SUPPORTING INFORMATION FOR

Quantum-CORMs: Quantum Dot sensitized CO releasing molecules.

A. Ruggi* and F. Zobi*

Département de Chimie, Université de Fribourg, Chemin du Musée 9, 1700 Fribourg, Switzerland. Email: albert.ruggi@unifr.ch, fabio.zobi@unifr.ch.

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S1. General experimental section and synthetic procedures

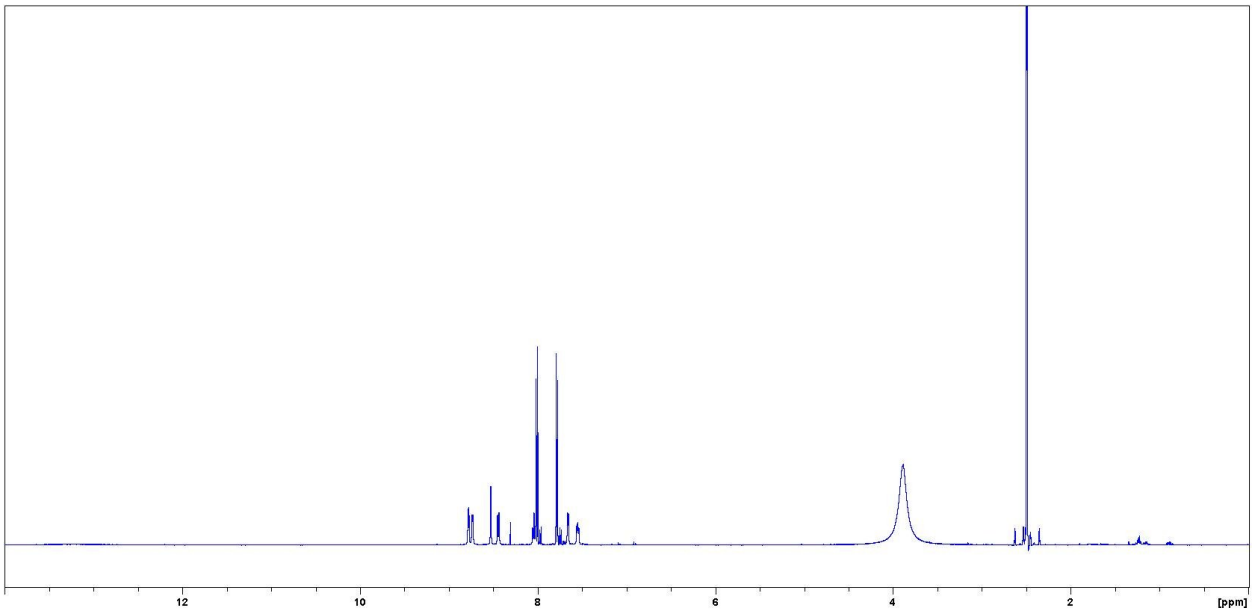
General experimental procedures

Reagents were purchased from commercial sources and used as received. CdSe/ZnS quantum dots, 5-amino-2,2'-bipyridine and 5-bromo-2,2'-bipyridine were synthesized according to literature procedures.[1] ^{1}H-NMR, ^{13}C-NMR, HMQC and HMBC were performed on a Bruker Avance III spectrometer operating at 500 MHz. High resolution mass spectra were measured with a Bruker FTMS 4.7T BioAPEXII spectrometer. IR spectra were measured with a Bruker Tensor 27. UV-Vis spectroscopy was performed using a Perkin-Elmer Lambda 35. Irradiation at 510 nm was performed using an Edinburgh FS5 fluorimeter (excitation slit: 1 nm) equipped with a 150 W Xe lamp. Time-resolved fluorescence decay were obtained using an Edinburgh LifeSpec II

fluorimeter equipped with a LED excitation source (406 nm, repetition rate 100 ns) and collecting the emission light at 520 nm. An excitation vertical polarization and an emission polarization filter oriented at the magic angle 54.7° was used to remove depolarisation effects. The fitting of the lifetime decay was performed with the software provided by Edinburgh. Photodecomposition kinetics were calculated upon fitting of the monoexponential decay by using the software Origin 7.5.

4-[2,2'-bipyridin]-4-ylethynyl)benzoic acid (Ligand L2). 60 mg (0.26 mmol) of 4-bromo-2,2'-bipyridine are dissolved in 20 ml of dry acetonitrile and 6 mg (0.023 mmol) of $Pd(CH_3CN)_2Cl_2$, 27 mg (0.057 mmol) of XPhos (XPhos = 2-cyclohexylphosphino-2',4',6'-triisopropylbiphenyl) and 200 mg (0.6 mmol) of Cs_2CO_3 are added. The resulting suspension is degassed with 3 Ar/vacuum cycles and stirred 1 h under Ar atmosphere. 45 mg (0.28 mmol) of methyl 4-ethynylbenzoate are added and the resulting mixture is heated at 80°C for 24 h under Ar atmosphere. The solvent is then evaporated and the crude is dissolved in 50 ml of chloroform and washed 3 times with 30 ml of water, then with 30 ml of brine and the organic phase is eventually dried over Na_2SO_4. The solvent is then removed and the resulting solid is purified by crystallization from boiling methanol. The resulting product is dissolved in 30 ml of THF and treated overnight with 10 ml of an aqueous solution of NaOH 1M at room temperature. After THF evaporation, the free acid is precipitated upon acidification of the aqueous solution with HCl. Obtained 20 mg of pure product (0.07 mmol; 30% overall).

^{1}H-NMR (500 MHz, d6-DMSO): δ (ppm)= 13.26 (br s, 1H), 8.78 (d, 2H, J = 5 Hz), 8.73 (d, 2H, J = 4 Hz), 8.52 (s, 1H), 8.44 (d, 1H, J = 7 Hz), 8.06-7.99 (m, 3H), 7.77 (d, 2H, J = 6 Hz), 7.66 (d, 1H, J = 6 Hz), 7.54 (t, 1H, J = 6 Hz). ^{13}C-NMR (125 Hz, d6-DMSO) δ = 156.5, 155.9, 153.6, 149.6, 148.9, 138.2, 132.0, 131.4, 131.0, 129.6, 125.7, 126.4, 124.9, 92.9, 89.9. HR-ESI (m/z): Calc. for $C_{19}H_{13}N_2O_2$ $[M + H]^+$: 301.0977. Found: 301.0973.



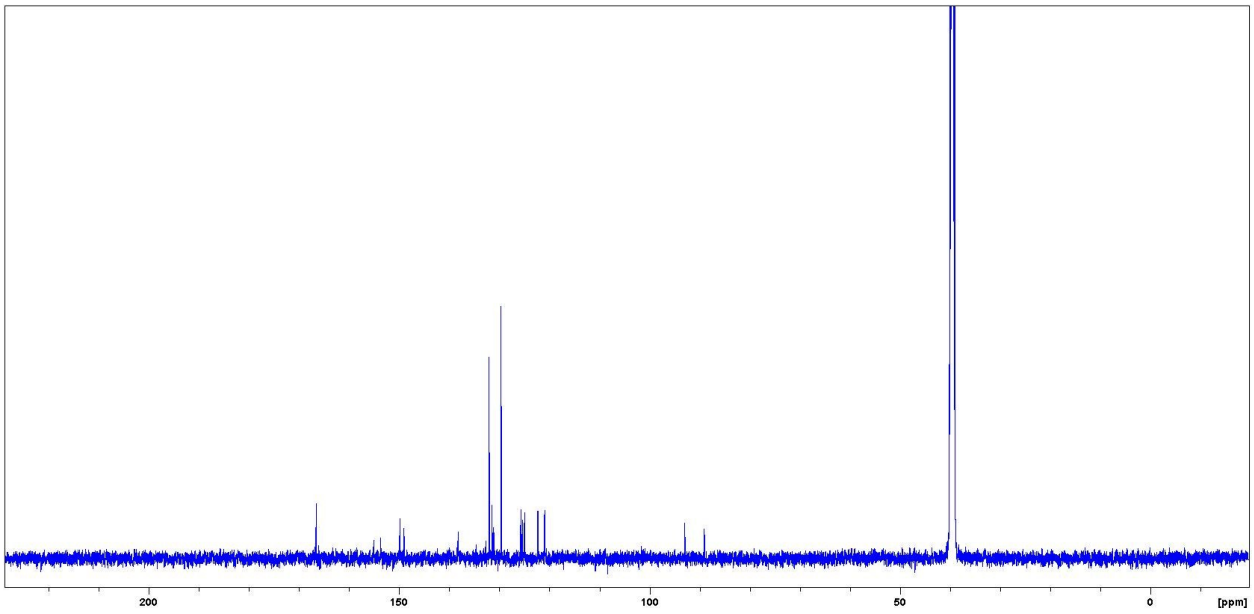


Figure S1. ^{1}H NMR (top) and ^{13}C NMR (bottom) of ligand **L2** in d6-DMSO.

4-[2,2'-bipyridin]-4-ylethynyl)aniline (Ligand L4). 540 mg of 4-bromo-2,2'-bipyridine (2.3 mmol), (236 mg, (0.5 mmol) of XPhos, 1.7 mg of Cs_2CO_3 (5 mmol) and 49 mg of $Pd(CH_3CN)_2Cl_2$ (0.19 mmol) are dissolved in 50 ml of CH_3CN. The mixture is degassed with three Ar/vacuum cycles and stirred at room temperature for 1 hour before adding 292 mg of 4-ethynylaniline (2.5 mmol). The mixture is refluxed for 2 days under N_2. The solvent is removed and the brownish oil is purified by column chromatography on a SiO_2 column using CH_2Cl_2/MeOH, 98:2 as eluting solvent to yield ligand **L4** (370 mg, 1.38 mmol; 60%). 100 mg. ^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm): 8.71 (d, 1H, J = 5 Hz), 8.63 (d, 1H, J = 5 Hz), 8.48 (s, 1H), 8.41 (d, 1H, J = 8 Hz), 7.64 (t, 1H, J = 8 Hz), 7.38-7.33 (m, 4H), 6.66 (d, 2H, J = 8 Hz). ^{13}C-NMR (125 Hz, $CDCl_3$): δ (ppm) = 156.0, 155.7, 149.2, 149.0, 147.5, 137.0, 133.5, 133.2, 125.0, 124.0, 123.0, 121.1, 114.7, 111.4, 95.4, 85.4. HR-ESI (m/z) : Calc. for $C_{18}H_{14}N_3$ $[M + H]^+$: 272.1188. Found: 272.1180.

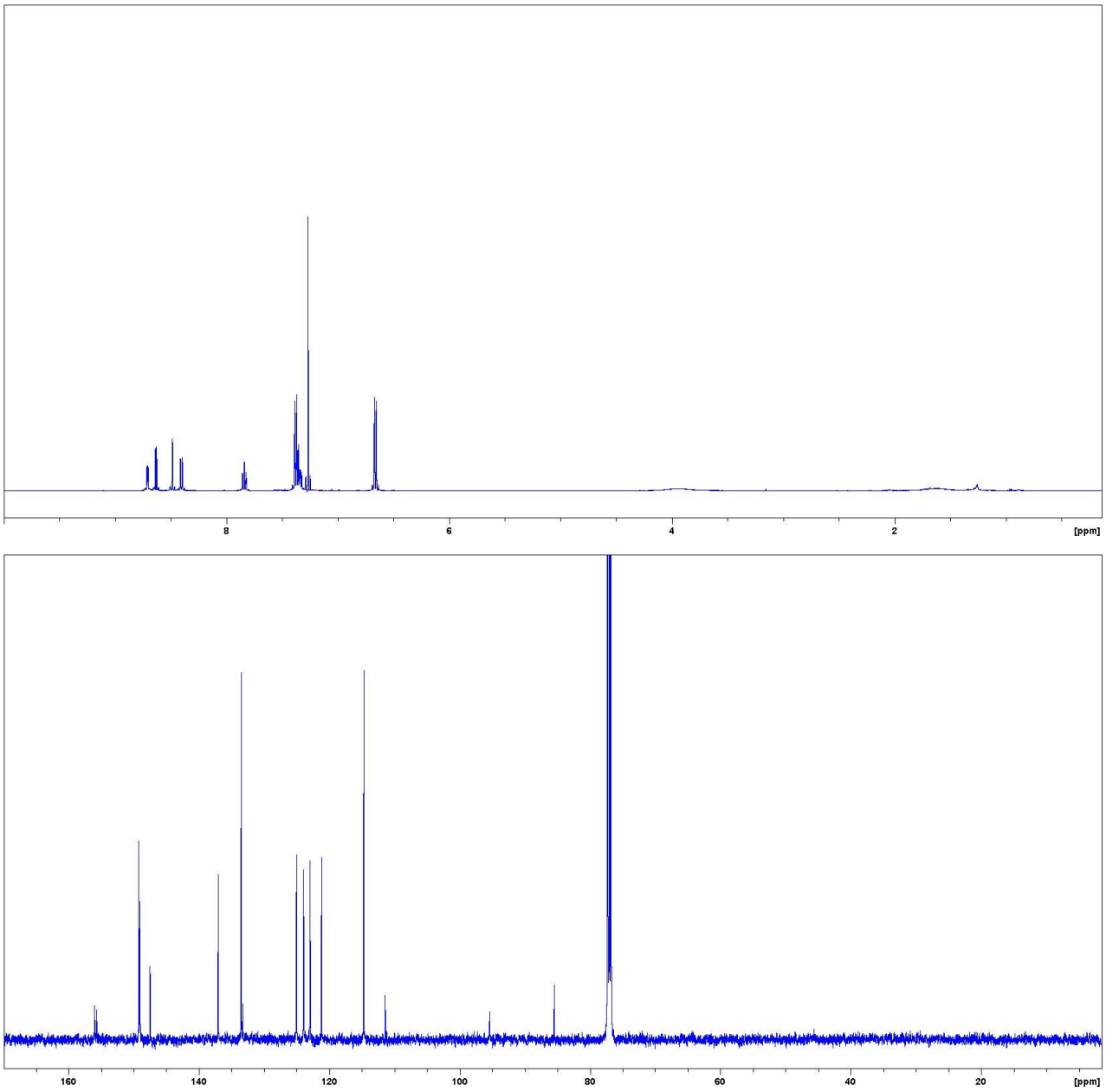


Figure S2. ^{1}H NMR (top) and ^{13}C NMR (bottom) of ligand **L4** in $CDCl_3$.

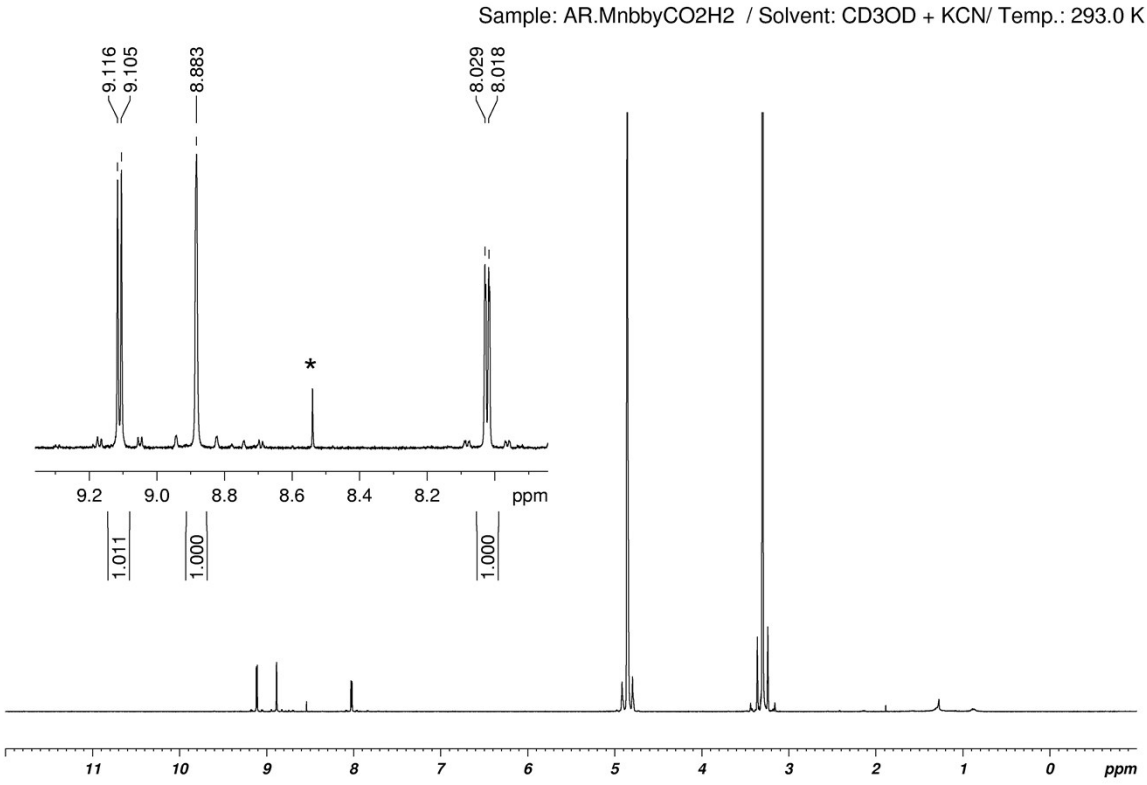
Synthesis of *fac*-[Mn(CO)$_3$LBr] complexes.

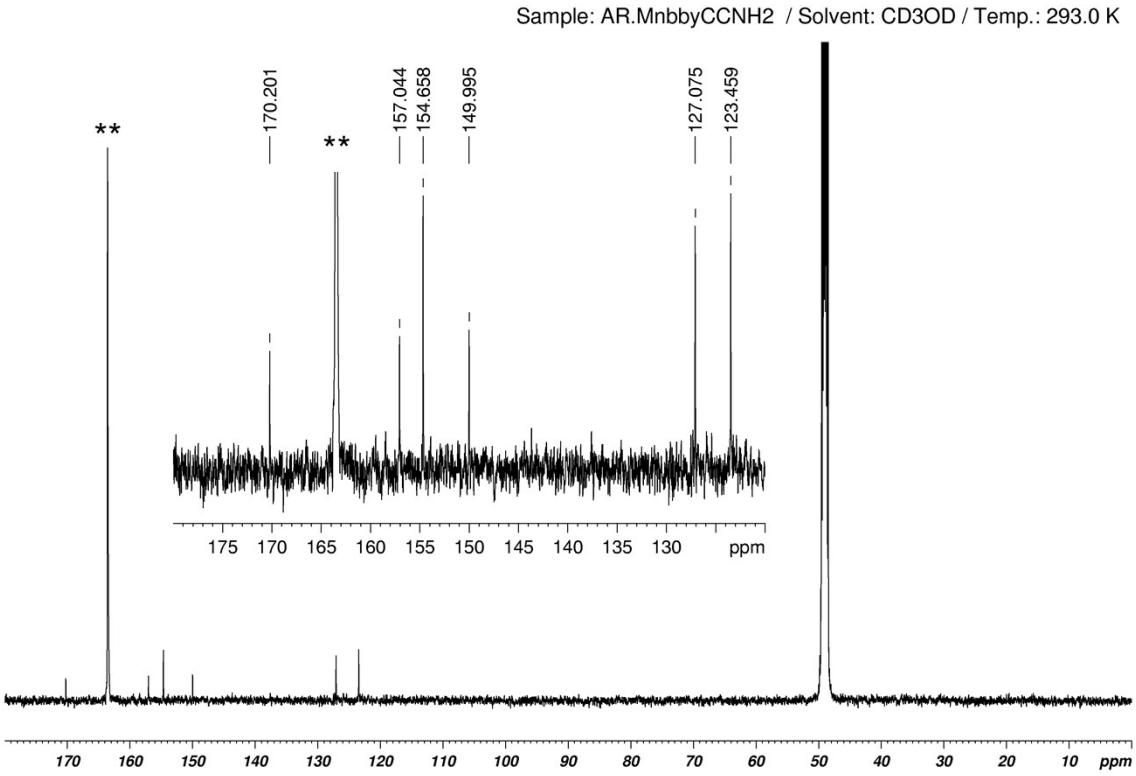
Species **1**-**4** were synthesized according to the procedure described by Sampson et al. with slight modifications.[2] Briefly. $Mn(CO)_5Br$ (100 mg, 0.37 mmol) was added to 15 mL of diethyl ether (Et_2O) in ambient air. The selected ligand (0.37 mmol) was added to the mixture and heated to reflux. For species **2**-**4** the solution turned orange within 60 min, and the product precipitated out of solution. After 3 h, the mixture was cooled to room temperature, and the precipitate was filtered off and washed with Et_2O. The orange solid was then dried overnight under vacuum. For species **1** the precipitate was identified as a mixture of unreacted ligand and $Mn(CO)_5Br$. The reaction mixture was filtered off and the solution containing **1** was dried under vacuum. Compounds were then purified via HPLC. All compounds show a dynamic equilibrium

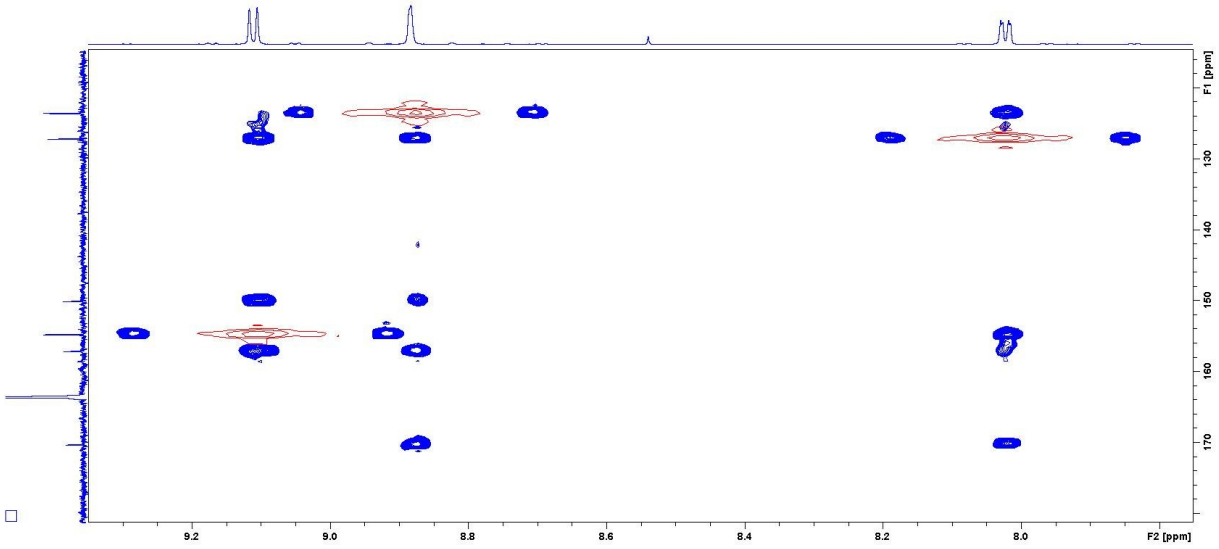
in the presence of coordinating solvents. Such equilibrium can be shifted towards the formation of a single species upon addition of an excess of KCN, as evidenced by the NMR shown in Figure S8. Therefore when needed (complexes **1**, **2**, and **4**) KCN was added to the NMR solutions.

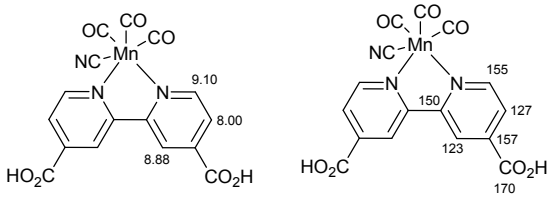
Analytical HPLC method. Instrument: MERCK HITACHI LaChrom with a D-7000 interface coupled with a Diode Array detector L-7455 and a pump L-7100 system. Column: Macherey-Nagel, EC250/3 Nucleosil 100-5 C18. Flow rate 0.5 mL/min. Absorbance monitored at 250 nm. Solutions: A: 0.1% trifluoroacetic acid in water; B: methanol. Chromatographic method: 0-5 min: isocratic flow of 75% A - 25% B; 5-35 min: linear gradient to 100% B; 35-45 min: isocratic flow of 100% B.

Analytical data for **1**: Yield 65 mg (24%). HPLC retention time (min): 21.17. ^{1}H-NMR (500 MHz, CD_3OD + KCN): δ (ppm) = 9.11 (d, 2H, J = 6 Hz), 8.88 (s, 2H), 8.02 (d, 2H, , J = 6 Hz). ^{13}C-NMR (125 MHz, CD_3OD + KCN): see figure S3. IR (KBr) νCO: 2027, 1943, 1913, 1733 cm^{-1}. HR-ESI (m/z) : Calc. for $C_{15}H_7BrMnN_2O_7$ $[M - H]^-$: 460.8823. Found: 460.8826.




Sample: AR.MnbbyCCNH2 / Solvent: CD3OD / Temp.: 293.0 K
**
**
170.201
157.044
154.658
149.995
127.075
123.459
175 170 165 160 155 150 145 140 135 130 ppm
170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm


9.2
9.0
8.8
8.6
8.4
8.2
8.0
F2 [ppm]
F1 [ppm]


OC
CO
CO
NC
Mn
N
N
9.10
8.00
8.88
HO2C
CO2H
155
150
127
157
123
170

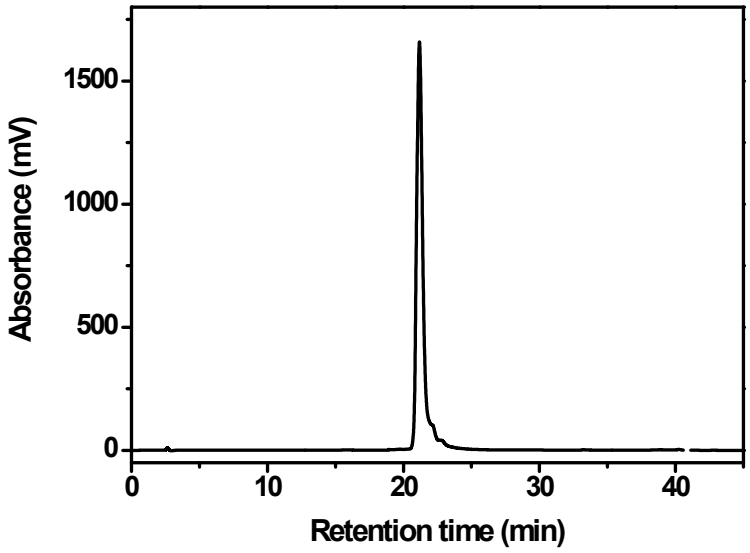


Figure S3. (from top to bottom) ^{1}H-NMR, ^{13}C-NMR, HMQC/HMBC-NMR (aromatic region) spectra (CD_3OD + KCN) with ^{1}H and ^{13}C signals assignment of **1** and HPLC chromatogram. * = KCN methanolysis product, ** = KCN.

Analytical data for **2**: Yield 150 mg (78%). HPLC retention time (min): 27.99. IR (KBr) νCO: 2026, 1925, 1736 cm^{-1}. HR-ESI (m/z) : Calc. for $C_{22}H_{11}BrMn\,N_2O_5$ $[M - H]^-$: 518.9217. Found: 518.9218. Although this species was isolated as a single HPLC peak, it undergoes a rapid equilibrium (see Figure S5) giving two HPLC peaks having identical mass (m/z : 439.0 $[M\text{-}Br]^+$). This equilibrium mixture cannot be completely shifted by addition of KCN, therefore the ^{1}H-NMR spectrum of the unresolved mixture is given, along with the tentative peak assignment of the major and minor species (relative ratio: 1.4:1).

Major species: ^{1}H-NMR (500 MHz, CD_3OD + KCN): δ (ppm) = 9.10 (d, 1H, J= 5Hz), 9.06 (d, 1H, J = 6 Hz), 8.67-8.65 (m, 2H), 8.21 (t, 1H, J = 7 Hz), 8.0 (d, 2H, J = 8 Hz), 7.73 (d, 1H, J = 6 Hz), 7.70 (t, 1H, J = 7 Hz), 7.64 (d, 2H, J = 8 Hz).

Minor species: ^{1}H-NMR (500 MHz, CD_3OD + KCN): δ (ppm) = 8.60 (d, 2H, J = 8 Hz), 8.40 (s, 1H), 8.34 (d, 1H, J = 8Hz), 7.99-7.94 (m, 3H), 7.58 (d, 2H, J = 8Hz), 7.53 (d, 1H, J = 5 Hz), 7.47 (t, 1H, J = 7 Hz).

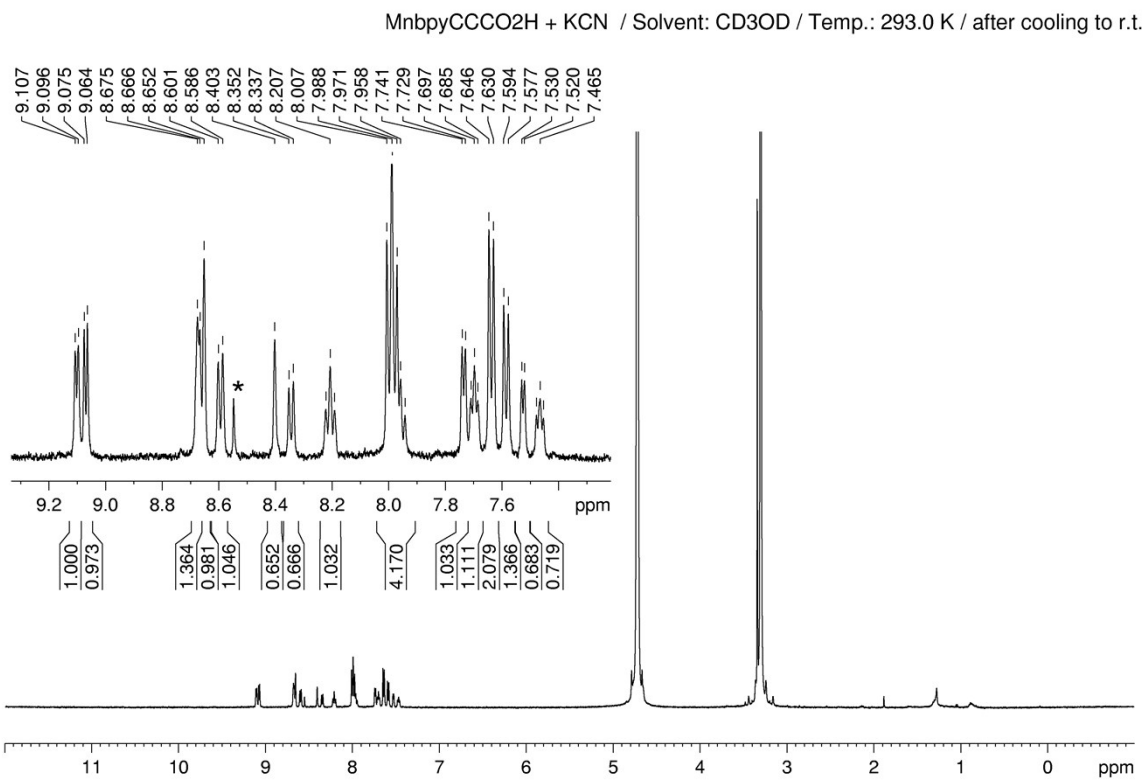
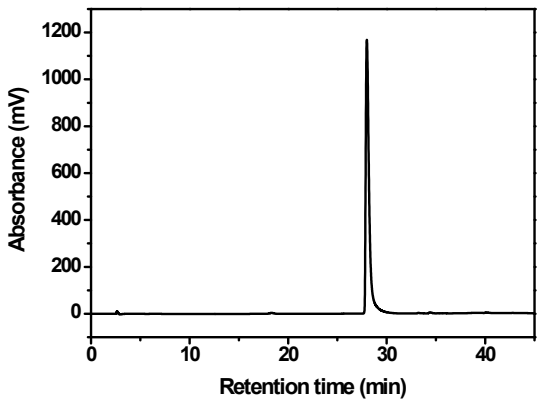
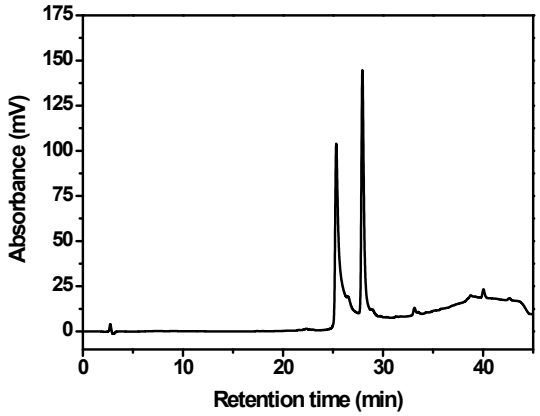


Figure S4 ^{1}H-NMR of **2** (CD_3OD + KCN). * = KCN methanolysis product.



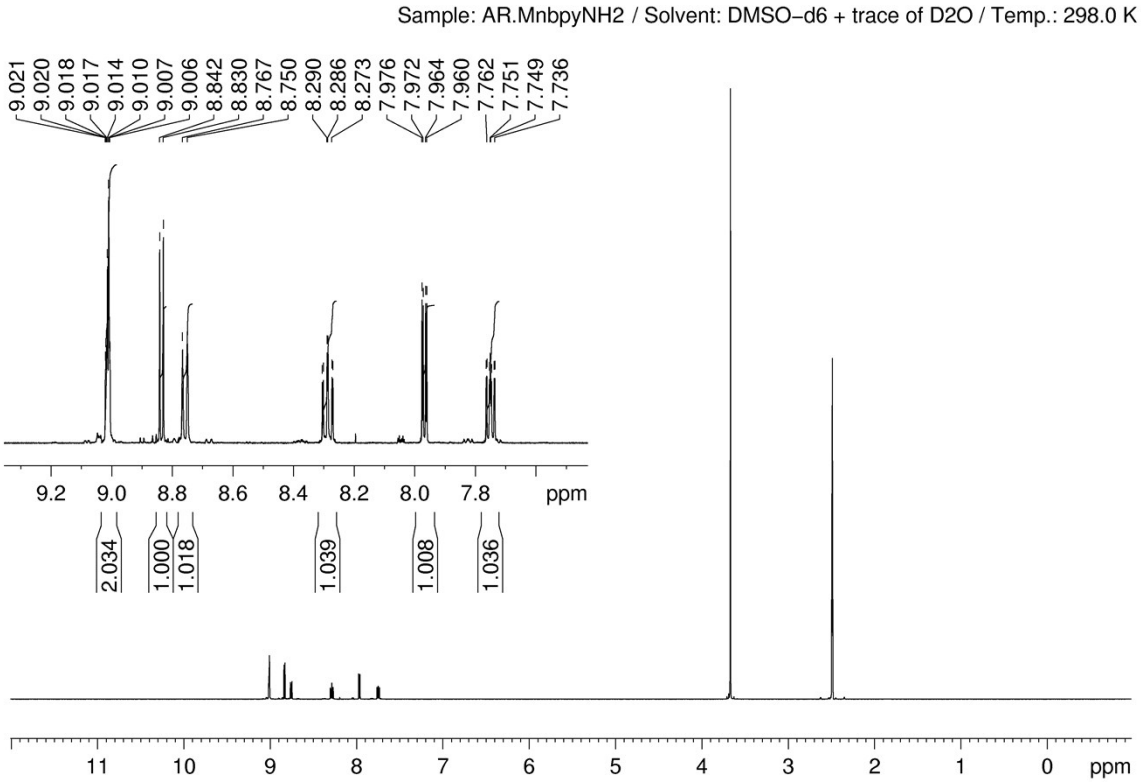
HPLC chromatogram of purified **2**.

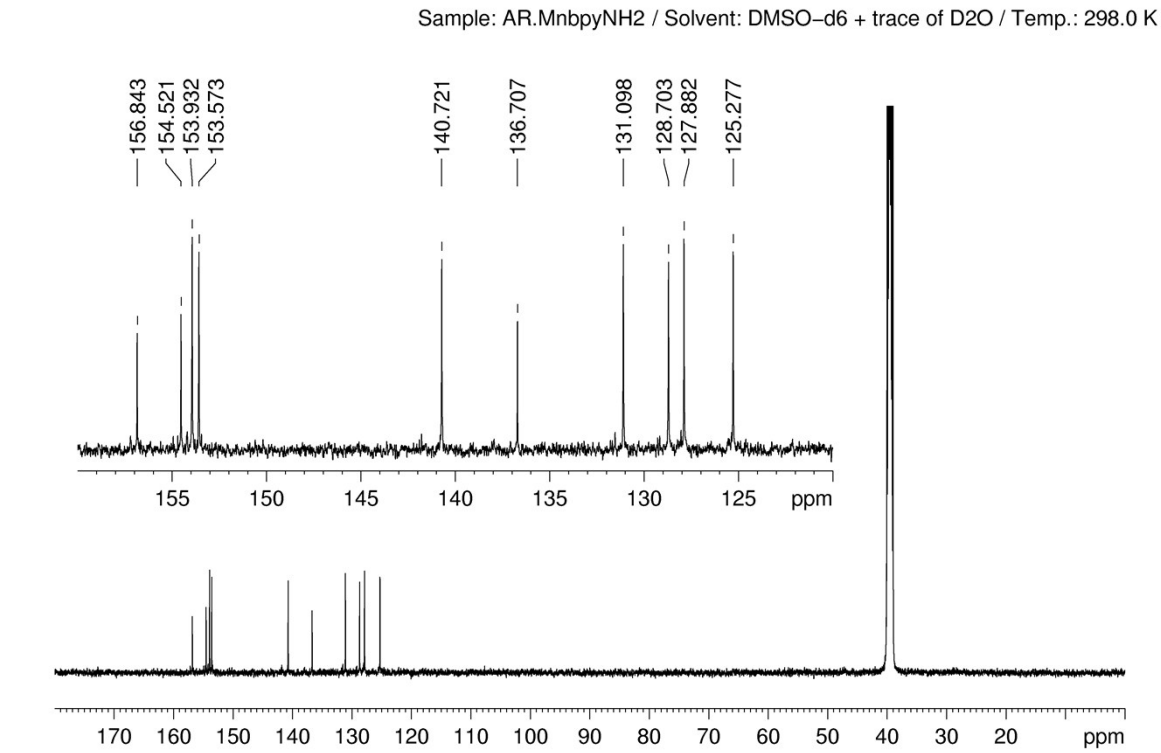


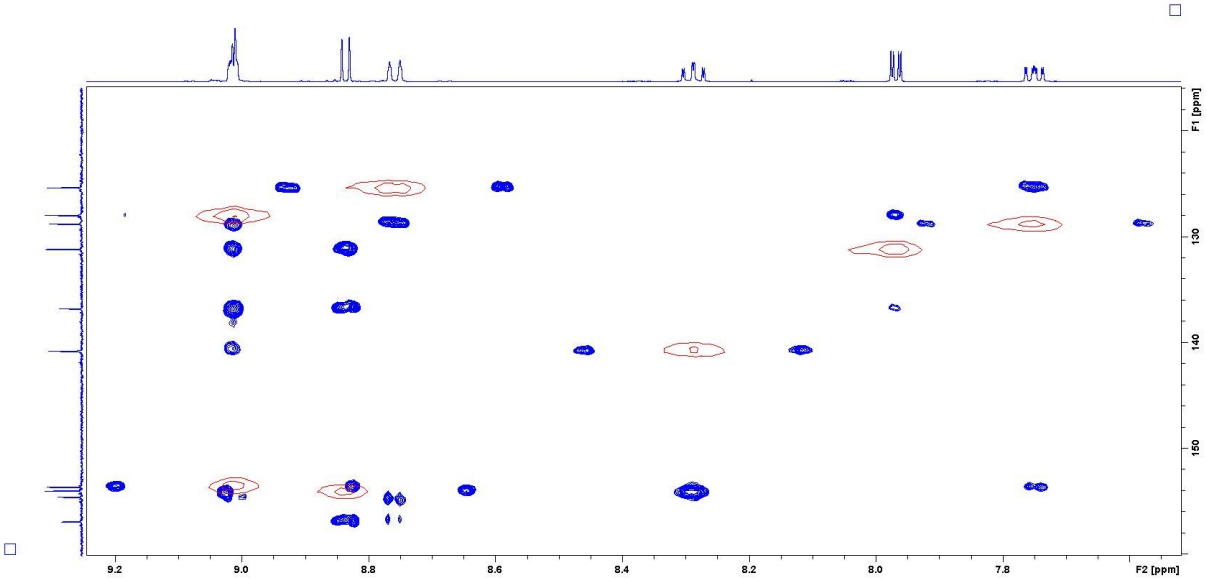
HPLC chromatogram of same compound above (i.e. purified **2**) left in solution for 10 min and then re-injected.

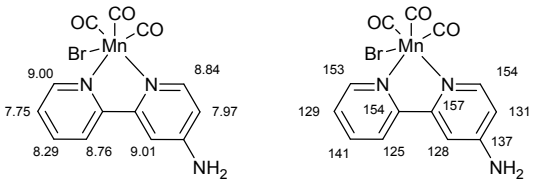
Figure S5. HPLC chromatograms of **2** showing the equilibration of the purified species upon standing.

Analytical data for **3**: Yield 90 mg (62%). HPLC retention time (min): 21.95. ^{1}H-NMR (500 MHz, d6-DMSO + D_2O): δ (ppm) = 9.02 – 9.00 (m, 2H), 8.83 (d, 1H, J = 6 Hz), 8.77 (d, 1H, J = 8 Hz), 8.29 (t, 1H, J = 8 Hz), 7.97 (dd, 1H, J = 6 Hz), 7.75 (t, 1H, J = 6 Hz.). ^{13}C-NMR (125 MHz, d6-DMSO+D_2O): see figure S6. IR (KBr) νCO: 2022, 1940 cm^{-1}. HR-ESI (m/z) : Calc. for $C_{13}H_9Mn\,N_3O_3$ $[M - Br]^+$: 310.0024. Found: 310.0024.




Sample: AR.MnbpyNH2 / Solvent: DMSO–d6 + trace of D2O / Temp.: 298.0 K
156.843
154.521
153.932
153.573
140.721
136.707
131.098
128.703
127.882
125.277
155 150 145 140 135 130 125 ppm
170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 ppm


9.2 9.0 8.8 8.6 8.4 8.2 8.0 7.8 F2 [ppm]
F1 [ppm]
130
140
150


OC
CO
CO
Br
Mn
N
N
9.00
8.84
7.75
7.97
8.29
8.76
9.01
NH2
153
154
129
131
154
157
141
125
128
137

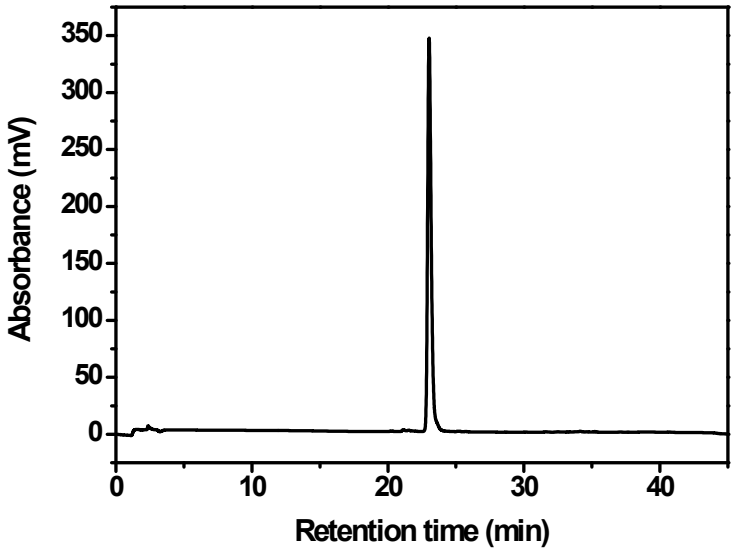
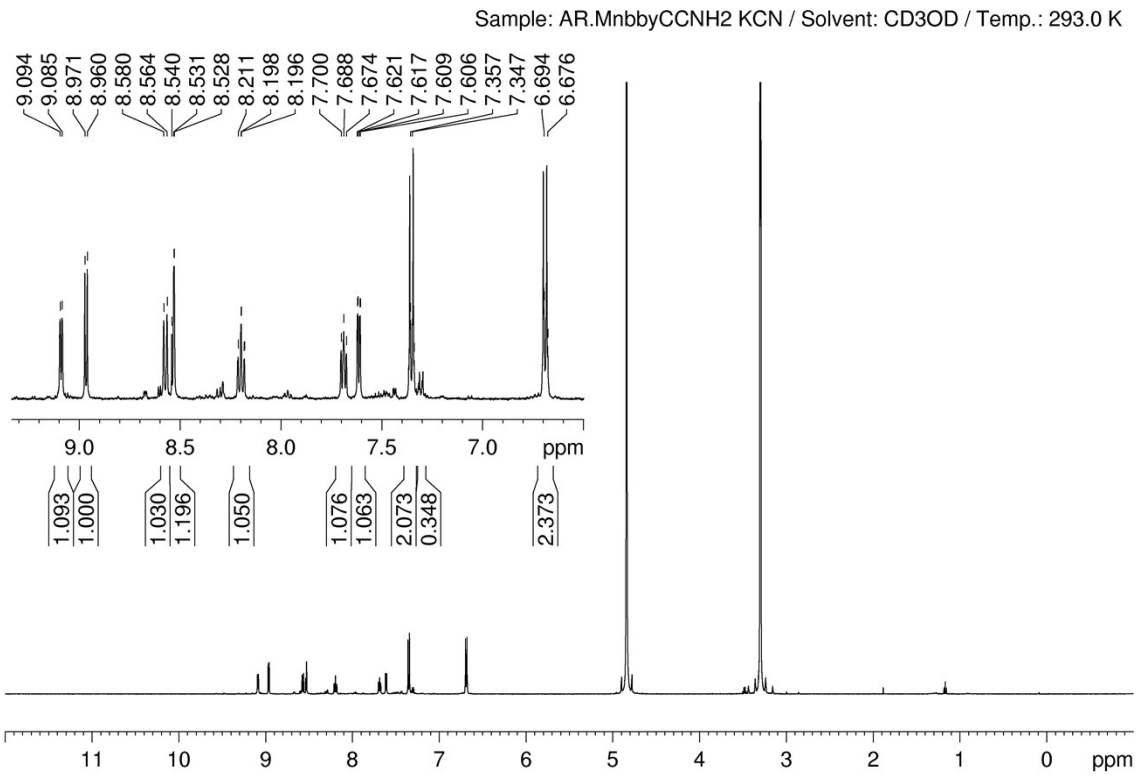


Figure S6. (from top to bottom) ^{1}H-NMR, ^{13}C-NMR, HMQC/HMBC-NMR (aromatic region) spectra (d6-DMSO + trace of D_2O) with ^{1}H and ^{13}C signals assignment of **3** and HPLC chromatogram.

Analytical data for **4**: Yield 108 mg (60%). HPLC retention time (min): 26.45. ^{1}H-NMR (500 MHz, CD_3OD+KCN): δ (ppm) = 9.09 (d, 1H, J = 5 Hz), 8.97 (d, 1H, J = 6 Hz), 8.57 (d, 1H, J = 8 Hz), 8.53 (s, 1H), 8.20 (t, 1H, J = 8 Hz), 7.69 (t, 1H, J = 7 Hz), 7.61 (d, 1H, J = 6 Hz), 7.35 (d, 2H, J = 7 Hz), ^{13}C-NMR (125 MHz, CD3OD + KCN): see figure S7. IR (KBr) ν*C*O: 2023, 1928, 1910 cm^{-1}. HR-ESI (m/z) : Calc. for $C_{21}H_{13}Mn\,N_3O_3$ $[M - Br]^+$: 410.0337. Found: 410.0331.


Sample: AR.MnbbyCCNH2 KCN / Solvent: CD3OD / Temp.: 293.0 K
9.094
9.085
8.971
8.960
8.580
8.564
8.540
8.531
8.528
8.211
8.198
8.196
7.700
7.688
7.674
7.621
7.617
7.609
7.606
7.357
7.347
6.694
6.676
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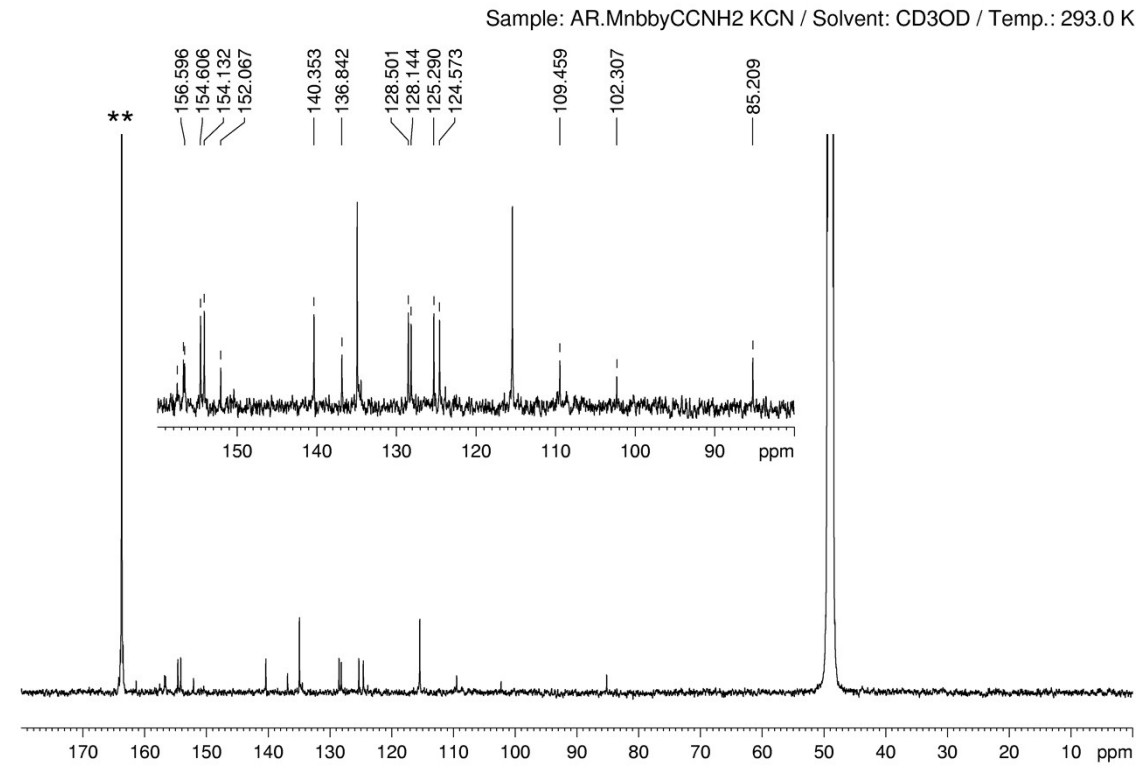
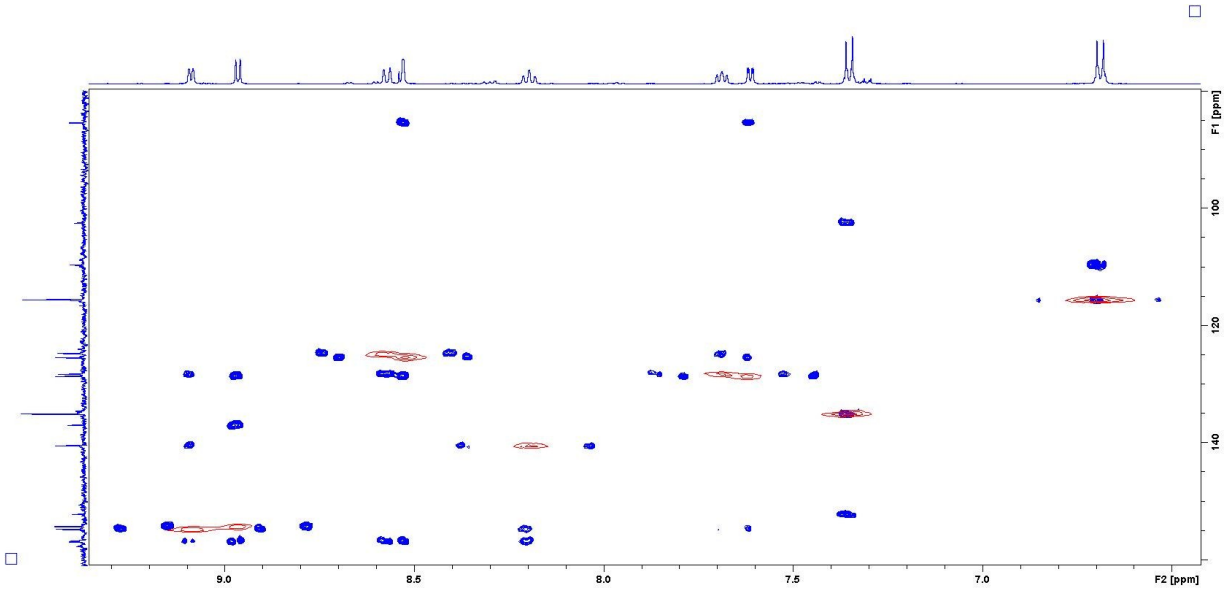
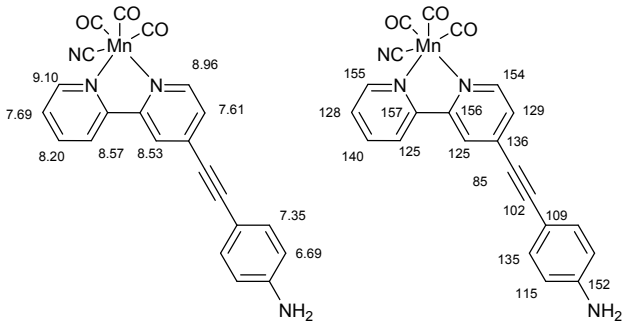
1.076
1.063
2.073
0.348
2.373
ppm


Sample: AR.MnbbyCCNH2 KCN / Solvent: CD3OD / Temp.: 293.0 K
**
156.596
154.606
154.132
152.067
140.353
136.842
128.501
128.144
125.290
124.573
109.459
102.307
85.209
ppm





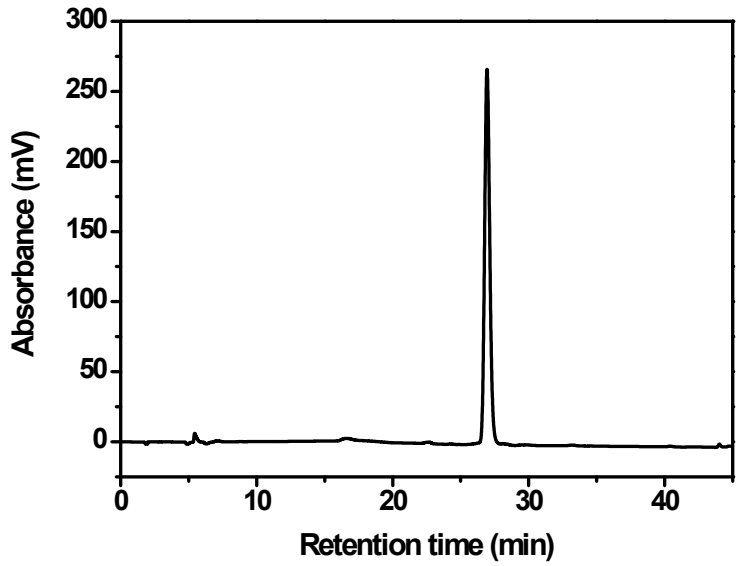


Figure S7. (from top to bottom) ^{1}H-NMR, ^{13}C-NMR, HMQC/HMBC-NMR (aromatic region) spectra (CD_3OD + KCN) with ^{1}H and ^{13}C signals assignment of **4** and HPLC chromatogram.. ** = KCN.

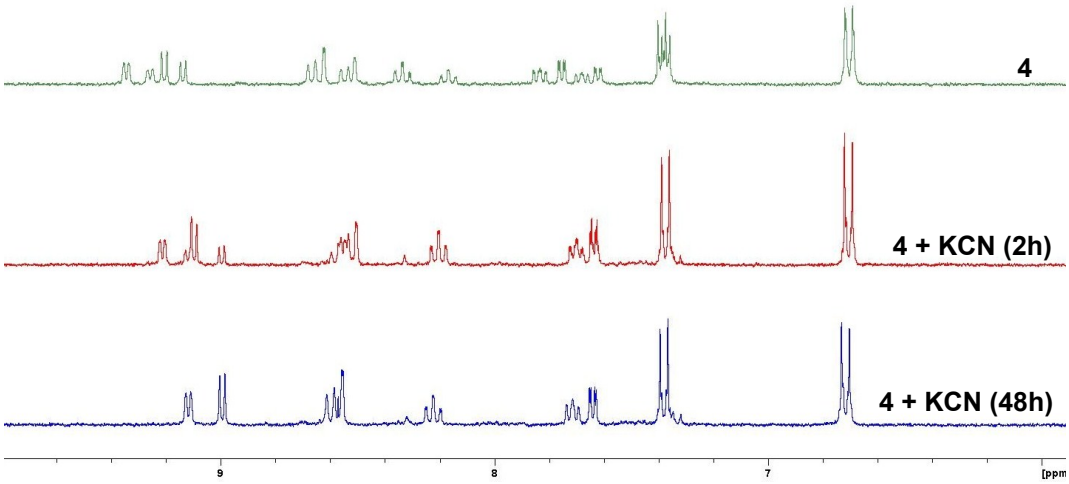


Figure S8. Evidence of ligand exchange equilibrium upon addition of KCN to a CD_3OD solution of **4**.

S2. Synthesis of QD-Mn conjugates and estimation of [Mn]:[QD] ratio.

0.5 ml of the stock solution0.038 mM of QD in THF were added to 5 equivalents of Mn complex suspended in 1.5 ml of THF (in the case of complexes **3** and **4**, the compounds were previously treated with 0.1 ml of CS_2 for 1h and then dried under vacuum). The resulting mixture was stirred overnight in the dark and then centrifuged to remove unreacted complex. The conjugated were then characterised by UV-Vis and used without further purification. For the irradiation test, 0.1 ml of this solution were dissolved in 1.8 ml of THF and 0.1 ml of MeOH.

To evaluate the [Mn]:[QD] ratio, the UV-Vis of the conjugated was compared with an equimolar solution of QD prepared by following the same procedure but without addition of Mn complexes (Figure S9). The estimation of the [Mn]:[QD] ratio in conjugate **QD-1** is here given as example.

By assuming the additivity of absorption spectra, the Mn contribution to the absorption at 313 nm $^{313}Abs(Mn)_{\mathbf{QD\text{-}1}}$ was evaluated using the equation

$$^{313}Abs(Mn)_{\mathbf{QD\text{-}1}} = {}^{313}Abs_{\mathbf{QD\text{-}1}} - {}^{313}Abs_{\mathbf{QD}}$$

where $^{313}Abs_{\mathbf{QD\text{-}1}}$ and $^{313}Abs_{\mathbf{QD}}$ are the absorption of the **QD-1** conjugate solution and of the QD solution at 313 nm, respectively.

[Mn] concentration is then evaluated using Lambert-Beer equation and the previously determined ε of **1**. [QD] is evaluated using the literature procedure.[3]

In the case of **QD-1**, the obtained values are

$^{313}Abs(Mn)_{\mathbf{QD\text{-}1}} = 0.13$

$[Mn]_{QD\text{-}1} = 0.13 / 15063 = 8.6 \cdot 10^{-5}$ M.

$[QD] = 5 \cdot 10^{-6}$ M

[Mn]:[QD] = 1.7

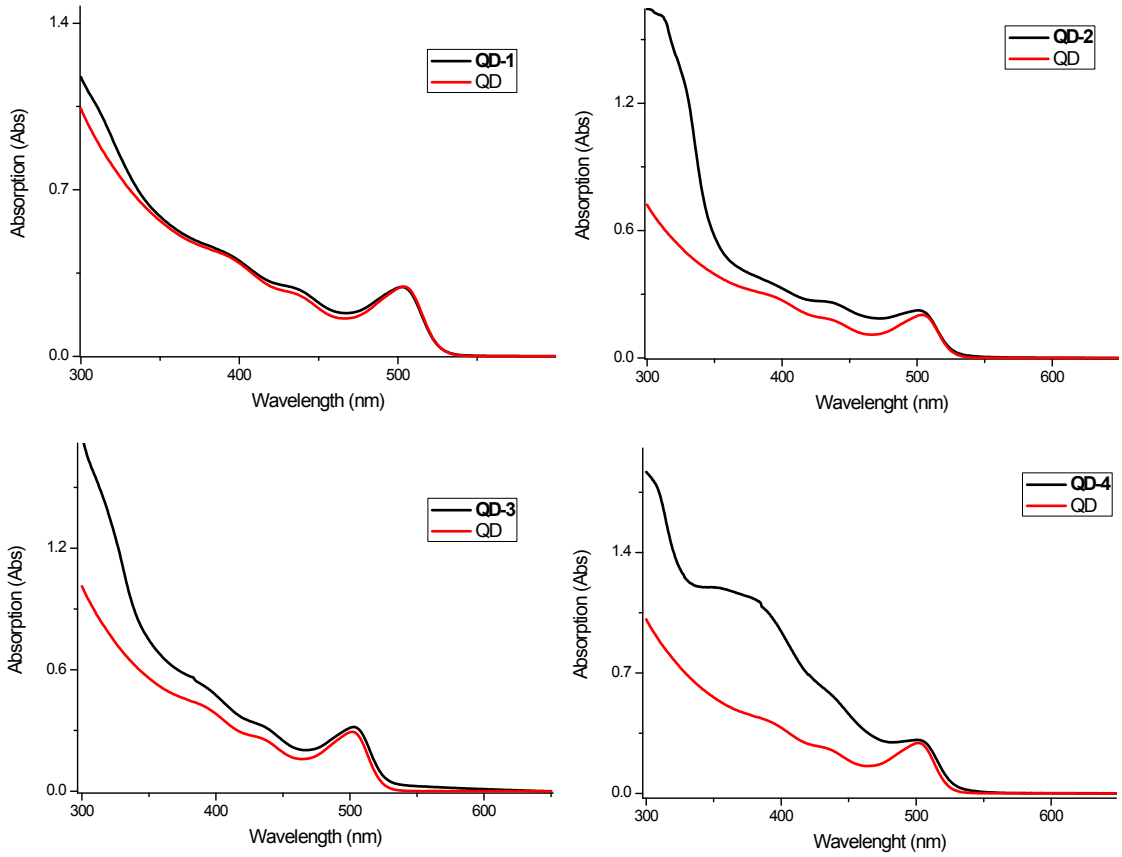
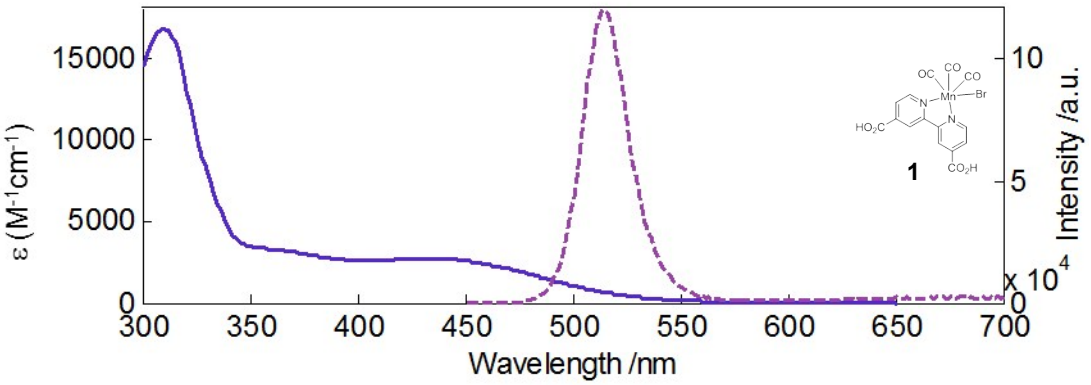
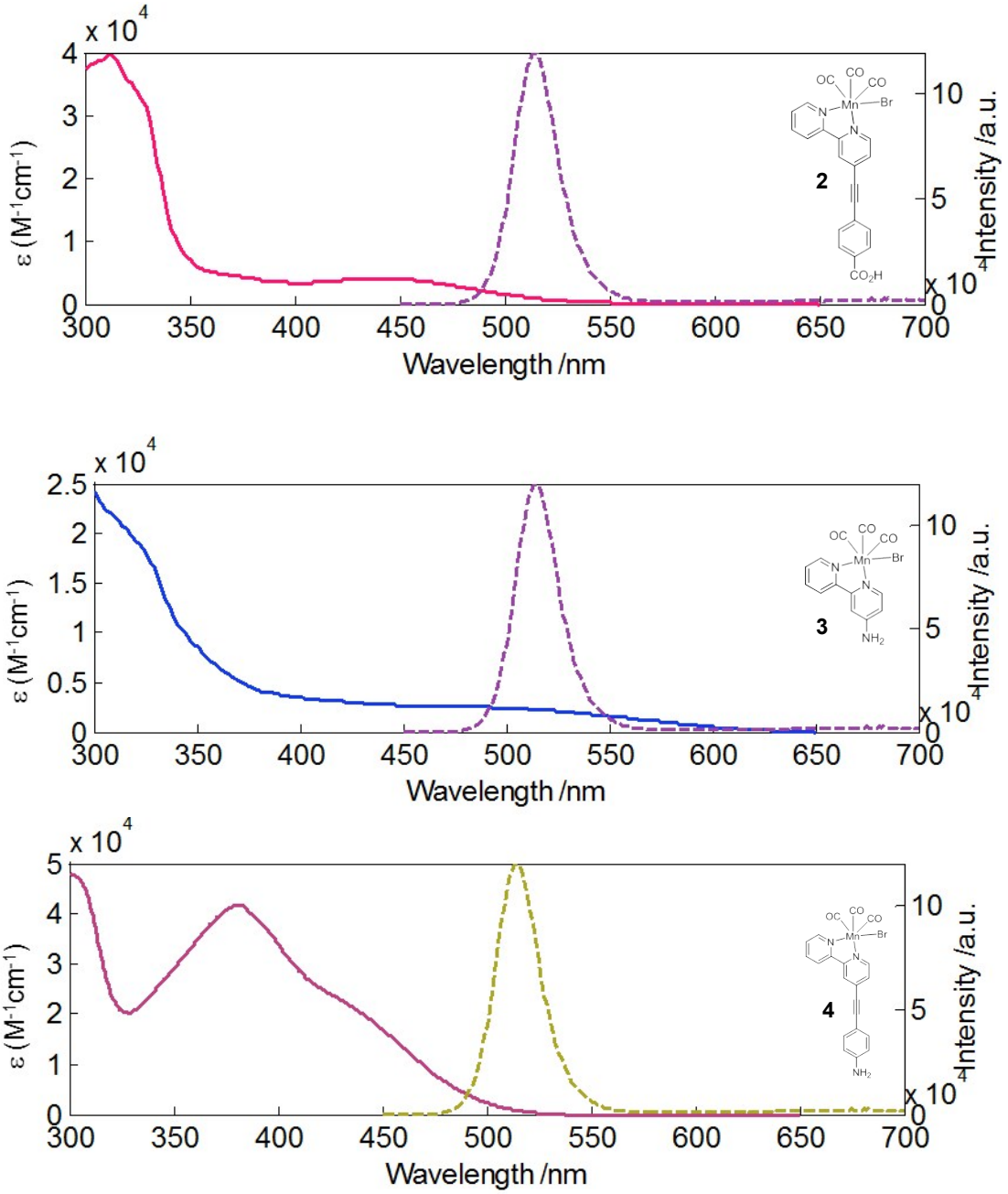


Figure S9. UV-Vis absorption spectrum of equimolar solutions of QD and of QD-Mn used for the estimation of [Mn]:[QD] ratio.

S3. **UV-Vis spectra of Mn(I) complexes and integral overlapping with CdSe/ZnS QD emission.**





The overlapping integral (J) was calculated using the software a/e UV-Vis-IR Spectral Software (v. 2.0) available on www.fluorotools.com.

S4. Calculation of the normalised quenching constants

Quenching constants normalised according to the number of Mn(I) complexes attached to the CdSe/ZnS quantum dots were obtained by using the equation[4]

$$nk_q = \frac{1}{\tau} - \frac{1}{\tau_0}$$

where τ and τ_0 are the average emission lifetimes in the presence and in the absence of quencher, respectively and n is the number of Mn complexes.

S5. Evidence of CO evolution upon irradiation.

Qualitative evidence of CO evolution was obtained via myoglobin (Mb) assay.[5] Complexes **1-4** were dissolved in DMSO and added as a 10-fold molar excess to an aqueous solution of reduced horse heart Mb having a 26 μM concentration in the case of complexes **1** and **4** and a 31 μM concentration in the case of complexes **2** and **3**. In all cases denaturation of the protein (and subsequent scattering) occurs within the first 15 minutes of irradiation. Prolonged irradiation leads to a complete denaturation and precipitation of the protein with consequent loss of signal. The lower Mb concentration in the case of complexes **1** and **4** is due to our efforts to minimize the effect outlined above.

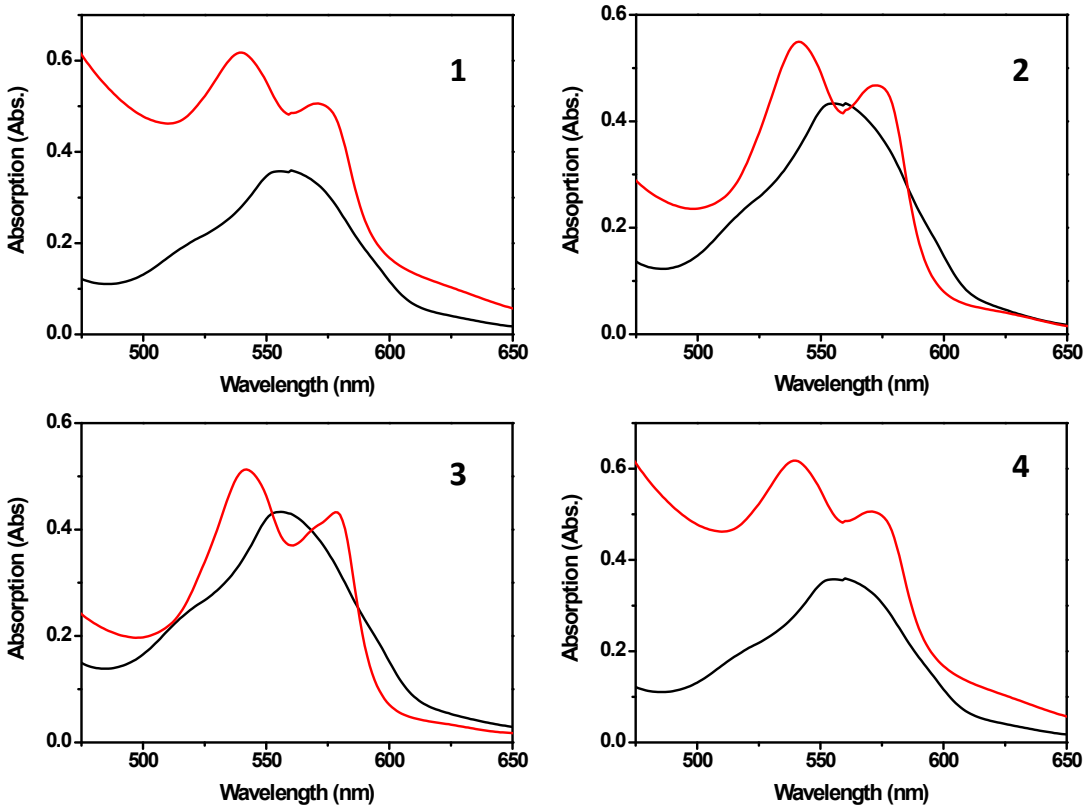


Figure S10. Changes occurring in the UV-Vis spectra of a reduced myoglobin solution (black) upon addition of Mn(I) complexes **1-4** and subsequent irradiation at 510 nm (red).

In the case of QD-Mn systems a THF solution was used due to the insolubility of such systems in DMSO. A pronounced scattering was observed upon addition the QD-Mn system to the 26 μM aqueous Mb solution (as evidenced in Figure S11, see black and blue lines) as a consequence of QD-Mn precipitation in water. However, qualitative evidence of CO release upon irradiation (red line) could still be obtained within the timeframe of the experiment (15 min.). Analogously to what observed for complexes **1-4**, prolonged irradiation leads to a complete denaturation and precipitation of the protein with consequent loss of signal. The typical spectral changes are shown in Figure S11 for QD-3. All other species show similar behaviours.

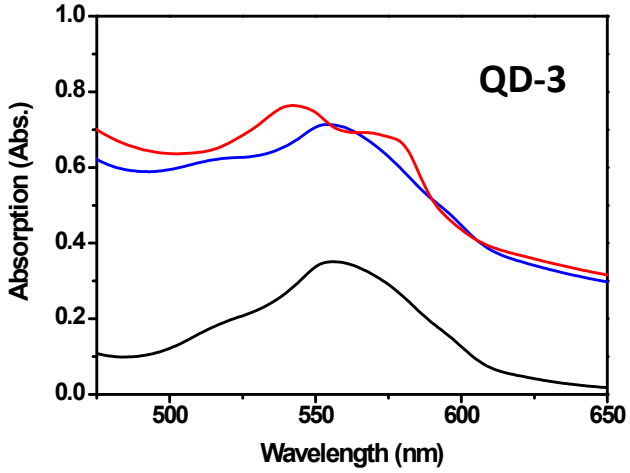


Figure S11. Changes occurring in the UV-Vis spectra of a reduced myoglobin solution (black) upon addition of **QD-3** system (blue) and subsequent irradiation at 510 nm (red).

S6. References

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