Supplementary Information:

Substituent Effects on Fluoride Binding by Lanthanide Complexes of DOTA-tetraamides

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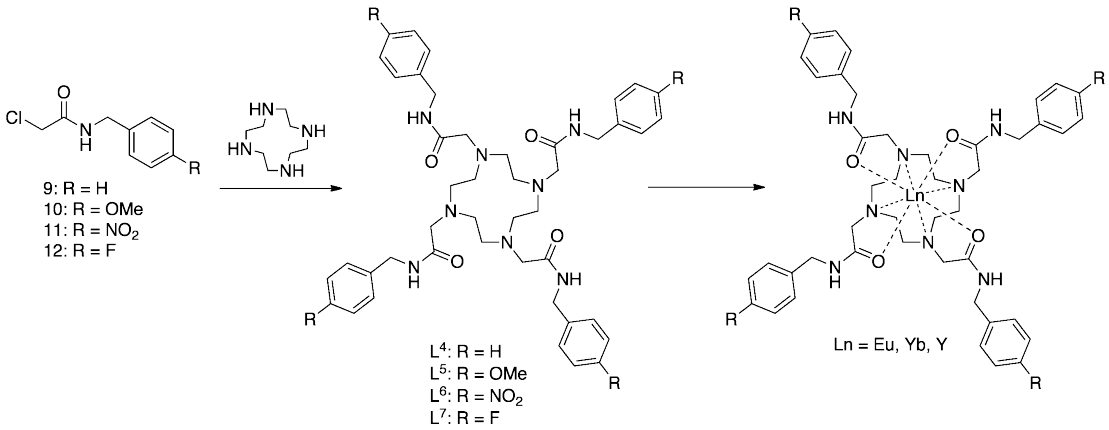
1 Materials and Methods

1.1 Synthesis of Compounds



Scheme S1. Synthesis of benzyl-substituted ligands and complexes.

Commercially available reagents and solvents were used without further purification. Compounds **9**,[1] **10**,[2] **11**,[3] **12**,[4] **L1**,[5] **L2**,[6] **L3**,[7] **L4**,[8] **L6**,[3] were synthesised by literature procedures. All complexes were isolated as their trifluoromethanesulfonate salts.

NMR spectra were recorded on a Bruker Avance III HD nanobay 400MHz NMR with EXSY spectra and VT on a Bruker Avance III 500MHz NMR at 298 K unless expressed otherwise. All coupling constants are quotes in Hz. Abbreviations when quoting NMR data are as follows: singlet (s), doublet (d), triplet (t), multiplet (m), doublet of doublet of doublets (ddd), broad (br). Mass spectra were obtained using either an Aligent Technology 1260 Infinity or a Waters LCT Premier XS. Luminescence measurements were obtained using a HORIBA FluoroLog3 fluorimeter. All data fitting was done in Dynafit.[9]

2,2',2'',2'''-(1,4,7,10-Tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-(4-methoxybenzyl)acetamide) (L^5) Cyclen (0.12 g, 0.70 mmol), **10** (0.60 g, 2.81 mmol) and triethylamine (0.49 mL, 3.51 mmol) were dissolved in dry tetrahydrofuran (50 mL). The mixture was heated at 70°C for 48 h. The resultant solid was filtered off, washed with water and ethanol, and recrystallized from acetonitrile and chloroform (1:1, v/v) to give a white solid (0.15 g, 24%). *m/z* (ES+): 452 $[M+Na+H]^{2+}$, 441 $[M+2H]^{2+}$. NMR (400 MHz, $CDCl_3$) δ_H (ppm) 2.44 (s, 16H, ring C$\underline{H}_2$), 2.89 (s, 8H, C$\underline{H}_2$CO), 3.76 (s, 12H, OC$\underline{H}_3$), 4.25 (s, 8H, C$\underline{H}_2$NH), 6.84 (d, J = 8.7, 8H, Ar), 7.06 (t, 4H, NH), 7.11 (d, J = 8.6, 8H Ar). Anal. Calcd (%) for $C_{48}H_{64}N_8O_8$: C, 65.43; H, 7.32; N, 12.72. Found: C, 65.37; H, 7.36; N, 12.53.

2,2'2,'',2'''-(1,4,7,10-Tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-(4-fluorobenzyl)acetamide) (L^7) Cyclen (0.20 g, 1.18 mmol), **12** (1.00 g, 4.97 mmol) and triethylamine (1.4 mL, 10.0 mmol) in DMF (50 mL) were heated overnight at 85 °C. Water (170 mL) was added and the solution was heated at 100 °C for 30 min. After cooling, the beige precipitate was filtered, washed with H_2O (30 mL) and dried. The solid was suspended in DMF (12 mL) and water (8 mL) and the mixture heated at 100 °C for 30 min. After cooling, the solid was filtered and dried to give a beige solid (0.26 g, 27 %). *m/z* (ES+): 833.4 $[M + H]^+$. HR-ESMS found *m/z* 833.41235, calculated *m/z* 833.41204 for $[C_{44}H_{53}O_4N_8F_4]^+$. NMR (400 MHz, DMSO-$d_6$) δ_H (ppm) 8.46 (t, J = 6.1, 4H, N$\underline{H}$), 7.25 - 7.22 (m, 8H, Ar), 7.11 - 7.07 (m, 8H, Ar), 4.22 (d, J = 5.9, 8H, NC$\underline{H}_2$CO), 2.97 (s, 8H, NC$\underline{H}_2$Ar), 2.52 (s, 16H, NC$\underline{H}_2$). NMR (376 MHz, DMSO-d_6) δ_F $\{^1H\}$ (ppm) 116.7. δ_c 170.3, 161.1 (d, $^1J_{CF}$ = 242.2 Hz, C), 135.7 (d, $^4J_{CF}$ = 3.2 Hz, C), 129.1 (d, $^3J_{CF}$ = 8.1 Hz, CH), 114.9 (d, $^2J_{CF}$ = 21.1 Hz, CH), 57.8,

53.6, 41.1 ppm. Found: C, 63.34; H, 6.27; N, 13.34. Calc. for $C_{44}H_{52}F_4N_8O_4$: C, 63.45; H, 6.29; N, 13.45 %.

Ytterbium (III) 2,2',2'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-benzylacetamide) (YbL^4) L^4 (0.10 g, 0.13 mmol) and $Yb(OTf)_3$ (0.10 g, 0.13 mmol) were dissolved in acetonitrile (10 mL). The mixture was heated to 60°C for 2 d. Any unreacted ligand was filtered off and the remaining solution was concentrated *in vacuo*. Dichloromethane was added until a precipitate formed and the mixture was cooled to 5°C for 18 h. The precipitate was filtered off, yielding a white solid (0.047 g, 40%). *m/z* (ES+): 311 $[M–3OTf]^{3+}$. NMR (400 MHz, D_2O) δ_H (ppm) 98.95, 18.25, 15.22, 4.55, 3.60, 3.06, 2.40, 0.02, -4.48, -26.79, -32.49, -62.13. Anal. Calcd (%) for $C_{47}H_{56}F_9N_8O_{13}S_3Yb$: C, 40.87; H, 4.09; N, 8.11. Found: C, 40.54; H, 3.91; N, 8.02.

Europium (III) 2,2',2'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-benzylacetamide) (EuL^4) This compound was prepared in a manner identical to YbL^4 using L^4 (0.08 g, 0.011 mmol) and $Eu(OTf)_3$ (0.06 g, 0.011 mmol) in acetonitrile (10 mL) to yield a white solid (0.08 g, 79%). *m/z* (ES+): 1211 $[M–OTf]^+$, 531 $[M–2OTf]^{2+}$. NMR (400 MHz, D_2O) δ_H (ppm) 26.73, 6.31, 6.11, 3.02, 2.35, -2.53, -6.39, -7.95, -13.40, -13.93. Anal. Calcd (%) for $C_{47}H_{56}F_9N_8O_{13}S_3Eu$: C, 41.50; H, 4.15; N, 8.24. Found: C, 41.56; H, 4.07; N, 8.19.

Yttrium (III) 2,2',2'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-benzylacetamide) (YL^4) This compound was prepared in a manner identical to YbL^4 using L^4 (0.08 g, 0.011 mmol) and $Y(OTf)_3$ (0.06 g, 0.011 mmol) in acetonitrile (10 mL) to yield a white solid (0.06 g, 68%). *m/z* (ES+): 498 $[M–2OTf]^{2+}$. NMR (400 MHz, D_2O) δ_H (ppm) 1.96-2.44 (16H, m, ring $NC\underline{H}_2$), 2.85-3.14 (8H, m, $C\underline{H}_2CO$), 4.40 (8H, t, $C\underline{H}_2NH$), 7.34 (20H, s, Ar). Anal. Calcd (%) for $C_{47}H_{56}F_9N_8O_{13}S_3Y$: C, 43.52; H, 4.35; N, 8.64. Found: C, 43.23; H, 4.76; N, 8.57.

Lutetium (III) 2,2',2'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-benzylacetamide) (LuL^4) This compound was made in a manner identical to YbL^4 with L^4 (0.10 g, 0.13 mmol), $Lu(OTf)_3$ (0.081 g, 0.13 mmol) in acetonitrile (10 mL) to give a white solid (0.097 g 53%). *m/z:* 1233 $[M–OTf]^+$, 542

[M–OTf]$^{2+}$, NMR (400MHz, D_2O) δ_H (ppm) 1.86-2.56 (16H, m, ring NC$\underline{H}_2$), 2.85-3.20 (8H, m, C$\underline{H}_2$CO), 4.41 (8H, s, C$\underline{H}_2$NH), 7.35 (20H, m, Ar).

Ytterbium (III) 2,2',2'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-(4-methoxybenzyl)acetamide) (YbL^5) The was prepared in a manner identical to YbL^4 using L^5 (0.05 g, 0.056 mmol) and Yb(OTf)$_3$ (0.04 g, 0.056 mmol) dissolved in acetonitrile (10 mL). This yielded a white solid (0.06 g, 65%). *m/z:* 458 [M–2OTf+Na]$^{3+}$. NMR (400 MHz, D_2O) δ_H (ppm) 97.82, 18.32, 15.60, 5.83, 4.70, 3.48, 2.05, 1.10, -1.07, -4.46, -26.09, -31.64, -60.58. Anal. Calcd (%) for $C_{51}H_{64}F_9N_8O_{17}S_3Yb$: C, 40.80; H, 4.30; N, 7.46. Found: C, 39.72; H, 4.04; N, 7.72.

Europium (III) 2,2',2'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-(4-methoxybenzyl)acetamide) (EuL^5) The compound was prepared in a manner identical to YbL^4 using L^4 (0.05 g, 0.06 mmol) and Eu(OTf)$_3$ (0.03 g, 0.06 mmol) dissolved in acetonitrile (10 mL) to yield a white solid (0.02 g, 34%). *m/z*: 591[M–2OTf]$^{2+}$. NMR (400 MHz, D_2O) δ(ppm) 26.29, 6.61, 6.10, 3.48, 3.21, 2.75, 2.24, 1.10, 0.33, -2.61, -6.10, -7.88, -12.79, -13.62. Anal. Calcd for $C_{51}H_{64}F_9N_8O_{17}S_3Eu$: C, 41.38; H, 4.36; N, 7.57. Found: C, 41.38; H, 4.13; N, 7.97.

Yttrium (III) 2,2',2'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-(4-methoxybenzyl)acetamide) (YL^5) The compound was prepared in a manner identical to YbL^4 using L^5 (0.05 g, 0.06 mmol) and Y(OTf)$_3$ (0.03 g, 0.06 mmol) in acetonitrile (10 mL) to yield a white solid (0.07 g, 85%). NMR (400 MHz, D_2O) δ_H (ppm) 2.07-2.52 (m, ring, 16H, NC$\underline{H}_2$), 3.01-3.22 8H, C$\underline{H}_2$CO), 4.32 (t, 8H, C$\underline{H}_2$NH), 6.86 (d, J = 1.2, 8H, Ar), 7.30 (d, J = 1.2, 8H, Ar). Anal. Calcd (%) for $C_{51}H_{64}F_9N_8O_{17}S_3Y$: C, 43.22; H, 4.55; N, 7.61. Found: C, 44.47; H, 3.97; N, 8.15.

Ytterbium (III) 2,2'2,'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-(4-nitrobenzyl)acetamide) (YbL^6) The compound was prepared in a manner identical to YbL^4 using L^6 (0.051 g, 0.061 mmol) and Yb(OTf)$_3$ (0.038 g, 0.061 mmol) dissolved in acetonitrile (5 mL) to yield a yellow solid (0.054 g, 61%). *m/z* (ES+): 1412 [M–OTf]$^+$, 631 [M–2OTf]$^{2+}$. NMR (400 MHz, D_2O) δ_H (ppm) 88.45, 16.59, 13.81 (7.01, .031, -3.28), -23.21, -28.37, -52.72. Anal. Calcd (%) for

$C_{47}H_{52}F_9N_{12}O_{21}S_3Yb$: C, 36.25; H, 3.11; N, 10.98. Found: C, 36.18; H, 3.16; N, 10.66.

Europium (III) 2,2'2,'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-(4-nitrobenzyl)acetamide) (EuL^6) This compound was prepared in a manner identical to YbL^4 using L^6 (0.051 g, 0.061 mmol) and Eu(OTf)$_3$ (0.036 g, 0.061 mmol) in acetonitrile (5 mL) to yield a white solid (0.051 g, 59%). *m/z* (ES+): 1391 $[M–OTf]^+$, 621 $[M–2OTf]^{2+}$. NMR (400 MHz, D_2O) δ_H (ppm) 23.95, 7.79, 3.40, 2.86, -3.00, -5.23, -8.43, -10.68, -12.78. Anal. Calcd (%) for $C_{47}H_{52}F_9N_{12}O_{21}S_3Eu$: C, 36.75; H, 3.15; N, 10.94. Found: C, 36.88; H, 3.26; N, 10.84.

Yttrium (III) 2,2'2,'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-(4-nitrobenzyl)acetamide) (YL^6) This compound was prepared in a manner identical to YbL^4 using L^6 (0.045 g, 0.053 mmol) and Y(OTf)$_3$ (0.029 g, 0.053 mmol) dissolved in acetonitrile (5 mL) to yield a white solid (0.048 g, 65%). *m/z* (ES+): 589 $[M–2OTf]^{2+}$. NMR (400 MHz, D_2O) δ_H (ppm) 2.09-2.65 (16H, m, ring NC$\underline{H}_2$), 3.18-3.32 (8H, m, C$\underline{H}_2$CO), 4.47-4.60 (8H, t, C$\underline{H}_2$NH), 7.53 (8H, d, J = 8.6, Ar), 8.14 (8H, d, J = 8.7, Ar) Anal. Calcd (%) for $C_{47}H_{52}F_9N_{12}O_{21}S_3Y$: C, 38.22; H, 3.55; N, 11.36 Found: C, 38.06; H, 3.79; N, 11.28.

Ytterbium 2,2',2'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-(4-fluorobenzyl)acetamide) (YbL^7) This compound was prepared in a manner identical to YbL^4 using L^7 (0.051 g, 0.061 mmol) and Yb(OTf)$_3$ (0.038 g, 0.061 mmol) dissolved in acetonitrile (5 mL) to yield a white solid (0.054 g, 61%). NMR (400 MHz, D_2O) δ_H (ppm) 95.0, 17.6, 14.7, 4.6, 3.7, -0.2, -4.2, -25.5, -31.0, -59.1. NMR (376 MHz, DMSO-d_6) δ_F $\{^1H\}$ (ppm) -118.6. *m/z* (ES+): 577.7 $[M–2OTf]^{2+}$. HR-ESMS found *m/z* 1302.24866, calculated *m/z* 1302.24464 for $[C_{46}H_{52}O_{10}N_8F_{10}S_2Yb]^+$. Anal. Calcd (%) for $C_{47}H_{52}YbF_{13}N_8O_{13}S_3$: C, 38.85; H, 3.61; N, 7.71. Found: C, 38.66; H, 3.52; N, 7.62.

Europium (III) 2,2',2'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-(4-fluorobenzyl)acetamide) (EuL^7) This compound was prepared in a manner identical to YbL^4 using L^7 (0.051 g, 0.061 mmol) and Eu(OTf)$_3$ (0.036 g, 0.061 mmol) dissolved in acetonitrile (5 mL) to yield a white solid (0.051 g, 59%).

NMR (400 MHz, D_2O) δ_H (ppm) 25.9, 6.7, 6.3, 3.7, 3.1, 2.5, -2.6, -6.0, -8.0, -12.5, -13.4. NMR (376 MHz, DMSO-d_6) δ_F $\{^1H\}$ (ppm) -115.9. *m/z* (ES+): 567.3 for $[M–2OTf]^{2+}$. HR-ESMS found *m/z* 328.44150, calculated *m/z* 328.44145 for $[C_{44}H_{52}O_4N_8EuF_4]^{3+}$. Anal. Calcd (%) for $C_{47}H_{52}EuF_{13}N_8O_{13}S_3$: C, 39.42; H, 3.66; N, 7.82. Found: C, 39.54; H, 3.54; N, 7.75.

Yttrium (III) 2,2',2'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetrakis(*N*-(4-fluorobenzyl)acetamide) (YL^7) This compound was prepared in a manner identical to YbL^4 using L^7 (0.045 g, 0.053 mmol) and $Y(OTf)_3$ (0.029 g, 0.053 mmol) dissolved in acetonitrile (5 mL) to yield a white solid (0.048 g, 65 %). ^1H NMR (400 MHz, D_2O) δ_H 7.40 - 7.37 (m, 8H, Ar), 7.10 (t, *J* = 8.7, 8H, Ar), 4.48 - 4.39 (m, 8H, ArC$\underline{H}_2$), 3.25 (t, *J* = 14.3, 4H, ring NC$\underline{H}_2$), 3.08 (d, *J* = 16.5, 4H, NC$\underline{H}_2$CO), 2.57 (d, *J* = 14.3, 4H, ring NC$\underline{H}_2$), 2.33 - 2.23 (m, 8H, ring NC$\underline{H}_2$ and NC$\underline{H}_2$CO), 2.03 (t, *J* = 14.3, 4H, ring NC$\underline{H}_2$) NMR (376 MHz, DMSO-d_6) δ_F $\{^1H\}$ (ppm) -114.9. *m/z* (ES+): 535.1 $[M–2OTf]^{2+}$. HR-ESMS found *m/z* 307.10287, calculated *m/z* 307.10299 for $[C_{44}H_{52}O_4N_8F_4Y]^{3+}$. Anal. Calcd (%) for $C_{47}H_{52}YF_{13}N_8O_{13}S_3$: C, 41.23; H, 3.83; N, 8.18. Found: C, 41.06; H, 3.71; N, 8.66.

2 NMR Studies

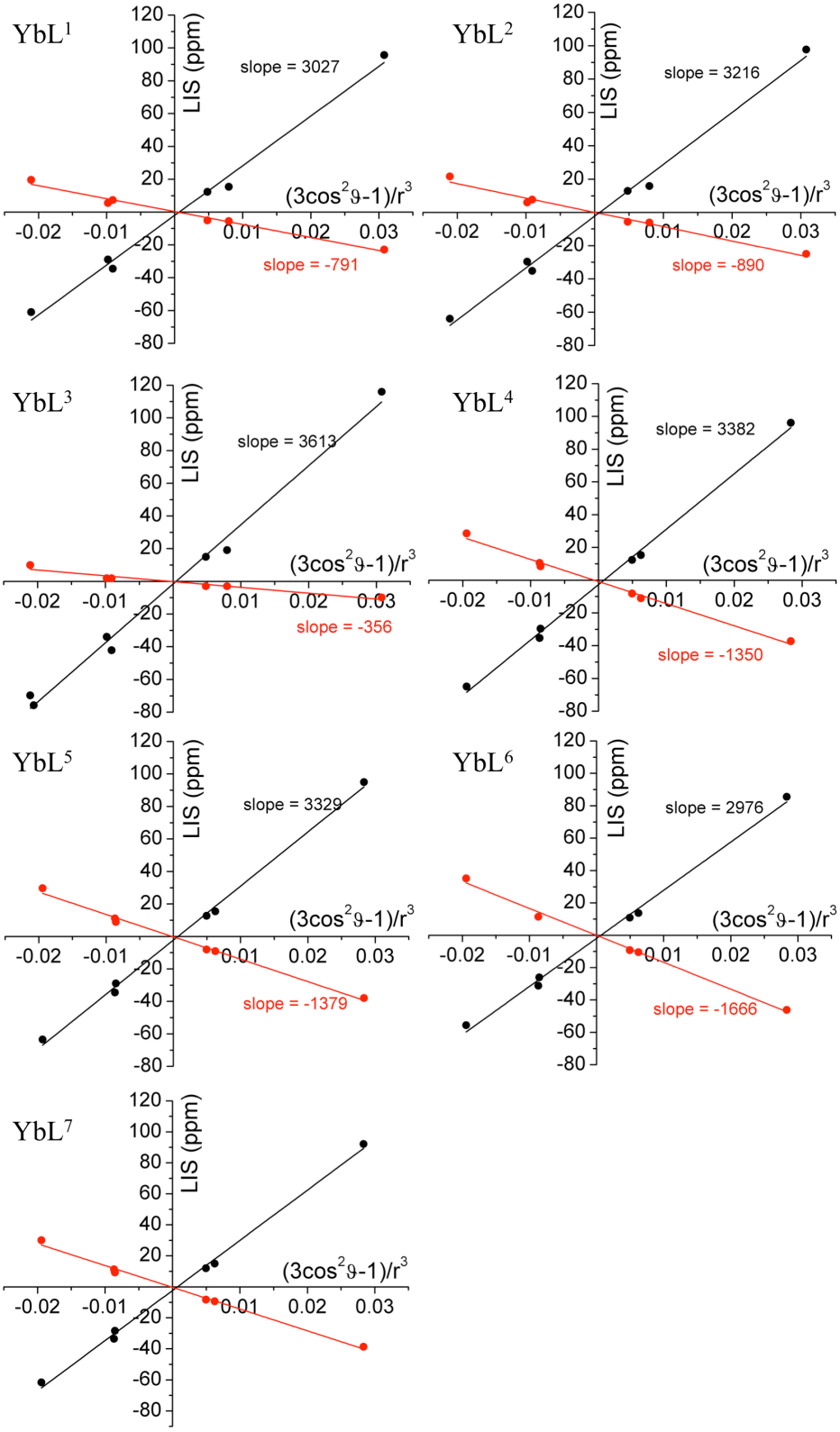
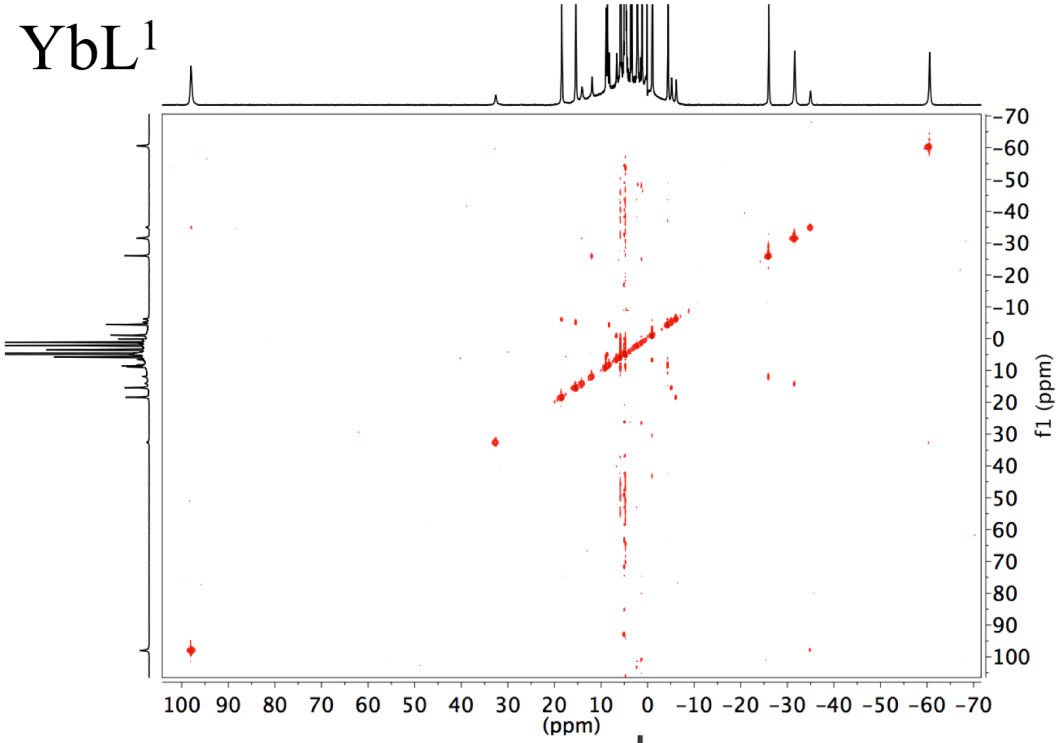


Figure S1. Bleaney plots and associated gradients for YbL^{1-7}-OH_2 (black) and YbL^{1-7}-F (red) in D_2O using crystal structures from references 6 (YbL^{1-3}) and 10 (YbL^{4-7}).

Table S1. Values of $\chi_{\parallel}$ and $\chi_{\perp}$ calculated from the slopes of the Bleaney plots in Figure S1,[11] using an estimate of $\chi_{av}T$ as 2.50 $cm^3mol^{-1}K$ to determine χ_{av}.

	Water bound		**Fluoride bound**	
	$\chi_{\parallel}$ / cm^3mol^{-1}	$\chi_{\perp}$/ cm^3mol^{-1}	$\chi_{\parallel}$/ cm^3mol^{-1}	$\chi_{\perp}$/ cm^3mol^{-1}
YbL^1	0.01203	0.00657	0.00744	0.00887
YbL^2	0.01226	0.00645	0.00732	0.00893
YbL^3	0.01274	0.00621	0.00796	0.00860
YbL^4	0.01246	0.00635	0.00676	0.00920
YbL^5	0.01240	0.00638	0.00673	0.00922
YbL^6	0.01197	0.00660	0.00638	0.00939
YbL^7	0.01228	0.00644	0.00670	0.00923

YbL^1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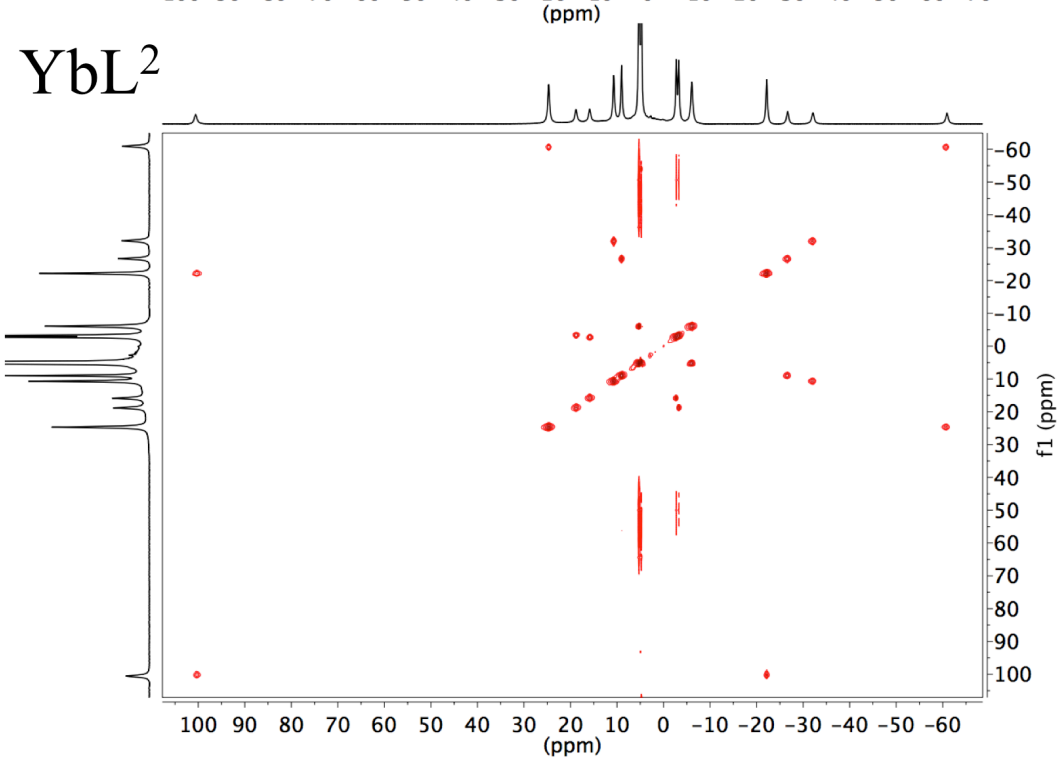
(ppm)

YbL^2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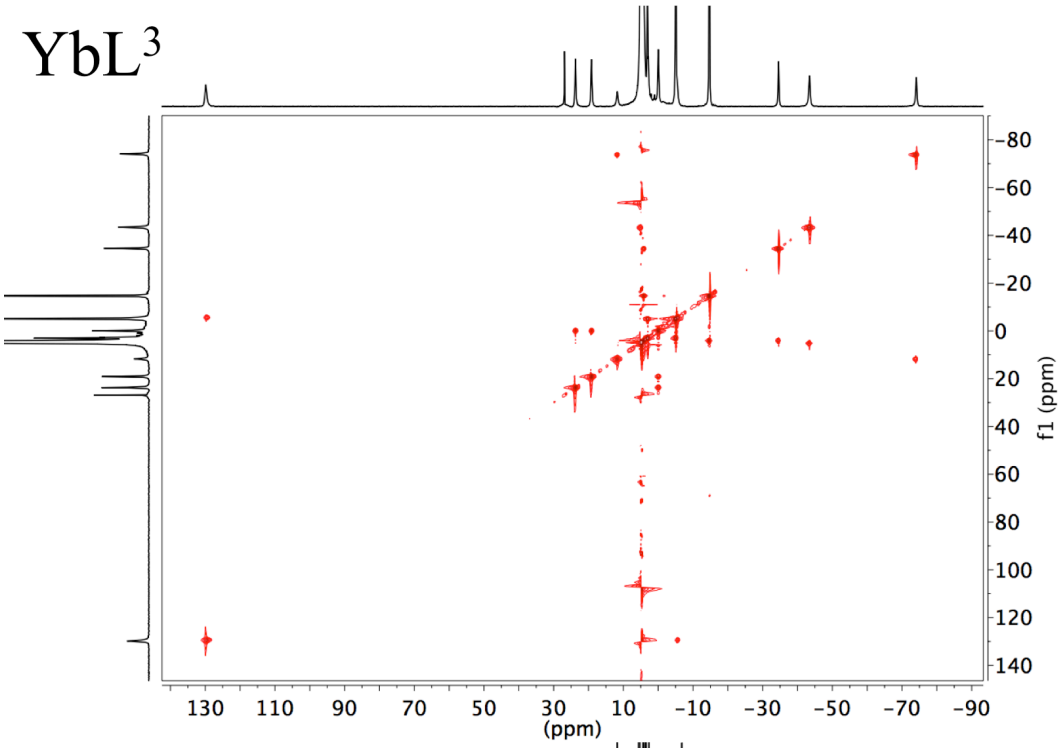
(ppm)

YbL^3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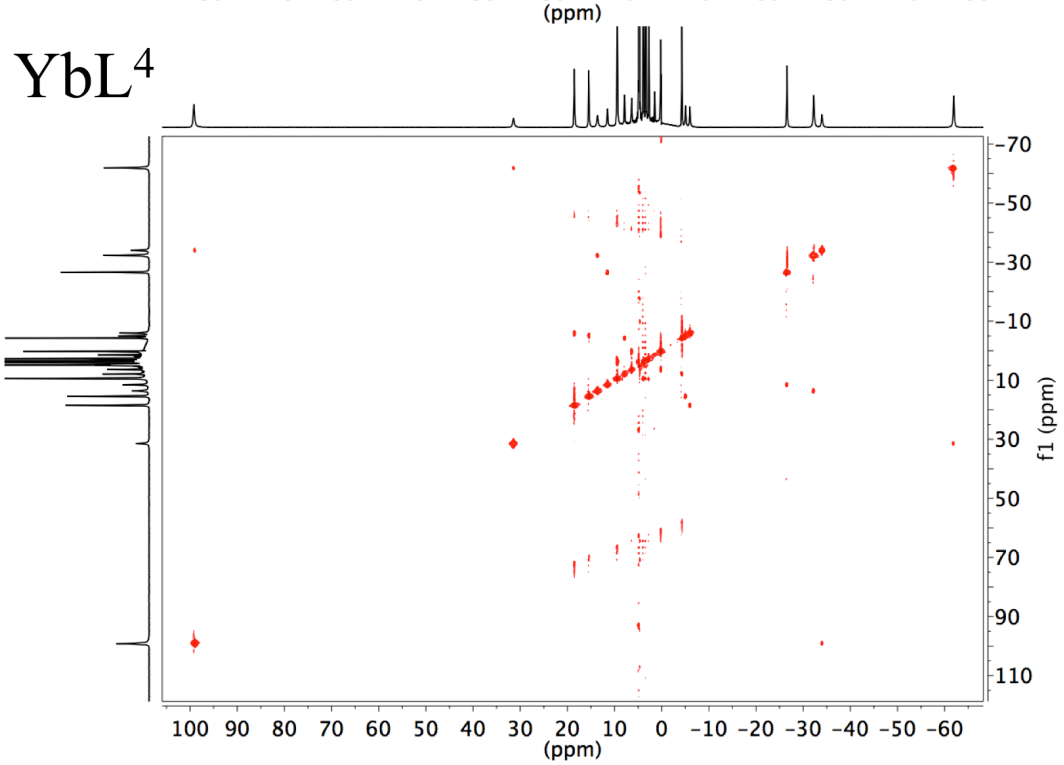
(ppm)

YbL^4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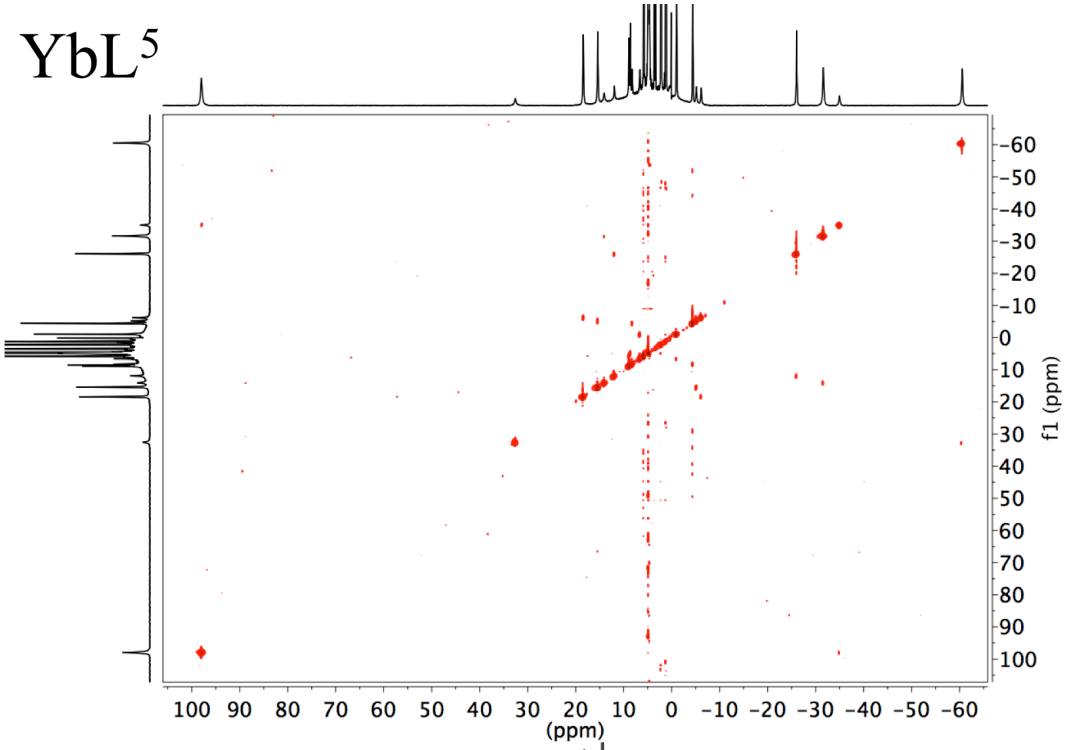
(ppm)

YbL^5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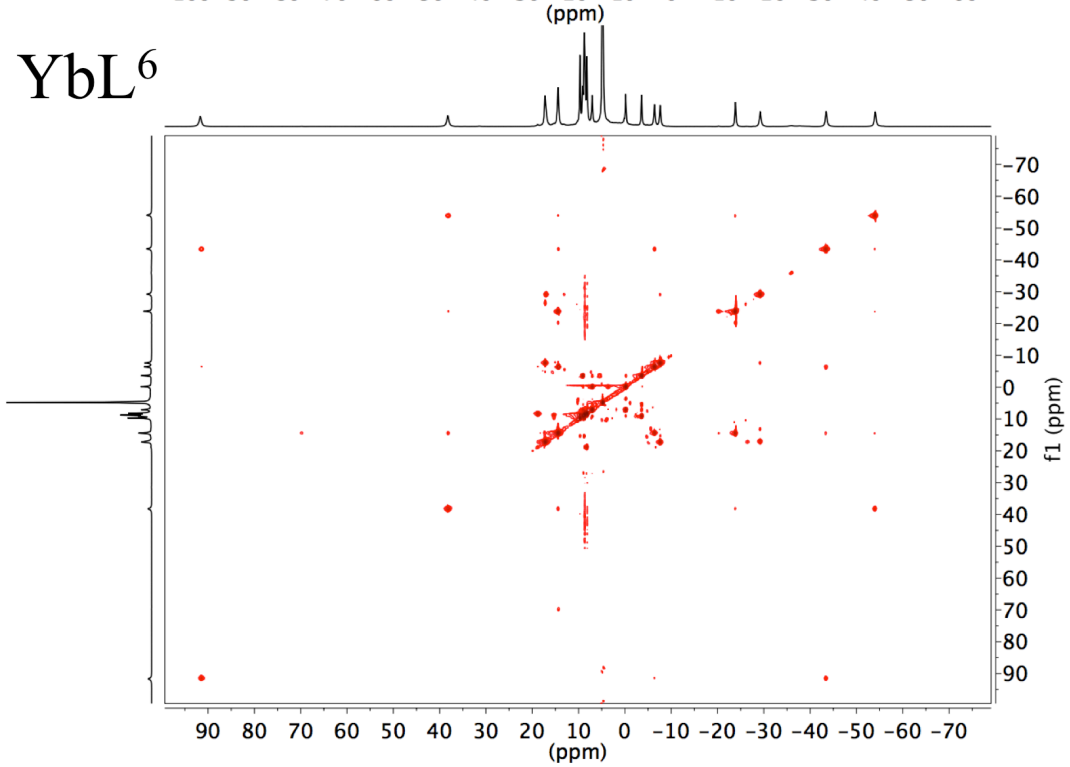
f1 (ppm)

YbL^6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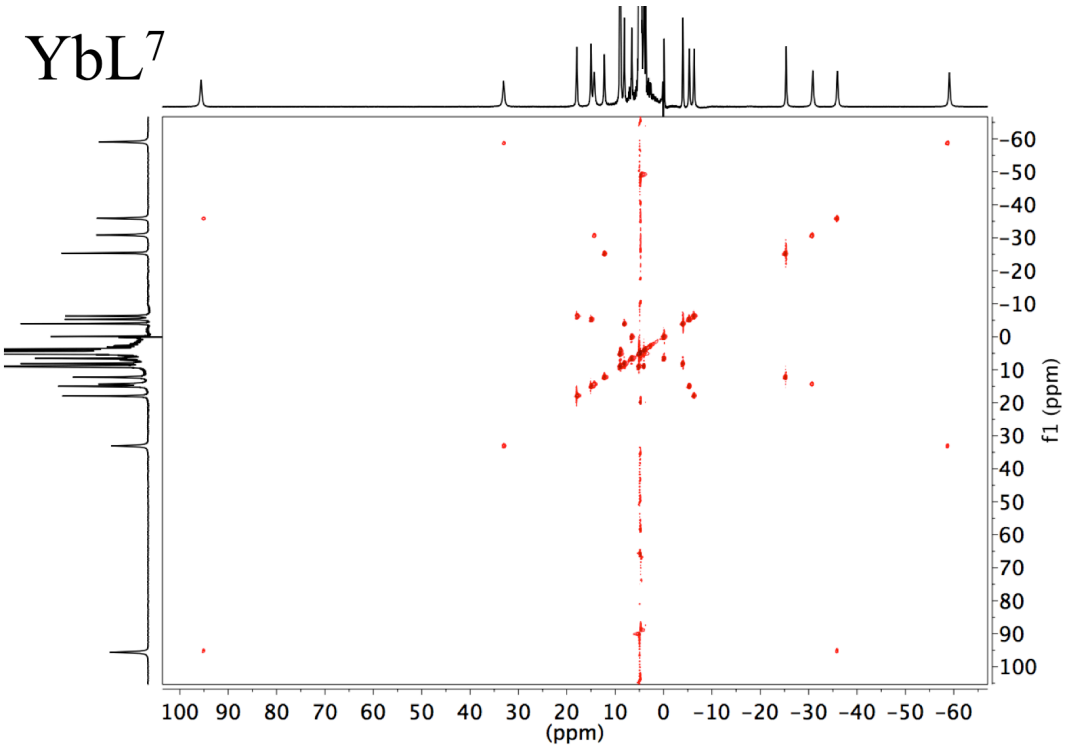

Figure S2. ^{1}H EXSY spectra (500 MHz, D_2O, 298 K) of complexes YbL^{1-7} with added fluoride showing the exchange between hydrated and fluoride-bound species.

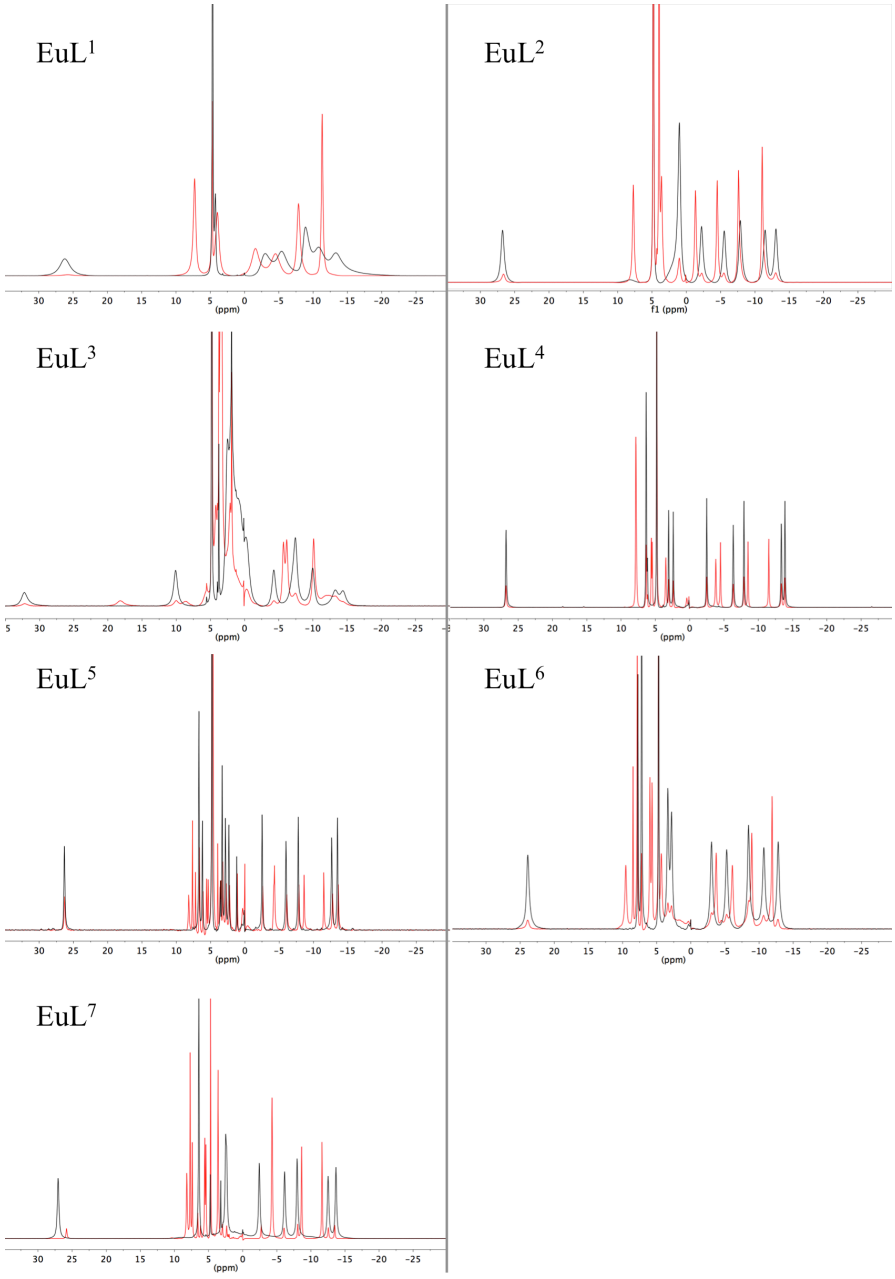

Figure S3. ^{1}H NMR spectra (D_2O, 298 K) of complexes EuL^{1-7} in the absence (black) and presence (red) of an excess of sodium fluoride.

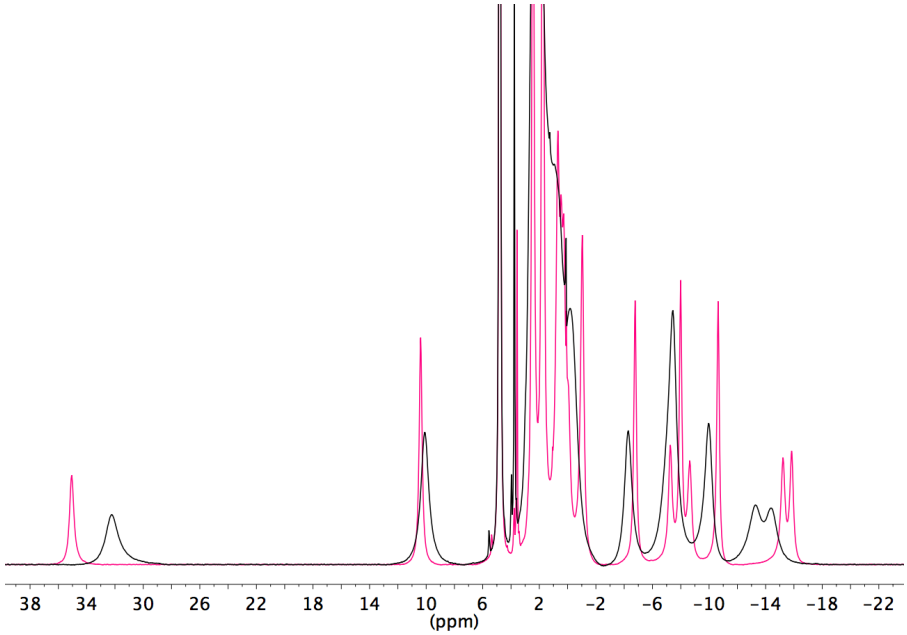

Figure S4. ^{1}H NMR spectra (500 MHz, D_2O, 298 K) of EuL^3 at 298 K (black) and 278 K (pink).

3 Titration data

3.1 Luminescence titrations

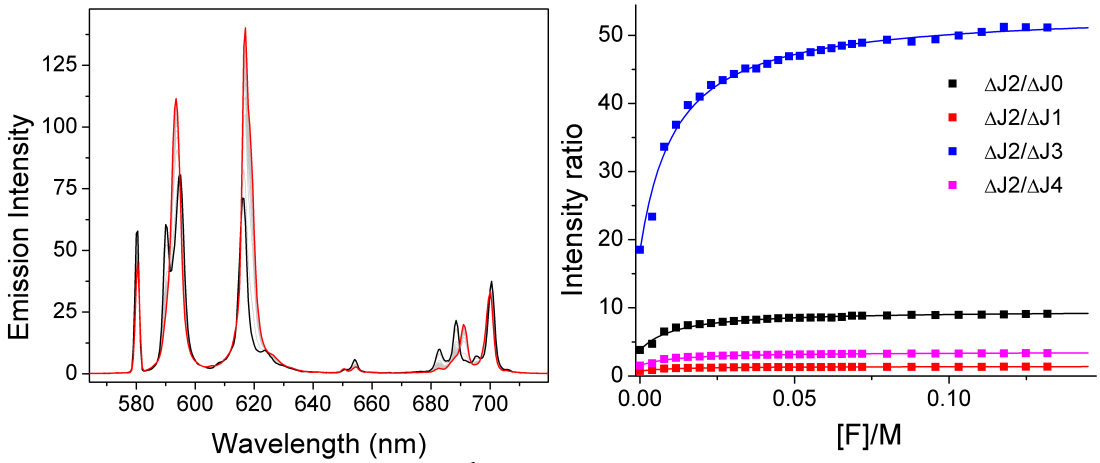

Figure S5. Left: Changes to the EuL^1 emission spectrum on addition of sodium fluoride start of titration (black), end of titration (red), intermediate concentrations (grey). Right: Binding isotherms and fits using the intensity ratios $\Delta J = 2/\Delta J = 0$, $\Delta J = 2/\Delta J = 1$, $\Delta J = 2/\Delta J = 3$ and $\Delta J = 2/\Delta J = 4$.

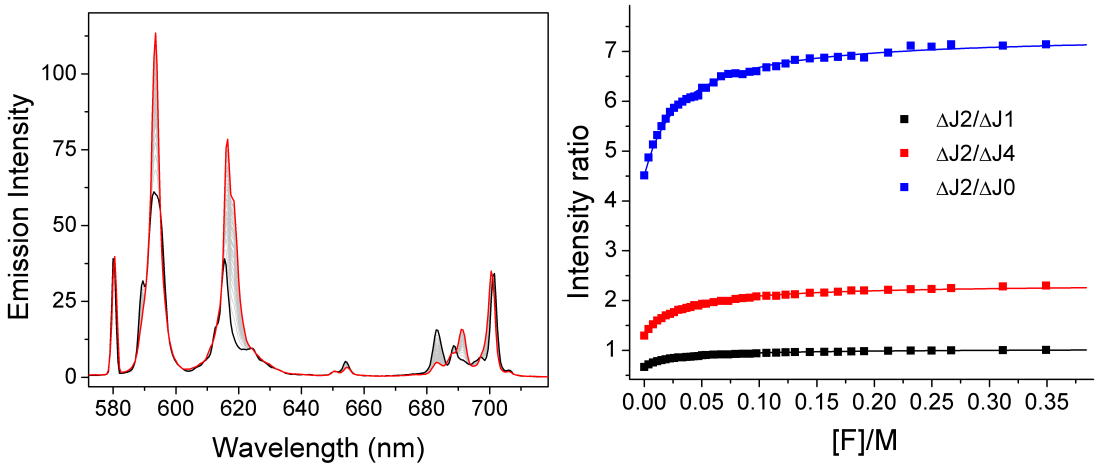

Figure S6. Left: Changes to the EuL[3] emission spectrum on addition of sodium fluoride start of titration (black), end of titration (red), intermediate concentrations (grey). Right: Binding isotherms and fits using the intensity ratios.

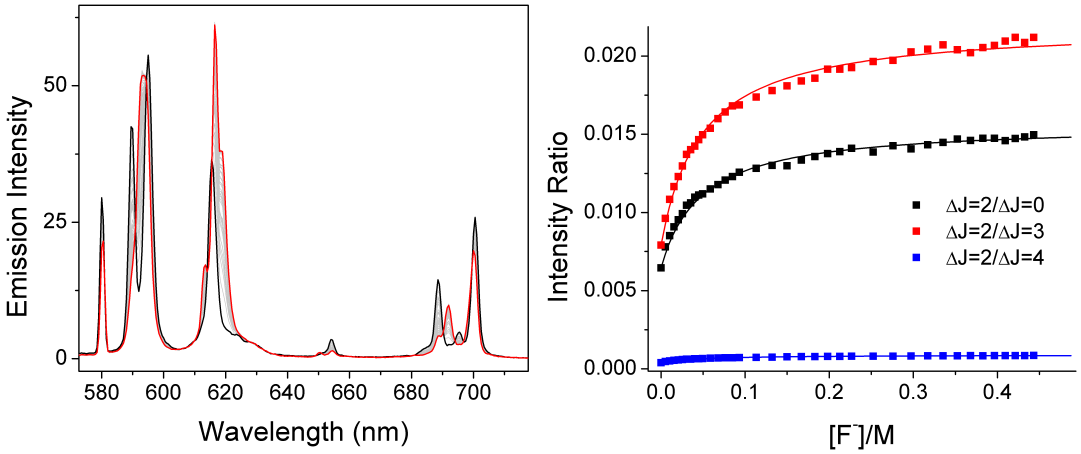

Figure S7. Left: Changes to the EuL[4] emission spectrum on addition of sodium fluoride start of titration (black), end of titration (red), intermediate concentrations (grey). Right: Binding isotherms and fits using Binding isotherms and fits using the intensity ratios.

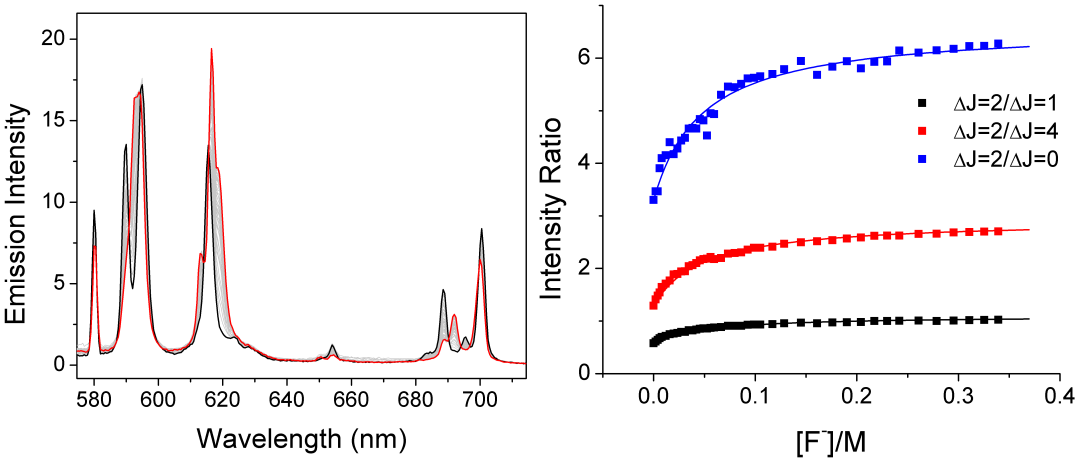

Figure S8. Left: Changes to the EuL[5] emission spectrum on addition of sodium fluoride start of titration (black), end of titration (red), intermediate concentrations

(grey). Right: Binding isotherms and fits using Binding isotherms and fits using the intensity ratios.

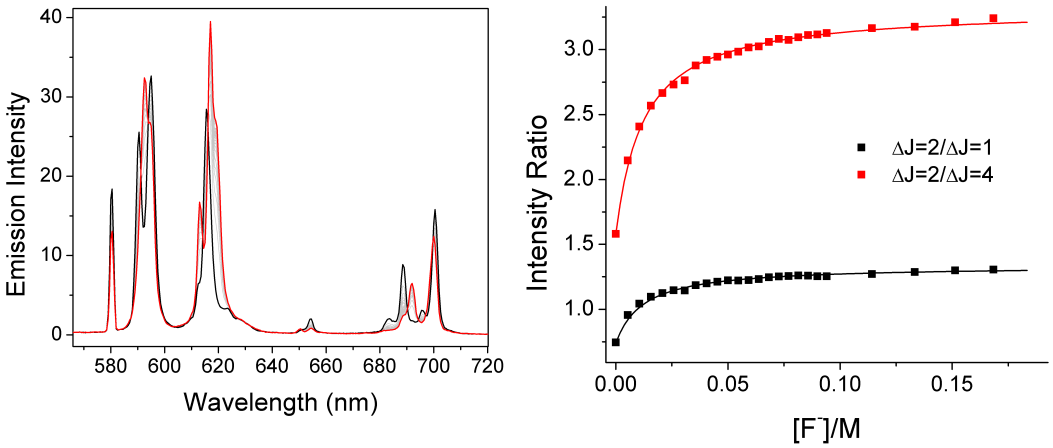

Figure S9. Left: Changes to the EuL[6] emission spectrum on addition of sodium fluoride start of titration (black), end of titration (red), intermediate concentrations (grey). Right: Binding isotherms and fits using Binding isotherms and fits using the intensity ratios.

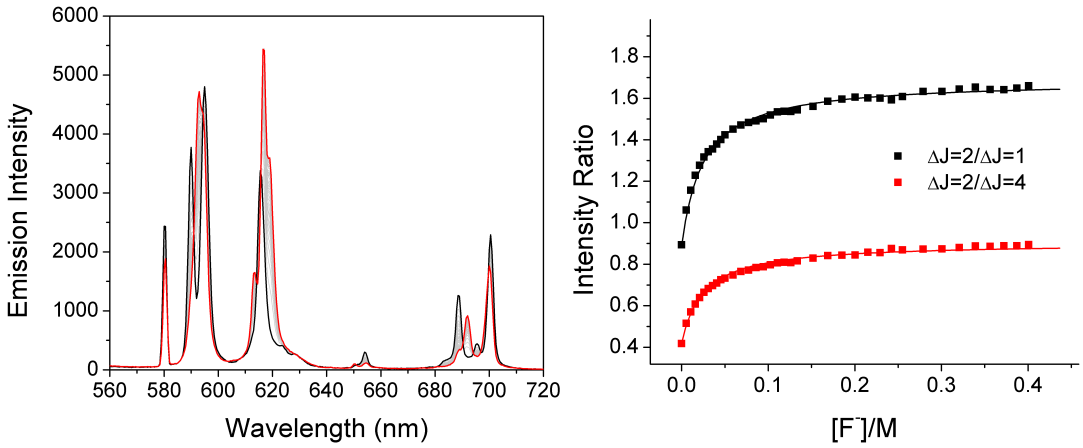

Figure S10. Left: Changes to the EuL[7] emission spectrum on addition of sodium fluoride start of titration (black), end of titration (red), intermediate concentrations (grey). Right: Binding isotherms and fits using the Binding isotherms and fits using the intensity ratios.

3.2 NMR titrations

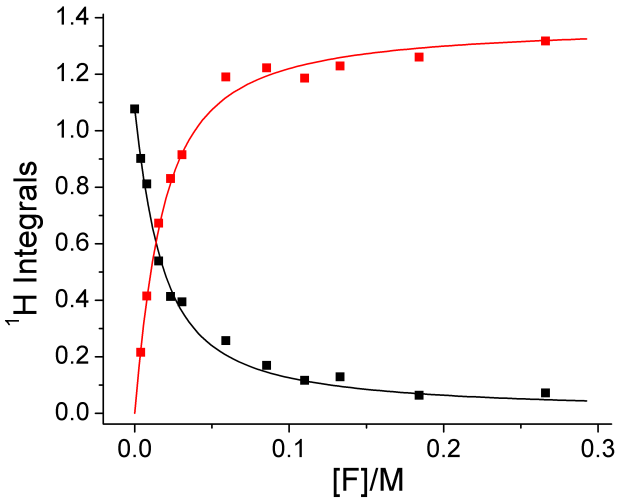

Figure S11. Binding isotherms and fits for titration of EuL[1] with NaF monitoring ^{1}H NMR integrals relative to DSS at 298 K.

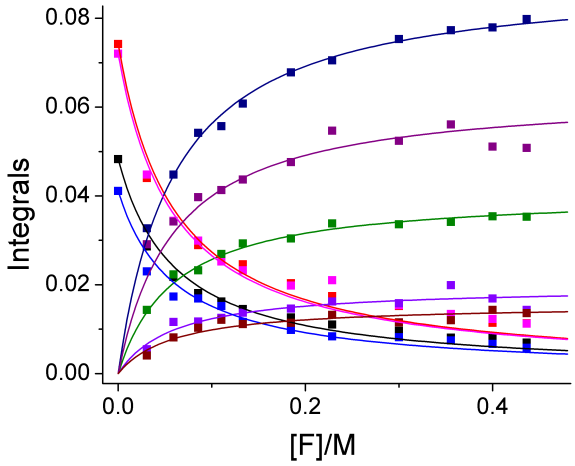

Figure S12. Binding isotherms and fits for titration of EuL[3] with NaF monitoring ^{1}H NMR integrals relative to DMF and ^{19}F NMR integrals relative to OTf at 278 K.

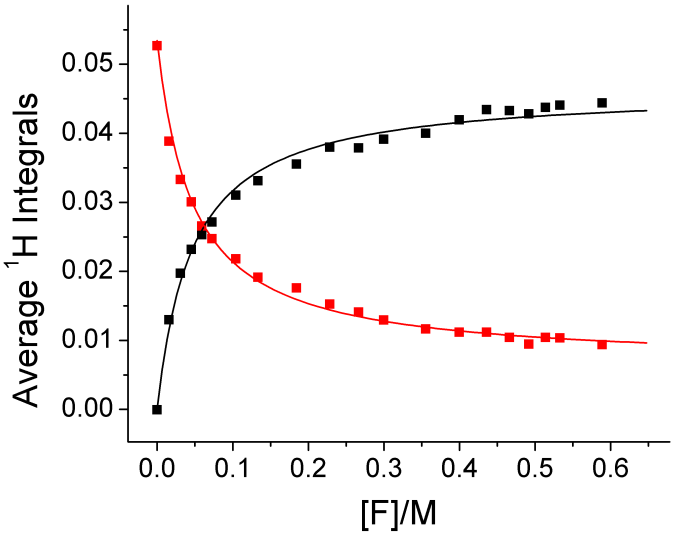

Figure S13. Binding isotherms and fits for titration of EuL^4 with NaF monitoring ^{1}H NMR integrals relative to DSS at 298 K.

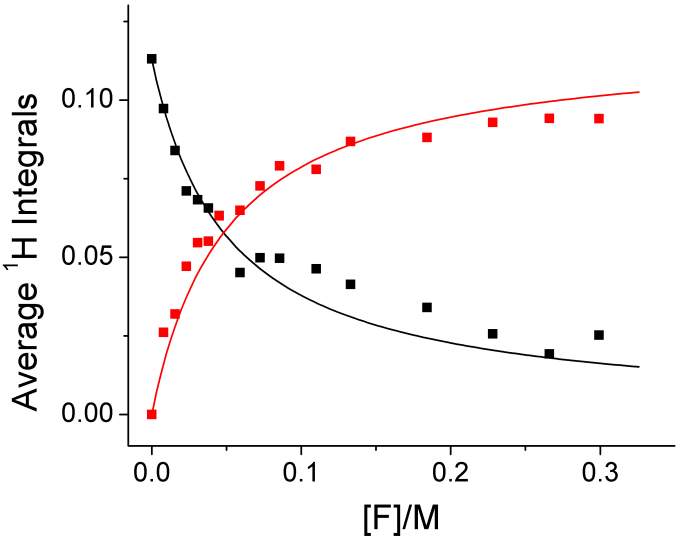

Figure S14. Binding isotherms and fits for titration of EuL^5 with NaF monitoring ^{1}H NMR integrals relative to DSS at 298 K.

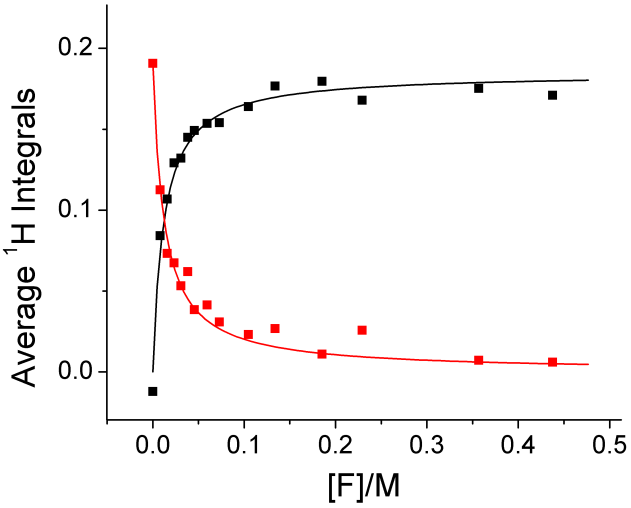

Figure S15. Binding isotherms and fits for titration of EuL[6] with NaF monitoring ^{1}H NMR integrals relative to DSS at 298 K.

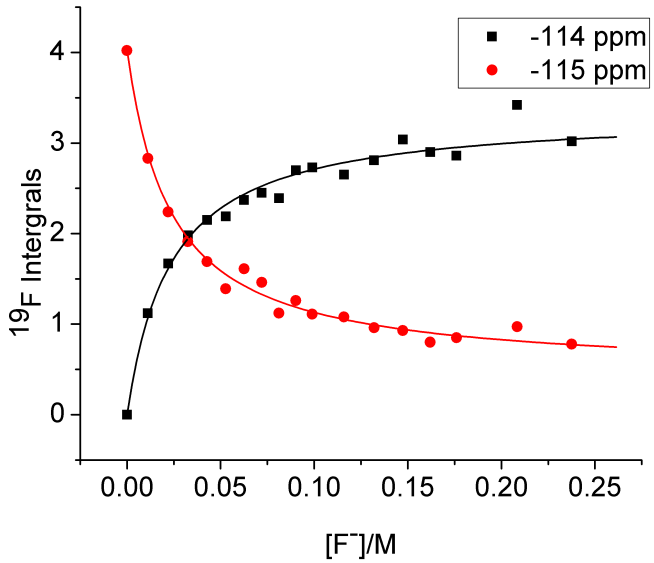

Figure S16. Binding isotherms and fits for titration of EuL[7] with NaF monitoring ^{19}F NMR integrals of the ligand fluorines relative to OTf at 298 K.

4 lnK vs. D_1

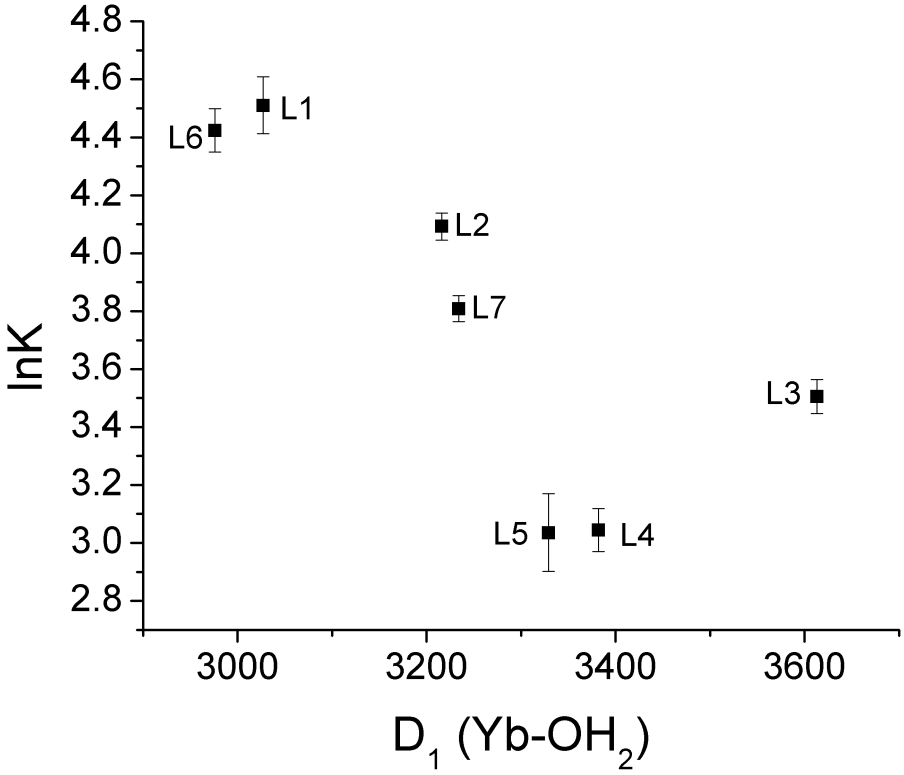

Figure S17. Correlation between lnK (measured by luminescence) of the Eu complexes of L^{1-7} and D_1 values for the Yb complexes from ^{1}H Bleaney plots.

5 Rates of Exchange

5.1 LuL^x ^{1}H NMR spectra

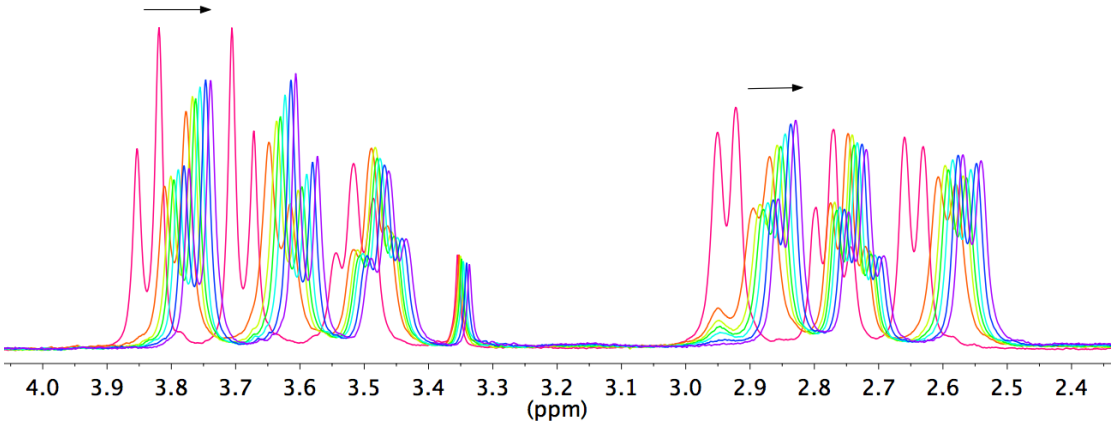

Figure S18. ^{1}H NMR spectra (D_2O, 298 K) of LuL^1 upon addition of increasing amounts of sodium fluoride.

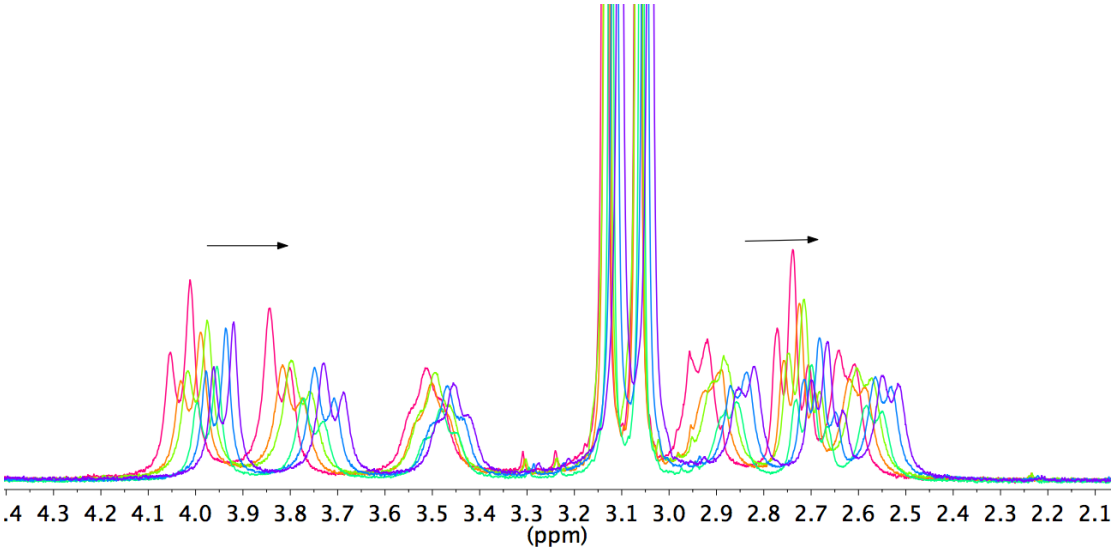

Figure S19. ^{1}H NMR spectra (D_2O, 298 K) of LuL^3 upon addition of increasing amounts of sodium fluoride.

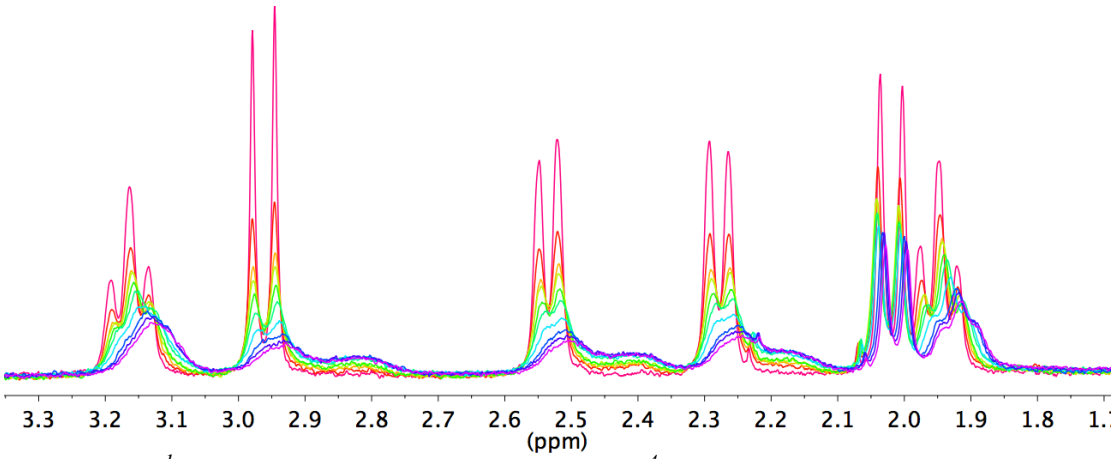

Figure S20. ^{1}H NMR spectra (D_2O, 298 K) of LuL^4 upon addition of increasing amounts of sodium fluoride.

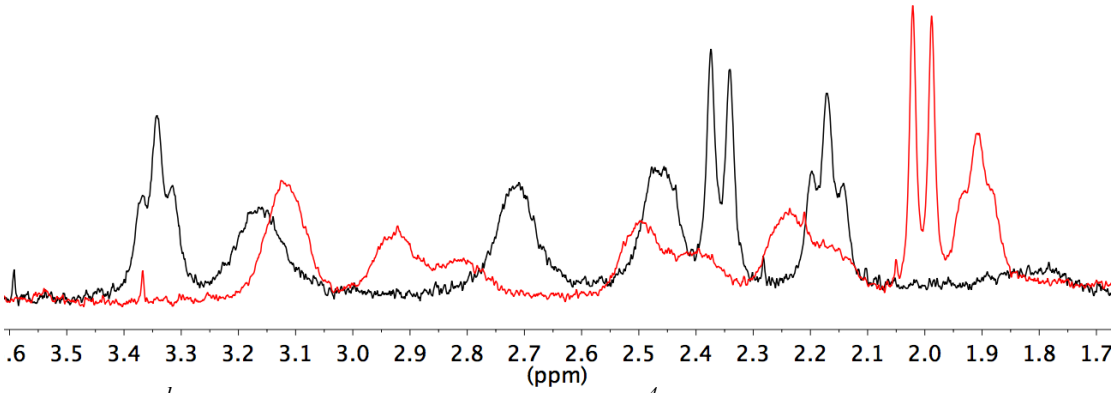

Figure S21. ^{1}H NMR spectra (D_2O, 298 K) of LuL^4 (bottom) with added sodium fluoride at 298 K (red) and 323 K (black).

5.2 $^{1}H/^{19}F$ Inversion recovery data

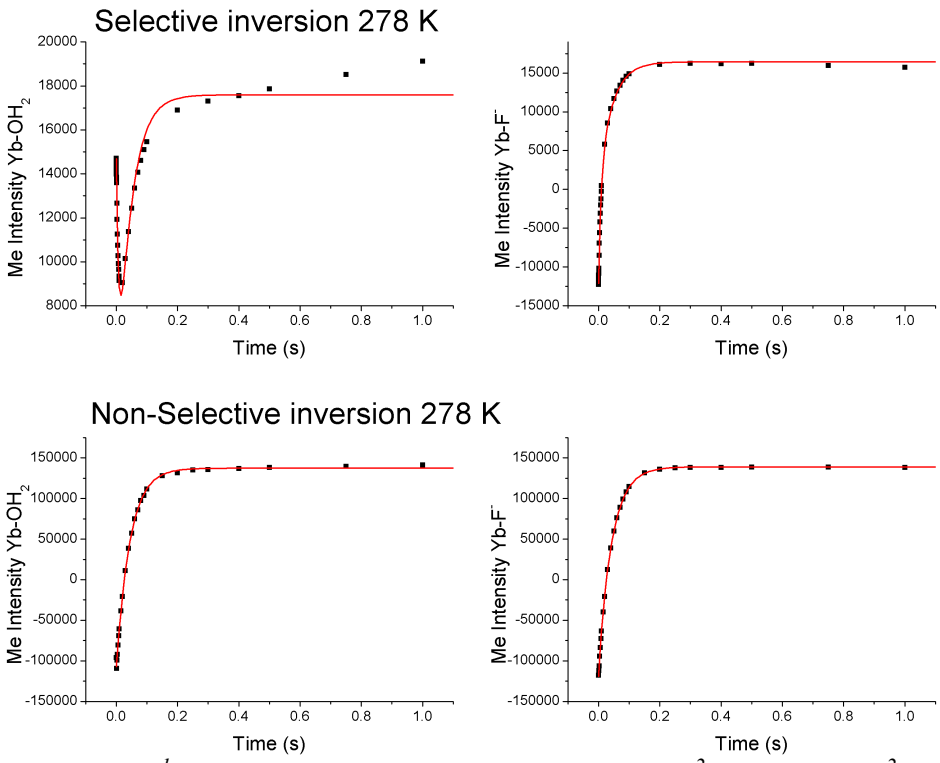

Figure S22. ^{1}H intensities of the methyl groups of YbL^{2}-OH_2 and YbL^{2}-F^- following selective inversion (top) and non-selective inversion (bottom) at 278 K, fits are shown in red.

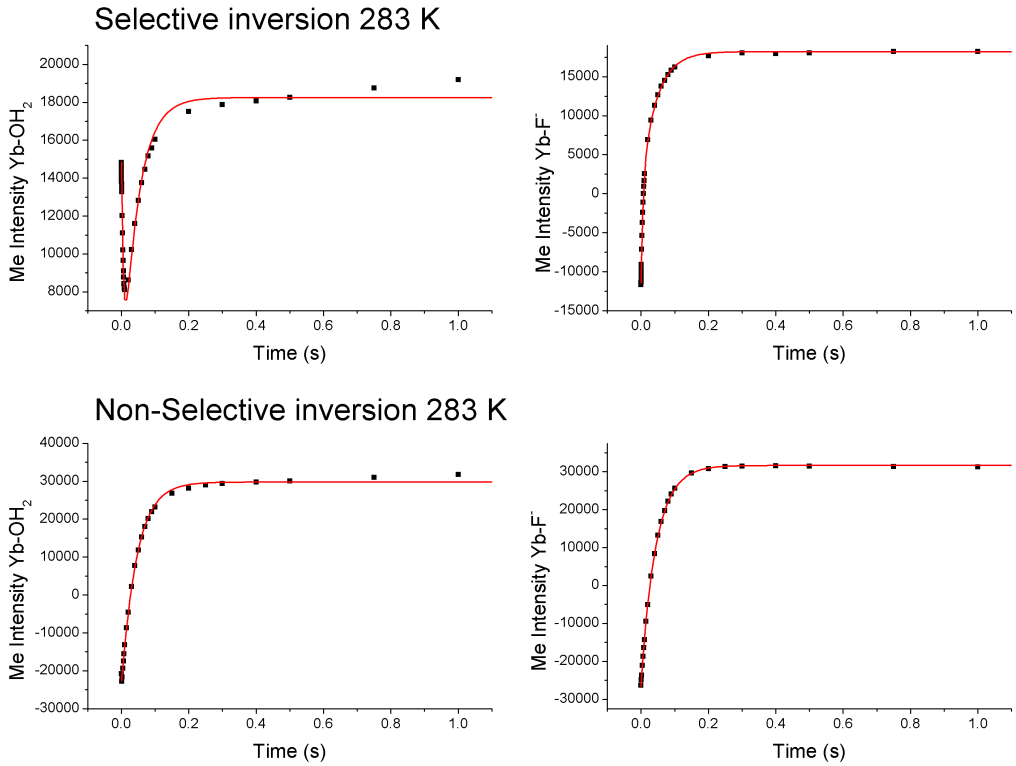

Figure S23. ^{1}H intensities of the methyl groups of YbL^{2}-OH_2 and YbL^{2}-F^- following selective inversion (top) and non-selective inversion (bottom) at 283 K, fits are shown in red.

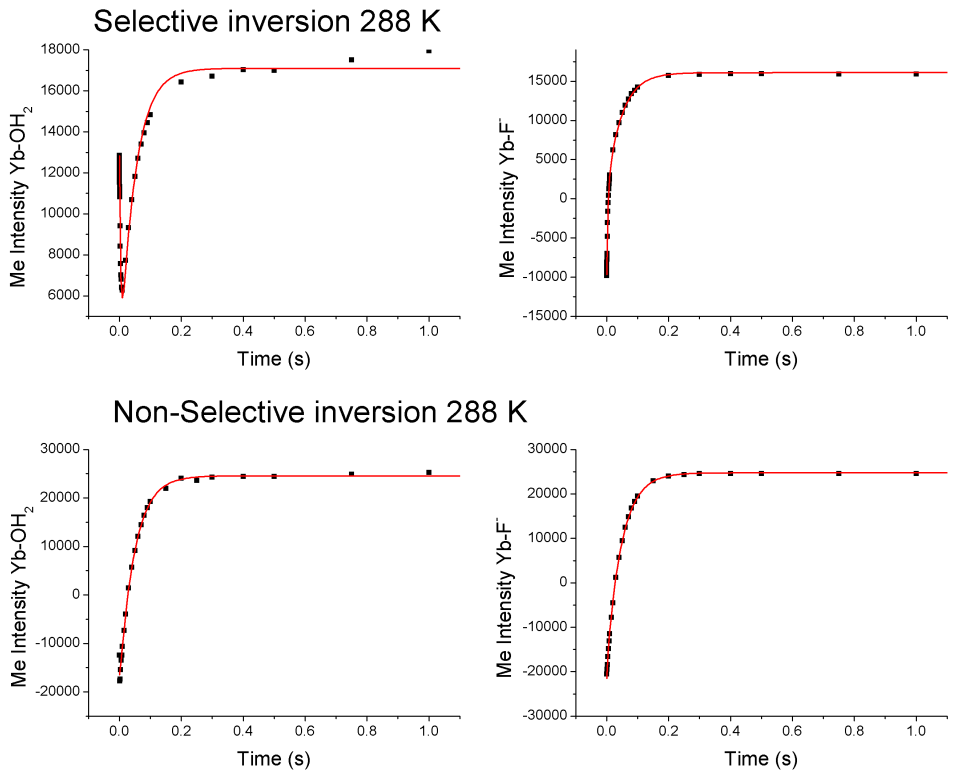

Figure S24. ^{1}H intensities of the methyl groups of YbL^{2}-OH_2 and YbL^{2}-F^- following selective inversion (top) and non-selective inversion (bottom) at 288 K, fits are shown in red.

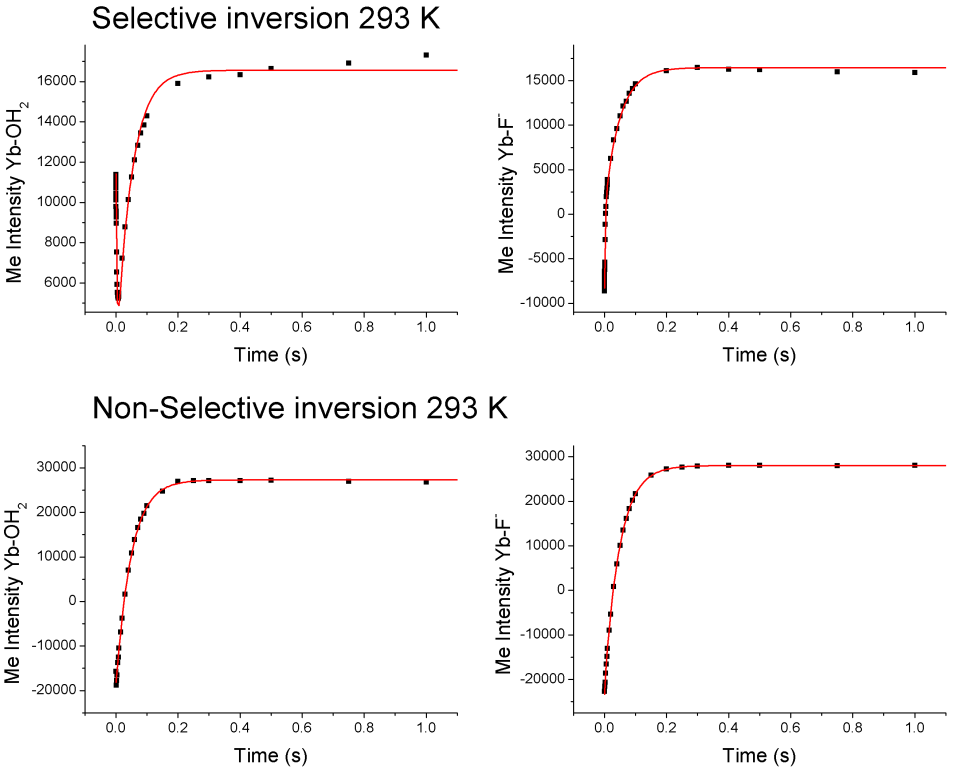

Figure S25. ^{1}H intensities of the methyl groups of YbL^{2}-OH_2 and YbL^{2}-F^- following selective inversion (top) and non-selective inversion (bottom) at 293 K, fits are shown in red.

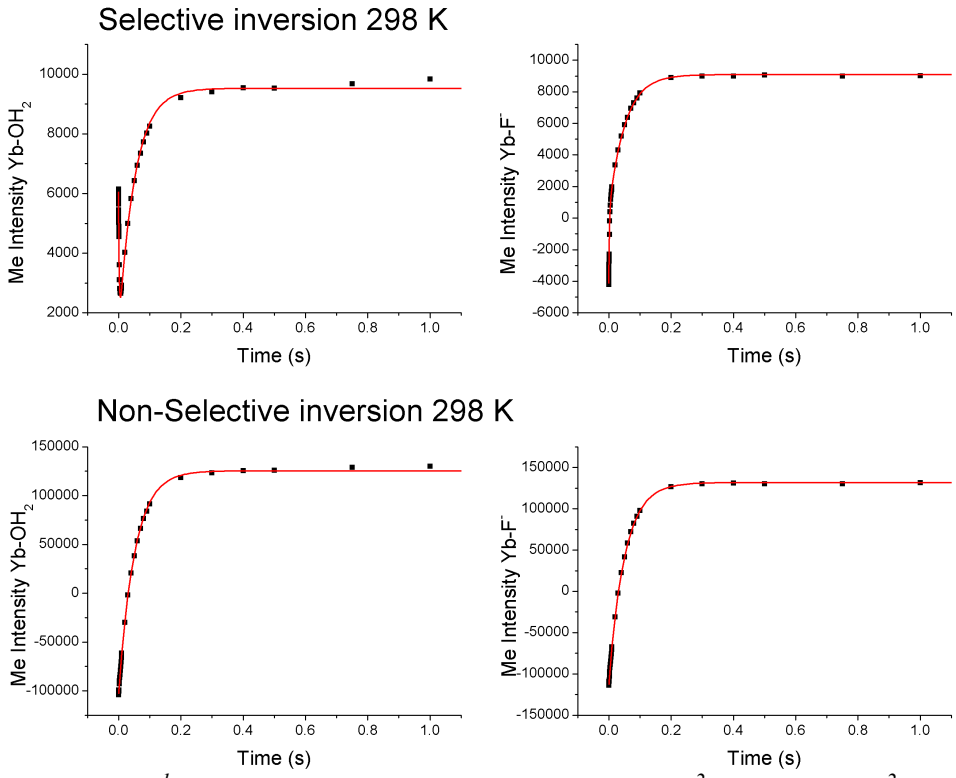

Figure S26. ^{1}H intensities of the methyl groups of YbL^{2}-OH_2 and YbL^{2}-F^- following selective inversion (top) and non-selective inversion (bottom) at 298 K, fits are shown in red.

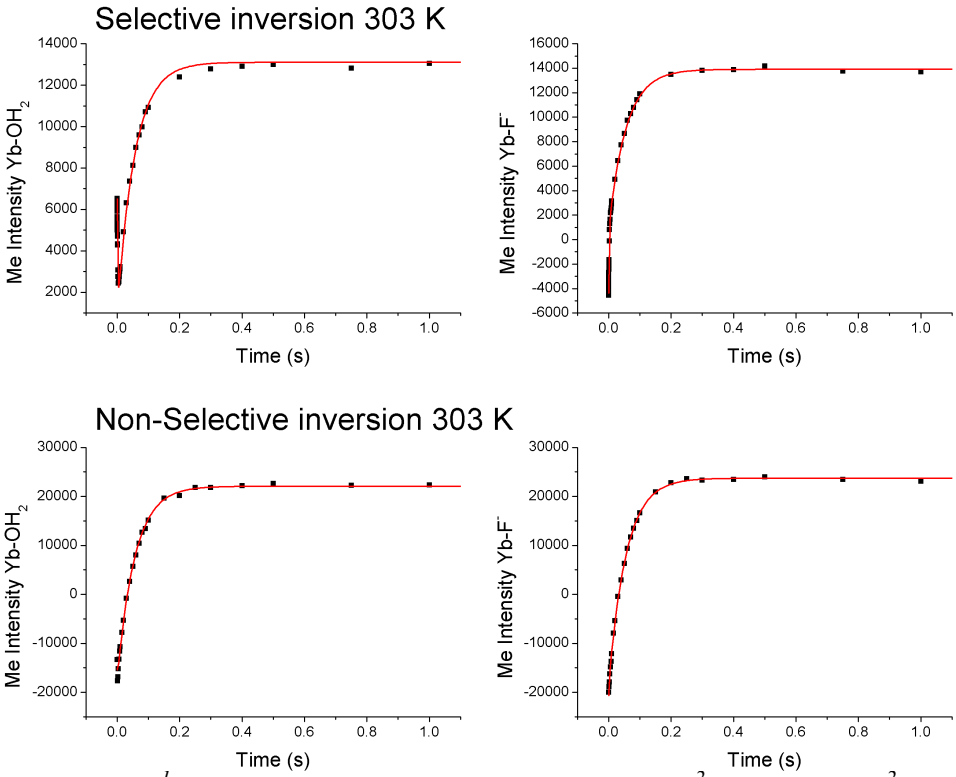

Figure S27. ^{1}H intensities of the methyl groups of YbL^{2}-OH_2 and YbL^{2}-F^- following selective inversion (top) and non-selective inversion (bottom) at 303 K, fits are shown in red.

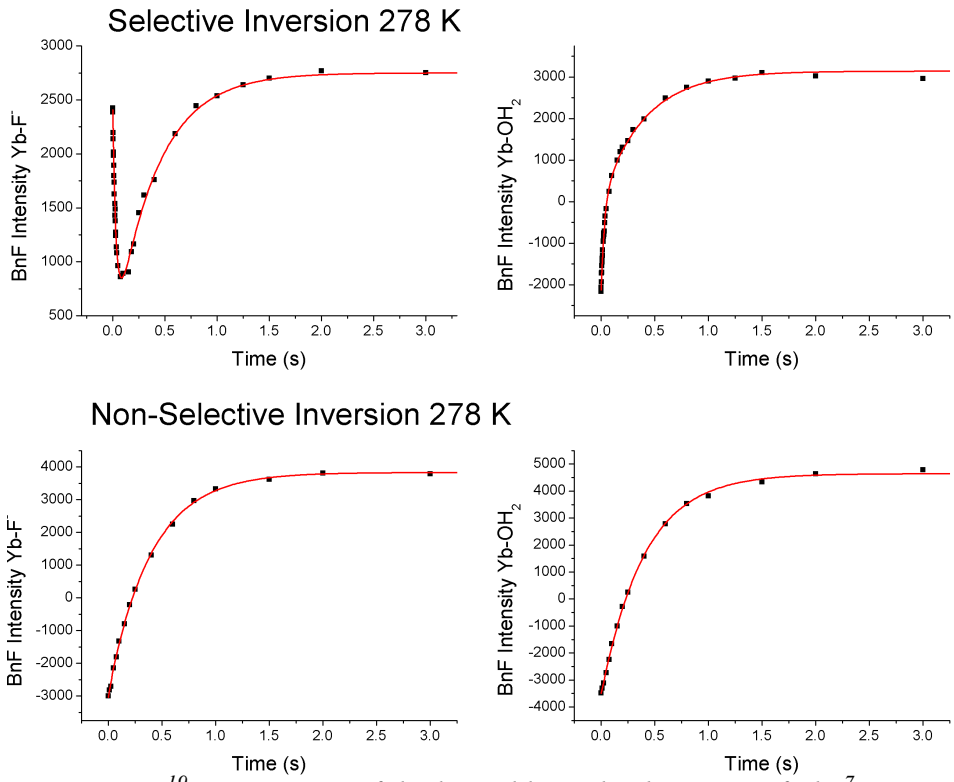

Figure S28. ^{19}F intensities of the ligand benzyl substituent of YbL^7-OH_2 and YbL^7-F^- following selective inversion (top) and non-selective inversion (bottom) at 278 K, fits are shown in red.

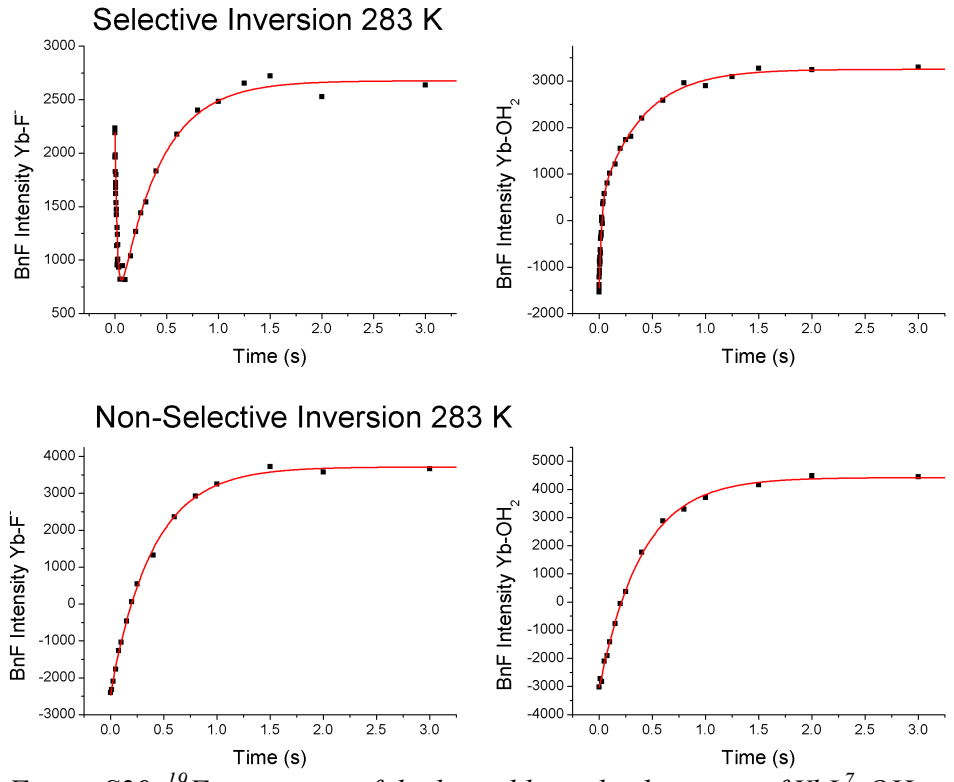

Figure S29. ^{19}F intensities of the ligand benzyl substituent of YbL^7-OH_2 and YbL^7-F^- following selective inversion (top) and non-selective inversion (bottom) at 283 K, fits are shown in red.

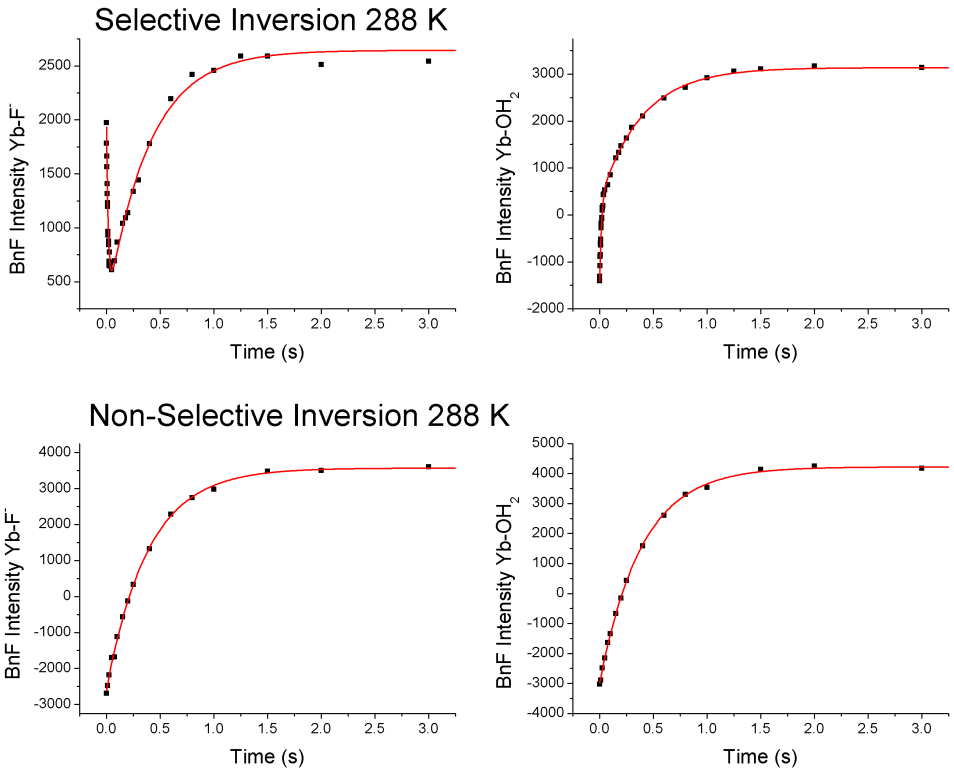

Figure S30. ^{19}F intensities of the ligand benzyl substituent of YbL^7-OH_2 and YbL^7-F^- following selective inversion (top) and non-selective inversion (bottom) at 288 K, fits are shown in red.

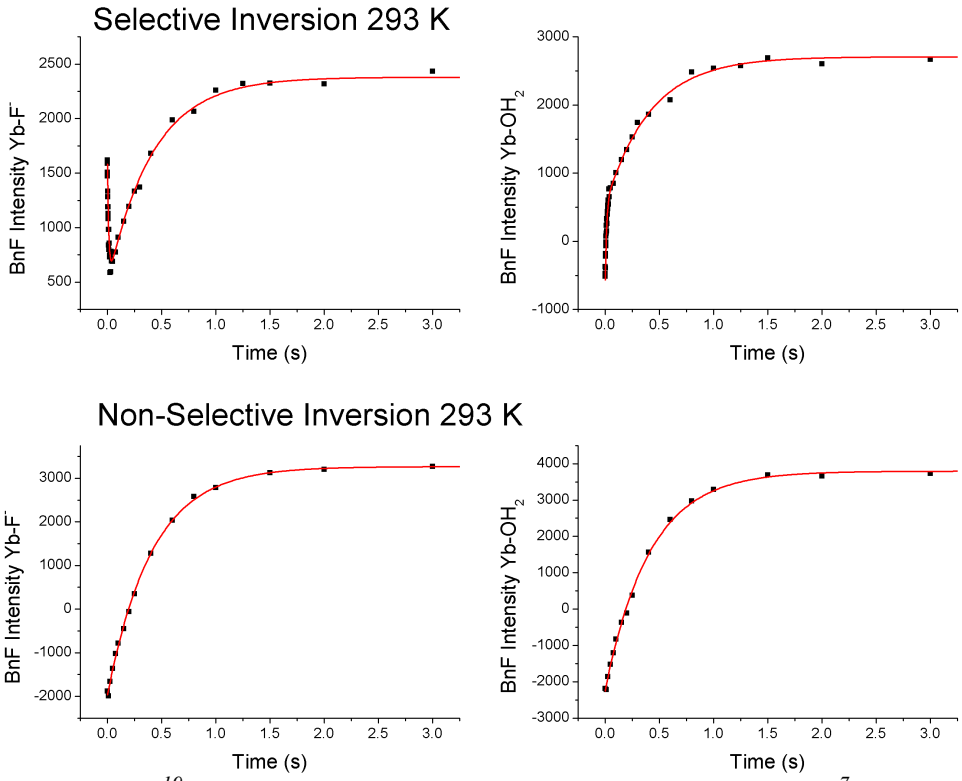

Figure S31. ^{19}F intensities of the ligand benzyl substituent of YbL^7-OH_2 and YbL^7-F^- following selective inversion (top) and non-selective inversion (bottom) at 293 K, fits are shown in red.

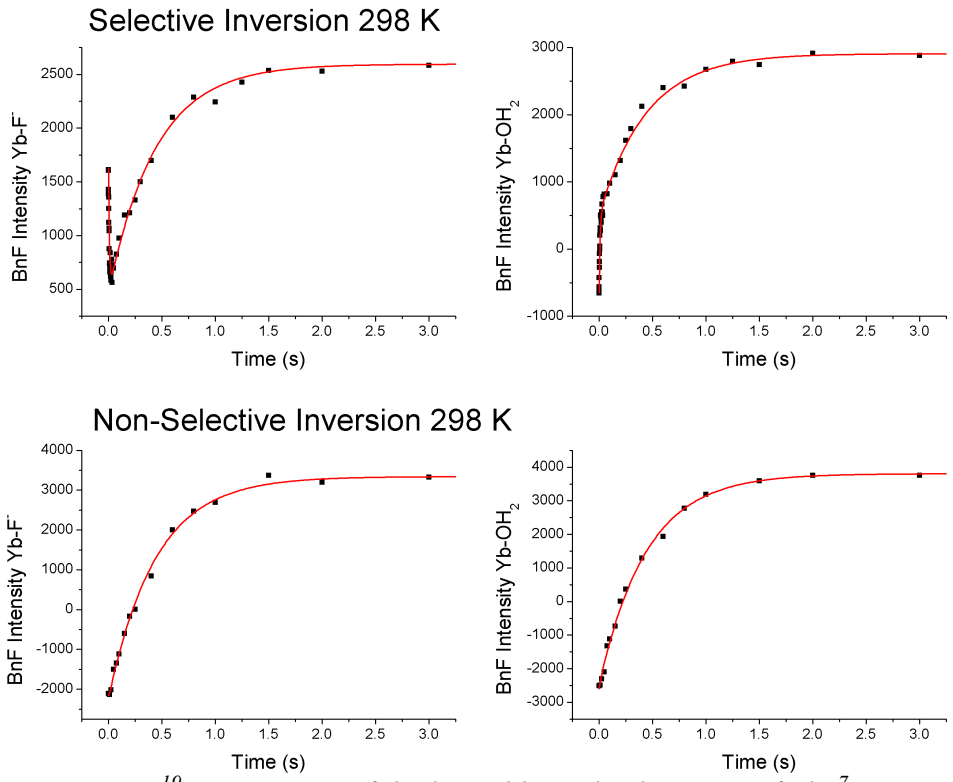

Figure S32. ^{19}F intensities of the ligand benzyl substituent of YbL^7-OH_2 and YbL^7-F^- following selective inversion (top) and non-selective inversion (bottom) at 298 K, fits are shown in red.

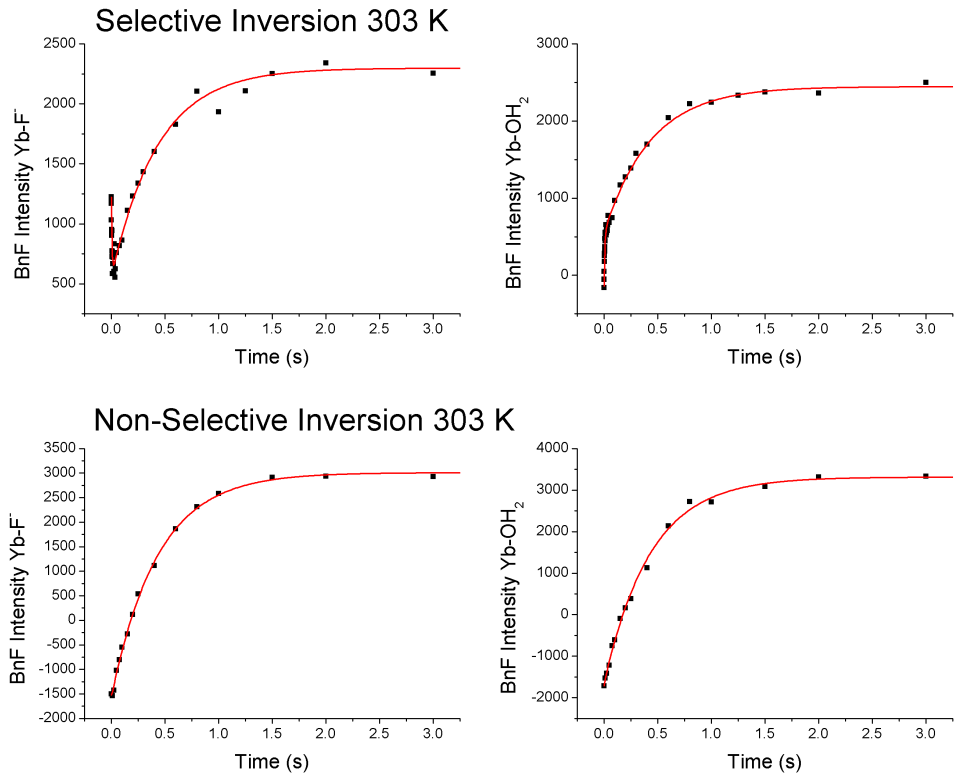

Figure S33. ^{19}F intensities of the ligand benzyl substituent of YbL^7-OH_2 and YbL^7-F^- following selective inversion (top) and non-selective inversion (bottom) at 303 K, fits are shown in red.

Table S2. Rates of exchange at multiple temperatures measured using selective inversion and fit using CIFIT[12] for YbL[2] and YbL[7] with fluoride in D_2O at 500 MHz.

YbL^2		**YbL^7**	
Temperature (K)	**k (s^{-1})**	**Temperature (K)**	**k (s^{-1})**
278	50.0 ± 1.0	278	14.8 ± 0.3
283	71.0 ± 1.1	283	22.7 ± 1.0
288	108.3 ± 1.6	288	31.5 ± 1.0
293	160.7 ± 4.0	293	42.8 ± 2.0
298	215.7 ± 3.0	298	61.2 ± 3.6
303	283.1 ± 6.0	303	84.2 ± 7.8

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[10] R. S. Dickins, J. A. K. Howard, C. W. Lehmann, J. Moloney, D. Parker, and R. D. Peacock, *Angew. Chem. Int. Ed.*, 1997, **36**, 521–523.

[11] From equations 2 and 3 in the main paper, it should be clear that

$$\delta_{PC} = D_1 \frac{(3cos^2\theta - 1)}{r^3} = \frac{1}{2N_A}\left[\frac{(3cos^2\theta - 1)}{r^3}(\chi_{\parallel} - \chi_{av})\right]$$

so,

$$D_1 = \frac{1}{2N_A}[(\chi_{\parallel} - \chi_{av})]$$

[12] A. D. Bain and J. Cramer, *Journal of Magnetic Resonance, Series A*, 1996, **118**, 21–27.