Supporting Information

A long lifetime luminescent iridium(III) complex chemosensor for selective switch-on detection of Al^{3+} ions

Wanhe Wang,[‡a] Zhifeng Mao,[‡a] Modi Wang,[‡a] Li-Juan Liu,[b] Daniel W. J. Kwong,[a]

Chung-Hang Leung*[b] and Dik-Lung Ma*[a]

[a] *Department of Chemistry, Hong Kong Baptist University, Kowloon Tong, Hong Kong, China. E-mail: edmondma@hkbu.edu.hk.*
[b] *State Key Laboratory of Quality Research in Chinese Medicine, Institute of Chinese Medical Sciences, University of Macau, Macao, China. E-mail: duncanleung@umac.mo.*
‡ These authors contributed equally to this work.

Materials. Reagents, unless specified, were purchased from Sigma Aldrich (St. Louis, MO) and used as received. Iridium chloride hydrate ($IrCl_3.xH_2O$) was purchased from Precious Metals Online (Australia). The fetal bovine serum 10270 (GIBCO®, origin: South America, EU approved origin) we used in time-resolved emission spectra measurement was purchased from life technologies.

General experimental. Mass spectrometry was performed at the Mass Spectroscopy Unit at the Department of Chemistry, Hong Kong Baptist University, Hong Kong (China). Deuterated solvents for NMR purposes were obtained from Armar and used as received.

^1H and ^{13}C NMR were recorded on a Bruker Avance 400 spectrometer operating at 400 MHz (^1H) and 100 MHz (^{13}C). ^1H and ^{13}C chemical shifts were referenced internally to solvent shift (CD_3CN: ^1H, δ 1.94, ^{13}C δ 118.7; d_6-DMSO: ^1H δ 2.50, ^{13}C δ 39.5). Chemical shifts (δ) are quoted in ppm, the downfield direction being defined as positive. Uncertainties in chemical shifts are typically ±0.01 ppm for ^1H and ±0.05 for ^{13}C. Coupling constants are typically ± 0.1 Hz for ^1H-^1H and ±0.5 Hz for ^1H-^{13}C couplings. The following abbreviations are used for convenience in reporting the multiplicity of NMR resonances: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; br, broad. All NMR data was acquired and processed using standard Bruker software (Topspin).

Photophysical measurement. Emission spectra and lifetime measurements for complexes were performed on a PTI TimeMaster C720 Spectrometer (Nitrogen laser: pulse output 337 nm). Error limits were estimated: λ (±1 nm); τ (±10%); φ (±10%). All solvents used for the lifetime measurements were degassed using three cycles of freeze-vac-thaw.

Live cell imaging assay. HepG2 cells were seeded in at a density of 1 X 10^6 cells per mL in coverglass-bottom confocal dishes. The cells were pre-incubated with **1** at the concentration of 10 μM for 1 h at 37 ^oC. Cells were then washed with PBS for three times and treated with vehicle control or Al^{3+} (100 μM) for a further 30 min at 37 ^oC. Cells were then washed with PBS for three times and incubated with fresh medium. The luminescence images of the cells were taken using Leica TCS SP8 confocal microscope using 20 × objective lens.

Synthesis of 1. Compound **S1** was synthesized using a modified literature method.[35] 1,10-Phenanthroline-5,6-dione (0.315 g, 1.5 mmol), *p*-toluidine (0.16 g, 1.5 mmol), 4-hydroxy-3-nitrobenzaldehyde (0.25 g, 1.5 mmol) and ammonium acetate (1.16 g, 15 mmol) were added to acetic acid (10 mL) in a round bottomed flask. The reaction was

allowed to stir and refluxed at 125 °C overnight. The reaction mixture was poured into ice water (200 mL), neutralized with ammonium hydroxide. The resulting solution was extracted into dichloromethane (3 × 50 mL), dried (Na_2SO_4) and the volatiles removed in vacuo. Silica gel column chromatography was carried out to purify the residue (eluent, ethyl acetate: methanol, 10: 1, *v/v*) to afford the desired product **S1**. Yield: 54%. ^{1}H-NMR (400 MHz; DMSO-d_6): 9.07 (dd, J = 4.0, 1.6 Hz, 1H), 8.99 (dd, J = 8.4, 2.0 Hz, 1H), 8.94 (dd, J = 4.4, 2.0 Hz, 1H), 8.03 (d, J = 2.4 Hz, 1H), 7.85 (dd, J = 8.0, 4.4 Hz, 1H), 7.75 (dd, J = 8.8, 2.0 Hz, 1H), 7.68 (d, J = 8.0 Hz, 2H), 7.56 (d, J = 8.0 Hz, 2H), 7.49 (dd, J = 8.4, 4.0 Hz, 1H), 7.40 (dd, J = 8.4, 4.0 Hz, 1H), 7.13 (d, J = 8.8 Hz, 1H), 2.52 (s, 3H). ^{13}C-NMR (400 MHz; DMSO-d_6): δ 152.8, 149.8, 148.5, 147.5, 143.9, 143.6, 140.4, 136.4, 135.1, 134.9, 134.6, 131.2, 129.7, 128.5, 127.3, 126.6, 125.7, 123.8, 123.2, 122.5, 120.7, 119.3, 119.2, 21.0. HRMS: Calcd. for $C_{26}H_{17}N_5O_3$: *m/z* = 448.1410. Found: *m/z* = 448.1448. [M+H].

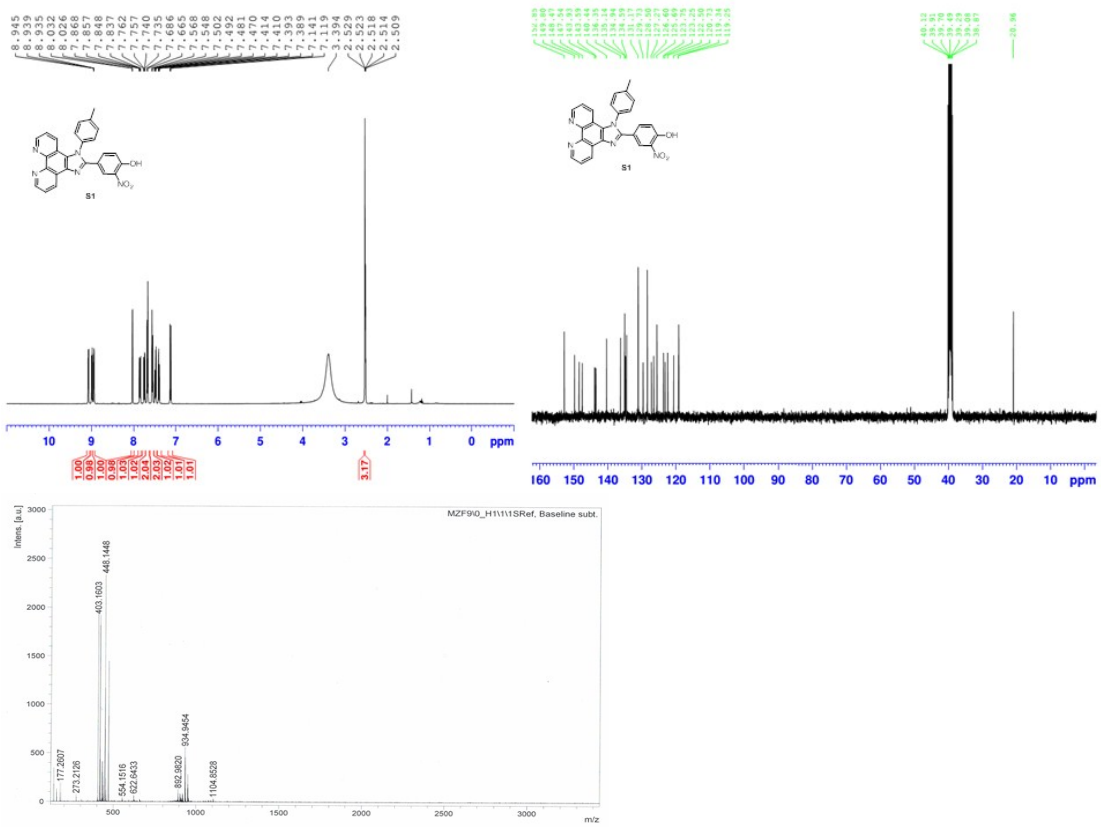
Compound **S2** was synthesized using a modified literature method.[36] Compound **S1** (0.224 g, 0.5 mmol) was dissolved in ethanol (30 mL) with stirring for 1 h. Pd/C (0.20 g, 10 % Pd) and $NH_2NH_2{\cdot}H_2O$ (8 mL) were then added and the solution refluxed overnight. The hot solution was filtered and evaporated to remove the solvent under low pressure condition. Silica gel column chromatography was carried out to purify the residue (eluent, ethyl acetate: methanol, 10:2, *v/v*) to afford the desired product **S2**. Yield: 48%. ^{1}H-NMR (400 MHz; DMSO-d_6): 9.44 (s, 1H), 9.05 (dd, J = 4.4, 2.0 Hz, 1H), 8.95 (dd, J = 8.4, 2.0 Hz, 1H), 8.90 (dd, J = 4.4, 1.6 Hz, 1H), 7.83 (dd, J = 8.4, 4.4 Hz, 1H), 7.54-7.43 (m, 5H), 7.33 (dd, J = 8.4, 1.6 Hz, 1H), 7.11 (d, J = 2.4 Hz, 1H), 6.49 (d, J = 8.4 Hz, 1H), 6.39 (dd, J = 8.4, 2.4 Hz, 1H), 4.67 (s, 2H), 2.48 (s, 3H). ^{13}C-NMR (400 MHz; DMSO-d_6): δ 153.2, 148.2, 147.1, 145.2, 143.7, 143.5, 139.7, 136.6, 135.3, 134.9, 130.8, 129.6, 128.6, 127.1, 126.2, 123.6, 123.4, 122.3, 121.0, 119.5, 117.5, 115.6, 113.5. HRMS: Calcd. for $C_{26}H_{19}N_5O$: *m/z* = 417.1590. Found: *m/z* = 417.1579.

Complex **S3** was synthesized using a modified literature method.[37] A solution of ligand **S2** (12.84 mg, 0.03078 mmol) and the dichloro-bridged $[Ir(ppy)_2Cl]_2$ (15 mg, 0.014 mmol) in dichloromethane (3 mL) and methanol (3 mL) was stirred at 25 °C overnight. After the reaction completed, an excess of solid NH_4PF_6 was added and stirred for another 0.5 h at 25 °C. The solvent was removed under reduced pressure and silica gel column chromatography was carried out to purify the residue (eluent, methanol: dichloromethane, 1:20, *v/v*) to yield **S3** as a brown powder. Yield: 65%. ^{1}H-NMR (400 MHz; DMSO-d_6): 9.56 (s, 1H), 9.23 (dd, J = 8.4, 1.2 Hz, 1H), 8.28-8.20 (m, 3H), 8.11 (dd, J = 8.4, 4.8 Hz, 1H), 8.03 (dd, J = 5.2, 1.6 Hz, 1H), 7.96-7.84 (m, 4H), 7.74 (dd, J = 8.8, 5.2 Hz, 1H), 7.60-7.45 (m, 7H), 7.12 (d, J = 2.4 Hz, 1H),

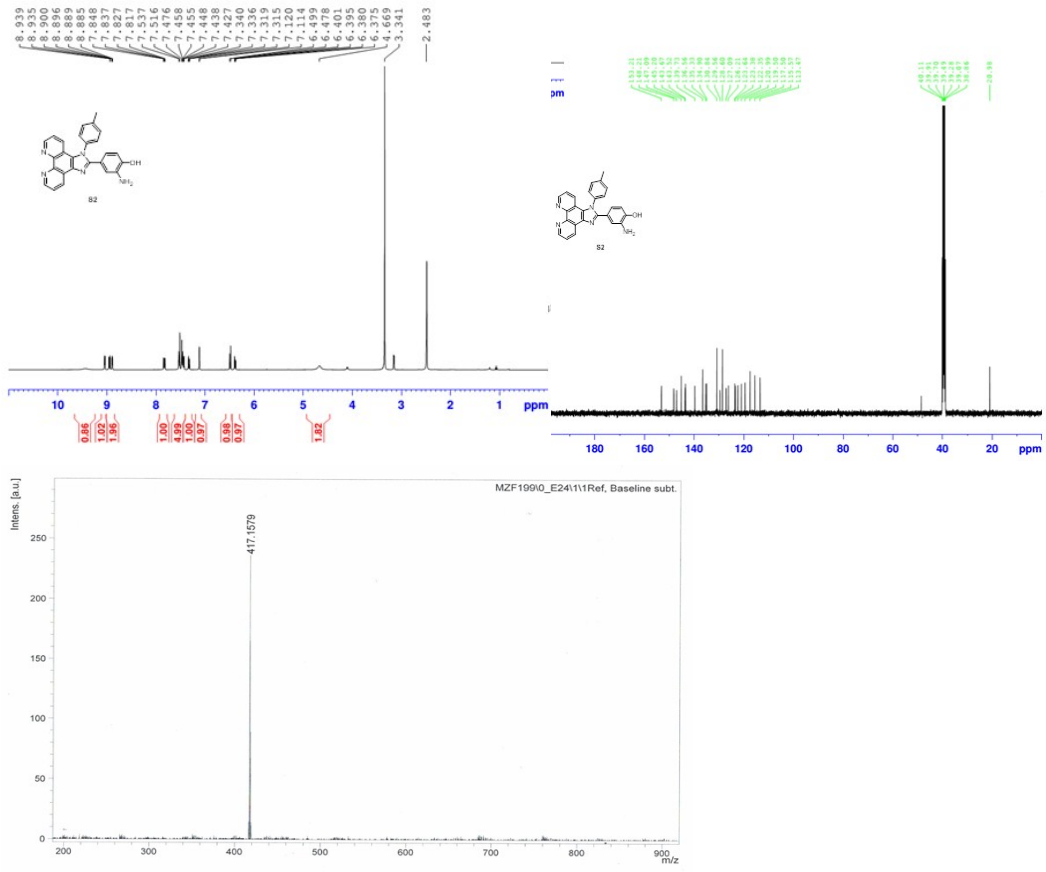
7.12-6.90 (m, 6H), 6.51 (d, J = 8.4 Hz, 1H), 6.42 (dd, J = 8.0, 2.4 Hz, 1H), 6.25 (dd, J = 11.2, 7.2 Hz, 1H), 4.73 (s, 2H), 2.48 (s, 3H). ^{13}C-NMR (400 MHz; DMSO-d_6): δ 166.8, 155.2, 150.6, 150.2, 149.1, 149.0, 147.8, 145.8, 144.2, 144.1, 144.0, 140.5, 138.7, 136.8, 136.0, 134.5, 132.3, 131.2, 131.1, 130.3, 129.4, 128.5, 127.5, 127.4, 126.3, 125.9, 125.1, 123.9, 123.8, 122.3, 122.0, 120.2, 120.0, 117.7, 115.4, 113.6, 21.0. HRMS: Calcd. for $C_{48}H_{35Ir}N_7O$: m/z = 918.2532. Found: m/z = 918.2532.

Complex **1**. A solution of 2-hydroxyl-benzaldehyde (1.9 mg, 0.0155 mmol) in absolute ethanol was added to a solution containing complex **S3** (15 mg, 0.0141 mmol) in ethanol (5 mL). The mixture was refluxed under nitrogen for 5 h. The solution was then cooled to 25 ^{o}C, and the solvent was removed. The brown product was obtained through recrystallization from dichloromethane and diethyl ether to yield complex **1**. Yield: 68%. ^{1}H-NMR (400 MHz; $CDCl_3$): δ 12.2 (s, 1H), 9.32 (d, J = 8.4 Hz, 1H), 8.40 (s, 1H), 8.23 (dd, J = 5.2, 1.2 Hz, 1H), 8.15 (dd, J = 4.8, 1.2 Hz, 1H), 7.90 (d, J = 8.0 Hz, 2H), 7.81-7.67 (m, 7H), 7.58 (d, J = 7.2 Hz, 1H), 7.52-7.47 (m, 2H), 7.42-7.31 (m, 7H), 7.10-7.02 (m, 3H), 7.00-6.91 (m, 5H), 6.86-6.83 (m, 1H), 6.41-6.38 (m, 2H), 2.55 (s, 3H). ^{13}C-NMR (400 MHz; CD_3CN): 167.1, 160.5, 150.2, 150.1, 149.8, 149.2, 149.0, 148.4, 148.2, 144.7, 144.4, 143.8, 138.1, 136.2, 134.3, 133.2, 132.0, 131.3, 130.9, 130.0, 129.8, 128.1, 127.6, 126.1, 125.7, 124.5, 123.1, 122.2, 119.4, 119.0, 118.9, 20.3. HRMS: Calcd. for $C_{55}H_{39}IrN_7O_2$[M–PF_6]+: 1022.2794 Found: 1022.2756. Anal.: ($C_{55}H_{41}IrN_7O_2PF_6$) +1.5H_2O C, H, N: calcd. 55.23, 3.71, 8.20; found 55.07, 3.33, 8.32.

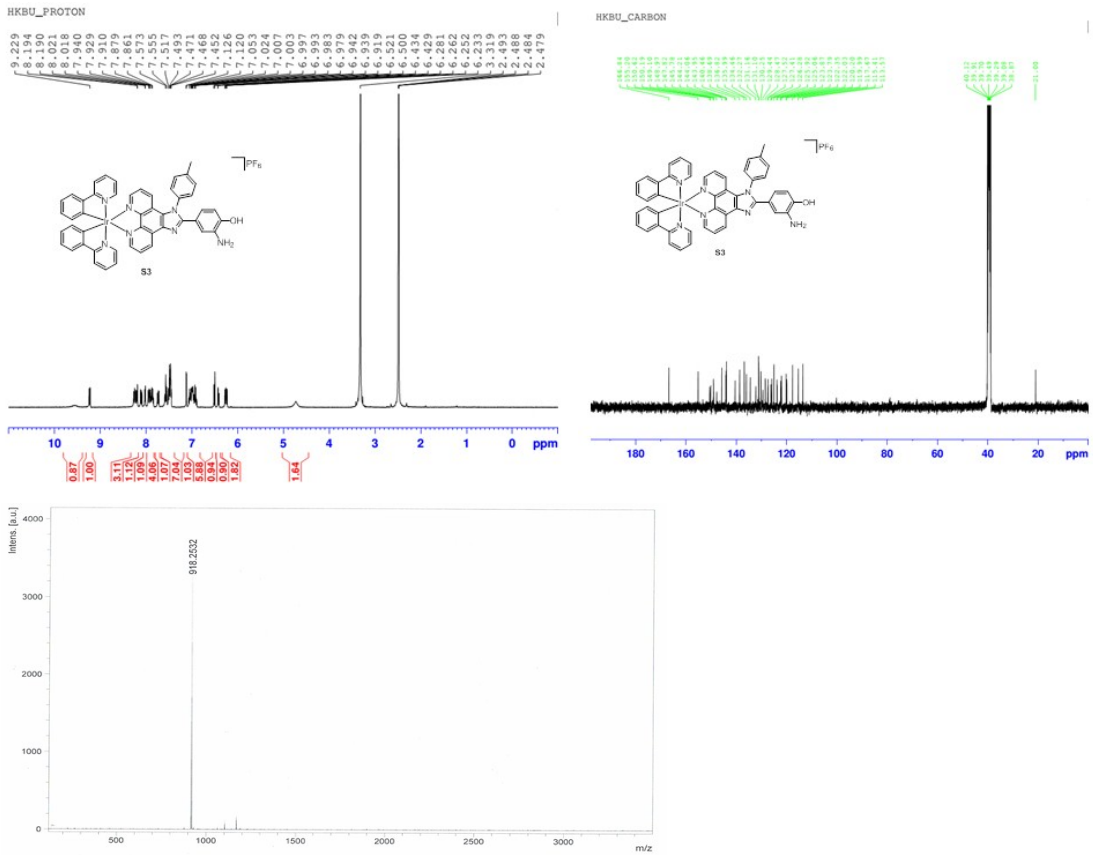
Al^{3+} ions detection. 10 mM of complex stock solution was prepared by dissolving complex **1** in acetonitrile. The complex was then added into acetonitrile to a final concentration of 20 μM. Different concentrations of Al^{3+} ions were then added to 995 μL of acetonitrile containing complex **1** (20 μM) and 5 μL H_2O in a cuvette. Emission spectra was recorded. Luminescence emission spectra were recorded on a PTI QM-4 spectrofluorometer (Photo Technology International, Birmingham, NJ) at 25 °C, with the slits for both excitation and emission set at 2.5 nm. UV-Vis absorption spectra were recorded on a Cary UV-300 spectrophotometer (double beam).



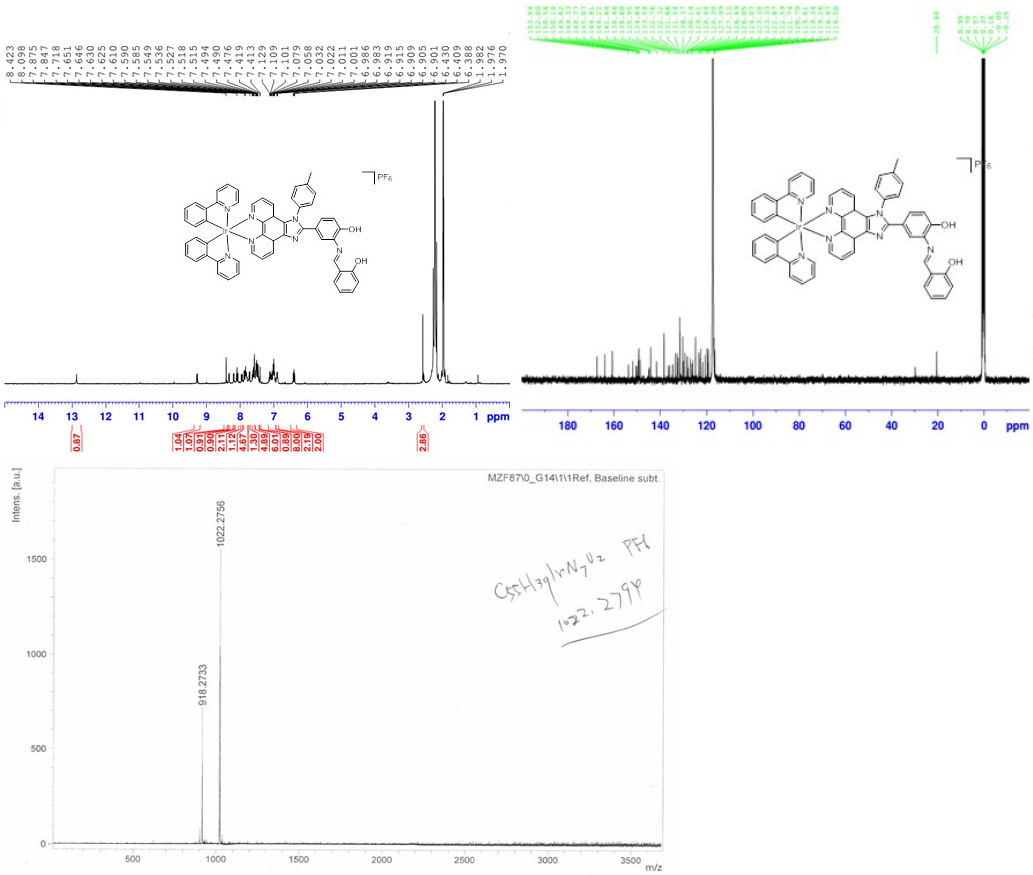
^{1}H-NMR, ^{13}C-NMR and mass spectrum of **S1**.



^{1}H-NMR, ^{13}C-NMR and mass spectrum of **S2**.



^{1}H-NMR, ^{13}C-NMR and mass spectrum of **S3**.



^{1}H-NMR, ^{13}C-NMR and mass spectrum of **1**.

Table S1 Photophysical properties of iridium(III) complex **1**.

Quantum yield	λ_{em}/ nm	Lifetime/ μs	UV/vis absorption λ_{abs} / nm (ε/ dm^3 mol^{-1} cm^{-1})
0.0082	573	4.201	259 (7.06× 10^4), 353 (2.38× 10^4)

Table S2 Comparison of the recent chemosensors for the detection of Al^{3+} ions.

Target	Detection range	Detection limit	Reference
Al^{3+}	1–30 μM	1 μM	This study
Al^{3+}	1−20 μM	1 μM	15
Al^{3+}	1−12 μM	1 μM	18
Al^{3+}	-	2 μM	16
Al^{3+}	1.25–1000 μM	1.25 μM	19
Al^{3+}	-	0.887 μM	24
Al^{3+}	1−8 μM	0.6 μM	8
Al^{3+}	0.5–25 μM	-	10
Al^{3+}	-	0.5 μM	9
Al^{3+}	-	0.12 μM	22
Al^{3+}	0.1−1.5 μM	40 nM	17
Al^{3+}	0.1−5 μM	21.6 nM	21
Al^{3+}	0.1−5 μM	10 nM	7
Al^{3+} and Zn^{2+}	20−120 nM	3.1 nM	5
Al^{3+}	9.9 nM−0.198 μM	1.35 nM	12
Al^{3+}	40 pM−150 μM	32.2 pM	6

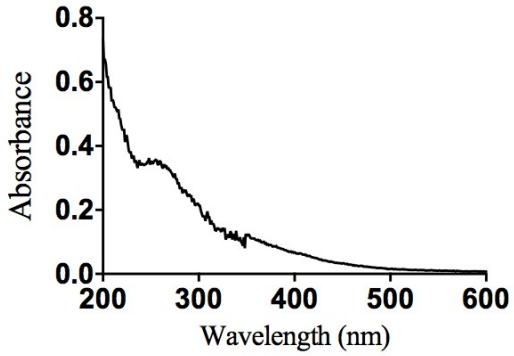


Fig. S1 UV-Vis absorption spectra of **1** (5 μM) in acetonitrile.

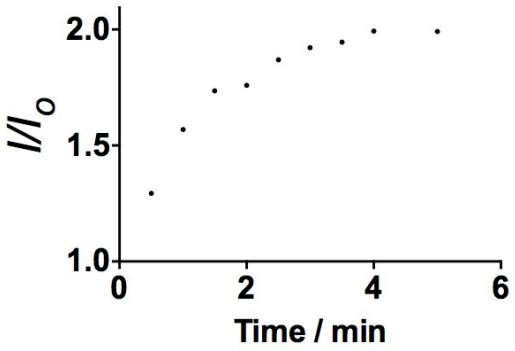


Fig. S2 Time course of luminescence response of **1** (20 μM) in the presence of 3 μM Al^{3+} ions at 25 °C.

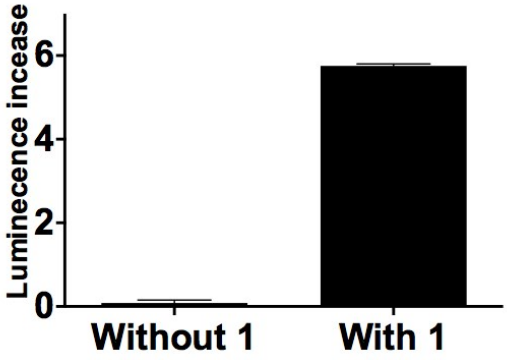


Fig. S3 Luminescence enhancement of system in response to 20 μM Al^{3+} in the presence or absence of 20 μM **1**.

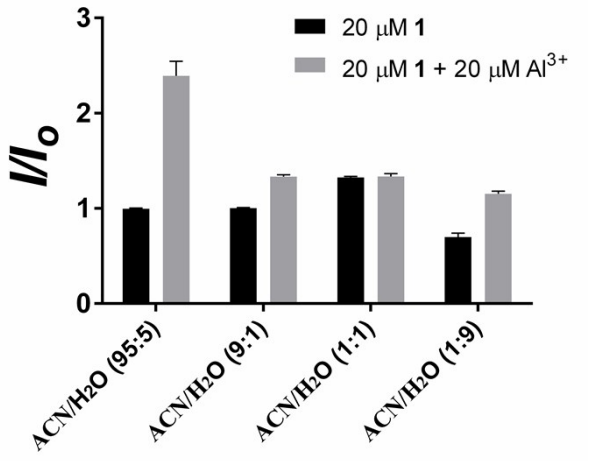


Fig. S4 Luminescence enhancement of 20 μM **1** with 20 μM Al^{3+} in various ACN:H_2O mixtures.

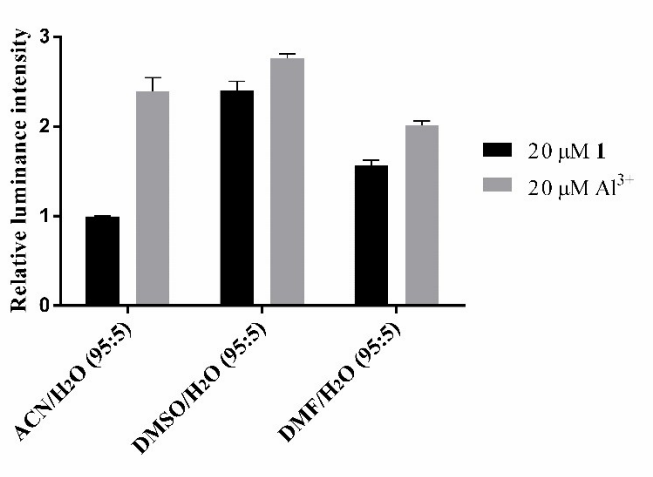


Fig. S5 Luminescence enhancement of 20 μM **1** with 20 μM Al^{3+} in various types of organic solvents with 5% water.

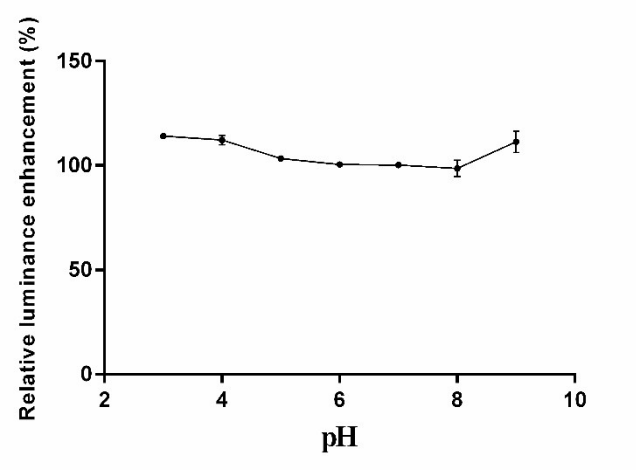


Fig. S6 Effect of pH on the relative luminescence enhancement of 20 μM **1** towards 20 μM Al^{3+}.

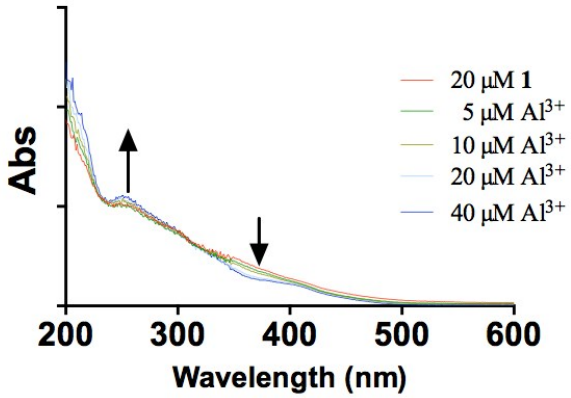


Fig. S7 UV-Vis absorption spectra of **1** (20 μM) with various amounts of Al^{3+} ions (0–40 μM).

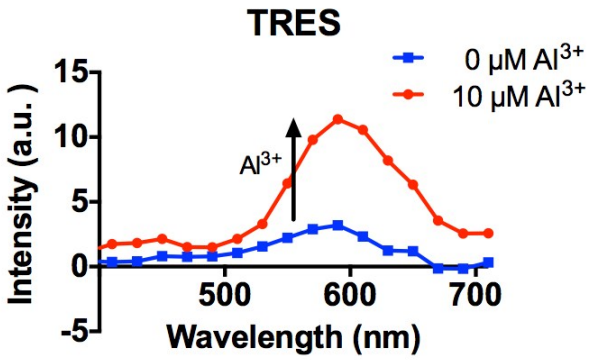


Fig. S8 time-resolved emission spectra (TRES) of **1** in 2.5% (*v/v*) serum in the absence and presence of 10 μM Al^{3+} ions.