Chemistry–A European Journal

Supporting Information

Hydrogen-Bonded Dimeric Capsules with Appended Spiropyran Units: Towards Controlled Cargo Release

Pedro Ferreira, Giulia Moncelsi, Gemma Aragay, and Pablo Ballester*

Contents

1. General information and instruments

Solvents and reagents were of reagent grade quality and were obtained from commercial suppliers and used without further purification unless otherwise stated. Dry solvents were either obtained from commercial suppliers or taken from a solvent system *MB SPS 800* and freshly distilled. Thin-layer chromatography (TLC) was performed with DC-Alufolien Kieselgel 60 F_{254} (Merck) or neutral Al_2O_3 F_{254} (Sigma-Aldrich). Column chromatography was performed with silica gel 60 Å for chromatography (Sigma-Aldrich). Routine ^1H and ^{13}C NMR spectra were recorded on *Bruker* Avance 300 (300 MHz for ^1H NMR), Avance 400 (400 MHz for ^1H NMR) or Avance 500 (500 MHz for ^1H NMR) ultra-shield spectrometers. Deuterated solvents from Eurisotop are indicated in the characterization and chemical shifts are reported in ppm. ^1H NMR splitting patterns are designated as singlet (s), doublet (d), or triplet (t). Splitting patterns that could not be easily interpreted are designated as multiplet (m) or broad (br). All NMR *J* values are given in Hz. UV-Vis measurements were carried out on a *Shimadzu UV-2401PC* spectrophotometer equipped with a photomultiplier detector, double beam optics and D_2 and W light sources. The spectra were recorded in a quartz cuvette (10 mm path length). UV-Vis spectroscopy purity solvents from *Merck* were used.
HRMS measurements for SP-C4A were performed in an AutoFlex (Bruker Daltonics) MALDI-TOF-MS. HRMS measurements for SP-C4P were completed with a Water's Synapt G2-S ion mobility time of flight mass spectrometer (Manchester, UK) equipped with a Z-spray electrospray ionisation source. A capillary voltage of 4.00 kV was used with the sample cone and source offset both set to 25 eV and 25 eV. A source temperature of 40ºC and desolvation temperature of 30ºC were used during measurements. Final sample concentration was 50μM in dichloromethane with 5% formic acid and was injected with a flow rate of 5μL/min.

Experimental details of the photo-induced isomerization experiments.

We prepared SP-C[4]A or SP-C[4]P solutions in the corresponding solvent (DMSO or DCM) and thermo-equilibrated them overnight in the dark at 30ºC or 60ºC, respectively, before starting the photo-isomerization experiments. Irradiation of the samples was performed using a high-power light source purchased from *Sahlmann Photochemical Solutions* and consisting of 3 LED-diodes from *Nichia* (365 nm, 241.5 $mW \cdot cm^{-2}$). Samples were irradiated inside the NMR tube or the UV-Vis cuvettes using a custom-made sample holder which located the sample at 1.5 cm distance from the power source (LED). Finally, the solutions were thermally equilibrated at 30ºC or 60ºC overnight in the dark to recover the starting spectra.

Experimental details of the acid/base-induced isomerization experiments.

Standard 150 mM solutions of triflic acid (TfOH) and freshly distilled triethylamine (Et_3N) in the corresponding solvent of the experiment ($(CH_3)_2SO$ or CH_2Cl_2 or their deuterated analogues) were used for the acid/base induced isomerization studies of the monomers and homo-dimers.

2. Synthesis and characterization data

2.1. Tetra-spiropyran tetra-urea calix[4]arene SP-C[4]A

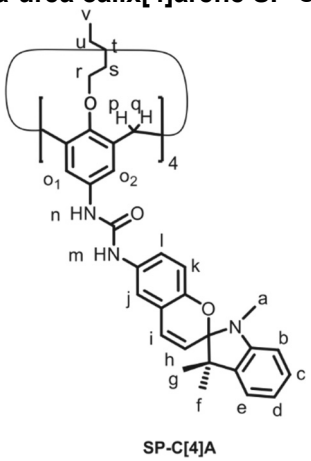


Figure S1. Chemdraw structure of the tetra-spiropyran tetra-urea calix[4]arene SP-C[4]A with the corresponding proton assignment.

Tetra-spiropyran tetra-urea calix[4]arene SP-C[4]A. 67% yield. R_f = 0.37 (CH_2Cl_2:CH_3OH 99:1). m.p. = >230 °C (decompose). ^{1}H NMR ($(CD_3)_2SO$, 500 MHz) δ (ppm): 8.11 (s, 4H); 8.09 (s, 4H); 7.22 (s, 4H); 7.08 (m, 4H); 7.06 (d, *J* = 7.8 Hz, 4H); 6.95 (d, *J* = 8.6 Hz, 4H); 6.93 (d, *J* = 10.2 Hz, 4H); 6.78 (s, 8H); 6.75 (m, 4H); 6.55 (d, *J* = 8.6 Hz, 4H); 6.52 (d, *J* = 7.8 Hz, 4H); 5.73 (d, *J* = 10.2 Hz, 4H); 4.32 (d, *J* = 12.0 Hz, 4H); 3.80 (s, 8H); 3.08 (d, *J* = 12.0 Hz, 4H); 2.61 (s, 12H); 1.90 (s, 8H); 1.38 (s, 16H); 1.18 (s, 8H); 1.06 (s, 8H); 0.93 (s, 12H). ^{13}C {^{1}H} NMR ($CDCl_3$, 126 MHz) δ (ppm): 152.6; 151.0; 148.9; 147.8; 136.3; 134.3; 133.5; 132.4; 129.4; 127.3; 121.3; 120.2; 119.7; 118.8; 118.4; 118.1; 117.0; 114.2; 106.7; 103.4; 74.8; 51.2; 30.7; 29.4; 28.5; 27.9; 25.6; 22.3; 19.8; 14.0. FT-IR ν (cm^{-1}) = 3368 (urea N-H stretching); 2955 (C-H stretching); 1666, 1606, 1539, 1483 (aromatic C=C stretching). HRMS (MALDI/+) m/z: $[M+H]^+$ Calcd. for $C_{128}H_{141}N_{12}O_{12}$: 2038.0786; found: 2038.0759.

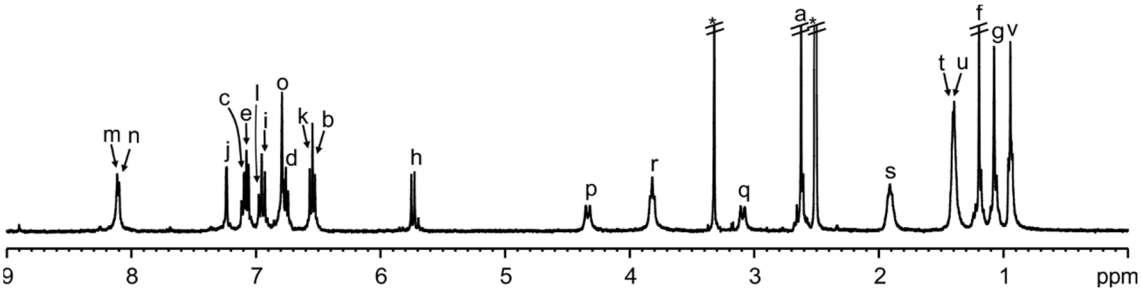


Figure S2. ^{1}H NMR ($(CD_3)_2SO$, 500 MHz) spectrum of compound 2 mM solution of SP-C[4]A. * Residual solvent peaks. See **Figure S1** for proton assignment.

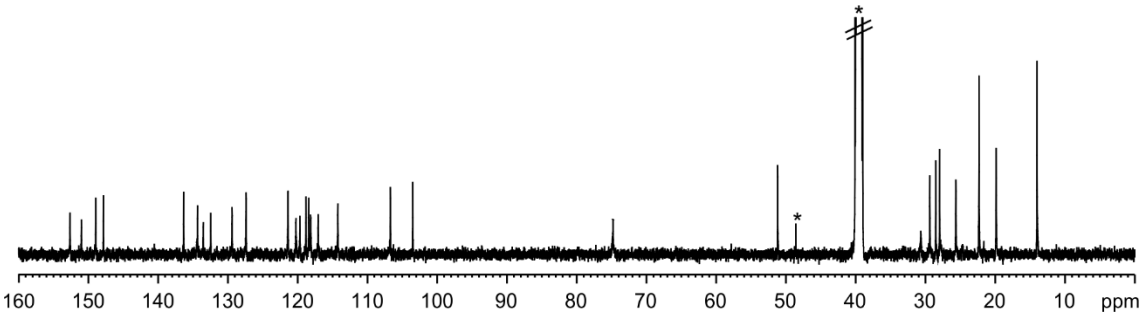


Figure S3. ^{13}C NMR ($(CD_3)_2SO$, 126 MHz) spectrum of 2 mM solution of SP-C[4]A. * Residual solvent peaks.

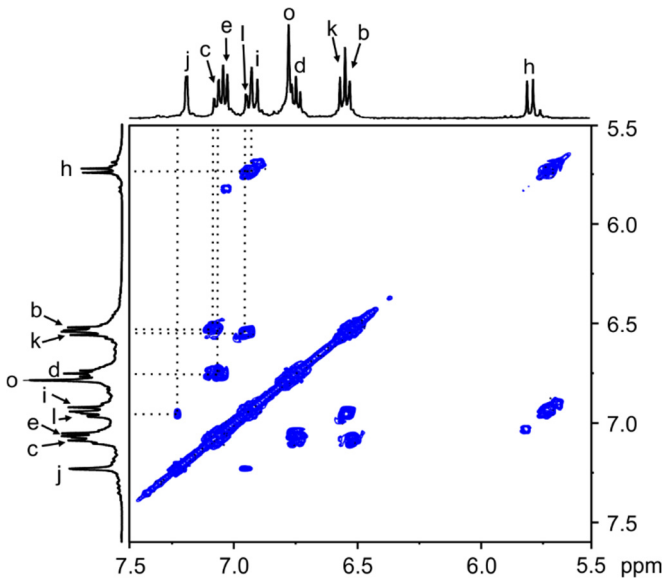


Figure S4. Selected aromatic region of the ^{1}H COSY NMR ($(CD_3)_2SO$, 500 MHz) spectrum of a 2 mM solution of SP-C[4]A. Relevant cross-peaks are highlighted.

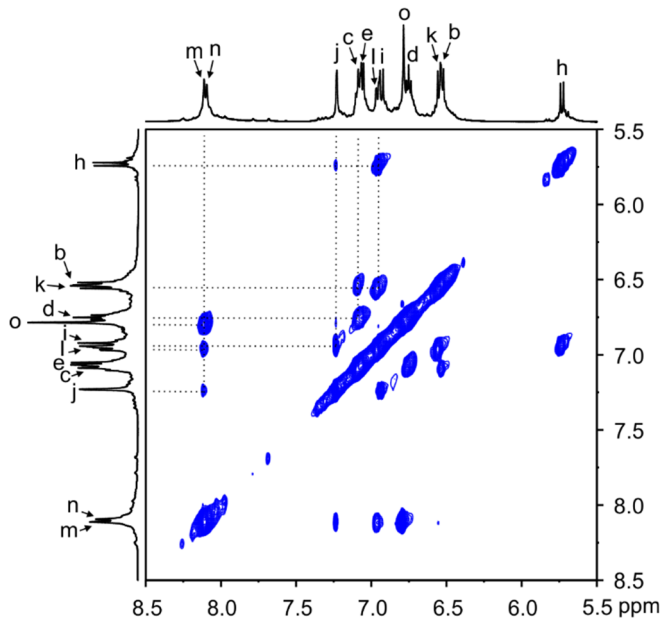


Figure S5. Selected aromatic region of the ^{1}H NOESY NMR ($(CD_3)_2SO$, 500 MHz) spectrum of a 2 mM solution of SP-C[4]A. Relevant cross peaks for proton assignment are highlighted.

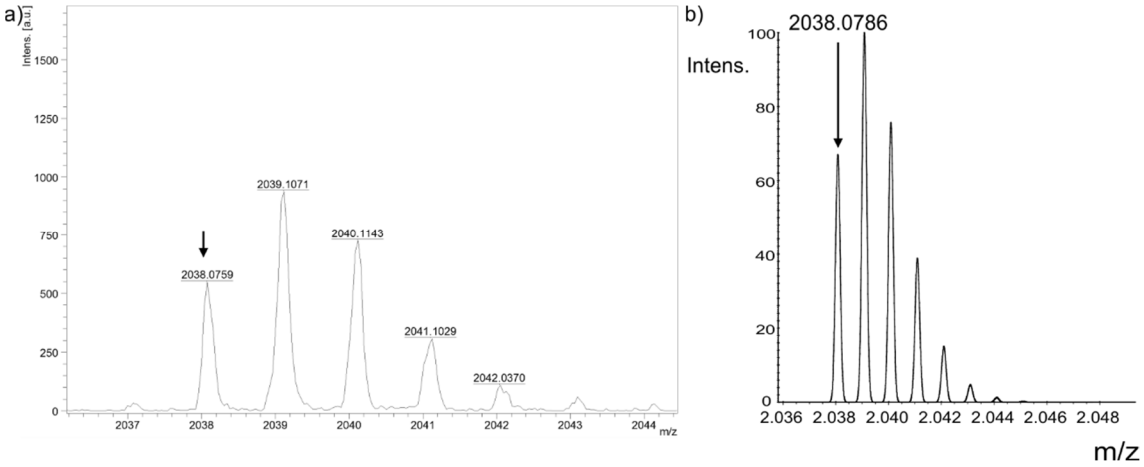
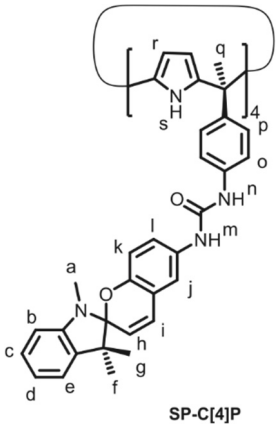


Figure S6. a) Experimental and b) theoretical isotopic distributions for $[M+H]^+$ peak of SP-C[4]A. The exact mass for the monoisotopic peak in a) and b) is indicated.

2.2. Tetra-spiropyran tetra-urea calix[4]pyrrole SP-C[4]P



SP-C[4]P

Figure S7. Molecular structure of tetra-spiropyran tetra-urea calix[4]pyrrole SP-C[4]P with the corresponding proton assignment.

Tetra-spiropyran tetra-urea calix[4]pyrrole SP-C[4]P: (47% yield). m.p. = >230 °C (decompose). ^{1}H NMR (400 MHz, $(CD_3)_2SO$, 298K): δ (ppm)= 9.56 (s, 4H); 8.50 (s, 4H); 8.347 (s, 4H); 7.30 (s, 12H); 7.05 (m, 8H); 6.99 (d, J=10.2 Hz, 4H); 6.84 (d, J=8.9 Hz, 8H); 6.73 (m, 4H); 6.54 (d, J=8.9 Hz, 4H); 6.50 (d, J=9.9 Hz, 4H); 5.94 (s, 8H); 5.67 (d, J=10.2 Hz, 4H); 2.58 (s, 12H); 1.77 (s, 12H); 1.61 (s, 12H); 1.03 (s, 12H). ^{13}C {^{1}H} NMR ($(CD_3)_2SO$ 3, 126 MHz) δ (ppm): 152.7; 149.1; 147.8; 143.4; 138.3; 137.3; 136.3; 132.3; 129.4; 127.4; 127.2; 121.4; 120.5; 119.8; 118.8; 118.5; 117.9; 117.2; 114.3; 106.7; 104.7; 103.5; 51.2; 43.7; 31.3; 28.5; 25.7; 19.9. FT-IR ν (cm^{-1}) = 3370 (urea N-H stretching); 2975, 2868 (C-H stretching); 1682, 1539, 1485 (aromatic C=C stretching). HRMS (ESI/+) m/z: $[M+2H]^{2+}$ Calc for ($C_{128}H_{122}N_{16}O_8$): 1005.4810; found: 1005.4821. $[M+3H]^{3+}$ Calc for ($C_{128}H_{123}N_{16}O_8$): 670.6565; found: 670.6587.

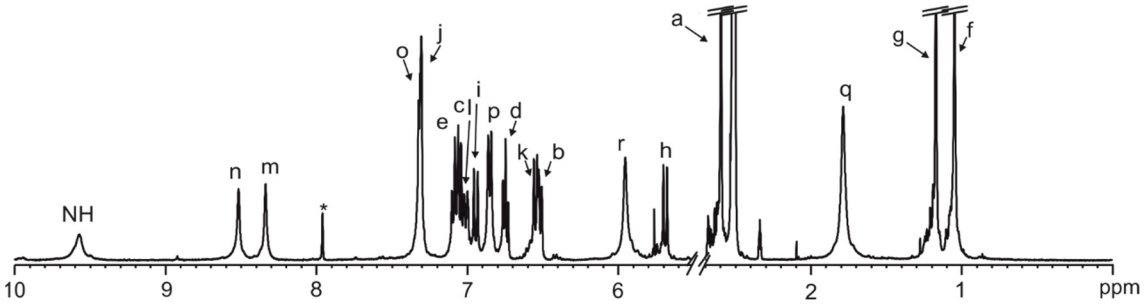


Figure S8. ^{1}H-NMR ($(CD_3)_2SO$, 400 MHz) spectrum of SP-C[4]P. *Residual solvent peak. See **Figure S7** for proton assignment.

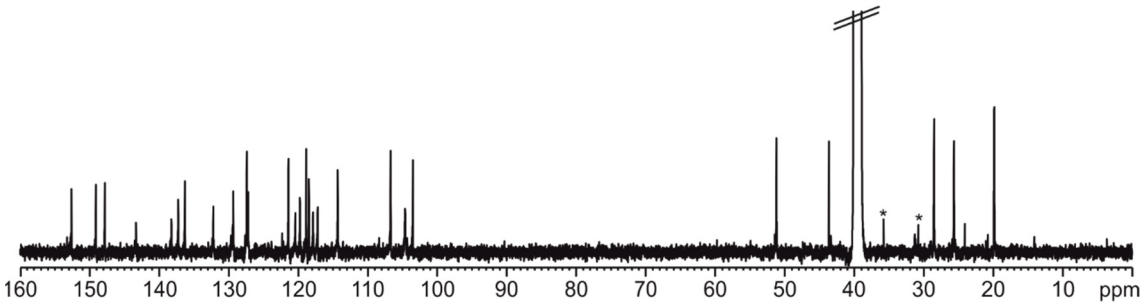


Figure S9. ^{13}C NMR ($(CD_3)_2SO$, 126 MHz) spectrum of SP-C[4]P.* Residual solvent peaks.

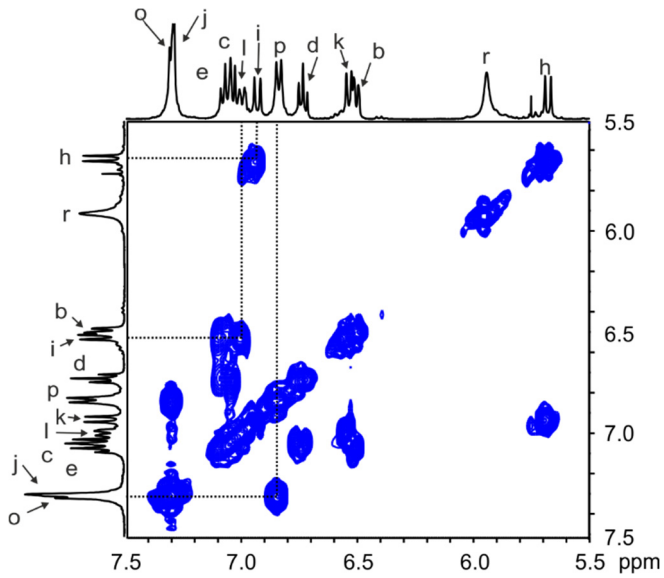


Figure S10. Selected aromatic region of the ^{1}H COSY NMR ($(CD_3)_2SO$, 400 MHz) spectrum of SP-C[4]P. Relevant cross-peaks for proton assignment are highlighted.

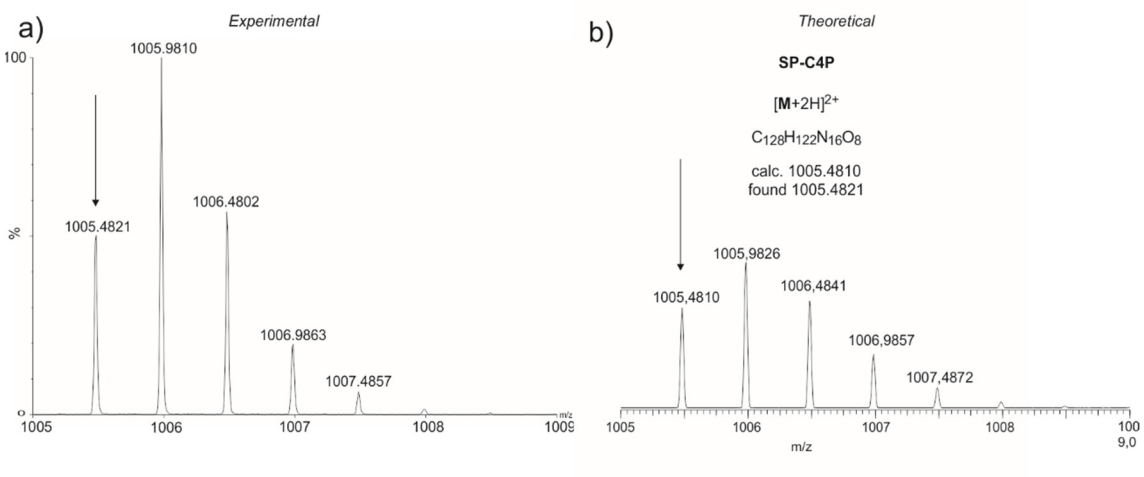
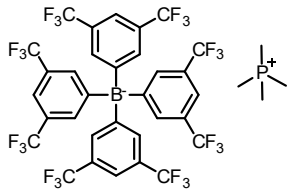


Figure S11. a) Experimental and b) theoretical isotopic distributions for $[M+2H]^{2+}$ of compound SP-C[4]P. The exact mass for the monoisotopic peak in a) and b) is indicated.

2.3. Tetramethylphosphonium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate



8

Tetramethylphosphonium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate 4 BArF$^-$ (**$Me_4P^+BArF^-$**): a solution of sodium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate (Na^+BArF^-, 260 mg, 0.29 mmol, 1.2 equiv.) in 4 mL of anhydrous methanol was added dropwise to a 3 mL solution of tetramethylphosphonium chloride (31 mg, 0.24 mmol, 1 equiv.) in the same solvent under Ar atmosphere. The reaction was stirred at r.t. under Ar atmosphere. After 12 h the reaction was stopped. The solvent was evaporated under reduced pressure and the resulting solid was resuspended in 5 mL of water. The mixture was sonicated to generate a white suspension. The product was filtered off and washed several times with water, then dried under high vacuum to afford a white solid (156 mg, 67% yield). ^{1}H NMR (CD_2Cl_2, 400 MHz) δ (ppm): 7.72 (br, 8H); 7.57 (s, 4H); 1.86 (d, J_{H-P} = 14 Hz, 12H). $^{13}C\{^1H\}$ NMR (CD_2Cl_2, 101 MHz) δ (ppm): 162.14 (q, $^1J_{B-C}$ = 50 Hz); 135.21; 129.26 (q, $^1J_{C-F}$ = 32 Hz); 126.36; 123.65; 117.91; 10.97 (d, J_{C-P} = 56 Hz). $^{31}P\{^1H, ^{13}C\}$ NMR (CD_2Cl_2, 162 MHz) δ (ppm): 25.76. $^{19}F\{^{13}C\}$ NMR (CD_2Cl_2, 376 MHz) δ (ppm): -62.89. $^{11}B\{^{13}C\}$ NMR (CD_2Cl_2, 128 MHz) δ (ppm): -6.61.

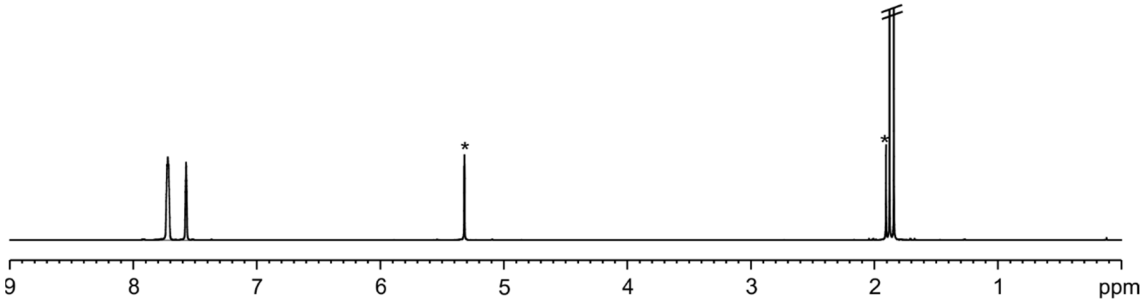


Figure S12. ^{1}H NMR (CD_2Cl_2, 400 MHz) spectrum of $Me_4P^+BArF^-$ (**4** $BArF^-$). * Residual solvent peaks.

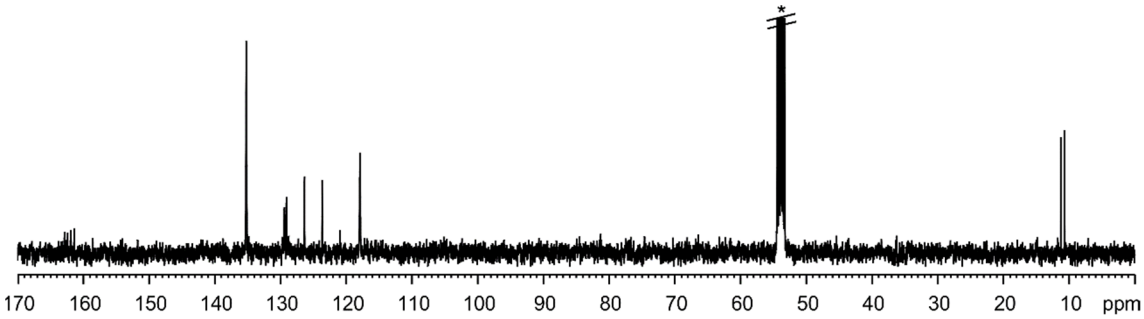


Figure S13. $^{13}C\{^{1}H\}$ NMR (CD_2Cl_2, 101 MHz) spectrum of $Me_4P^+BArF^-$ (**4** $BArF^-$). * Residual solvent peaks.

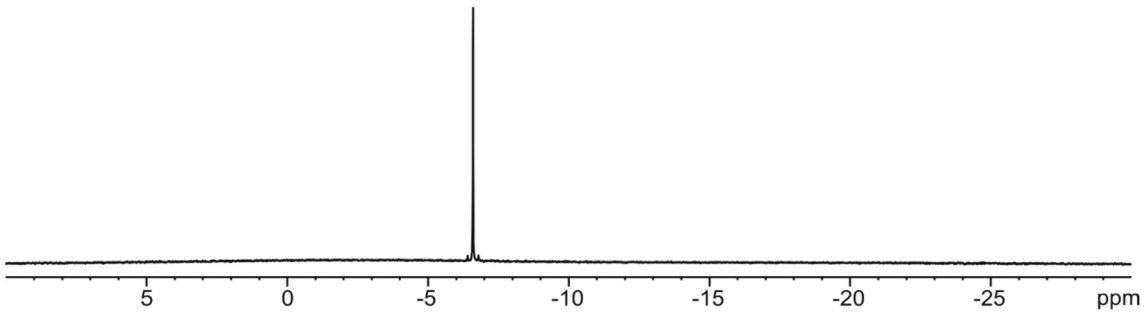


Figure S14. $^{11}B\{^{13}C\}$ NMR (CD_2Cl_2, 128 MHz) spectrum of $Me_4P^+BArF^-$ (**4** $BArF^-$).

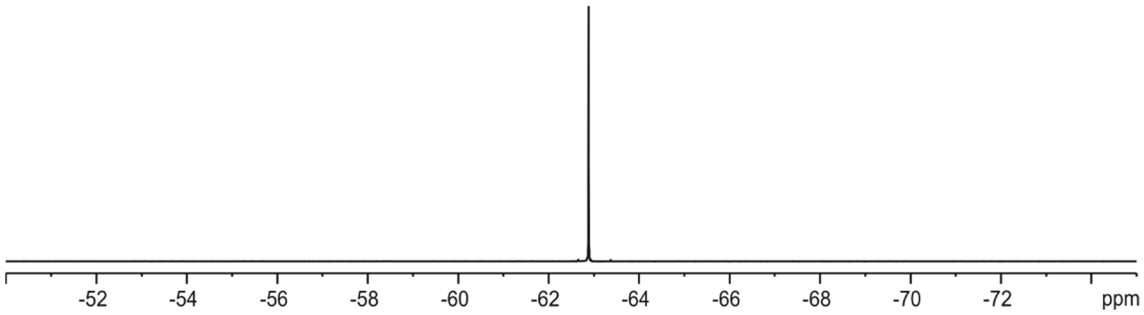


Figure S15. $^{19}F\{^{13}C\}$ NMR (CD_2Cl_2, 376 MHz) spectrum of $Me_4P^+BArF^-$ (**4** $BArF^-$).

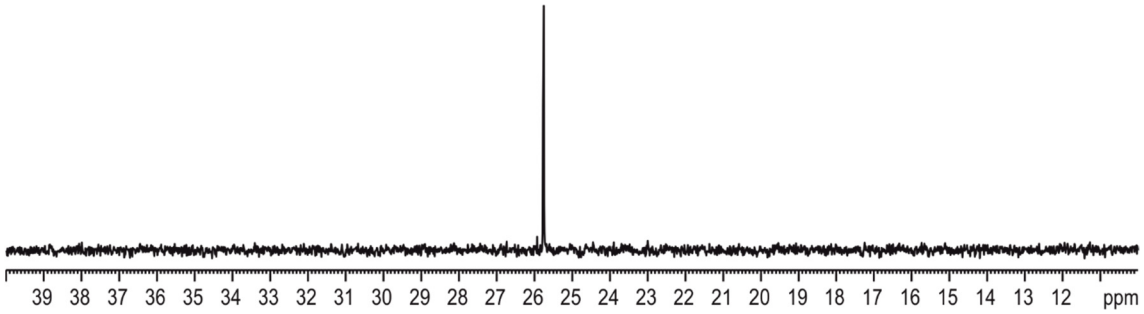


Figure S16. $^{31}P\{^{1}H, ^{13}C\}$ NMR (CD_2Cl_2, 162 MHz) spectrum of $Me_4P^+BArF^-$ (**4** $BArF^-$).

3. Spectral characterization of the photo- and acid-induced isomerization of all-SP-C[4]A and all-SP-C[4]P in DMSO

3.1. Photoisomerization studies in DMSO

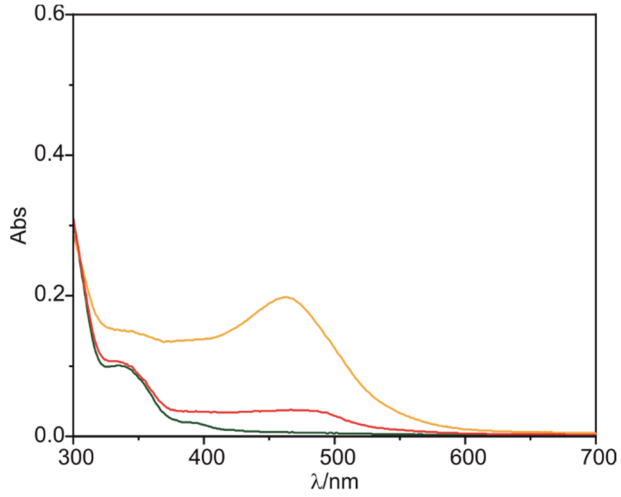


Figure S17. UV-Vis absorption spectra of a 20 μM $(CH_3)_2SO$ solution of SP-C[4]A before (green line); after irradiation at 365 nm for 12 min (yellow line) and after 24h at 60ºC (red line).

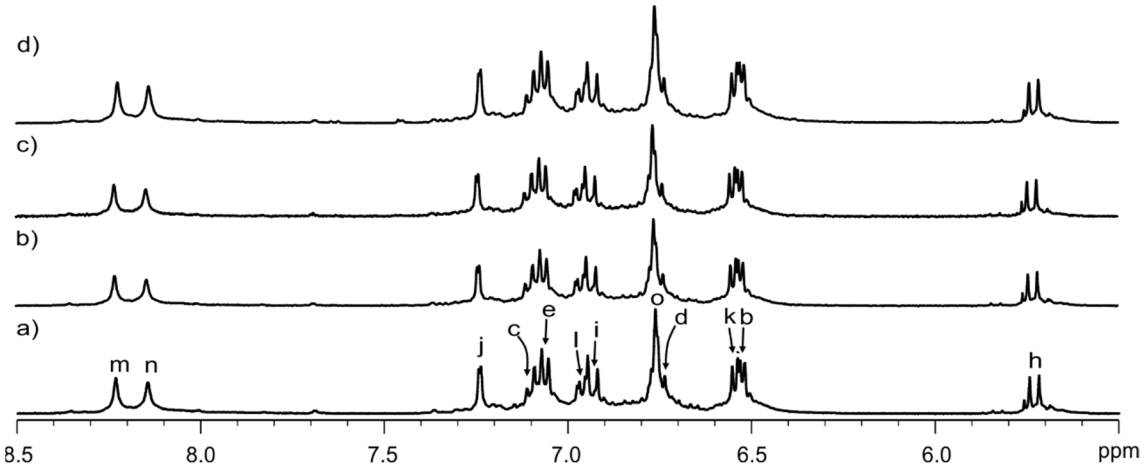


Figure S18. ^1H NMR ($(CD_3)_2SO$, 400MHz) spectra of a 2 mM thermo-equilibrated solution of SP-C[4]A before (a) and after irradiation at 365nm for b) 5, c) 10 min and d) after thermal equilibration. See **Figure S1** for proton assignment.

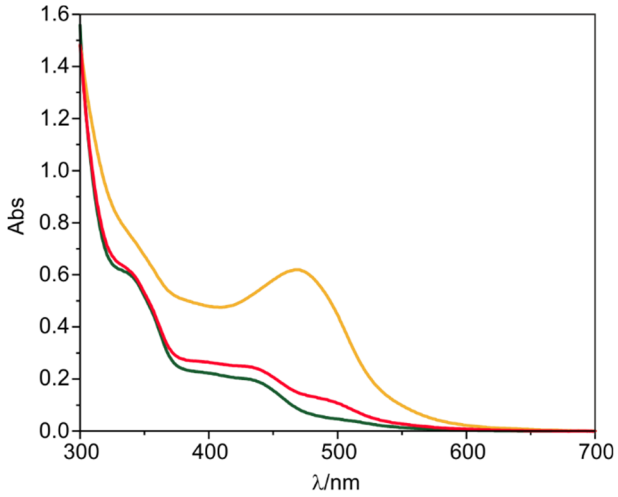


Figure S19. UV-Vis absorption spectra of a 50 μM $(CH_3)_2SO$ solution of SP-C[4]P before (green line); after irradiation at 365 nm for 14 min (orange line) and after 24h at 60ºC (red line).

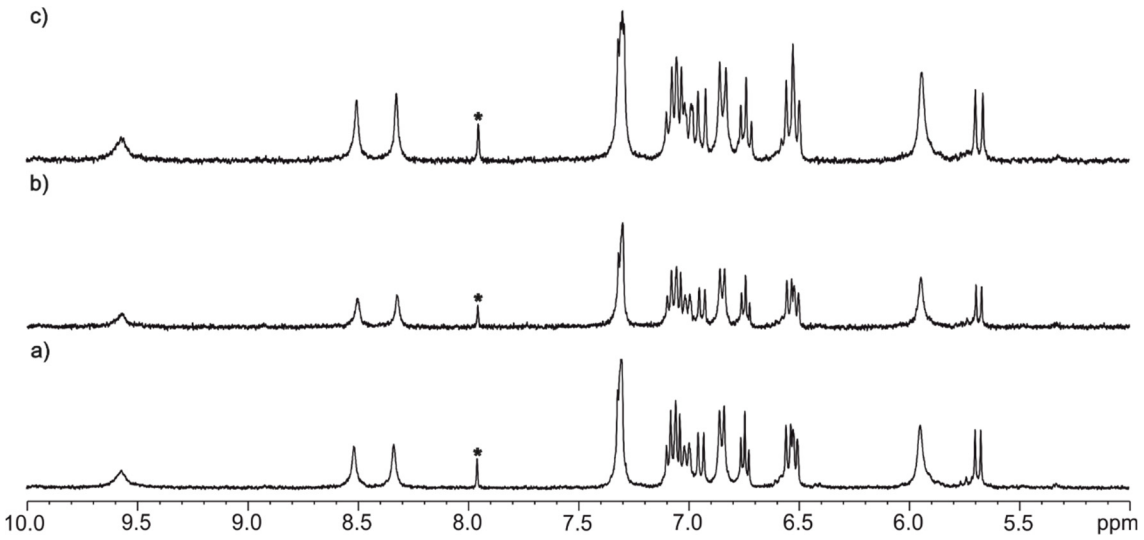


Figure S20. ^1H NMR ($(CD_3)_2SO$, 400MHz) spectra of a 1mM solution of SP-C[4]P light-irradiated at 365nm at a) 0 min; b) 10 min and c) thermal equilibration in the dark for 24h.

3.2. Acid-induced isomerization studies in DMSO

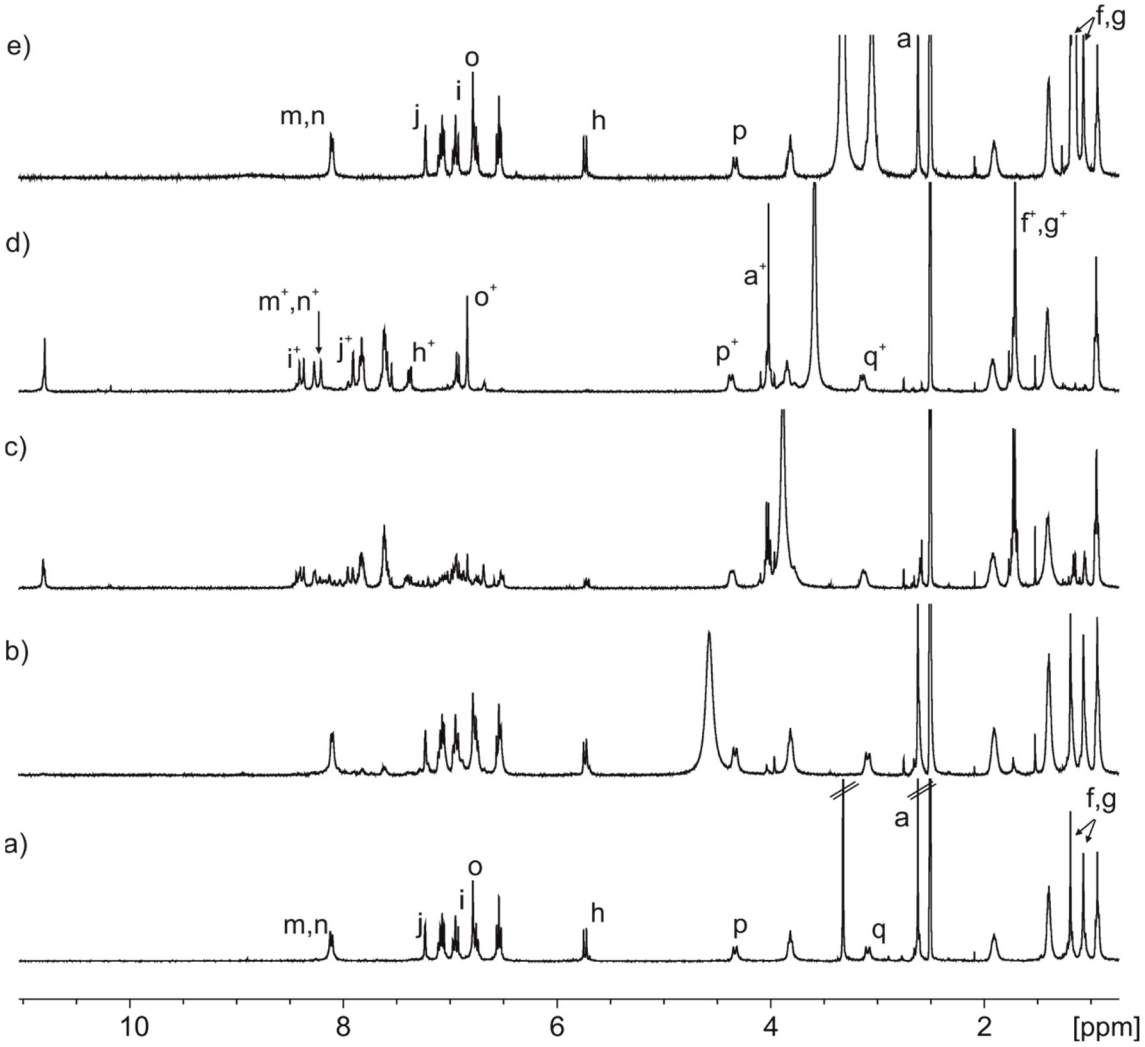


Figure S21. ^{1}H NMR ($(CD_3)_2SO$, 400 MHz) spectra at 298 K of a 2 mM solution of SP-C[4]A before (a) and immediately after (b) the addition of 4 equiv. of TfOH (8 mM); c) 12h after the addition of TfOH; d) 72h after the addition of TfOH and e) after further addition of 4 equiv. of Et_3N (8 mM) to solution of spectrum (d).

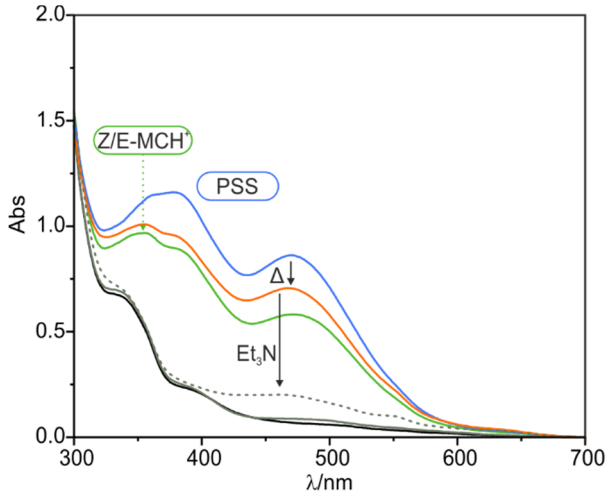


Figure S22. UV-Vis absorption spectra of a 50 μM $(CH_3)_2SO$ solution of SP-C[4]P. Black line – thermally equilibrated sample; grey line – upon addition of 4 equiv. of TfOH; green line – 24h after the addition of acid; blue line – light irradiation of the previous sample (green line species) at 365 nm for 30s; orange line – previous equilibrated sample in the dark for 24h and dotted grey line – upon addition of 4 equiv. of Et_3N.

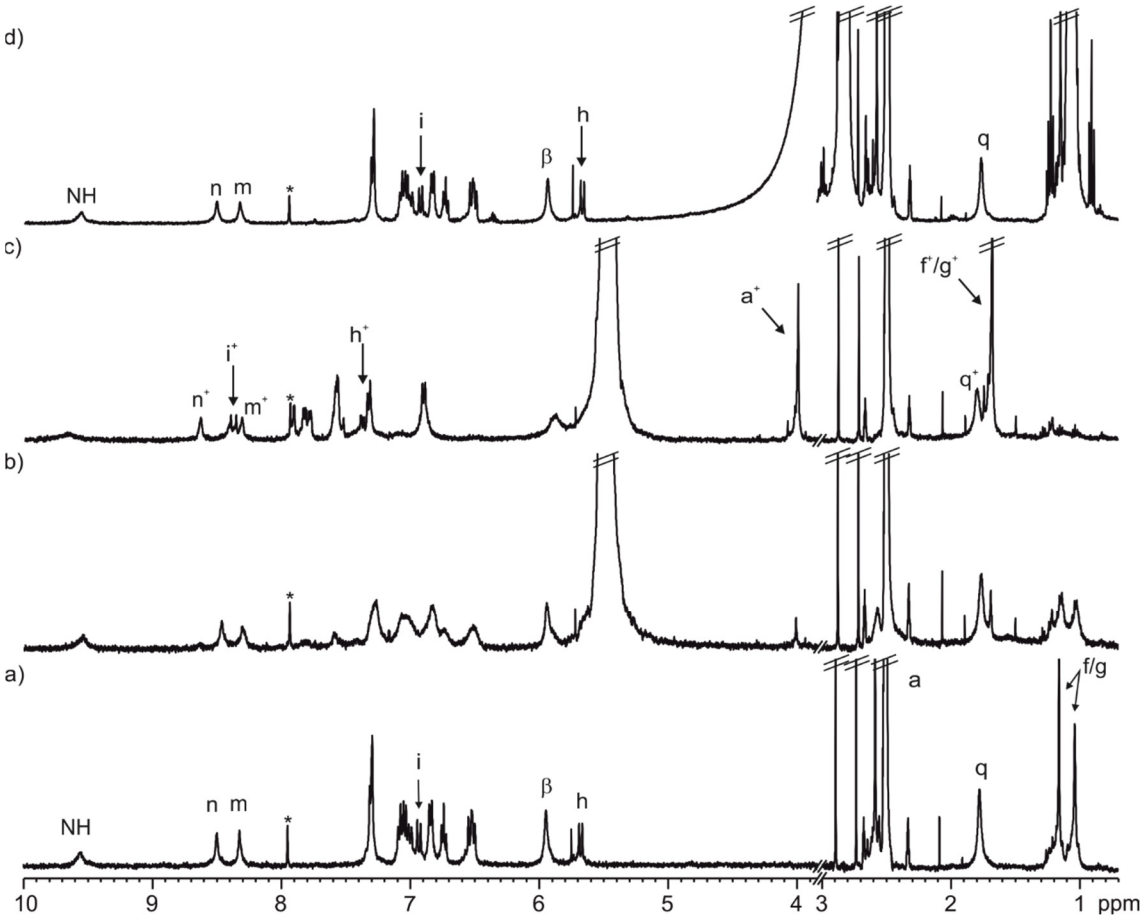


Figure S23. ^1H NMR ($(CD_3)_2SO$, 400 MHz) spectra at 298 K of a 2 mM solution of SP-C[4]P before (a) and immediately after (b) the addition of 4 equiv. of TfOH (8 mM), c) 72h after the addition of TfOH and d) after further addition of 4 equiv. of Et_3N (4 mM) to solution of spectrum (c). See **Figure S7** for proton assignment. * Residual solvent peaks.

4. Spectral characterization of the self-assembly of homo- and hetero-dimeric capsules in DCM

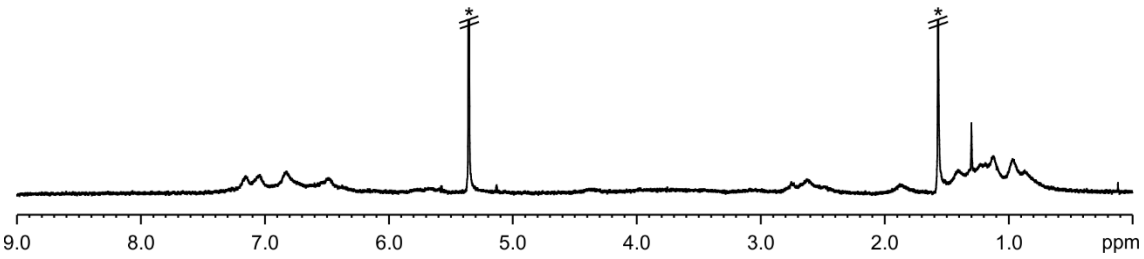


Figure S24. ^{1}H NMR (CD_2Cl_2, 400 MHz) spectrum of a 2 mM solution of SP-C[4]A. * Residual solvent peaks.

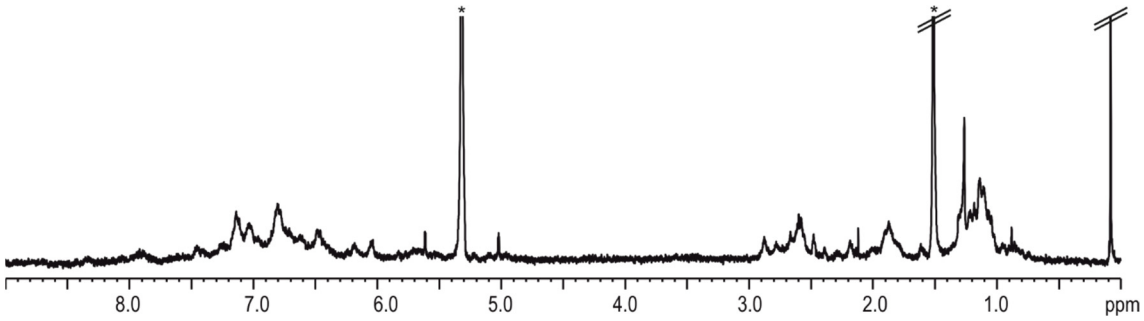


Figure S25. ^{1}H NMR (CD_2Cl_2, 400 MHz) spectrum of a 2 mM solution of SP-C[4]P. * Residual solvent peaks.

4.1. Homo-dimeric assembly 4⊂(SP-C[4]A)$_2$

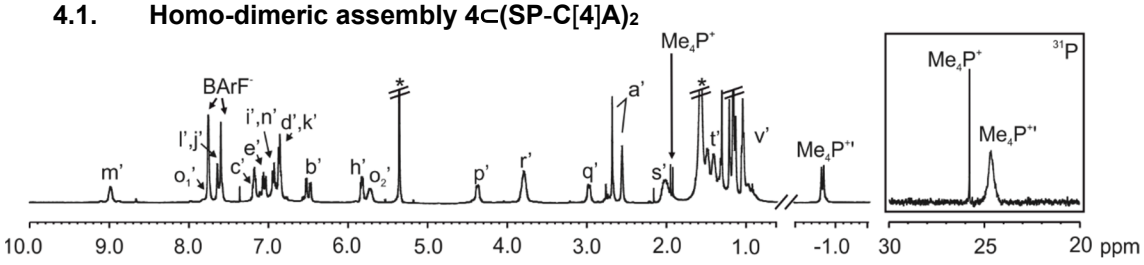


Figure S26. Selected regions of ^{1}H and ^{31}P{^{1}H, ^{13}C} NMR (CD_2Cl_2, 400 MHz) spectra of a 2 mM solution of **4**⊂(SP-C[4]A)$_2$. Primed letters correspond to proton signals assigned to the complex **4**⊂(SP-C[4]A)$_2$. See **Figure S1** for proton assignment. * Residual solvent peaks.

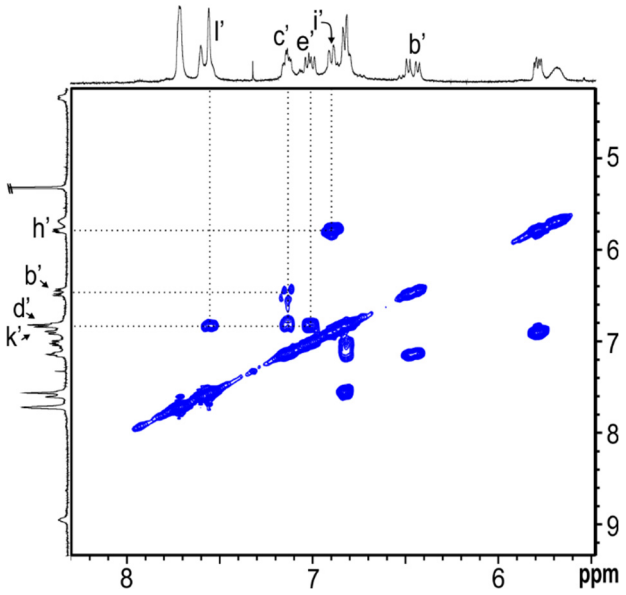


Figure S27. Selected downfield region of the ^{1}H COSY NMR spectrum (CD_2Cl_2, 400 MHz) of a 2 mM solution of **4**⊂(SP-C[4]A)$_2$. Primed letters correspond to proton signals assigned to the homo-dimeric assembly **4**⊂(SP-C[4]A)$_2$. See **Figure S7** for proton assignment.

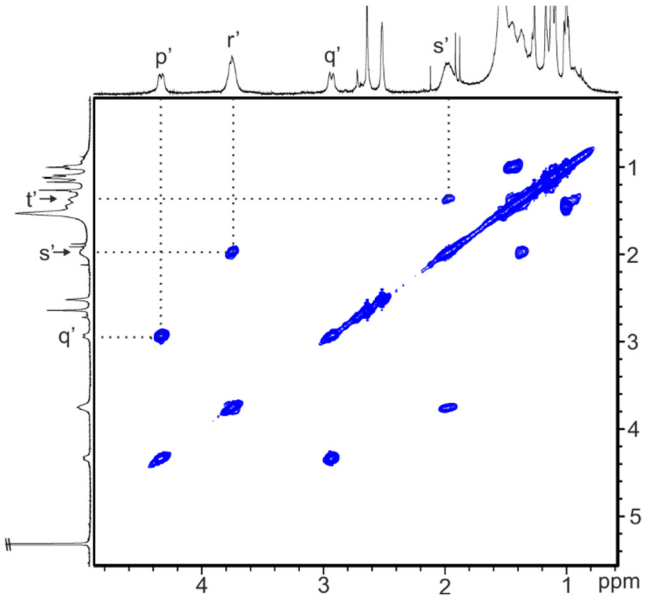


Figure S28. Selected upfield region of the ^{1}H COSY NMR spectrum (CD_2Cl_2, 400 MHz) of a 2 mM solution of **4**⊂(SP-C[4]A)$_2$. Primed letters correspond to proton signals assigned to the homo-dimeric assembly **4**⊂(SP-C[4]A)$_2$. See **Figure S7** for proton assignment.

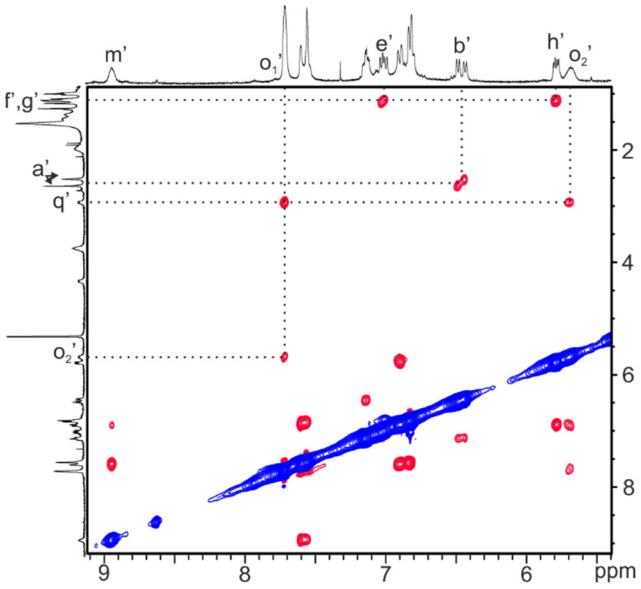


Figure S29. Selected downfield region of the ^{1}H ROESY NMR spectrum (CD_2Cl_2, 400 MHz) of 2 mM solution of **4**⊂(SP-C[4]A)$_2$. Primed letters correspond to proton signals assigned to the complex **4**⊂(SP-C[4]A)$_2$. See **Figure S1** for proton assignment.

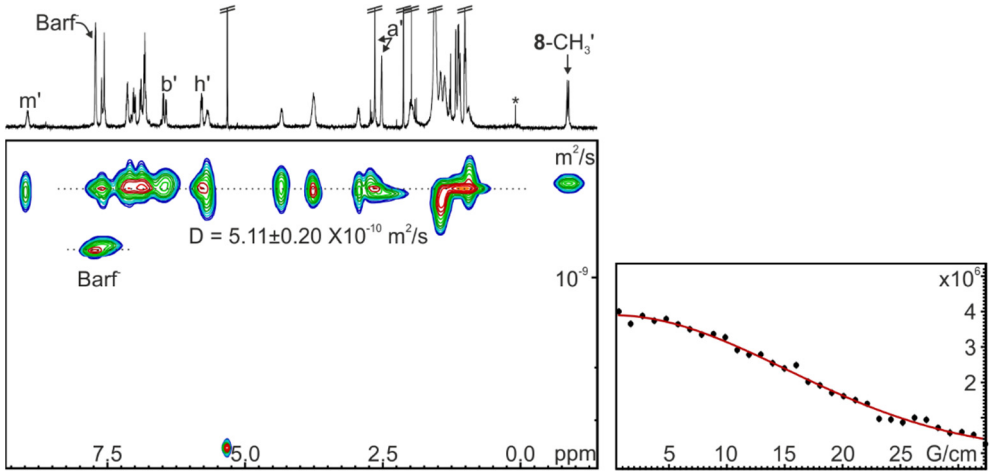


Figure S30. (left) ^{1}H pseudo 2D-plot DOSY (400 MHz, (CD_2Cl_2, 298 K, d20 = 0.10 s; p30 = 2.0 ms) of a 2 mM solution of **4**⊂(SP-C[4]A)$_2$; (right) fit of the decay of proton Hb' to a mono-exponential function using *Dynamics Center* software from *Bruker*. Errors are indicated as standard deviation. Primed letters correspond to proton signals assigned to the **4**⊂(SP-C[4]A)$_2$.

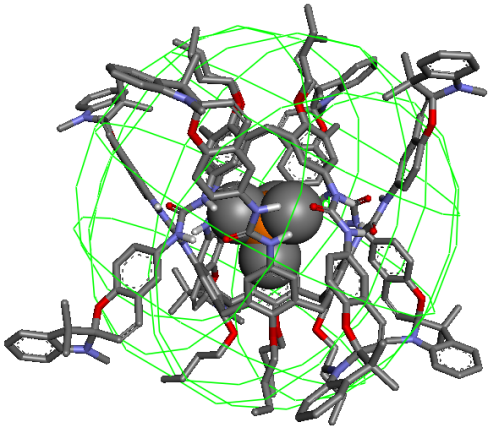


Figure S31. MM3 energy minimized structure of **4**⊂(SP-C[4]A)$_2$. The host is depicted in stick representation and the encapsulated guest Me_4P^+ as CPK model. Non-polar hydrogen atoms were removed for clarity. The green sphere defines the volume of a sphere having the hydrodynamic radius r_H calculated from the experimental diffusion coefficient *D* (Stokes-Einstein equation) (see previous figure), 10.34 ± 0.80 Å.

4.2. Homo-dimeric assembly 5⊂(SP-C[4]P)$_2$

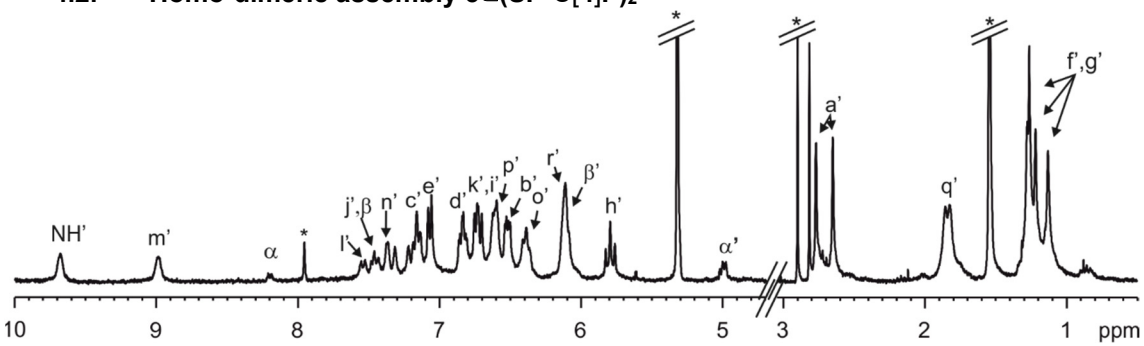


Figure S32. ^{1}H NMR (CD_2Cl_2, 400 MHz) spectra of a 4 mM solution of SP-C[4]P and 0.7 equiv. of 4,4'-bipyridine-*N*,*N'*-dioxide **5**. Primed letters correspond to proton signals assigned to complex **5**⊂(SP-C[4]P)$_2$. Non-primed letters correspond to proton signals of the free guest **5** in solution See **Figure S7** for proton assignment. * Residual solvent peaks.

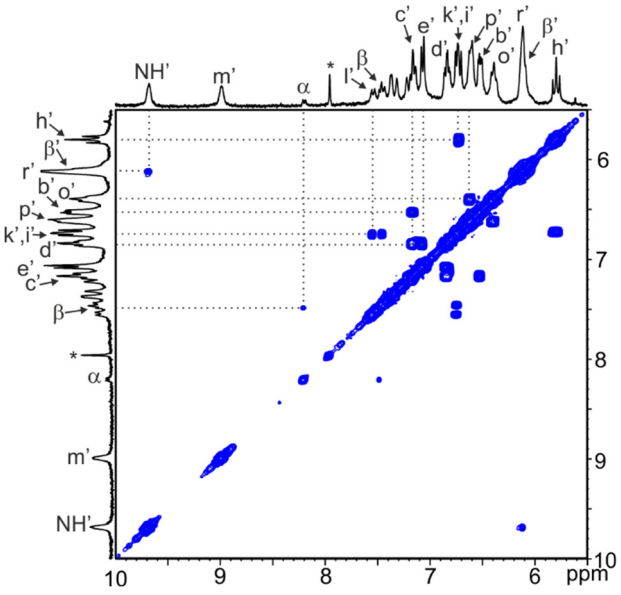


Figure S33. Selected downfield region of the ^{1}H COSY NMR spectrum (CD_2Cl_2, 400 MHz) a 4 mM solution of SP-C[4]P and 0.7 equiv. of 4,4'-bipyridine-*N*,*N'*-dioxide **5**. Primed letters correspond to proton signals assigned to complex **5**⊂(SP-C[4]P)$_2$. Non-primed letters correspond to proton signals of the free guest **5** in solution See **Figure S7** for proton assignment. * Residual solvent peaks.

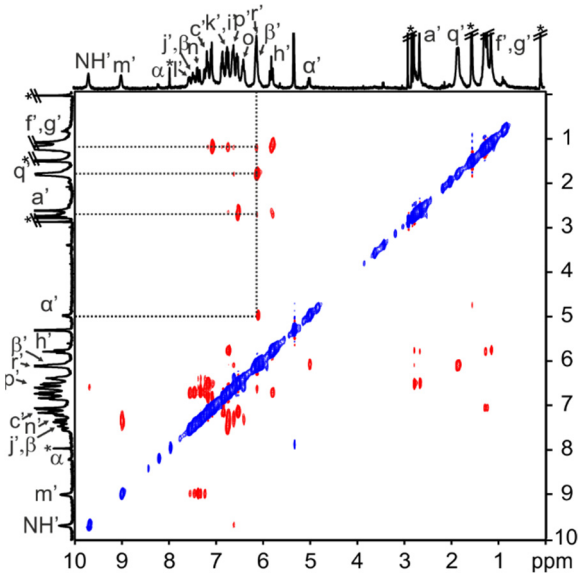


Figure S34. ^{1}H ROESY NMR spectrum (CD_2Cl_2, 400 MHz) a 4 mM solution of SP-C[4]P and 0.7 equiv. of 4,4'-bipyridine-*N*,*N'*-dioxide **5**. Primed letters correspond to proton signals assigned to complex **5**⊂(SP-C[4]P)$_2$. Non-primed letters correspond to proton signals of the free guest **5** in solution See **Figure S7** for proton assignment. * Residual solvent peaks.

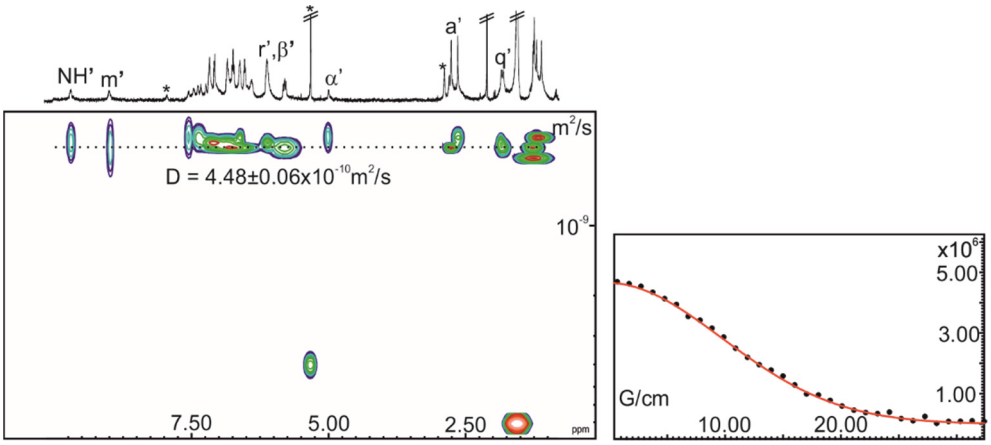


Figure S35. (left) ^{1}H pseudo 2D-plot DOSY (500 MHz, (CD_2Cl_2, 298 K, d20 = 0.10 s; p30 = 2.0 ms) 4 mM solution of SP-C[4]P and 0.7 equiv. of 4,4'-bipyridine-*N*,*N'*-dioxide **5**. Primed letters correspond to proton signals assigned to complex **5**⊂(SP-C[4]P)$_2$. (right) fit of the decay of signal Hr' to a mono-exponential function using *Dynamics Center* software from *Bruker*. Errors are indicated as standard deviations. See **Figure S7** for proton assignment. * Solvent residual peaks.

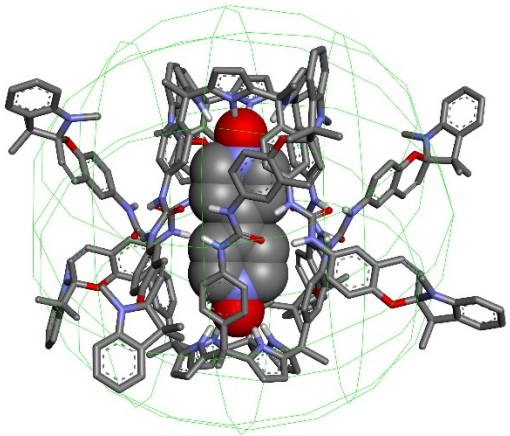


Figure S36. MM3 energy minimized structure of **5**⊂(SP-C[4]P)$_2$. The host is depicted in stick representation and the encapsulated guest **5** as CPK model. Non-polar hydrogen atoms were removed for clarity. The green sphere defines the volume of a sphere having the hydrodynamic radius r_H calculated from the experimental diffusion coefficient *D* (Stokes-Einstein equation) (see previous figure), 11.79 ± 0.10 Å.

4.3. Homo-dimeric assembly $\mathbf{6}_2\subset$(SP-C[4]P)$_2$

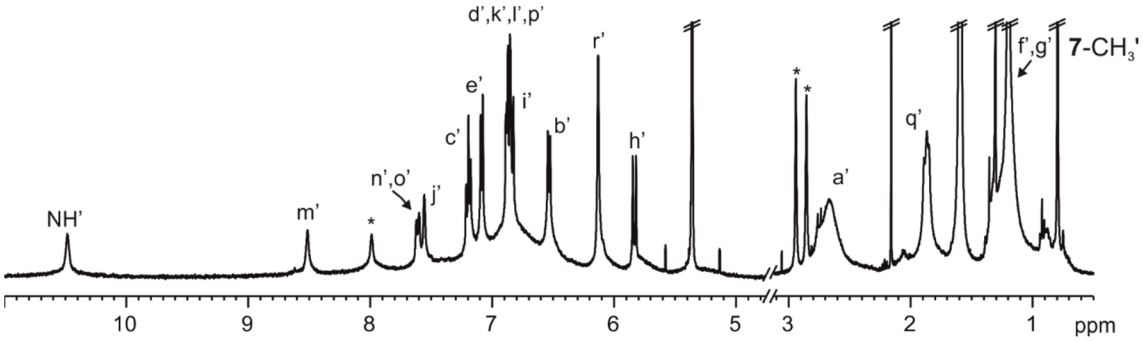


Figure S37. ^{1}H NMR (CD_2Cl_2, 400 MHz) spectra of a 4 mM solution of SP-C[4]P + 1 equiv. of trimethyl ammonium *N*-oxide **6** ($\mathbf{6}_2\subset$(SP-C[4]P)$_2$). Primed letters correspond to proton signals assigned to the encapsulation complex $\mathbf{6}_2\subset$(SP-C[4]P)$_2$. See **Figure S7** for proton assignment. * Residual solvent peaks.

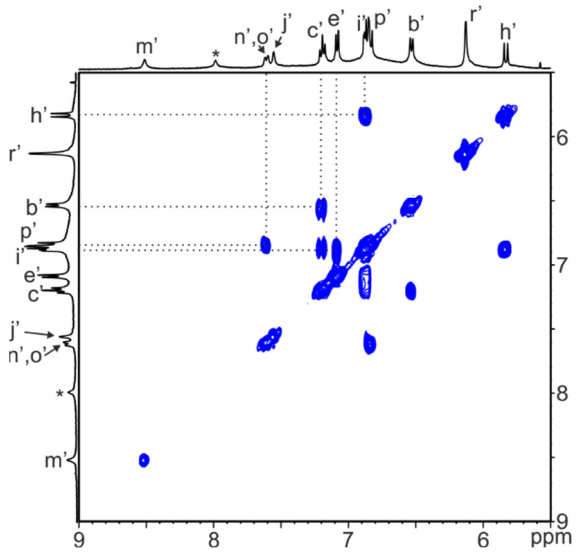


Figure S38. Selected downfield region of the ^{1}H COSY NMR spectrum (CD_2Cl_2, 400 MHz) of a 2 mM solution of $\mathbf{6}_2\subset$(SP-C[4]P)$_2$. Primed letters correspond to proton signals assigned to the homo-dimeric assembly $\mathbf{6}_2\subset$(SP-C[4]P)$_2$. See **Figure S7** for proton assignment. * Residual solvent peaks.

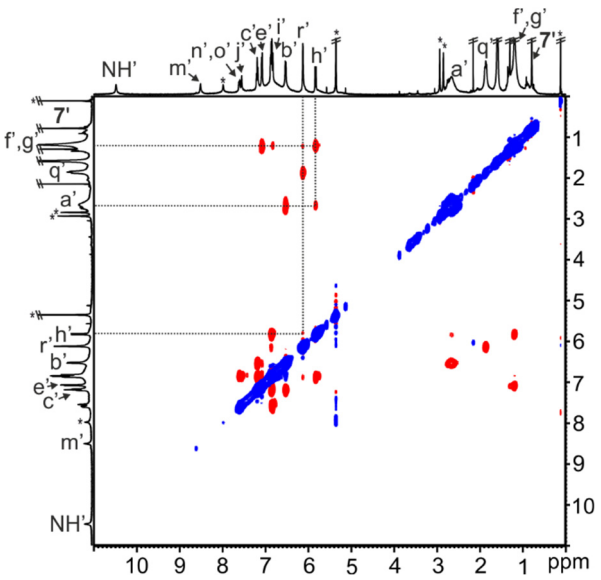


Figure S39. ^{1}H ROESY NMR spectrum (CD_2Cl_2, 400 MHz) of a 2 mM solution of **6**$_2$⊂(SP-C[4]P)$_2$. Primed letters correspond to proton signals assigned to the homo-dimeric assembly **6**$_2$⊂(SP-C[4]P)$_2$. See **Figure S7** for proton assignment. * Residual solvent peaks.

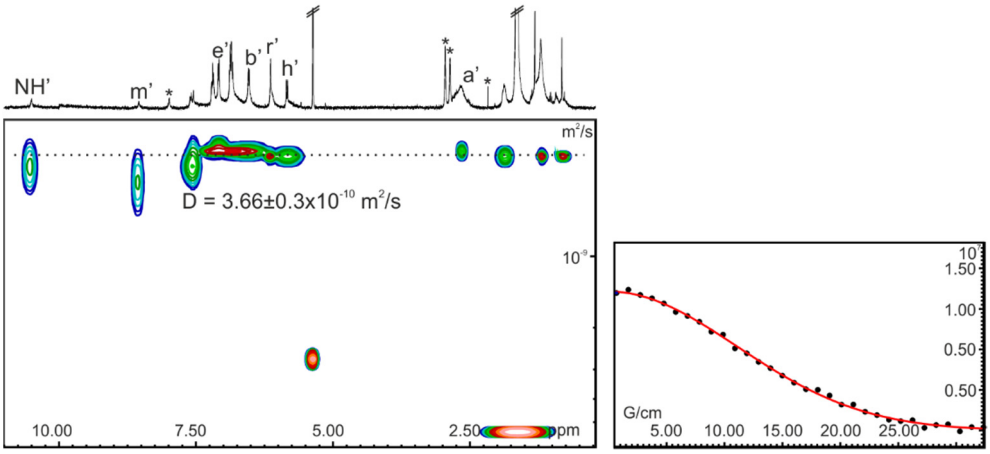


Figure S40. (left) 1H pseudo 2D-plot DOSY (400 MHz, (CD_2Cl_2, 298 K, D20 = 0.10 s; P30 = 2.0 ms) a 2 mM solution of **6**$_2$⊂(SP-C[4]P)$_2$. Primed letters correspond to proton signals assigned to complex **6**$_2$⊂(SP-C[4]P)$_2$. (right) fit of the decay of signal Hh' to a mono-exponential function using *Dynamics Center* software from *Bruker*. Errors are indicated as standard deviations. See **Figure S7** for proton assignment. * Solvent residual peaks.

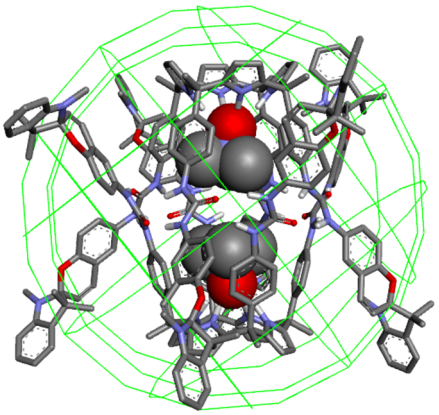


Figure S41. MM3 energy minimized structure of **6**$_2$⊂(SP-C[4]P)$_2$. The host is depicted in stick representation and the encapsulated guest Me_3NO **6** as CPK model. Non-polar hydrogen atoms were removed for clarity. The green sphere defines the volume of a sphere having the hydrodynamic radius r_H calculated from the experimental diffusion coefficient *D* (Stokes-Einstein equation) (see previous figure), 14.44 ± 1.20 Å.

4.4. Hetero-dimeric assembly 6⊂(SP-C[4]A·7)

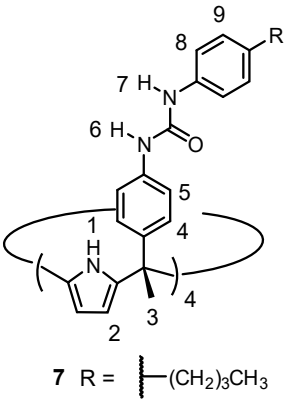


Figure S42. Molecular structure of tetra-urea calix[4]pyrrole **7** with the corresponding proton assignment.

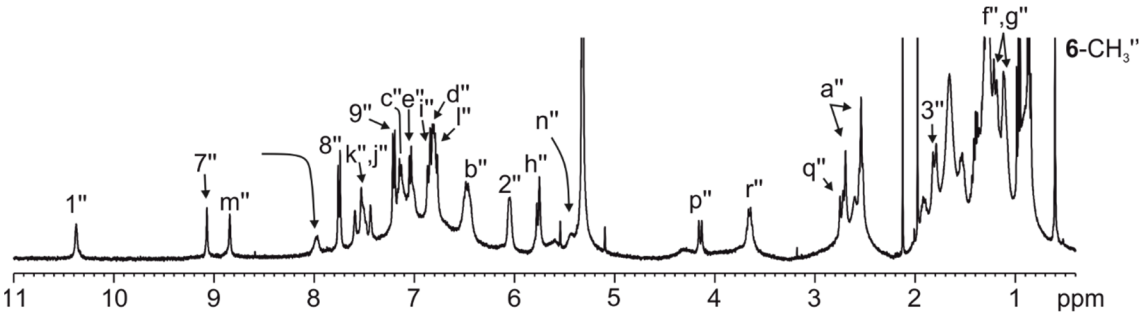


Figure S43. ^{1}H NMR (CD_2Cl_2, 400 MHz) spectra of 2 mM solution of SP-C[4]A, C[4]P **7** and guest **6** (1:1:1 molar ratio). Double primed letters and numbers correspond to proton signals assigned to the hetero-dimeric complex **6**⊂(SP-C[4]A·**7**). See **Figure S1**and **Figure S42** for proton assignments.

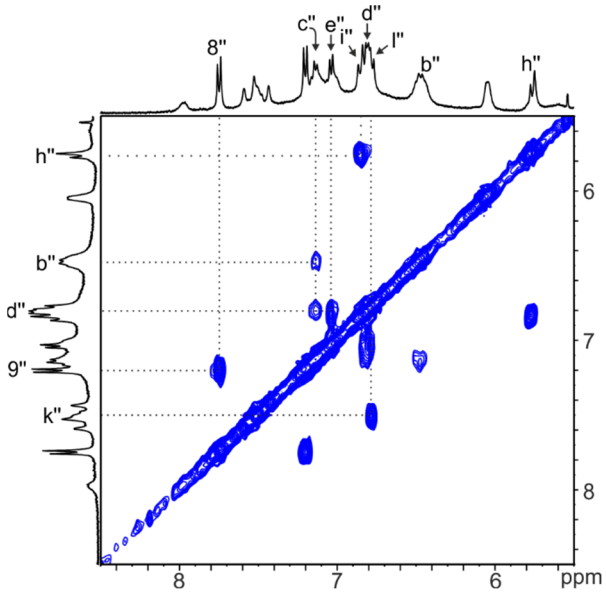


Figure S44. Selected downfield region of the ^{1}H COSY NMR spectrum (CD_2Cl_2, 400 MHz) of a 2 mM solution of **6**⊂(SP-C[4]A·**7**). Double primed letters and numbers correspond to proton signals assigned to the hetero-dimeric complex **6**⊂(SP-C[4]A·**7**). See **Figure S1**and **Figure S42** for proton assignment.

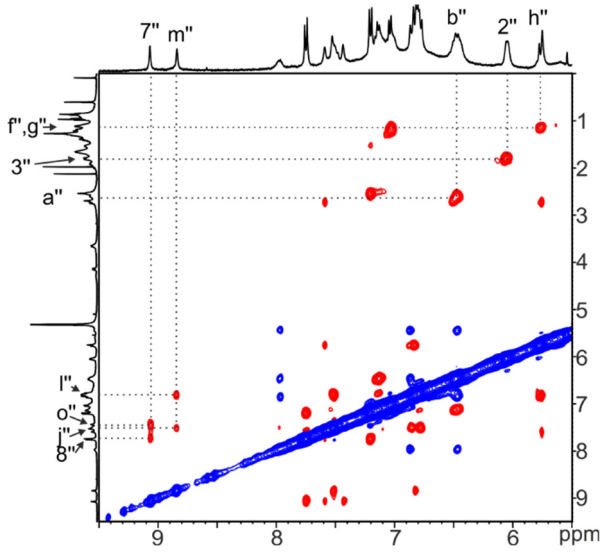


Figure S45. Selected downfield region of the ^{1}H NOESY NMR spectrum (CD_2Cl_2, 400 MHz) of a 2 mM solution of **6**⊂(SP-C[4]A·**7**). Double primed letters and numbers correspond to proton signals assigned to the hetero-dimeric complex **6**⊂(SP-C[4]A·**7**). See **Figure S1**and **Figure S42** for proton assignment.

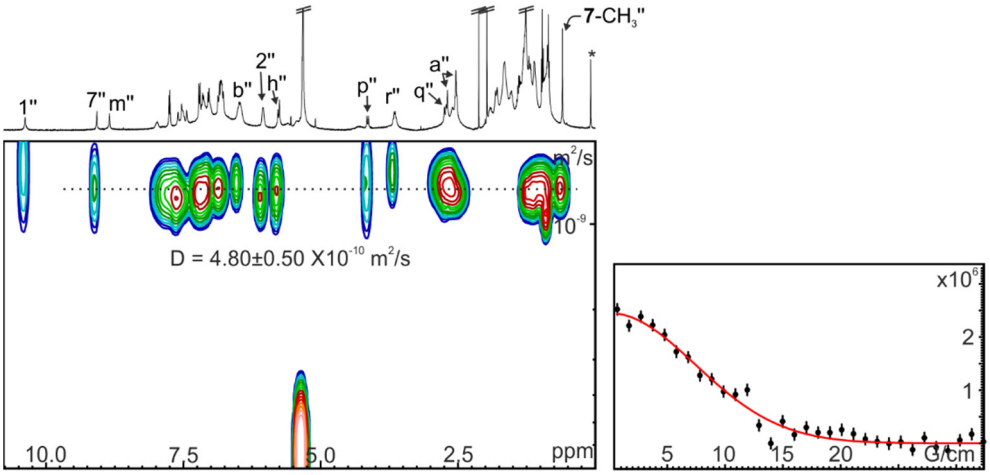


Figure S46. (left) ^{1}H pseudo 2D-plot DOSY (500 MHz, CD_2Cl_2, 298 K, d20 = 0.10 s; p30 = 2.0 ms) of a 2 mM solution of complex **6**⊂(SP-C[4]A·**7**). Doubled primed letters and numbers correspond to proton signals assigned to complex **6**⊂(SP-C[4]A·**7**). (right) fit of the decay of signal H2'' to a mono-exponential function using *Dynamics Center* software from *Bruker*. Errors are indicated as standard deviations. See **Figure S1**and **Figure S42** for proton assignments. * Solvent residual peaks.

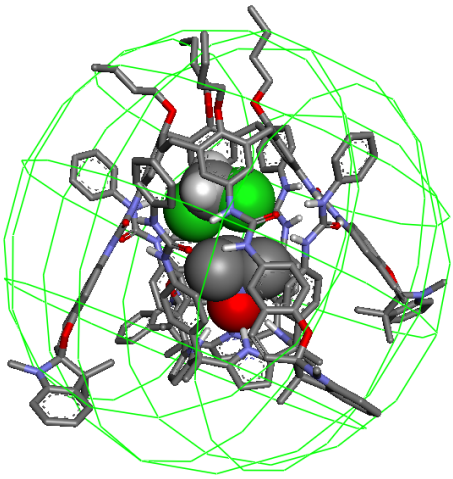
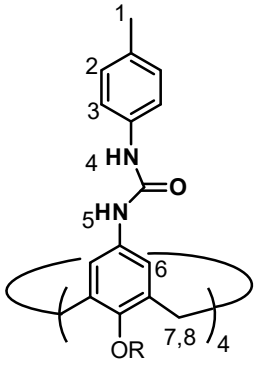


Figure S47. MM3 energy minimized structure of **6**⊂(SP-C[4]A·**7**). One molecule of CH_2Cl_2 was co-included in the cavity with guest **6**. The hosts are depicted in stick representation and the encapsulated guests Me_3NO **6** and DCM as CPK model. The alkyl chains of **7** were pruned to methoxy groups and non-polar hydrogen atoms were removed for clarity. The green sphere defines the volume of a sphere having the hydrodynamic radius r_H calculated from the experimental diffusion coefficient *D* (Stokes-Einstein equation) (see previous figure), 11.01 ± 1.28 Å.

4.5. Hetero-dimeric assembly 6⊂(SP-C[4]P·8)



8 R = $(CH_2)_4CH_3$

Figure S48. Line drawing structure of tetra-urea calix[4]arene **8** with the corresponding proton assignment.

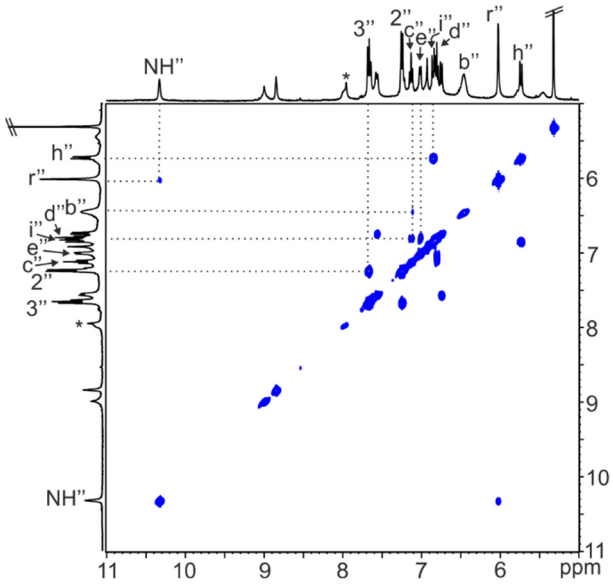


Figure S49. Selected downfield region of the ^{1}H COSY NMR spectrum (CD_2Cl_2, 400 MHz) of a 2 mM solution of **6**⊂(SP-C[4]P·**8**). Double primed letters and numbers correspond to proton signals assigned to the hetero-capsular assembly **6**⊂(SP-C[4]P·**8**). See **Figure S7** and **Figure S48** for proton assignment. * Residual solvent peaks.

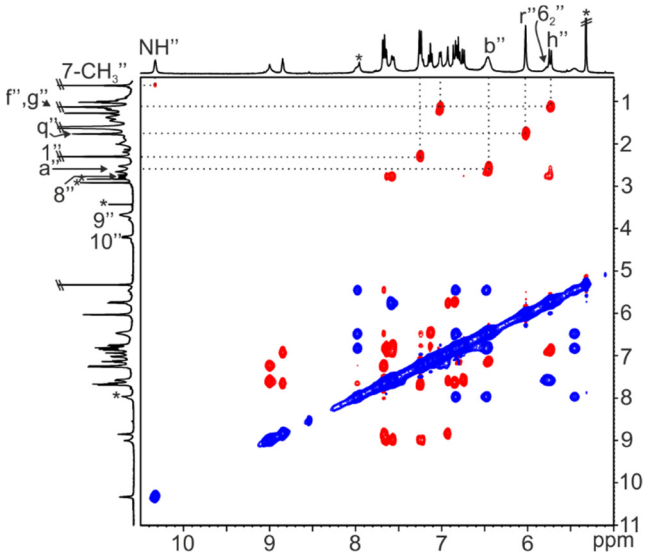


Figure S50. Selected downfield region of the ^{1}H ROESY NMR spectrum (CD_2Cl_2, 400 MHz) of a 2 mM solution of **6**⊂(SP-C[4]P·**8**). Double primed letters and numbers correspond to proton signals assigned to complex **6**⊂(SP-C[4]P·**8**). See **Figure S7** and **Figure S48** for proton assignment. * Residual solvent peaks.

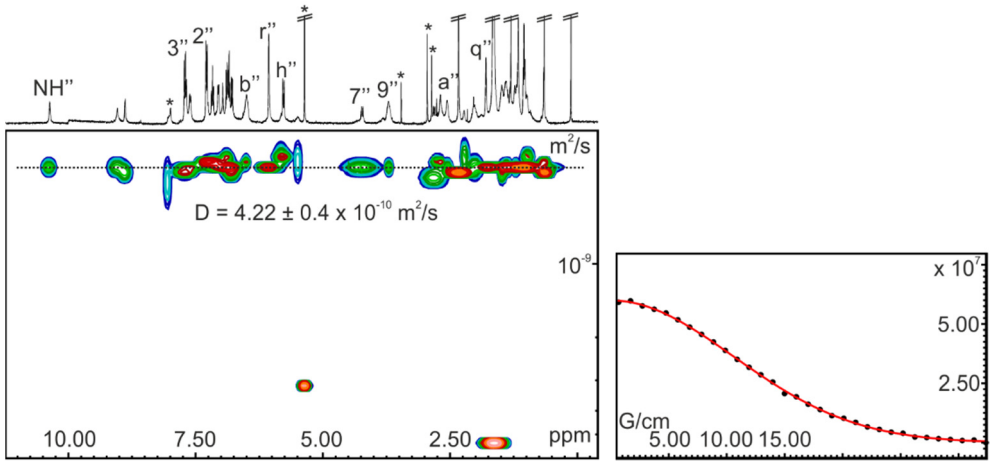


Figure S51. (left) 1H pseudo 2D-plot DOSY (400 MHz, (CD_2Cl_2, 298 K, D20 = 0.10 s; P30 = 2.0 ms) of a 2 mM solution of **6**⊂(SP-C[4]P·**8**). Double primed letters and numbers correspond to proton signals assigned to complex **6**⊂(SP-C[4]P·**8**). (right) fit of the decay of the signal r'' to a mono-exponential function using *Dynamics Center* software from *Bruker*. Errors are indicated as standard deviations. See **Figure S7** and **Figure S48** for proton assignment. * Residual solvent peaks.

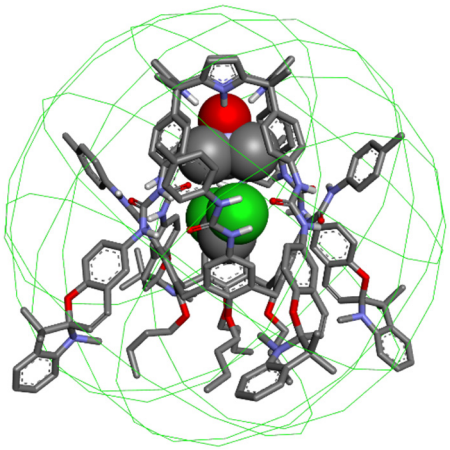


Figure S52. MM3 energy minimized structure of **6**⊂(SP-C[4]P·**8**). One molecule of CH_2Cl_2 was co-included in the cavity with guest **6**. The hosts are depicted in stick representation and the encapsulated guests Me_3NO and CH_2Cl_2 as CPK models. Non-polar hydrogen atoms were removed for clarity. The green sphere defines the volume of a sphere having the hydrodynamic radius r_H calculated from the experimental diffusion coefficient *D* (Stokes-Einstein equation) (see previous figure), 12.54 ± 0.05 Å.

5. Spectral characterization of the photo- and acid-induced isomerization of the homo-dimeric assemblies in DCM.

5.1. Photoisomerization studies in DCM

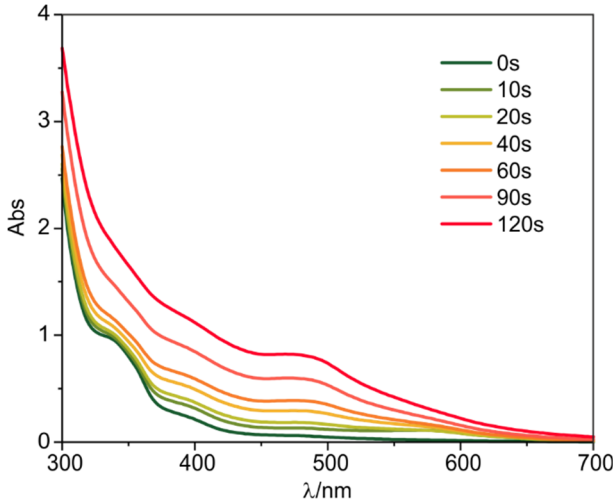


Figure S53. Set of UV-Vis spectra of a 50 μM solution of homo-dimeric assembly $\mathbf{6_2}$⊂(SP-C[4]P)$_2$ in CH_2Cl_2 at different times of irradiation at 365 nm.

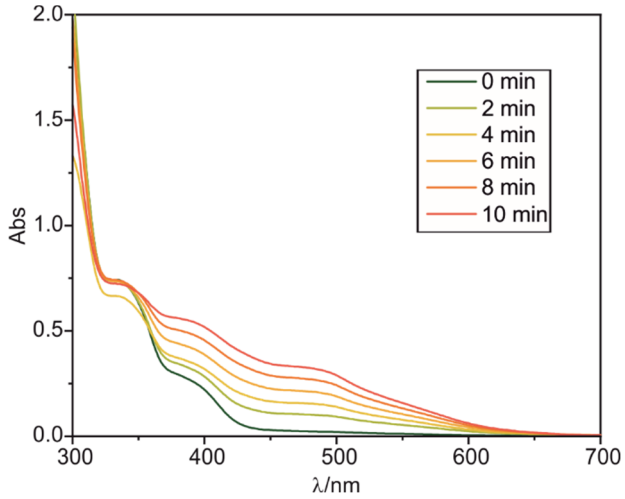


Figure S54. Set of UV-Vis spectra of a 50 μM solution of homo-dimeric assembly **4**⊂(SP-C[4]P)$_2$ in CH_2Cl_2 at different times of irradiation at 365 nm.

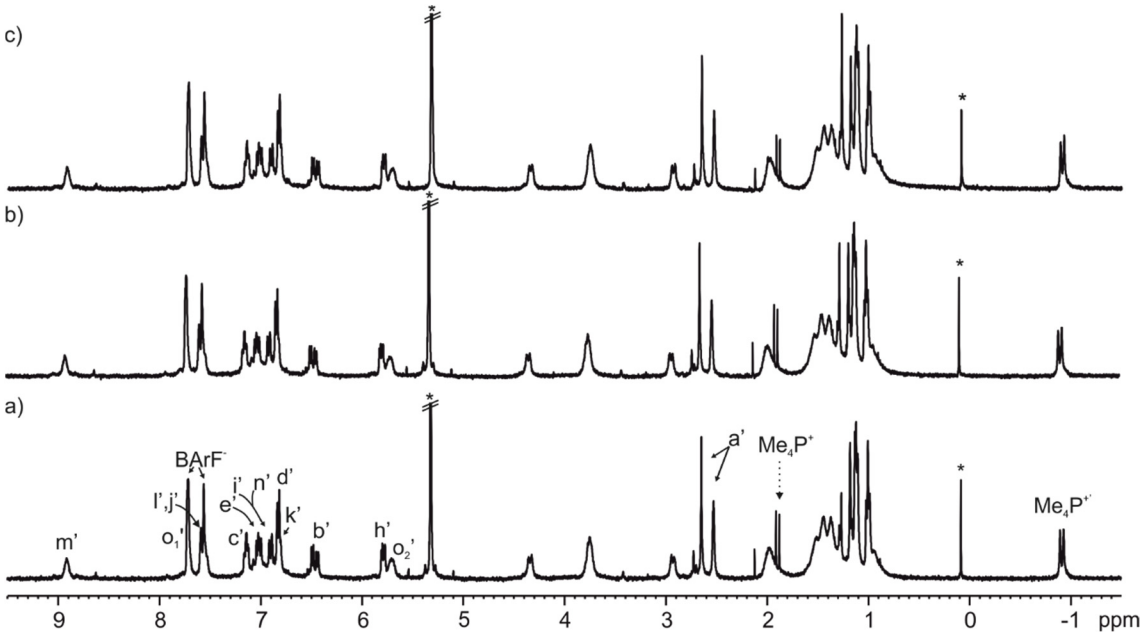


Figure S55. ^{1}H NMR (CD_2Cl_2, 400 MHz) spectra of a 2 mM solution of homo-dimeric assembly **4**⊂(SP-C[4]A)$_2$ thermally-equilibrated (a) and after irradiation at 365 nm for b) 1 and c) 5 min. Primed letters correspond to proton signals assigned to the homo-dimeric assembly **4**⊂(SP-C[4]A)$_2$. See **Figure S1** for proton assignment. * Residual solvent peaks.

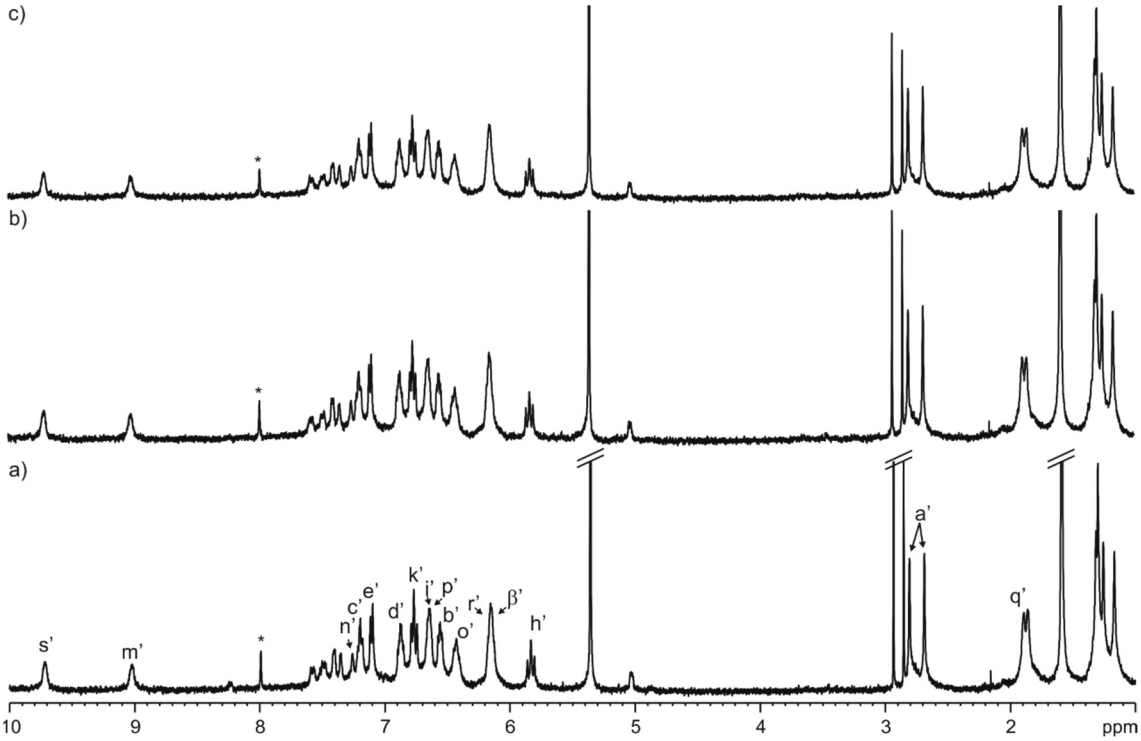


Figure S56. ^{1}H NMR (CD_2Cl_2, 400 MHz) spectra of a 2 mM solution of homo-dimeric assembly **5**⊂(SP-C[4]P)$_2$ thermally-equilibrated (a) and after irradiation at 365 nm for b) 1 and c) 5 min. Primed letters correspond to proton signals assigned to the homo-dimeric assembly **5**⊂(SP-C[4]P)$_2$. See **Figure S1** for proton assignment. * Residual solvent peaks.

5.2. Acid-induced isomerization studies in DCM

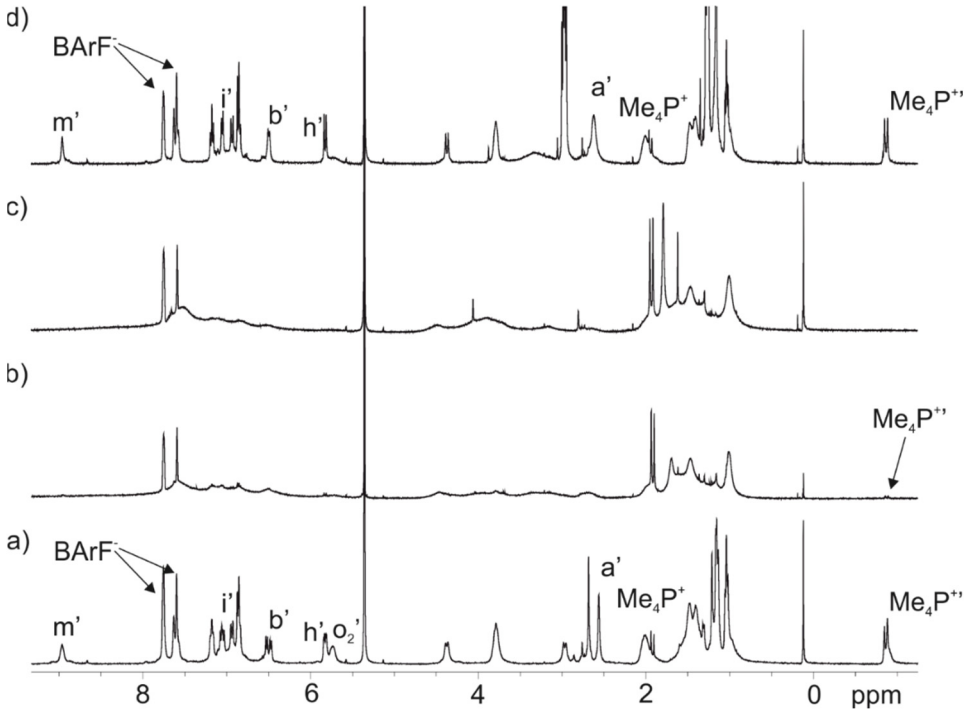


Figure S 57. ^{1}H NMR spectra (400 MHz, CD_2Cl_2, 298 K) of a 2 mM solution of **4**⊂(SP-C[4]A)$_2$ thermally-equilibrated (a) and b) immediately after the addition of 8 equiv. of TfOH (16 mM); c) 24h after the addition of 8 equiv. of TfOH (16 mM); d) immediately after the addition of 8 equiv. of Et_3N (16 mM) to solution of spectrum (c). Primed letters and numbers correspond to proton signals of **4**⊂(SP-C[4]A)$_2$. See **Figure S1** for proton assignment.

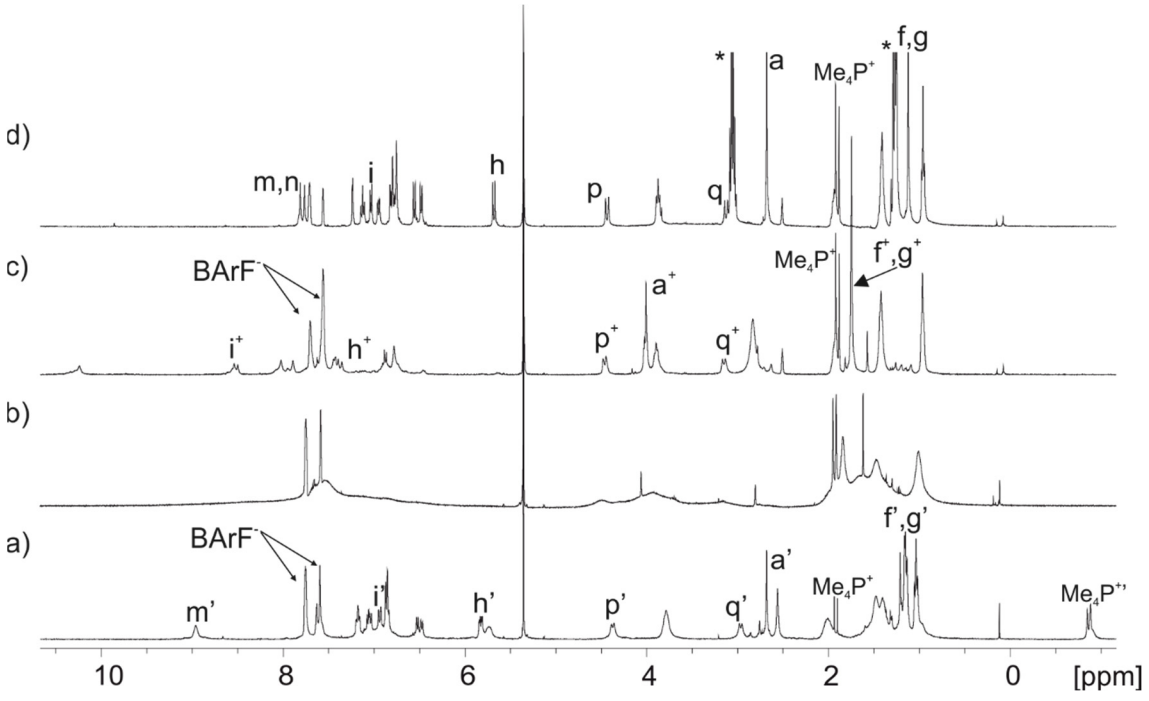


Figure S58. ^{1}H NMR spectra (400 MHz, CD_2Cl_2, 298 K) of a 2 mM solution of **4**⊂(SP-C[4]A)$_2$ thermally-equilibrated (a) and b) 24h after the addition of 8 equiv. of TfOH (16 mM); c) solution of spectrum (b) + 50 µL of $(CD_3)_2SO$ and d) solution of spectrum (c) after the addition of 8 equiv. of Et_3N (16 mM). Non-primed letters corresponding to all-SP-C[4]A monomeric species. Primed letters and numbers correspond to proton signals of **4**⊂(SP-C[4]A)$_2$. $^{+}$Signals attributed to the monomeric E-MCH^{+}-C[4]A species. See **Figure S1** for proton assignment. * Residual solvent peaks.

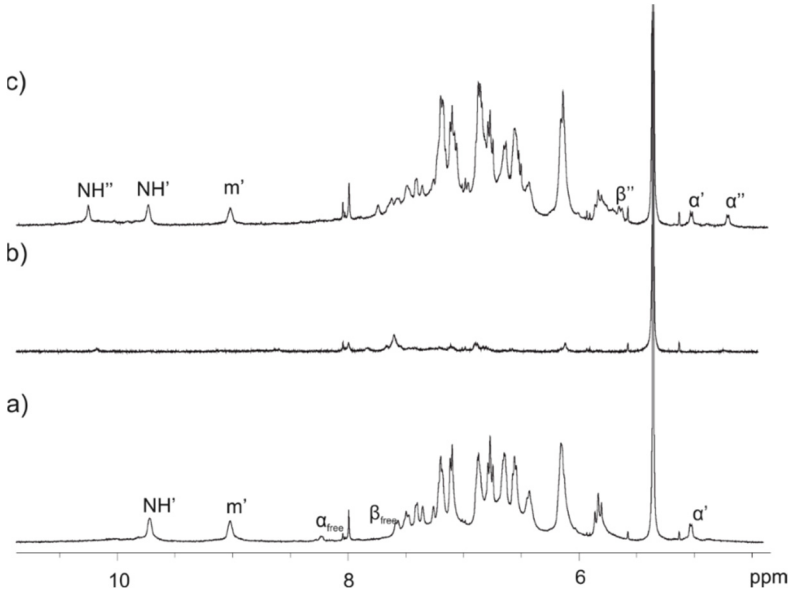


Figure S59. Selected region of the ^{1}H NMR (400 MHz, CD_2Cl_2, 298 K) spectra of a 2 mM solution of a) **5**⊂(SP-C[4]P)$_2$; b) **5**⊂(SP-C[4]P)$_2$ 24 h after the addition of 8 equiv. of TfOH (16 mM) and c) after the addition of 8 equiv. of Et_3N (16 mM). Primed letters correspond to proton signals of **5**⊂(SP-C[4]P)$_2$. Double primed letters correspond to proton signals of the putative 1:1 complex **5**⊂(SP-C[4]P). See **Figure S1** for proton assignment.