Electronic Supplementary Material (ESI) for ChemComm.


**Supporting information**

# Light-responsive peptide [2]rotaxanes as gatekeepers of mechanised nanocontainers

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## 1. General Experimental Section

Unless stated otherwise, all reagents were purchased from Aldrich Chemicals and used without further purification. HPLC grade solvents (Scharlab) were nitrogen saturated and were dried and deoxygenated using an Innovative Technology Inc. Pure-Solv 400 Solvent Purification System. Column chromatography was carried out using silica gel (60 Å, 70-200 μm, SDS) as stationary phase, and TLC was performed on precoated silica gel on aluminium cards (0.25 mm thick, with fluorescent indicator 254 nm, Fluka) and observed under UV light. All melting points were determined on a Kofler hot-plate melting point apparatus and are uncorrected. $^{1}$H- and $^{13}$C-NMR spectra were recorded on a Bruker Avance 200, 300 and 400 MHz instruments. $^{1}$H NMR chemical shifts are reported relative to $Me_4Si$ and were referenced via residual proton resonances of the corresponding deuterated solvent whereas $^{13}$C NMR spectra are reported relative to $Me_4Si$ using the carbon signals of the deuterated solvent. Signals in the $^{1}$H and $^{13}$C NMR spectra of the synthesized compounds were assigned with the aid of DEPT, APT, or two-dimensional NMR experiments (COSY, HMQC or HMBC). Solid-state CP/MAS $^{13}$C and $^{29}$Si NMR spectra were recorded on a Bruker Avance-600 (150.92 and 119.25 MHz, respectively) instrument (spinning rate:12 KHz, rotor: 80 μL). Abbreviations of coupling patterns are as follows: br, broad; s, singlet; d, doublet; t, triplet; q, quadruplet; m, multiplet. Mass spectra were recorded with Agilent 5973 (EI), Agilent VL (ESI) and HPLC/MS TOF 6220 mass spectrometers. The thermogravimetric analyses were performed on a SDT 2960 simultaneous DTA-TGA analyser. Elemental analyses were performed in a Carlo Erba EA-1108 apparatus. An UV-visible lamp (254 nm and 365 nm) was used as irradiation source for the isomerization experiments. The controlled release profiles were obtained via UV spectroscopy using a PerkinElmer Lambda 35 UV/Vis spectrometer. Scanning electron microscopy (SEM) images were collected on a JEOL JSM-6460LV instrument (20 kV). Au coating of the nanoparticles used for imaging was carried out by sputtering for 2 min. Transmission electron microscopy (TEM) images were obtained with a JEOL JEM 3000F instrument (300 kV). TEM samples were prepared by pipetting a drop of ethanolic suspension of nanoparticles onto a 200-mesh copper grid coated with carbon.

Abbreviation list:

DCM: dichloromethane

AcOEt: ethyl acetate

DMSO: dimethylsulfoxide

DMAP: dimethylaminopyridine

DCC: *N*,*N*´-dicyclohexylcarbodiimide

$Boc_2O$: Di-*tert*-butyl dicarbonate

DMF: *N*,*N*-dimethylformamide

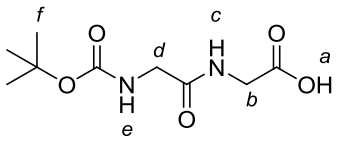
TFA: trifluoroacetic acid

EDCI: *N*-(3-Dimethylaminopropyl)-*N´*-ethylcarbodiimide hydrochloride

BOP: (Benzotriazol-1-yloxy)tris(dimethylamino)phosphonium hexafluorophosphate

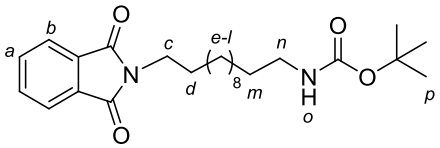
## 2. Synthesis of fragment S1

### *N*-Boc-Glycylglycine (3)




To a solution of glycylglycine (1.00 g, 7.58 mmol) in an aqueous solution of NaOH (1M, 22.8 mL) at 0 ºC was added a solution of $Boc_2O$ (1.82 g, 8.34 mmol) in 1,4-dioxane (7.8 mL). The reaction mixture was stirred for 20 hours at room temperature after which time it was concentrated under reduced pressure. To the resulting residue was added an aqueous solution of NaOH (1M, 15 mL). The mixture was then acidified with an aqueous solution of HCl (1M) to pH 2 and extracted con AcOEt (5 x 90 mL). The organic phase was dried over anhydrous $MgSO_4$, concentrated under reduced pressure to give the title product as a white solid (**3**, 0.97 g, 4.18 mmol, 55%). M.p. 136-138 ºC; $^1$H NMR (400 MHz, DMSO-*d6*) δ: 12.29 (broad s, 1H, $OH_a$), 8.03 (t, *J* = 5.8 Hz, 1H, $NH_c$), 6.98 (t, *J* = 6.0 Hz, 1H, $NH_e$), 3.74 (d, *J* = 5.8 Hz, 2H, $H_b$), 3.55 (d, *J* = 6.0 Hz, 2H, $H_d$), 1.37 (s, 9H, $H_f$). This compound was described in R. Warfield, P. Bardelang, H. Saunders, W. C. Chan, C. Penfold, R. James, N. R. Thomas, *Org. Biomol. Chem.* **2006**, *4*, 3626-3638, and showed identical spectroscopic data as those reported therein.

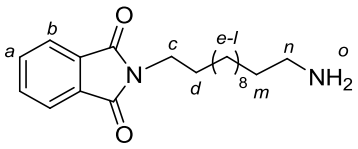
### *N*-Boc-aminododecylphthalimide (4)




To a solution of the commercially available 12-(*tert*-butoxycarbonylamino)dodecylamine (0.50 g, 1.67 mmol) in toluene (50 mL) was added phthalic anhydride (0.24 g, 1.67 mmol). The reaction mixture was refluxed for 12 hours with a Dean-stark trap. After this time the reaction was allowed to cool and the solvent was removed under reduced pressure. The resulting residue was purified by column chromatography on silica gel using $CHCl_3$ as eluent to give the title product as a white solid (**4**, 0.62 g, 1.44 mmol, 88%). M.p. 68-70 ºC; $^1$H NMR (300 MHz, $CDCl_3$) δ: 7.90-7.78 (m, 2H, $H_a$), 7.78-7.64 (m, 2H, $H_b$), 4.49 (broad s, 1H, $NH_o$), 3.64 (t, *J* = 7.3 Hz, 2H, $H_c$), 3.06 (t, *J* = 7.1 Hz, 2H, $H_n$), 1.72-1.59 (m, 2H, $H_d$), 1.51-1.39 (m, 11H, $H_m$+$H_p$), 1.38-1.18 (m, 16H, $H_e$-$H_l$); $^{13}$C NMR (75 MHz, $CDCl_3$) δ: 168.61

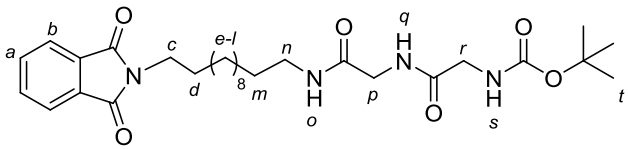
(CO), 156.17 (CO), 133.96 (CH), 132.31 (C), 123.28 (CH), 79.27 (C), 40.89, 38.21, 30.18, 29.63 (x2), 29.58, 29.41, 29.30, 28.72 (x3), 28.56 ($CH_3$), 26.98, 26.92; IR (Nujol) ν: 3579 (w), 3379 (w), 2957 (m), 2913 (vs), 2848 (m), 1748 (w), 1736 (w), 1708 (w), 1454 (w), 1381 (w), 1274 (w), 1111 (w), 729 (w); HRMS (ESI) calcd for $C_{25}H_{39}N_2O_4$ $[M + H]^+$ 431.2910, found 431.2729.

**_N_-(12-aminododecyl)phthalimide (5)**




To a solution of *N*-Boc-dodecylphthalimide **4** (1.77 g, 4.11 mmol) en dry DCM (60 mL) was added TFA (3.16 mL, 41.06 mmol) under $N_2$ atmosphere and the reaction mixture was stirred for 12 hours. After this time the solvent and the excess of the TFA was removed under reduced pressure. The resulting residue was diluted with $CHCl_3$ (50 mL) and washed with an aqueous solution of $K_2CO_3$ 1M (2 x 50 mL) y brine (2 x 50 mL). The organic phase was dried over anhydrous $MgSO_4$ and concentrated under reduced pressure to give the title product as a white solid (**5**, 1.23 g, 3.73 mmol, 91%). M.p. 76-78 ºC; $^1$H NMR (300 MHz, $CDCl_3$) δ: 7.83-7.74 (m, 2H, $H_a$), 7.69 (m, 2H, $H_b$), 3.65 (t, *J* = 7.2 Hz, 2H, $H_c$), 3.34 (m, 4H, $H_n$+$H_o$), 1.72-1.48 (m, 2H, $H_d$), 1.43-1.09 (m, 18H, $H_e$-$H_l$+$H_m$); $^{13}$C NMR (75 MHz, $CDCl_3$) δ: 168.61 (CO), 133.98 (CH), 132.27 (C), 123.27 (CH), 40.42, 38.20, 29.66 (x2), 29.61(x2), 29.52, 29.46, 29.31, 28.72, 27.11, 26.99; IR (Nujol) ν: 3251 (w), 2957 (vs), 2921 (vs), 2853 (vs), 1716 (w), 1628 (w), 1538 (w), 1463 (s), 1377 (m), 1310 (w), 1153 (w), 1057 (w), 721 (w); HRMS (ESI) calcd for $C_{20}H_{31}N_2O_2$ $[M + H]^+$ 331.2386, found 331.2384.

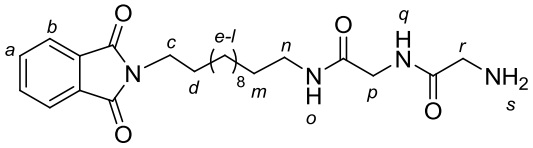
**12-phthalimidododecyl _N_-Boc-Glycylglycinate (6)**




To a solution of amine **5** (2.50 g, 7.56 mmol) in dry DCM (100 mL) was added acid **1** (1.60 g, 6.90 mmol) and DMAP (0.92 g, 7.56 mmol) under $N_2$ atmosphere. The reaction mixture was cooled to 0ºC and EDCI (1.45 g, 7.56 mmol) was added, stirring for 72 hours at room temperature. After this time the reaction mixture was diluted with DCM (50 mL) and washed with water (3 x 100 mL). The organic phase was dried over anhydrous $MgSO_4$, concentrated under reduced pressure and purified by column chromatography on silica gel using a $CHCl_3$:MeOH (95:5) mixture as eluent to give the title product as a white solid (**6**, 1.34 g, 2.46 mmol, 36%). M.p. 117-119 ºC; $^1$H NMR (300 MHz, $CDCl_3$) *as a mixture of*

*rotamers A(3):B(2)* δ: 7.84-7.78 (m, 2H, $H_a$; A), 7.74-7.66 (m, 2H, $H_b$; A), 7.54-7.48 (m, 2H, $H_a$; B), 7.44-7.38 (m, 2H, $H_b$; B), 7.21 (broad s, 1H, NH; A/B), 7.12 (broad s, 1H, NH; A/B), 6.83 (broad s, 1H, NH; A/B), 6.65 (broad s, 1H, NH; A/B), 5.42 (m, 2H, 2 NHs), 3.85-3.68 (m, 8H), 3.68-3.60 (m, 4H), 3.35 (m, 2H; A), 3.19 (dd, *J* = 13.1, 6.8 Hz, 2H; B), 1.75-1.38 (m, 22H), 1.38-1.15 (m, 36H); $^{13}$C NMR (75 MHz, $CDCl_3$) δ: 170.04 (CO), 169.51 (CO), 168.60 (CO), 156.35 (CO), 134.83 (C), 133.97, 132.25 (C), 130.16, 128.39, 123.25, 80.57 (C), 43.03, 40.41, 39.81, 38.17, 29.64, 29.48, 29.44, 29.37, 29.32, 29.27, 29.17, 28.69, 28.40 ($CH_3$), 27.10, 26.96, 26.90, 26.85; IR (Nujol) ν: 3583 (w), 3428 (w), 3303 (w), 2929 (s), 2856 (m), 2253 (s), 1771 (w), 1711 (vs), 1656 (s), 1523 (m), 1468 (m), 1397 (m), 1369 (m), 1169 (m), 1092 (w), 925 (vs), 739 (vs); HRMS (ESI) calcd for $C_{29}H_{45}N_4O_6$ $[M + H]^+$ 545.3339, found 545.3340.

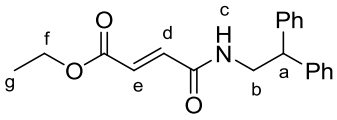
**Fragment S1**




To an ice-cooled solution of **6** (1.29 g, 2.37 mmol) in dry DCM (40 mL) was added TFA (1.83 mL, 23.7 mmol) under $N_2$ atmosphere and the mixture was stirred for 12 hours at room temperature. After this time the solvent and the excess of TFA was removed under reduced pressure. The resulting residue was diluted with $CHCl_3$ (50 mL) and washed with an aqueous solution of $K_2CO_3$ 1M (2 x 50 mL) y brine (2 x 50 mL). The organic phase was dried over anhydrous $MgSO_4$ and concentrated under reduced pressure to give a white solid (**S1**, 0.70 g, 1.58 mmol, 67%), which was used directly in the next step with further purification.

**3. Synthesis of [2]rotaxane S2**

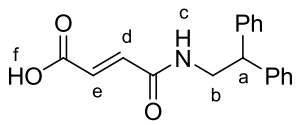
***(E)*-ethyl 4-(2,2-diphenylethylamino)-4-oxobut-2-enoate (7)**




To a solution of (*E*)-4-ethoxy-4-oxobut-2-enoic acid (3.32 g, 23.03 mmol) in dry DCM (150 mL) was added 2,2-diphenylethylamine (5.00 g, 25.33 mmol) and DMAP (2.81 g, 23.03 mmol) under $N_2$ atmosphere. The reaction mixture was cooled to 0 ºC and EDCI (4.42 g, 23.03 mmol) was added. The reaction mixture was allowed to stirr for 48 hours at room temperature. After this time the mixture was diluted with DCM (50 mL) and was washed with a aqueous solution of HCl 2M (2 x 200 mL) and a

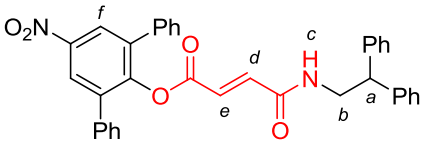
saturated solution of $NaHCO_3$ (3 x 200 mL). The organic phase was dried over anhydrous $MgSO_4$ and concentrated under reduced pressure to give the title product as a white solid (**7**, 5.26 g, 16.28 mmol, 71%). M.p. 121-123 ºC; $^1$H NMR (400 MHz, $CDCl_3$) δ: 7.35-7.21 (m, 10H, Ph), 6.80-6.71 (m, 2H, $H_e$+$H_d$), 5.91 (s, 1H, $NH_c$), 4.25-4.16 (m, 3H, $H_f$+$H_a$), 3.99 (dd, *J*= 5.9, 8.0 Hz, 2H, $H_b$), 1.29 (t, *J* = 7.2 Hz, 3H, $H_g$). This compound was described in A. Altieri, G. Bottari, F. Dehez, D. A. Leigh, J. K. Y. Wong, F. Zerbetto, *Angew. Chem. Int. Ed.* **2003**, *42*, 2296-2300, and showed identical spectroscopic data as those reported therein.

**(*E*)-4-(2,2-diphenylethylamino)-4-oxobut-2-enoic acid (S3)**




To a solution of ester **7** (5.18 g, 16.04 mmol) in EtOH (100 mL) was added an aqueous solution of KOH (1.86 g, 33.20 mmol of KOH in 12.4 mL of $H_2O$) and was stirred for 12 hours at room temperature. After this time the solvent was removed under reduced pressure and an aqueous solution of HCl 1M was added. The white precipitate was filtered and dried (**S3**, 4.26 g, 14.44 mmol, 90%). M.p. 201-203 ºC; $^1$H NMR (400 MHz, DMSO-*d6*) δ: 12.57 (s, 1H, OH), 8.57 (t, *J* = 5.6 Hz, 1H, $NH_c$), 7.35-7.15 (m, 10H, Ph), 6.86 (d, *J* = 15.5 Hz, 1H, $H_d$), 6.48 (d, *J* = 15.5 Hz, 1H, $H_e$), 4.22 (t, *J* = 8.0 Hz, 1H, $H_a$), 3.81 (dd, *J* = 8.0, 5.6 Hz, 2H, $H_b$). This compound was described in A. Altieri, G. Bottari, F. Dehez, D. A. Leigh, J. K. Y. Wong, F. Zerbetto, *Angew. Chem. Int. Ed.* **2003**, *42*, 2296-2300, and showed identical spectroscopic data as those reported therein.

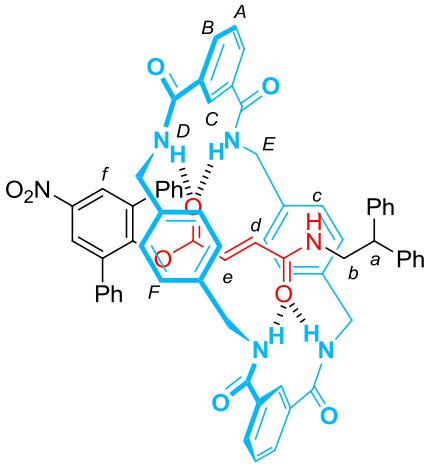
**Thread 8**




To a solution of acid **S3** (0.50 g, 1.69 mmol) in $CHCl_3$ (70 mL) was added 4-nitro-2,6-diphenylphenol (2.46 g, 8.45 mmol), triethylamine (3.52 mL, 24.35 mmol) and BOP (1.12 g, 2.54 mmol). The reaction mixture was stirred under $N_2$ atmosphere for 24 hours. After this time the solvent was removed under reduced pressure and the resulting residue was purified by column chromatography on silica gel using a mixture hexane:$Et_2O$ (1:1) as eluent to give the title product as a white solid (**8**, 0.69 g, 1.21 mmol, 72%). M.p. 181-183 ºC; $^1$H NMR (400 MHz, $CDCl_3$) δ: 8.29 (s, 2H, $H_f$), 7.45-7.18 (m, 20H, Ph), 6.63 (d, *J* = 15.3 Hz, 1H, $H_d$), 6.45 (d, *J* = 15.3 Hz, 1H, $H_e$), 5.59 (t, *J* = 5.6 Hz, 1H, $NH_c$), 4.16 (t, *J* = 8.0 Hz, 1H, $H_a$),

3.94 (dd, $J$ = 8.0, 5.6 Hz, 2H, $H_b$); $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 162.73 (CO), 162.70 (CO), 149.59 (C), 146.05 (C), 141.32 (C), 138.20 (CH), 137.57 (C), 135.52 (C), 129.02 (CH), 128.88 (CH), 128.83 (CH), 128.77 (CH), 128.26 (CH), 128.04 (CH), 127.25 (CH), 125.11 (CH), 50.22 (CH), 44.03 ($CH_2$); IR (Nujol) ν: 3600 (w), 3327 (w), 2943 (m), 2924 (s), 2853 (m), 1729 (w), 1658 (w), 1635 (w), 1532 (w), 1461 (w), 1377 (w), 1138 (w); HRMS (ESI) calcd for $C_{36}H_{29}N_2O_5$ $[M + H]^+$ 569.2076, found 569.2079.

**[2]Rotaxane S2**




Thread **8** (0.40 g, 0.70 mmol) and $Et_3N$ (1.17 mL, 8.45 mmol) under $N_2$ atmosphere in anhydrous $CHCl_3$ (250 mL) were stirred vigorously whilst solutions of *p*-xylylenediamine (0.77 g, 5.63 mmol) plus $Et_3N$ (1.17 mL, 8.45 mmol) in anhydrous $CHCl_3$ (20 mL) and isophthaloyl dichloride (1.14 g, 5.63 mmol) in anhydrous $CHCl_3$ (20 mL) were simultaneously added over a period of 4 hours using motor-driven syringe pumps. After a further 4 hours the resulting suspension was filtered through a Celite pad and the solvent removed under reduced pressure. The resulting residue was subjected to column chromatography on silica gel using a mixture $CHCl_3$/MeOH (98.5/1.5) as eluent to give the title compound as a white solid (**S2**, 0.21 g, 0.21 mmol, 26%). M.p. 155-157 ºC; $^1$H NMR (400 MHz, $CDCl_3$) δ: 8.15 (d, $J$ = 7.8 Hz, 4H, $H_B$), 8.12 (s, 2H, $H_f$), 8.11 (s, 2H, $H_C$), 7.59 (t, $J$ = 7.8 Hz, 2H, $H_A$), 7.43-6.94 (m, 25H, Ph+$NH_c$+$NH_D$), 6.50 (s, 8H, $H_F$), 5.89 (d, $J$ = 15.2 Hz, 1H, $H_d$), 5.32 (d, $J$ = 15.2 Hz, 1H, $H_e$), 4.45-4.30 (m, 8H, $H_E$), 3.80 (t, $J$ = 7.6 Hz, 1H, $H_a$), 3.16 (dd, $J$ = 7.6, 5.6 Hz, 2H, $H_b$); $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 166.65 (CO), 163.62 (CO), 162.34 (CO), 148.56 (C), 145.90 (C), 141.57 (C), 137.71 (CH), 137.40 (C), 136.78 (C), 135.35 (C), 133.98 (C), 130.83 (CH), 129.25 (CH), 128.98 (CH), 128.84 (CH), 128.77 (CH), 128.59 (CH), 128.16 (CH), 127.79 (CH), 126.87 (CH), 125.53 (CH), 125.06 (CH) 49.27 (CH), 44.75 ($CH_2$), 44.04 ($CH_2$); IR (Nujol) ν: 3586 (w), 2971 (m), 2923 (m), 2853 (m), 1361 (w), 1529 (w), 1462 (w), 1377 (w), 1343 (w), 1129 (w); HRMS (ESI) calcd for $C_{68}H_{57}N_6O_9$ $[M + H]^+$ 1101.4187, found 1101.4179.

## 4. Synthesis and characterization of MSN-1

**MSN-1** were synthesized following the procedure described in S. Huh, J. W. Wiench, J.-C. Yoo, M. Pruski, V. S.-Y. Lin, *Chem. Mat.* **2003**, *15*, 4247-4256. The morphology of the obtained **MSN-1** was revealed by Scanning Electron Microscopy (SEM). The mesoporous structure of **MSN-1** was observed by High Resolution Transmission Electron Microscopy (HRTEM).

(a) (b)

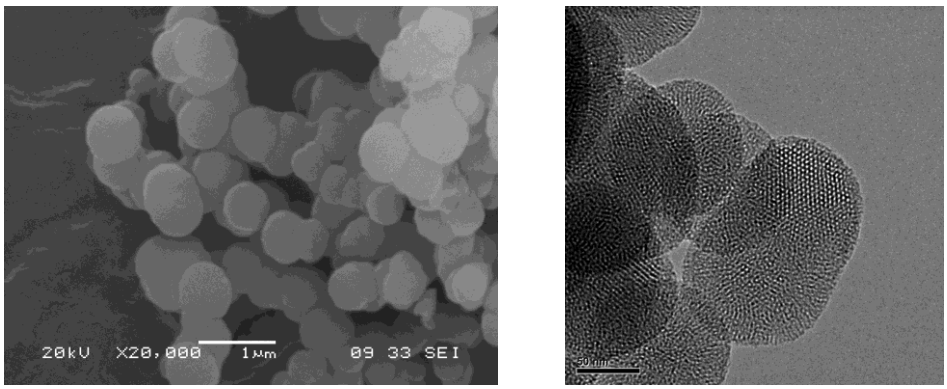
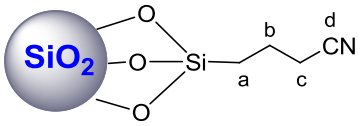



**Figure S1**. (a) SEM image of calcined **MSN-1**. (b) HRTEM image of **MSN-1**.

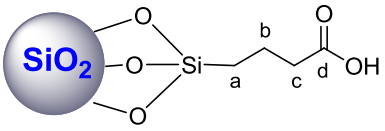
## 5. Synthesis of MSN-6

**MSN-2**



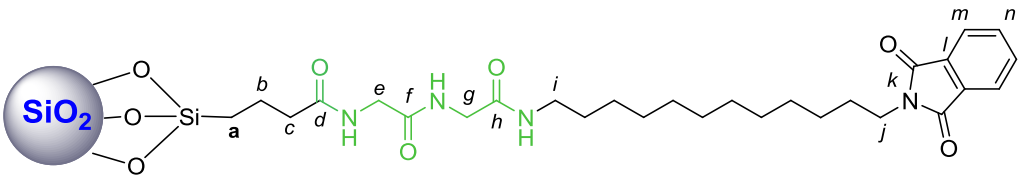

Synthesized **MSN-1** (1 g) were heated at 130 ºC for 12 hours in an oven. After this time, 3-cyanopropyltriethoxysilane (2.15 mL, 9 mmol) and anhydrous toluene (50 mL) were added under N2 atmosphere and the reaction mixture were refluxed for 72 hours. The solid was filtered, washed with warm toluene (100 mL) and $Et_2O$ (100 mL) and dried (**MSN-2**, 1.27 g). Solid state $^{13}C$ NMR (150 MHz) δ: 118.8 ($C_d$), 19.9 ($C_a$), 17.4 ($C_c$), 11.1 ($C_b$); Solid state $^{29}Si$ NMR (119.25 MHz) δ: -54.7, -61.9, -109.5; IR (KBr) ν: 3442 (m), 2984 (w), 2937 (w), 2895 (w), 2254 (w), 1633 (m), 1397 (m), 1245 (s), 1086 (vs), 795 (m), 461 (s); Elemental analysis: obtained (%): C, 13.09; H, 2.02; N, 2.28; Maximum level of functionalization: 2.722 mmol/g of silica (E. A.); 3.207 mmol/g of silica (TGA).

**MSN-3**



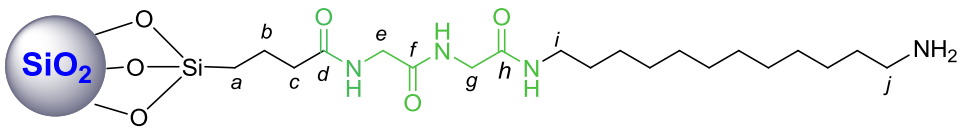

To **MSN-2** (1.27 g) was added an aqueous 50 % (v/v) $H_2SO_4$ solution (100 mL) and was refluxed for 24 hours. After this time the mixture was cooled to room temperature and was filtered through a sintered glass Büchner funnel under vacuum. The solid was washed with $H_2O$ (300 mL), acetone (200 mL) and $Et_2O$ (100 mL) and was dried at 120ºC during 12h (**MSN-3**, 823 mg). Solid state $^{13}C$ NMR (150 MHz) δ: 179.0 ($C_d$), 35.3 ($C_c$), 17.5 ($C_a$), 11.2 ($C_b$); Solid state $^{29}Si$ NMR (119.25 MHz) δ: -59.0, -65.8, -110.9; IR (KBr) ν: 3434 (m), 2953 (w), 1726 (m), 1633 (w), 1416 (m), 1241 (vs), 1082 (vs), 803 (m), 454 (vs); Elemental analysis: obtained (%): C, 7.89; H, 1.53; N, 0.08; Maximum level of functionalization: 1.644 mmol/g of silica (E. A.); 1.858 mmol/g of silica (TGA).

**MSN-4**




0.64 g (1.43 mmol) of amine **S1** was dissolved in anhydrous THF (50 mL) and **MSN-3** (0.42 g, 0.84 mmol) and DCC (0.30 g, 1.43 mmol) was added under $N_2$ atmosphere. The mixture was stirred and refluxed during 72 hours. After this time solvent was removed under vacuum and the resulting residue was purified in Soxhlet extractor using ethanol as solvent during 48 hours. The resulting solid was dried under vacuum during 8 hours (**MSN-4**, 500 mg). Solid state $^{13}C$ NMR (150 MHz) δ: 175.2 y 168.2 ($C_d$+$C_f$+$C_h$+$C_k$), 132.1 and 123.6 ($C_l$+$C_m$+$C_n$), 57.8 ($C_e$+$C_g$+$C_j$), 39.1 ($C_c$+$C_i$), 29.4 ($C_{aliph\ chain}$), 17.7 ($C_a$), 12.4 ($C_b$); IR (KBr) ν: 3424 (m), 2938 (m), 2856 (w), 1757 (w), 1716 (s), 1659 (m), 1544 (m), 1457 (w), 1414 (m), 1409 (m), 1371 (m), 1242 (vs), 1086 (vs), 796 (w), 723 (w), 462 (s).

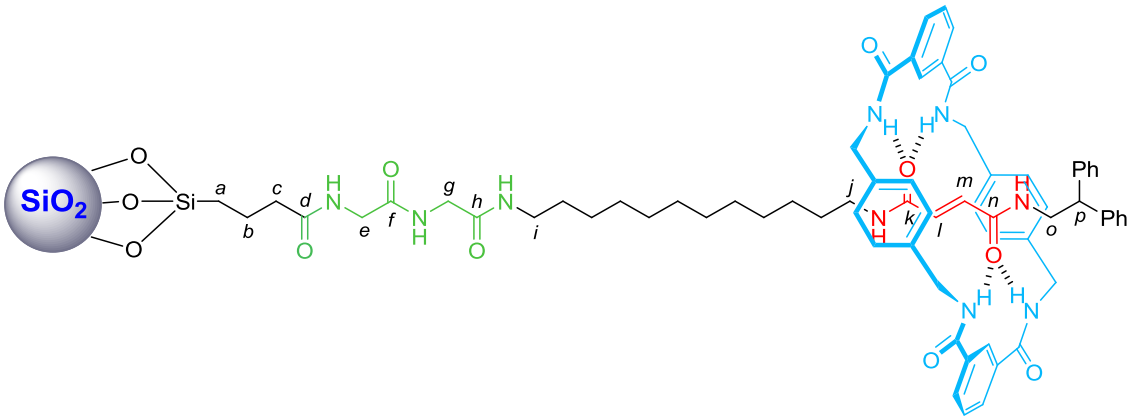
**MSN-5**




To a suspension of **MSN-4** (200 mg, 0.40 mmol) in EtOH (15 mL) was added hydrazine monohydrate (0.19 mL, 4 mmol) under $N_2$ atmosphere. The mixture was stirred at room temperature for 12 hours. After

this time the reaction mixture was purified in Soxhlet extractor using ethanol as solvent during 7 hours. The resulting material was dried under vacuum for 8 hours (**MSN-5**, 140 mg). Solid state $^{13}$C NMR (150 MHz) δ: 177.3 and 172.3 ($C_d$+$C_f$+$C_h$), 58.0 ($C_e$+$C_g$), 40.1 ($C_c$+$C_i$+$C_j$), 29.2 ($C_{aliph\ chain}$), 17.9 ($C_a$), 11.1 ($C_b$); IR (KBr) ν: 3431 (m), 2931 (w), 2858 (w), 1655 (w), 1544 (w), 1234 (m), 1082 (vs), 802 (w), 460 (m).

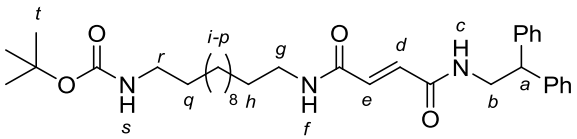
**MSN-6**



To a suspension of **MSN-5** (185.3 mg) in $CHCl_3$ (25 mL) was added rotaxane **S2** (0.36 g, 0.33 mmol) under $N_2$ atmosphere and was refluxed during 10 days. After this time the mixture was cooled to room temperature and filtered through a sintered glass Büchner funnel under vacuum. The resulting solid was washed with $CHCl_3$ (3% MeOH) and dried (**MSN-6**, 157.1 mg). Solid state $^{13}$C NMR (150 MHz) δ: 174.1, 168.7 and 163.3 (*C*ON), 126.9 ($C_{Ar}$), 72.0 (CO*C*$H_2$NH´s macrocycle), 62.0 and 57.0 (CO*C*$H_2$NH´s thread), 37.8, 27.1 ($C_{aliph\ chain}$), 15.7 ($C_a$), 11,3 ($C_b$); IR (KBr) ν: 3428 (w), 2925 (w), 2856 (w), 1646 (m), 1540 (w), 1413 (w), 1422 (vs), 1082 (vs), 809 (w), 453 (s). Elemental analysis: obtained (%): C, 19.06; N, 3.24; Maximum level of functionalization: 0.227 mmol/g of silica (E. A.); 0.278 mmol/g of silica (TGA).

## 6. Synthesis of MSN-7

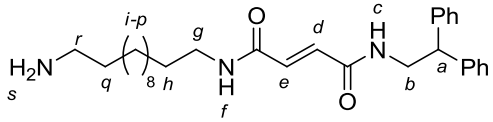
***(E)-N*-(12-Boc-aminododecyl)-4- (2,2-diphenylethylamine)-4-oxobut-2-enamide (9)**



To a solution of the commercially available 12-(*tert*-butoxycarbonylamino)dodecylamine (1.02 g, 3.39 mmol) in dry DCM (80 mL) was added anhydrous $Et_3N$ (0.71 mL, 5.09 mmol), acid **S3** (1.00 g, 3.39 mmol) and BOP (2.25 g, 5.09 mmol). The mixture was stirred under $N_2$ atmosphere during 4 hours. After

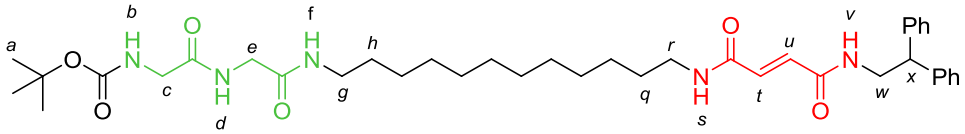
this time solvent was removed under vacuum, and the residue was diluted with $CHCl_3$ (100 mL) and washed with $H_2O$ (100 mL), aqueous solution of HCl 1 M (100 mL), $NaHCO_3$ (sat) (100 mL) and brine (100 mL). The organic phase was dried over anhydrous $MgSO_4$ and concentrated under reduced pressure to give the title product as a white solid (**9**, 1.75 g, 3.03 mmol, 90%). M.p. 166-168 ºC; $^1$H NMR (300 MHz, $CDCl_3$+$CD_3OD$) δ: 7.24-7.07 (m, 10H, Ph), 6.69 (d, *J* = 15.1 Hz, 1H, $H_e$), 6.57 (d, *J* = 15.1 Hz, 1H, $H_d$), 4.16 (t, *J* = 7.9 Hz, 1H, $H_a$), 3.84 (d, *J* = 7.9 Hz, 2H, $H_b$), 3.44-3.35 (s, 3H, $NH_f$+$NH_c$+$NH_s$), 3.16 (t, *J* = 7.2 Hz, 2H, $H_r$), 2.97 (t, *J* = 7.0 Hz, 2H, $H_g$), 1.45-1.30 (m, 13H, $H_h$+$H_q$+$H_t$), 1.30-1.00 (m, 16H, $H_i$-$H_p$); $^{13}$C NMR (75 MHz, $CDCl_3$+$CD_3OD$) δ: 165.28 (CO), 165.03 (CO), 156.53 (CO), 141.85 (C), 132.85 (CH), 132.10 (CH), 128.60 (CH), 127.93 (CH), 126.74 (CH), 79.26 (C), 50.22 (CH), 44.27, 39.80, 29.88, 29.46 (x3), 29.22 (x2), 29.01, 28.28 ($CH_3$), 26.87, 26.72; IR (Nujol) ν: 3364 (w), 3316 (w), 2956 (s), 2924 (vs), 2920 (s), 1675 (w), 1623 (w), 1483 (m), 1371 (w); HRMS (ESI) calcd for $C_{35}H_{52}N_3O_4$ $[M+H]^+$ 578.3958, found 578.3954.

***(E)-N*-(12-Boc-aminododecyl)-4- (2,2-diphenylethylamine)-4-oxobut-2-enamide (1)**




To a solution of carbamate **9** (0.50 g, 0.87 mmol) in dry DCM (30 mL) was added TFA (0.67 mL, 8.70 mmol) and the mixture was stirred under $N_2$ atmosphere during 12 hours. After this time solvent and excess of TFA were removed under vacuum. The resulting residue was dissolved in a $CHCl_3$:*i*PrOH (3:1) mixture and was extracted with an aqueous solution of $K_2CO_3$ 1M (2 x 250 mL) and brine (2 x 250 mL). The organic phase was dried over anhydrous $MgSO_4$, filtered and concentrated under reduced pressure, giving a white solid which was used in the next step without further purification (**1**, 0.52 g, 0.87 mmol, 99%).

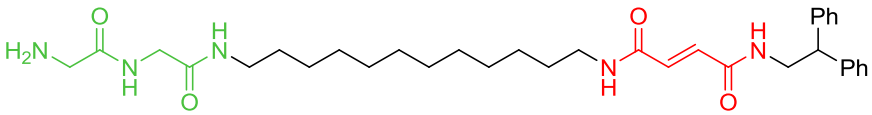
**Fragment 10**




To a solution of the amine **1** (0.46 g, 0.78 mmol) in dry DCM (30 mL) was added acid **3** (0.27 g, 1.18 mmol), $Et_3N$ (0.33 mL, 2.35 mmol) and DMAP (0.12 g, 0.94 mmol). The mixture was cooled to 0ºC and EDCI (0.23 g, 1.18 mmol) was added, stirring for 48 hours under $N_2$ atmosphere. After this time the resulting mixture was diluted with $CHCl_3$: *i*PrOH (3:1) (100 mL) and washed with $H_2O$ (100 mL). The organic phase was dried over anhydrous $MgSO_4$, filtered and concentrated under reduced pressure. The

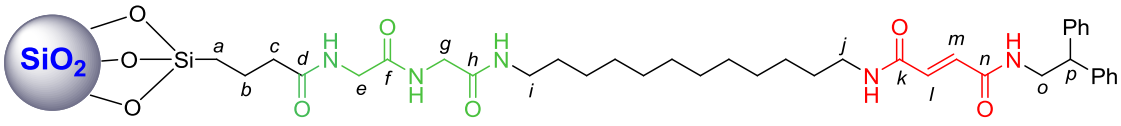
resulting residue was purified by column chromatography on silica gel using a $CHCl_3$:MeOH (93:7) mixture as eluent to give the title product as a white solid (**10**, 0.39 g, 0.56 mmol, 71%). M.p. 162-164 ºC; $^1$H NMR (300 MHz, DMSO-*d6*) δ: 8.45 (broad s, 1H, $NH_d$), 8.33 (broad s, 1H, $NH_f$), 8.02 (broad s, 1H, $NH_v$), 7.66 (broad s, 1H, $NH_s$), 7.38-7.12 (m, 10H, Ph), 7.04 (broad s, 1H, $NH_b$), 6.78 (d, *J* = 15.2 Hz, 1H, $H_u$), 6.71 (d, *J* = 15.2 Hz, 1H, $H_t$), 4.22 (t, *J* = 7.8 Hz, 1H, $H_x$), 3.89-3.73 (m, 2H, $H_w$), 3.70-3.49 (m, 4H, $H_c$+$H_e$), 3.16-2.97 (m, 4H, $H_g$+$H_r$), 1.49-1.32 (m, 13H, $H_h$+$H_q$+$H_a$), 1.31-1.12 (m, 16H, $H_i$-$H_p$); $^{13}$C NMR (75 MHz, DMSO-*d6*) δ: 169.81 (CO), 168.60 (CO), 163.98 (CO), 163.70 (CO), 156.12 (CO), 142.77 (C), 132.85 (CH), 132.41 (CH), 128.54 (CH), 127.92 (CH), 126.49 (CH), 78.39 (C), 50.06 (CH), 43.58, 43.45, 42.12, 38.85, 29.11, 29.06, 28.93, 28.82, 28.79, 28.25 ($CH_3$), 26.48, 26.42; IR (Nujol) ν: 3297 (w), 2958 (s), 2925 (vs), 2844 (s), 2370 (w), 1720 (w), 1626 (w), 1544 (w), 1467 (w), 1373 (w), 1315 (w), 1172 (w); HRMS (ESI) calcd for $C_{39}H_{58}N_5O_6$ $[M+H]^+$ 692.4387, found 692.4379.

**Fragment 2**



To a solution of carbamate **10** (0.61 g, 0.88 mmol) in dry DCM (30 mL) was added TFA (0.68 g, 8.78 mmol) and the mixture was stirred under $N_2$ atmosphere during 12 hours. After this time solvent and excess of TFA were removed under vacuum. The resulting residue was dissolved in a $CHCl_3$:*i*PrOH (3:1) mixture and was extracted with an aqueous solution of $K_2CO_3$ 1M (2 x 250 mL) and brine (2 x 250 mL). The organic phase was dried over anhydrous $MgSO_4$, filtered and concentrated under reduced pressure, giving a white solid which was used in the next step without further purification (**2**, 0.29 g, 0.49 mmol, 48%).

**MSN-7**



To a solution of the amine **2** (0.25 mg, 0.42 mmol) in anhydrous THF (35 mL) was added **MSN-2** (0.12 mg, 0.25 mmol) and DCC (0.09 g, 0.42 mmol) under $N_2$ atmosphere and the mixture was refluxed during 72 hours. After this time the reaction mixture was purified in a Soxhlet extractor using ethanol as solvent during 12 hours. The resulting solid was dried under vacuum at 60ºC during 6 hours (**MSN-7**, 0.12 g). Solid state $^{13}$C NMR (150 MHz) δ: 173.5, 169.1 y 163.3 (CON), 152.0, 140.3 y 126.1 ($C_{Ar}$), 56.8 and 48.9 ($COCH_2NH$), 38.2, 27.8 ($C_{aliph\ chain}$), 15.2 ($C_a$), 10.9 ($C_b$); IR (KBr) ν: 3409 (w), 3085 (w), 2933 (w),

2858 (w), 2361 (w), 2333 (w), 1640 (m), 1544 (m), 1442 (m), 1234 (s), 1066 (vs), 803 (w), 461 (s); Elemental analysis: obtained (%): C, 21.52; H, 2.85; N, 2.83; Maximum level of functionalization: 0.472 mmol/g of silica (E. A.); 0.521 mmol/g of silica (TGA).

## 7. Stacked $^{1}$H NMR spectra of thread 8 and rotaxane S2

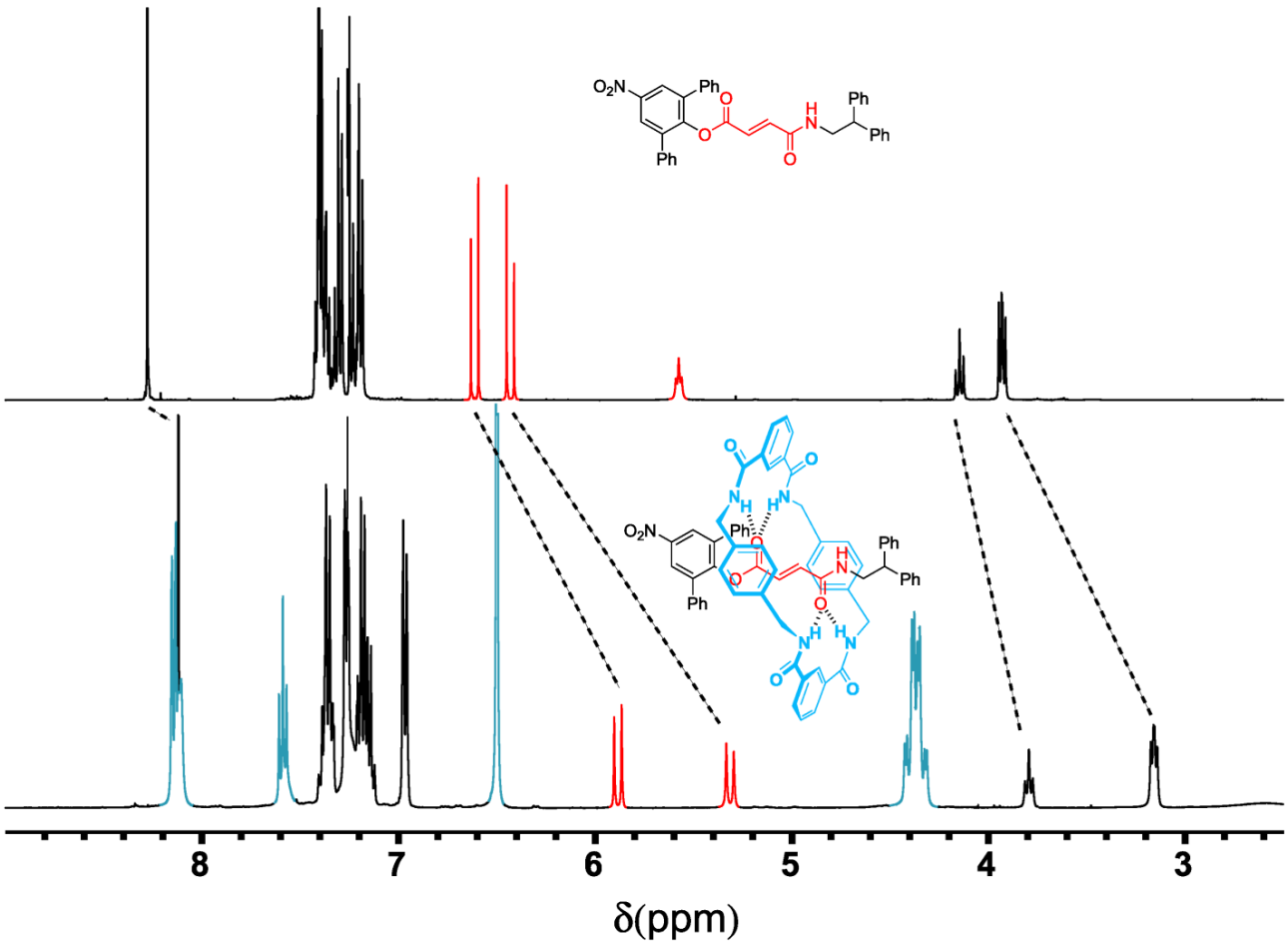



**Figure S2.** $^{1}$H NMR spectra (400 MHz, $CDCl_3$, 298 K) of thread **8** and rotaxane **S2**.

## 8. Solid state FT-IR spectra

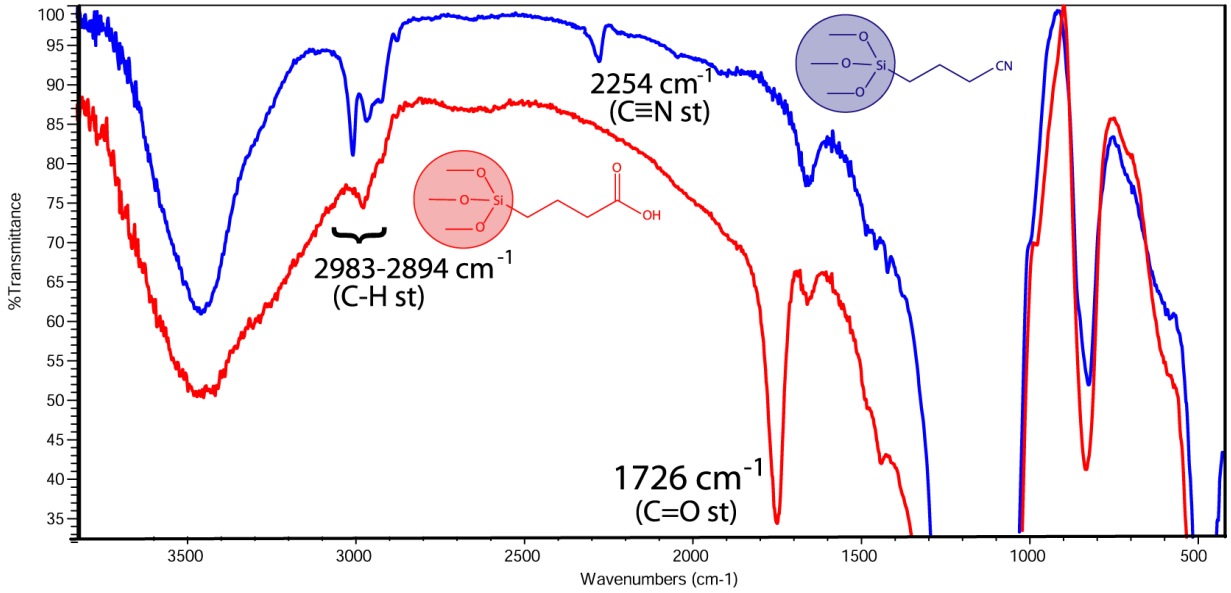



**Figure S3.** FT-IR spectra of **MSN-2** (blue) and **MSN-3** (red).

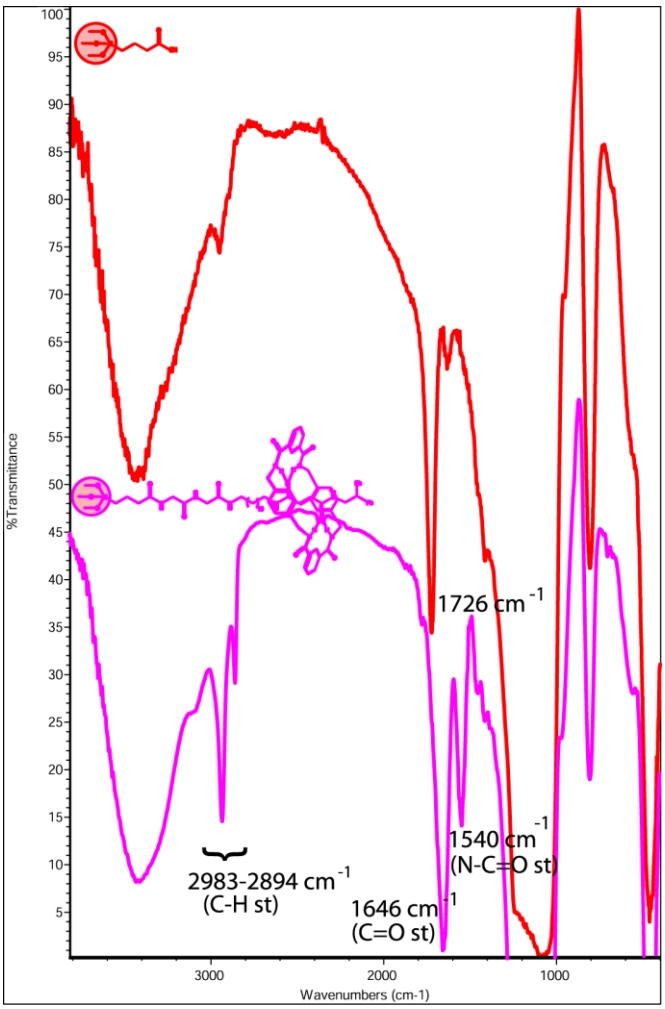



**Figure S4.** FT-IR spectra of **MSN-3** (red) y **MSN-6** (pink).

## 9. Solid-state $^{29}$Si and $^{13}$C NMR spectra

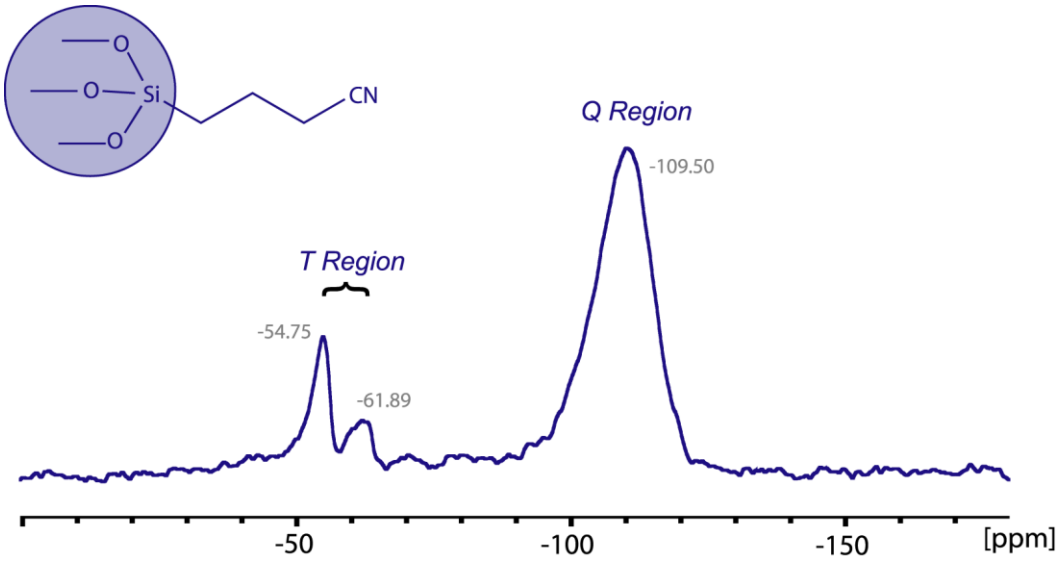



**Figure S5.** $^{29}$Si SSNMR (119.25 MHz, spinning rate: 12 KHz, rotor: 80 µL) of **MSN-2**

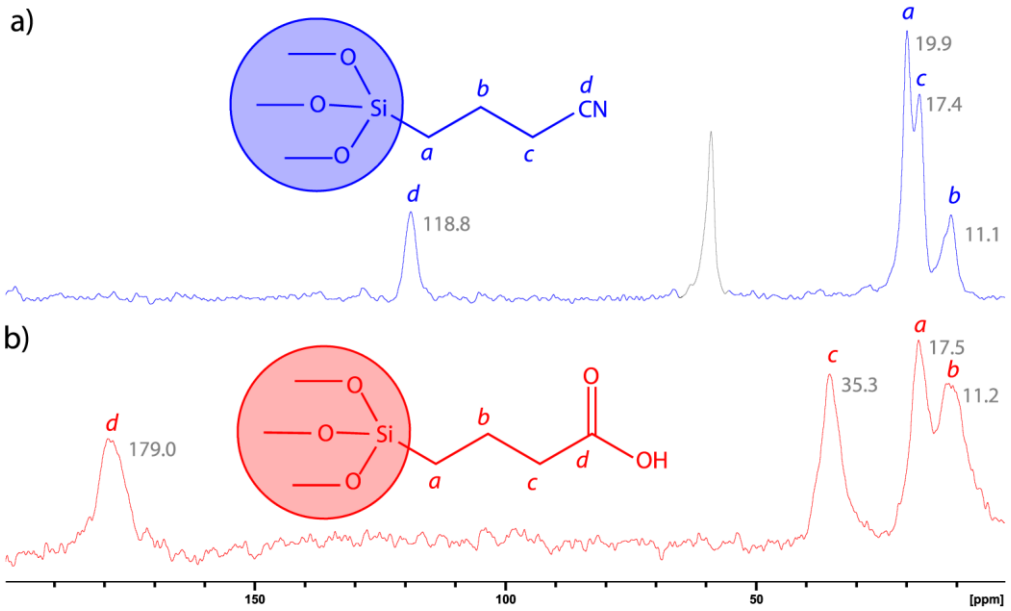



**Figure S6.** $^{13}$C SSNMR (150.92 MHz, spinning rate: 12 KHz, rotor: 80 µL) of: a) **MSN-2**, b) **MSN-3**.

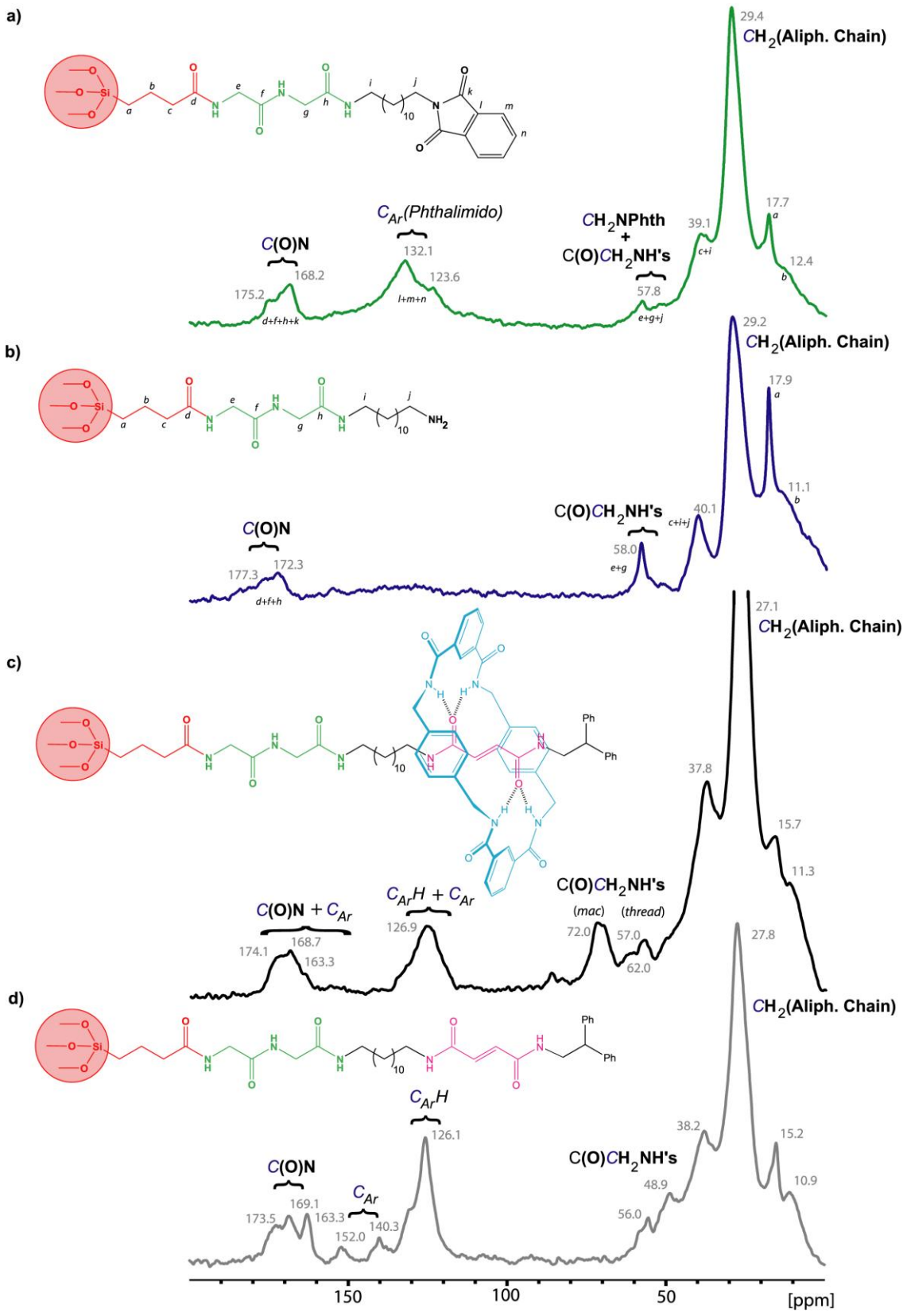



**Figure S7.** $^{13}$C SSNMR (150.92 MHz, spinning rate: 12 KHz, rotor: 80 µL) of: a) **MSN-4**; b) **MSN-5**; c) **MSN-*E*-6**; d) **MSN-7**.

## 10. Thermogravimetric analysis

Figure S8 shows a comparison between the TGA of **MSN-3** and rotaxane-containing **MSN-*E*-6**. The mass loss detected at temperatures above 150 °C is assigned to the organic matter attached to the surface of the particles. In the graph it is observed that the mass loss in rotaxane-containing **MSN-*E*-6** (33.3%) is higher than for **MSN-3** (15.9%), indicative of the elevated presence of organic material in **MSN-*E*-6**.

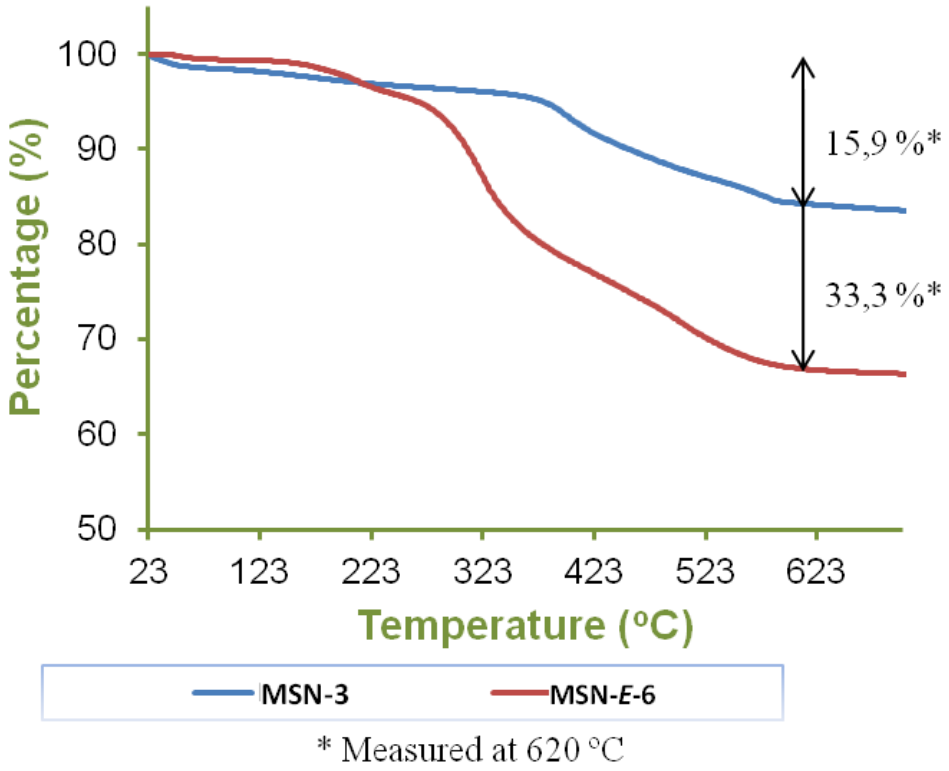



**Figure S8.** Superposition of TGA of materials **MSN-3** (blue) and **MSN-*E*-6** (red).

## 11. Loading and release experiments for MSN-6 with Rhodamine B

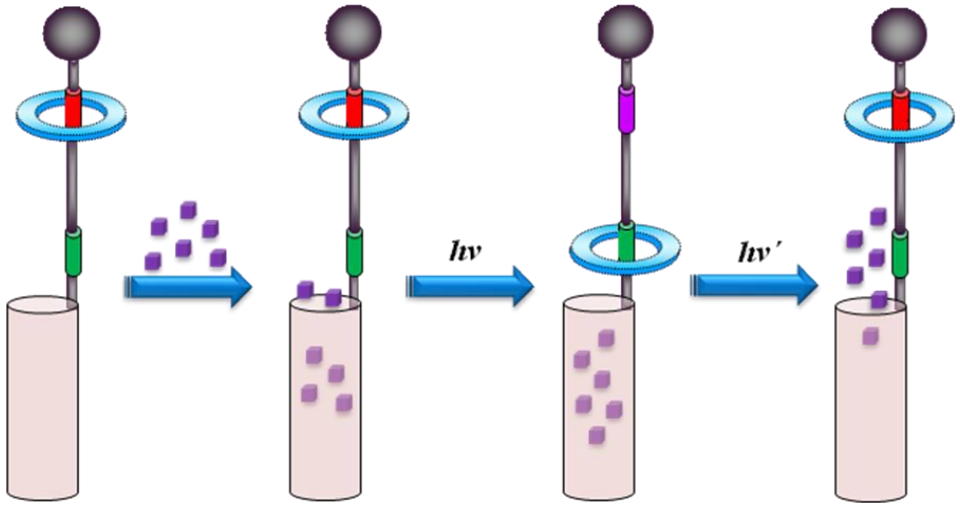



**Figure S9**. Schematic representation of Rhodamine B-loading and release processes for **MSN-6**.

### Loading MSN-*E*-6 with Rhodamine B.

Aqueous Rhodamine B (1 mM) solution was prepared using volumetric equipment. Rhodamine B solution (2 mL, 1 mM) was added to a vial containing **MSN-*E*-6** (25 mg). The particles were stirred and sonicated in solution to maximize dispersion during 1 hour. The suspension was then stirred 24 hours to allow Rhodamine B to diffuse into the nanopores. After this time the loaded **RhB loaded MSN-*E*-6** were removed from solution by centrifugation and washed with water. The **RhB-MSN-*E*-6** were dried under high vacuum for 24 hours.

### Closing RhB-MSN-*E*-6 nanopores by photoisomerization process.

Loaded **RhB-MSN-*E*-6** (10 mg) were suspended in a Rhodamine B solution (2 mL, 1 mM, DCM). The suspension was stirred and irradiated under 254 nm at room temperature during 1 hour in order to enable the *trans*-to-*cis* photoisomerization of the fumaramide unit leading the macrocycle to move along the aliphatic chain, and staying on the glycylglycine unit for the closure of the nanopores. After this time the particles were removed from solution by centrifugation and washed with DCM (5 x times). The closed **RhB-MSN-*Z*-6** were dried under high vacuum for 12 hours.

Note: Rhodamine B starts to be damaged by UV irradiation (254 nm) after exposure for periods of time longer than 2 hours.[1]

[1] T. Kornprobst, *Int. J. Photoenergy*, **2012**, Article ID 398230, 6 pages, doi:10.1155/2012/398230.

**Controlled release experiments.**

Closed and loaded **RhB-MSN-*Z*-6** (1 mg) were placed in a vial and 5 mL of the appropriate solvent was added. The resulting suspension was stirred while irradiating at 365 nm at room temperature to enable the *cis*-to-*trans* photoisomerization of the maleamide unit, allowing the opening of the pores. After centrifugation the clear solution was placed in a cuvette and the absorbance measured.

For verifying that the opening of the pores was occurring, due to the isomerization of the maleamide unit to the corresponding fumaramide, followed by the traslational movement of the macrocycle along the thread, similar experiments were also run in the absence of irradiation.

- Release experiments in dichloromethane for **RhB-MSN-*Z*-6**:

The absorbance of the solution was monitored *versus* time. For calculating the % of release, the absorbance of the solution after stirring for 24 hours under dark was chosen as the value of maximum absorbance (100 % release).

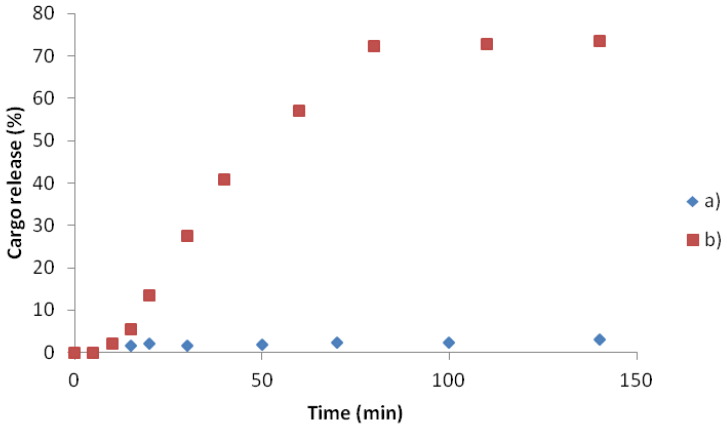



**Figure S10.** % release of Rhodamine B *versus* time using DCM as solvent: a) without irradiation; b) with a continuous irradiation (λ: 365 nm) starting at minute 10.

- Release experiments in water for **RhB-MSN-*Z*-6**:

The absorbance of the solution was monitored *versus* time. For calculating the % of release, the absorbance of the solution after stirring for 24 hours was chosen as the value of maximum absorbance (100% release).

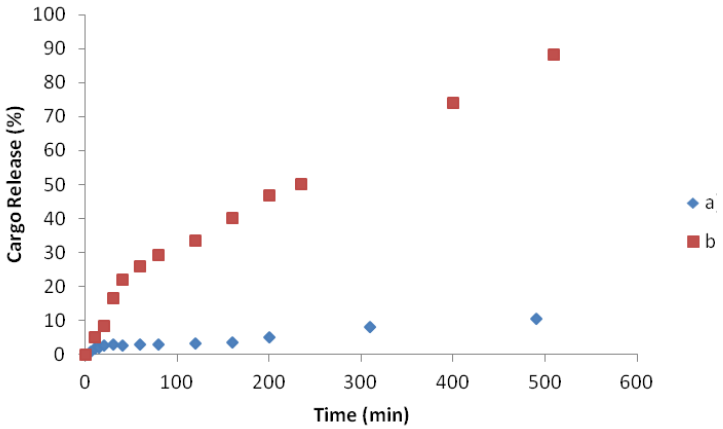



**Figure S11.** % release of Rhodamine B *versus* time using water as solvent: a) without irradiation; b) with a constant irradiation (λ 365 nm) after minute 10.

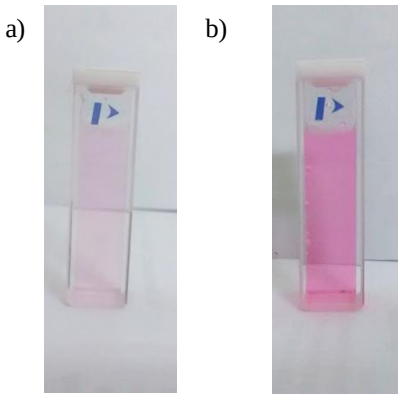



**Figure S12.** Visual changes observed in the DCM solution during time: a) min 0; b) after 2 hours of stirring under irradiation.

- Control experiment in water/DCM for **RhB-MSN-7**:

Control experiments were performed for nanoparticles **MSN-7** using both solvents (DCM or water).

Experiment 1: Nanoparticles **MSN-7** were loaded with RhB employing the same method described for **MSN-*Z*-6**. These control particles were washed as RhB loaded **MSN-*Z*-6** and dried. Since the benzylic macrocycle is not present in **MSN-7** for closing the nanopores, RhB is eliminated during the washing step and there is no increasing in the absorbance during time.

Experiment 2: Nanoparticles **MSN-7** were loaded with RhB employing the same method described for **MSN-*Z*-6**. The particles were then centrifuged and the RhB solution was removed. The corresponding RhB loaded **MSN-7** were dried under vacuum. RhB loaded **MSN-7** (1 mg) were placed in a vial and 5 mL of the appropriate solvent was added. The suspension was stirred and centrifuged, measuring the absorbance during time. In this case, since the benzylic macrocycle is not present in **MSN-7** for closing

the nanopores, in the first 5 minutes of the experiment all RhB was released out of the particles, observing an important increasing in the absorbance, which was stabilized immediately.

**Calculation of the amount of RhB in RhB-MSN-*Z*-6 by the Beer-Lambert law.**

The molar extinction coefficient of RhB (ε) was calculated by plotting different concentrations of RhB *versus* the absorbance measured at 553 nm, using dichloromethane as solvent.

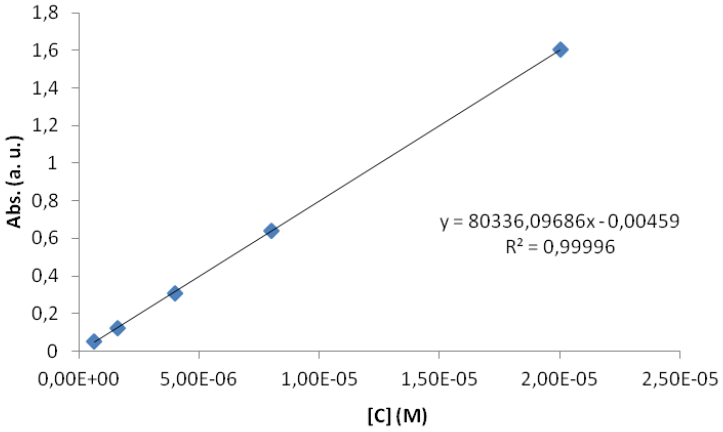



**Figure S13.** Beer-Lambert plot of different RhB solutions (DCM, $\lambda_{max}$: 553 nm).

For calculating the total amount of RhB loaded inside the pores, we stirred a solution of **RhB-MSN-*Z*-6** (3 mg in 12 mL of DCM) while irradiating at 365 nm for a period of 2 hours. The solution was stirred for another 24 hours under dark to allow a complete cargo release. After this time the absorbance was measured, observing a value of 1.17, which corresponds with a concentration of $1.46 \cdot 10^{-5}$ M. This result allows us to calculate the % amount of RhB (per mg of **RhB-MSN-*Z*-6**), being 2.8wt%.

## 12. Transmission Electron Microscopy Observations

The changes of the porous surface of the silica during the functionalization and the RhB loading were monitored by high-resolution transmission electron microscopy.

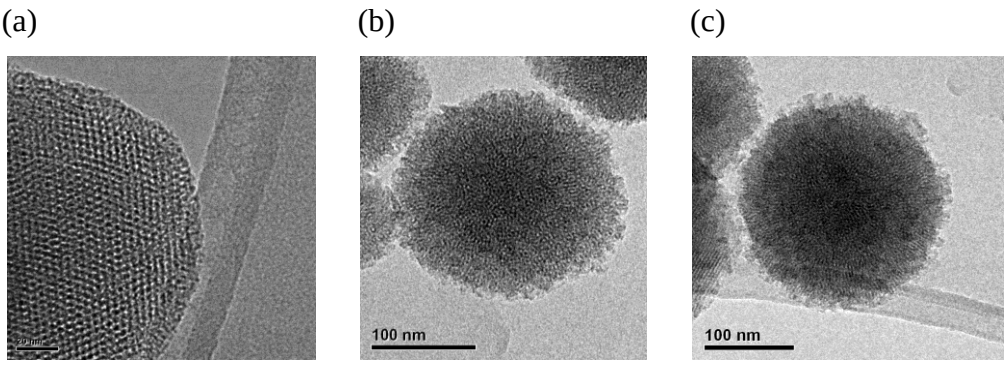
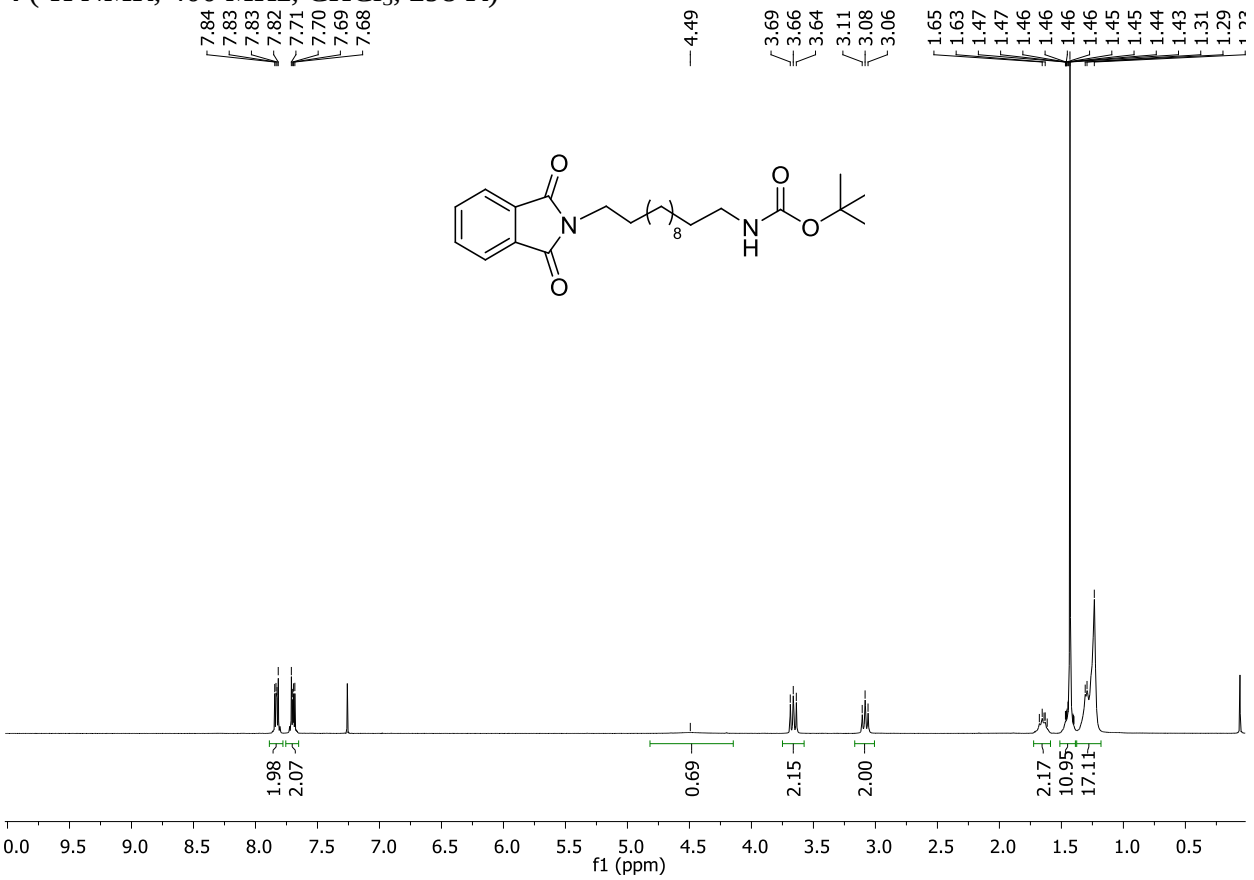


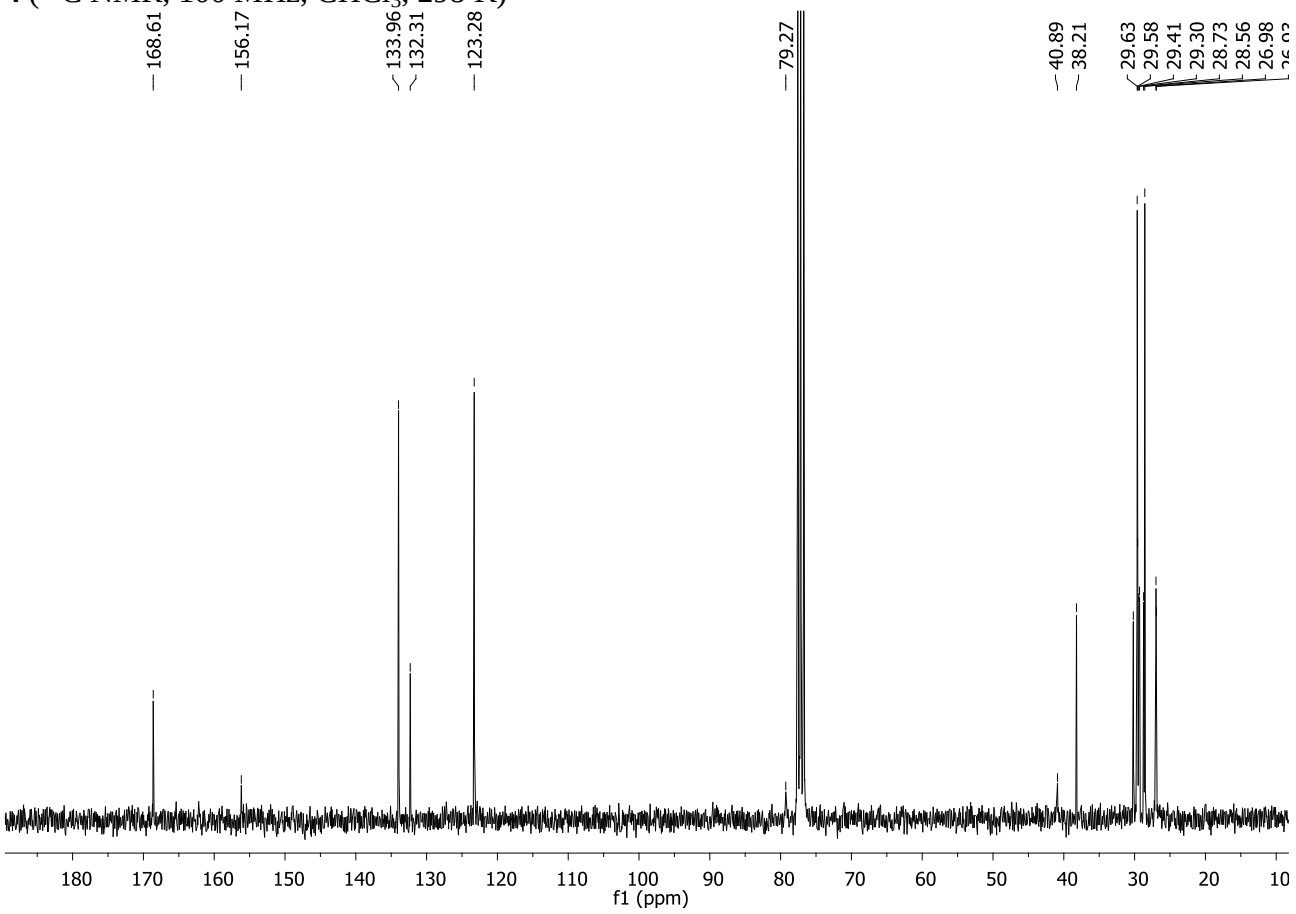

**Figure S14.** HR-TEM images of (a) **MSN-1**, b) **MSN-*E*-6** and c) **RhB-loaded MSN-*Z*-6**

## 13. NMR Spectra of synthesized compounds

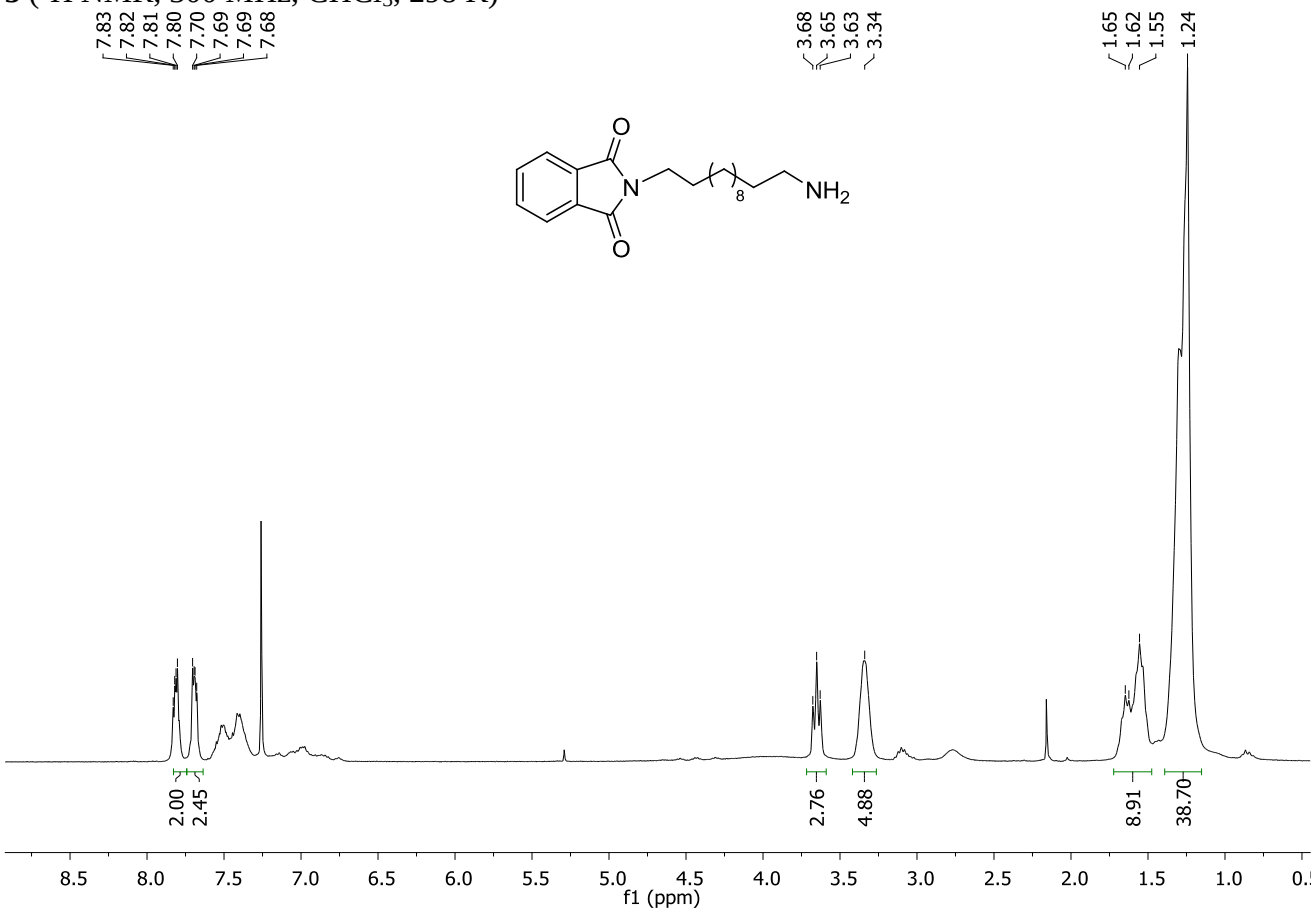
**4** ($^{1}$H NMR, 400 MHz, $CHCl_3$, 298 K)



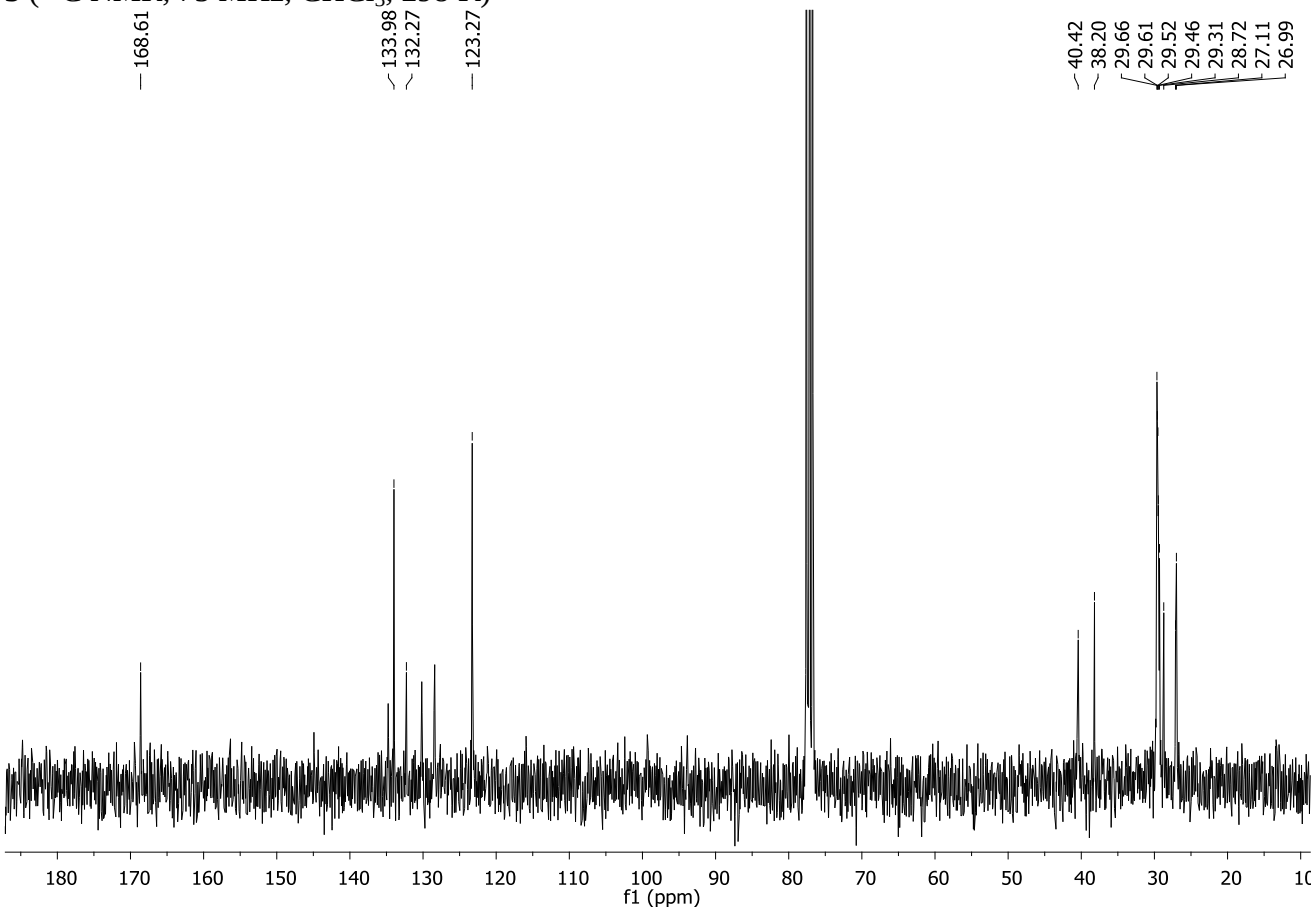

**4** ($^{13}$C NMR, 100 MHz, $CHCl_3$, 298 K)



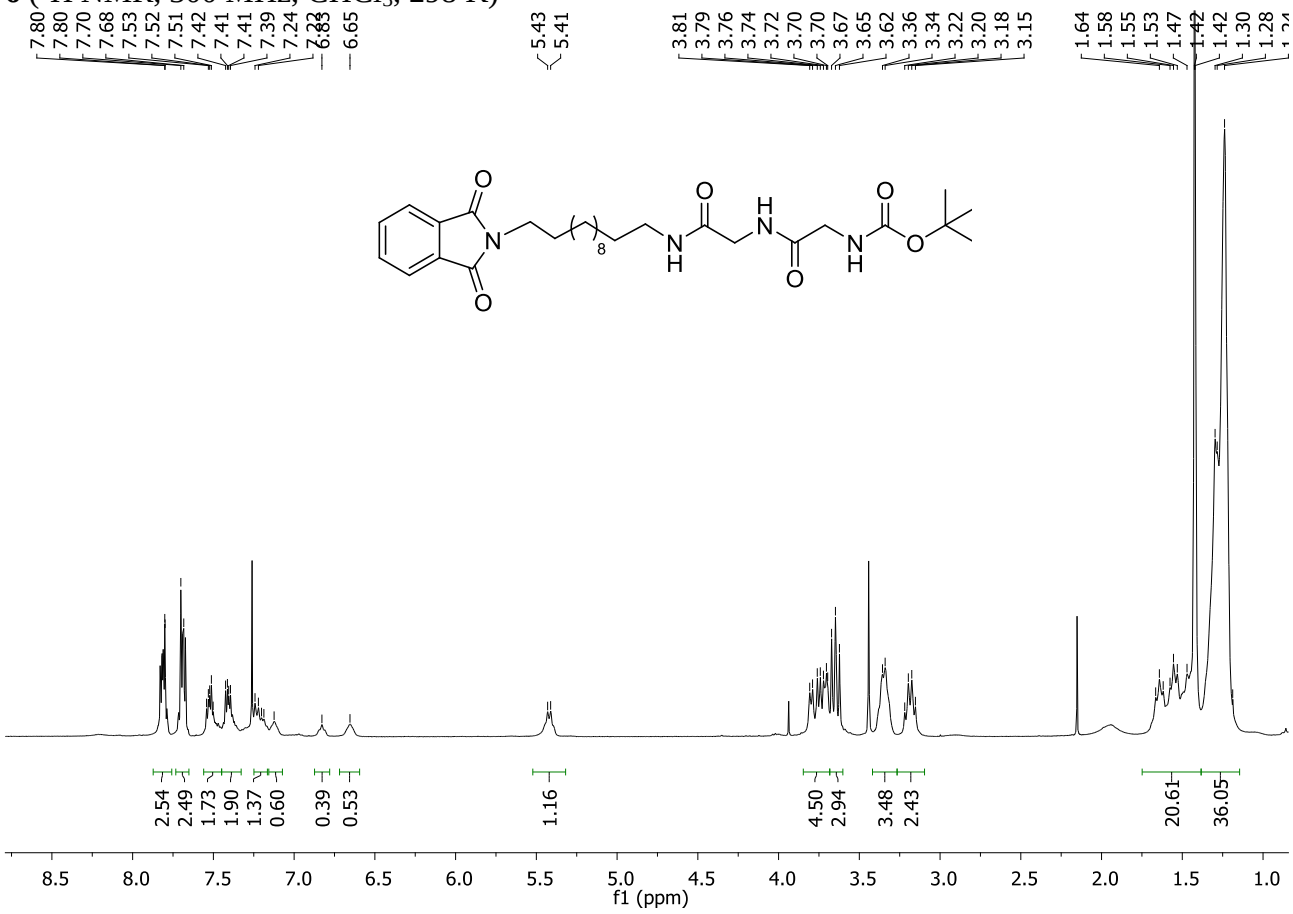
**5** ($^{1}$H NMR, 300 MHz, $CHCl_3$, 298 K)



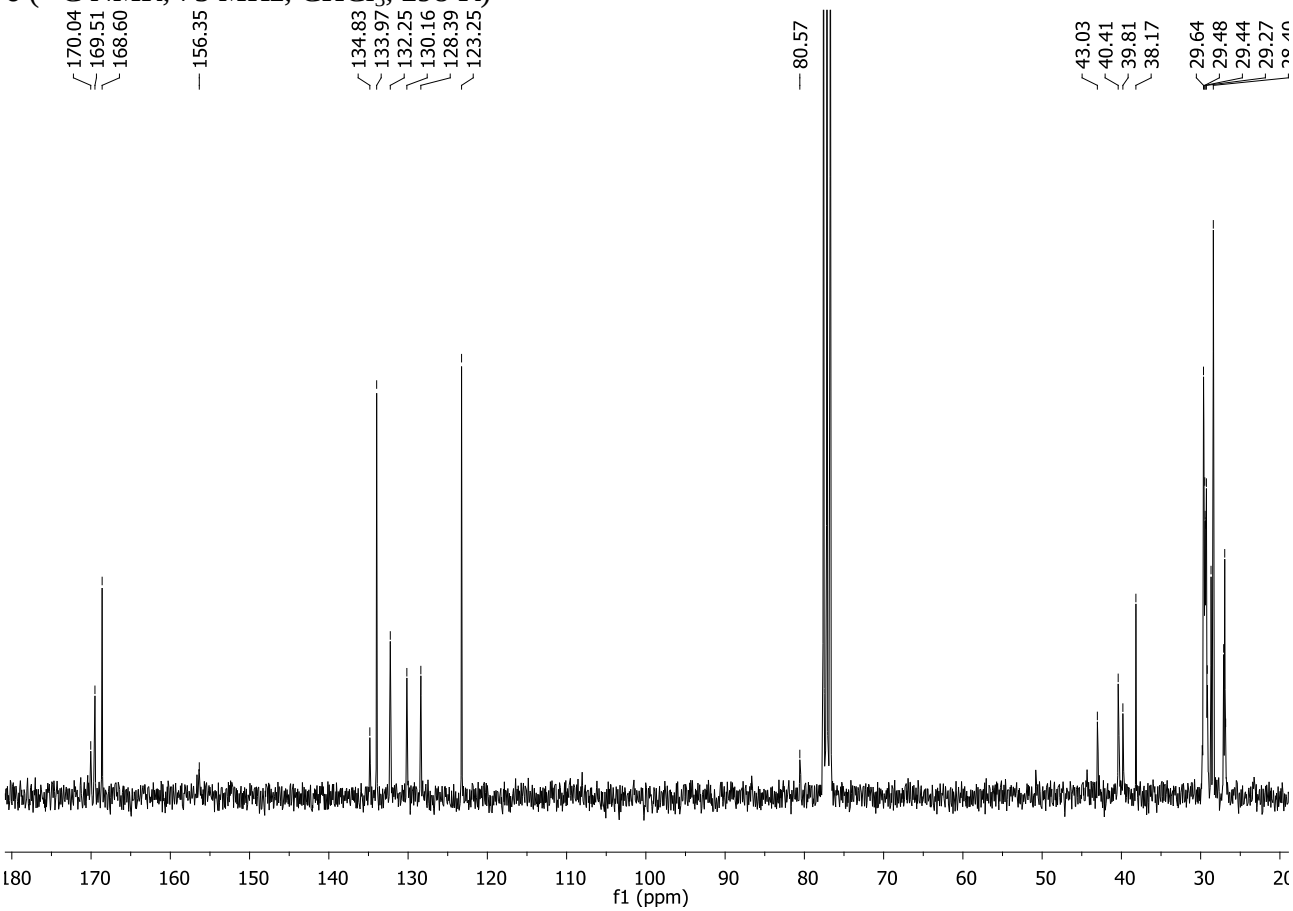

**5** ($^{13}$C NMR, 75 MHz, $CHCl_3$, 298 K)



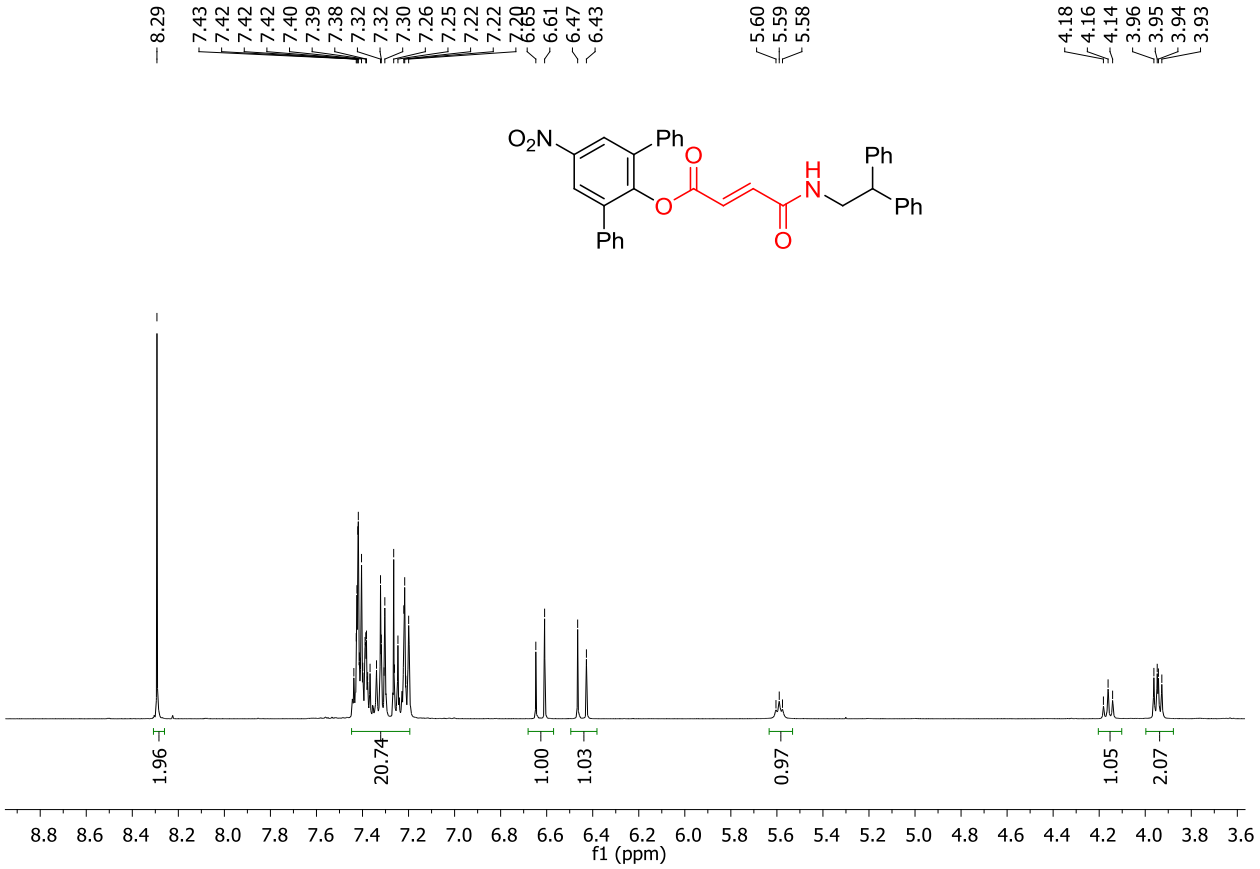
**6** ($^{1}$H NMR, 300 MHz, $CHCl_3$, 298 K)



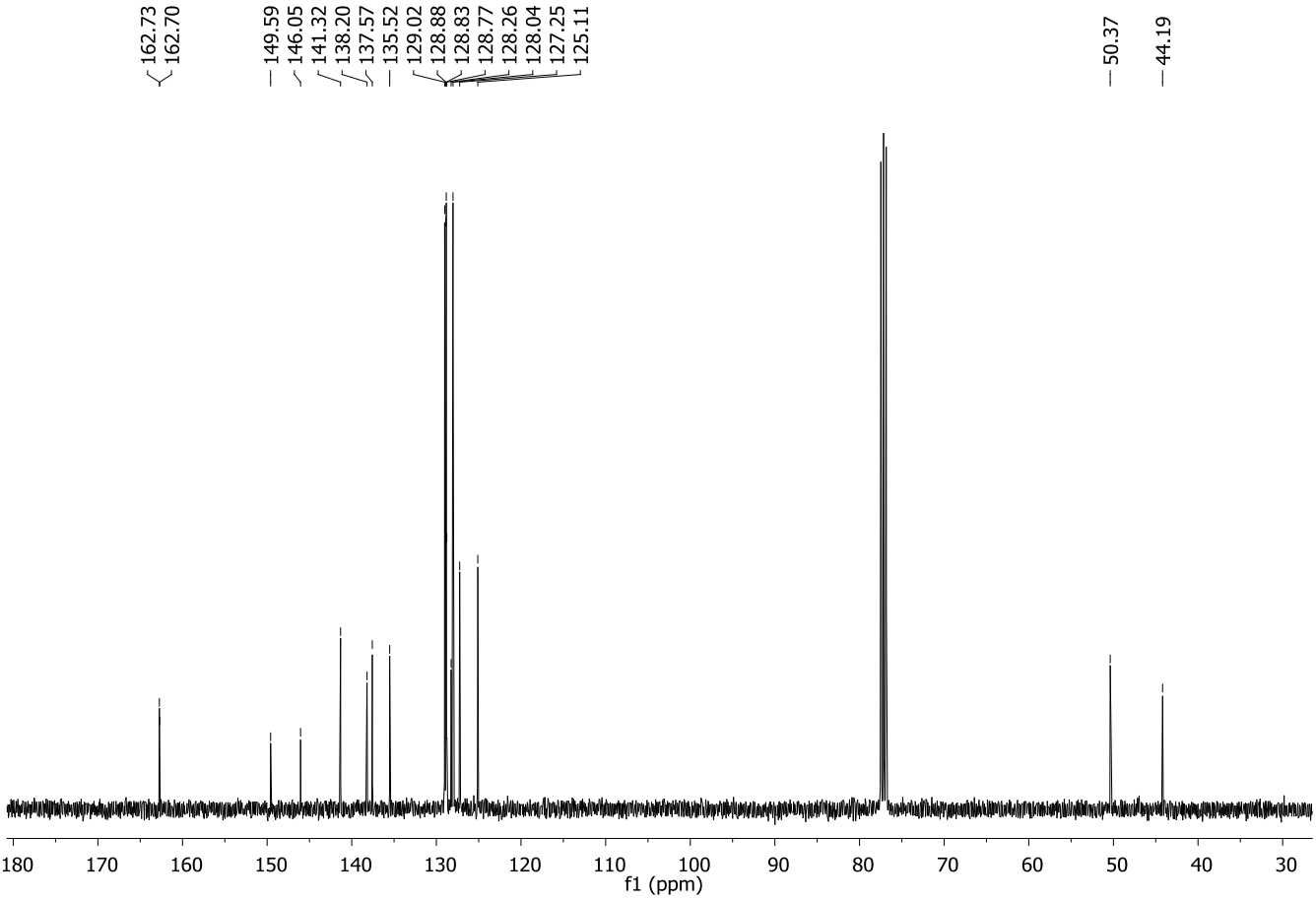

**6** ($^{13}$C NMR, 75 MHz, $CHCl_3$, 298 K)



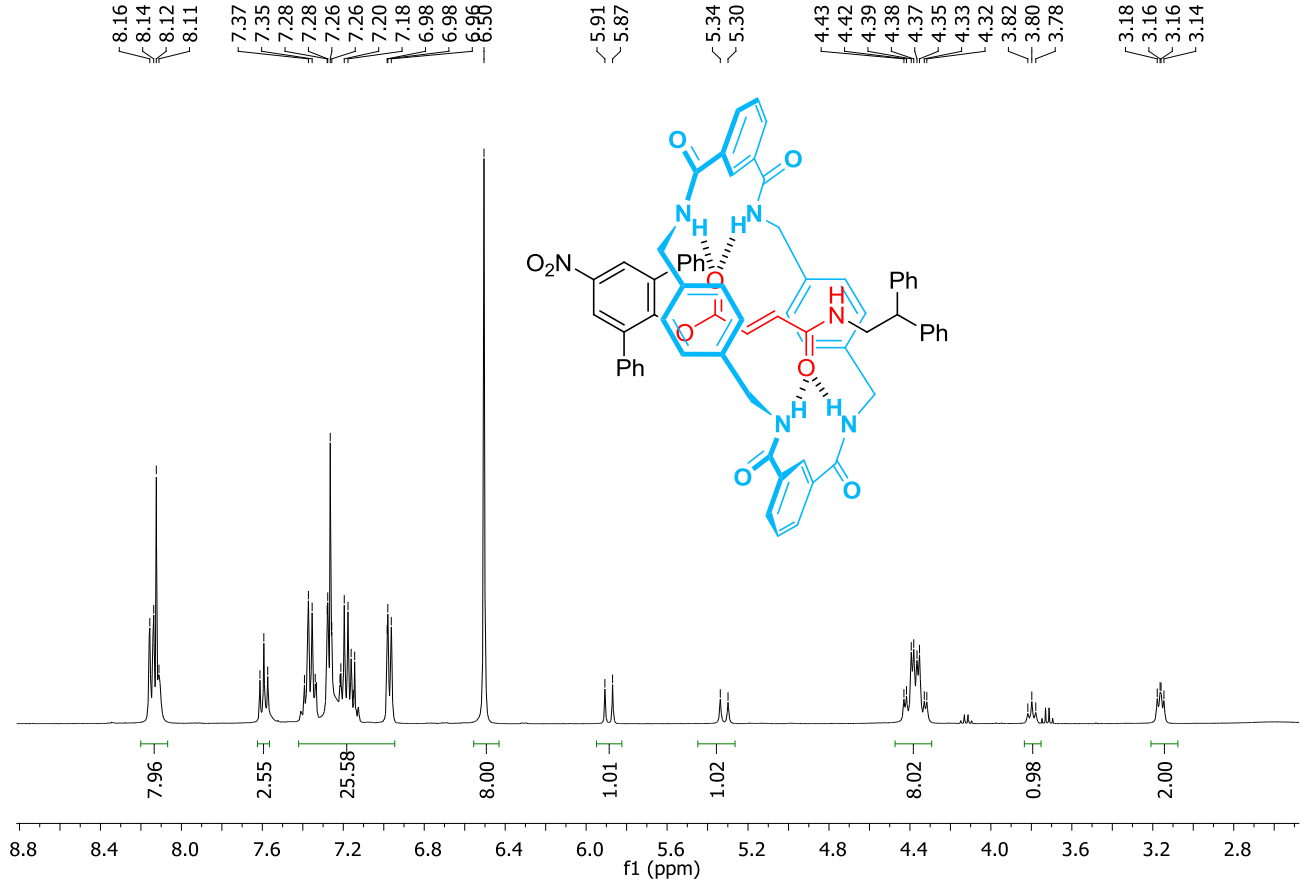
**8** ($^{1}$H NMR, 400 MHz, $CHCl_3$, 298 K)



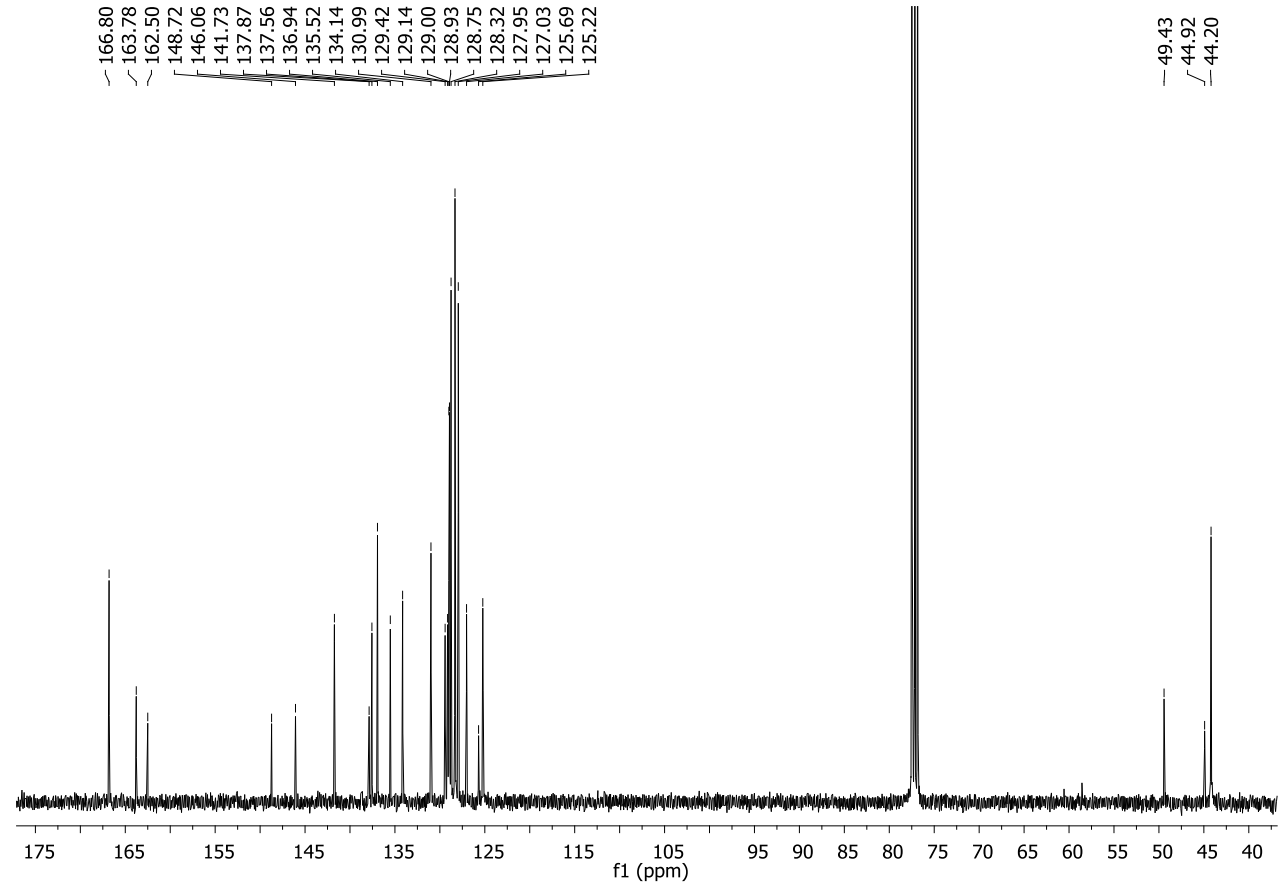

**8** ($^{13}$C NMR, 100 MHz, $CHCl_3$, 298 K)



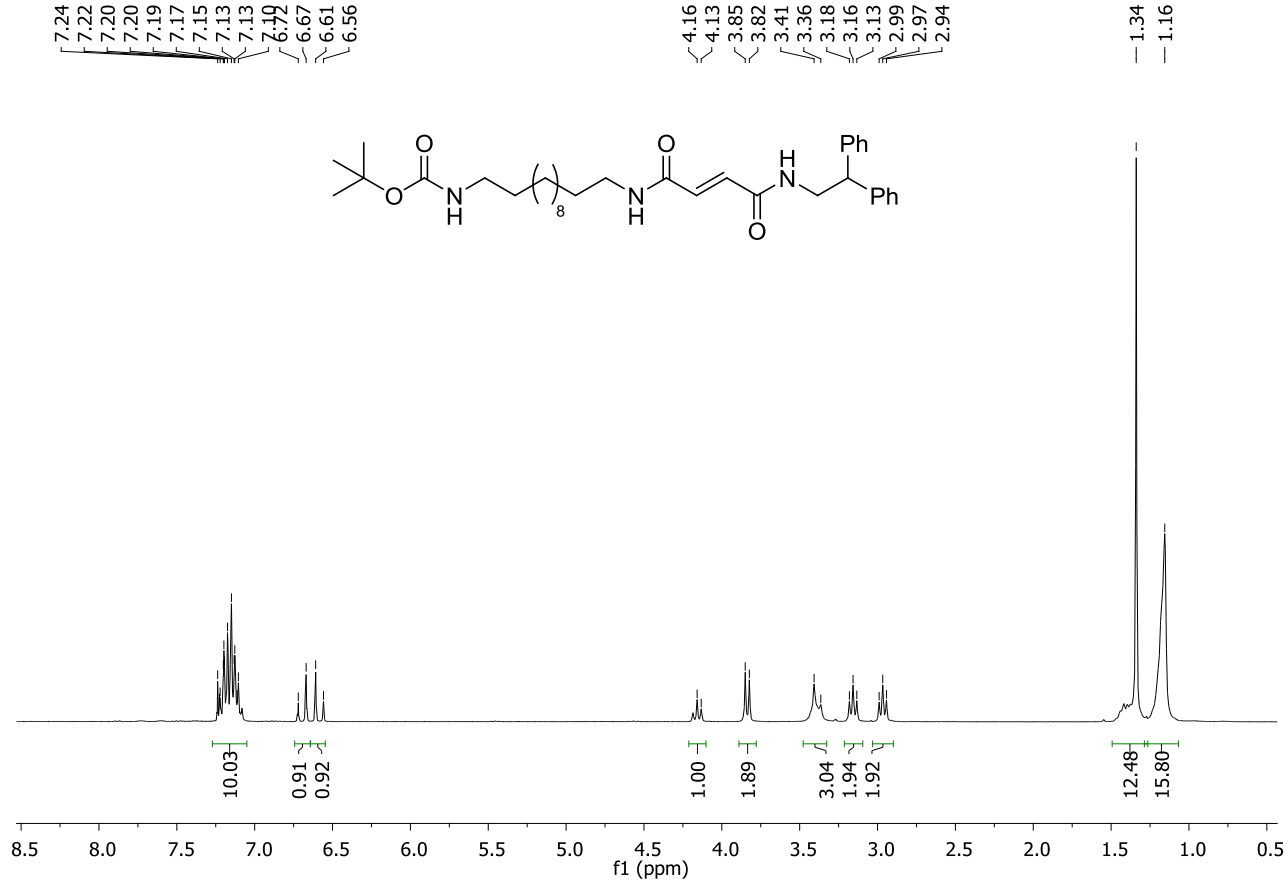
**S2** ($^{1}$H NMR, 400 MHz, $CHCl_3$, 298 K)



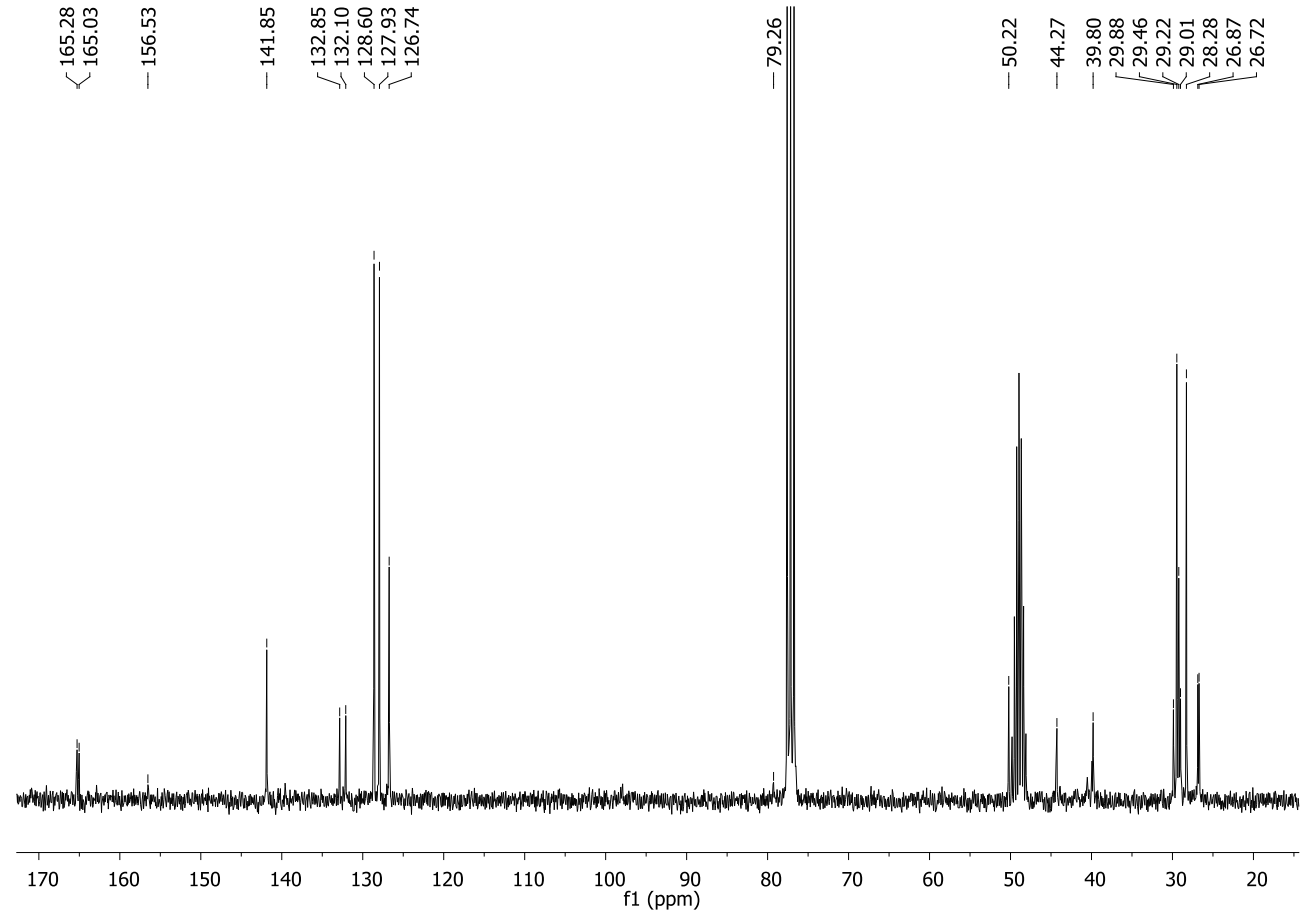

**S2** ($^{13}$C NMR, 100 MHz, $CHCl_3$, 298 K)



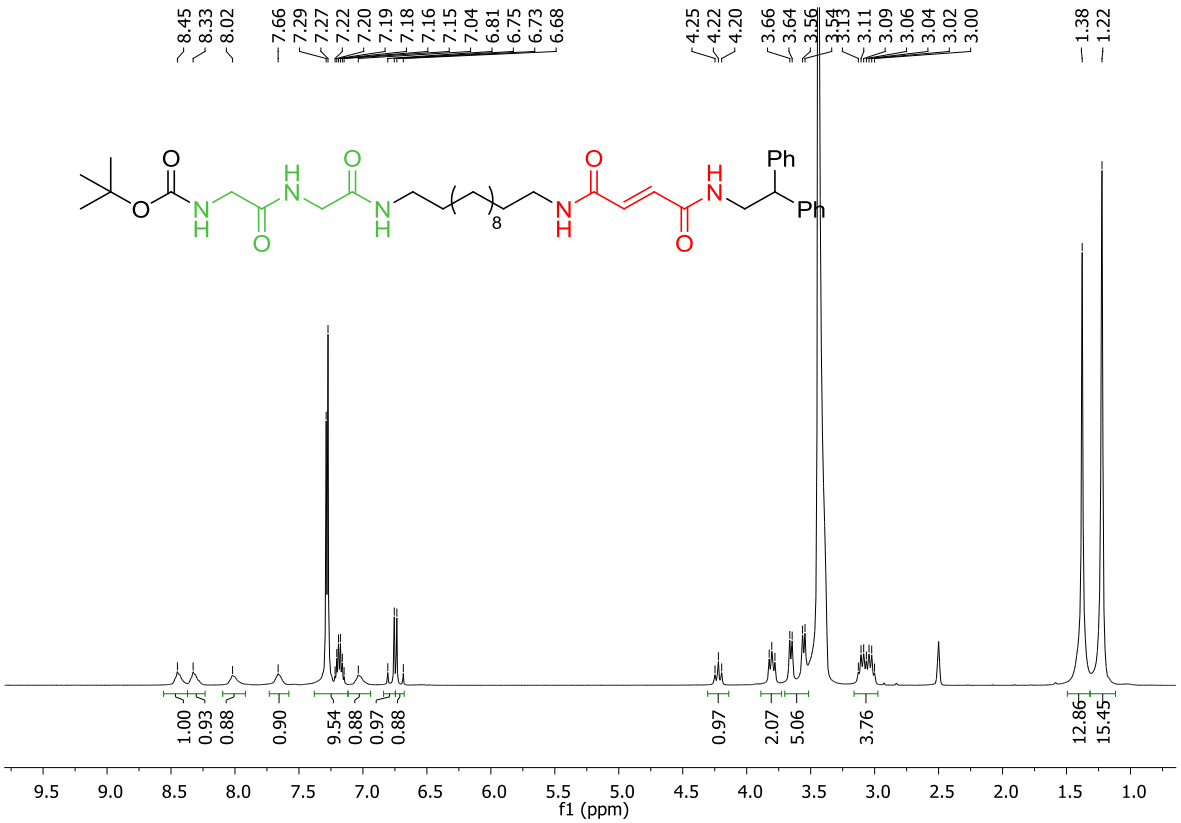
**9** ($^{1}$H NMR, 300 MHz, $CHCl_3$+MeOD, 298 K)




**9** ($^{13}$C NMR, 75 MHz, $CHCl_3$+MeOD, 298 K)



**10** ($^{1}$H NMR, 300 MHz, DMSO-*d6*, 298 K)




**10** ($^{13}$C NMR, 75 MHz, DMSO-*d6*, 298 K)