

Electronic Supporting Informations for

Hydrophobic metal organic capsule capable of encapsulating hydrophilic guest in organic solvent

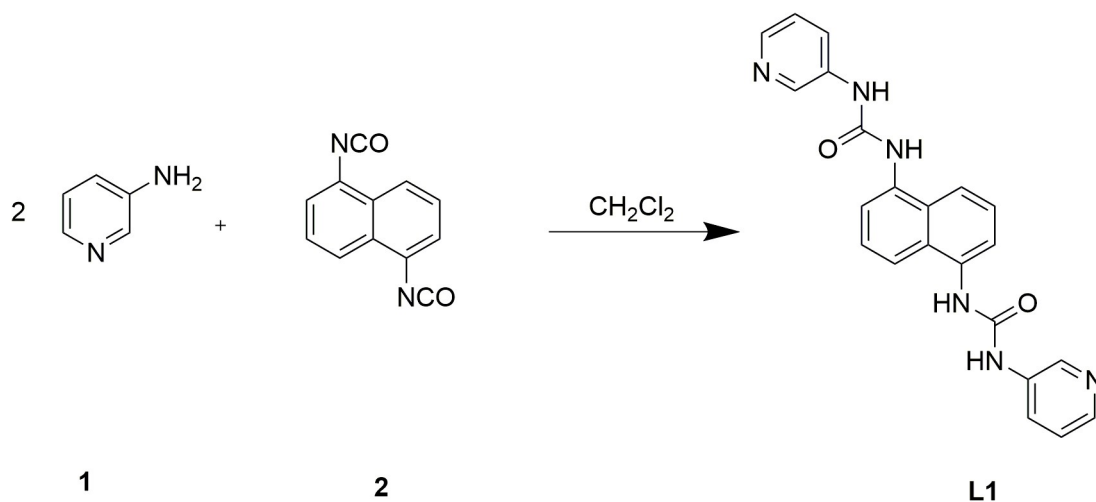
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General methods

All chemicals were of reagent grade obtained from commercial sources and used without further purification. ^1H NMR, ^{13}C NMR spectra was recorded on a Bruker AVANCE III 400 (400 MHz) or an ARX 300 MHz Bruker. Chemical shifts are reported as δ values (ppm) with TMS or corresponding solvent as an internal standard. Mass spectrometric studies were performed in the positive ion mode using a quadrupole mass spectrometer (Micromass, Platform II) equipped with a Waters 616HPLC pump. HRESI-TOF mass spectra were measured on Bruker maXis 4G. The data analyses of ESI-TOF mass spectra were processed on Bruker Data Analysis. Fluorescence spectra were recorded in Perkin Elmer LS-55, using a quartz cuvette (2 ml), with excitation and emission slit width at 8 nm.



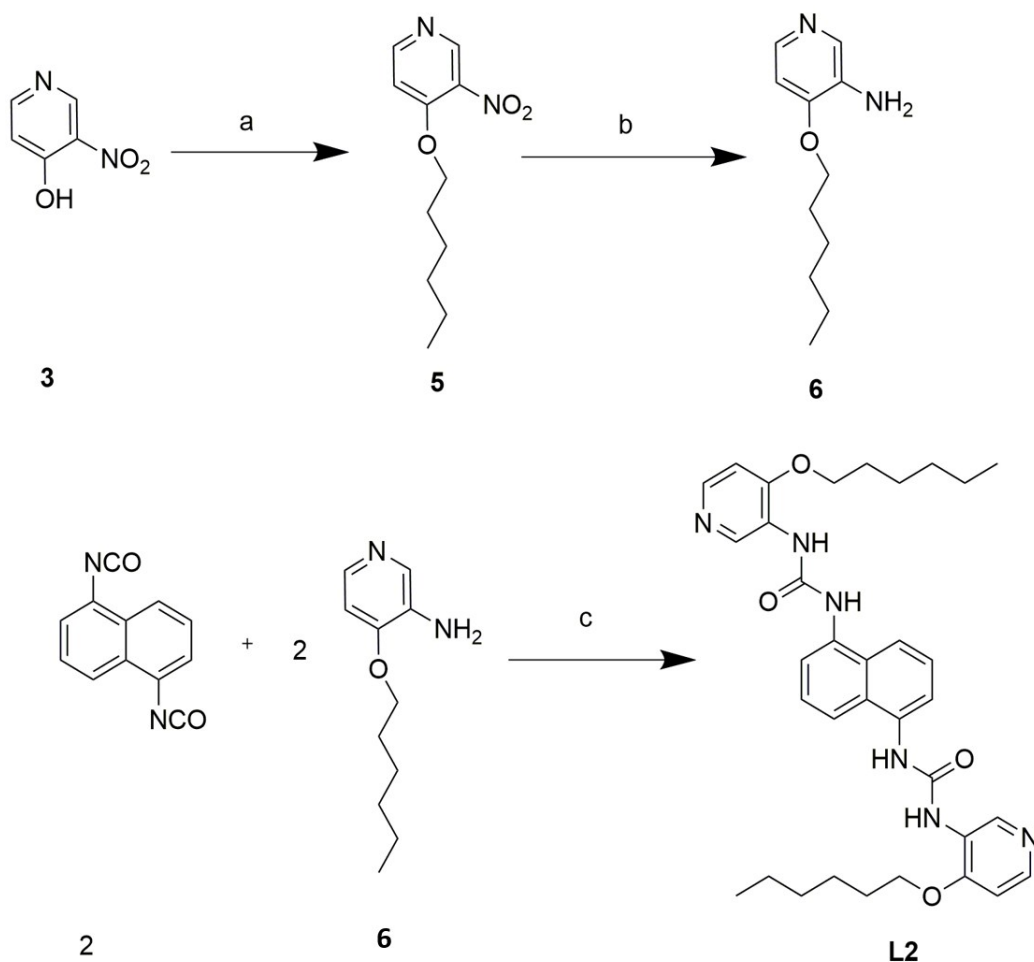
Scheme S1. Synthesis of ligand **L1**.

1,1'-(naphthalene-1,5-diyl)bis(3-(pyridin-3-yl)urea) (**L1**)

3-aminopyridine (0.2 g, 1 mmol) was dissolved in anhydrous CH_2Cl_2 (20 mL) under nitrogen. 0.5 equiv. of 1,5-diisocyanatonaphthalene (0.11 g, 0.5 mmol) was added to the solution. Large amount of precipitate was formed after stirring overnight. The precipitate was collected by filtration, washed by CH_2Cl_2 to afford pure **L1** (0.23 g, 73%). ^1H NMR (400 MHz, $\text{DMSO}-d_6$, 298 K) δ 9.23 (s, 1H), 8.91 (s, 1H), 8.66 (s, 1H), 8.22 (d, $J = 4.5$ Hz, 1H), 8.02 (t, $J = 8.8$ Hz, 2H), 7.89 (d, $J = 8.5$ Hz, 1H), 7.58 (t, $J = 8.0$ Hz, 1H), 7.35 (dd, $J = 8.1, 4.8$ Hz, 1H). ^{13}C NMR (101 MHz, $\text{DMSO}-d_6$, 298 K) δ 153.49, 143.40, 140.45, 136.97, 134.99, 127.42, 126.10, 125.54, 124.14, 1180.61, 117.24. IR (ATR): ν (cm^{-1}) = 3268, 1639, 1589, 1547, 1476, 1412, 1331, 1242, 778, 665.

Cage 1·(PF_6)₄, **C1**: Compound **L1** (100 mg, 0.25 mmol) and 0.5 equiv. of $\text{Pd}(\text{CH}_3\text{CN})_4(\text{BF}_4)_2$ (56 mg, 0.13 mmol) was dissolved in 5 mL of DMSO solution. The mixture was stirred at 80 °C overnight. After the solution cooled to room temperature, around 10 mL of ethyl acetate was added to the mixture to precipitate the the cage **C1**. A whitish solid was collected as **C1**·(BF_4)₄ (105 mg, 77%) after the filtration. ^1H NMR (400 MHz, $\text{DMSO}-d_6$, 298 K) δ 10.03 (s, 8H), 9.44 (s, 8H), 8.97 (s, 8H), 8.90 (d, $J = 4.9$ Hz, 8H), 7.85 (d, $J = 7.3$ Hz, 8H), 7.75 (d, $J = 8.5$ Hz, 8H), 7.65 – 7.45 (m, 16H), 7.17 (t, $J = 7.9$ Hz, 8H). The solubility of **C1** in DMSO was too low to measure the ^{13}C NMR of the cage **C1**. ESI-MS calcd for $[\text{C}_{88}\text{H}_{72}\text{N}_{24}\text{O}_8\text{Pd}_2]^{4+}$: 451.60, found: 451.40. HR ESI-

MS calcd for $[C_{88}H_{72}N_{24}O_8Pd_2]^{4+}$: 451.6012, found: 451.5938. IR (ATR): ν (cm^{-1}) = 3268, 1639, 1589, 1547, 1476, 1412, 1331, 1242, 778, 665.



Scheme S2. Synthesis of ligand **L2**.

4-(hexyloxy)-3-nitropyridine (5)¹: A suspension of 4-hydroxy-3-nitropyridine (2.0 g, 14.3 mmol) and phosphorus pentachloride (3.2 g, 15.4 mmol) in 1,2-dichloroethane (20 mL) was heated under reflux until a clear solution was formed. The solution was cooled to room temperature and n-hexanol (10 mL) was added dropwise. The mixture was heated again under reflux for at least 3 hours and then cooled to room temperature. The precipitate formed was filtered and washed with water and cold ethanol. A white solid as hydrochloride salt of the desired compound was obtained. After neutralization with aqueous sodium hydroxide, the mixture was treated with $CHCl_3$. The organic layer was dried by anhydrous $MgSO_4$. Finally, an oily product was obtained after the vacuum evaporation (2.0 g, 62%). The crude product was directly used in the next step of reaction, no further characterization was done except 1H NMR. 1H NMR (400 MHz, $CDCl_3$, 298 K) δ 8.98 (s, 1H), 8.60 (d, $J = 5.8$ Hz, 1H), 7.03 (d, $J = 5.8$ Hz, 1H), 4.20 (t, $J = 6.4$ Hz, 2H), 1.99 – 1.77 (m, 2H), 1.57 – 1.44 (m, 2H), 1.35 (s, 4H), 0.92 (d, $J = 5.7$ Hz, 3H).

4-(hexyloxy)pyridin-3-amine (6): **5** (1.3 g, 20.0 mmol) and Pd/C (10%, 0.26 g) were stirred in methanol (30 mL) under the atmosphere of hydrogen gas (1 atm) at room temperature for 8 h. The solid was filtered off and the filtrate concentrated in vacuo to give **6** as transparent crystal (1.05 g, 93%). 1H NMR (400 MHz, $DMSO-d_6$, 298

K) δ 7.85 (s, 1H), 7.70 (d, J = 5.2 Hz, 1H), 6.79 (d, J = 5.3 Hz, 1H), 4.74 (s, 2H), 4.00 (t, J = 6.4 Hz, 2H), 1.81 – 1.65 (m, 2H), 1.52 – 1.37 (m, 2H), 1.36 – 1.25 (m, 4H), 0.88 (t, J = 6.6 Hz, 3H). ^{13}C NMR (101 MHz, DMSO- d_6 , 298 K) δ 151.36, 139.37, 135.68, 134.72, 106.94, 67.88, 31.47, 28.91, 25.56, 22.53, 14.39. ESI-MS calcd for $[\text{C}_{11}\text{H}_{19}\text{N}_2\text{O}]^+$: 195.15, found: 195.26. IR (ATR): ν (cm^{-1}) = 3400, 2930, 1693, 1608, 1536, 1438, 1417, 1307, 1203, 1167, 997, 839, 781, 556.

1,1'-(naphthalene-1,5-diyl)bis(3-(4-(hexyloxy)pyridin-3-yl)urea) (L2): **6** (0.2 g, 1 mmol) was dissolved in anhydrous CH_2Cl_2 (20 mL) under nitrogen. 0.5 equiv. of 1,5-diisocyanatonaphthalene (0.11 g, 0.5 mmol) was added to the solution. Large amount of precipitate was formed after stirring overnight. The precipitate was collected by filtration, washed by CH_2Cl_2 to afford pure **L2** as off-white solid (0.23 g, 73%). ^1H NMR (300 MHz, DMSO- d_6 , 298 K) δ 9.40 (s, 2H), 9.15 (s, 2H), 8.51 (s, 2H), 8.13 (d, J = 5.5 Hz, 2H), 8.01 (d, J = 7.5 Hz, 2H), 7.94 (d, J = 8.5 Hz, 2H), 7.58 (t, J = 8.1 Hz, 2H), 7.10 (d, J = 5.6 Hz, 2H), 4.19 (t, J = 6.7 Hz, 4H), 1.89 – 1.75 (m, 4H), 1.46 (d, J = 7.7 Hz, 4H), 1.33 (m, 8H), 0.88 (t, J = 7.0 Hz, 6H). ^{13}C NMR (75 MHz, DMSO- d_6 , 298 K) δ 153.74, 153.33, 144.84, 141.25, 135.01, 127.58, 126.23, 125.96, 119.05, 117.58, 107.62, 68.90, 31.42, 28.77, 25.42, 22.54, 14.35. ESI-MS calcd for $[\text{C}_{34}\text{H}_{43}\text{N}_6\text{O}_4]^+$: 599.43, found: 599.33. IR (ATR): ν (cm^{-1}) = 3400, 2930, 2859, 1693, 1608, 1536, 1438, 1417, 1307, 1220, 1203, 1167, 1090, 997, 839, 781, 739, 556. UV-vis, λ_{max} (DMSO)/nm 270, 327.

Cage 2·(PF₆)₄, C2: Ligand **L2** (80 mg, 0.13 mmol) and 0.5 equiv. of $\text{Pd}(\text{CH}_3\text{CN})_4(\text{BF}_4)_2$ (30 mg, 0.07 mmol) was dissolved in 2 mL of DMSO solution. The mixture was stirred at 80 °C overnight. After the solution cooled to room temperature, around 10 mL of saturated aqueous KPF_6 was added to the mixture to precipitate the compound. A brown solid was obtained as **C2** (90 mg, 85%) after the filtration. ^1H NMR (300 MHz, CD_3CN , 298 K) δ 9.83 (s, 8H), 8.40 (d, J = 6.4 Hz, 8H), 7.93 (s, 8H), 7.83 (d, J = 8.5 Hz, 8H), 7.72 (s, 8H), 7.66 (d, J = 7.3 Hz, 8H), 7.29 – 7.20 (m, 8H), 7.08 (d, J = 6.5 Hz, 8H), 4.22 (t, J = 6.6 Hz, 24H), 1.93 – 1.81 (m, 16H), 1.57 – 1.44 (m, 16H), 1.38 (dt, J = 7.4, 3.8 Hz, 32H), 0.93 (t, J = 7.1 Hz, 24H). ^{13}C NMR (75 MHz, CD_3CN , 298 K) δ 156.30, 153.40, 146.02, 140.40, 134.82, 130.30, 129.62, 126.59, 122.35, 120.94, 109.92, 71.28, 32.10, 29.20, 26.01, 23.25, 14.26. HR ESI-MS calcd for $[\text{C}_{136}\text{H}_{168}\text{N}_{24}\text{O}_{16}\text{Pd}_2]^{4+}$: 651.7793, found: 651.7900. IR (ATR): ν (cm^{-1}) = 3400, 2930, 2859, 1693, 1608, 1536, 1438, 1417, 1307, 1220, 1203, 1167, 1090, 997, 839, 781, 739, 556. UV-vis, λ_{max} (DMSO)/nm 225, 295.

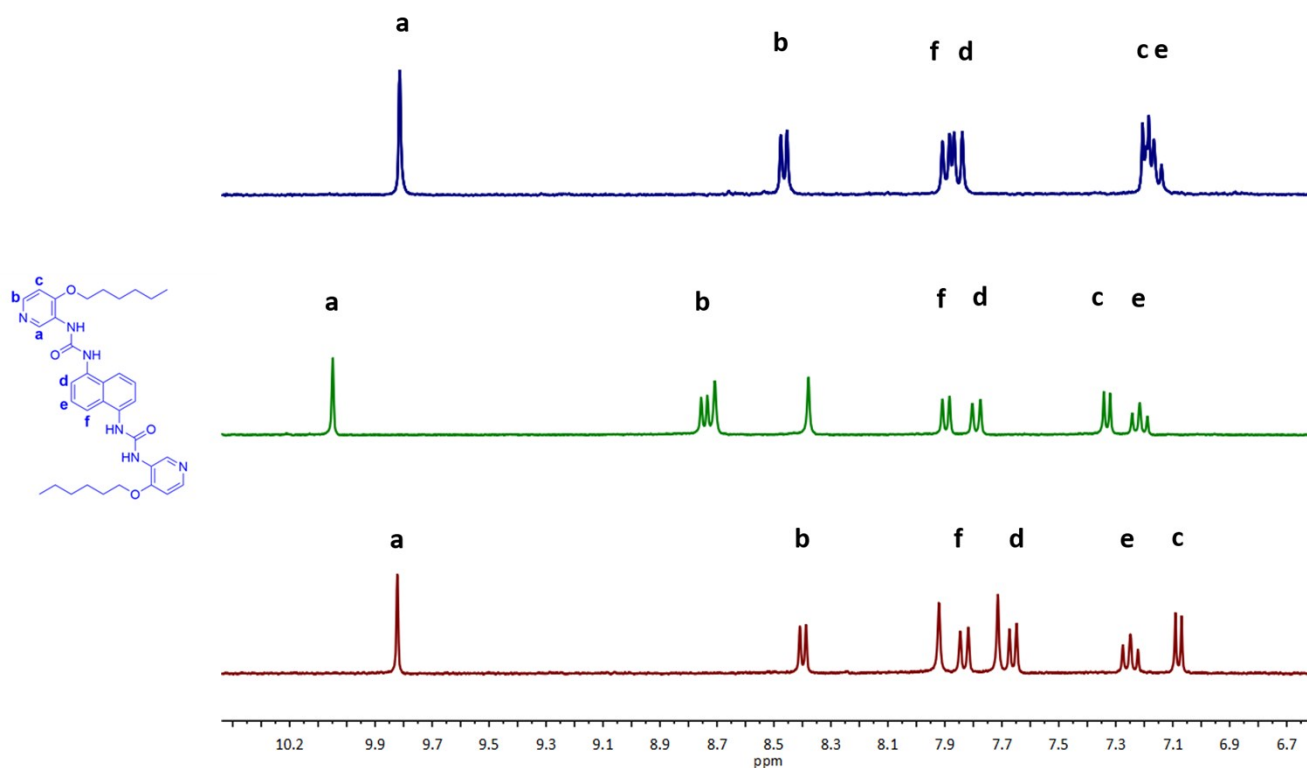


Fig. S1 ¹H NMR (300 MHz, 298 K) spectra of **C2** in CD₃CN (red), acetone-*d*₆ (green) and MeOD (blue).

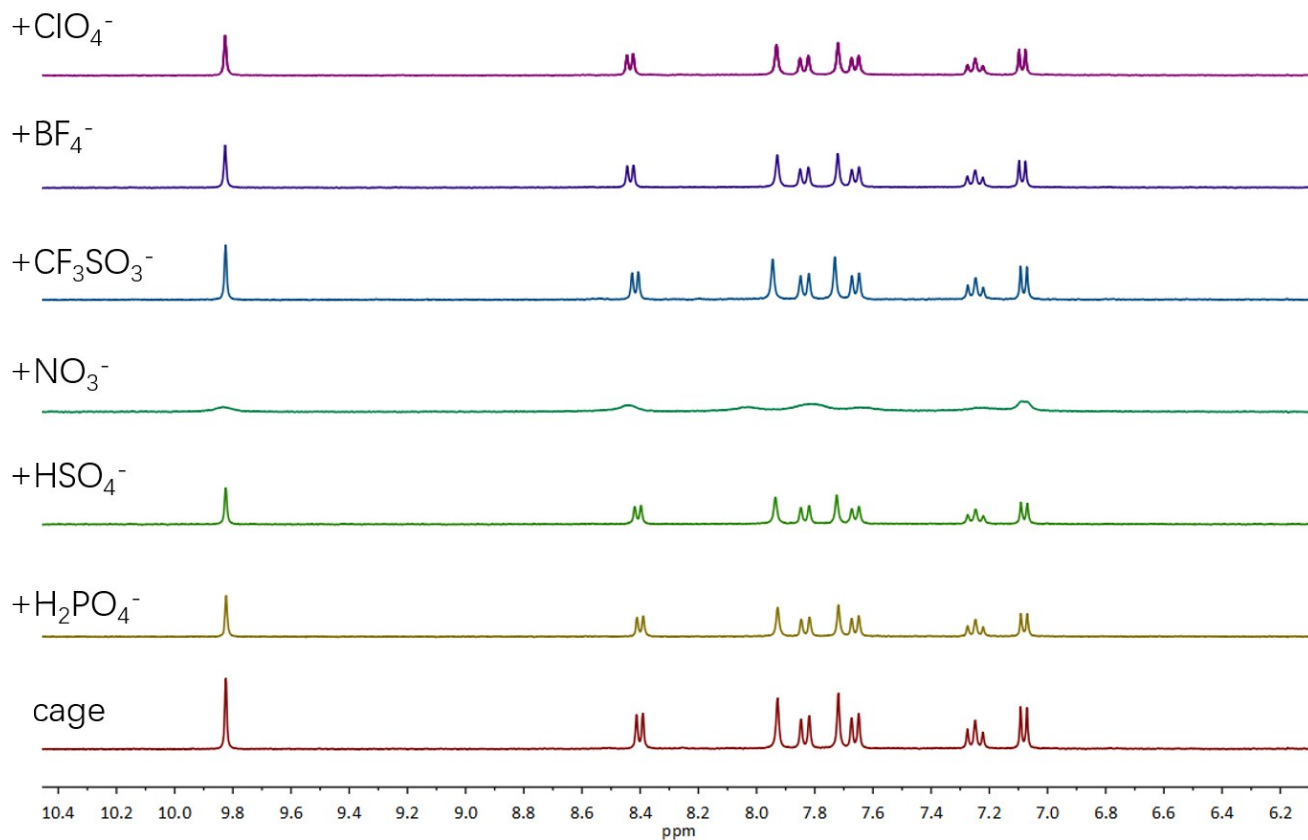


Fig. S2 Aromatic area from the ^1H NMR (300 MHz, CD_3CN , 298 K) spectra of the cage **C2** after the addition of different anions (TBA salts, at least 2 equiv. of the salt were added in each case).

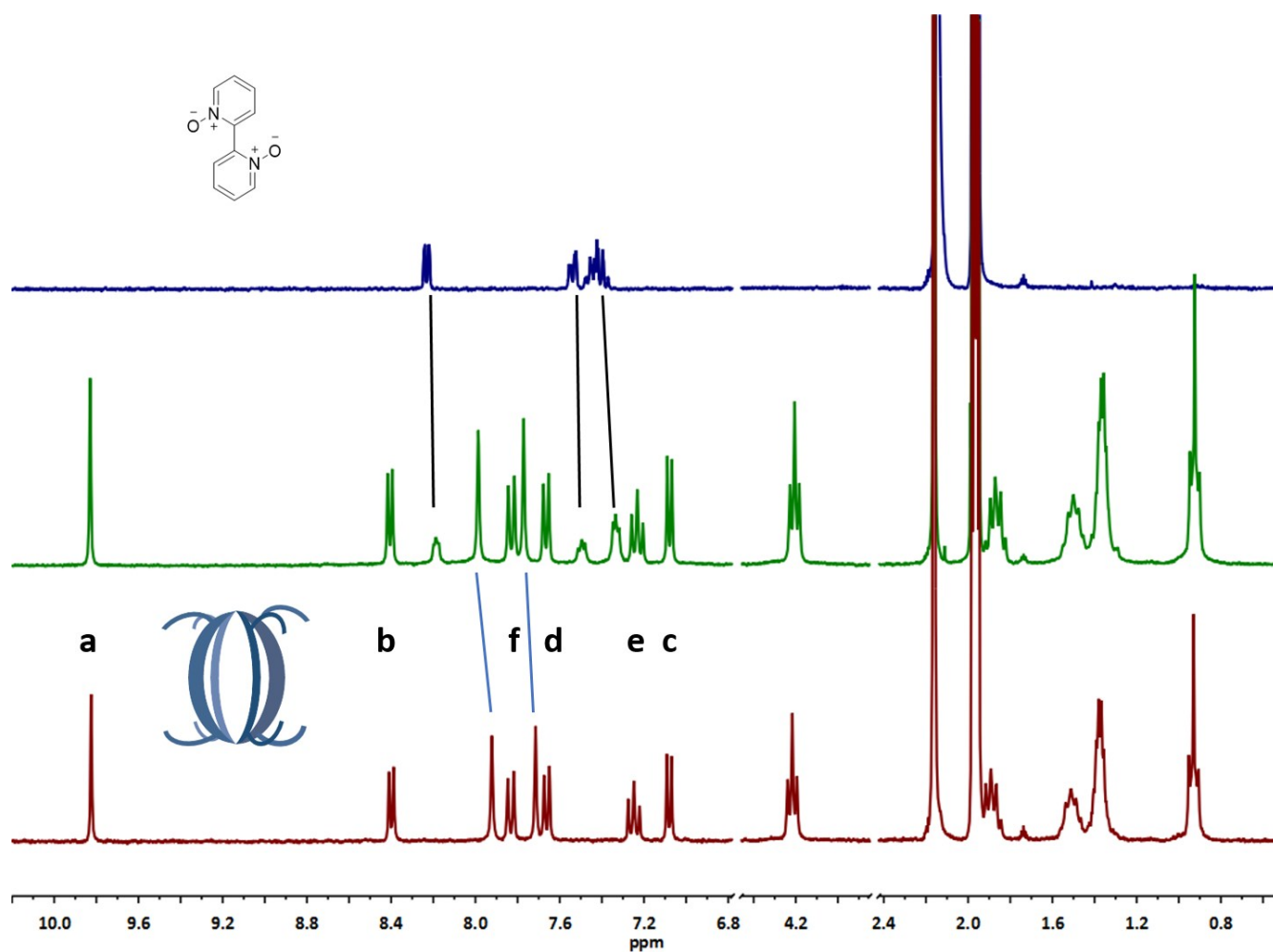


Fig. S3 Stacked partial ¹H NMR (300 MHz, CD₃CN, 298 K) spectra of **C2** (red), **C2** in presence of 2,2'-dipyridyl- N,N'-dioxide (green) and 2,2'- dipyridyl N,N'-dioxide alone (blue). Blue lines indicate the proton shifts from ureido group, other protons from **C2** see no changes. Black lines indicate the proton shifts from the guest.

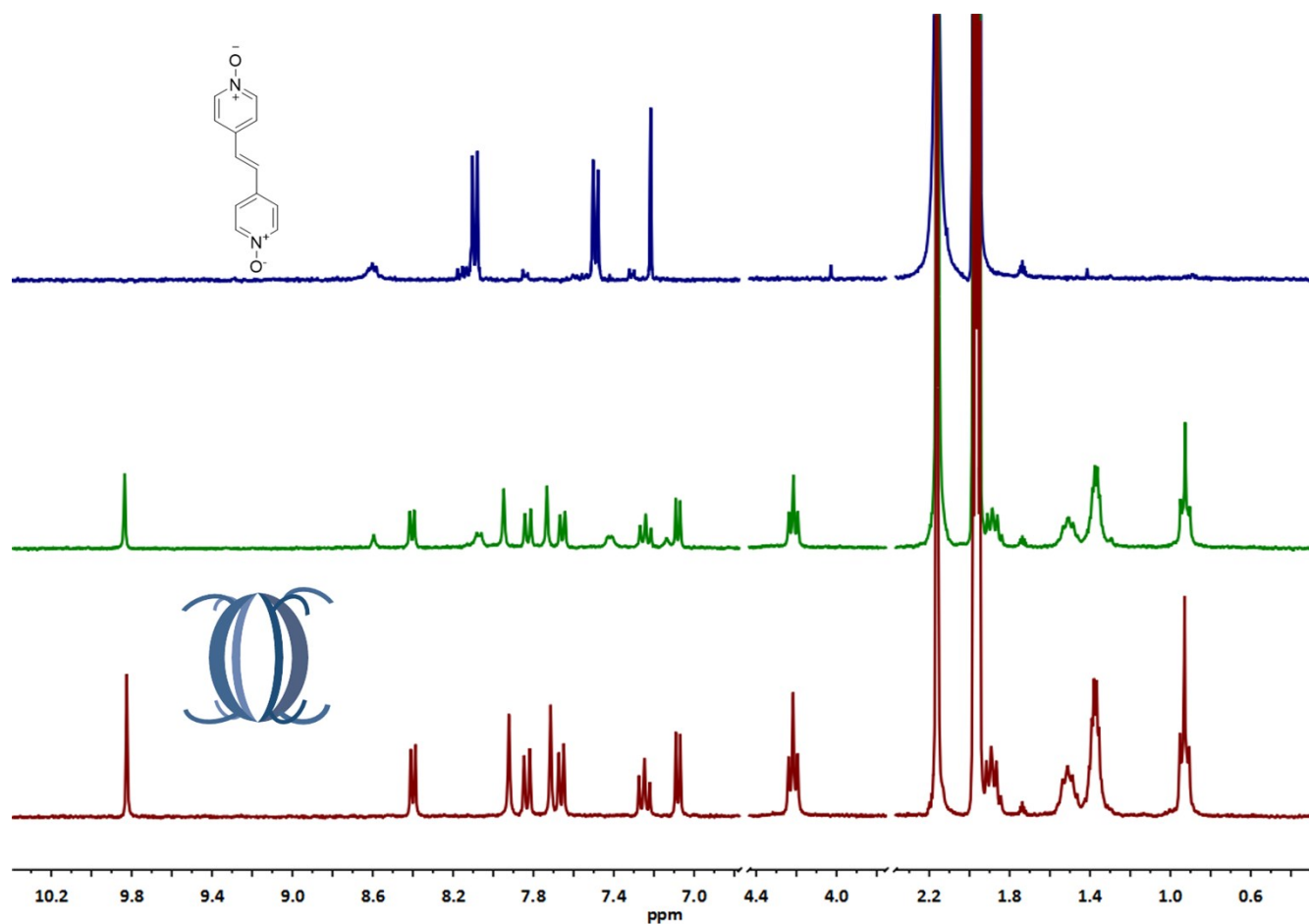


Fig. S4 Stacked partial ^1H NMR (300 MHz, CD_3CN , 298 K) spectra of **C2** (red), **C2** in presence of 1,2-Di(4-pyridyl)ethylene- $\text{N,N}'$ -dioxide (green) and 1,2-Di(4-pyridyl)ethylene- $\text{N,N}'$ -dioxide (blue). The smaller peaks from the spectrum of guests are from cis-isomer, all of which see no changes after mixing with the **C2**.

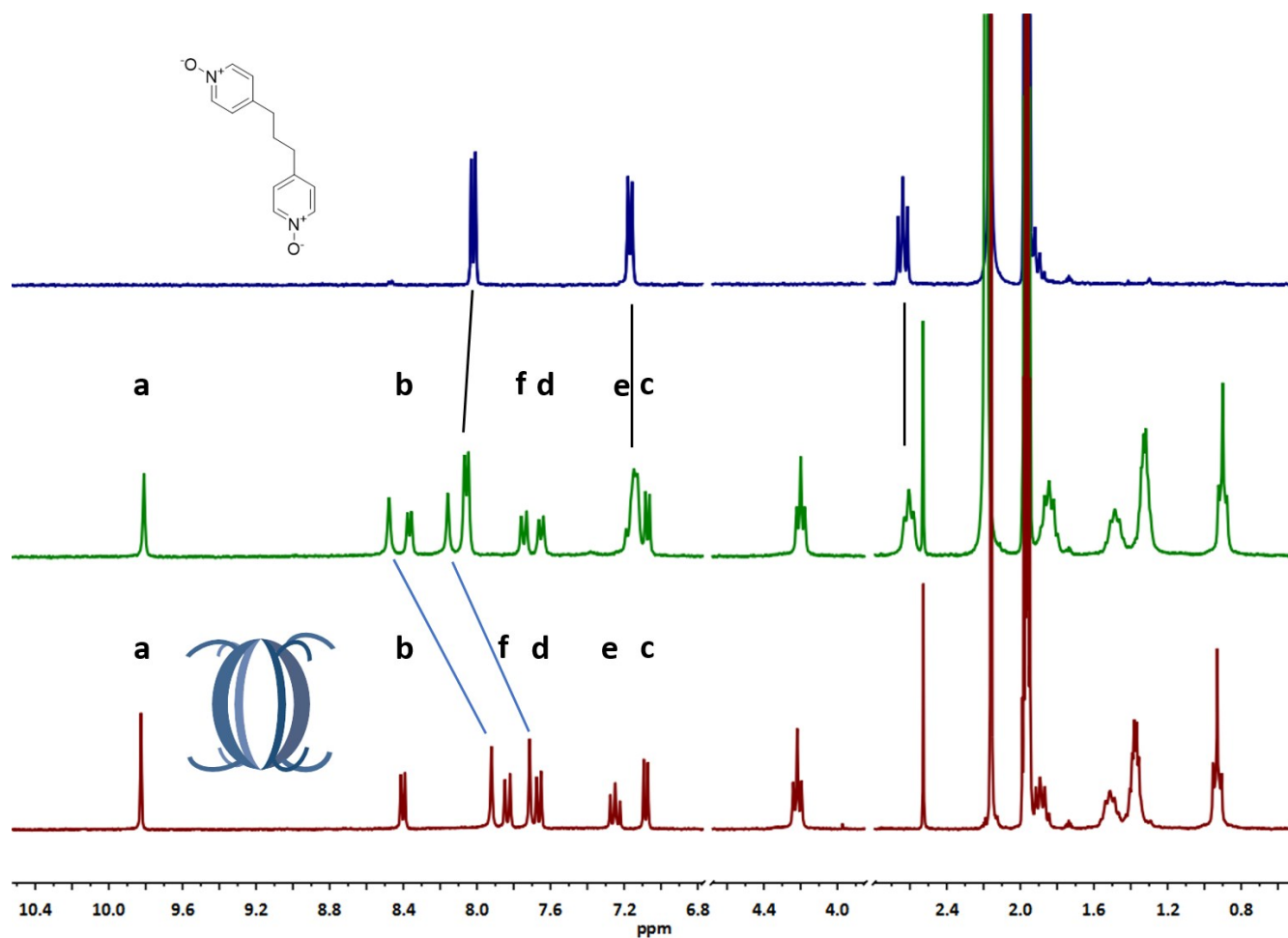


Fig. S5 Stacked partial ¹H NMR (300 MHz, CD₃CN, 298 K) spectra of **C2** (red), **C2** in presence of 4,4'-(propane-1,3-diyl)bis(pyridine 1-oxide) (green) and 4,4'-(propane-1,3-diyl)bis(pyridine 1-oxide) (blue). Blue lines indicate the proton downfield shifts from ureido group, proton f and d showed small upfield shifts (0.09 ppm). Black lines indicate the proton signals from the guest, the protons from guest barely shifts upon mixing with **C2**.

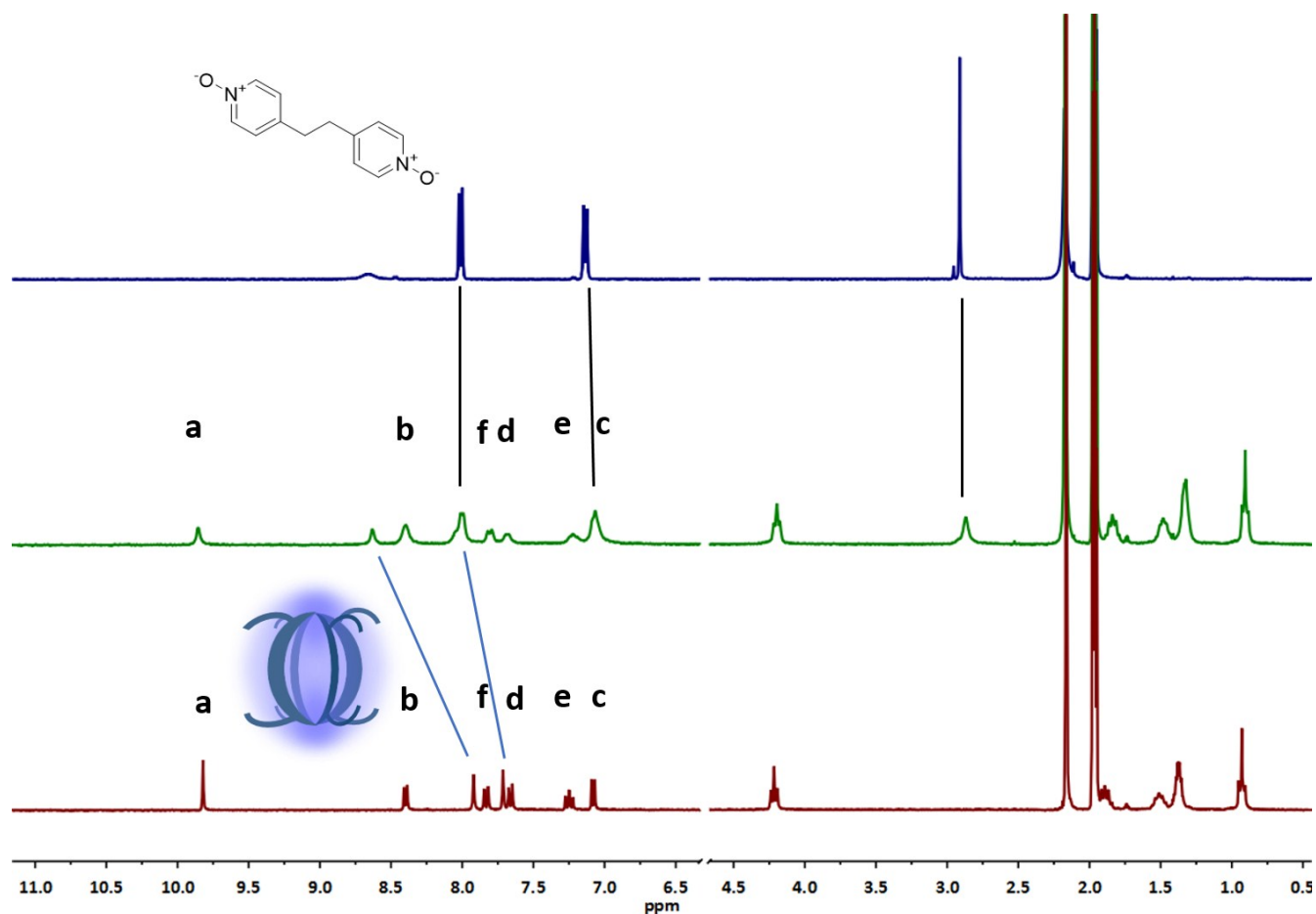


Fig. S6 Stacked partial ^1H NMR (300 MHz, CD_3CN , 298 K) spectra of **C2** (red), **C2** in presence of 4,4'-(ethane-1,2-diyl)bis(pyridine 1-oxide) (green) and 4,4'-(ethane-1,2-diyl)bis(pyridine 1-oxide) alone (blue). Blue lines indicate the proton shifts from ureido group, other protons from **C2** see no changes. Black lines indicate the proton shifts from the guest.

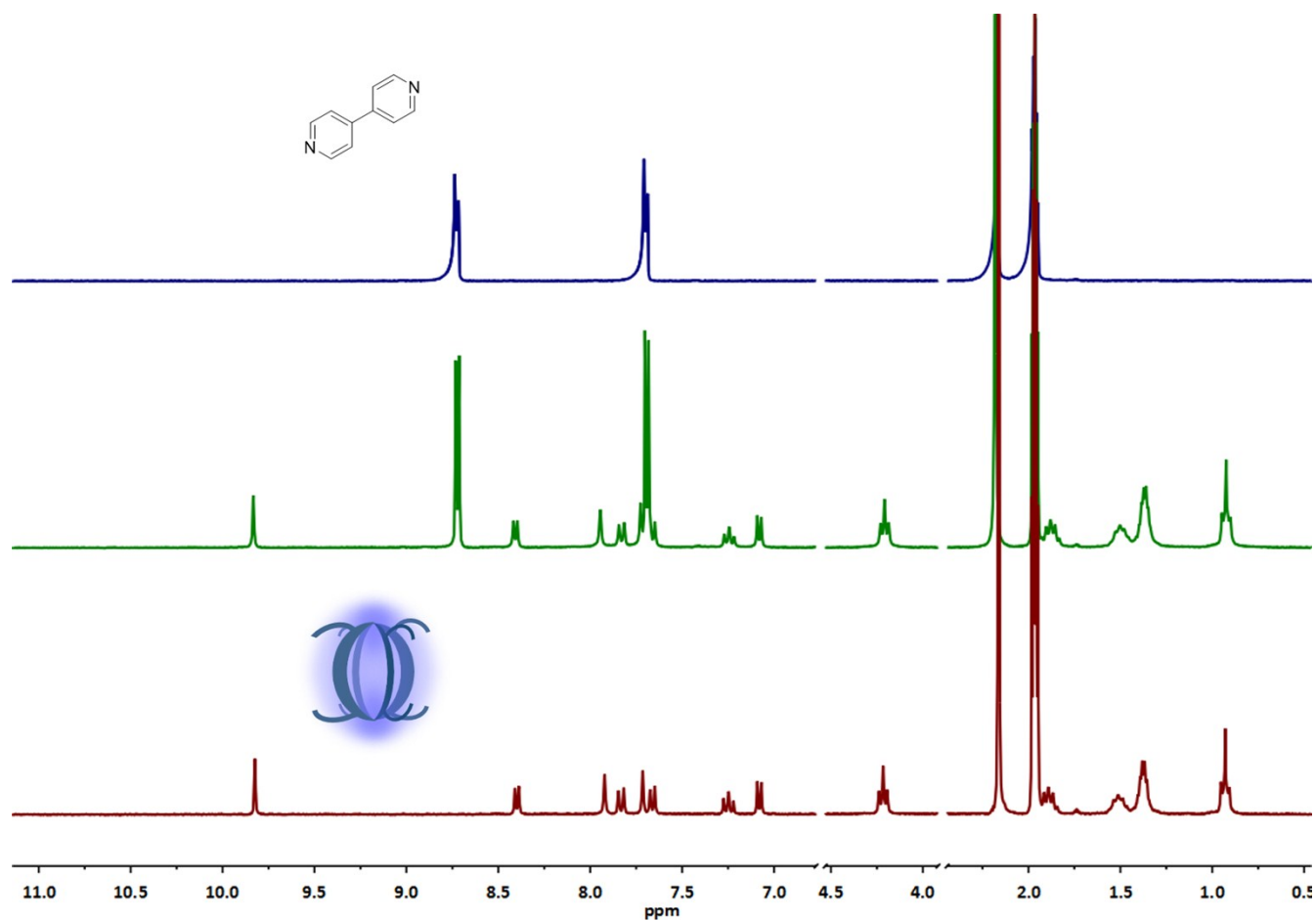


Fig. S7 Stacked partial ^1H NMR (300 MHz, CD_3CN , 298 K) spectra of **C2** (red), **C2** in presence of 4,4'-bipyridyl (green) and 4,4'-bipyridyl alone (blue).

Binding constant K_a determination between **C2** and **G1** from titration data obtained by fluorescence spectroscopy

Titration conditions:

$[\text{C2}] = 2.5 \times 10^{-5} \text{ M}$, the concentration of host was kept constant throughout the titration experiment, small aliquots of guest solution were titrated in the cuvette. The data were fitted according to the reference model adopted from several recent reports.² The spectra were displayed as Fig. 3.

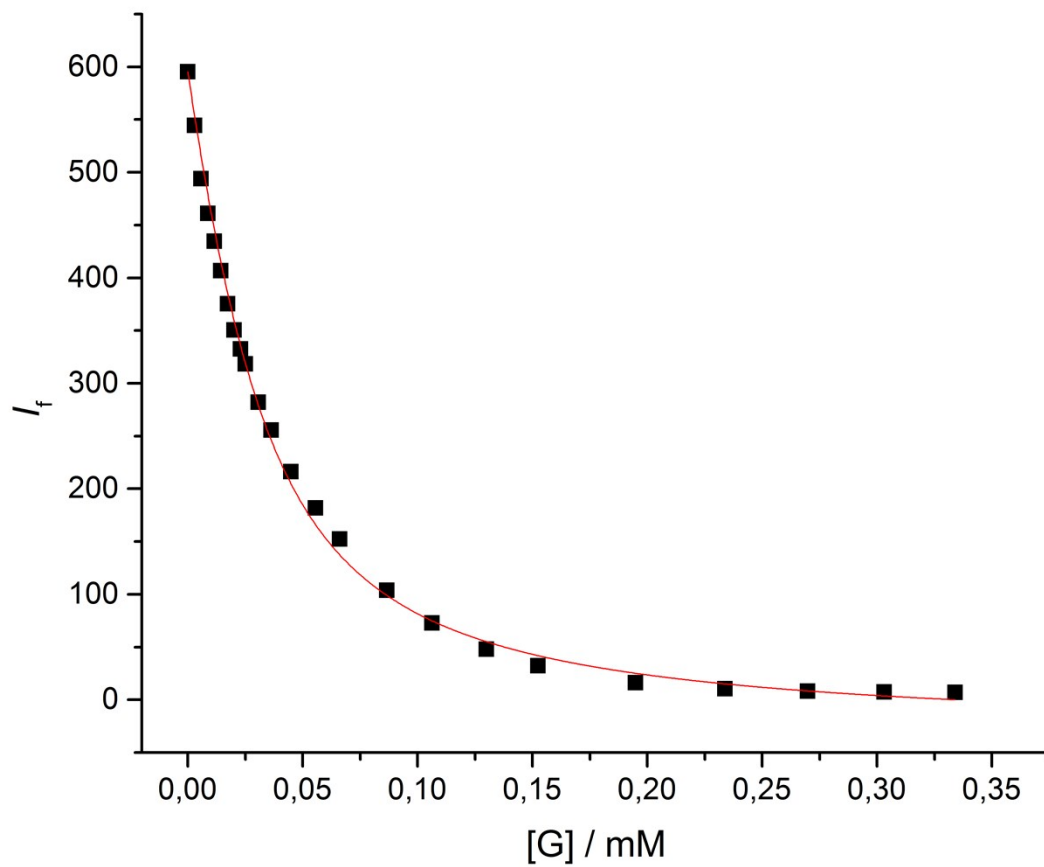


Fig. S8 Data fitting curves of the fluorescence intensities vs. the guest concentration. A binding constant of $5.6 \times 10^4 \pm 2.6 \times 10^3$ was determined ($R^2 = 0.9971$).

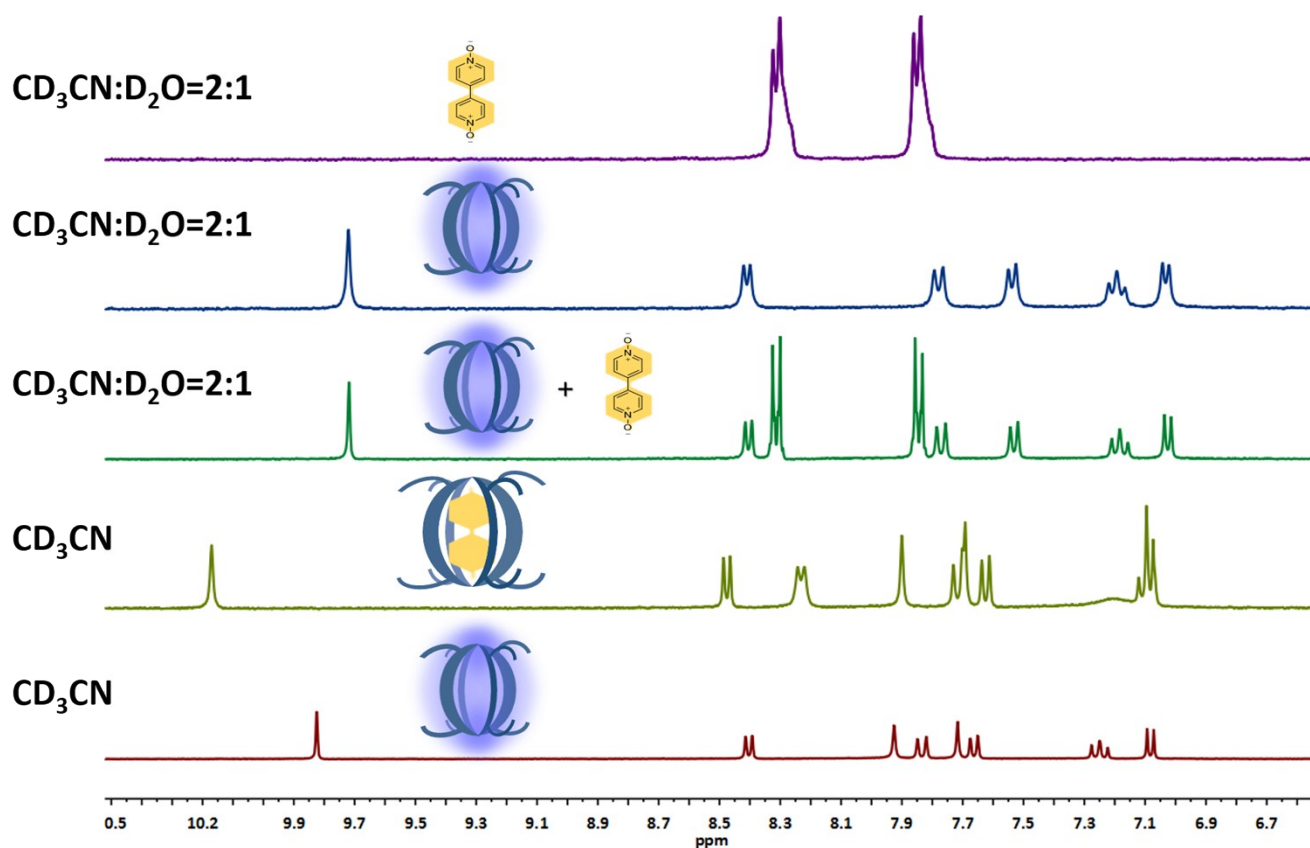
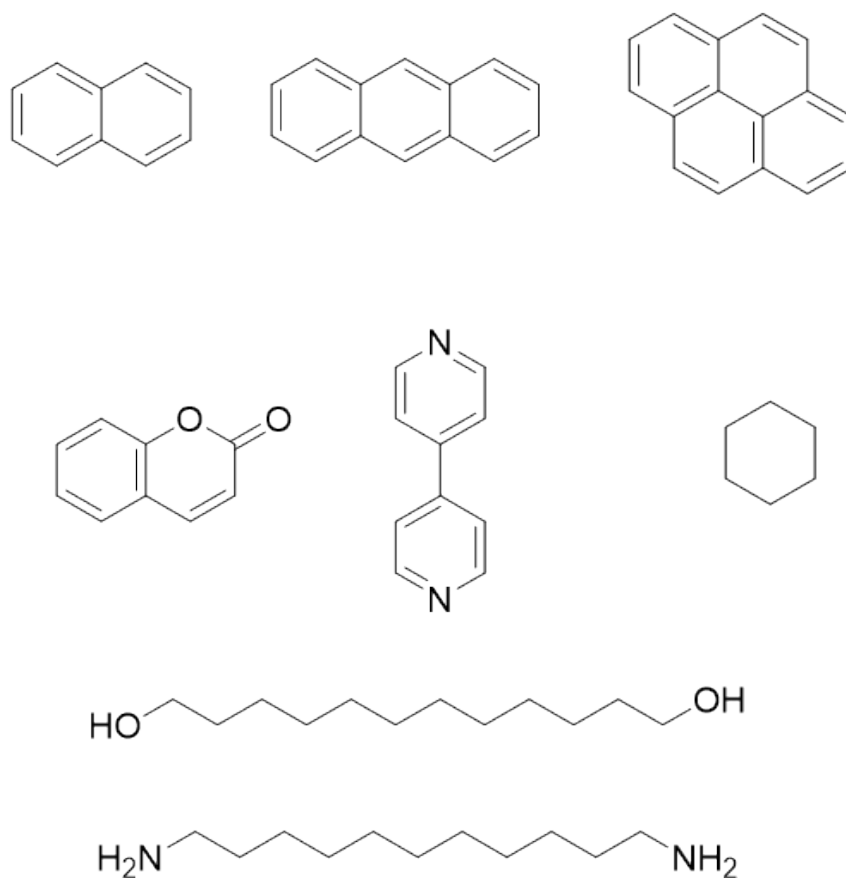


Fig. S9 Stacked ^1H NMR (300 MHz, 298 K) spectra (aromatic area) of **C2** in CD_3CN (red), the exact **C2** sample added with 4,4'-dipyridyl N,N'-dioxide (brown), the host-guest mixture in presence of D_2O (green), **C2** (blue) in $\text{CD}_3\text{CN}/\text{D}_2\text{O}$ (v/v = 2:1) and 4,4'-dipyridyl N,N'-dioxide (purple) in $\text{CD}_3\text{CN}/\text{D}_2\text{O}$ (v/v = 2:1) for comparison



Scheme S3 Guests used for encapsulation experiments, all of which are added excessive to the **C2** in CD₃CN, CD₃CN:D₂O (2:1, v:v) or MeOD solution .

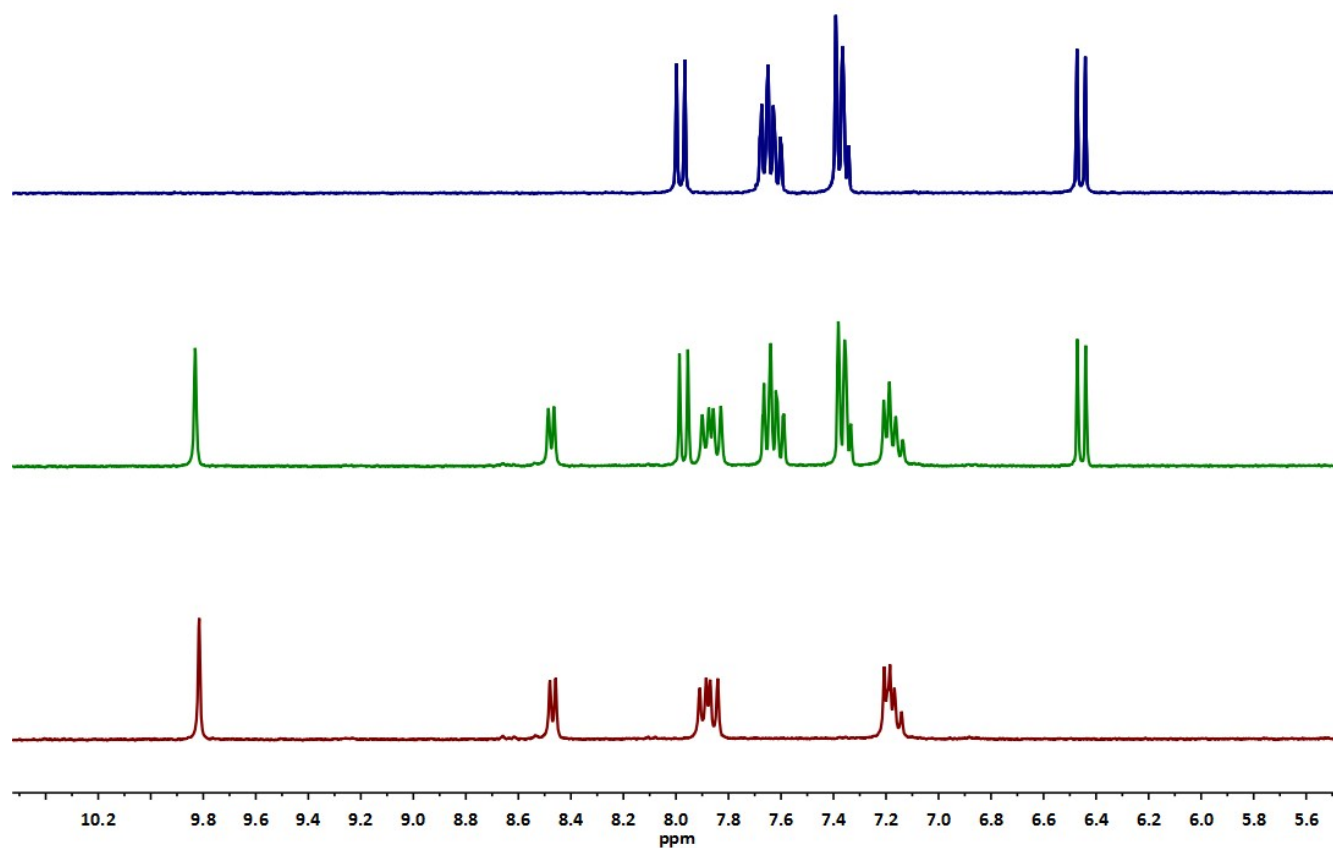


Fig. S10 Stacked partial ¹H NMR (300 MHz, CD₃OD, 298 K) spectra (aromatic area) of **C2** (red), **C2** in presence of coumarin (green) and coumarin alone (blue).

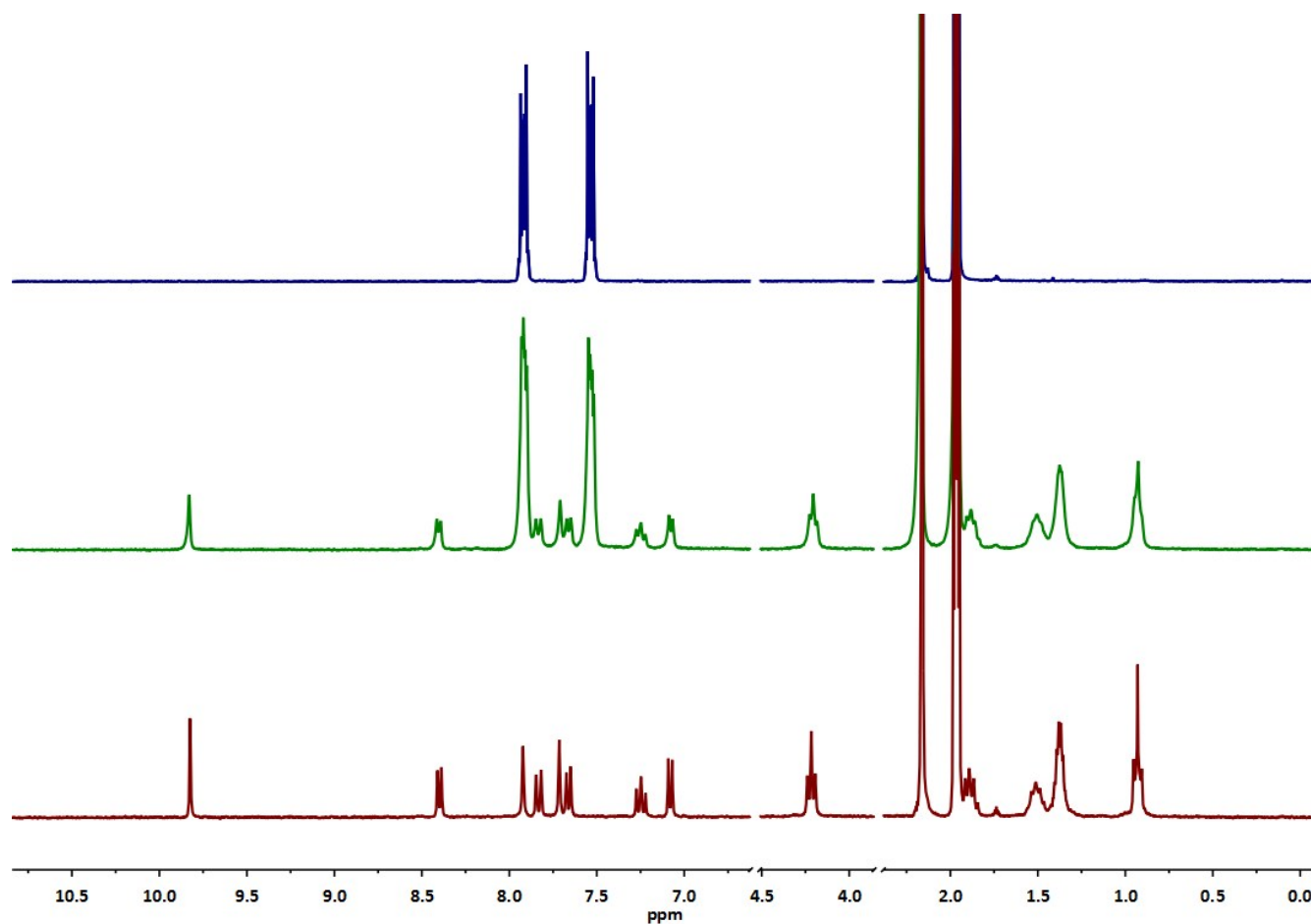


Fig. S11 Stacked partial ¹H NMR (300 MHz, CD₃CN, 298 K) spectra of **C2** (red), **C2** in presence of naphthalene (green) and naphthalene alone (blue).

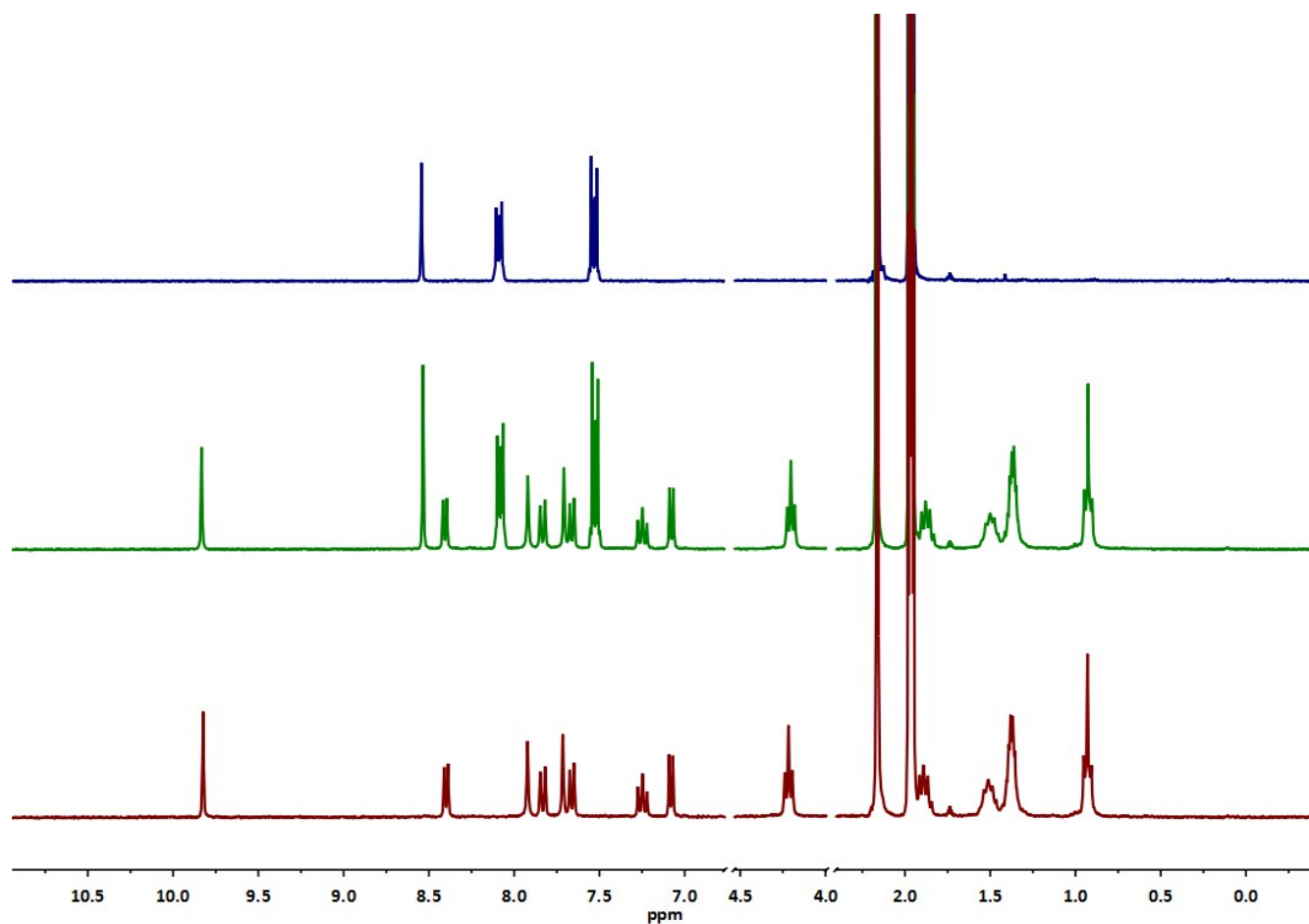


Fig. S12 Stacked partial ¹H NMR (300 MHz, CD₃CN, 298 K) spectra of **C2** (red), **C2** in presence of anthracene (green) and anthracene alone (blue).

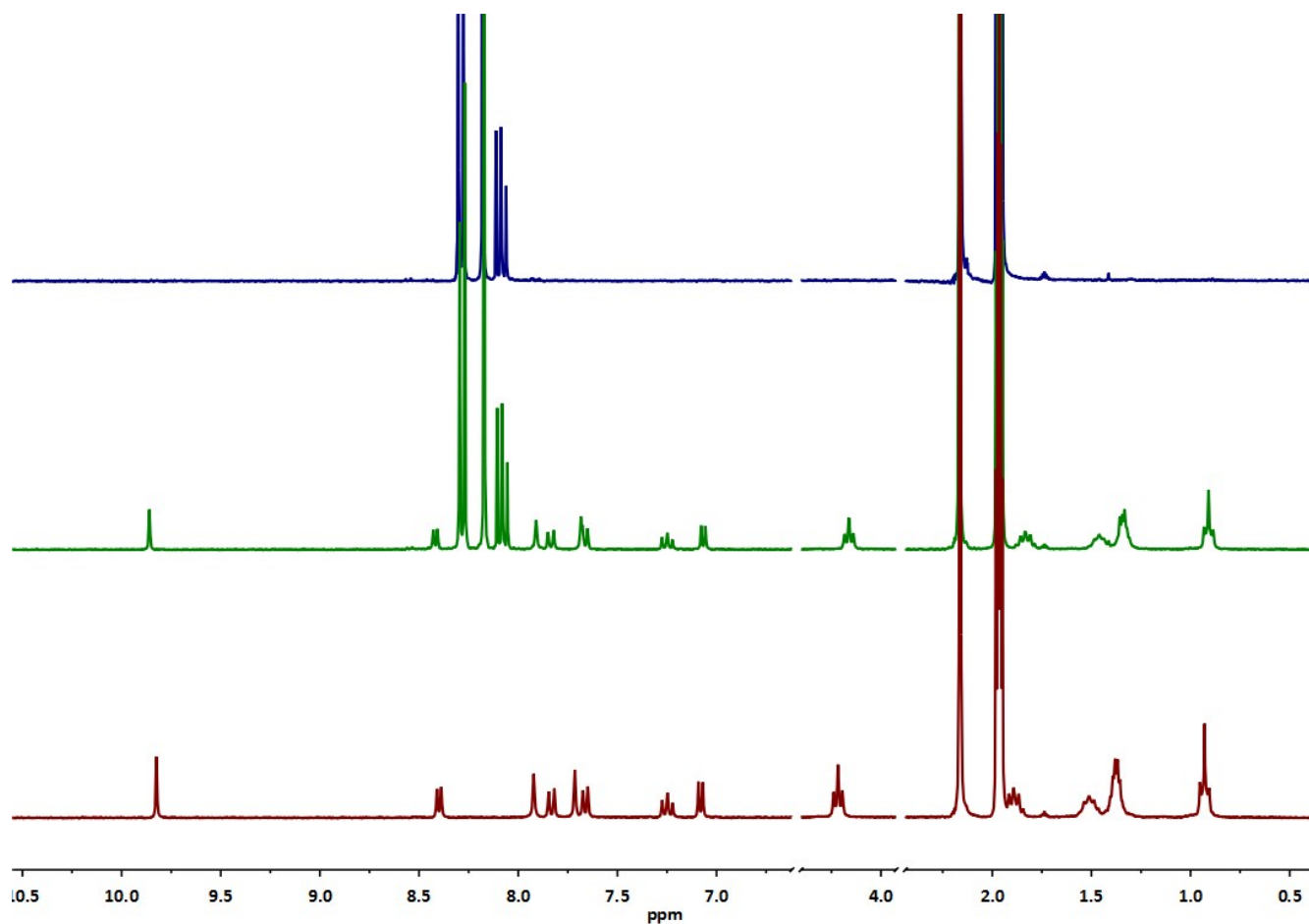


Fig. S13 Stacked partial ¹H NMR (300 MHz, CD₃CN, 298 K) spectra of **C2** (red), **C2** in presence of pyrene (green) and pyrene alone (blue).

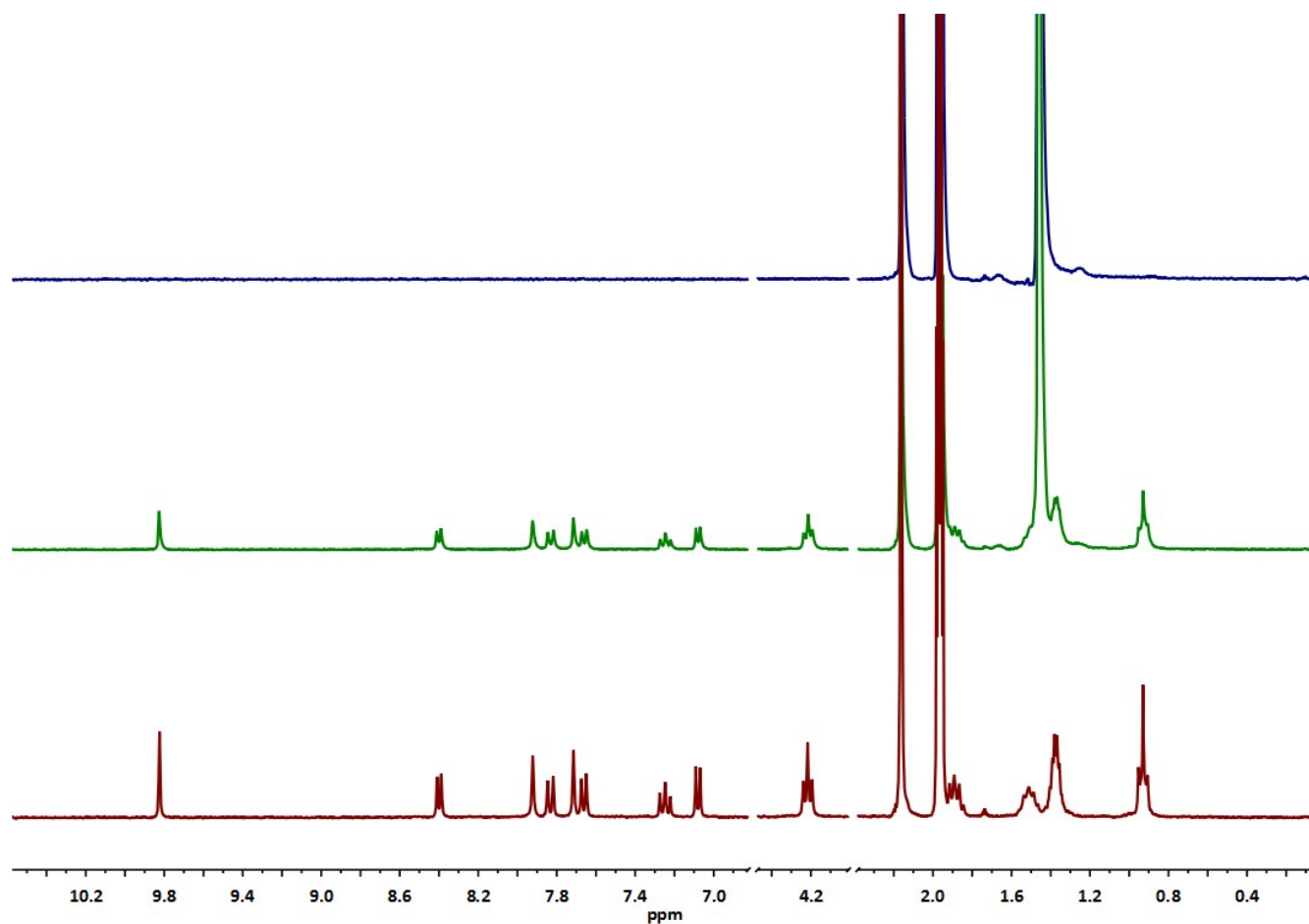


Fig. S14 Stacked partial ^1H NMR (300 MHz, CD_3CN , 298 K) spectra of **C2** (red), **C2** in presence of cyclohexane (green) and cyclohexane alone (blue).

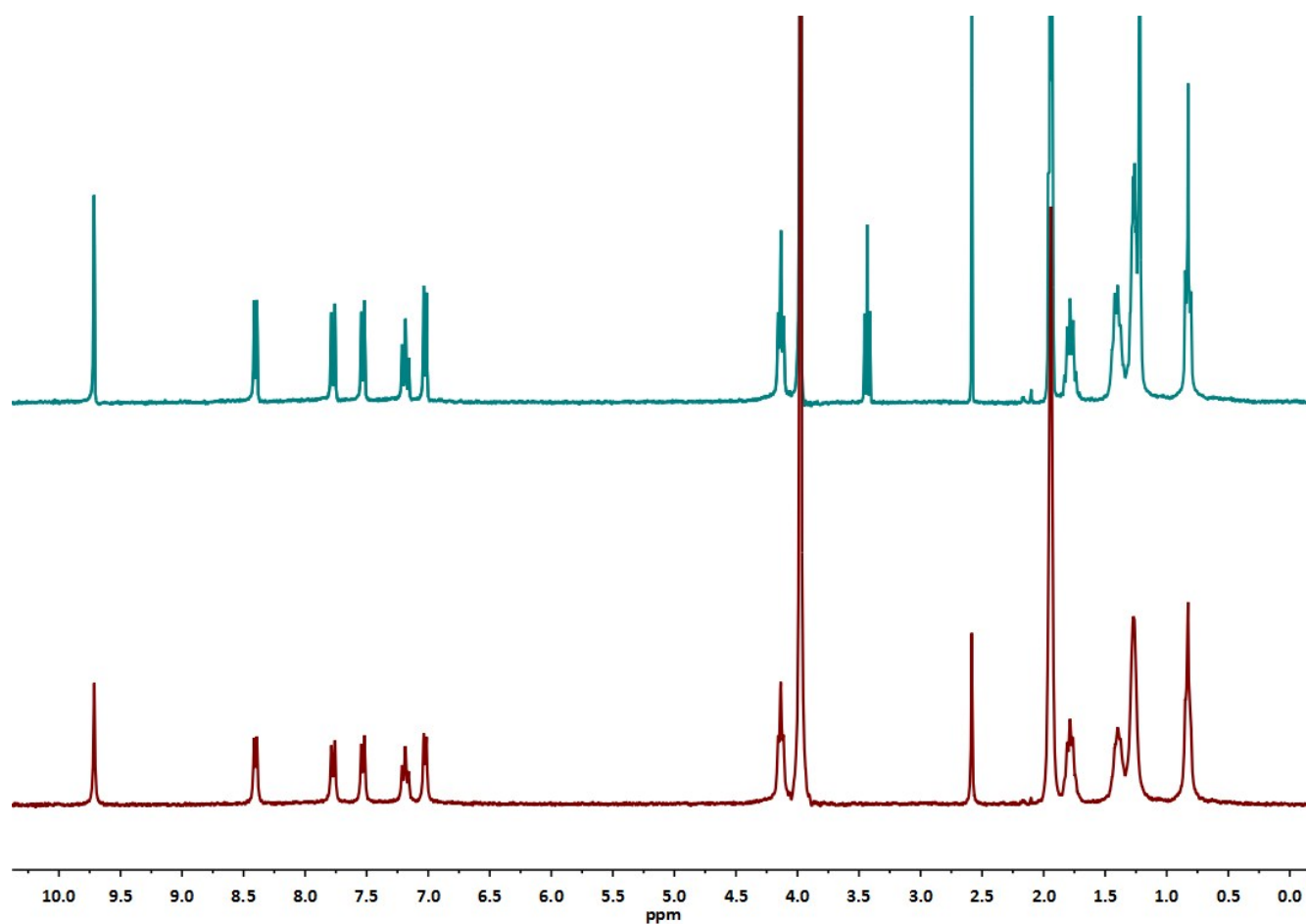


Fig. S15 Stacked ^1H NMR (300 MHz, $\text{CD}_3\text{CN}:\text{D}_2\text{O}=2:1(\text{v}:\text{v})$, 298 K) spectra of **C2** (red), **C2** in presence of dodecane-1,12-diol (turquoise).

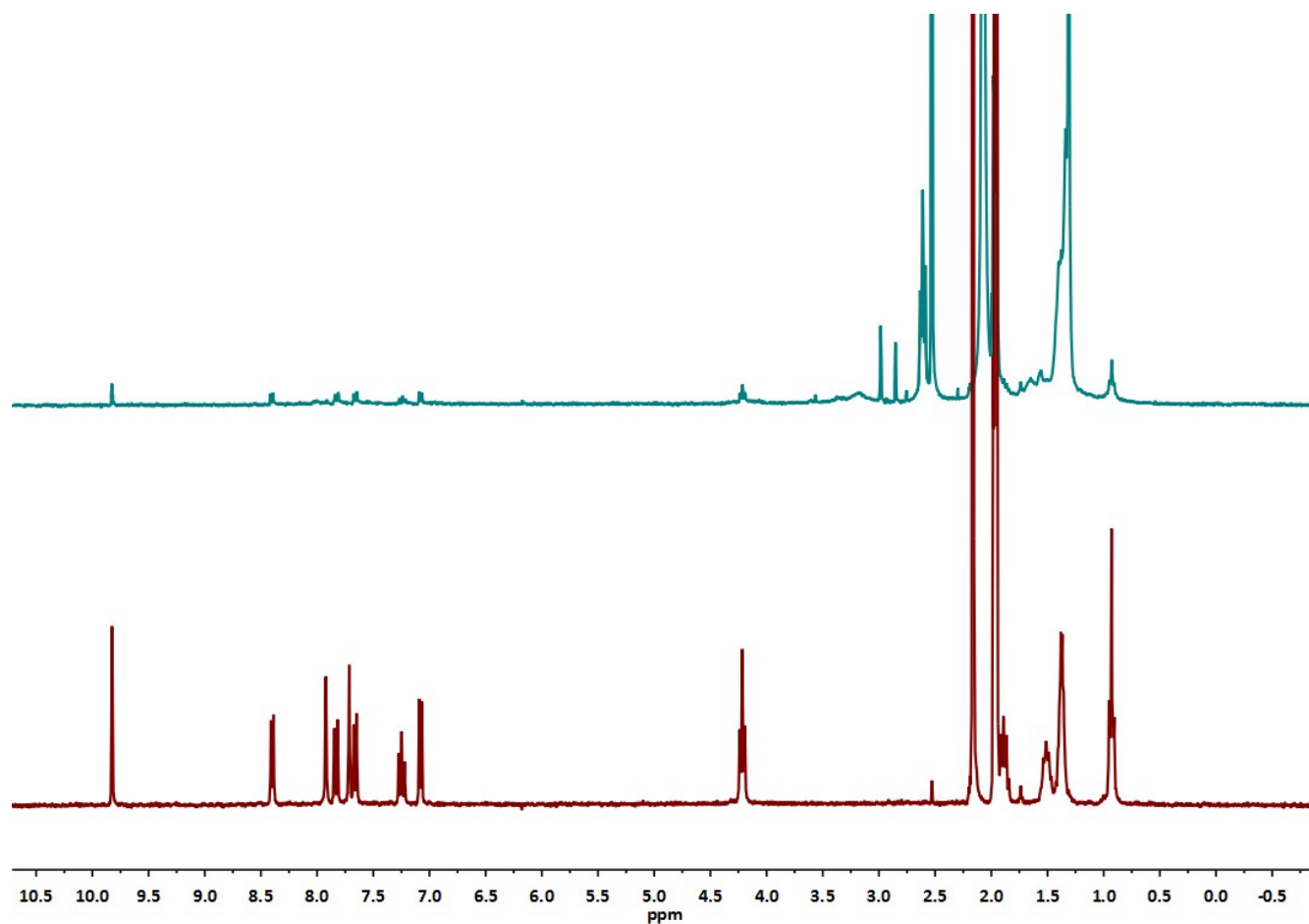


Fig. S16 Stacked ^1H NMR (300 MHz, CD_3CN , 298 K) spectra of **C2** (red), **C2** in presence of undecane-1,11-diamine (turquoise), the cage is destroyed by the amine.

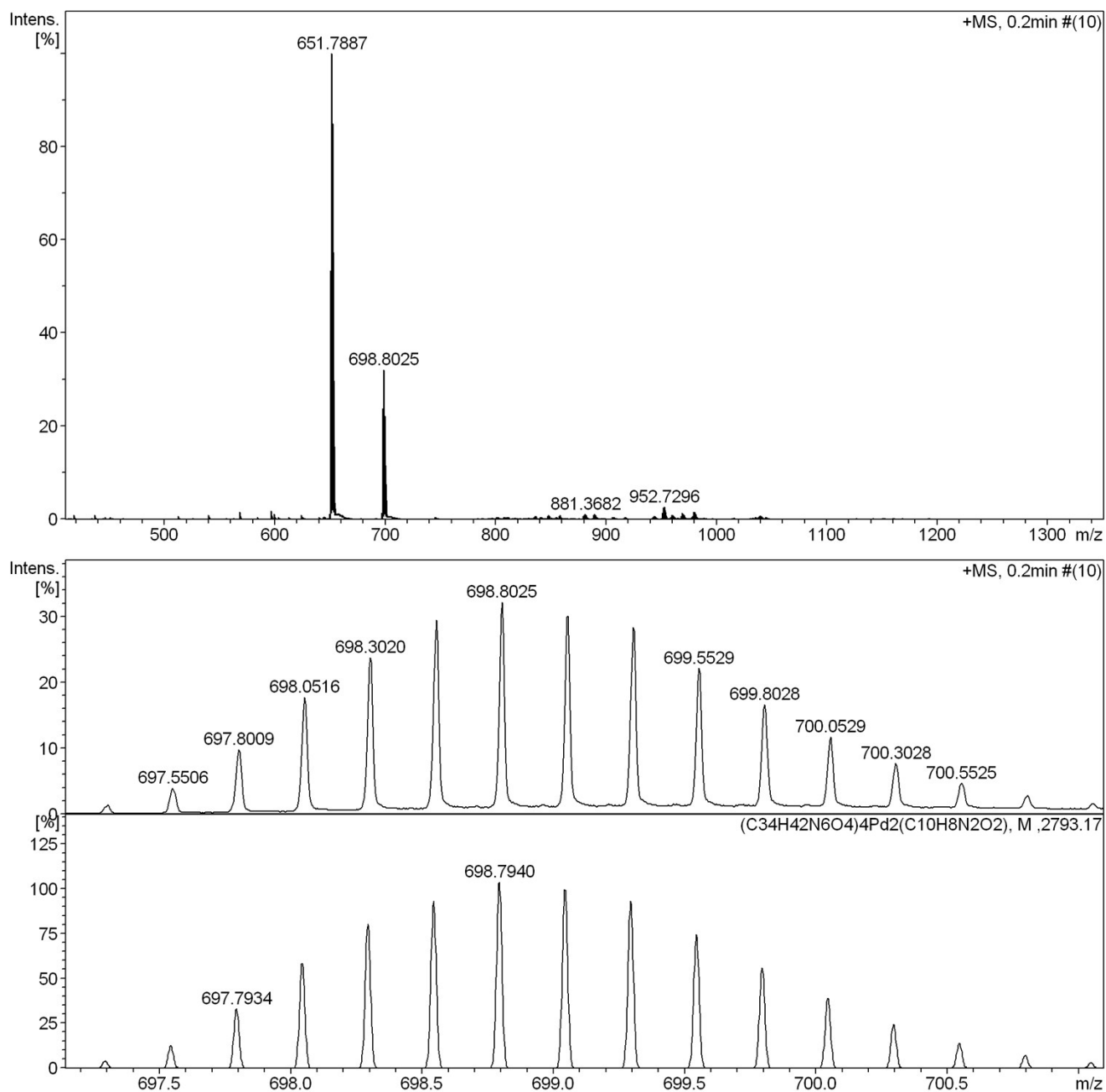


Fig. S17 Hi resolution picture of the ESI mass spectrum of the solution of **C2** after addition of 4,4'-dipyridyl N,N' -dioxide, peaks corresponding to host-guest adduct were abstracted to compare with the theoretical peaks (bottom).

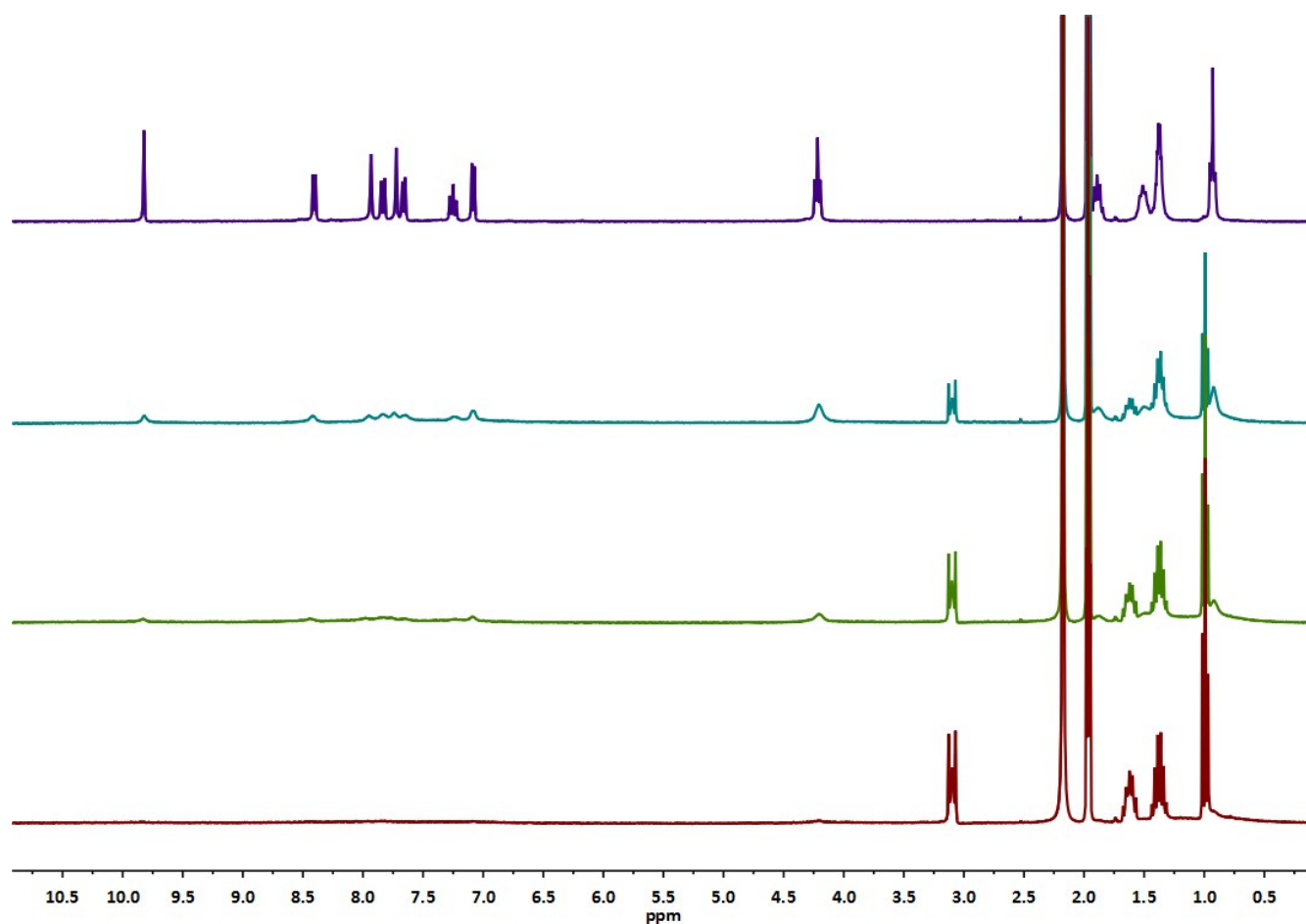


Fig. S18 Stacked ¹H NMR (300 MHz, CD₃CN, 298 K) spectra of **C2** (purple), **C2** in presence of 1 equiv. TBACl (turquoise), after addition of 2 equiv. TBACl (green) and addition of 3 equiv. TBACl (red) for which the signals of the ligand cannot be observed. Meanwhile, the peaks reminiscent of **C2** disappeared, while a yellow precipitate was formed indicative of the presence of the ligand, since the ligand is not soluble in acetonitrile.

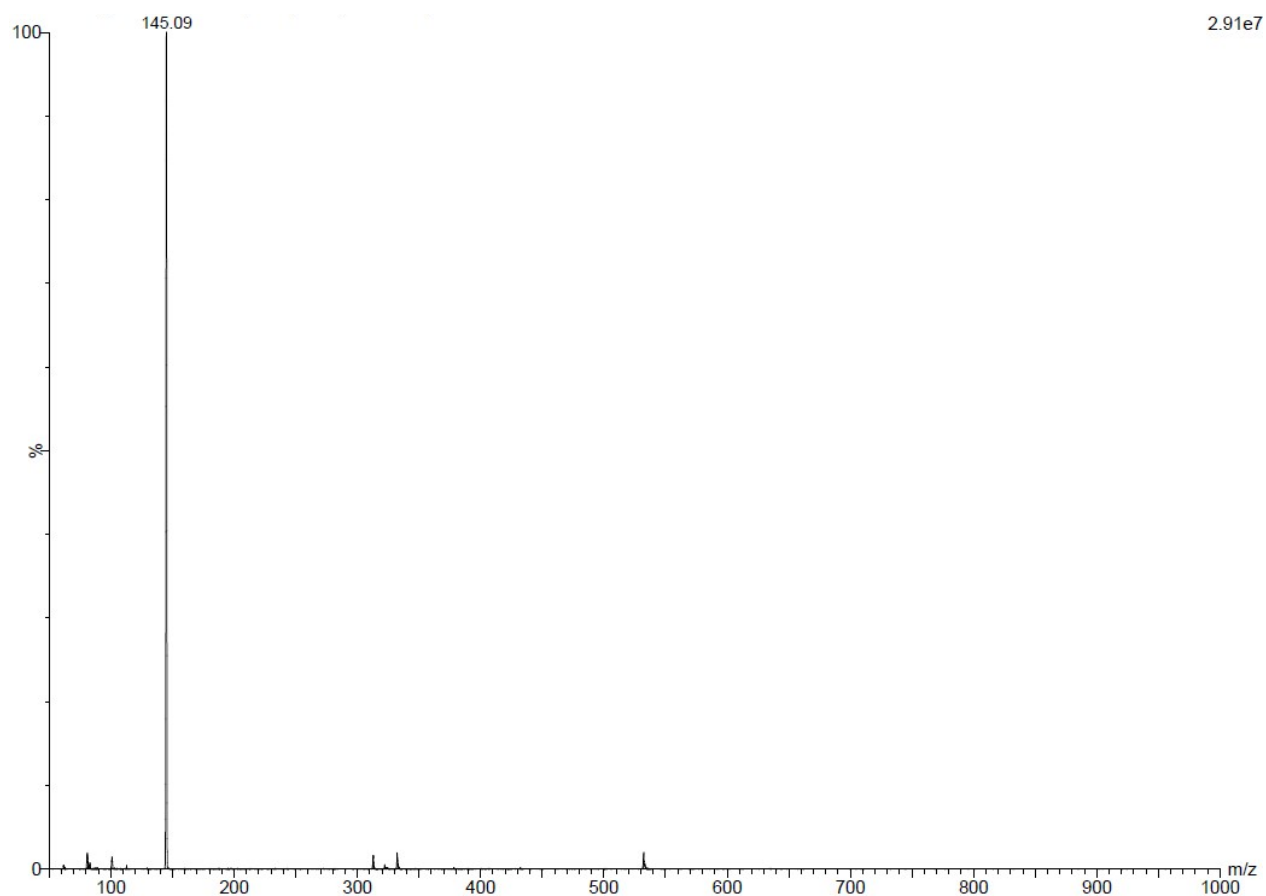


Fig. S19 Negative ESI-MS spectrum after the addition of chloride to **C2**. The most prominent peak correspond to the complex $\text{Pd}(\text{CH}_3\text{CN})\text{Cl}_4^{2-}$ (calcd m/z 144.40), other peaks including $\text{Na}[\text{Pd}(\text{CH}_3\text{CN})\text{Cl}_4]^-$ (312.41, calcd m/z 311.79), $\text{TBA}[\text{Pd}(\text{CH}_3\text{CN})\text{Cl}_4]^-$ (532.00, calcd m/z 531.09).

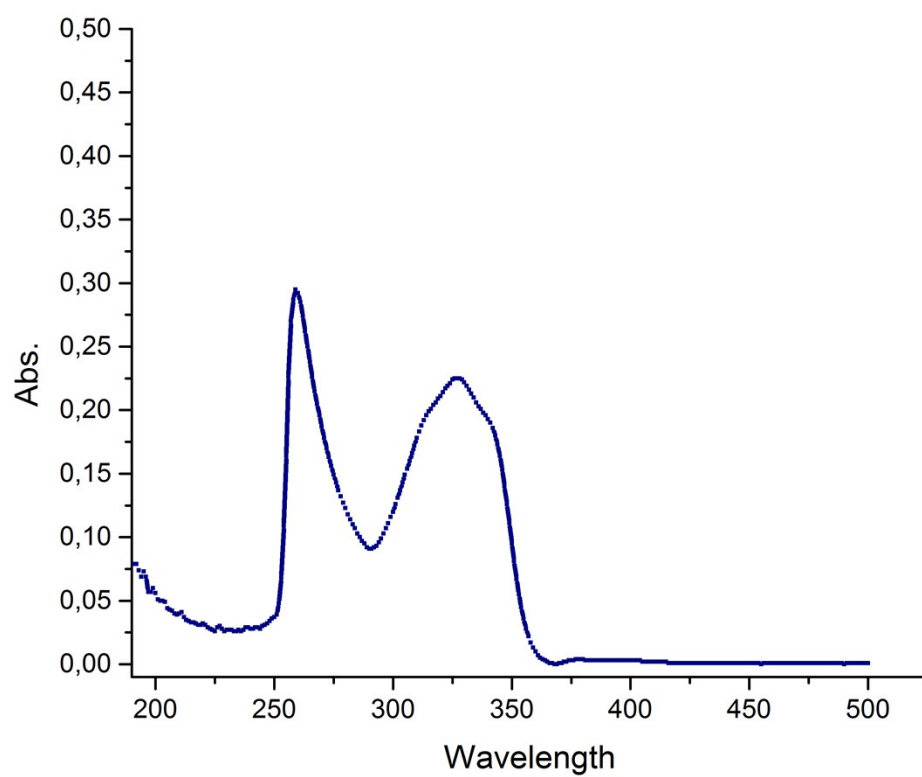


Fig. S20 UV-vis spectrum of **L2** (8.89×10^{-6} M in DMSO).

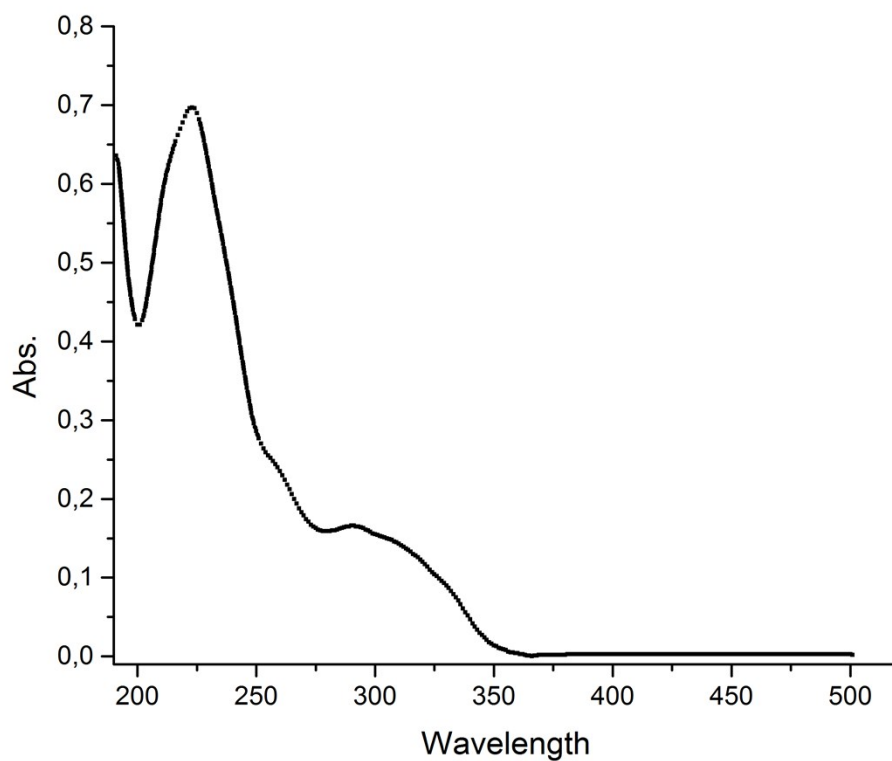


Fig. S21 UV-vis spectrum of **C2** (2.20×10^{-6} M in CH_3CN).

1. Z.-Q. Wu, C.-Z. Li, D.-J. Feng, X.-K. Jiang and Z.-T. Li, *Tetrahedron*, 2006, **62**, 11054.
2. (a) P. Thordarson, *Chem. Soc. Rev.*, 2011, **40**, 1305; (b) P. Spenst and F. Würthner, *Angew. Chem. Int. Ed.*, 2015, **54**, 10165.