Supplementary Information for

Anomalous Photochromism and Mechanochromism of a Linear Naphthopyran Enabled by a Polarizing Dialkylamine Substituent

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Table of Contents

I. Materials and Methods

Reagents from commercial sources were used without further purification unless otherwise stated. Methyl acrylate was passed through a short plug of basic alumina to remove inhibitor immediately prior to use. Amberlyst 15 was washed with acetone prior to use. Copper wire was soaked in 1 M HCl for 30 min and then rinsed consecutively with water and acetone immediately prior to use. Dry solvents were obtained from a Pure Process Technology solvent purification system. All reactions were performed under a N_2 atmosphere unless specified otherwise. Column chromatography was performed on a Biotage Isolera system using SiliCycle SiliaSep HP flash cartridges.

NMR spectra were recorded using a 400 MHz Bruker Avance III HD with Prodigy Cryoprobe or a 600 MHz Varian spectrometer with 5 mm triple resonance inverse probe. All ^{1}H NMR spectra are reported in δ units, parts per million (ppm), and were measured relative to the signals for residual chloroform (7.26 ppm), acetone (2.05 ppm), dichloromethane (5.32 ppm), or dimethyl sulfoxide (2.50 ppm) in deuterated solvent. All ^{13}C NMR spectra were measured in deuterated solvents and are reported in ppm relative to the signals for chloroform (77.16 ppm), acetone (206.26 ppm), dichloromethane (54.00 ppm), or dimethyl sulfoxide (39.52 ppm).

High resolution mass spectra (HRMS) were obtained from a Waters LCT Premier XE time-of-flight mass spectrometer equipped with an electrospray ionization (ESI) probe, a JEOL JMS-600H magnetic sector mass spectrometer equipped with a FAB+ probe, or via direct injection on an Agilent 1260 Infinity II Series HPLC coupled to a 6230 LC/TOF system in electrospray ionization (ESI+) mode.

Analytical gel permeation chromatography (GPC) was performed using an Agilent 1260 series pump equipped with two Agilent PLgel MIXED-B columns (7.5 x 300 mm), an Agilent 1200 series diode array detector, a Wyatt 18-angle DAWN HELEOS light scattering detector, and a Optilab rEX differential refractive index detector. The mobile phase was THF at a flow rate of 1 mL/min. Molecular weights and molecular weight distributions were calculated by light scattering using a dn/dc value of 0.062 mL/g (25 °C) for poly(methyl acrylate).

UV-vis absorption spectra were recorded on a Thermo Scientific Evolution 220 spectrometer.

Ultrasound experiments were performed using a Vibra Cell 505 liquid processor equipped with a 0.5-inch diameter solid probe (part #630-0217), sonochemical adapter (part #830-00014), and a Suslick reaction vessel made by the Caltech glass shop (analogous to vessel #830-00014 from Sonics and Materials). Polymer solutions were continuously sampled for UV-vis analysis using a Cole Parmer Masterflex L/S pump system (item #EW-77912-10) composed of an L/S pump head (part #77390-00) and L/S precision variable speed drive (part #07528-20) using 4x6 mm PTFE tubing (part #77390-60) and a quartz flow-through cell (Starna, part #583.4-Q-10/Z8.5), which was connected using M6-threaded PTFE tubing (Starna, part #M6-SET). A Thermo Scientific EK45 Immersion Cooler (part #3281452) was used to maintain a constant temperature bath for sonication experiments. Photoirradiation with UV light was performed using either a DR/9W-UVA 365 nm lamp or a Philips PL-S 9W/01/2P UVB bulb with a narrow emission of 305–315 nm and a peak at 311 nm under ambient conditions unless indicated otherwise.

II. Supplementary Figures

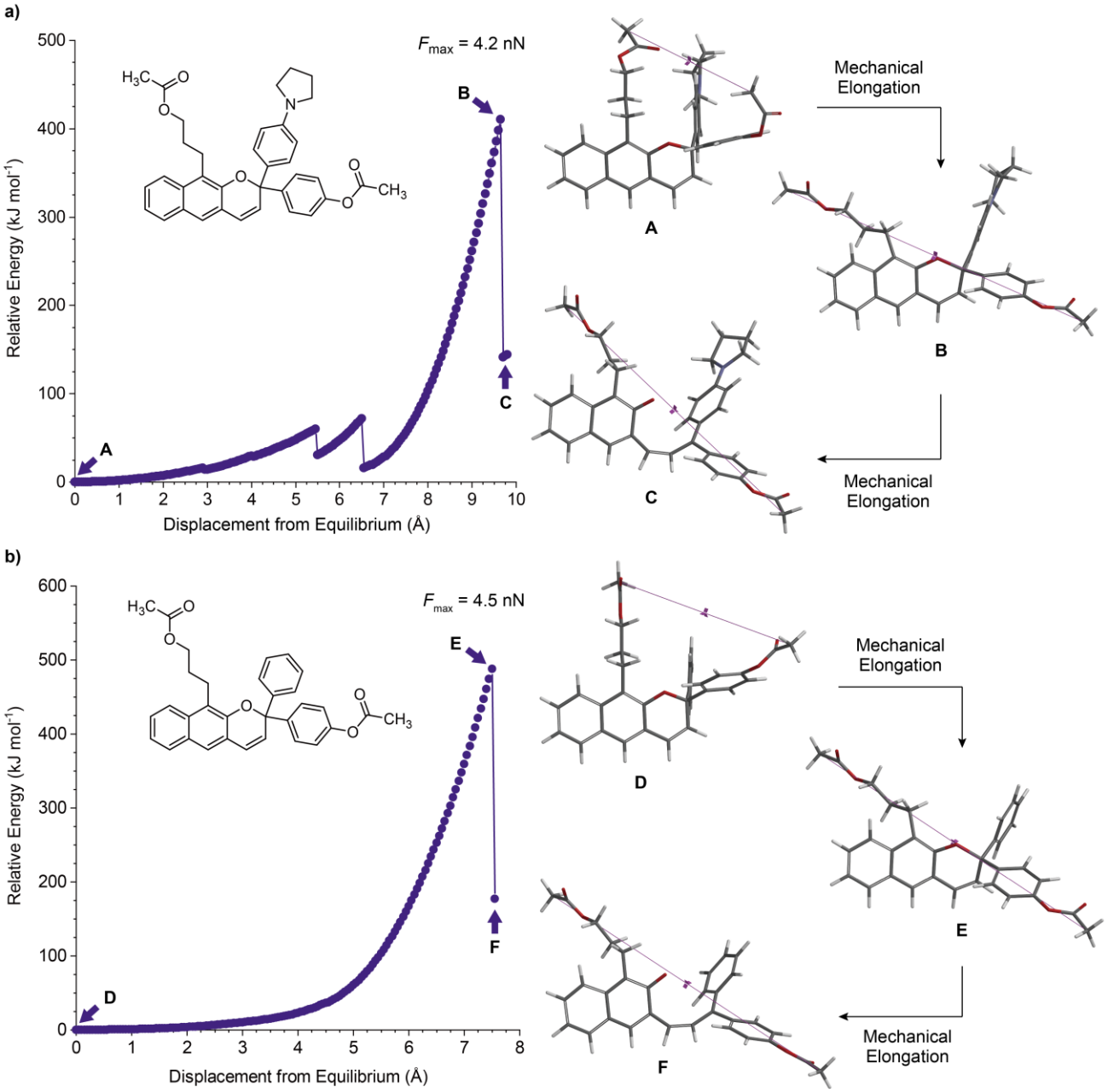


Figure S1. Density functional theory (DFT) calculations using the constrained geometries simulate external force (CoGEF) method performed on linear 2*H*-naphtho[2,3-*b*]pyran models with (a) *para*-pyrrolidine, and (b) *para*-H substitution predict a ring-opening reaction upon mechanical elongation. The structures at various points in the CoGEF profile are shown at right, corresponding to the positions denoted by the arrows. Calculations were performed at the B3LYP/6-31G* level of theory. The carbon atoms of the terminal methyl groups were used to define the distance constraint.

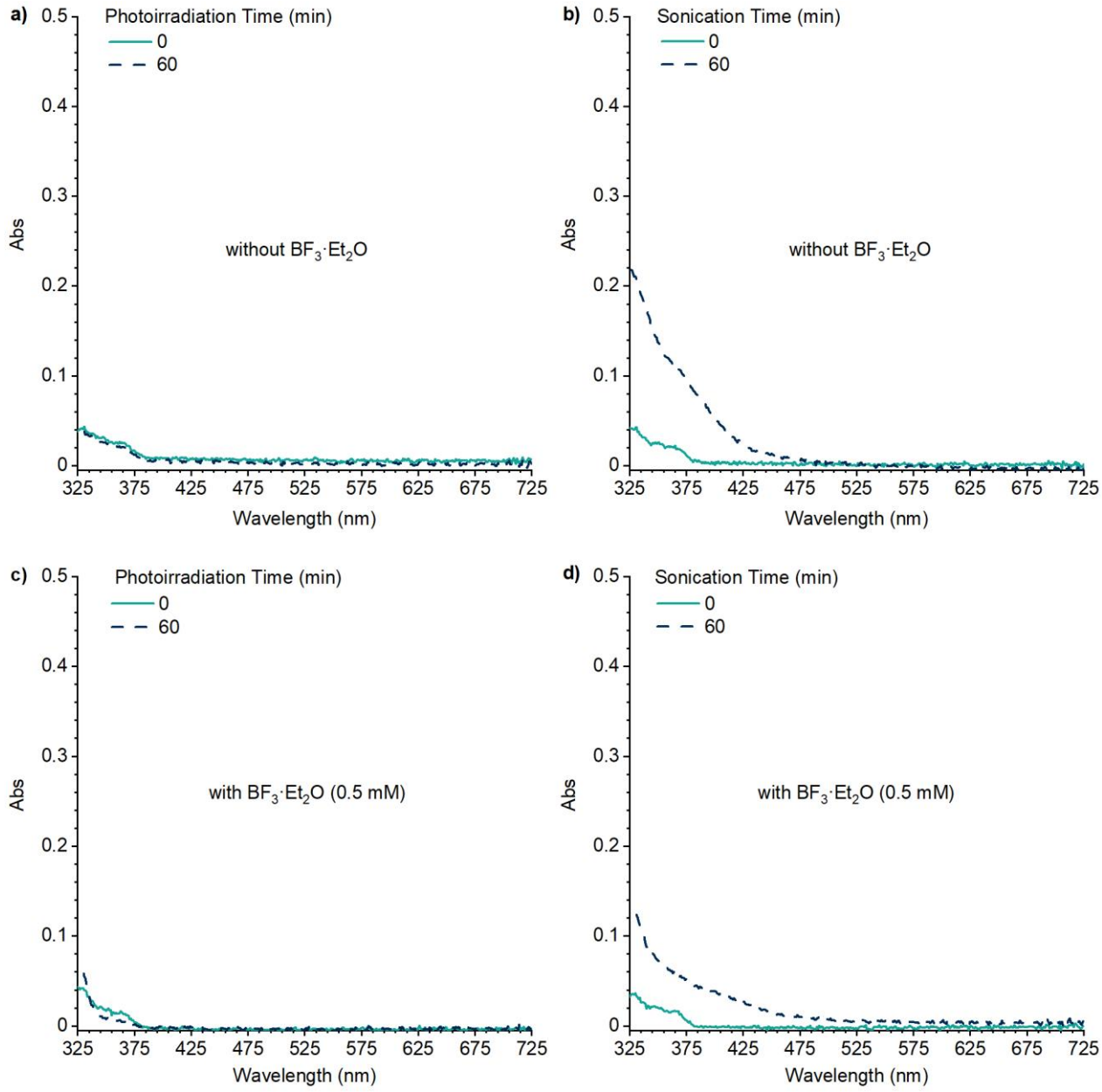


Figure S2. Comparison of the photochemical and mechanochemical reactivity of **PMA-LNP** in the presence or absence of $BF_3{\cdot}Et_2O$. UV-vis absorption spectra of **PMA-LNP** in CH_3CN (2 mg/mL with 30 mM BHT) before and after (a) photoirradiation at −30 °C with 311 nm UV light, and (b) continuous ultrasonication at −15 °C for 60 min. UV-vis absorption spectra of **PMA-LNP** in CH_3CN (2 mg/mL with 30 mM BHT) with 0.5 mM $BF_3{\cdot}Et_2O$ before and after (c) photoirradiation at −30 °C with 311 nm UV light, and (d) continuous ultrasonication at −15 °C for 60 min. No photochromic or mechanochromic response was observed under any conditions.

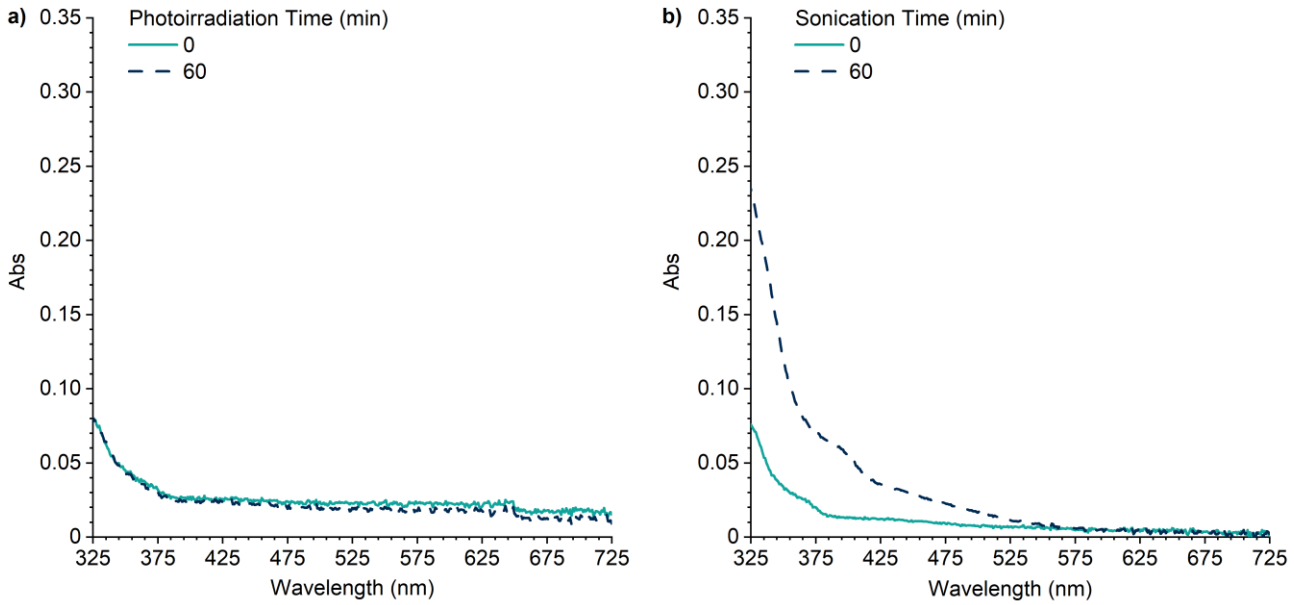


Figure S3. UV-vis absorption spectra of **PMA-PyLNP** in CH_3CN (2 mg/mL with 30 mM BHT) before and after (a) photoirradiation at −30 °C with 311 nm UV light, and (b) continuous ultrasonication at −15 °C for 60 min. No photochromic or mechanochromic response was observed from **PMA-PyLNP** in the absence of $BF_3{\cdot}Et_2O$.

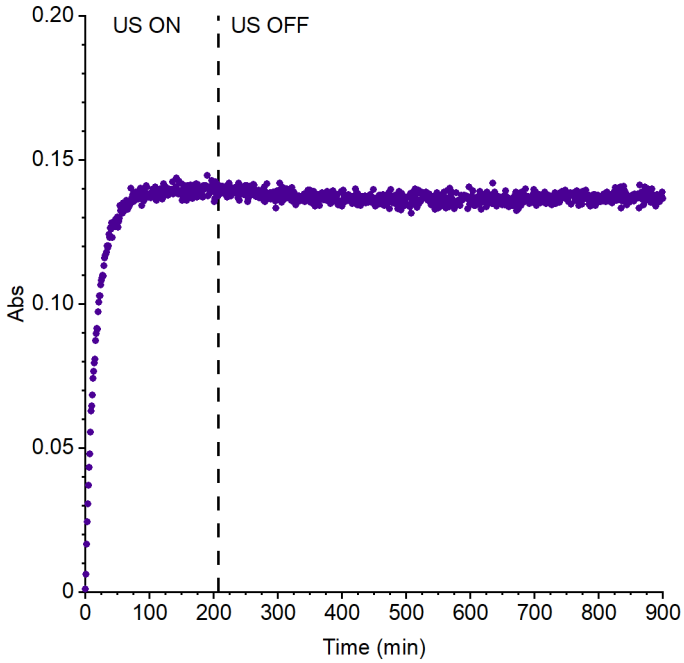


Figure S4. Absorbance recorded at 540 nm during ultrasonication of **PMA-PyLNP** in CH_3CN (2 mg/mL with 30 mM BHT) in the presence of 0.5 mM $BF_3{\cdot}Et_2O$, and then after cessation of ultrasonication. Ultrasound-induced mechanochemical activation of **PMA-PyLNP** produces a persistent merocyanine product with no thermal reversion observed upon cessation of ultrasonication. Absorption was monitored at λ_{max}.

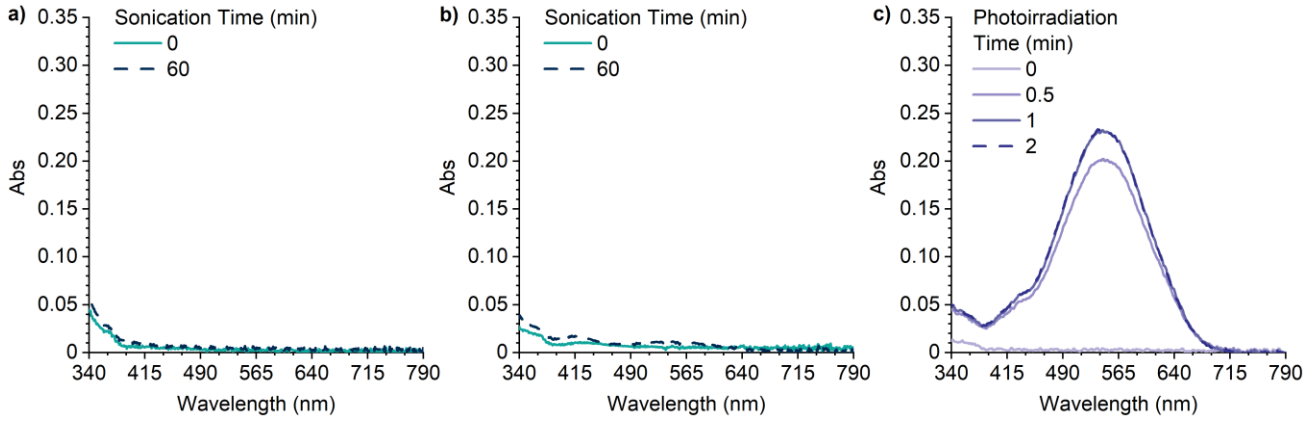


Figure S5. UV-vis absorption spectra of **PMA-Control** in CH_3CN (2 mg/mL with 30 mM BHT) before and after continuous ultrasonication at −15 °C for 60 min (a) without $BF_3{\cdot}Et_2O$, and (b) in the presence of 0.5 mM $BF_3{\cdot}Et_2O$. No changes in absorption are observed for **PMA-Control** upon ultrasonication in direct contrast to **PMA-PyLNP**, which contains the linear naphthopyran mechanophore near the chain midpoint where it is susceptible to mechanical force. (c) UV-vis absorption spectra of **PMA-Control** in CH_3CN (2 mg/mL with 30 mM BHT) in the presence of 0.5 mM $BF_3{\cdot}Et_2O$ before and after irradiation with 311 nm UV light, confirming the presence of the linear naphthopyran moiety at the polymer chain end. For this experiment, photoirradiation was performed in a quartz cuvette at room temperature without use of the flow setup.

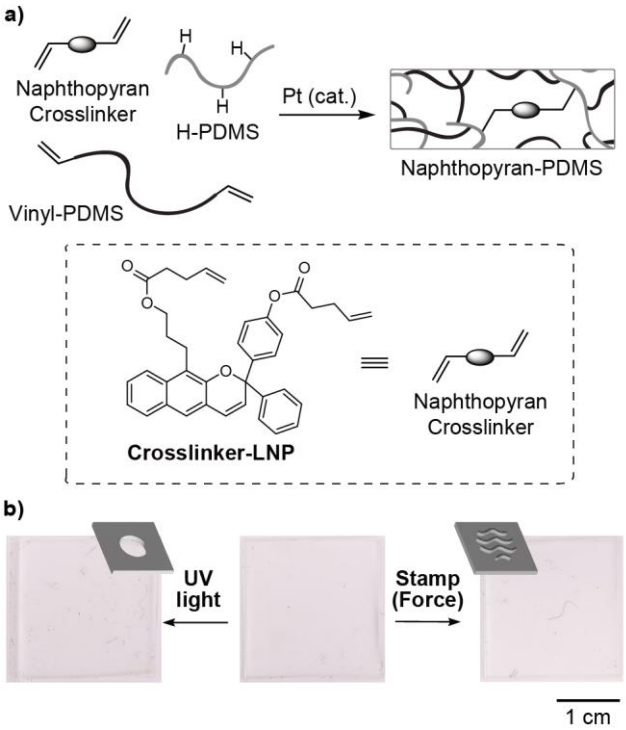
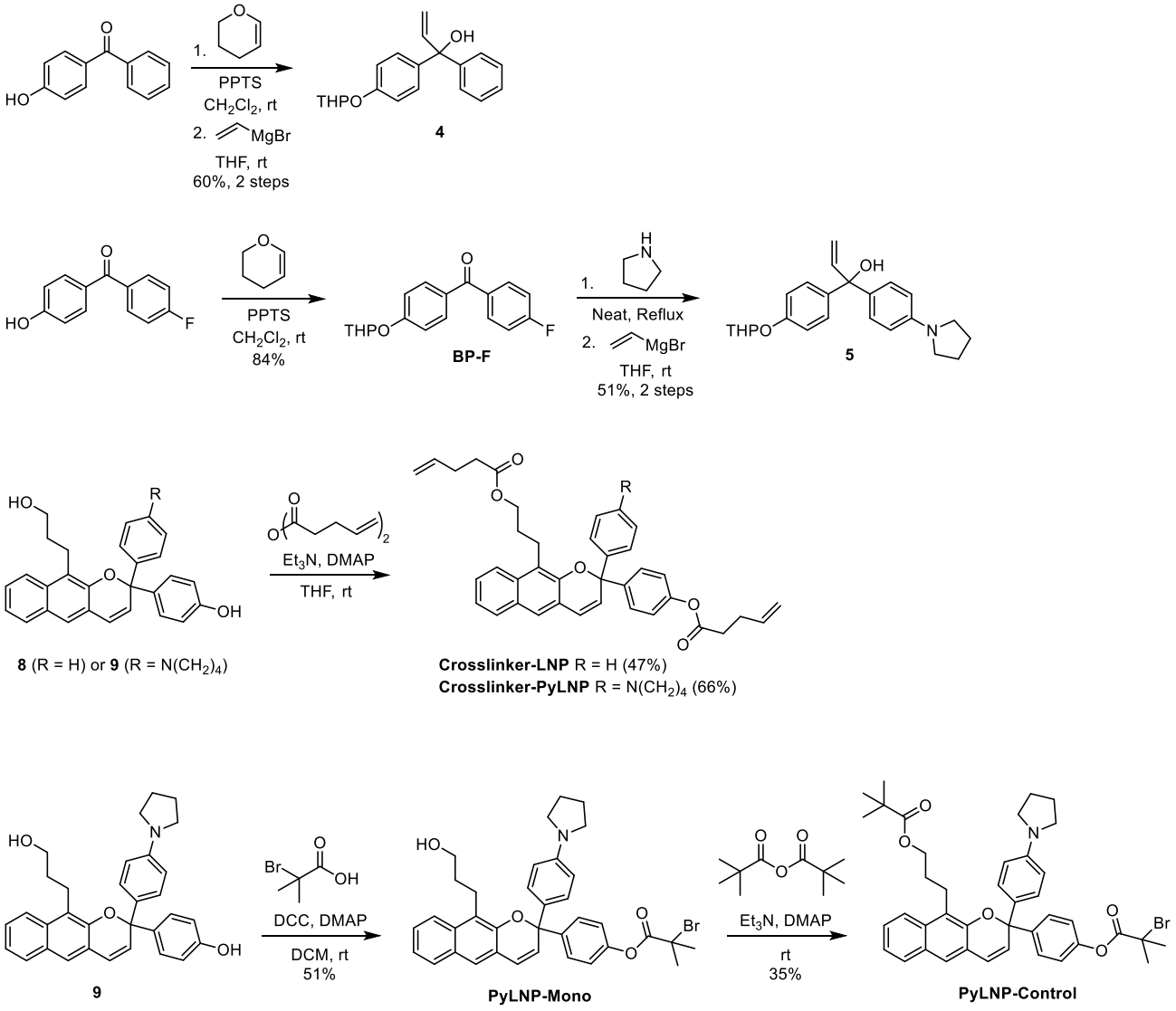
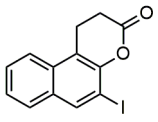


Figure S6. (a) PDMS networks covalently crosslinked with linear 2*H*-naphthopyran mechanophore **Crosslinker-LNP** (1.0 wt%) without a *para*-pyrrolidine substituent prepared via Pt-catalyzed hydrosilylation. (b) Photographs of the material before and after photoirradiation with 365 nm UV light for 120 s through a photomask, and after mechanical force applied via compression (2×) using an embossed stamp. Schematic representations of the photomask and stamp are shown. No photochromic or mechanochromic response is observed in contrast to the analogous materials incorporating **Crosslinker-PyLNP** with a polarizing dialkylamine substituent.

III. Synthetic Details

Scheme S1. Synthesis of compounds used in this study not described in Scheme 2.





1

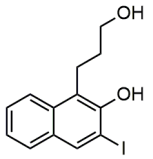
5-iodo-1,2-dihydro-3H-benzo[f]chromen-3-one (1). A flame-dried 10 mL round-bottom flask equipped with a stir bar was charged with 3-iodonaphthalen-2-ol (200 mg, 0.741 mmol), Amberlyst 15 (200 mg), and 4 Å molecular sieves (200 mg). The flask was evacuated and backfilled with N_2 three times. Dry toluene (2 mL) was then added via syringe, followed by the addition of acrylic acid (0.10 mL, 1.5 mmol) under N_2. After stirring at reflux overnight, the flask was removed from heat and the crude mixture was filtered, concentrated under reduced pressure, and purified by column chromatography on silica gel (0–15% ethyl acetate/hexanes) to produce the title compound **1** as a pale yellow solid (177 mg, 74%).

TLC (25% EtOAc/hexanes): R_f = 0.50

^{1}H NMR (400 MHz, Chloroform-*d*) δ: 8.28 (s, 1H), 7.84 (d, *J* = 8.5 Hz, 1H), 7.71 (d, *J* = 8.2 Hz, 1H), 7.61 – 7.53 (m, 1H), 7.50 – 7.43 (m, 1H), 3.34 (t, *J* = 7.6 Hz, 2H), 2.89 (dd, *J* = 8.2, 6.7 Hz, 2H).

^{13}C{^{1}H} NMR (101 MHz, Chloroform-*d*) δ: 167.4, 147.9, 138.7, 132.1, 130.9, 127.74, 127.66, 126.0, 122.9, 116.9, 84.7, 28.7, 20.6.

HRMS (FD, *m/z*): calcd for $[C_{13}H_9IO_2]^{+\cdot}$ $(M)^{+\cdot}$, 323.9647; found, 323.9644.



2

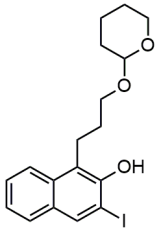
1-(3-hydroxypropyl)-3-iodonaphthalen-2-ol (2). A flame-dried 250 mL round-bottom flask equipped with a stir bar was charged with lithium aluminum hydride (700 mg, 18.4 mmol). The flask was evacuated and backfilled with N_2 three times and then dry THF (60 mL) was added via syringe. The flask was cooled in an ice bath and a solution of **1** (3.03 g, 9.35 mmol) in dry THF (20 mL) was added dropwise via syringe. After complete addition, the mixture was warmed to room temperature and stirred for 1 h. The flask was subsequently cooled in ice and ethyl acetate (20 mL) was added dropwise followed by a 10% aqueous solution of Rochelle's salt (100 mL). The mixture was stirred at room temperature overnight followed by addition of 1 M HCl (50 mL). The crude mixture was concentrated under reduced pressure and partitioned between water and ethyl acetate. The aqueous layer was discarded and the organic layer was washed with water and then dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude product was purified by column chromatography (0–30% EtOAc/hexanes) to afford the title product as a yellow solid (2.98 g, 97%).

TLC (50% EtOAc/hexanes): R_f = 0.56

^{1}H NMR (400 MHz, Chloroform-*d*) δ: 8.22 (s, 1H), 7.88 (d, *J* = 8.6 Hz, 1H), 7.67 (d, *J* = 8.1 Hz, 1H), 7.53 – 7.45 (m, 1H), 7.38 – 7.29 (m, 1H), 3.64 (t, *J* = 5.8 Hz, 2H), 3.39 (dd, *J* = 7.3, 6.1 Hz, 2H), 2.09 – 1.95 (m, 2H).

^{13}C{^{1}H} NMR (101 MHz, Chloroform-*d*) δ: 150.1, 137.4, 133.3, 130.9, 127.7, 127.0, 123.9, 123.0, 119.2, 89.3, 61.0, 30.7, 21.8.

HRMS (ESI, *m/z*): calcd for $[C_{13}H_{12}IO_2]^-$ $(M-H)^-$, 326.9887; found, 326.9884.



3

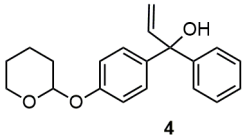
3-iodo-1-(3-((tetrahydro-2H-pyran-2-yl)oxy)propyl)naphthalen-2-ol (3). A flame-dried 100 mL round-bottom flask equipped with a stir bar was charged with **2** (3.08 g, 9.39 mmol) and pyridinium *p*-toluenesulfonate (PPTS, 689 mg, 2.75 mmol). The flask was evacuated and backfilled with N_2 three times. Dry CH_2Cl_2 (20 mL) was added via syringe, followed by the addition of 3,4-dihydro-2*H*-pyran (0.80 mL, 9.1 mmol). After stirring at room temperature overnight, the mixture was concentrated under reduced pressure and partitioned between water and CH_2Cl_2. The aqueous phase was discarded and the organic phase was dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude product was purified by column chromatography (0–15% EtOAc/hexanes) to afford the title product as yellow solid (3.40 g, 88%).

TLC (10% EtOAc/hexanes): R_f = 0.31

^{1}H NMR (400 MHz, Chloroform-*d*) δ: 8.22 (s, 1H), 7.88 (d, *J* = 8.6 Hz, 1H), 7.67 (d, *J* = 8.1 Hz, 1H), 7.48 (ddd, *J* = 8.4, 6.8, 1.3 Hz, 1H), 7.32 (ddd, *J* = 8.1, 6.9, 1.1 Hz, 1H), 7.29 (s, 1H),4.67 (dd, *J* = 4.6, 3.0 Hz, 1H), 3.93 (ddd, *J* = 11.0, 6.3, 3.7 Hz, 1H), 3.78 (dt, *J* = 10.2, 5.5 Hz, 1H), 3.60 – 3.50 (m, 1H), 3.46 (dt, *J* = 10.2, 5.8 Hz, 1H), 3.26 (t, *J* = 7.0 Hz, 2H), 2.08 – 1.99 (m, 2H), 1.98 – 1.86 (m, 1H), 1.86 – 1.78 (m, 1H), 1.79 – 1.68 (m, 1H), 1.63 – 1.56 (m, 3H).

^{13}C{^{1}H} NMR (101 MHz, Chloroform-*d*) δ: 150.1, 137.3, 133.3, 130.9, 127.7, 126.9, 123.8, 123.1, 119.9, 99.1, 89.5, 65.9, 62.9, 30.7, 28.9, 25.4, 22.5, 19.7.

HRMS (FD, *m/z*): calcd for $[C_{18}H_{21}IO_3]^{+\cdot}$ $(M)^{+\cdot}$, 412.0535; found, 412.0539.



4

1-phenyl-1-(4-((tetrahydro-2H-pyran-2-yl)oxy)phenyl)prop-2-en-1-ol (4). A flame-dried round-bottom flask equipped with a stir bar was charged with 4-hydroxybenzophenone (2.03 g, 10.3 mmol) and pyridinium *p*-toluenesulfonate (PPTS, 400 mg, 1.59 mmol). The flask was evacuated and backfilled with N_2 three times. Dry CH_2Cl_2 (20 mL) was added via syringe followed by the addition of 3,4-dihydro-2*H*-pyran (1.0 mL, 11 mmol). After stirring at room temperature overnight, the mixture was concentrated under reduced pressure and partitioned between water and CH_2Cl_2. The aqueous phase was discarded and the organic phase was dried over Na_2SO_4, filtered, and concentrated under reduced pressure. Next, the crude yellow oil was added to a flame-dried round-bottom flask equipped with a stir bar and the flask was evacuated and backfilled with N_2 three times. Dry THF (20 mL) was added via syringe and the flask was cooled in an ice bath followed by the slow addition of vinylmagnesium bromide (1 M in THF, 12 mL, 12 mmol). After complete addition, the reaction mixture was allowed to warm to room temperature and stirred for 5 h. The flask was cooled in an ice bath and water was added dropwise. The crude reaction mixture was concentrated under reduced pressure and partitioned between water and ethyl acetate. The aqueous phase was discarded and the organic phase was

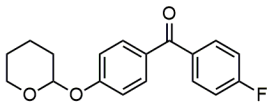
dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude product was purified by column chromatography (0–30% EtOAc/hexanes) to afford the title product as yellow oil (1.91 g, 60%).

TLC (20% EtOAc/hexanes): R_f = 0.57

^{1}H NMR (400 MHz, DMSO-d_6) δ: 7.37 – 7.26 (m, 4H), 7.25 – 7.17 (m, 3H), 6.98 – 6.89 (m, 2H), 6.52 (dd, *J* = 16.9, 10.7 Hz, 1H), 5.86 (s, 1H), 5.43 (t, *J* = 3.4 Hz, 1H), 5.24 – 5.11 (m, 2H), 3.74 (ddd, *J* = 12.0, 8.7, 3.6 Hz, 1H), 3.52 (dt, *J* = 10.8, 4.4 Hz, 1H), 1.93 – 1.66 (m, 3H), 1.65 – 1.39 (m, 3H).

^{13}C{^{1}H} NMR (101 MHz, DMSO-d_6) δ: 155.2, 147.1, 144.6, 140.1, 127.9, 127.7, 126.6, 126.4, 115.6, 112.7, 95.7, 77.6, 61.5, 29.9, 24.7, 18.7.

HRMS (ESI, *m/z*): calcd for $[C_{20}H_{22}NaO_3]^+$ $(M+Na)^+$, 333.1461; found, 333.1462.



BP-F

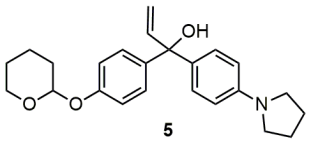
(4-fluorophenyl)(4-((tetrahydro-2H-pyran-2-yl)oxy)phenyl)methanone (BP-F). A flame-dried 100 mL round-bottom flask equipped with a stir bar was charged with 4-fluoro-4'-hydroxybenzophenone (4.08 g, 18.9 mmol) and pyridinium *p*-toluenesulfonate (PPTS, 690 mg, 2.75 mmol). The flask was evacuated and backfilled with N_2 three times. Dry CH_2Cl_2 (20 mL) was added via syringe followed by addition of 3,4-dihydro-2*H*-pyran (2.5 mL, 27 mmol). After stirring at room temperature overnight, the mixture was concentrated under reduced pressure and partitioned between water and CH_2Cl_2. The aqueous phase was discarded and the organic phase was dried over Na_2SO_4, filtered and concentrated under reduced pressure. The crude product was purified by column chromatography (0–15% EtOAc/hexanes) to afford the title product as white solid (4.74 g, 84%).

TLC (10% EtOAc/hexanes): R_f = 0.49

^{1}H NMR (400 MHz, Chloroform-*d*) δ: 7.87 – 7.74 (m, 4H), 7.20 – 7.07 (m, 4H), 5.54 (t, J_{HH} = 3.2 Hz, 1H), 3.88 (ddd, J_{HH} = 11.4, 9.8, 3.1 Hz, 1H), 3.64 (ddd, J_{HH} = 11.3, 4.0, 1.4 Hz, 1H), 2.09 – 1.95 (m, 1H), 1.93 – 1.86 (m, 2H), 1.78 – 1.65 (m, 2H), 1.65 – 1.59 (m, 1H).

^{13}C{^{1}H} NMR (101 MHz, Chloroform-*d*) δ: 194.4, 165.2 (d, J_{CF} = 253 Hz), 160.9, 134.5 (d, J_{CF} = 3.1 Hz), 132.5 (d, J_{CF} = 8.9 Hz), 132.4, 130.8, 116.0, 115.5 (d, J_{CF} = 21.8 Hz), 96.2, 62.2, 30.2, 25.2, 18.6.

HRMS (FD, *m/z*): calcd for $[C_{18}H_{17}FO_3]^{+\cdot}$ $(M)^{+\cdot}$, 300.1162; found, 300.1159.



5

1-(4-(pyrrolidin-1-yl)phenyl)-1-(4-((tetrahydro-2H-pyran-2-yl)oxy)phenyl)prop-2-en-1-ol (5). A flame-dried round-bottom flask equipped with a stir bar was charged with **BP-F** (6.50 g, 21.7 mmol) and the flask was evacuated and backfilled with N_2 three times. Pyrrolidine (5 mL) was then added via syringe. After stirring at reflux for 1 h, the flask was removed from heat and the crude mixture was diluted with CH_2Cl_2. The organic phase was washed with sat. $NaHCO_3$ (aq), dried over Na_2SO_4, filtered, and concentrated under reduced pressure. Next, the crude yellow solid was added to a flame-dried round-bottom flask equipped with a stir bar

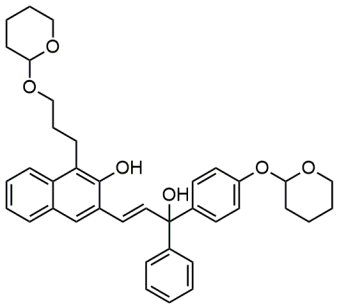
and the flask was evacuated and backfilled with N_2 three times. Dry THF (100 mL) was added via syringe and the flask was cooled in an ice bath, followed by the slow addition of vinylmagnesium bromide (1 M in THF, 24 mL, 24 mmol). After complete addition, the reaction mixture was allowed to warm to room temperature and stirred for 1 h. The flask was again cooled in an ice bath and water was added dropwise. The crude mixture was concentrated under reduced pressure and partitioned between water and ethyl acetate. The aqueous phase was discarded and the organic phase was dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude product was purified by column chromatography (0–15% EtOAc/hexanes) to afford the title product as yellow oil (4.23 g, 51%).

TLC (20% EtOAc/hexanes): R_f = 0.46

^{1}H NMR (400 MHz, CD_2Cl_2) δ: 7.31 – 7.22 (m, 2H), 7.21 – 7.12 (m, 2H), 7.01 – 6.91 (m, 2H), 6.52 – 6.42 (m, 3H), 5.38 (t, *J* = 3.4 Hz, 1H), 5.28 (dd, *J* = 17.1, 1.5 Hz, 1H), 5.23 (dd, *J* = 10.5, 1.5 Hz, 1H), 3.92 (ddd, *J* = 11.5, 9.4, 3.2 Hz, 1H), 3.59 (ddd, *J* = 11.4, 4.2, 1.5 Hz, 1H), 3.31 – 3.22 (m, 4H), 2.28 (s, 1H), 2.05 – 1.93 (m, 5H), 1.89 – 1.77 (m, 2H), 1.73 – 1.50 (m, 3H).

^{13}C{^{1}H} NMR (101 MHz, Chloroform-*d*) δ: 156.14, 156.11, 147.2, 144.4, 139.6, 132.84, 132.82, 128.18, 128.16, 128.12, 115.93, 115.91, 112.9, 111.2, 96.51, 96.47, 79.1, 62.2, 47.7, 30.5, 25.6, 25.4, 19.0.

HRMS (ESI, *m/z*): calcd for $[C_{24}H_{30}NO_3]^+$ $(M+H)^+$, 380.2220; found, 380.2231.



6

(E)-3-(3-hydroxy-3-phenyl-3-(4-((tetrahydro-2H-pyran-2-yl)oxy)phenyl)prop-1-en-1-yl)-1-(3-((tetrahydro-2H-pyran-2-yl)oxy)propyl)naphthalen-2-ol (6). A flame-dried round-bottom flask equipped with a stir bar was charged with **3** (100 mg, 0.243 mmol), **4** (83 mg, 0.27 mmol), $Pd(OAc)_2$ (16 mg, 0.071 mmol), and Cs_2CO_3 (78 mg, 0.24 mmol). The flask was evacuated and backfilled with N_2 three times followed by addition of dry CH_3CN (2 mL) via syringe. After stirring at 80 °C for 1.5 h, the flask was removed from heat and the crude mixture was diluted with ethyl acetate and washed with water. The aqueous phase was discarded and the organic phase was dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude product was purified by column chromatography (0–25% EtOAc/hexanes) to afford the title product as yellow solid (58 mg, 40%).

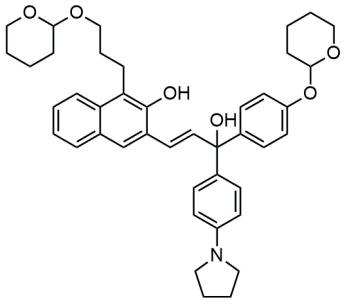
TLC (25% EtOAc/hexanes): R_f = 0.27

^{1}H NMR (400 MHz, Acetone-d_6) δ: 7.99 – 7.91 (m, 2H), 7.80 (d, *J* = 7.4 Hz, 1H), 7.56 – 7.52 (m, 2H), 7.46 – 7.38 (m, 3H), 7.36 – 7.12 (m, 6H), 7.04 – 6.94 (m, 2H), 5.43 (t, *J* = 3.4 Hz, 1H), 4.64 (dd, *J* = 4.2, 2.8 Hz, 1H), 3.89 – 3.72 (m, 3H), 3.55 (ddd, *J* = 11.4, 4.3, 1.3 Hz, 1H), 3.50 – 3.42 (m, 2H), 3.21 (td, *J* = 7.3, 2.6 Hz, 2H), 2.00 – 1.92 (m, 3H), 1.89 – 1.45 (m, 13H).

^{13}C{^{1}H} NMR (101 MHz, Acetone-d_6) δ: 157.0, 151.1, 148.5, 141.4, 139.2, 133.6, 130.2, 129.4, 129.07, 129.06, 128.6, 128.5, 127.86, 127.85, 127.4, 126.7, 125.4, 124.68, 124.67, 123.9, 123.6, 120.9, 116.6, 99.4, 97.0, 79.2,

67.1, 62.6, 62.4, 31.4, 31.1, 26.2, 26.0, 22.2, 20.2, 19.6.

HRMS (ESI, *m/z*): calcd for $[C_{38}H_{41}O_5]^+$ $(M\text{-}OH)^+$, 577.2949; found, 577.2954.



7

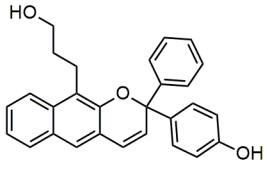
(E)-3-(3-hydroxy-3-(4-(pyrrolidin-1-yl)phenyl)-3-(4-((tetrahydro-2H-pyran-2-yl)oxy)phenyl)prop-1-en-1-yl)-1-(3-((tetrahydro-2H-pyran-2-yl)oxy)propyl)naphthalen-2-ol (7). A flame-dried round-bottom flask equipped with a stir bar was charged with **3** (200 mg, 0.485 mmol), **5** (200 mg, 0.528 mmol), $Pd(OAc)_2$ (33 mg, 0.15 mmol), and Cs_2CO_3 (160 mg, 0.492 mmol). The flask was evacuated and backfilled with N_2 three times followed by addition of dry CH_3CN (2 mL) via syringe. After stirring at 80 °C for 1.5 h, the flask was removed from heat and the crude mixture was diluted with ethyl acetate and washed with water. The aqueous phase was discarded and the organic phase was dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude product was purified by column chromatography (0–25% EtOAc/hexanes) to afford the title product as yellow solid (57 mg, 18%).

TLC (25% EtOAc/hexanes): R_f = 0.30

^{1}H NMR (400 MHz, Acetone-d_6) δ: 7.98 – 7.89 (m, 2H), 7.83 – 7.75 (m, 2H), 7.45 – 7.36 (m, 3H), 7.32 – 7.24 (m, 3H), 7.20 (d, *J* = 15.8 Hz, 1H), 7.10 (d, *J* = 15.8 Hz, 1H), 7.02 – 6.94 (m, 2H), 6.56 – 6.45 (m, 2H), 5.42 (t, *J* = 3.4 Hz, 1H), 4.63 (dd, *J* = 4.2, 2.9 Hz, 1H), 4.53 (s, 1H), 3.91 – 3.69 (m, 3H), 3.55 (dt, *J* = 11.5, 4.6 Hz, 1H), 3.49 – 3.42 (m, 2H), 3.27 – 3.12 (m, 6H), 2.01 – 1.91 (m, 6H), 1.89 – 1.47 (m, 12H).

^{13}C{^{1}H} NMR (101 MHz, Acetone-d_6) δ: 156.7, 151.2, 147.8, 142.0, 140.1, 135.0, 133.5, 130.3, 129.3, 128.98, 128.97, 128.8, 128.7, 126.6, 125.2, 123.8, 123.67, 123.66, 123.56, 120.9, 116.40, 116.38, 111.8, 99.4, 97.1, 79.2, 67.1, 62.6, 62.4, 48.2, 31.4, 31.1, 26.2, 26.02, 25.97, 22.2, 20.2, 19.6.

HRMS (ESI, *m/z*): calcd for $[C_{42}H_{48}NO_5]^+$ $(M-OH)^+$, 646.3527; found, 646.3546.



8

4-(10-(3-hydroxypropyl)-2-phenyl-2H-benzo[g]chromen-2-yl)phenol (8) A flame-dried round bottom flask equipped with a stir bar was charged with **6** (46 mg, 0.077 mmol) and silica gel (150 mg). The flask was evacuated and backfilled with N_2 three times followed by addition of dry DMF (5 mL) via syringe. The reaction mixture was stirred at 135 °C for 40 h. After cooling to room temperature, Amberlyst 15 (100 mg) and methanol (10 mL) were added and the reaction mixture was stirred at room temperature for 60 h. The crude mixture

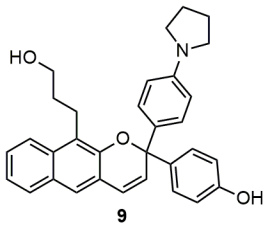
was filtered and the filtrate was diluted with DCM and washed consecutively with 10% LiCl solution and water. The organic layer was dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography (0–40% EtOAc/hexanes) to afford title compound as a pale yellow solid (30 mg, 95%).

TLC (50% EtOAc/hexanes): R_f = 0.44

^{1}H NMR (400 MHz, CD_2Cl_2) δ: 7.88 (d, *J* = 8.6 Hz, 1H), 7.72 (d, *J* = 8.1 Hz, 1H), 7.48 – 7.38 (m, 4H), 7.35 – 7.23 (m, 6H), 6.84 (d, *J* = 9.9 Hz, 1H), 6.76 – 6.70 (m, 2H), 6.38 (d, *J* = 9.8 Hz, 1H), 3.61 – 3.46 (m, 2H), 3.36 – 3.13 (m, 2H), 1.93 – 1.75 (m, 2H).

^{13}C{^{1}H} NMR (101 MHz,CD_2Cl_2) δ: 156.4, 148.1, 145.3, 136.9, 133.9, 132.1, 130.4, 129.4, 129.1, 128.8, 128.1, 127.3, 126.9, 124.8, 124.5, 124.3, 123.7, 122.3, 122.0, 115.6, 83.9, 62.1, 32.9, 21.1. A small grease peak is present at 30.2 ppm in the included spectrum.

HRMS (ESI, *m/z*): calcd for $[C_{28}H_{25}O_3]^+$ $(M+H)^+$, 409.1798; found, 409.1804.



9

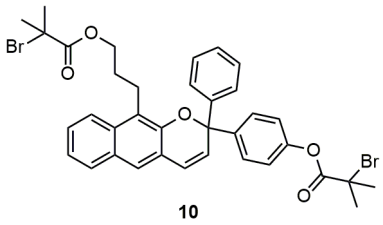
4-(10-(3-hydroxypropyl)-2-(4-(pyrrolidin-1-yl)phenyl)-2H-benzo[g]chromen-2-yl)phenol (9) A flame-dried round bottom flask equipped with a stir bar was charged with **7** (58 mg, 0.087 mmol) and silica gel (180 mg). The flask was evacuated and backfilled with N_2 three times followed by addition of dry DMF (5 mL) via syringe. The reaction mixture was stirred at 135 °C for 2 h. After cooling to room temperature, Amberlyst 15 (500 mg) and methanol (5 mL) were added and the reaction mixture was stirred at room temperature for 1 h. The crude mixture was filtered and the filtrate was diluted with DCM and washed consecutively with 10% LiCl solution and water. The organic layer was dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography (0–40% EtOAc/hexanes) to afford title compound as a yellow solid (11 mg, 26%).

TLC (50% EtOAc/hexanes): R_f = 0.50

^{1}H NMR (400 MHz, Acetone-d_6) δ: 8.32 (s, 1H), 7.94 (d, *J* = 8.6 Hz, 1H), 7.73 (d, *J* = 8.1 Hz, 1H), 7.47 (s, 1H), 7.41 – 7.36 (m, 1H), 7.35 – 7.31 (m, 2H), 7.30 – 7.24 (m, 3H), 6.85 (d, *J* = 9.8 Hz, 1H), 6.81 – 6.76 (m, 2H), 6.50 – 6.44 (m, 2H), 6.40 (d, *J* = 9.8 Hz, 1H), 3.71 – 3.62 (m, 2H), 3.57 – 3.51 (m, 1H), 3.25 – 3.12 (m, 6H), 1.99 – 1.91 (m, 4H), 1.87 – 1.75 (m, 2H).

^{13}C{^{1}H} NMR (101 MHz, Acetone-d_6) δ: 157.4, 148.8, 148.2, 137.8, 134.3, 133.9, 132.5, 130.6, 129.3, 129.1, 128.8, 126.8, 124.5, 124.2, 124.0, 123.9, 123.4, 123.1, 115.6, 111.8, 83.8, 62.6, 48.1, 34.1, 26.0, 22.1.

HRMS (ESI, *m/z*): calcd for $[C_{32}H_{32}NO_3]^+$ $(M+H)^+$, 478.2382; found, 478.2377.



10

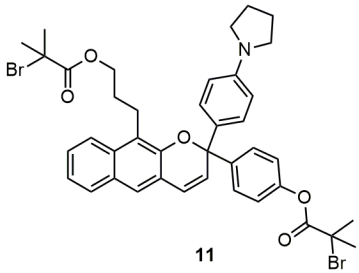
3-(2-(4-((2-bromo-2-methylpropanoyl)oxy)phenyl)-2-phenyl-2H-benzo[g]chromen-10-yl)propyl 2-bromo-2-methylpropanoate (10). An oven-dried 20 mL vial equipped with a stir bar was charged with diol **8** (25 mg, 0.061 mmol) and the vial was evacuated and backfilled with N_2 three times. Dry THF (5 mL) was added via syringe followed by addition of Et_3N (20 µL, 0.14 mmol) and then α-bromoisobutyryl bromide (20 µL, 0.162 mmol). After stirring at room temperature overnight, the solid precipitate was filtered off and discarded. The filtrate was diluted with ethyl acetate and washed with water. The organic layer was dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography (0–15% EtOAc/hexanes) to afford title compound as a pale yellow solid (7 mg, 16%).

TLC (25% EtOAc/hexanes): R_f = 0.67

^{1}H NMR (400 MHz, CD_2Cl_2) δ: 7.88 (d, *J* = 8.7 Hz, 1H), 7.73 (d, *J* = 8.0 Hz, 1H), 7.55 – 7.39 (m, 6H), 7.37 – 7.24 (m, 4H), 7.13 – 7.06 (m, 2H), 6.90 (d, *J* = 9.9 Hz, 1H), 6.35 (d, *J* = 9.8 Hz, 1H), 4.26 (t, *J* = 6.3 Hz, 2H), 3.25 – 3.14 (m, 2H), 2.03 (s, 6H), 1.95 – 1.88 (m, 8H).

^{13}C{^{1}H} NMR (101 MHz, CD_2Cl_2) δ: 172.1, 170.7, 150.7, 147.8, 145.1, 143.4, 133.8, 131.7, 130.3, 129.2, 128.9, 128.9, 128.3, 127.6, 127.0, 125.0, 124.9, 124.3, 123.5, 122.4, 122.2, 121.3, 83.3, 66.7, 56.9, 56.2, 31.2, 31.0, 30.3, 29.4, 22.0.

HRMS (ESI, *m/z*): calcd for $[C_{36}H_{35}Br_2O_5]^+$ $(M+H)^+$, 705.0851; found, 705.0848.



11

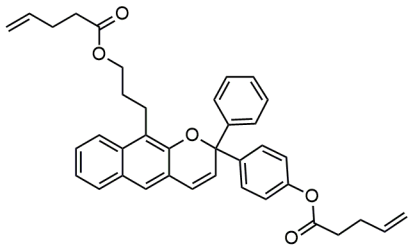
3-(2-(4-((2-bromo-2-methylpropanoyl)oxy)phenyl)-2-(4-(pyrrolidin-1-yl)phenyl)-2H-benzo[g]chromen-10-yl)propyl 2-bromo-2-methylpropanoate (11). A flame-dried round bottom flask equipped with a stir bar was charged with diol **9** (42 mg, 0.088 mmol) and the flask was evacuated and backfilled with N_2 three times. Dry THF (6 mL) was added via syringe followed by addition of Et_3N (50 µL, 0.36 mmol). The flask was cooled in an ice bath and α-bromoisobutyryl bromide (50 µL, 0.40 mmol) was added slowly. After stirring at room temperature overnight, the solid precipitate was filtered off and discarded. The filtrate was diluted with ethyl acetate and washed with water. The organic layer was dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography (0–30% EtOAc/hexanes) to afford the title compound as a pale yellow solid (10 mg, 15%).

TLC (15% EtOAc/hexanes): R_f = 0.50

^{1}H NMR (400 MHz, CD_2Cl_2) δ: 7.87 (d, *J* = 8.5 Hz, 1H), 7.72 (d, *J* = 8.0 Hz, 1H), 7.56 – 7.50 (m, 2H), 7.45 – 7.38 (m, 2H), 7.36 – 7.25 (m, 3H), 7.15 – 7.05 (m, 2H), 6.86 (d, *J* = 9.8 Hz, 1H), 6.63 (bs, 2H), 6.30 (d, *J* = 9.7 Hz, 1H), 4.26 (t, *J* = 6.3 Hz, 2H), 3.35 – 3.24 (m, 4H), 3.20 (t, *J* = 7.9 Hz, 2H), 2.04 (s, 6H), 2.02 – 1.97 (m, 4H), 1.96 – 1.92 (m, 2H), 1.91 – 1.88 (m, 6H).

^{13}C{^{1}H} NMR (101 MHz, Chloroform-*d*) δ: 171.9, 170.3, 149.9, 147.8, 143.8, 133.5, 131.9, 129.7, 128.72, 128.67, 128.5, 126.3, 124.3, 123.8, 123.6, 123.0, 122.2, 121.4, 120.7, 111.2, 83.1, 66.4, 56.2, 55.5, 47.7, 30.94, 30.92, 30.8, 28.9, 25.6, 21.6. A small grease peak is present at 29.8 ppm in the included spectrum.

HRMS (ESI, *m/z*): calcd for $[C_{40}H_{42}Br_2NO_5]^+$ $(M+H)^+$, 774.1430; found, 774.1412.



Crosslinker-LNP

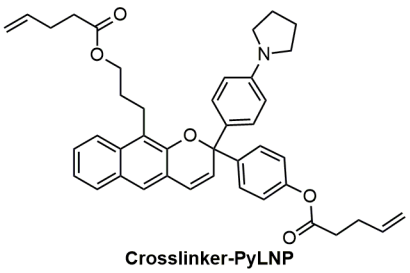
3-(2-(4-(pent-4-enoyloxy)phenyl)-2-phenyl-2H-benzo[g]chromen-10-yl)propyl pent-4-enoate (Crosslinker-LNP). An oven-dried 20 mL vial equipped with a stir bar was charged with diol **8** (30 mg, 0.074 mmol) and DMAP (2.0 mg, 0.016 mmol). The vial was evacuated and backfilled with N_2 three times. Dry THF (5 mL) was then added via syringe followed by the addition of Et_3N (50 µL, 0.36 mmol) and 4-pentenoic anhydride (40 µL, 0.22 mmol). After stirring at room temperature overnight, the filtrate was diluted with ethyl acetate and washed with water. The organic layer was dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography (0–10% EtOAc/hexanes) to afford title compound as a pale yellow solid (20 mg, 47%).

TLC (20% EtOAc/hexanes): R_f = 0.61

^{1}H NMR (400 MHz, CD_2Cl_2) δ: 7.85 (d, *J* = 8.6 Hz, 1H), 7.72 (d, *J* = 8.2 Hz, 1H), 7.52 – 7.38 (m, 6H), 7.37 – 7.25 (m, 4H), 7.06 – 7.00 (m, 2H), 6.88 (d, *J* = 9.8 Hz, 1H), 6.36 (d, *J* = 9.8 Hz, 1H), 5.94 – 5.74 (m, 2H), 5.16 – 4.93 (m, 4H), 4.16 (t, *J* = 6.3 Hz, 2H), 3.24 – 3.09 (m, 2H), 2.67 – 2.59 (m, 2H), 2.52 – 2.41 (m, 2H), 2.41 – 2.27 (m, 4H), 1.92 – 1.82 (m, 2H).

^{13}C{^{1}H} NMR (101 MHz, CD_2Cl_2) δ: 173.4, 171.9, 150.7, 147.8, 145.2, 143.0, 137.6, 137.1, 133.8, 131.8, 130.2, 129.2, 128.8, 128.7, 128.2, 127.5, 126.9, 125.0, 124.8, 124.3, 123.5, 122.5, 122.3, 121.9, 116.1, 115.6, 83.2, 64.9, 34.1, 30.3, 29.5, 29.42, 29.35, 22.0.

HRMS (ESI, *m/z*): calcd for $[C_{38}H_{37}O_5]^+$ $(M+H)^+$, 573.2641; found, 573.2631.



Crosslinker-PyLNP

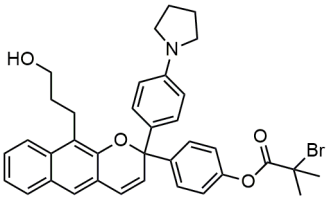
3-(2-(4-(pent-4-enoyloxy)phenyl)-2-(4-(pyrrolidin-1-yl)phenyl)-2H-benzo[g]chromen-10-yl)propyl pent-4-enoate (Crosslinker-PyLNP). A flame-dried 25 mL round bottom flask equipped with a stir bar was charged with diol **9** (60 mg, 0.13 mmol) and DMAP (2.0 mg, 0.016 mmol). The flask was evacuated and backfilled with N_2 three times. Dry THF (10 mL) was added via syringe followed by the addition of Et_3N (50 µL, 0.36 mmol) and 4-pentenoic anhydride (60 µL, 0.33 mmol). After stirring at room temperature overnight, the filtrate was diluted with ethyl acetate and washed with water. The organic layer was dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography (0–15% EtOAc/hexanes) to afford title compound as a pale yellow solid (55 mg, 66%).

TLC (15% EtOAc/hexanes): R_f = 0.50

^{1}H NMR (400 MHz, CD_2Cl_2) δ: 7.84 (d, *J* = 8.5 Hz, 1H), 7.71 (d, *J* = 8.2 Hz, 1H), 7.52 – 7.47 (m, 2H), 7.43 – 7.37 (m, 2H), 7.33 – 7.23 (m, 3H), 7.08 – 6.99 (m, 2H), 6.84 (d, *J* = 9.8 Hz, 1H), 6.56 – 6.43 (m, 2H), 6.32 (d, *J* = 9.8 Hz, 1H), 5.98 – 5.55 (m, 2H), 5.18 – 4.94 (m, 4H), 4.16 (t, *J* = 6.4 Hz, 2H), 3.30 – 3.19 (m, 4H), 3.16 (t, *J* = 7.9 Hz, 2H), 2.70 – 2.60 (m, 2H), 2.51 – 2.42 (m, 2H), 2.41 – 2.28 (m, 4H), 1.99 – 1.91 (m, 4H), 1.91 – 1.80 (m, 2H).

^{13}C{^{1}H} NMR (101 MHz, Chloroform-*d*) δ: 173.3, 171.6, 149.8, 147.9, 147.3, 143.4, 137.0, 136.4, 133.5, 132.0, 130.9, 129.7, 128.7, 128.6, 128.3, 126.2, 124.2, 123.7, 123.6, 123.0, 122.2, 121.6, 121.2, 116.1, 115.5, 111.1, 83.1, 64.7, 47.6, 33.8, 33.7, 29.1, 29.03, 29.01, 25.6, 21.6. A small grease peak is present at 29.8 ppm in the included spectrum.

HRMS (ESI, *m/z*): calcd for $[C_{42}H_{44}NO_5]^+$ $(M+H)^+$, 642.3219; found, 642.3221.



PyLNP-Mono

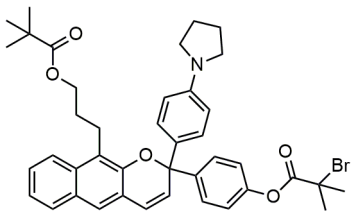
4-(10-(3-hydroxypropyl)-2-(4-(pyrrolidin-1-yl)phenyl)-2H-benzo[g]chromen-2-yl)phenyl 2-bromo-2-methylpropanoate (PyLNP-Mono). An oven-dried 20 mL vial equipped with a stir bar was charged with diol **9** (30 mg, 0.063 mmol), DMAP (2.0 mg, 0.016 mmol), and dicyclohexylcarbodiimide (DCC, 15 mg, 0.073 mmol). The vial was evacuated and backfilled with N_2 three times and dry DCM (3 mL) was added via syringe. The vial was opened briefly and α-Bromoisobutyric acid (12 mg, 0.072 mmol) was added under a flow of nitrogen. After stirring at room temperature for 2 h, the solid precipitate was filtered off and discarded. The filtrate was diluted with DCM (20 mL) and washed with water. The organic layer was dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography (0–20% EtOAc/hexanes) to afford the title compound as a pale purple solid (20 mg, 51%).

TLC (25% EtOAc/hexanes): R_f = 0.40

^{1}H NMR (400 MHz, CD_2Cl_2) δ: 7.88 (d, *J* = 8.6 Hz, 1H), 7.72 (d, *J* = 8.2 Hz, 1H), 7.57 – 7.49 (m, 2H), 7.45 – 7.37 (m, 2H), 7.33 – 7.25 (m, 3H), 7.14 – 7.03 (m, 2H), 6.85 (d, *J* = 9.8 Hz, 1H), 6.61 (bs, 2H), 6.34 (d, *J* = 9.8 Hz, 1H), 3.55 (td, *J* = 6.2, 1.9 Hz, 2H), 3.31 – 3.24 (m, 4H), 3.19 (t, *J* = 7.4 Hz, 2H), 2.04 (s, 6H), 2.01 – 1.95 (m, 4H), 1.85 – 1.76 (m, 2H).

^{13}C{^{1}H} NMR (101 MHz, Chloroform-*d*) δ: 170.4, 150.0, 147.9, 147.5, 143.3, 133.5, 131.7, 130.5, 129.9, 128.7, 128.6, 128.5, 126.3, 124.3, 123.9, 123.8, 123.3, 121.9, 121.5, 120.7, 111.2, 83.6, 61.9, 55.5, 47.7, 32.5, 30.7, 25.6, 20.7. A small grease peak is present at 29.9 ppm in the included spectrum.

HRMS (ESI, *m/z*): calcd for $[C_{36}H_{37}BrNO_4]^+$ $(M+H)^+$, 626.1900; found, 626.1885.



PyLNP-Control

3-(2-(4-((2-bromo-2-methylpropanoyl)oxy)phenyl)-2-(4-(pyrrolidin-1-yl)phenyl)-2H-benzo[g]chromen-10-yl)propyl pivalate (PyLNP-Control). An oven-dried 20 mL vial equipped with a stir bar was charged with **PyLNP-Mono** (25 mg, 0.040 mmol) and DMAP (3.0 mg, 0.025 mmol). The vial was evacuated and backfilled with N_2 three times. Pivalic anhydride (1.0 mL, 4.9 mmol) was added via syringe followed by the addition of Et_3N (10 µL, 0.072 mmol). After stirring at room temperature for 4 h, the solution was diluted with ethyl acetate (20 mL) and washed with water. The organic layer was dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography (0–10% EtOAc/hexanes) to afford title compound as a pale yellow solid (10 mg, 35% yield).

TLC (10% EtOAc/hexanes): R_f = 0.44

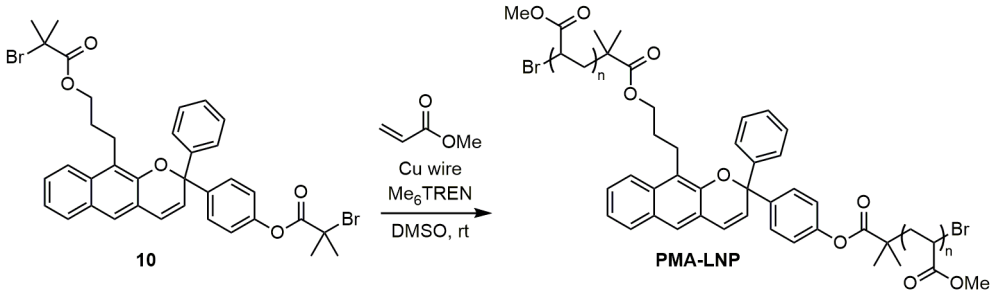
^{1}H NMR (400 MHz, CD_2Cl_2) δ: 7.85 (d, *J* = 8.6 Hz, 1H), 7.72 (d, *J* = 8.1 Hz, 1H), 7.56 – 7.49 (m, 2H), 7.44 – 7.36 (m, 2H), 7.35 – 7.25 (m, 3H), 7.14 – 7.05 (m, 2H), 6.85 (d, *J* = 9.8 Hz, 1H), 6.55 (bs, 2H), 6.31 (d, *J* = 9.7 Hz, 1H), 4.15 (t, *J* = 6.3 Hz, 2H), 3.32 – 3.21 (m, 4H), 3.16 (t, *J* = 8.0 Hz, 2H), 2.05 (s, 6H), 2.01 – 1.94 (m, 4H), 1.93 – 1.82 (m, 2H), 1.20 (s, 9H).

^{13}C{^{1}H} NMR (101 MHz, CD_2Cl_2) δ: 178.9, 170.8, 150.4, 148.1, 144.4, 133.8, 132.5, 130.2, 129.1, 128.9, 128.6, 126.7, 124.6, 124.5, 124.1, 123.5, 122.8, 122.3, 121.2, 112.0, 83.4, 65.0, 56.3, 48.7, 39.2, 31.0, 29.6, 27.6, 25.9, 22.1. A small grease peak is present at 30.2 ppm in the included spectrum.

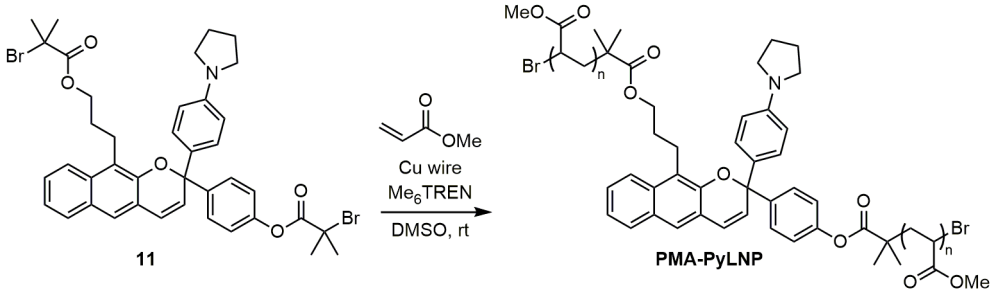
HRMS (ESI, *m/z*): calcd for $[C_{41}H_{45}BrNO_5]^+$ $(M+H)^+$, 710.2476; found, 710.2466.

General Procedure for the Synthesis of Poly(Methyl Acrylate) (PMA) Polymers Incorporating a Linear Naphthopyran Unit. Polymers were synthesized by controlled radical polymerization following the procedure by Nguyen *et al*.[1] A flame-dried Schlenk flask equipped with a stir bar was charged with freshly cut 20 G copper wire (2 cm), initiator, DMSO, and methyl acrylate. The flask was sealed and the solution was degassed via three freeze-pump-thaw cycles, then backfilled with nitrogen and warmed to room temperature. Me_6TREN was

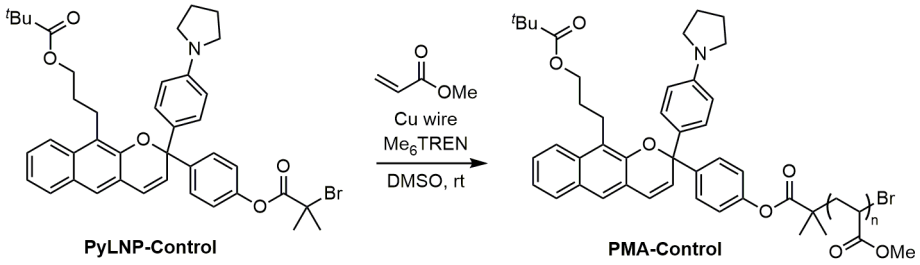
added via microsyringe and the reaction was stirred at room temperature for the indicated amount of time. Upon completion of the polymerization, the flask was opened to atmosphere and diluted with a minimal amount of DCM. The polymer was precipitated 3x into methanol cooled with dry ice and then dried under vacuum. The GPC traces for each polymer are shown below in Figure S7.



PMA-LNP. Synthesized according to the general procedure using bis-initiator **10** (3.0 mg, 0.0042 mmol), Me_6TREN (4.5 µL, 0.017 mmol), DMSO (1.20 mL), and methyl acrylate (1.20 mL, 13.3 mmol). Polymerization for 70 min afforded the title polymer as a tacky pale yellow solid (300 mg, 27%). M_n = 132 kg/mol, $Đ$ = 1.12.



PMA-PyLNP. Synthesized according to the general procedure using bis-initiator **11** (4.3 mg, 0.0056 mmol), Me_6TREN (6.0 µL, 0.022 mmol), DMSO (1.50 mL), and methyl acrylate (1.50 mL, 16.7 mmol). Polymerization for 60 min afforded the title polymer as a tacky pale yellow solid (570 mg, 40%). M_n = 262 kg/mol, $Đ$ = 1.15.



PMA-Control. Synthesized according to the general procedure using mono-functional initiator **PyLNP-Control** (2.0 mg, 0.0028 mmol), Me_6TREN (3.0 µL, 0.011 mmol), DMSO (0.75 mL), and methyl acrylate (0.75 mL, 8.5 mmol). Polymerization for 60 min afforded the title polymer as a tacky pale yellow solid (160 mg, 22%). M_n = 238 kg/mol, $Đ$ = 1.09.

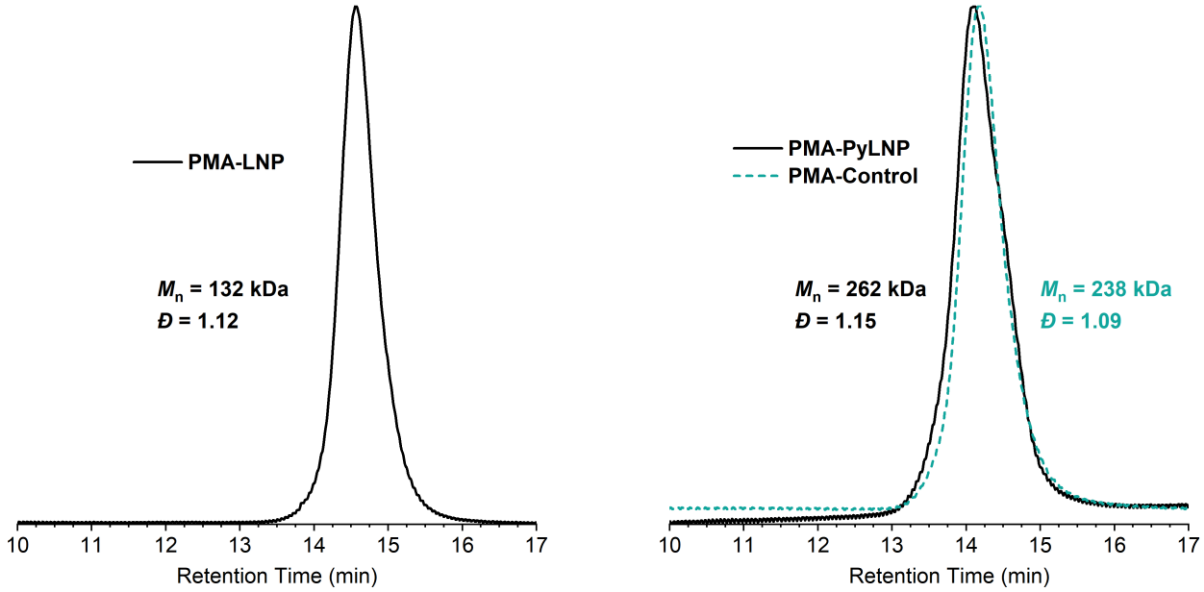


Figure S7. GPC traces (RI response) normalized to peak height for **PMA-LNP**, **PMA-PyLNP**, and **PMA-Control**.

IV. PDMS Materials

PDMS materials incorporating linear naphthopyrans (1.0–1.5 wt%) were prepared following previously reported procedures using the two-part Sylgard® 184 elastomer kit (Dow Corning).[2,3] PDMS sheets approximately 0.5 mm thick were cut into 2 cm x 2 cm samples for testing.

General Procedure for Preparation of PDMS Materials. A representative procedure is provided for the preparation of PDMS materials incorporating linear naphthopyran crosslinker **Crosslinker-PyLNP**. Naphthopyran crosslinker **Crosslinker-PyLNP** (26 mg) was dissolved in xylenes (1.5 mL) in a 20 mL scintillation vial. Sylgard® 184 prepolymer base (1.704 g) was added and the mixture was thoroughly mixed in a vortex mixer to form a homogenous, pale yellow opaque dispersion. Sylgard® 184 curing agent (169.0 mg) was added and the contents were mixed using a vortex mixer. The mixture was pipetted onto a 5 cm x 5 cm Delrin plate which was placed inside a vacuum chamber and evacuated under high vacuum (< 50 mTorr) for 2 h. The Delrin plate was then transferred to an oven and cured at 80 °C overnight. After curing, the plate was removed from the oven and the PDMS film was peeled off and cut into 2 cm x 2 cm samples with a razor blade. For the preparation of PDMS materials incorporating the crosslinker without a *para*-pyrrolidine substituent, a similar procedure was followed using linear naphthopyran crosslinker **Crosslinker-LNP** (10 mg), Sylgard® 184 prepolymer base (0.995 g), and Sylgard® 184 curing agent (101.5 mg) with a 2.5 cm x 2.5 cm Delrin plate.

Details of the Patterning Procedure Applied to PDMS Films. The stamp used in the patterning experiments to apply localized compression was 3D printed from poly(lactic acid) with embossed features in the shape of a wavy pattern,[4] as illustrated in Figure 3 in the main text. The stamp was manually compressed into a 4 cm^2 film under a weight of ~72 kg to achieve mechanochemical activation without causing irreversible deformation or tearing of the PDMS. For the photopatterning experiment, a 4 cm^2 film was irradiated with 365 nm UV light for 120 s through a cardboard photomask containing a small central hole.

V. DFT Calculations (CoGEF)

CoGEF calculations were performed using Spartan '20 Parallel Suite according to previously reported methods.[5,6] Ground state energies were calculated using DFT at the B3LYP/6-31G* level of theory. Truncated models of each mechanophore with terminal acetoxy groups were used in the calculations. The equilibrium conformations of the unconstrained molecule were initially calculated using molecular mechanics (MMFF) followed by optimization of the equilibrium geometries using DFT (B3LYP/6-31G*). Starting from the equilibrium geometry of the unconstrained molecules (energy = 0 kJ/mol), the distance between the carbon atoms in the terminal methyl groups of the truncated structures was increased in increments of 0.05 Å and the energy was minimized at each step. The maximum force associated with the mechanochemical reaction was calculated from the slope of the curve immediately prior to bond cleavage.

VI. Details for Photoirradiation and Sonication Experiments

To continuously monitor reaction progress by UV–vis absorption spectroscopy, a previously described experimental setup[7,8] was assembled using a peristaltic pump to transport the solution from the reaction vessel through a quartz flow cell in a UV-vis spectrometer and return the solution to the reaction vessel. The flow rate through the system was maintained at 8 mL/min, corresponding to a setting of 50 RPM on the peristaltic pump at the selected occlusion. The UV-vis spectrometer was programmed to acquire full spectra at regular time intervals. Absorbance values were measured at 790 nm and subtracted from the absorbance values across the rest of the spectrum at each time point to account for drift during the experiments.

General Procedure for Sonication Experiments. A sonication vessel was placed onto the sonication probe and charged with a 2 mg/mL solution of polymer in CH_3CN containing 30 mM BHT (20.0 mL), which was added to minimize decomposition side reactions resulting from free radicals generated during sonication.[9,10] An additional 6.2 mL of solution was pumped into the dead space of the circulatory setup. If applicable, $BF_3{\cdot}Et_2O$ was added to the sonication vessel via microsyringe to provide a final concentration of 0.5 mM $BF_3{\cdot}Et_2O$. Teflon inlet and outlet tubes were inserted into the solution in the sonication vessel through punctured septa, and the pump was engaged to start the flow of solution through the system. The sonication vessel was submerged in a −45 °C bath and degassed by sparging with N_2 for 30 min. The inert gas line was then removed into the headspace of the reaction vessel and the system was maintained under an inert atmosphere throughout the sonication experiment. Continuous sonication was then initiated (20 kHz, 20% amplitude, 6.8 ± 0.5 W/cm^2 unless indicated otherwise). The temperature inside the reaction vessel equilibrated to −15 °C, as measured by a thermocouple inserted into the solution (Digi-Sense EW-91428-02 thermometer with Digi-Sense probe EW-08466-83). Reaction progress was monitored by UV–vis absorption spectroscopy. The entire system was kept in the dark for the duration of the experiment. After completion of each experiment involving $BF_3{\cdot}Et_2O$, the flow cell was purged sequentially with CH_3CN, deionized water, a saturated aqueous solution of $Ca(OH)_2$, deionized water, and finally CH_3CN to remove residual $BF_3{\cdot}Et_2O$ and any potentially hazardous byproducts of sonication.[11] Sonication experiments on **PMA-LNP** were performed using a different sonication probe with an acoustic intensity of 10.5 ± 0.2 W/cm^2. Sonication intensity was calibrated via the literature method.[12]

General Procedure for Photoirradiation Experiments. Photoirradiation experiments were performed under conditions that closely mimic those of the ultrasonication experiments. A sonication vessel was placed onto the sonication probe and charged with a 2 mg/mL solution of polymer in CH_3CN containing 30 mM BHT (20.0 mL) for consistency with ultrasonication experiments. An additional 6.2 mL of solution was pumped into the dead space of the circulatory setup. If applicable, $BF_3{\cdot}Et_2O$ was added to the sonication vessel via microsyringe

to give a final concentration of 0.5 mM $BF_3{\cdot}Et_2O$. Teflon inlet and outlet tubes were inserted into the solution in the sonication vessel through punctured septa, and the pump was engaged to start the flow of solution through the system. The sonication vessel was submerged in a −45 °C bath and degassed by sparging with N_2 for 30 min. The system was then maintained under an inert atmosphere throughout the photoirradiation experiment. Without sonication, the temperature inside the reaction vessel equilibrated to −30 °C. The vessel was then exposed to a UV light source (λ = 311 nm) positioned ~2 in away, which was also submerged in the cooling bath and encased within a quartz tube. Reaction progress was monitored by UV-vis absorption spectroscopy. The entire system was protected from external light for the duration of the experiment.

VII. References

(1) Nguyen, N. H.; Rosen, B. M.; Lligadas, G.; Percec, V. Surface-Dependent Kinetics of Cu(0)-Wire-Catalyzed Single-Electron Transfer Living Radical Polymerization of Methyl Acrylate in DMSO at 25 °C. *Macromolecules* **2009**, *42*, 2379–2386.

(2) Gossweiler, G. R.; Hewage, G. B.; Soriano, G.; Wang, Q.; Welshofer, G. W.; Zhao, X.; Craig, S. L. Mechanochemical Activation of Covalent Bonds in Polymers with Full and Repeatable Macroscopic Shape Recovery. *ACS Macro Lett.* **2014**, *3*, 216–219.

(3) Robb, M. J.; Kim, T. A.; Halmes, A. J.; White, S. R.; Sottos, N. R.; Moore, J. S. Regioisomer-Specific Mechanochromism of Naphthopyran in Polymeric Materials. *J. Am. Chem. Soc.* **2016**, *138*, 12328–12331.

(4) Overholts, A. C.; Granados Razo, W.; Robb, M. J. Mechanically gated formation of donor–acceptor Stenhouse adducts enabling mechanochemical multicolour soft lithography. *Nat. Chem.* **2023**, *15*, 332–338.

(5) Beyer, M. K. The mechanical strength of a covalent bond calculated by density functional theory. *J. Chem. Phys.* **2000**, *112*, 7307–7312.

(6) Klein, I. M.; Husic, C. C.; Kovács, D. P.; Choquette, N. J.; Robb, M. J. Validation of the CoGEF Method as a Predictive Tool for Polymer Mechanochemistry. *J. Am. Chem. Soc.* **2020**, *142*, 16364–16381.

(7) McFadden, M. E.; Robb, M. J. Force-Dependent Multicolor Mechanochromism from a Single Mechanophore. *J. Am. Chem. Soc.* **2019**, *141*, 11388–11392.

(8) May, P. A.; Munaretto, N. F.; Hamoy, M. B.; Robb, M. J.; Moore, J. S. Is Molecular Weight or Degree of Polymerization a Better Descriptor of Ultrasound-Induced Mechanochemical Transduction? *ACS Macro Lett.* **2016**, *5*, 177–180.

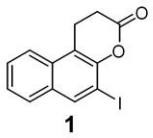
(9) Yang, J.; Horst, M.; Werby, S. H.; Cegelski, L.; Burns, N. Z.; Xia, Y. Bicyclohexene-*peri*-naphthalenes: Scalable Synthesis, Diverse Functionalization, Efficient Polymerization, and Facile Mechanoactivation of Their Polymers. *J. Am. Chem. Soc.* **2020**, *142*, 14619–14626.

(10) Overholts, A. C.; McFadden, M. E.; Robb, M. J. Quantifying Activation Rates of Scissile Mechanophores and the Influence of Dispersity. *Macromolecules* **2022**, *55*, 276–283.

(11) McFadden, M. E.; Osler, S. K.; Sun, Y.; Robb, M. J. Mechanical Force Enables an Anomalous Dual Ring-Opening Reaction of Naphthodipyran. *J. Am. Chem. Soc.* **2022**, *144*, 22391–22396.

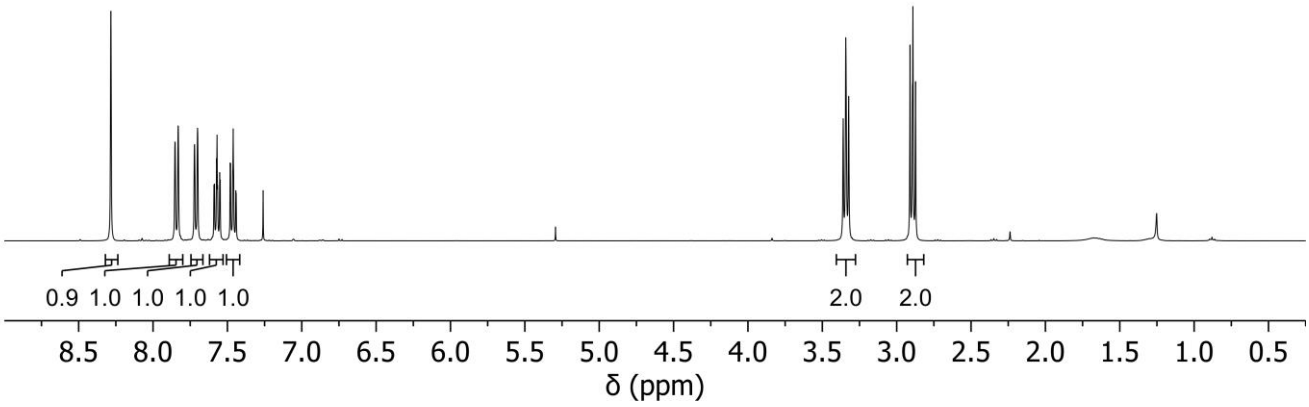
(12) Berkowski, K. L.; Potisek, S. L.; Hickenboth, C. R.; Moore, J. S. Ultrasound-Induced Site-Specific Cleavage of Azo-Functionalized Poly(ethylene glycol). *Macromolecules* **2005**, *38*, 8975–8978.

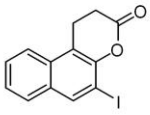
VIII. ^{1}H and ^{13}C NMR Spectra



1

^{1}H (400 MHz, $CDCl_3$)





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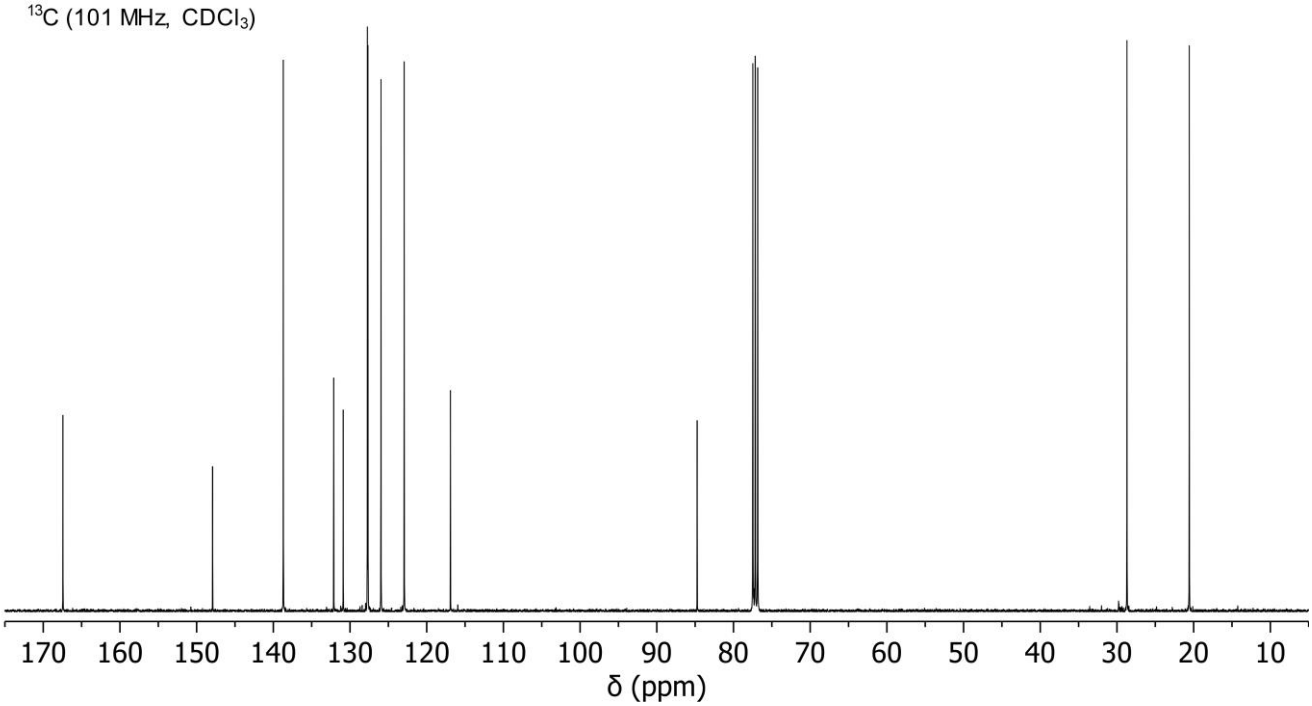

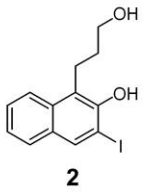

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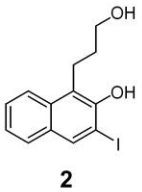

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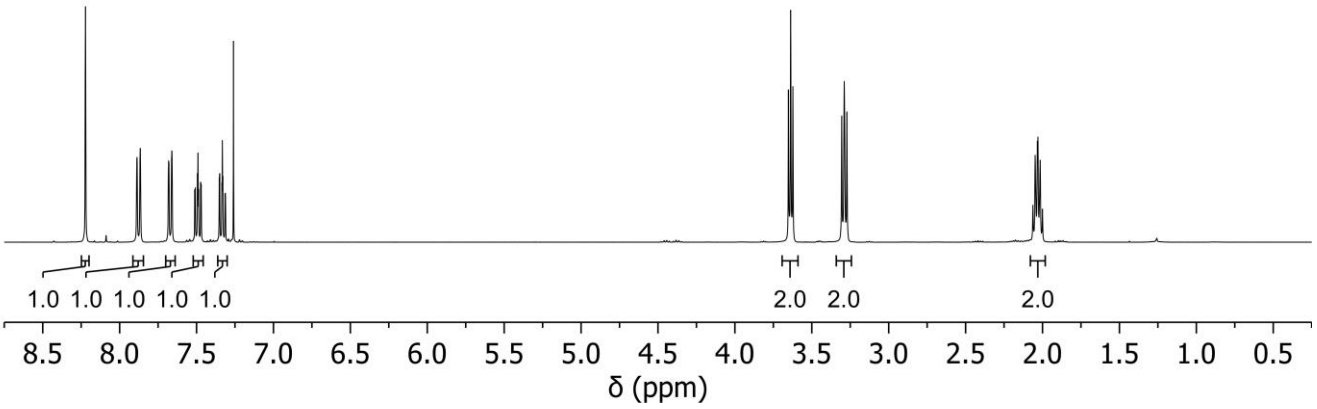

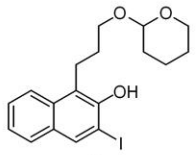

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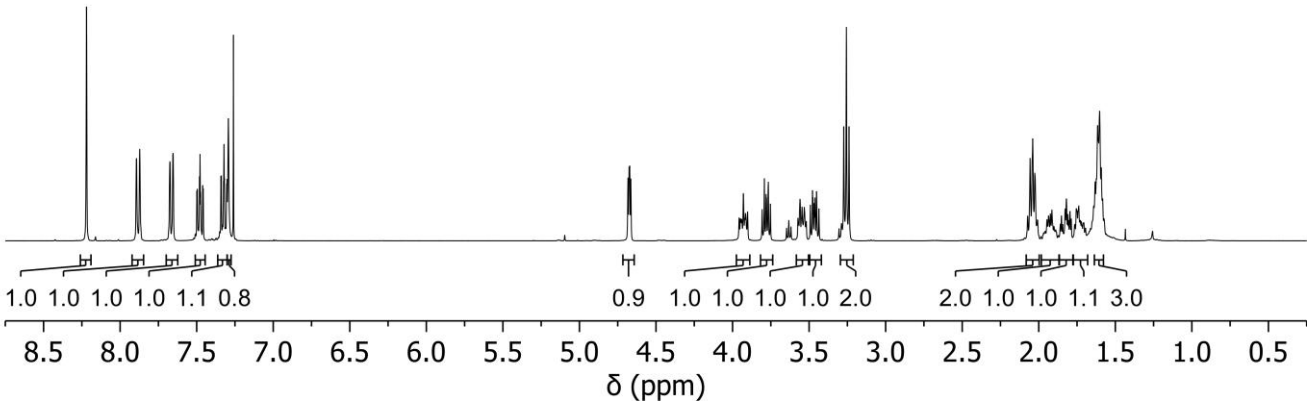

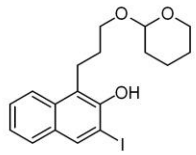

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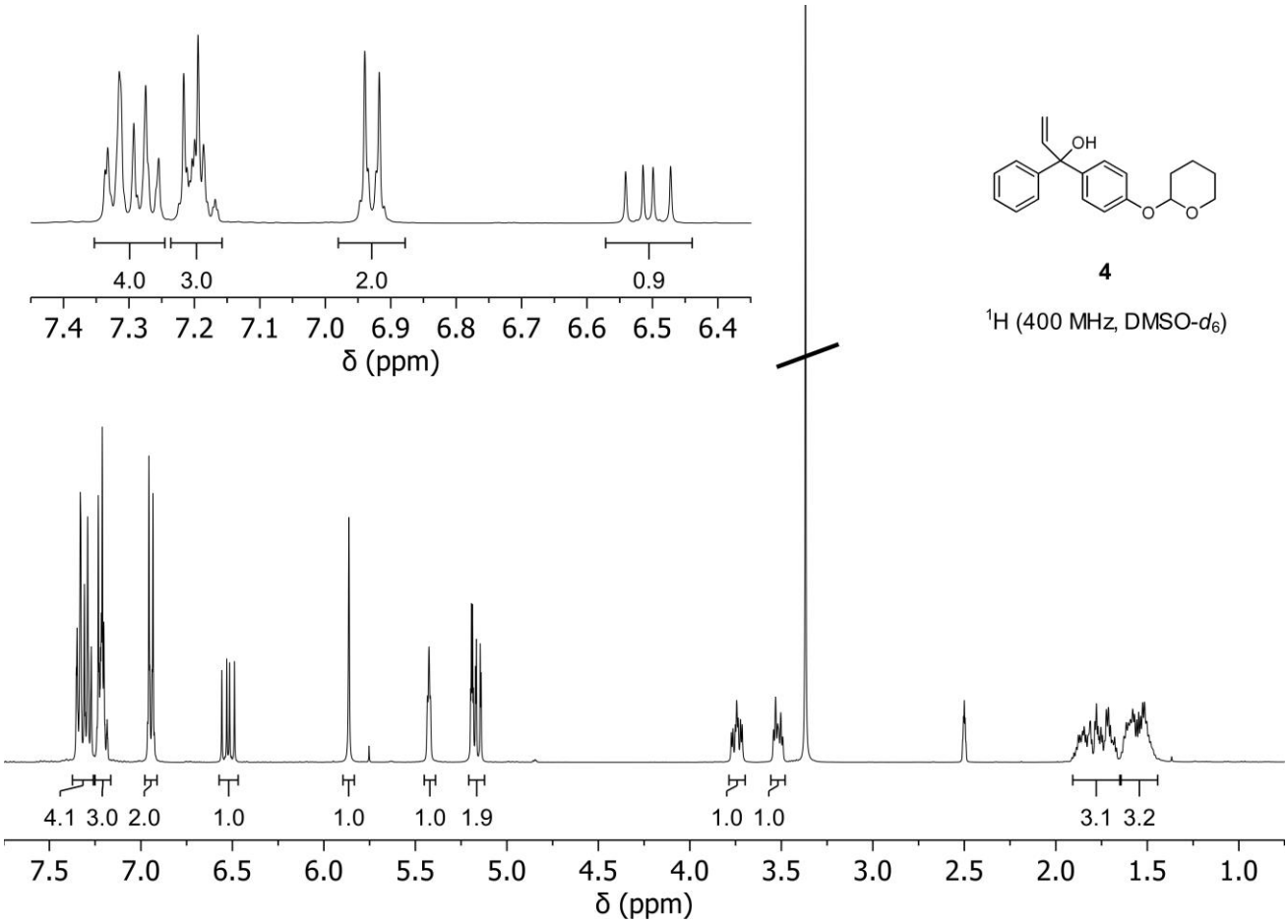

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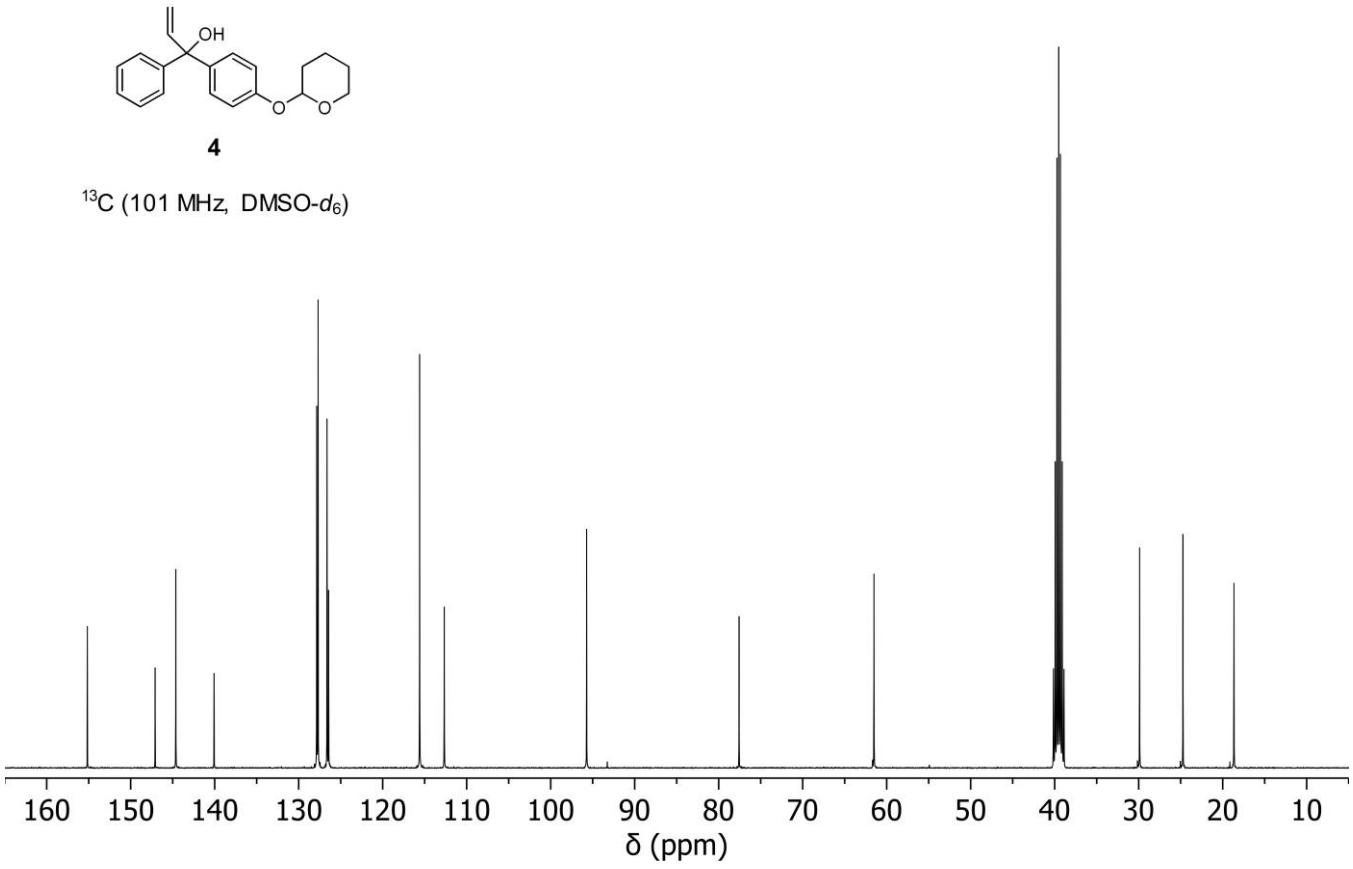

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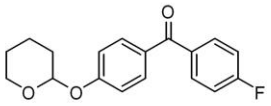

BP-F

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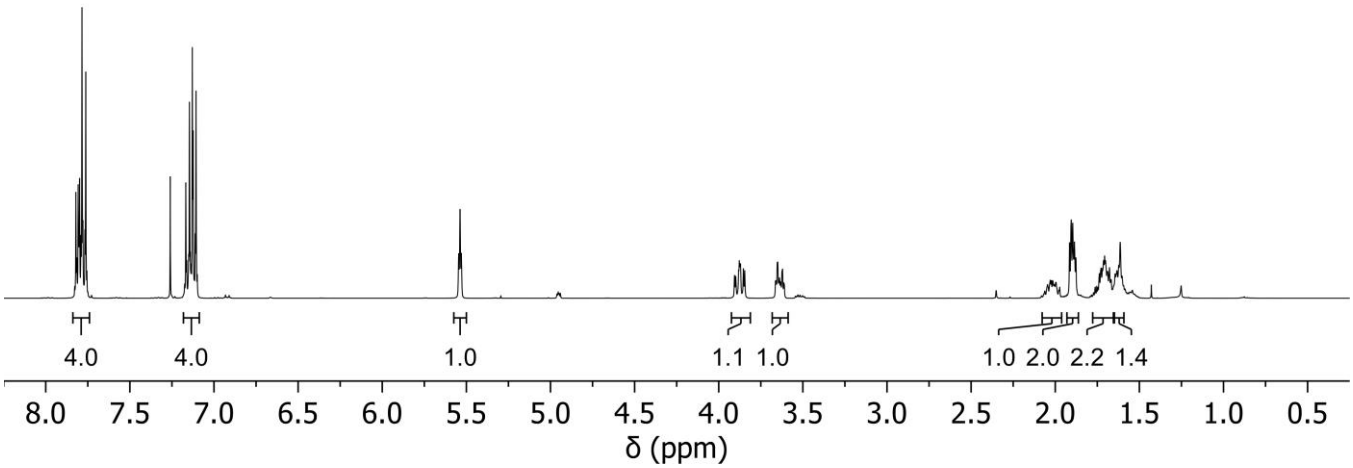

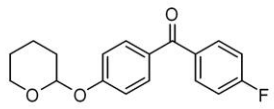

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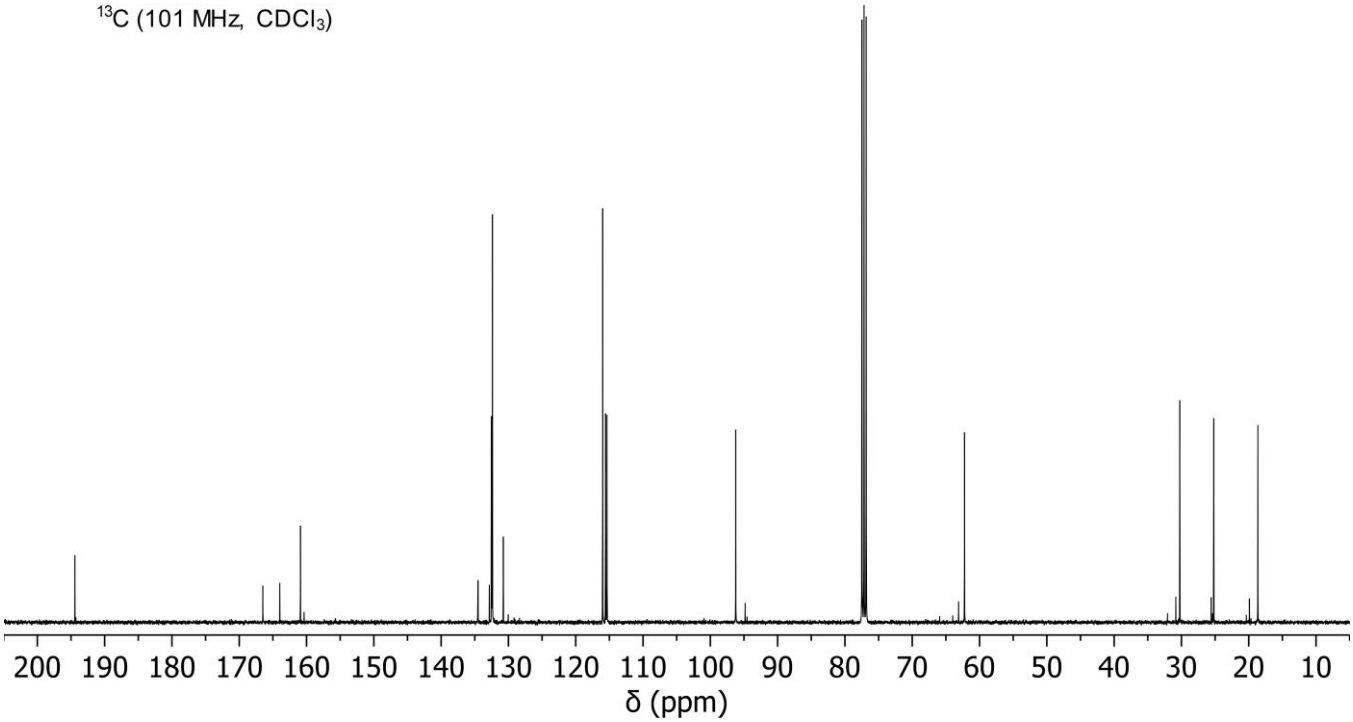

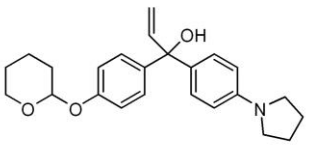

5

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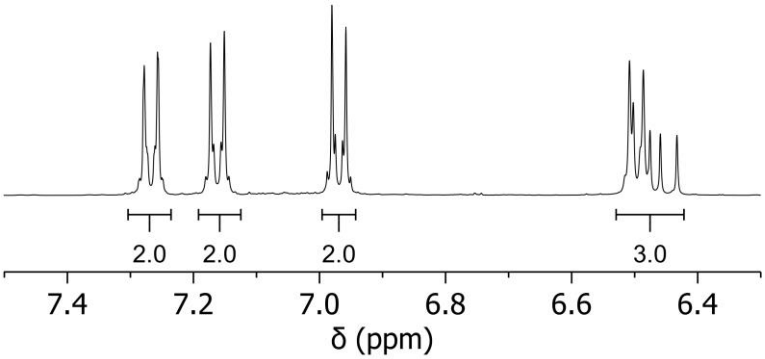

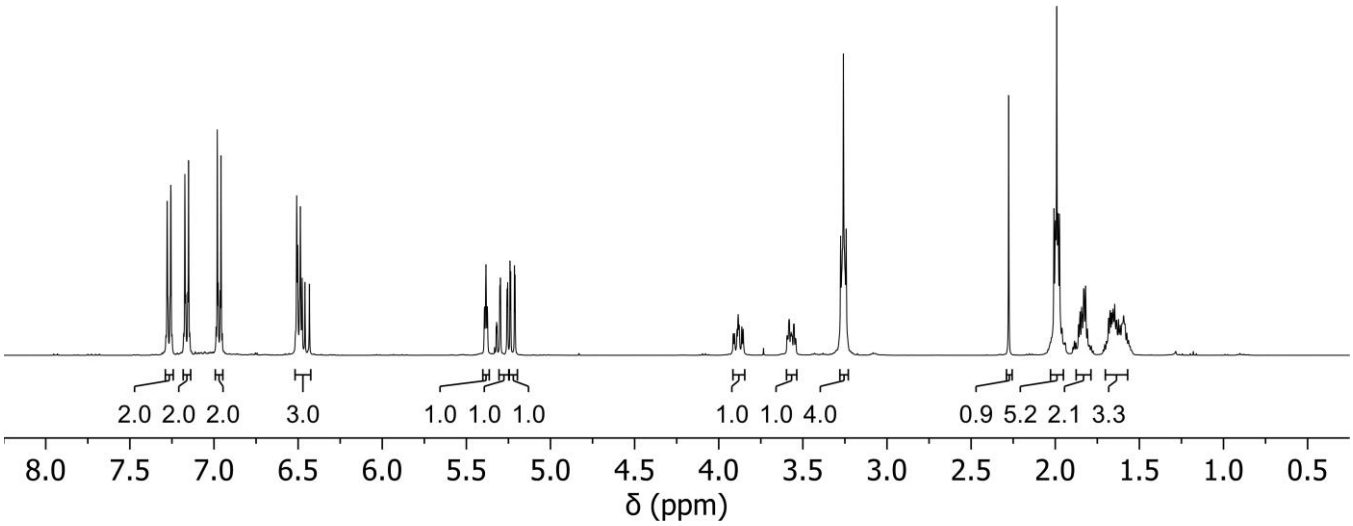

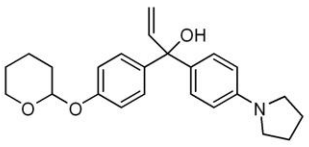

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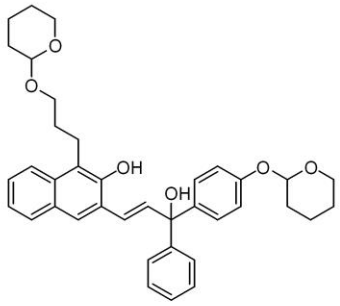

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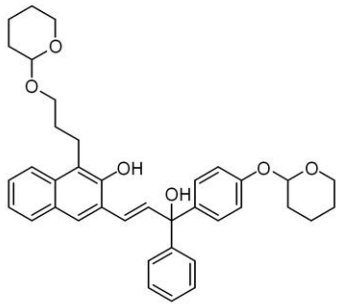
^{1}H (400 MHz, acetone-d_6)



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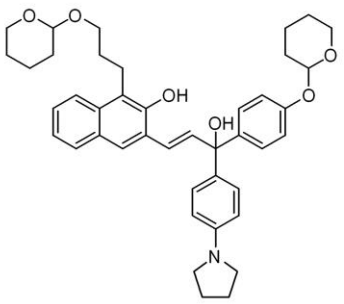
^{13}C (101 MHz, acetone-d_6)



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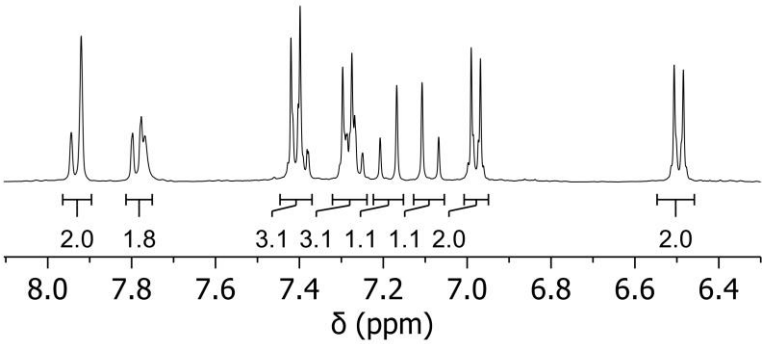
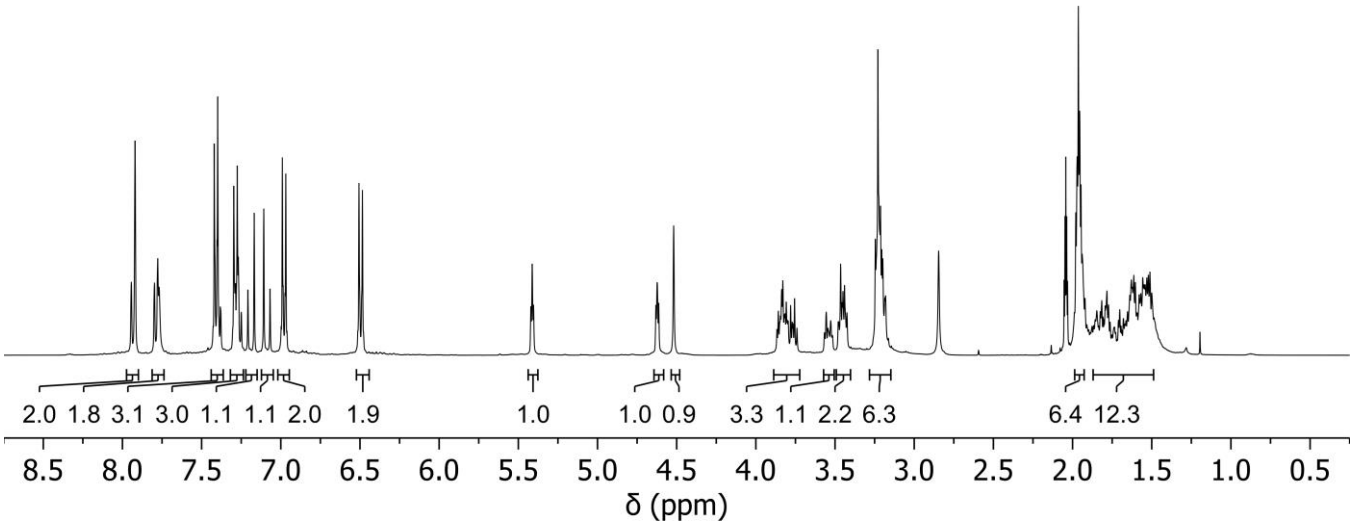
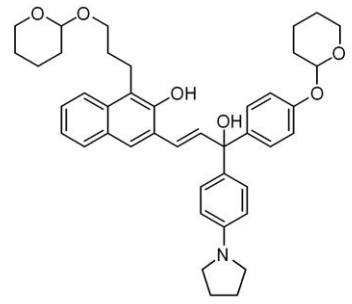
^{1}H (400 MHz, acetone-d_6)

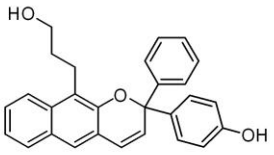






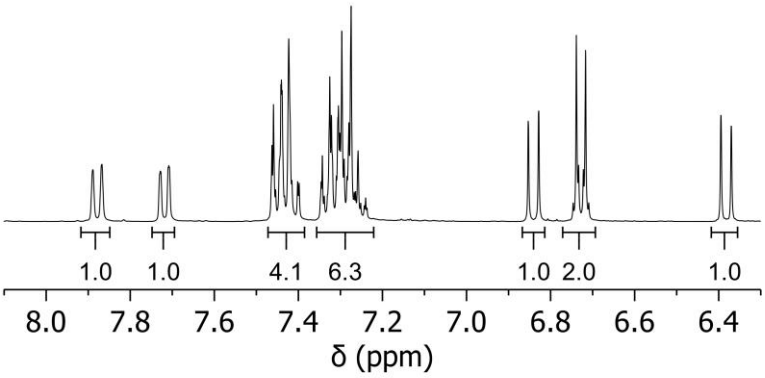
7

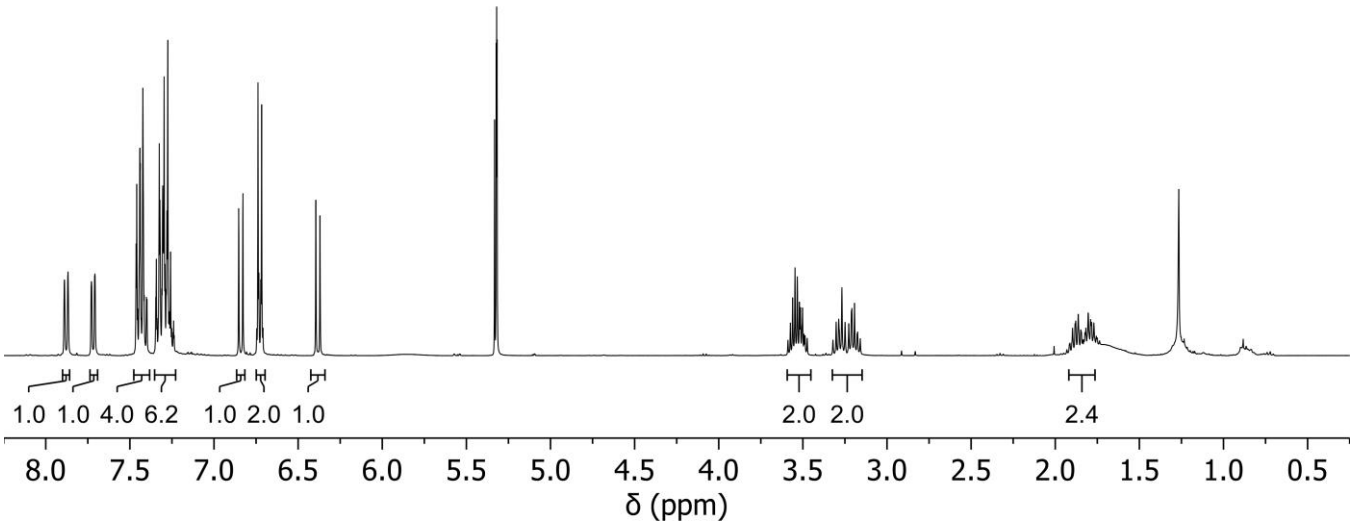
^{13}C (101 MHz, acetone-d_6)

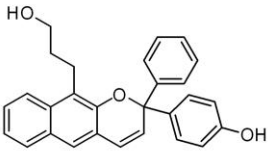


8

^{1}H (400 MHz, CD_2Cl_2)

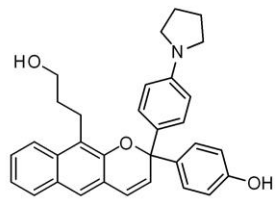






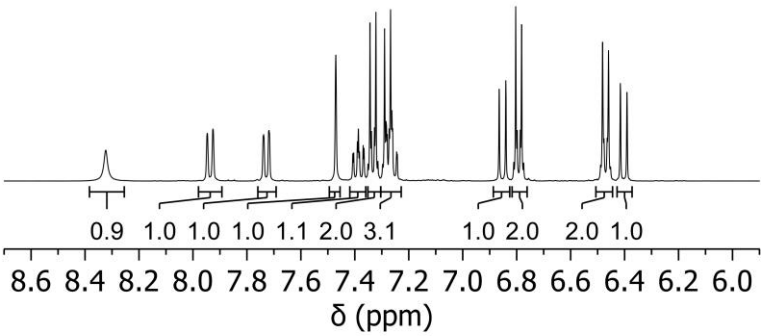
8

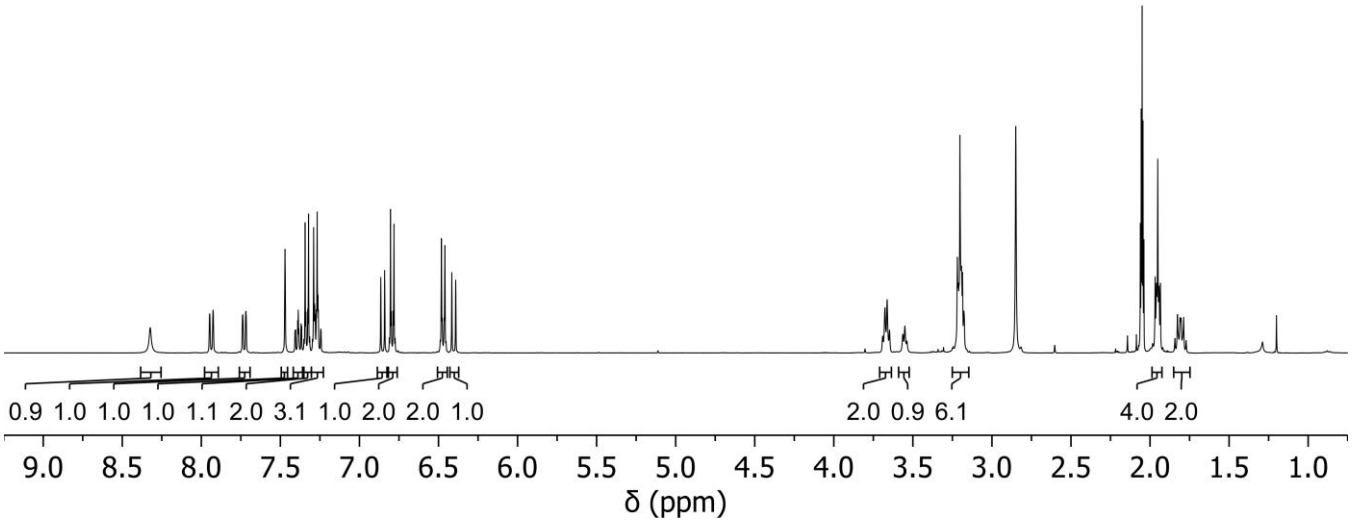
^{13}C (101 MHz, CD_2Cl_2)

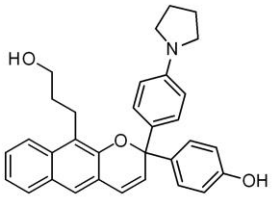


9

^{1}H (400 MHz, acetone-d_6)

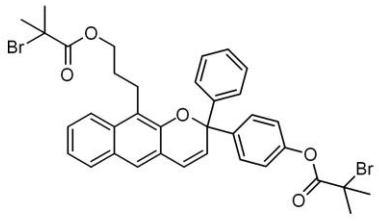






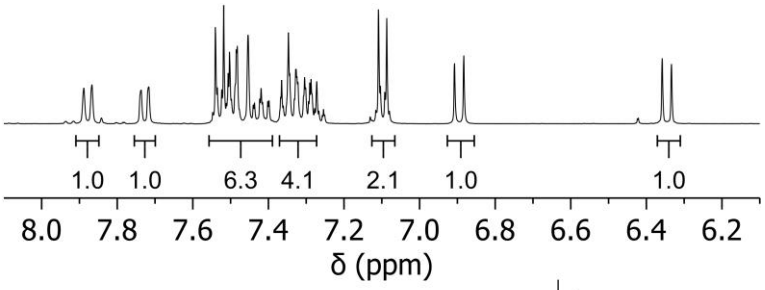
9

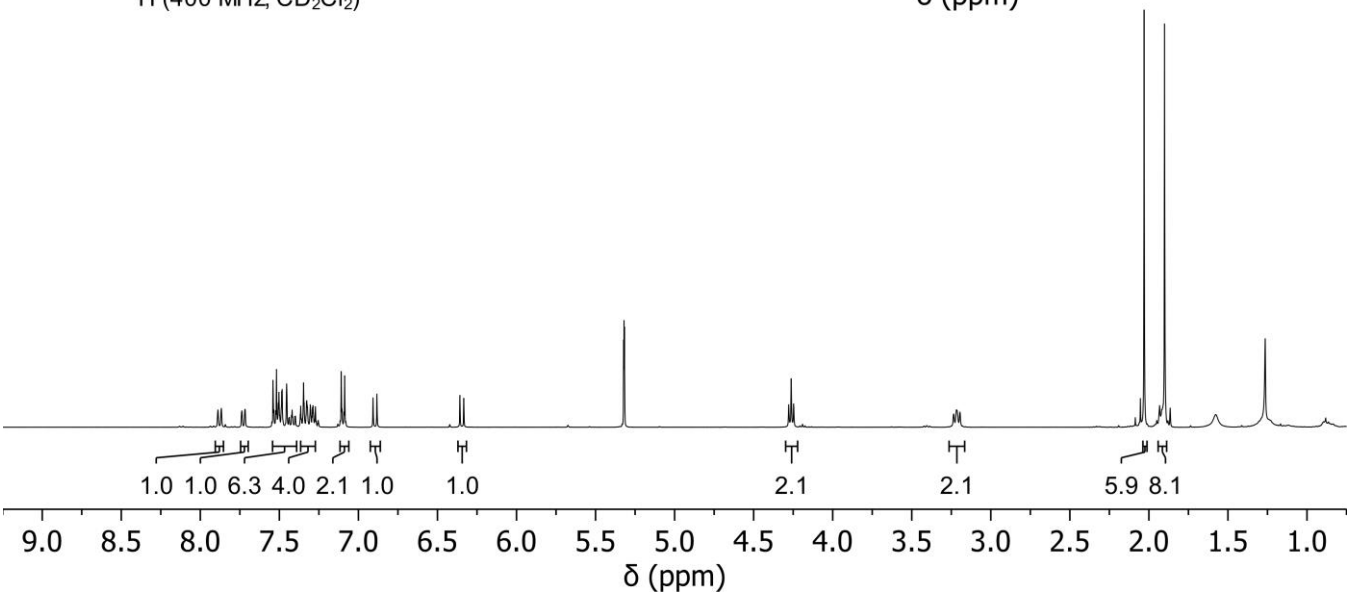
^{13}C (101 MHz, acetone-d_6)

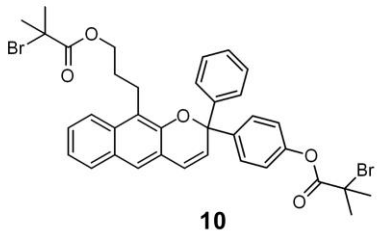


10

^{1}H (400 MHz, CD_2Cl_2)

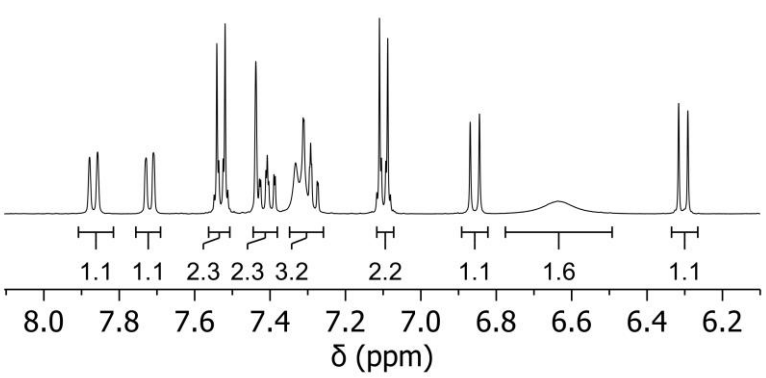


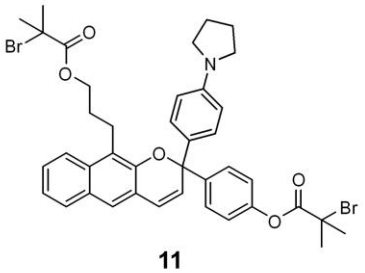




10

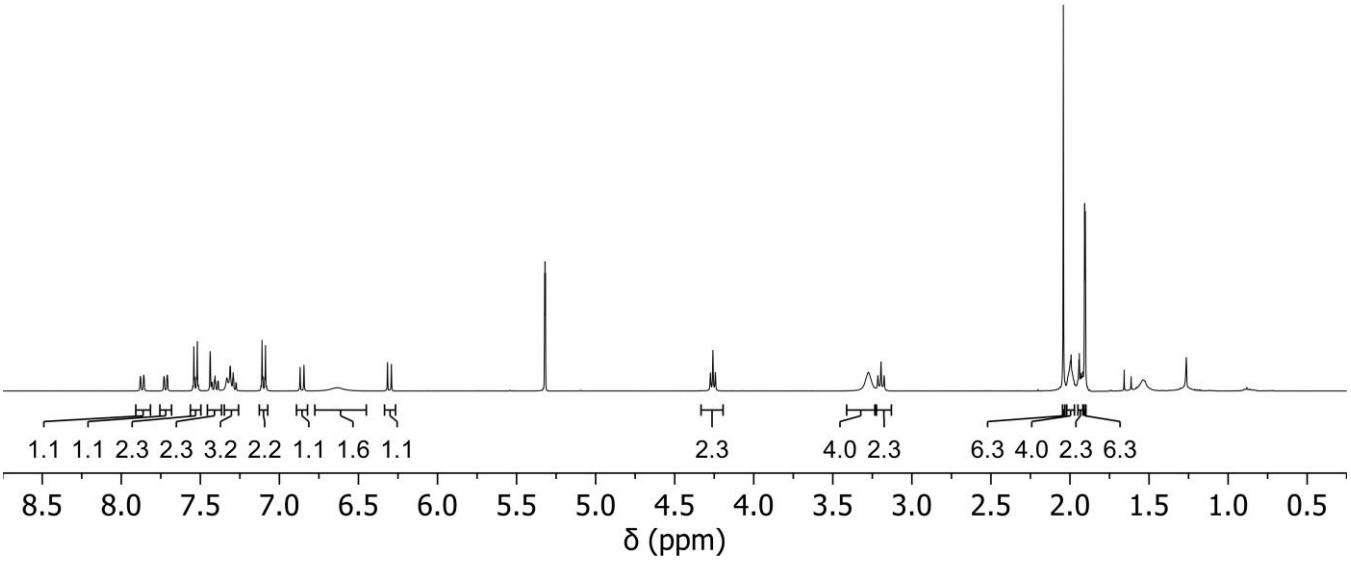
^{13}C (101 MHz, CD_2Cl_2)

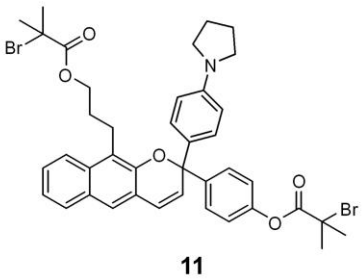




11

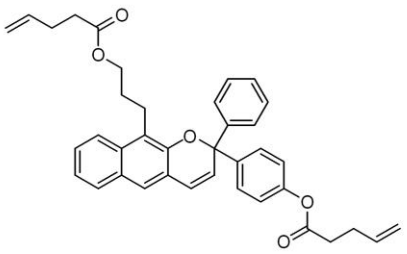
^{1}H (400 MHz, CD_2Cl_2)





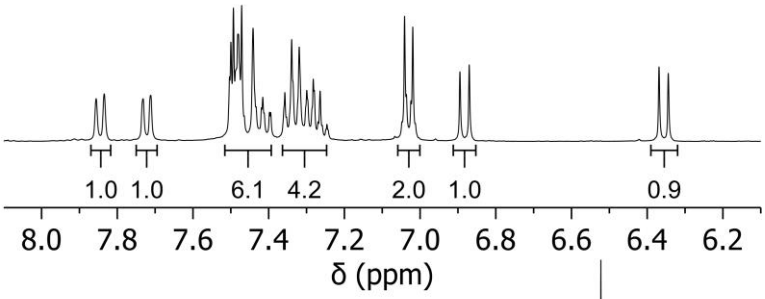
11

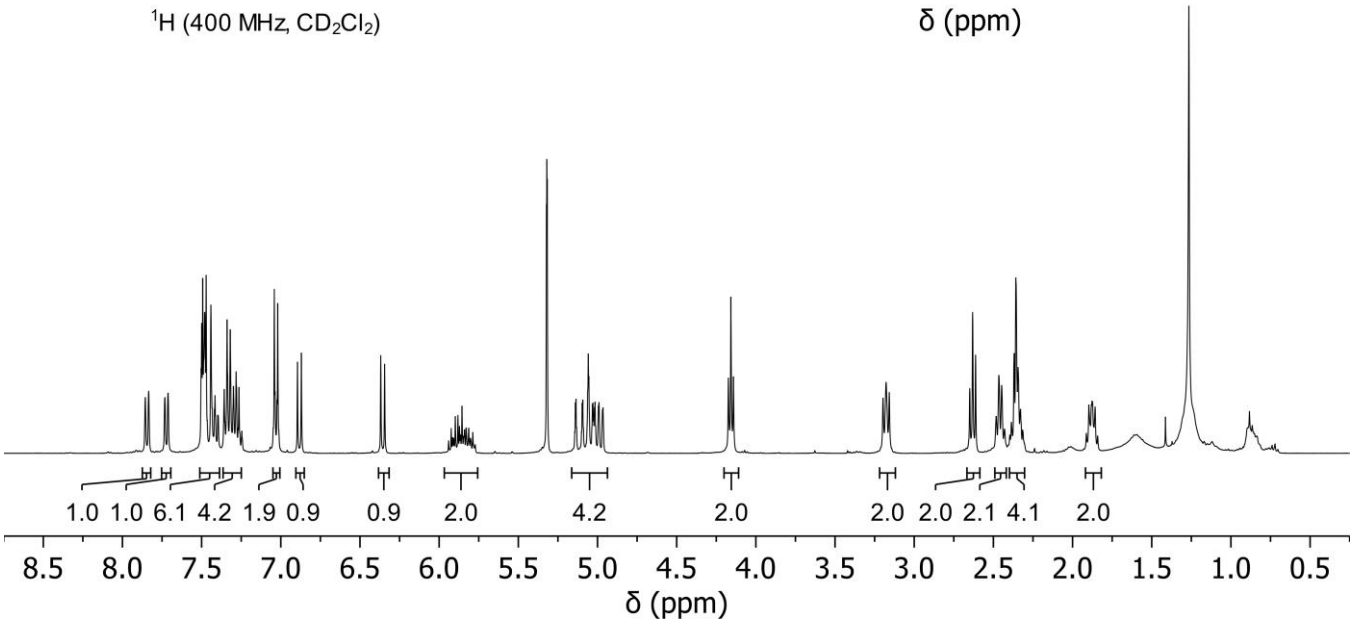
^{13}C (101 MHz, $CDCl_3$)

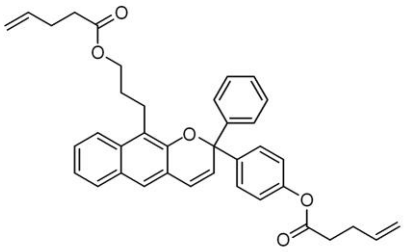


Crosslinker-LNP

^{1}H (400 MHz, CD_2Cl_2)

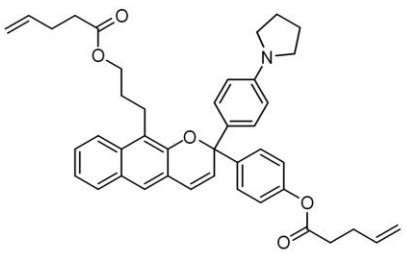






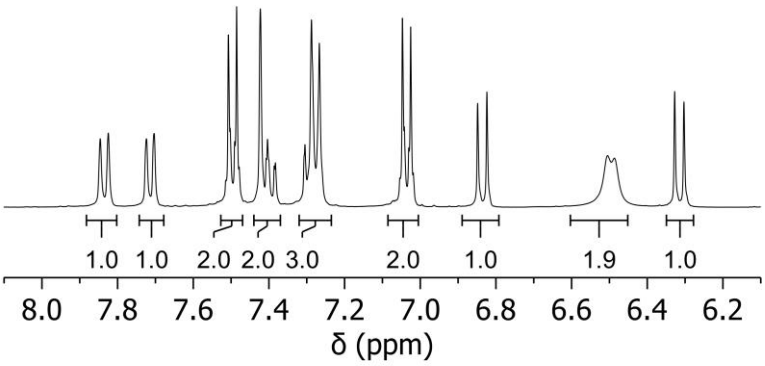
Crosslinker-LNP

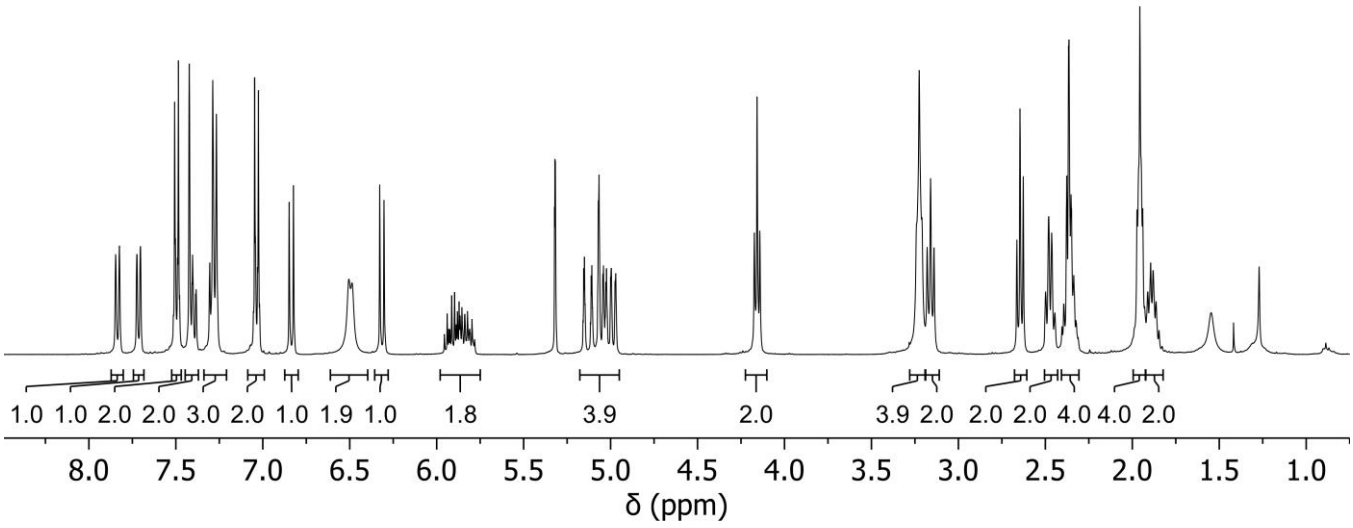
^{13}C (101 MHz, CD_2Cl_2)

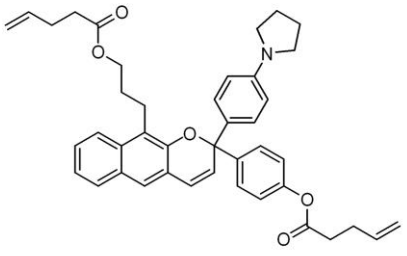


Crosslinker-PyLNP

^{1}H (400 MHz, CD_2Cl_2)

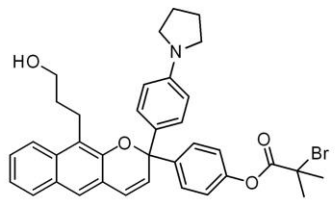






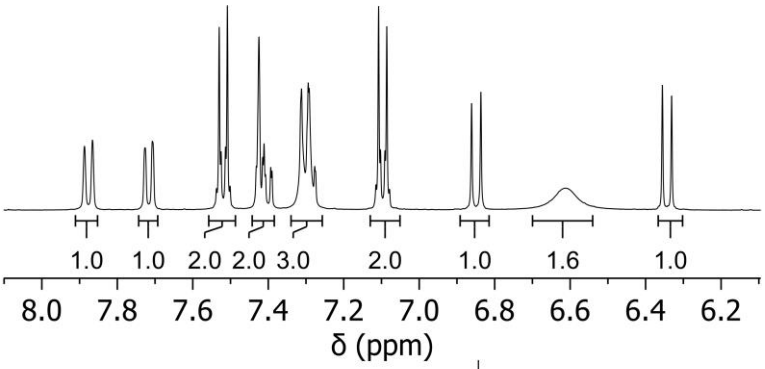
Crosslinker-PyLNP

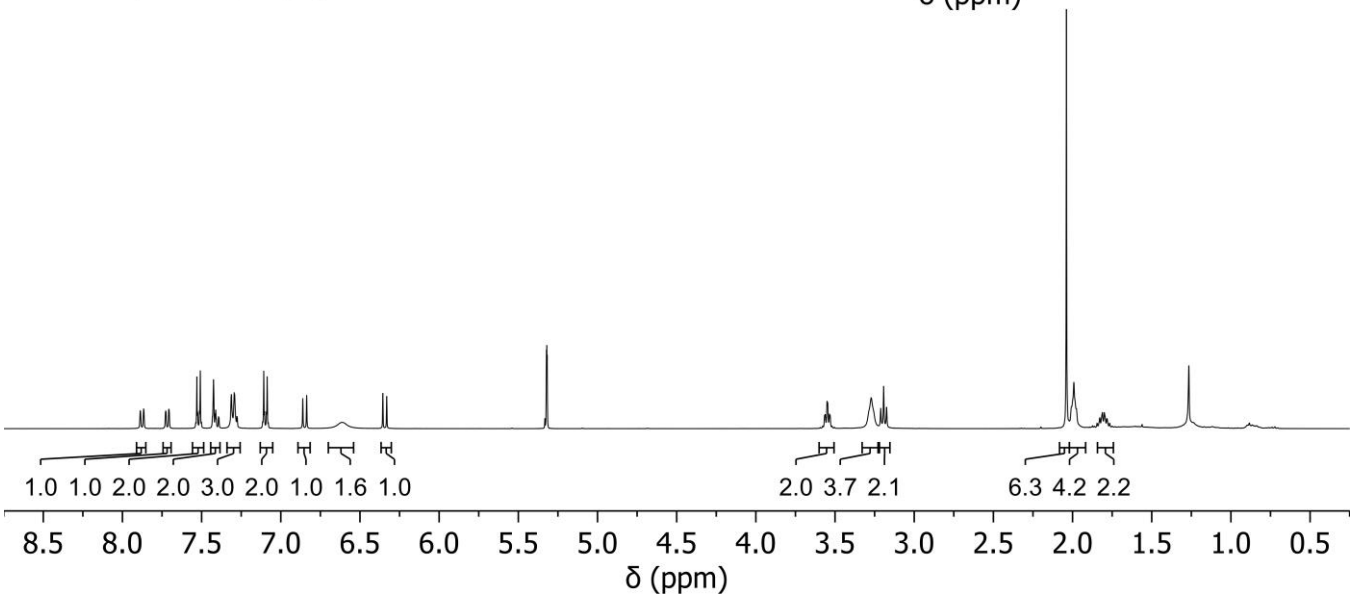
^{13}C (101 MHz, $CDCl_3$)

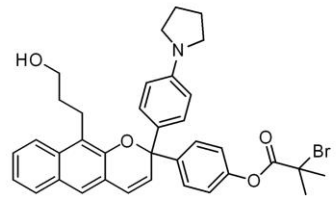


PyLNP-Mono

^{1}H (400 MHz, CD_2Cl_2)

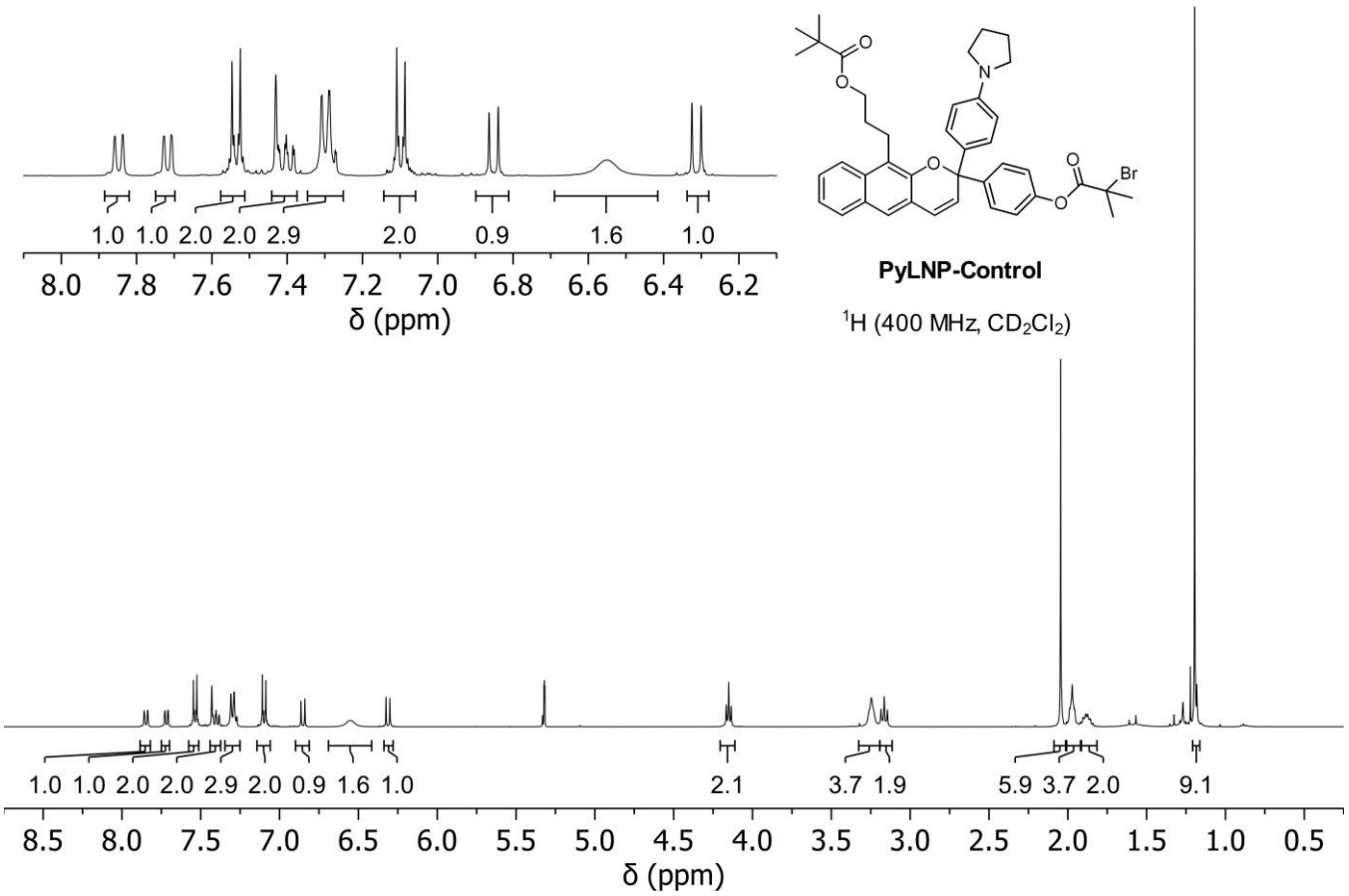


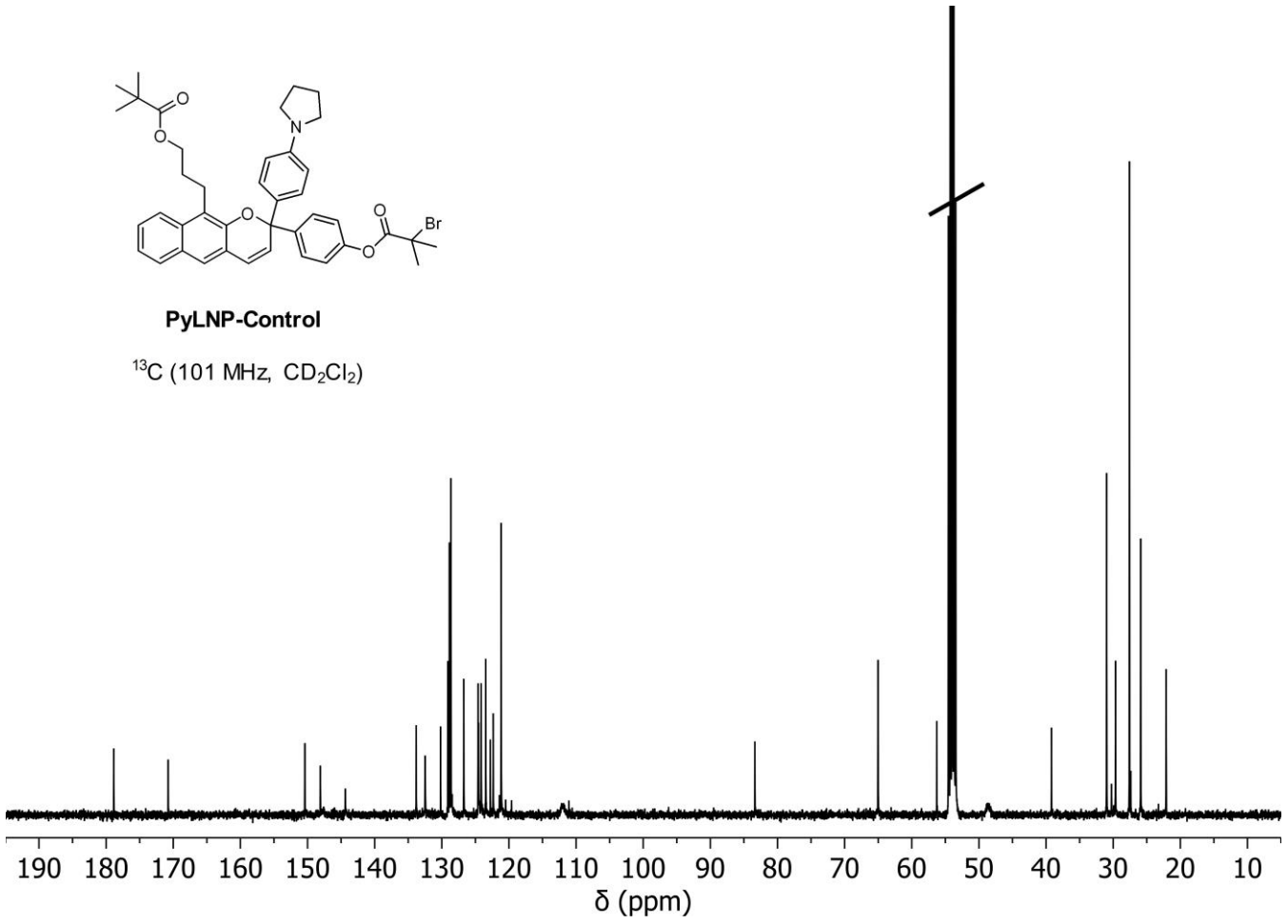




PyLNP-Mono

^{13}C (101 MHz, $CDCl_3$)


1.0 1.0 2.0 2.0 2.9 2.0 0.9 1.6 1.0
8.0 7.8 7.6 7.4 7.2 7.0 6.8 6.6 6.4 6.2
δ (ppm)
PyLNP-Control
^{1}H (400 MHz, CD_2Cl_2)
1.0 1.0 2.0 2.0 2.9 2.0 0.9 1.6 1.0
2.1
3.7 1.9
5.9 3.7 2.0
9.1
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
δ (ppm)


PyLNP-Control
^{13}C (101 MHz, CD_2Cl_2)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
δ (ppm)