 (m, 2H, arom.), 7.99-8.01 (m, 2H, arom.), 10.02 (s, 1H, COOH). **^{13}C-NMR** (100 MHz, CD_3CN): δ=18.5 (CH_3), 23.3 (CH_2), 24.8 (CH_3), 30.0 (CH_2), 42.2 (NCH_2), 51.9 ($C(CH_3)_2$), 106.4, (arom.), 114.8 (C spiro.), 118.5, 118.9, 119.7, 121.3, 121.4, 122.3, 125.1, 127.3, 127.7, 135.7 (arom.), 146.7 (CNO_2), 157.5 (arom.), 159.0 (CO), 173.1 (COOH). **HRMS (*m/z* -ES) :** Found: 395.1607 ($(M+H)^+$, $C_{22}H_{22}N_2O_5$ Requires: 395.1607). **υ (cm^{-1}) :** 2965, 1731, 1661, 1578, 1477, 1333, 1274. **mp :** 99ºC.

1,1',3,3,3',3'-hexamethyl-5,5'-bi[6,6'-nitrospiro[chromene-2,2'-indoline]] (SP1-SP1)

Compound **SP1** (100 mg, 0.31 mmol) was dissolved in 10 ml of acetonitrile and $Cu(ClO_4)_2$ $6H_2O$ (117 mg, 0.31 mmol) was dissolved in 200 ml of distilled water. The aqueous solution containing copper (II) was added to the organic solution containing compound **SP1** which was stirred for 24 h at room temperature. The solvent was evaporated under reduced pressure and the crude was dissolved in 10 ml of DCM and filtered. The filtrate was washed with a saturated solution of $NaHCO_3$ (3 x 5 ml) containing the 5% of EDTA. The organic phase was then dried over Na_2SO_4 and the solvent was distilled under reduced pressure affording a brown solid which was purified *via* flash chromatography on silica gel using a mixture of hexane/ethyl acetate 9:1 as eluent (*Rf* = 0.5). The procedure afforded 45 mg of a yellow solid, yield 43%. **^{1}H-NMR** (400 MHz, CD_3CN): *d* = 1.25 (s, 6H, CH_3), 1.36 (s, 6H, CH_3), 2.79 (s, 6H, NCH_3), 6.02 (d, 2H, *J*=10.4 Hz, CH ethylene), 6.68 (d, 2H, *J*=8.0 Hz, arom.), 6.82 (d, 2H, *J*=9.2 Hz, arom.), 7.14 (d, 2H, *J*=10.4 Hz, H ethylene), 7.42 (d, 2H, *J*=2.0 Hz), 7.45 (dd, 2H, *J1*=8.0 Hz, *J2*=2.0 Hz, arom.), 8.05 (dd, 2H, *J1*=9.2 Hz, *J2*=2.8 Hz, arom.), 8.13 (d, 2H, *J*=2.8 Hz, arom.). **^{13}C-NMR** (100 MHz, CD_3CN): *d* = 19.1 (CH_3), 25.2 (CH_3), 28.2 (NCH_3), 52.2 ($C(CH_3)_2$), 106.8 (C spiro.), 107.3, 115.2, 119.1, 120.2, 121.5 (arom.), 122.7 (vinylic), 125.6, 125.9 (arom.), 128.2 (vinylic), 133.5, 137.1, 141.1, 146.8, 159.7 (arom.). **HRMS (*m/z* - MALDI-TOF) :** Found: 642.2464 ($(M)^+$, $C_{38}H_{34}N_4O_6$ Requires: 642.2478). **υ (cm^{-1}) :** 2961, 1613, 1515, 1477, 1332, 1267,1086, 947. **mp :**163ºC.

5,5'-bi[ethyl 4,4'-(3',3'-dimethyl-6-nitrospiro[chromene-2,2'-indoline]-1'-yl)butanoate] (SP3-SP3)

Compound **SP3** (100 mg, 0.24 mmol) was dissolved in 10 ml of acetonitrile and $Cu(ClO_4)_2$ $6H_2O$ (87 mg, 0.24 mmol) was dissolved in 200 ml of distilled water. The aqueous solution containing copper (II) was added to the organic solution containing compound **SP3** which was stirred for 24 h at room temperature. The solvent was evaporated under reduced pressure and the crude was dissolved in 10 ml of DCM and filtered. The filtrate was washed with a saturated solution of $NaHCO_3$ (3 x 5 ml) containing the 5% of EDTA. The organic phase was then dried over Na_2SO_4 and the solvent was distilled under reduced pressure affording a brown solid which was purified *via* flash chromatography on silica gel using a mixture of hexane/ethyl acetate 7:3 as eluent (*Rf* = 0.38). The procedure afforded 48 mg of a green solid, yield 46%. **^{1}H-NMR** (400 MHz, CD_3CN): *d* = 1.25 (s, 6H, CH_3), 1.36 (s, 6H, CH_3), 2.79 (s, 6H, NCH_3), 6.02 (d, 2H, *J*=10.4 Hz, CH ethylene), 6.68 (d, 2H, *J*=8.0 Hz, arom.), 6.82 (d, 2H, *J*=9.2 Hz, arom.), 7.14 (d, 2H, *J*=10.4 Hz, H ethylene), 7.42 (d, 2H, *J*=2.0 Hz), 7.45 (dd, 2H, *J1*=8.0 Hz, *J2*=2.0 Hz, arom.), 8.05 (dd, 2H, *J1*=9.2 Hz, *J2*=2.8 Hz, arom.), 8.13 (d, 2H, *J*=2.8 Hz, arom.). **^{13}C-NMR** (100 MHz, CD_3CN): *d* = 13.1 (CH_3CH_2O), 18.6 (CH_3), 23.4 (CH_2), 24.8 (CH_3), 30.6 (CH_2COO), 42.2 (CH_2N), 52.1 ($C(CH_3)_2$), 59.6 (CH_3CH_2O), 106.6, 106.7, 118.5, 119.9 (arom.), 121.3 (vinylic), 122.3, 125.1, 125.4, 125.5 (arom.), 127.7 (vinylic), 132.8, 136.4, 140.6, 145.6, 158.9 arom.), 172.5 (COO). **HRMS**

(*m/z* - MALDI-TOF) : Found: 842.3503 ($(M)^+$, $C_{48}H_{50}N_4O_{10}$ Requires: 842.3527). **υ (cm^{-1}) :** 2965, 1728, 1612, 1516, 1476, 1332, 1266, 1086, 949. **mp :**198ºC.

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^{1}H NMR and ^{13}C NMR spectra

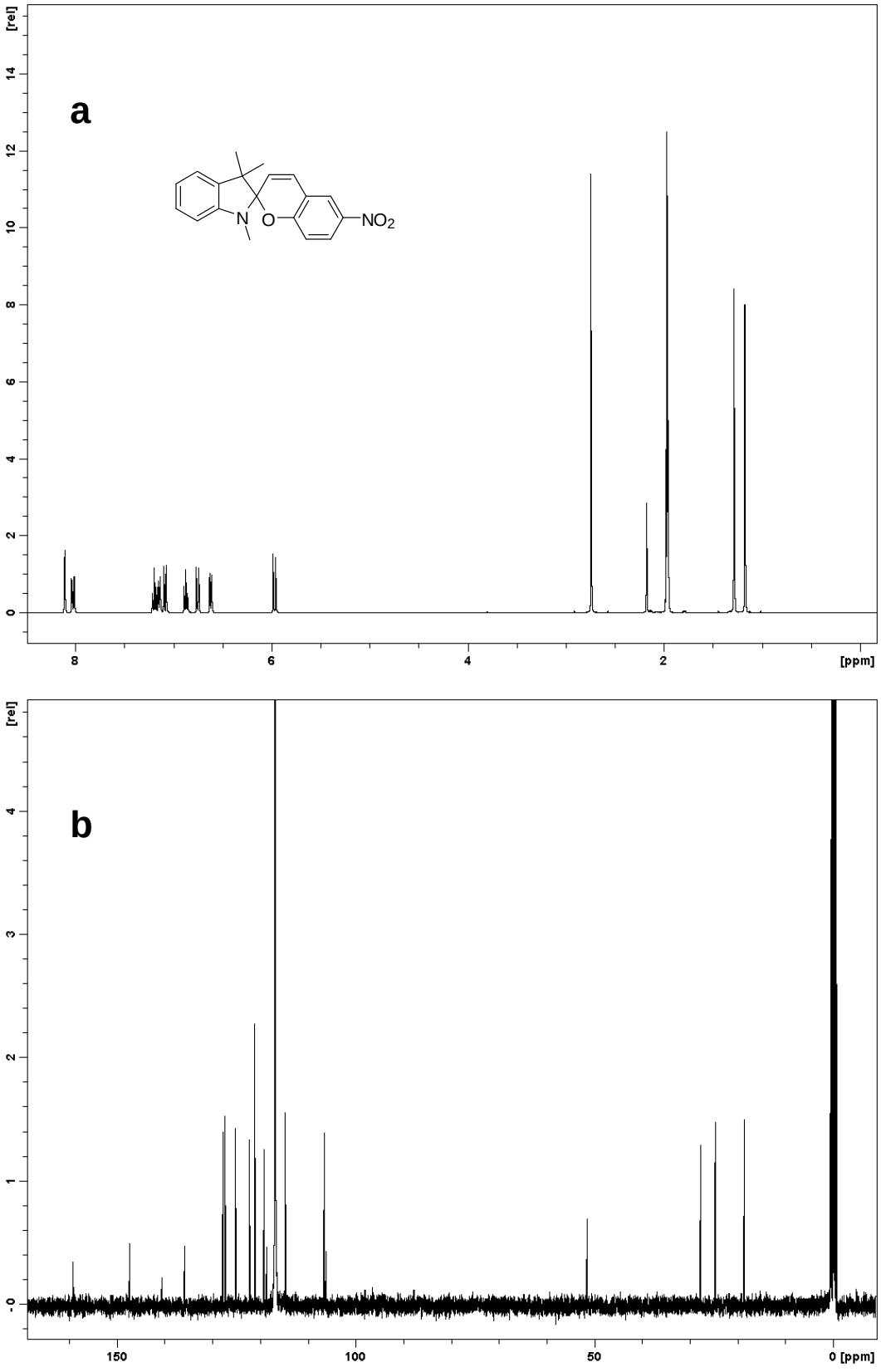

Fig S4 (**a**) ^{1}H NMR (400 MHz) and (**b**)^{13}C NMR (100 MHz) of **SP1** in CD_3CN.

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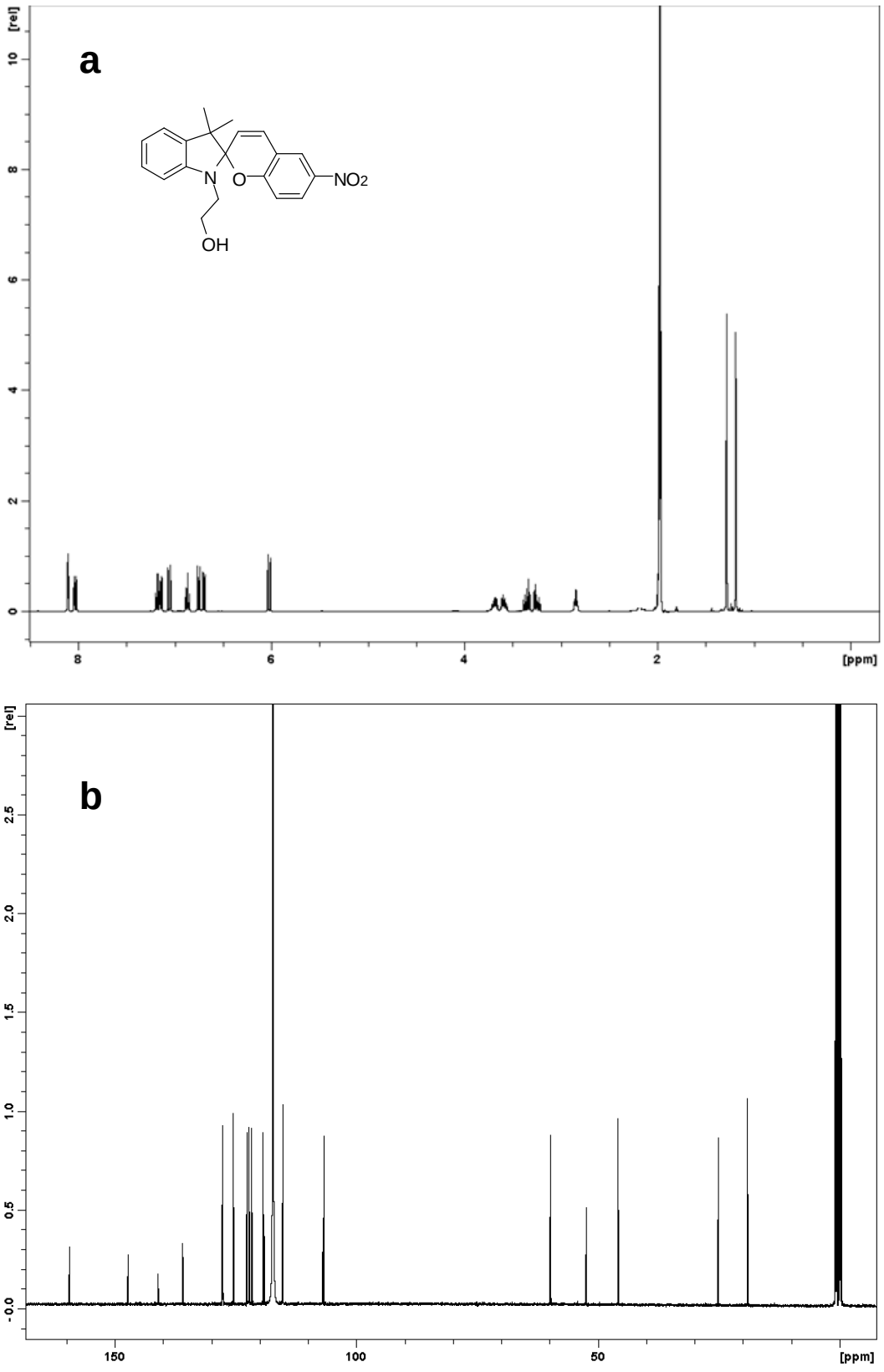

Fig S5 (**a**) ^{1}H NMR (400 MHz) and (**b**)^{13}C NMR (100 MHz) of **SP2** in CD_3CN.

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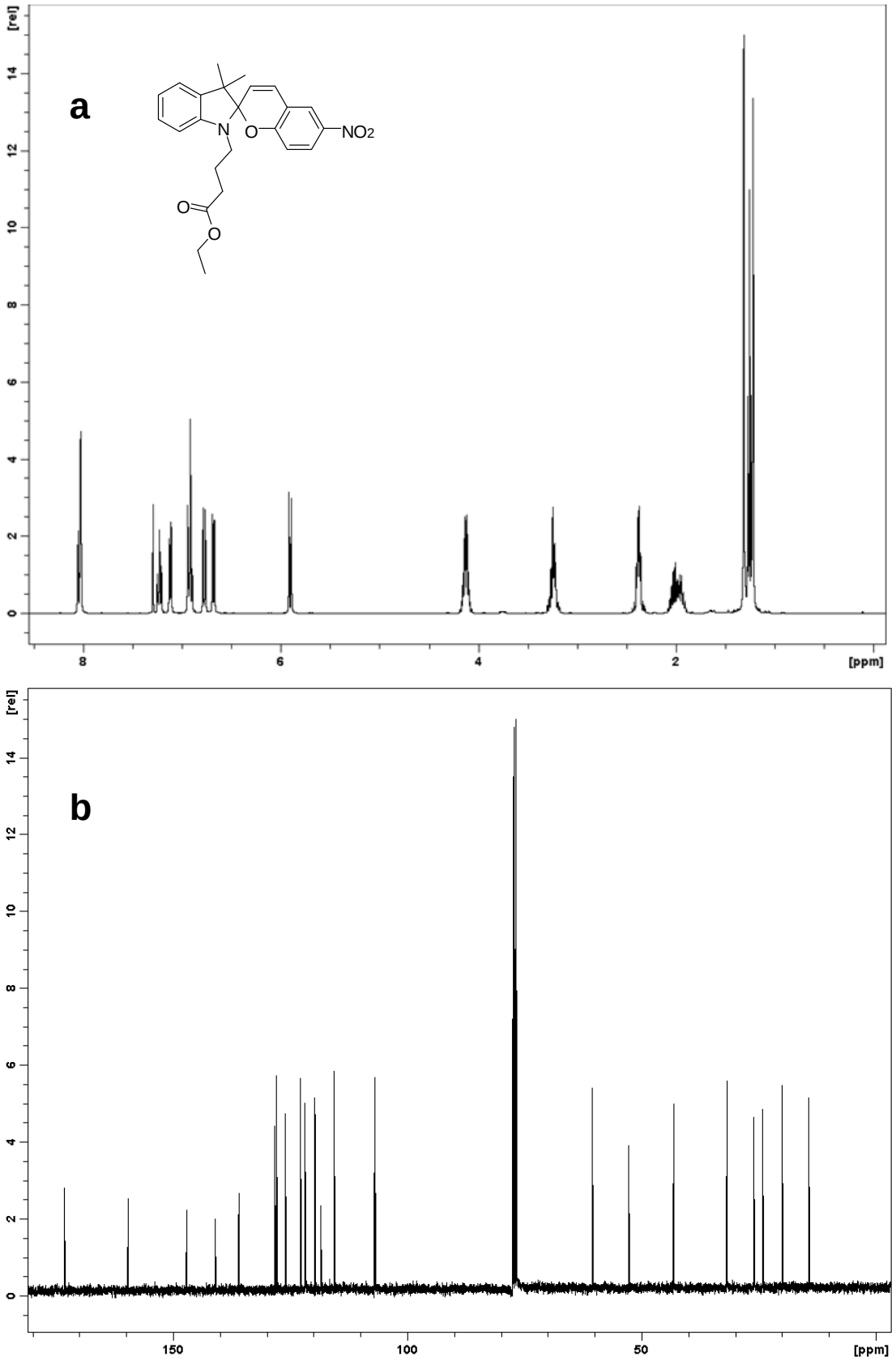

Fig S6 (**a**) ^{1}H NMR (400 MHz) and (**b**)^{13}C NMR (100 MHz) of **SP3** in $CDCl_3$.

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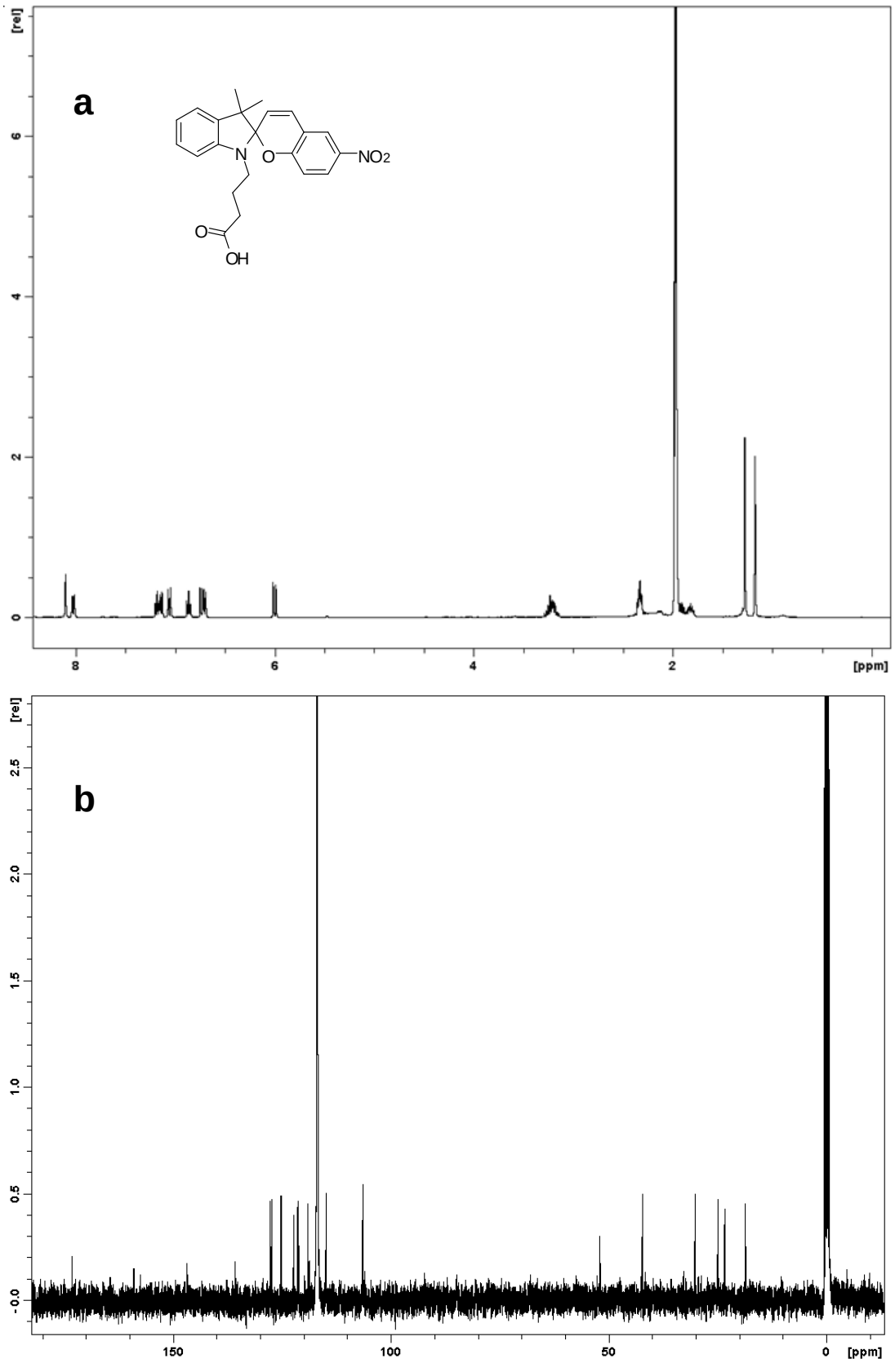

Fig S7 (**a**) ^{1}H NMR (400 MHz) and (**b**)^{13}C NMR (100 MHz) of **SP4** in CD_3CN.

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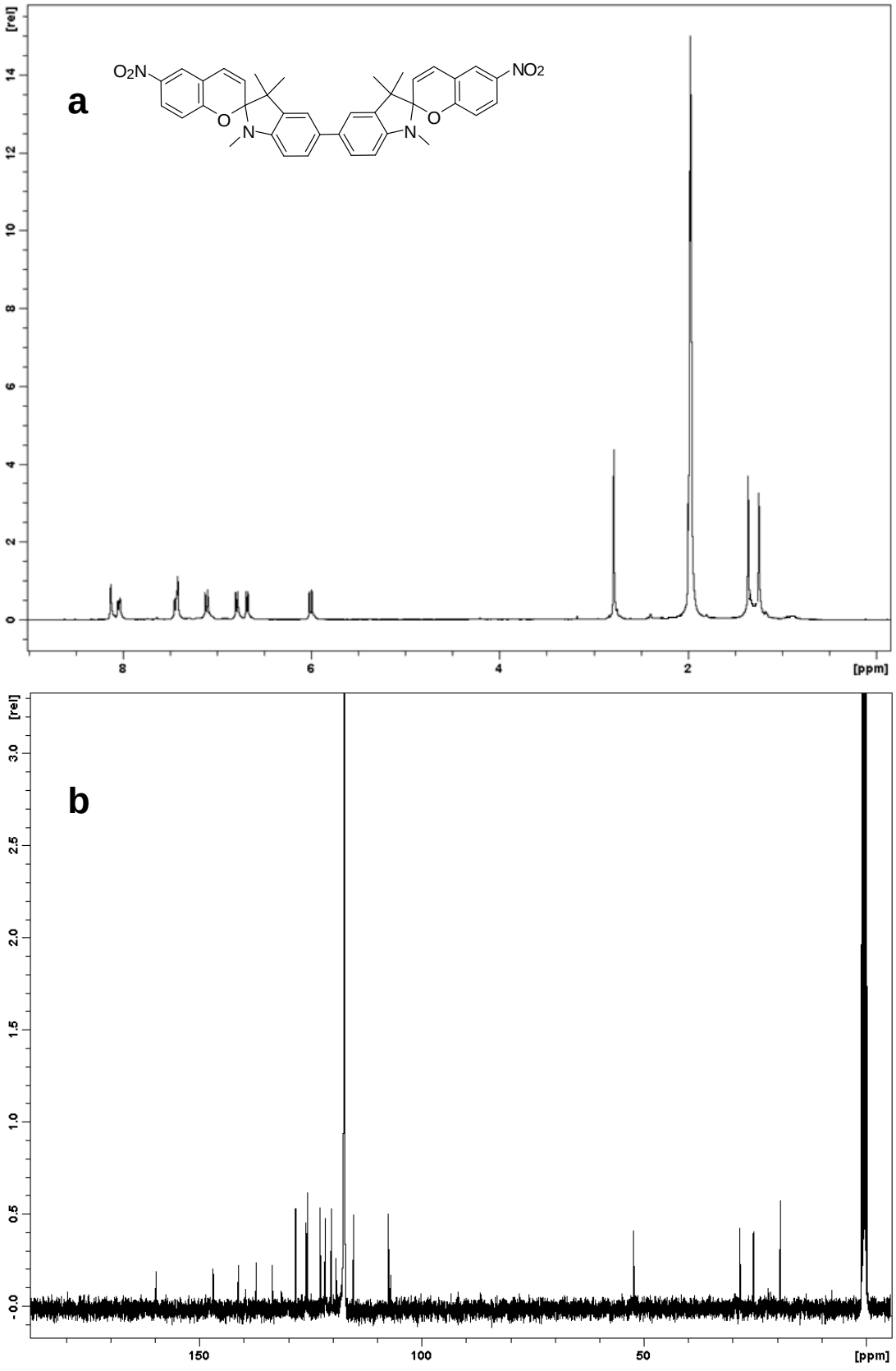

Fig S8 (**a**) ^{1}H NMR (400 MHz) and (**b**)^{13}C NMR (100 MHz) of **SP1-SP1** in CD_3CN.

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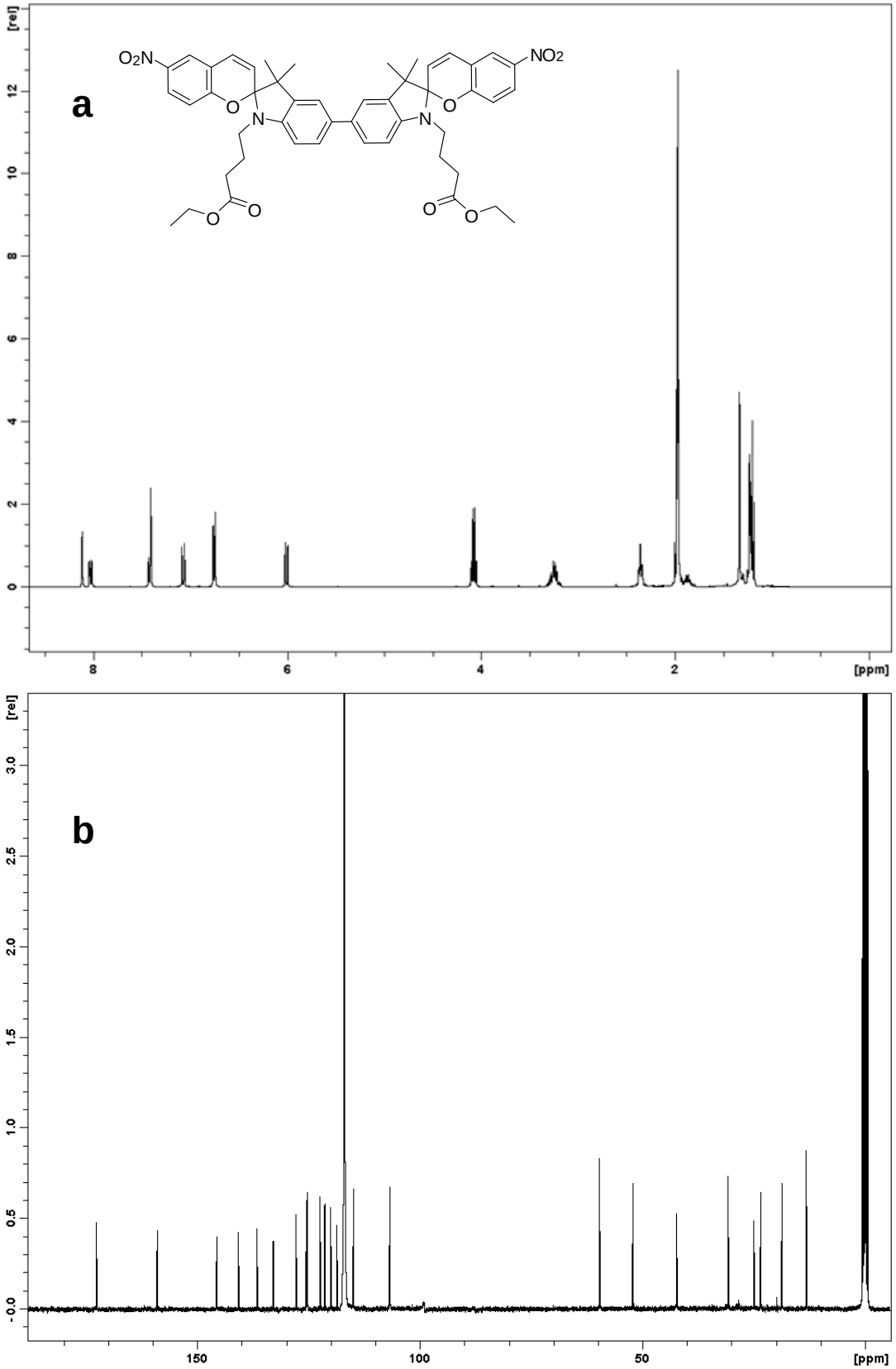

Fig S9 (**a**) ^{1}H NMR (400 MHz) and (**b**)^{13}C NMR (100 MHz) of **SP3-SP3** in CD_3CN.

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Notes and references

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