Electronic Supplementary Information

Water-soluble Phosphane-Substituted Cyclodextrin as Effective Bifunctional Additive in Hydroformylation of Higher Olefins

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Materials and methods

All chemicals were purchased from Acros, Strem or Aldrich Chemicals in their highest purity. NMR spectra were recorded on a Bruker DRX300 spectrometer operating at 300 MHz for ^{1}H nuclei and 75 MHz for ^{13}C nuclei. $CDCl_3$ (99.50% isotopic purity) were purchased from Eurisotop. GC-MS analysis were performed using a Shimadzu GC-17A gas chromatograph using a Varian capillary column (length 30 m, internal diameter 0.025 µm) and a Shimadzu GCMS-QP500 mass spectrometer. All the hydroformylation experiments were carried out in laboratory reactors from Parr Instrument Company (USA). To prevent oxidation of the catalyst precursors, the reaction mixture was transferred into the reactor using the standard Schlenk technique. The determination of the interfacial tensions γ was performed at room temperature by the pendant drop method using a commercial pendant drop tensiometer (DataPhysics, Model, OCA 15 plus). The system includes an illumination screen, a CCD camera, a dosing system, and the software for data evaluation. To measure γ, a quartz glass container was filled with the substrate (1-decene, 1-tetradecene, 1-hexadecene or 1-octadecene). A drop of the aqueous solution containing the modified cyclodextrin was then injected in the substrate using a syringe with a calibrated needle. The images of the drop were captured digitally by the camera and were processed using a computer every 2 seconds. After about ten minutes, γ reached an asymptotic plateau value. The average value of three measurements was taken as the interfacial tension.

ITC measurements

Calorimetric experiments were carried out on an isothermal calorimeter (ITC200, MicroCal Inc., USA), at 298 K. Degassed phosphate buffer solutions (50 mM, pH=6.5) were used in both cell (202.8 µL) and syringe (40 µL). Firstly, a release protocol was employed to characterize the self inter-inclusion behavior of **2** : concentrated solutions of **2** (8.1, 3.9 and 1.8 mM) were injected in the cell, only filled with the buffer solution. Then, a release protocol was used to evaluate the affinity of **2** for ibuprofene : a 5 mM Ibuprofen + 4 mM **2** solution was injected in the cell, only filled with the buffer solution. Finally, a competitive protocol was employed to characterize the affinity of **2** for adamantane carboxylate: a 5 mM ibuprofen / 3 mM **2** solution was injected on to a 0.5 mM adamantane carboxylate solution.

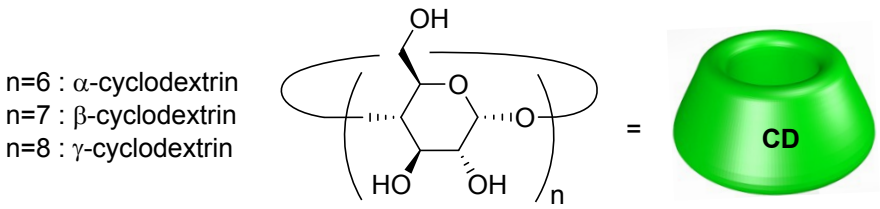
For these two latter experiments, negligible concentrations of the dimer form of **2** were expected, since the monomer/dimer equilibrium is largely shifted in the favour of the monomeric form, as a consequence of ibuprofen and adamantane carboxylate binding. Each experiment consisted in 11 additions of the syringe solution on the cell content, with a first small aliquot of 1 µL followed by 10 aliquots of 3.7 µL (injection duration 7.4 s, time interval 150 s, agitation speed 1000 rpm). The heat flow was recorded as a function of time. Blank experiments (buffer on host or guest solution, guest solution on buffer, or buffer on buffer) were appropriately subtracted to binding experiments. The complexation heat produced per injection was obtained by measuring each peak area. The first injection was discarded to eliminate any error of the initial injected volume at the beginning of the titrations. Binding constants (K in M^{-1}) and inclusion enthalpies (ΔH in $cal.mol^{-1}$) were obtained from binding isotherms (assuming a 1:1 stoichiometry), by nonlinear analyses of complexation heats as a function of total concentrations. Data treatments were realized by using a dedicated homemade program.[1]

Catalytic experiments

In a typical experiment, $Rh(CO)_2(acac)$ (3 mg, 0.012 mmol) was degassed three times by vacuum-N_2 cycles and dissolved in a degassed solution of **2** (90 mg, 0.058 mmol) in water (6 mL). The resulting solution was stirred at room temperature until all the rhodium complex was dissolved (2 h). The substrate (8.5 mmol) was poured into the autoclave and N_2-purged. The catalytic solution was then cannulated under nitrogen into the autoclave. Once the desired temperature was reached, the autoclave was pressurized under CO/H_2 (1/1) pressure (typically 50 bar) and the solution was vigorously stirred (2500 rpm). When the reaction was complete, the apparatus was cooled down to room temperature and depressurized. The products were analyzed by ^1H and ^{13}C NMR experiments. All runs were performed at least twice in order to ensure reproducibility.

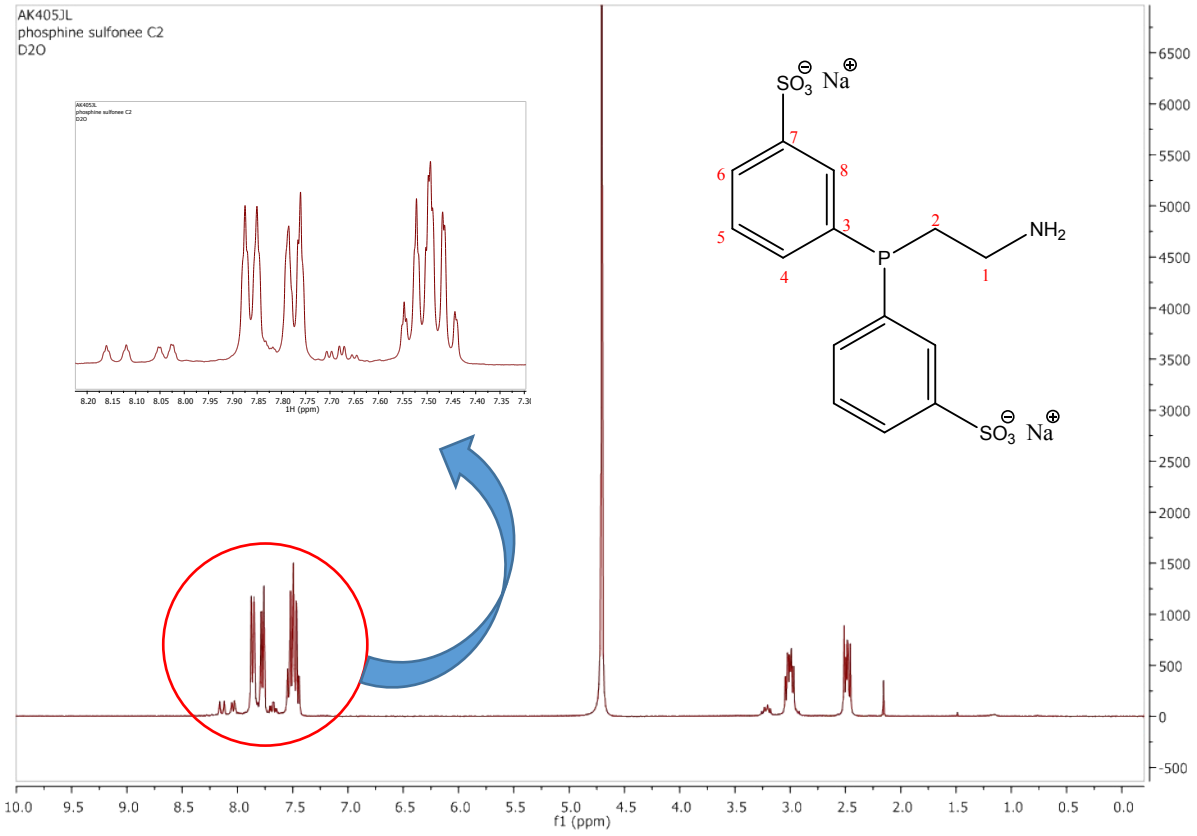
[1] E. Bertaut, D. Landy, Beilstein J. Org. Chem. 2014, 10, 2630-2641.

Figure S1. Structures of native cyclodextrins (CDs).



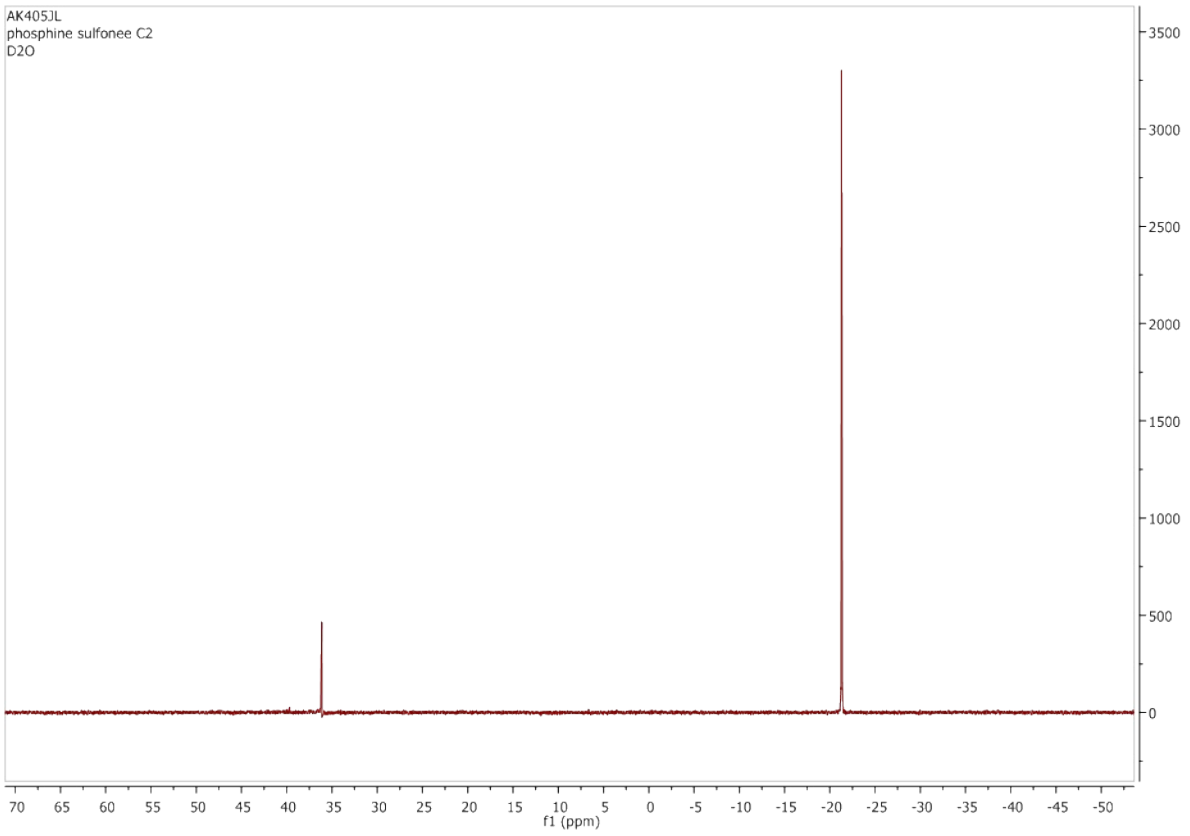
NMR spectra

Figure S2. ^{1}H NMR spectrum of **1**.



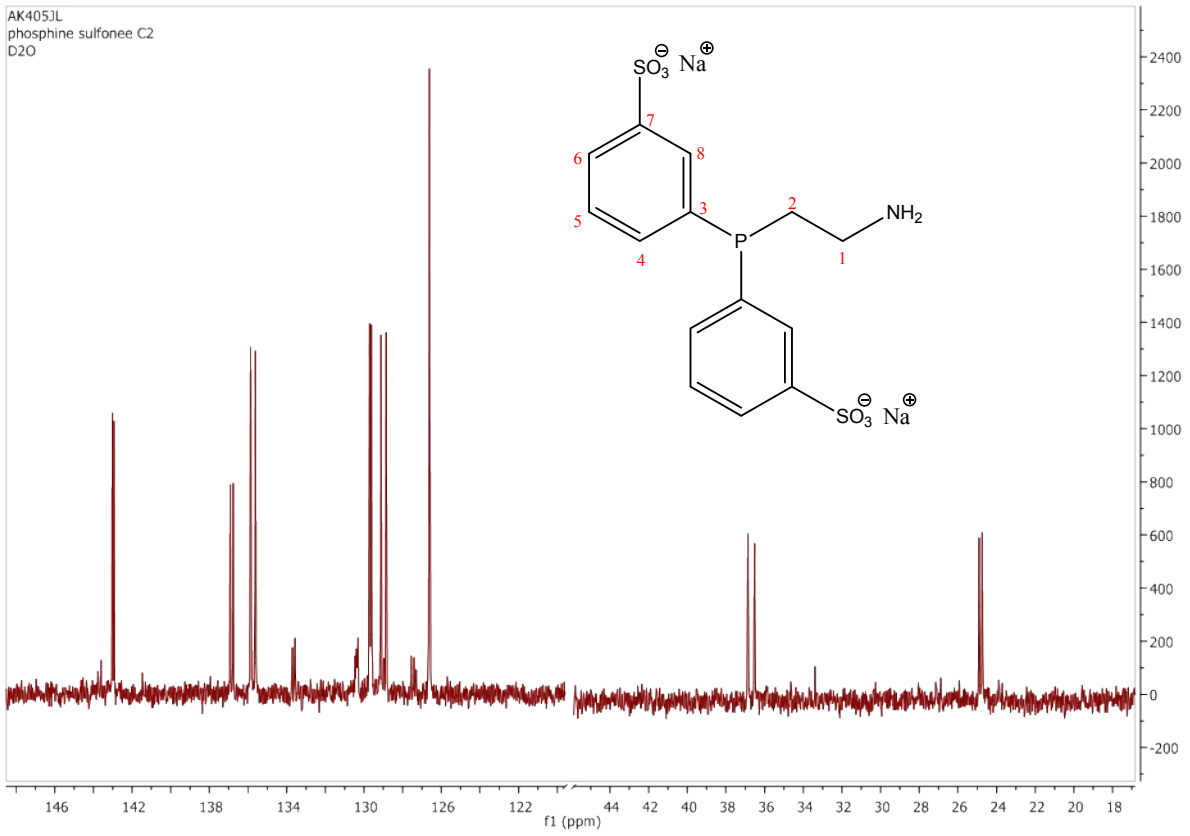
^{1}H NMR (D_2O): 2.48 (m, H-2), 3.01 (m, H-1), 7.50 (t, H-4, $^{3}J_{H\text{-}P}$ = 7.64Hz and $^{3}J_{H\text{-}H}$ = 7.64Hz), 7.50 (t, H-5, $^{3}J_{H\text{-}H}$ = 7.64Hz and $^{4}J_{H\text{-}P}$ = 7.64Hz), 7.77 (d, H-6, $^{3}J_{H\text{-}H}$ = 7.35Hz), 7.86 (d, H-8, $^{3}J_{H\text{-}P}$ = 7.46Hz).

Figure S3. ^{31}P NMR spectrum of **1**.



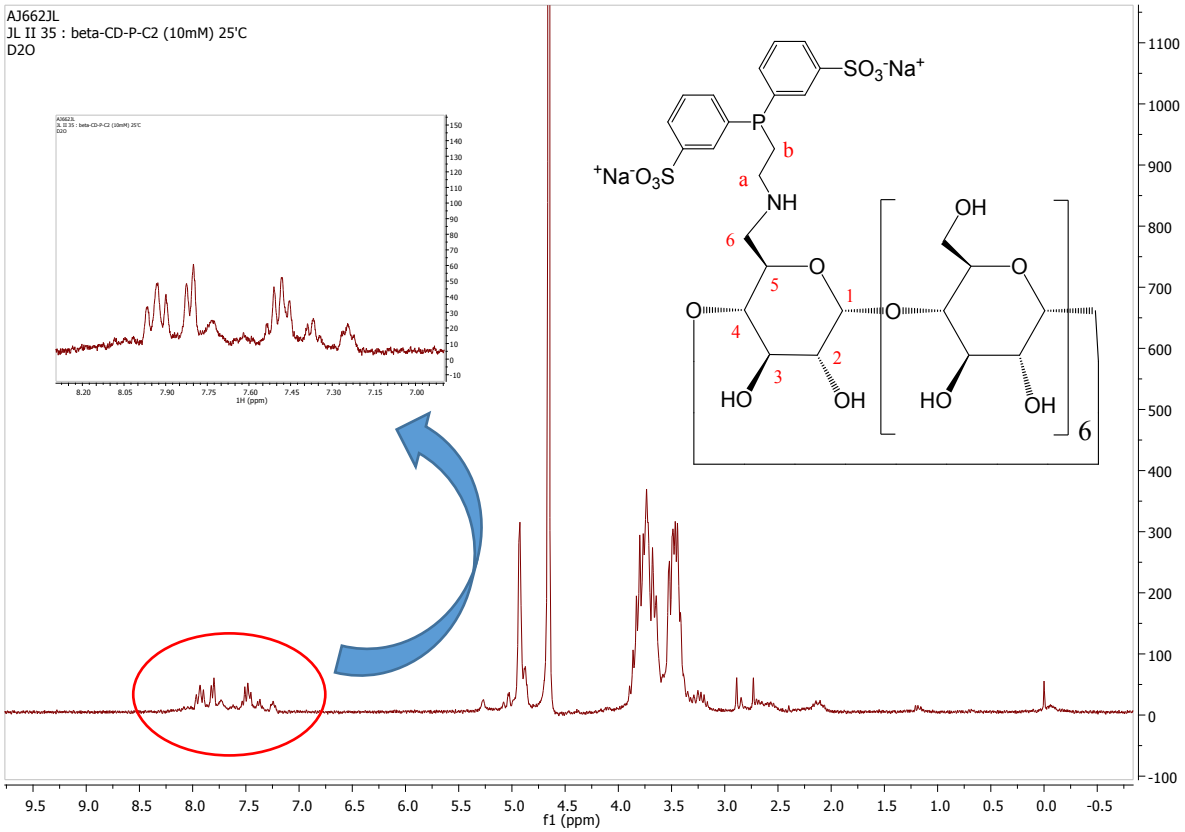
^{31}P NMR (D_2O): 36.1 (oxide), -21.3.

Figure S4. ^{13}C NMR spectrum of **1**.



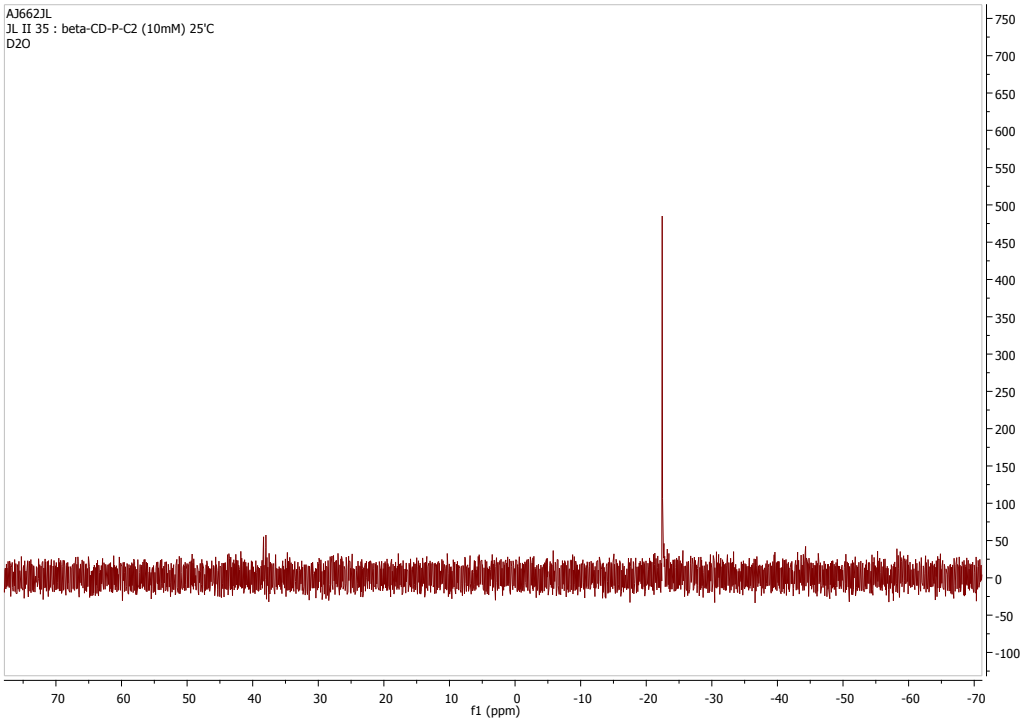
^{13}C NMR (D_2O): 24.8 (d, C-2), 36.6 (d, C-1), 126.6 (s, C-6), 128.99 (d, C-8), 129.6 (d, C-5), 135.7 (d, C-4), 136.8 (d, C-3), 143.0 (d, C-7).

Figure S5. ^{1}H NMR spectrum of **2**.



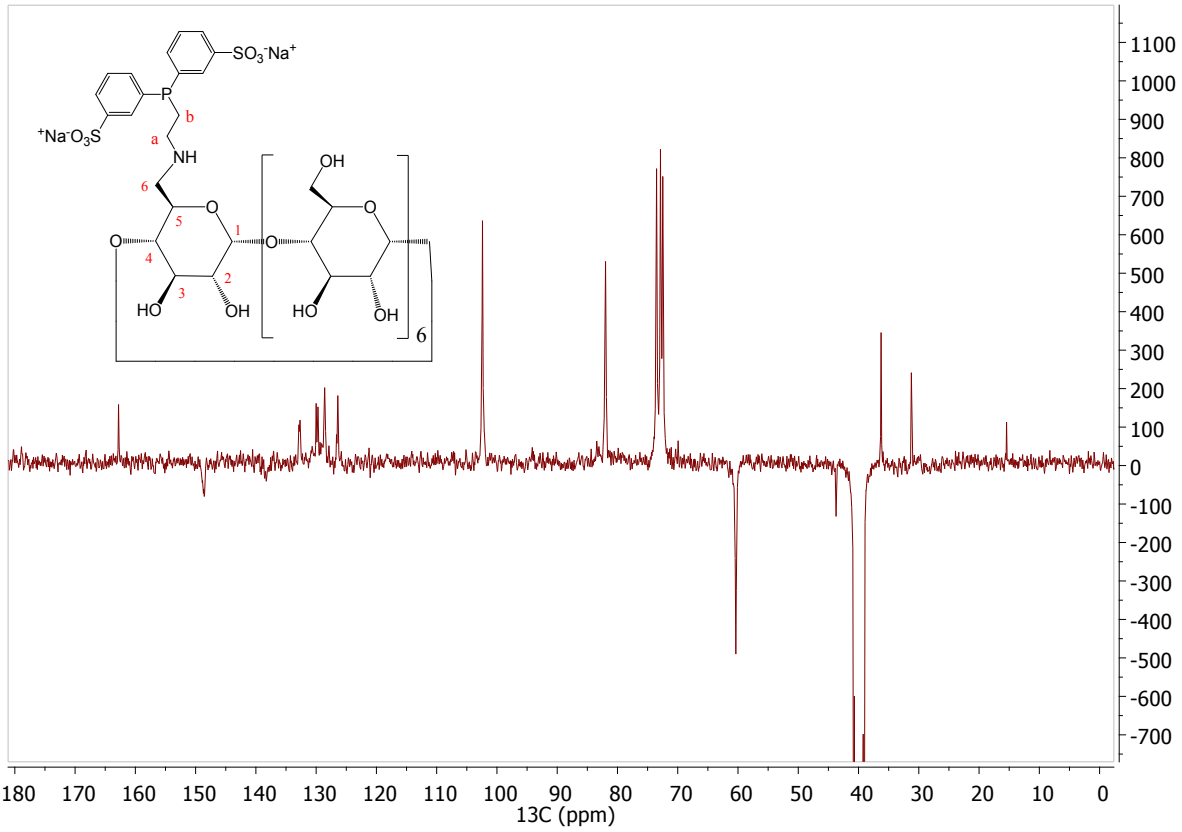
^{1}H NMR (D_2O): 2.13 (m, 2H, Hb), 2.69 (m, 2H, Ha), 3.36-3.60 (m, 14H, H-2$^{I\text{-}VII}_{CD}$, H-4$^{I\text{-}VII}_{CD}$), 3.60-3.91 (m, 26H, H-3$^{I\text{-}VII}_{CD}$, H-5$^{I\text{-}VII}_{CD}$, H-6$^{II\text{-}VII}_{CD}$ et H-6' $^{II\text{-}VII}_{CD}$), 4.84-5.01 (m, 8H, H-6$^{I}_{CD}$, H-6' $^{I}_{CD}$ and OH-6 ; m, 7H, H-1$^{I\text{-}VII}_{CD}$; m, 14H, OH-2 and OH-3), 7.21-7.99 (m, 8H, H-aromatic protons).

Figure S6. ^{31}P NMR spectrum of **2**.



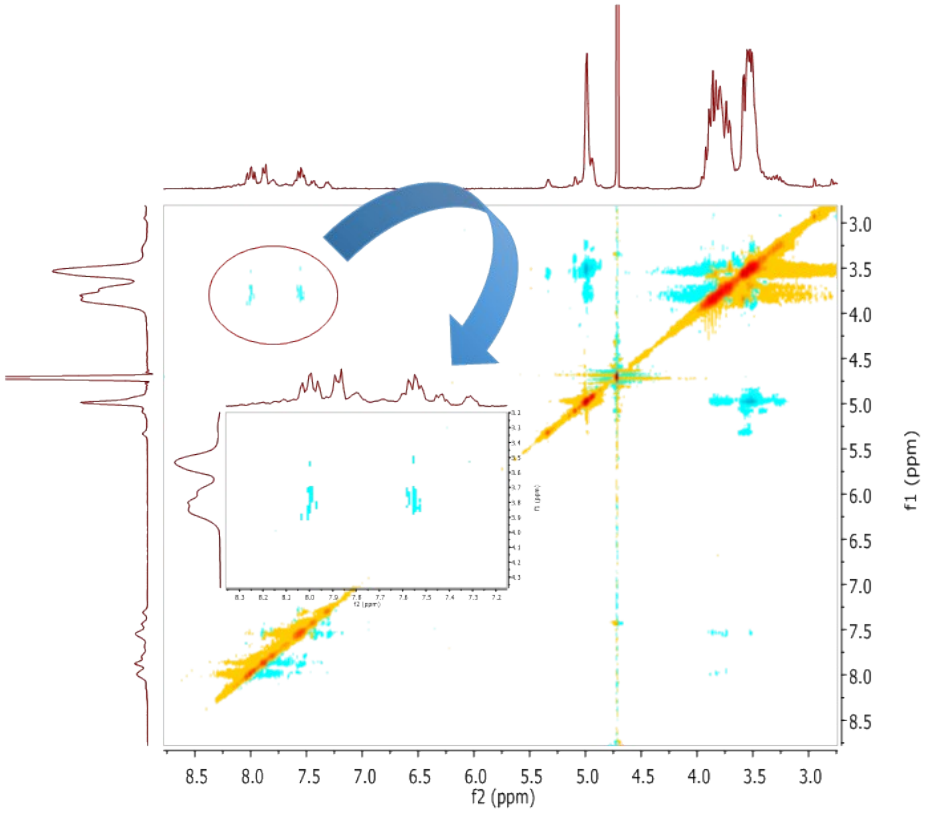
^{31}P NMR (D_2O): 38.0 (oxide), -22.4.

Figure S7. ^{13}C NMR spectrum of **2**.

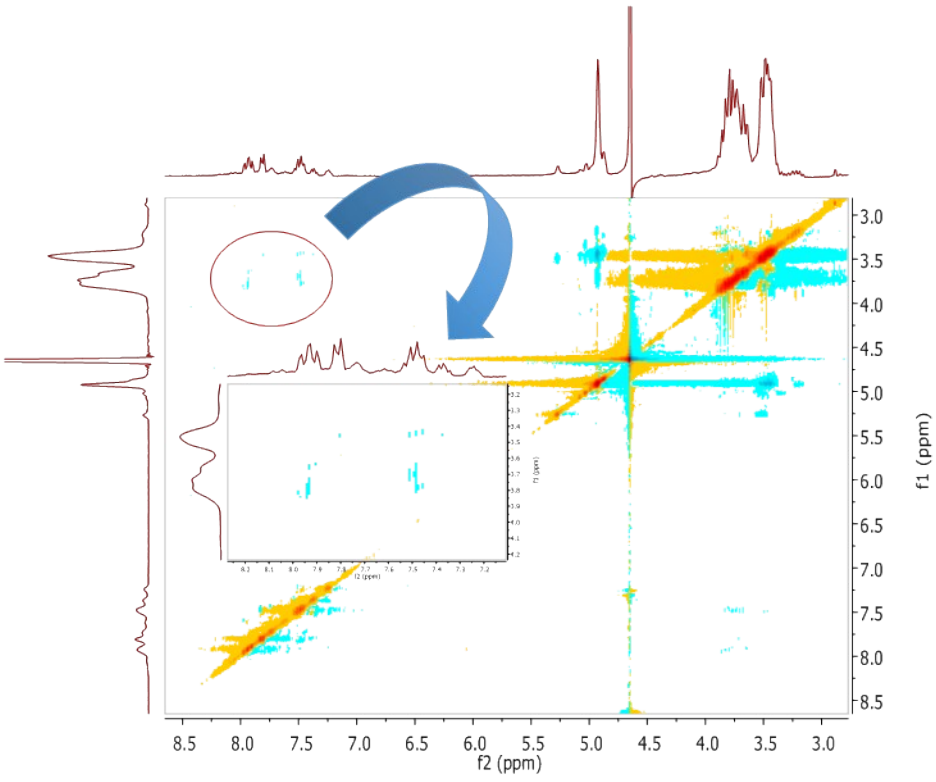


^{13}C NMR (DMSO): 31.26 (s, C-b), 36.29 (s, C-a), 60.37 (s, C-6), 72.49 (s, C-5), 72.87 (s, C-2), 73.52 (s, C-3), 81.99 (s, C-1), 102.41 (s, C-4), 125-135 ($C_{aromatiques}$).

Figure S8. 2D ROESY spectrum of **2** (10 mM) at 25 °C in D_2O after a) 15 min, and b) 72 h.



a)



b)

Figure S9. 2D T-ROESY NMR spectrum of **2** (10 mM) in DMF-d7 at 25 °C.

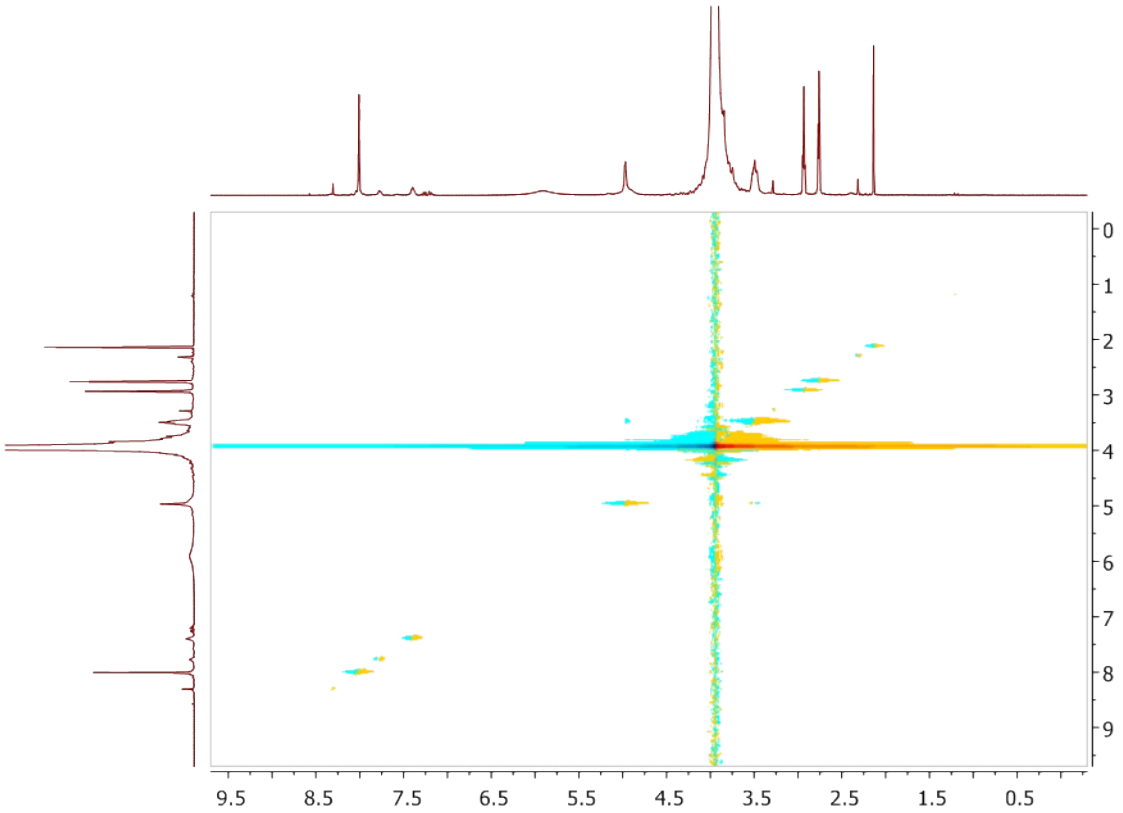
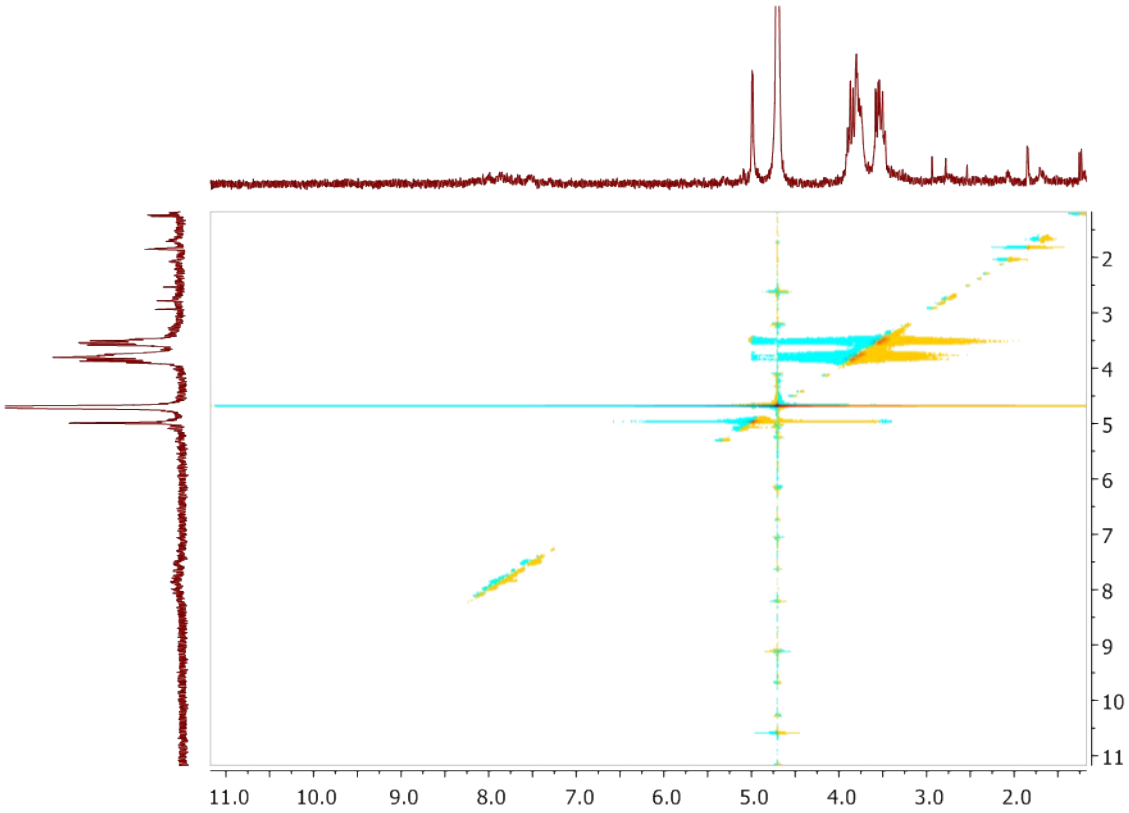


Figure S10. 2D T-ROESY NMR spectrum of **2** (1 mM) in D_2O at 25 °C.



Interfacial measurements (pendant drop method)

Figure S11. Surface tension of alkenes in neat water (blue), and phosphane-substituted CD **2** at 10.3 mM (green) and 17.3 mM (red) in water at 20 °C.