Electronic Supplementary Material (ESI) for Chemical Communications

Supporting Information

Rapid CO release from a Mn(I) carbonyl complex derived from azopyridine upon exposure to visible light and its phototoxicity toward malignant cells

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Experimental

$[MnBr(CO)_5]$ and $AgClO_4$. H_2O and $[MnBr(CO)_5]$ were purchased from Alpha Aesar, was used without further purification. $AgClO_4$. H_2O was triturated several times prior to use using dry acetonitrile. The ligand 2-phenylazopyridine (azpy)[1] and were synthesized following reported procedure. Solvents were purified and/or dried by standard techniques prior to use.[2] The 1H NMR spectra were recorded at 298 K on a Varian Unity Inova 500 MHz instrument. A Perkin-Elmer Spectrum-One FT-IR was employed to monitor the IR spectra of the reported compounds. UV-Vis spectra were obtained with a Varian Cary 50 UV-Vis spectrophotometer. Microanalyses (C, H, N) were performed using a Perkin-Elmer 2400 Series II elemental analyser. Horse heart myoglobin (Mb) was purchased from Sigma-Aldrich and used as received.

Caution! *Transition metal perchlorates should be prepared in small quantities and handled with great caution as metal perchlorates may explode upon heating.*

Synthesis of complexes

$[Mn(CO)_3(azpy)Br]$ 1. To 100mg (0.36 mmol) $[MnBr(CO)_5]$, 80mg (0.43 mmol) azpy was added in 20mL dichloromethane. The reaction mixture was stirred for 24 hours at room temperature covering the reaction set-up with aluminium foil affording a dark blue solution. Upon complete evaporation of the solvent the solid was washed thoroughly with hexanes. The solid thus obtained was then recrystallized by layering the hexanes over its dichloromethane solution. This afforded the dark block-shaped crystals in reasonable yield (91mg, 63%). Anal. Cald for $C_{14}H_9N_3O_3BrMn$: C 41.83, H 2.26, N 10.46. Found: C 39.2, H 2.41, N 10.52. Selected IR frequencies (KBr disk) ν_{CO} 2034, 1960 and 1940 cm^{-1} $\nu_{N=N}$ 1370 cm^{-1}. H^1 NMR (CD_3CN, 500MHz), δ(from TMS) 9.23(d, 1H), 8.66(d, 1H), 8.33(t, 1H),

7.87(d, 2H), 7.74 (t, 1H), 7.68 (d, 3H). Absorption spectrum in dichloromethane, $\lambda_{max\ (}$nm) [ε, $dm^3\ m^1\ cm^{-1}$]: (359) 11 990, (586) 3 856.

$[Mn(CO)_3(azpy)(PPh_3)](ClO_4)$ 2. In 10 mL of tetrahydrofuran, 33 mg (0.16 mmol) $AgClO_4$ was quantitatively transferred into 50 mg (0.12 mmol) $[MnBr(azpy)(CO)_3]$. The blue solution was then stirred at room temperature for 1 hour resulting in a purple colouration. AgBr thus formed was filtered and filtrate was evaporated to dryness. To the solid obtained triphenylphosphine 65.5mg (0.25mmol) was added quantitatively in 10 mL of dichloromethane and the reaction mixture was stirred for 24 hours. The reaction flask in all the steps are covered using aluminium foil. Upon evaporation of the solvent, the residue was washed thoroughly with benzene to remove any trace amount of PPh_3 which afforded the orange-red solid of $[Mn(azpy)(PPh_3)(CO)_3](ClO_4)$ in moderate yield (38 mg, 45%). Anal. Cald for $C_{32}H_{24}N_3O_7MnPCl$: C 56.20, H 3.54, N 6.15. Found: C 55.95, H 3.62, N 7.10. Selected IR frequencies (KBr disk) ν_{CO} 2040, 1980 and 1950 cm^{-1},$\nu_{N=N}$ 1370 cm^{-1}, ν_{ClO4} 1090 cm^{-1}. H^1 NMR ($CDCl_3$, 500MHz), δ(from TMS) 8.59, 8.43, 7.67, 7.52, 7.42, 7.26, 7.06 and 5.30 (the proper integration for all the signals could not be obtained with X-ray quality crystals due to the highly ill-resolved nature of the peaks). Absorption spectrum in dichloromethane, $\lambda_{max\ (}$nm) [ε, $dm^3\ m^{-1}\ cm^{-1}$]: (359) 11 990, (520) 3 856.

Crystallography. Data were collected on a Bruker APEX II single crystal X-ray diffractometer with graphite monochromated Mo-Kα radiation (λ = 0.71073 Å) by ω-scan technique in the range of $3 \geq 2\theta \geq 56$ for the two complexes. All the data were corrected for Lorentz polarization and absorption.[3] The metal atom are located from the Patterson maps and the rest of the non-hydrogen atoms emerged from successive Fourier syntheses. The structures were refined by full-matrix least squares procedure on F^2. All non-hydrogen atoms were refined anisotropically. All hydrogen atoms were included in calculated positions. The

absorption corrections are done using SADABS. Calculations were performed using SHELXTL V 6.14 program package.[4]

Photolysis experiment

The rates of CO release upon exposure to visible light were measured with solution of complexes **1** and **2** respectively in 1 cm X 0.4 cm quartz cuvette. The light sources employed in this study include a visible light (10-15 mW and 10 mW with a 520 nm cut-off filter Electro Fiber Optics Corporation, IL 410 illumination system) is used and electronic spectra recorded. Illumination of **1** in biological experiments consisted of a 0.5 mW the light source set approximately 2 ft above cellular plates (hood light) for no longer than 10 minutes. Apparent rates of CO were followed at an appropriate wavelength for each complex and the logarithm of the complex concentration versus time plot were generated. For the quantum yield measurements, a solution was used to ensure sufficient absorbance (≥99%) at the incident wavelength; no more than 10% photolysis occurred in each measurement. Standard actinometry using ferrioxalate was employed to calibrate the light source (Newport Oriel Apex Illuminator (1 mW power with 1 cm distance at 363 nm)[5]. Horse heart myoglobin was dissolved in phosphate buffered saline (PBS, 100 mM, pH 7.4) and reduced by adding sodium dithonite. Due to sodium dithionite facilitating the release of CO, an apparatus was constructed using two quartz cuvettes.[6] In the first cuvette under anaerobic condition, the photoactive complexes exposed to visible light evolving CO into the headspace. The photo released CO was then transferred into the second cuvette containing the reduced Mb solution by a positive pressure of N_2(g).

DFT and TDDFT Calculations

DFT calculations on $MnBr(azpy)(CO)_3$ were carried out using the double-ζ basis set 6-31G* for all atoms with two exceptions Br, 6-11G*, and Mn, for which LANL2DZ basis set and effective core potential (ECP) was implemented. Calculations were carried out with the aid of the program PC-GAMESS[7] using the hybrid functional PBE0 for TDDFT calculations. The X-ray coordinates of **1** were used as a starting point for the geometry optimization and molecular orbitals (MO) were visualized in MacMolPlt for analysis. Oscillation strengths greater than 0.0099 were taken for analysis of transitions.

Table S1: Calculated (TD-DFT) energies (E, nm), oscillator strengths(f), and nature of transitions[a] for complex **1**

Energy (nm)	Oscillator Strength	Transition
616.25	0.0099492	π(Mn–CO)–p(Br)→π*(azo–pyr–phe)
396.19	0.0720846	π(Mn–Br–CO) –π(pyr)→π*(azo–pyr–phe)
354.23	0.0797801	π(phe)–π(azo)–π(pyr)→ π*(azo–pyr–phe)
350.02	0.1818711	π(phe)–π(Mn–CO–Br)→π*(azo–pyr–phe)
348.05	0.0346971	π(Mn–Br–CO)→π*(azo–pyr–phe)
336.67	0.0267677	π(Mn–Br–CO)→π*(azo–pyr–phe)
331.44	0.0489395	π(azo)–π(pyr)–π(phe)→ π*(azo–pyr–phe)
326.90	0.0207783	π(Mn–Br–CO)→ π*(pyr)
324.06	0.0239514	π(Mn–CO)–π(phe)–π(phe)→π*(phe)–π*(CO)
320.00	0.0283438	π(Mn–CO)–p(Br)→π*(pyr)

[a] Orbitals with greater contributions listed first

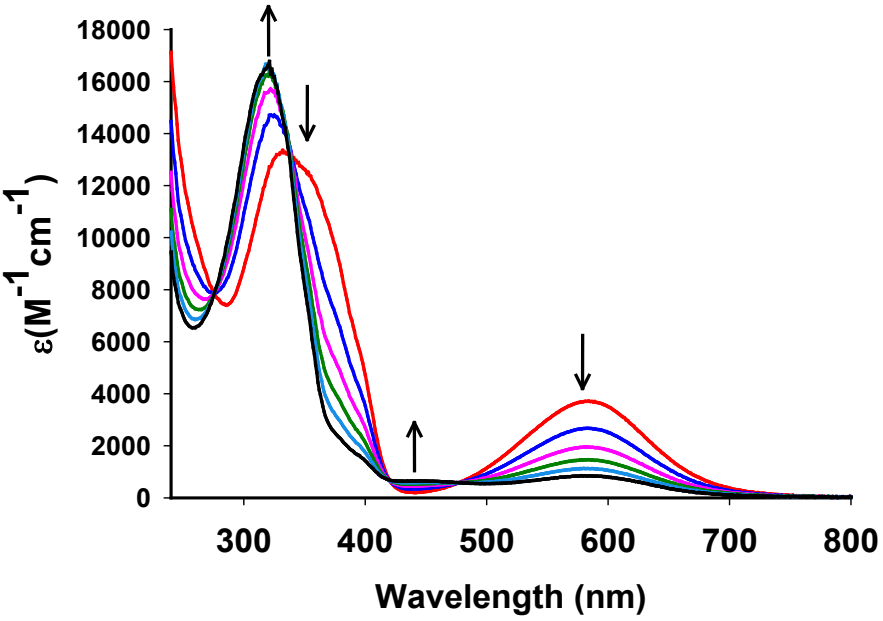

Fig. S1. Changes in the electronic absorption spectrum of **1** in dichloromethane solution upon exposure to visible light (Concentration of **1** in this experiment is 1.2258 X 10^{-4} M).

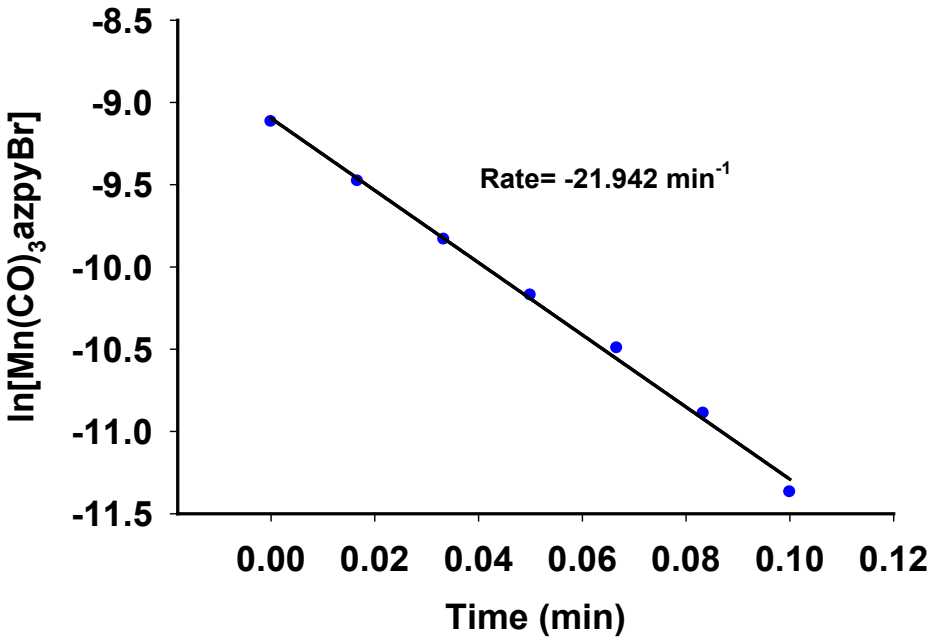

Fig. S2. Plot of ln[**1**] vs. time (min) in dichloromethane solution at 298 K upon exposure to visible light.

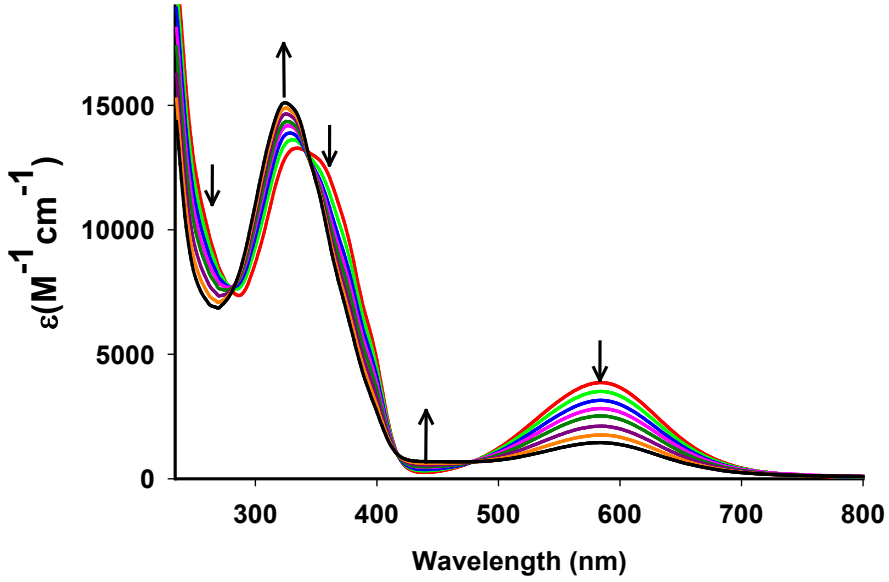

Fig. S3. Changes in the electronic absorption spectrum of **1** in dichloromethane solution upon exposure to visible light with 520 nm cut-off filter (Concentration of **1** in this experiment is 9.84 X 10^{-5} M).

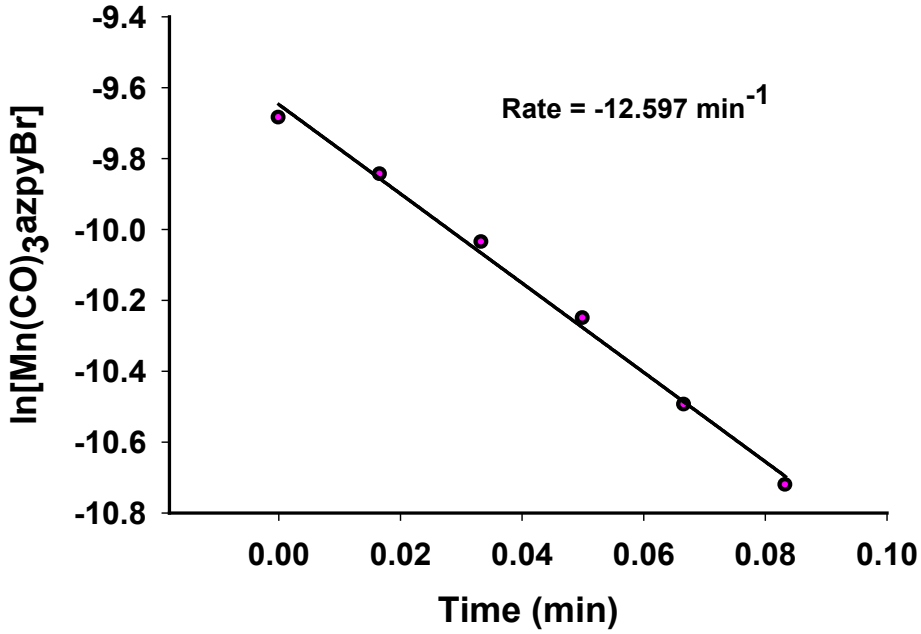

Fig. S4. Plot of ln[**1**] vs. time (min) in dichloromethane solution at 298 K upon exposure to visible light with 520 nm cut-off filter.

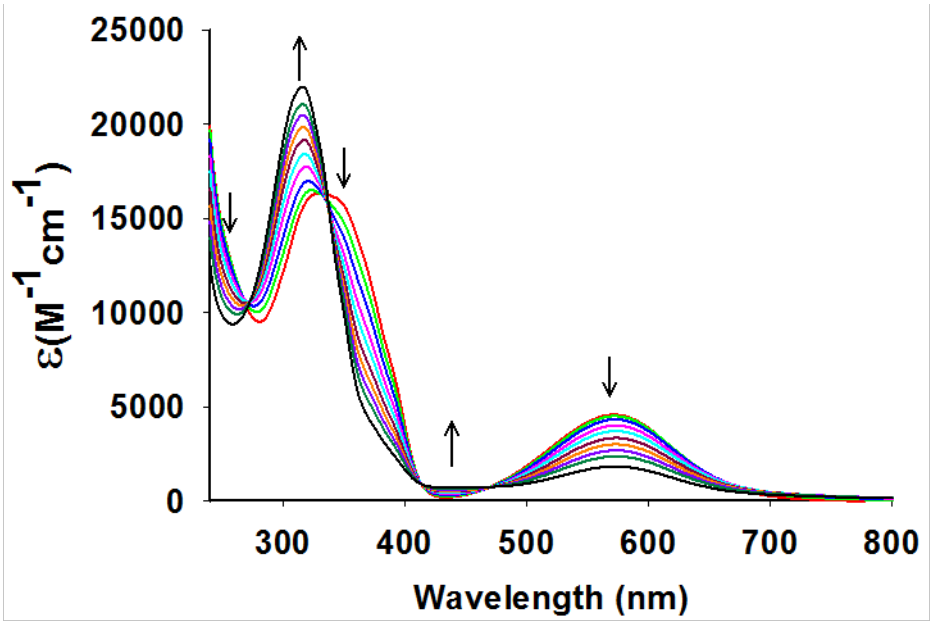

Fig. S5. Changes in the electronic absorption spectrum of **1** in acetonitrile solution upon exposure to visible light (Concentration of **1** in this experiment is 7.5008 X 10^{-5} M).

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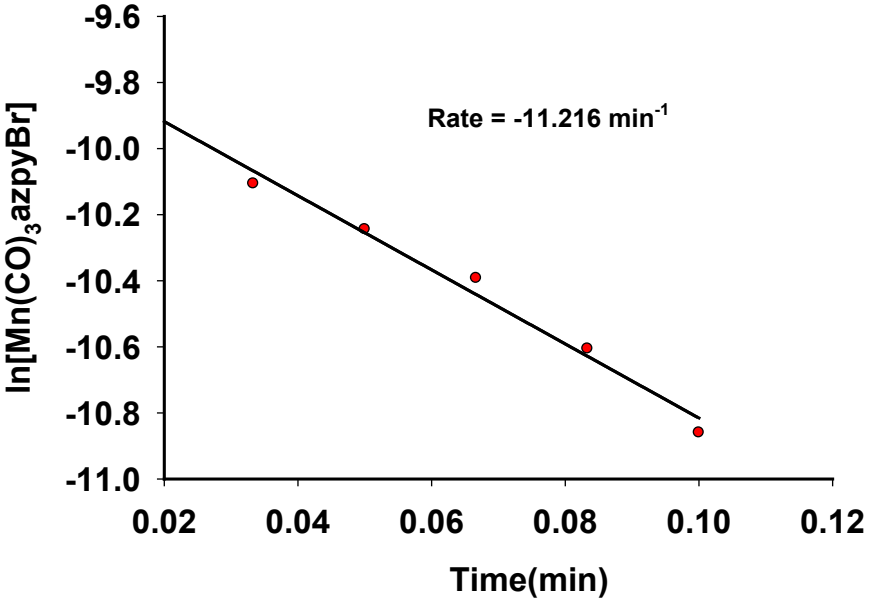

Fig. S6. Plot of ln[**1**] vs. time (min) in acetonitrile solution at 298 K upon exposure to visible light.

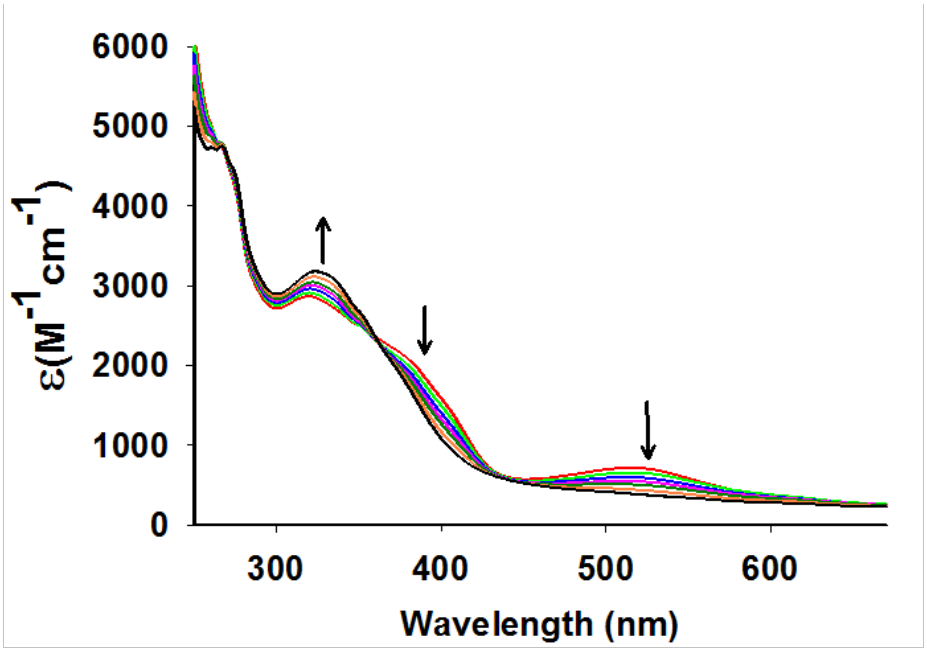

Fig. S7. Changes in the electronic absorption spectrum of **2** in dichloromethane solution upon exposure to visible light (Concentration of **2** in this experiment is 3.0662 X 10^{-4} M).

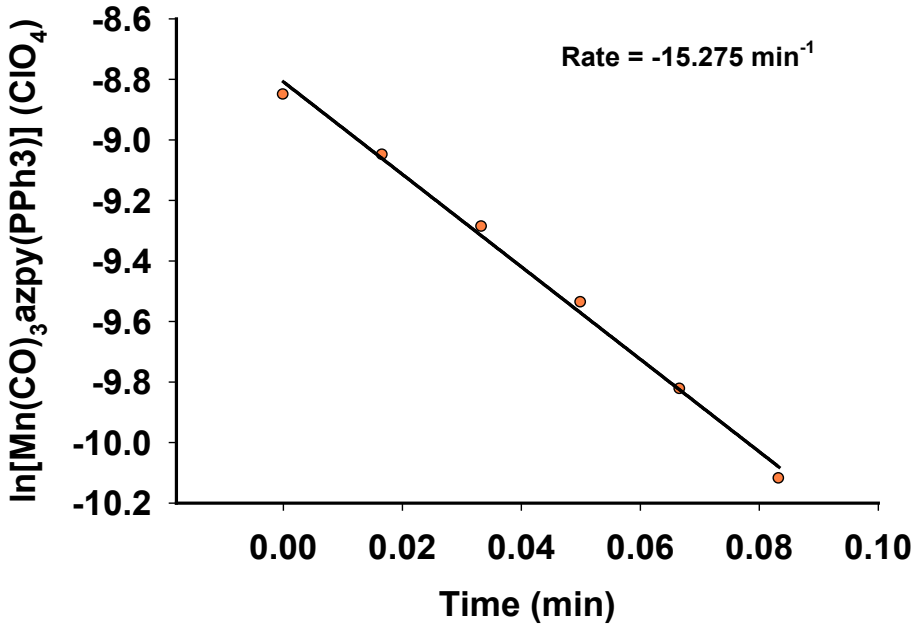

Fig. S8. Plot of ln[**2**] vs. time (min) in dichloromethane solution at 298 K upon exposure to visible light.

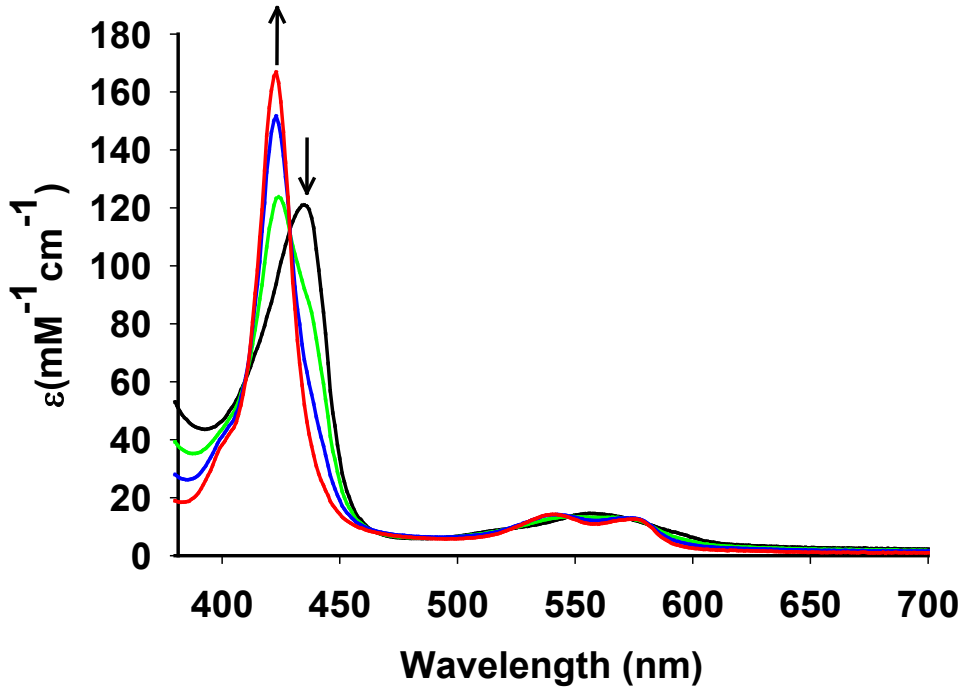

Fig. S9. UV-Vis traces from the Mb assay for **1**. Formation of the Mb-CO adduct from reduced Mb is evident by the shift in the Soret band from 435 to 424 nm

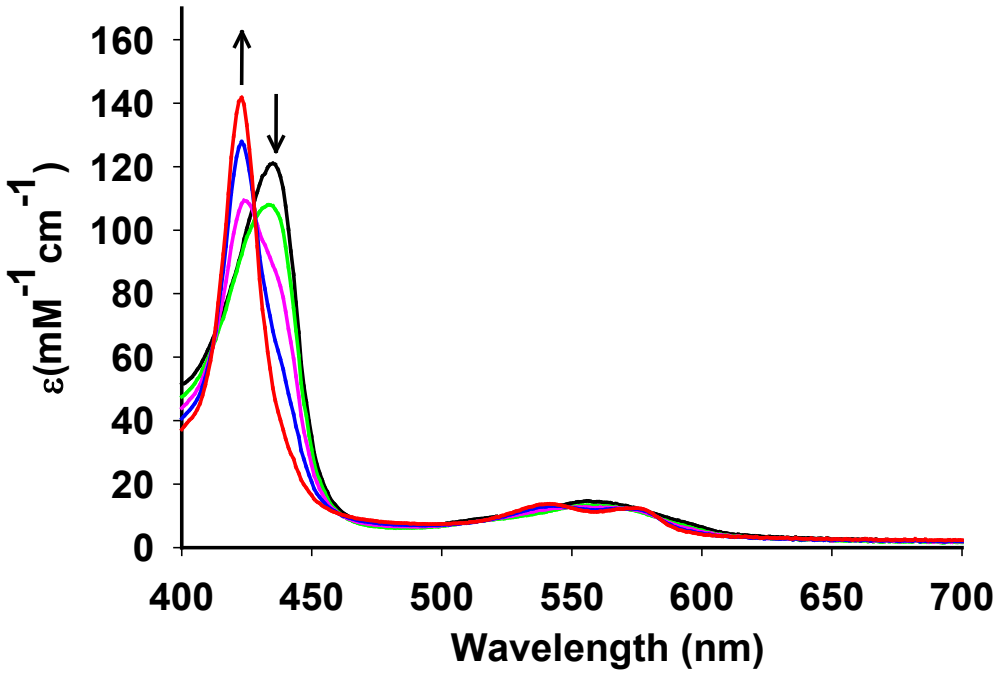

Fig. S10. UV-Vis traces from the Mb assay for **2**. Formation of the Mb-CO adduct from reduced Mb is evident by the shift in the Soret band from 435 to 424 nm

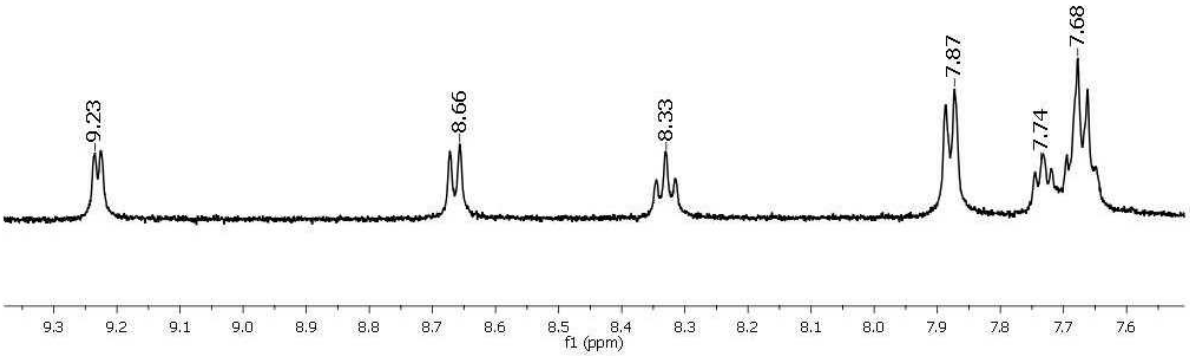

Fig. S11. ^{1}H NMR spectrum of **1** in CD3CN at 298 K

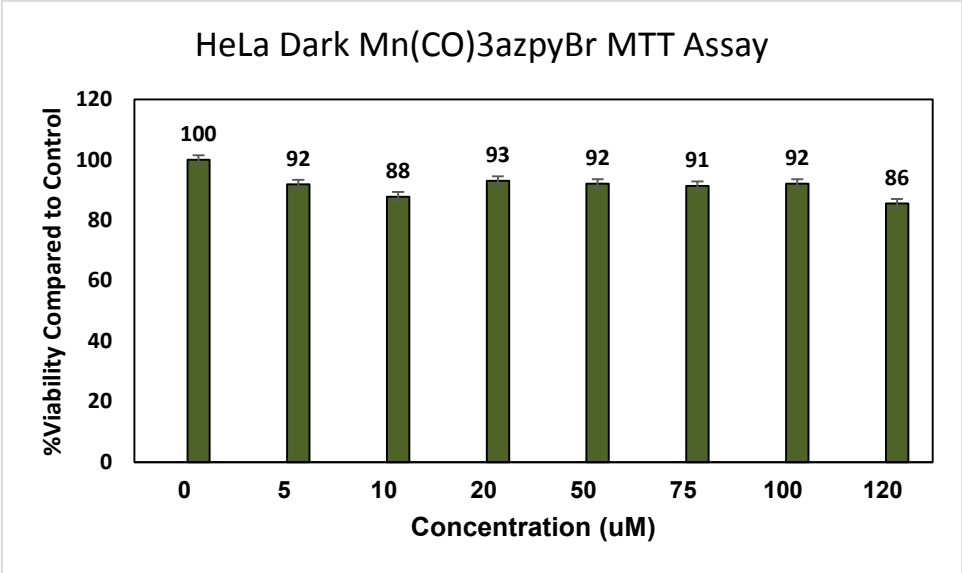

Fig. S12. Cell viability assay on HeLa with complex **1** without light exposure

References

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