Electronic Supplementary Information (ESI)

A Non-chiral Lithium Aluminate Reagent for the Determination of Enantiomeric Excess of Chiral Alcohols

Raúl García-Rodríguez, Schirin Hanf, Andrew D. Bond and Dominic S. Wright

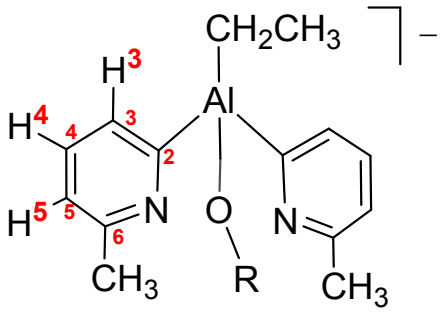
Chemistry Department, Cambridge University, Lensfield Road, Cambridge CB2 1EW (U.K.).

Table S1. Determination of enantiomeric excess for different alcohols using aluminate 1

alcohol	% *ee*	% Homochiral dimer	% Heterochiral dimer	% ee determined
2-butanol (**3**)				
	0	48.5	51.5	0
	12.1	49.7	50.3	15±3
	32.3	54.3	45.7	34.0±1.5
	51.0	62.0	38.0	51.8±1.0
	76.4	77.2	22.8	75.2±0.7
	100[a]	92.9	7.1	93.0±0.5
2-octanol(**4**)				
	0	50.0	50.0	0
	33.3	55.9	44.1	34.4±1.5
	53.8	65.0	35.0	54.8±1.0
	81.8	82.4	17.6	80.5±0.7
	90.5	88.8	11.2	88.1±0.5
	95.1	94.1	5.9	93.9±0.5
	100	100	< 1	>99
1-phenylethanol (**5**)				
	0	42.0	58.0	0
	33.3	48.3	51.7	35.6±1.5
	53.8	57.8	42.2	55.5±1.0
	81.8	80.1	19.9	83.3±0.6
	90.5	88.6	11.4	91.1±0.5
	95.1	94.0	6.0	95.5±0.5
	100	100	0	100

[a] The commercially supplied *R*-2-butanol (Aldrich) was found to only have an optical purity of 93.0±0.5% calculated using our technique and optical rotation . The error in the determination of % *ee* is calculated from the error in the determination of the % of each type of dimer by integration of their NMR signals (*ca* ±0.5%).

Scheme S1. Atom labeling and color code scheme used in the NMR studies for the heteroleptic pyridyl aluminates.



Experimental Section

Materials and general methods: All syntheses were carried out on a vacuum-line under argon atmosphere. Products were isolated and handled with the aid of a N_2-filled glove box (Saffron type α). ^{1}H and ^{13}C $\{^{1}H\}$ NMR spectra were recorded on a Bruker Avance 400 QNP or Bruker Avance 500 MHz Cryo spectrometer. ^{7}Li and ^{27}Al NMR spectra were recorded on a Bruker Avance 500 MHz Cryo-spectrometer. The unambiguous assignment of NMR resonances was accomplished by additional 2D NMR experiments (^{1}H-^{1}H COSY, ^{1}H-^{1}H NOESY, ^{1}H-^{13}C HMQC, ^{1}H-^{13}C HMBC and ^{1}H-^{7}Li HOESY experiments (see later for details). Elemental analysis was obtained on a Perkin Elmer 240 Elemental Analyser. 2-Butanol (*R*-2-Butanol, batch SHBD0787V Aldrich, 99% and *S*-2-butanol, batch SHBB6867V, Aldrich, 99%), 2-octanol and 1-phenylethanol were dried with 4Å molecular sieves and otherwise used as received. Toluene-d_8 was dried with 4Å molecular sieves and stored in a glovebox.

[EtAl(6-Me-2-py)$_3$Li·THF], **1**, was synthesized by a slightly modified procedure previously reported.[1] Synthesis of **1**; to a solution of an *in situ* generated 2-Li-6-methylpyridine in THF (prepared by reaction of BuLi and 6-methylpyridine at -78 °C) 0.33 eqv of $EtAlCl_2$ were added. The resulting mixture was allowed to reach ambient temperature and stirred for a further 20 h. The solvent was removed *in vacuo*, toluene (40 ml) added and the mixture was filtered over Celite. Concentration of the solution and storage at −15 °C gave colourless crystals of **1** that were dried under vacuum.

NMR determination of *ee*'s by reaction of alcohols containing different *ee*'s with 1

Typically, 25 mg of **1** was dissolved in 0.6mL of toluene-d_8 in a J-Young NMR tube in a glove box. To this solution a substoichiometric amount (typically 0.4-0.5 equivalents, *ca.* 4μL) of the corresponding alcohol 2-butanol, 2-octanol or 1-phenylethanol of known *ee* and freshly prepared was added (see later). The addition was carried out in air and at room temperature. Immediately after the addition the mixture was vigorously agitated by shaking and the resulting solution was studied by NMR spectroscopy. Determination of the ee's was achieved from the integration of the signals corresponding to the hetero and homochiral dimers in the ^{1}H NMR (or ^{7}Li NMR) spectrum by using equations 1 or 2 (see main text and later in the SI, pages S53-S54 and S56-S58). ^{7}Li NMR data were acquired with a recycle time of 10s using 4 scans (experimental time of around 1min).

Note: Control of the stoichiometry is very important to avoid di-substitution of the pyridyl rings of **1**. Side reactions when carrying out reactions at room temperature are prevented by vigorous stirring/shaking of the samples or by using sub-stoichiometric amounts of the alcohol. This is particularly important for 1-phenylethanol, while for 2-butanol and 2-octanol the selectivity is greater.

Preparation of alcohol samples containing known enantiomeric excess (*ee*'s) was carried out by mixing the corresponding amounts of enantiomerically pure alcohols in a small vial. All the mixtures were prepared immediately before their reaction with **1** and subsequent NMR study. Typical combined volumes of each enantiomer in the preparation of the mixtures of known *ee* are as follows (see also Figures S12-S14):

For 2-octanol: 33.3% *ee* (50µl of *R* and 100µL of *S*); 53.8% *ee* (30µl of *R* and 100µL of *S*); 81.8% (10µl of *R* and 100µL of *S*); 90.5% (5µl of *R* and 100µL of S); 95.1 (5µl of *R* and 200µL of *S*).

For 1-phenylethanol: 33.3% *ee* (50µl of *R* and 100µL of *S*); 53.8% (30µl of *R* and 100µL of *S*); 81.8% *ee* (10µl of *R* and 100µL of *S*); 90.5% *ee* (10µl of *R* and 200µL of *S*); 95.1% *ee* (5µl of *R* and 200µL of *S*).

After their reaction with **1**, *R*- and *S*-2-octanol and *R*- and *S*-1-phenylethanol were found to be enantiomerically pure (i.e., no or very little heterodimer, corresponding to *ee* > 98%). However, *R*-2-butanol and *S*-2-butanol were found to produce small amounts of heterodimer. The enantiomeric purity was determined to be 93.0±0.5% for *R*-butanol and 89.2±0.5% for *S*-butanol, in good agreement with the *ee*'s determined by optical rotation (93.5%, and 89.2%, respectively) see Section "Analysis of Enantiomeric Purity of R-/S-2-Butanol Samples" on page S55. This has to be taken into account, particularly for mixtures containing high *ee*'s .

For 2-butanol: 12.1% ee (80µ of S and 100µL of R); 32.3% ee (50µl of S and 100µL of R); 51.0% (30µl of S and 100µL of R); 76.4% (10µl of S and 100µL of R).

Synthesis of $[EtAl(OMe)(6\text{-Me-2-py})_2Li]_2$ (2): $[EtAl(6\text{-Me-2-py})_3Li\cdot$(550 mg, 1.62 mmol) was added to toluene (6 mL) and to this, methanol (66µL, 1.62 mmol) was added at -78°C. The mixture was allowed to reach room temperature. After reaching room temperature, the pale yellow mixture was stirred at room temperature for 2h and filtered over Celite. The colorless solution produced was concentrated and was layered with hexane. Storage at -15°C afforded colorless crystals of **2**·toluene.

Isolated crystalline yield *ca* 80 mg, 0.12 mmol, 15%. Isolation under vacuum gave amorphous material which was found to contain no toluene solvation and the spectroscopic and analytic results listed correspond to this material. Elemental analysis, cald. for **2**, C 64.8, H 7.2, N 10.1%. Found C 65.3, H 7.2, N 9.1.^{1}H NMR (298K, d_8-toluene, 500 MHz), δ = 7.59 (d, JHH = 7.1, 2H, H^3 py), 7.09 (t, JHH = 7.5, 2H, H^4 py, partially overlapped with residual toluene solvent signal), 6.57 (d, JHH = 7.6, 2H, H^5 py), 3.24 (s, 3H, OCH_3), 2.20 (s, 6H, Py-CH_3), 1.58 (t, J HH= 8.1 Hz, 3H, Al–$CH_2C\underline{H}_3$), 0.68 (q, JHH = 8.1 Hz, 2H, Al–CH_2). ^{13}C{^{1}H} NMR (298K, d_8-toluene, 100.6 MHz), δ = 187.22 (br, C^2 py), 156.51 (C^6 py), 133.66 (C^4 py), 130.56 (C^3 py), 120.93 (C^5 py), 51.10 (OCH_3,), 23.90 (Py-CH_3,), 10.59 (Al–$CH_2\underline{C}H_3$), -0.81 (br, Al–CH_2,). ^{27}Al NMR (298K, d_8-toluene, 130.3 MHz, ref. solution of $AlCl_3.6H_2O/D_2O$), δ = 141.23 (br, s). ^{7}Li NMR (298K, d_8-toluene, 194.4 MHz, ref. solution of $LiCl/D_2O$), δ = 2.75 (s).

Synthesis of [EtAl[OCH(CH_3)CH_2CH_3](6-Me-2-py)$_2$Li]$_2$ (*R*-, *S*- and *rac*-3): 2-butanol (148 μL, 1.62 mmol) was added at -78°C to a vigorously stirred suspension of **1** (550 mg, 1.62 mmol) in toluene (6 mL). The mixture was allowed to reach room temperature and it was stirred at room temperature for 2h. The resulting cloudy solution was stirred for 2h at room temperature and filtered over Celite. The colorless solution produced was concentrated and was layered with hexane. Storage at -15°C afforded colorless crystals of **3**. Isolated crystalline yield *ca* 50 mg, 0.078 mmol, 10%. Elemental analysis, cald. for **3**, C 67.5; H 8.2, N 8.8%. Found C 66.9, H 8.3, N 8.2. (*R*- or *S*-**3**) ^{1}H NMR (298K, d_8-toluene, 500 MHz), δ = 7.69 (dd, JHH = 7.0 and 2.0 Hz, 2H, H^3 py), 7.13 (t, JHH = 7.5, 2H, H^4 py), 6.65 (d, JHH = 7.7, 2H, H^5 py), 3.18 (m, 1H, OCH), 2.45 (s, 3H, Py-CH_3), 2.43 (s, 3H, Py-CH_3), 1.64 (m, 1H, CHC$\underline{H}_2$), 1.54-1.41 (m, 4H, Al–$CH_2C\underline{H}_3$ and CHC$\underline{H}_2$), 0.96 (d, JHH = 6.1 Hz, 3H, OCHC$\underline{H}_3$), 0.63 (q, JHH = 8.0 Hz, 2H, Al–CH_2), 0.20 (t, JHH = 7.4 Hz, 3H, $CHCH_2C\underline{H}_3$). ^{13}C{^{1}H} NMR (298K, d_8-toluene, 100.6 MHz), δ = 188.42 (br, C^2 py), 156.92 (C^6 py), 133.43 (C^4 py), 133.35 (C^4 py), 130.79 (C^3 py), 121.45 (C^5 py), 121.39 (C^5 py), 72.06 (OCH), 33.90 (OC$\underline{H}CH_2$), 25.29 (Py-CH_3,), 24.92 (Py-CH_3,), 22.93 (OC$\underline{H}CH_3$,), 11.06 (Al–$CH_2\underline{C}H_3$), 10.68 ($CHCH_2\underline{C}H_3$), 3.70 (br, Al–CH_2). ^{27}Al NMR (298K, d_8-toluene, 130.3 MHz, ref. solution of $AlCl_3.6H_2O/D_2O$), δ = 137.36 (br, s). ^{7}Li NMR (298K, d_8-toluene, 194.4 MHz, ref. solution of $LiCl/D_2O$), δ = 2.28 (s), 2.26 (s).

(*rac*-**3**) ^{1}H NMR (298K, d_8-toluene, 500 MHz), δ = 7.73(d, JHH = 7.3 Hz, 1H, H^3 py, *RS*), 7.69 (dd, JHH = 7.0 and 2.0 Hz, 2H, H^3 py, *RR*+*SS*), 7.65 (d, JHH = 7.3 Hz, 1H, H^3 py, *RS*), 7.17-7.09 (m, 2H, H^4 py, *RS* and *RR*+*SS*), 6.68-6.60 (m, 2H, H^5 py, *RS* and *RR*+*SS*), 3.21-3.11 (m, 1H, OCH, *RS* and *RR*+*SS*), 2.49 (s, 3H, Py-CH_3, *RS*), 2.45 (s, 3H, Py-CH_3, *RR*+*SS*), 2.43 (s, 3H, Py-CH_3, *RR*+*SS*), 2.38 (s, 3H, Py-

CH_3, *RS*), 1.64 (m, 1H, CHC$\underline{H}_2$, *RS* and *RR*+*SS*), 1.54-1.41 (m, 4H, Al–$CH_2C\underline{H}_3$ and CHC$\underline{H}_2$, *RS* and *RR*+*SS*), 0.99 (d JHH = 6.1 Hz, 3H, OCHC$\underline{H}_3$, *RS*), 0.96 (d, JHH = 6.1 Hz, 3H, OCHC$\underline{H}_3$, *RR*+*SS*), 0.68-0.58 (m, 2H, Al–CH_2, *RS* and *RR*+*SS*), 0.22-0.16 (m, 3H, $CHCH_2C\underline{H}_3$, *RR*+*SS*). $^{13}C\{^1H\}$ NMR (298K, d_8-toluene, 100.6 MHz), δ = 188.42 (br, C^2 py, *RR*+*SS* and *RS*), 156.92 (br,C^6 py, *RR*+*SS* and *RS*), 133.50 (C^4 py, *RS*), 133.43 (C^4 py, *RR*+*SS*), 133.35 (C^4 py, *RR*+*SS*), 133.30 (C^4 py, *RS*), 130.86 (C^3 py, *RS*), 130.79 (C^3 py *RR*+*SS*), 130.77 (C^3 py, *RS*), 121.47 (br,C^5 py, *RR*+*SS* and *RS*), 121.39 (br, C^5 py, *RR*+*SS* and *RS*),72.08 (OCH, br, *RR*+*SS* and *RS*), 33.90 (OCH$\underline{C}H_2$, *RR*+*SS*), 33.80 (OCH$\underline{C}H_2$, *RS*), 25.44 (Py-CH_3, *RS*), 25.30 (Py-CH_3, *RR*+*SS*), 24.93 (Py-CH_3, *RR*+*SS*), 24.80 (Py-CH_3, *RS*), 23.01 (OCH$\underline{C}H_3$, *RS*), 22.94 (OCH$\underline{C}H_3$, *RR*+*SS*), 11.07 (Al–$CH_2\underline{C}H_3$, *RR*+*SS*, *RS*), 10.72 ($CHCH_2\underline{C}H_3$, *RS*), 10.69 ($CHCH_2\underline{C}H_3$, *RR*+*SS*), 3.70 (br, Al–CH_2,). ^{27}Al NMR (298K, d_8-toluene ,130.3 MHz, ref. solution of $AlCl_3.6H_2O/D_2O$), δ = 137.2 (br, s). ^7Li NMR (298K, d_8-toluene, 194.4 MHz, ref. solution of $LiCl/D_2O$), δ = 2.31-2.24 (m).

Synthesis of $[EtAl[OCH(CH_3)C_6H_{13}](6\text{-Me-2-py})_2Li]_2$ (R-, S-, rac-4):

To a vigorously stirred suspension of **1** (65 mg, 0.19 mmol) in a small Schlenk tube at -78°C in toluene (1 mL) was added 2-octanol (30.5μL, 0.19 mmol). The mixture was allowed to reach room temperature and it was stirred at room temperature for 2h. The solvents were evaporated under vacuum and the residue was dried under vacuum for 2h with gentle heating. An oil was obtained that solidified at room temperature upon standing, to give a white solid: *ca*. 50 mg, 0.066 mmol, 70%. Elemental analysis, cald. for **4**, C 70.2; H 9.1, N 7.4%; Found C 69.7, H 9.3, N 6.5. (*R*-or *S*-**4**) ^1H NMR (298K, d_8-toluene, 500 MHz), δ = 7.70 (d, JHH = 7.2, 1H, H^3 py), 7.66 (d, JHH = 7.2, 1H, H^3 py), 7.15 (t, JHH = 7.5, 2H, H^4 py), 6.71-6.64 (m , 2H, H^5 py), 3.34 (m, 1H, OCH), 2.50 (s, 3H, Py-CH_3), 2.46 (s, 3H, Py-CH_3), 1.59-1.48 (m, 4H, Al–$CH_2C\underline{H}_3$ and OCHC$\underline{H}_2$), 1.36 (m, 1H, OCHC$\underline{H}_2$), 1.12-1.02 (m, 5H, OCHC$\underline{H}_3$ and CH_2), 0.94-0.76 (m, 7H, $CH_2C\underline{H}_3$ and $2CH_2$), 0.72-0.59 (m, 3H, Al–CH_2 and $OCHCH_2C\underline{H}_2$), 0.38 (m, 1H, $OCHCH_2C\underline{H}_2$). $^{13}C\{^1H\}$ NMR (298K, d_8-toluene, 100.6 MHz), δ = 188.49 (br, C^2 py), 156.94 (C^6 py), 156.85 (C^6 py), 133.45 (C^4 py), 133.37 (C^4 py), 130.81 (C^3 py), 121.47 (C^5 py), 121.38 (C^5 py), 70.60 (OCH), 41.10 (CH$\underline{C}H_2$), 32.15 (CH_2), 29.49 (CH_2), 26.96 (CH_2), 25.32 (Py-CH_3,), 25.28 (Py-CH_3,), 23.75 (OCH$\underline{C}H_3$), 22.96 (CH_2), 14.27 ($CH_2\underline{C}H_3$,), 11.07 (Al–$CH_2\underline{C}H_3$), 3.72 (br, Al–CH_2,). ^{27}Al NMR (298K, d_8-toluene, 130.3 MHz, ref. solution of $AlCl_3.6H_2O/D_2O$), δ = 139.4 (br, s). ^7Li NMR (298K, d_8-toluene, 194.4 MHz, ref. solution of $LiCl/D_2O$), δ = 2.28 (s), 2.26 (s).

(*rac*-**4**) ^1H NMR (298K, d_8-toluene, 500 MHz), δ = 7.72-7.64 (m, 2H, H^3 py, *RR*+*SS* and *RS*), 7.15 (t, JHH = 7.3, 2H, H^4 py, *RR*+*SS* and *RS*), 6.70-6.65 (m , 2H, H^5 py, *RR*+*SS* and *RS*), 3.34 (m, 1H, OCH,

RR+*SS* and *RS*), 2.50 (s, 3H, Py-CH_3, *RR*+*SS*), 2.49 (s, 3H, Py-CH_3, *RS*), 2.47 (s, 3H, Py-CH_3, *RS*), 2.46 (s, 3H, Py-CH_3, *RR*+*SS*), 1.59-1.48 (m, 4H, Al–$CH_2C\underline{H}_3$ and OCHC$\underline{H}_2$, *RR*+*SS* and *RS*), 1.36 (m, 1H, OCHC$\underline{H}_2$, *RR*+*SS* and *RS*), 1.12-1.02 (m, 5H, OCHC$\underline{H}_3$ and CH_2, *RR*+*SS* and *RS*), 0.94-0.76 (m, 7H, $CH_2C\underline{H}_3$ and $2CH_2$, *RR*+*SS* and *RS*), 0.73-0.60 (m, 3H, Al–CH_2 and 1H, $OCHCH_2C\underline{H}_2$, *RR*+*SS* and *RS*), 0.39 (m, 1H, $OCHCH_2C\underline{H}_2$, *RR*+*SS* and *RS*). $^{13}C\{^1H\}$ NMR (298K, d_8-toluene, 100.6 MHz), δ = 188.49 (br, C^2 py, *RR*+*SS* and *RS*), 156.94 (C^6 py, *RR*+*SS*), 156.92 (C^6 py, *RS*), 156.87 (C^6 py, *RS*), 156.85 (C^6 py, *RR*+*SS*), 133.44 (C^4 py, *RR*+*SS* and *RS*), 133.37 (C^4 py, *RR*+*SS* and *RS*), 130.81 (br, C^3 py, *RR*+*SS* and *RS*), 121.46 (C^5 py, *RR*+*SS* and *RS*), 121.38 (C^5 py, *RR*+*SS* and *RS*), 70.62 (OCH, *RS*), 70.59 (OCH, *RR*+*SS*), 41.10 (CH$\underline{C}H_2$, *RR*+*SS*), 41.06 (CH$\underline{C}H_2$, *RS*), 32.14 (CH_2, *RR*+*SS* and *RS*), 29.49 (CH_2, *RR*+*SS* and *RS*), 26.96 (CH_2, *RR*+*SS* and *RS*), 25.36 (Py-CH_3, *RS*), 25.32 (Py-CH_3, *RR*+*SS*), 25.28 (Py-CH_3, *RR*+*SS*), 25.23 (Py-CH_3, *RS*), 23.78 (OCH$\underline{C}H_3$, *RS*), 23.75 (OCH$\underline{C}H_3$, *RR*+*SS* and *RS*), 22.96 (CH_2, *RR*+*SS* and *RS*), 14.27 ($CH_2\underline{C}H_3$, *RR*+*SS* and *RS*), 11.07 (Al–$CH_2\underline{C}H_3$, *RR*+*SS* and *RS*), 3.72 (br, Al–CH_2, *RR*+*SS* and *RS*) ^{27}Al NMR (298K, d_8-toluene ,130.3 MHz, ref. solution of $AlCl_3.6H_2O/D_2O$), δ = 139.6 (br, s). ^7Li NMR (298K, d_8-toluene, 194.4 MHz, ref. solution of $LiCl/D_2O$), δ = 2.27 (m).

Synthesis of [EtAl[OCH(CH_3)C_6H_5](6-Me-2-py)$_2$Li]$_2$ (*R*-/*S*-, *rac*-5): 1-phenylethanol (108μL, 0.883 mmol) was added at -78°C to a vigorously stirred suspension of **1** (300 mg, 0.884 mmol) in toluene (8 mL). The cloudy solution was allowed to reach room temperature, was stirred at room temperature for 2h and filtered over Celite. The colorless solution produced was concentrated and was layered with hexane. Storage at -15°C afforded colorless crystals of **5**. Isolated crystalline yield *ca* 30 mg, 0.041 mmol, 9% (*R*- or *S*-**5**) ^1H NMR (298K, d_8-toluene, 500 MHz), δ = 7.80 (d, JHH = 7.1, 1H, H^3 py), 7.69 (d, JHH = 7.1, 1H, H^3 py), 7.19 (t, JHH = 7.4, 1H, H^4 py), 7.06 (t, JHH = 7.4, 1H, H^4 py), 6.87 (m, 2H, C_6H_5), 6.83-6.75 (m, 3H, C_6H_5), 6.66 (d, JHH = 7.5, 1H, H^5 py), 6.34 (d, JHH = 7.5, 1H, H^5 py), 4.72 (q, JHH = 6.5, 1H, OCH), 2.46 (s, 3H, Py-CH_3), 1.86 (s, 3H, Py-CH_3), 1.43 (t, JHH = 8.0, 3H, Al–$CH_2C\underline{H}_3$), 1.28 (d, JHH = 6.5, 3H, OCHC$\underline{H}_3$), 0.57 (m, 2H, Al–CH_2). $^{13}C\{^1H\}$ NMR (298K, d_8-toluene, 100.6 MHz), δ = 188.77 (br, C^2 py), 186.76 (br, C^2 py), 157.62 (C^6 py), 157.18 (C^6 py), 147.67 (*C quaternary* -C_6H_5), 133.66 (C^4 py), 133.30 (C^4 py), 131.01 (C^3 py), 130.59 (C^3 py), 128.16 (C_6H_5, overlapped with toluene-d_6 signal), 126.35 (C_6H_5), 125.58 (C_6H_5), 121.68 (C^5 py), 121.21 (C^5 py), 73.71 (OCH,), 29.18 (CH$\underline{C}H_3$,), 25.27 (Py-CH_3,), 24.64 (Py-CH_3,), 11.15 (Al–$CH_2\underline{C}H_3$), 4.42 (br, Al–CH_2,). ^{27}Al NMR (298K, d_8-toluene ,130.3 MHz, ref. solution of $AlCl_3.6H_2O/D_2O$), δ = 134.2 (v br,). ^7Li NMR (298K, d_8-toluene, 194.4 MHz, ref. solution of $LiCl/D_2O$), δ = 2.63 (s), 2.20 (s).

(*rac*-**5**) ^{1}H NMR (298K, d_8-toluene, 500 MHz), δ = 7.81-7.77(m, 1H, H^3 py, *RR*+*SS* and *RS*), 7.73 (d, JHH = 7.1, 1H, H^3 py, *RS*), 7.69 (d, JHH = 7.1, 1H, H^3 py, *RR*+*SS*), 7.21-7.15 (m, 1H, H^4 py, *RR*+*SS* and *RS*), 7.12-7.03(m, 1H, H^4 py, *RR*+*SS* and *RS*), 6.92-6.76 (m, 5H, C_6H_5, *RR*+*SS* and *RS*), 6.66 (d, JHH = 7.5, 1H, H^5 py, *RR*+*SS*), 6.59 (d, JHH = 7.5, 1H, H^5 py, *RS*), 6.40 (d, JHH = 7.5, 1H, H^5 py, *RS*), 6.33 (d, JHH = 7.5, 1H, H^5 py, *RR*+*SS*), 4.72 (q, JHH = 6.5, 1H, OCH, *RR*+*SS*), 4.56 (q, JHH = 6.5, 1H, OCH, *RS*), 2.46 (s, 3H, Py-CH_3, *RR*+*SS*), 2.33 (s, 3H, Py-CH_3, *RS*), 1.86 (s, 3H, Py-CH_3, *RR*+*SS*), 1.84 (s, 3H, Py-CH_3, *RS*), 1.49 (t, JHH = 8.0, 3H, Al–$CH_2C\underline{H}_3$, *RS*), 1.43 (t, JHH = 8.0, 3H, Al–$CH_2C\underline{H}_3$, *RR*+*SS*), 1.30-1.26 (m, 3H, OCHC$\underline{H}_3$, *RR*+*SS* and *RS*), 0.70-0.51 (m, 2H, Al–CH_2, *RR*+*SS* ad *RS*). $^{13}C\{^{1}H\}$ NMR (298K, d_8-toluene, 100.6 MHz), δ = 188.8 (br, C^2 py, *RR*+*SS* and *RS*), 187.25 (br, C^2 py, *RS*), 186.76 (br, C^2 py, *RR*+*SS*), 157.81 (C^6 py, *RS*), 157.66 (C^6 py, *RR*+*SS*), 157.20 (C^6 py, *RR*+*SS* and *RS*), 147.88 (C quaternary -C_6H_5, *RS*), 147.67 (*C quaternary* -C_6H_5, *RR*+*SS*), 133.36 (C^4 py, *RR*+*SS*), 133.33 (C^4 py, *RS*), 133.39 (C^4 py, *RS*), 133.30 (C^4 py, *RR*+*SS*), 131.14 (C^3 py, *RS*), 131.01 (C^3 py, *RR*+*SS*), 130.59 (C^3 py, *RR*+*SS*), 130.56 (C^3 py, *RS*), 128.16 (C_6H_5, overlapped with toluene-d_6 signal, *RR*+*SS* and *RS*), 126.47 (C_6H_5, *RS*), 126.35 (C_6H_5, *RR*+*SS*), 125.78 (C_6H_5, *RS*), 125.58 (C_6H_5, *RR*+*SS*), 121.68 (C^5 py, *RR*+*SS*), 121.55 (C^5 py, *RS*), 121.21 (C^5 py, *RR*+*SS* and *RS*), 73.71 (OCH, *RR*+*SS*), 73.63 (OCH, *RS*), 29.18 (CH$\underline{C}H_3$, *RR*+*SS*), 28.93 (CH$\underline{C}H_3$, *RS*) 25.26 (Py-CH_3, *RR*+*SS*), 25.16 (Py-CH_3, *RS*), 24.64 (Py-CH_3,*RR*+*SS*), 24.35 (Py-CH_3, *RS*), 11.21 (Al–$CH_2\underline{C}H_3$, *RS*), 11.14 (Al–$CH_2\underline{C}H_3$, *RR*+*SS*), 4.80 (br, Al–CH_2, *RR*+*SS* and *RS*). ^{27}Al NMR (298K, d_8-toluene ,130.3 MHz, ref. solution of $AlCl_3.6H_2O/D_2O$), δ = 134.2 (v br). ^{7}Li NMR (298K, d_8-toluene, 194.4 MHz, ref. solution of $LiCl/D_2O$), δ = 2.63 (s, *RR*+*SS*), 2.39(s, *RS*), 2.20 (s, *RR*+*SS*)

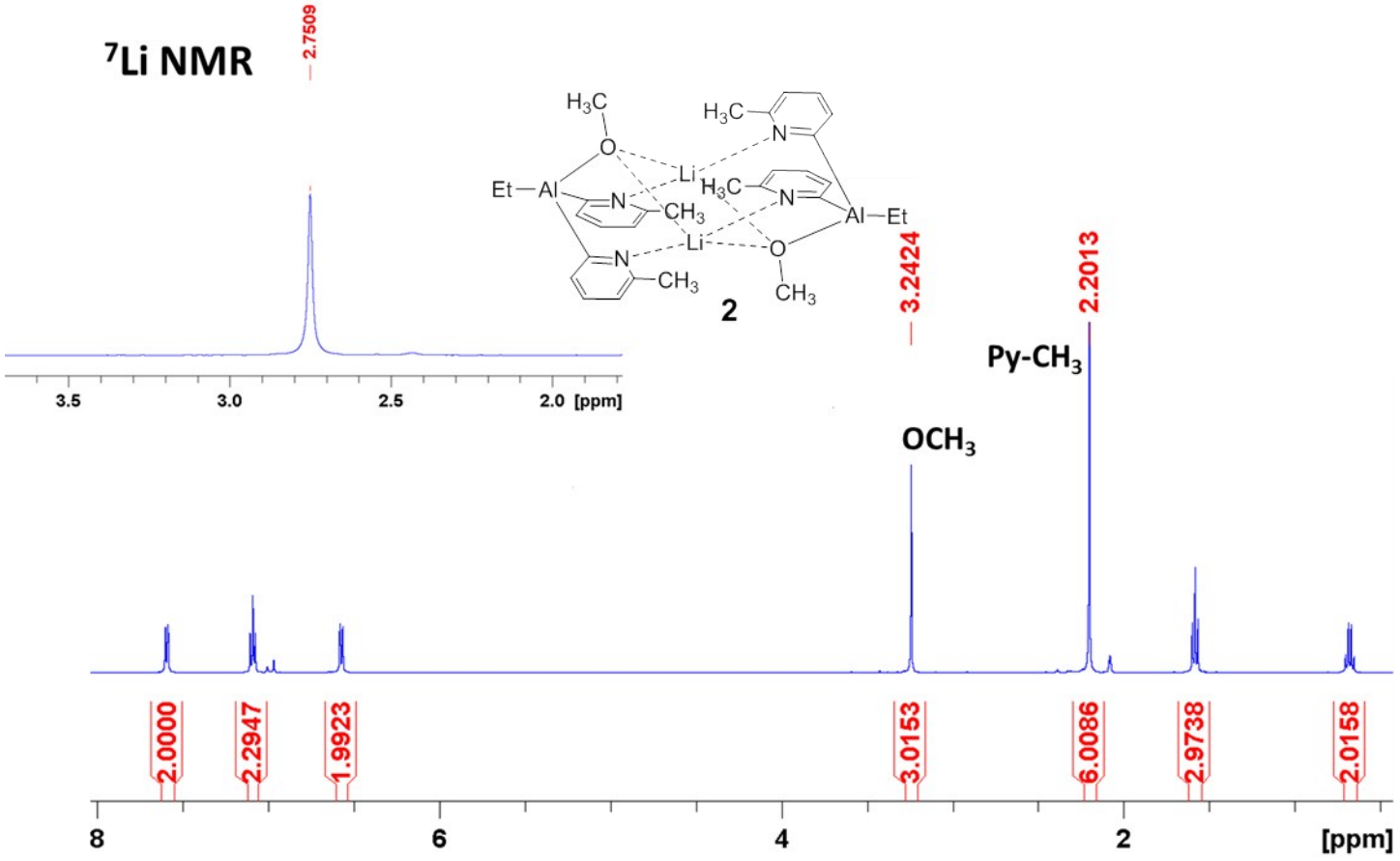


Figure S1. ^{1}H NMR spectrum of [{EtAl(6-CH_3-2-py)$_3$(OMe)}Li]$_2$ (**2**), showing a singlet at δ = 3.24 ppm for the OCH_3 group along with a singlet for the 6-*Me*-Py group at δ = 2.20 ppm. The insert shows the ^{7}Li NMR spectrum of **2**, featuring only one sharp singlet (δ = 2.75 ppm).

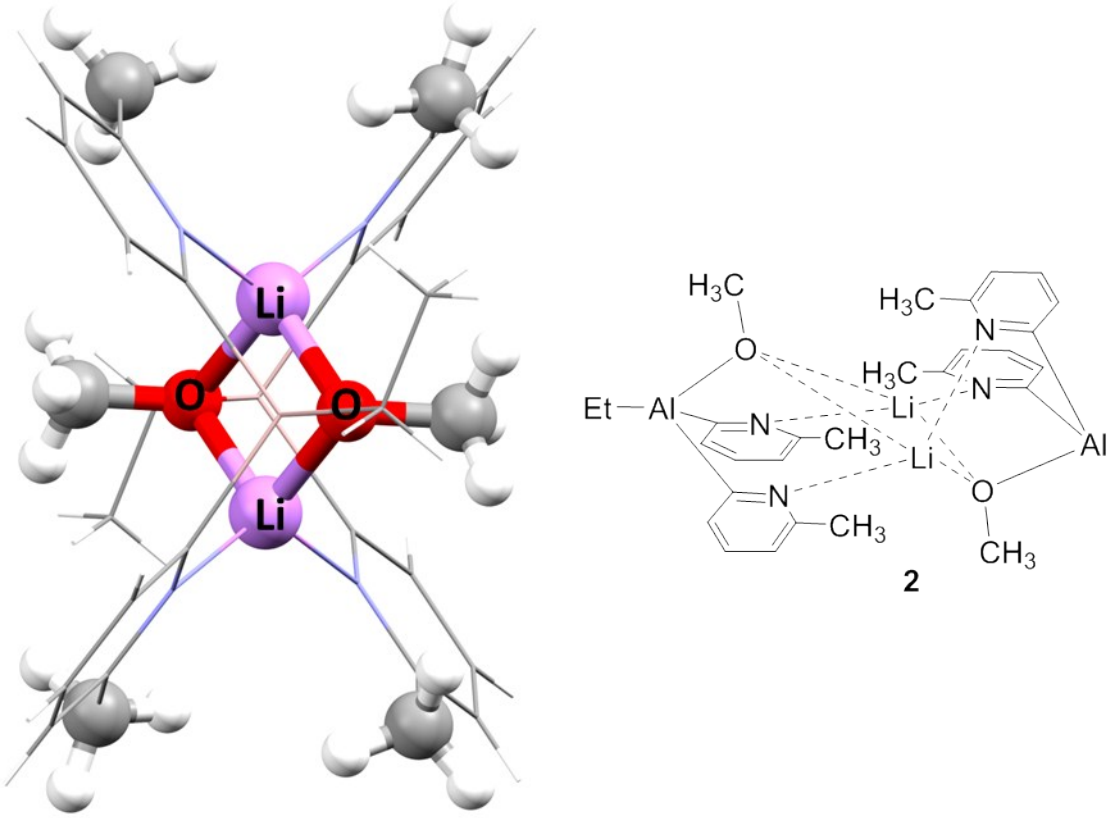


Figure S2. Single-crystal X-ray structure of [{EtAl(6-CH_3-2-py)$_2$(OMe)}Li]$_2$ (**2**).

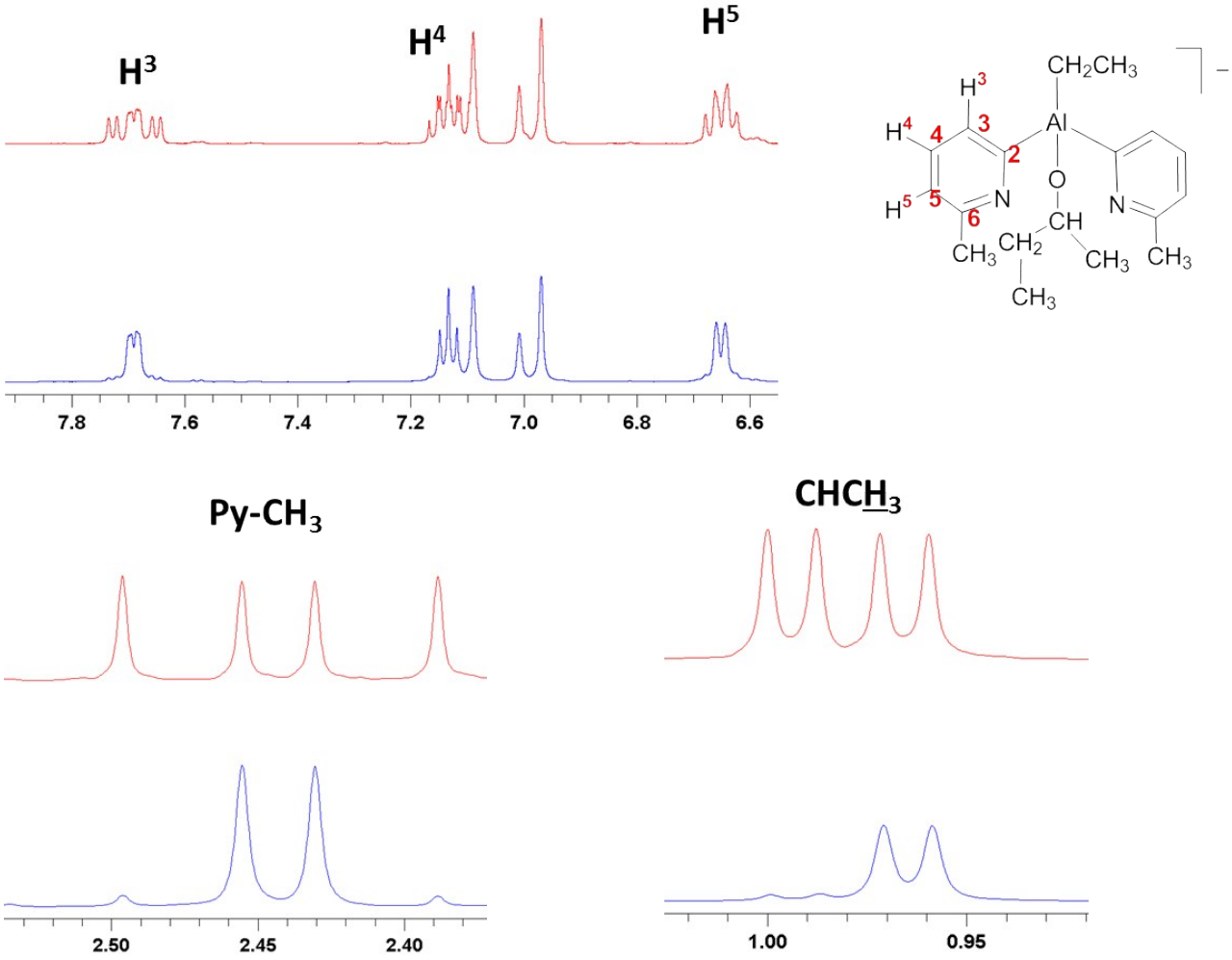


Figure S3. ^{1}H NMR (298K, d_8-toluene, 500 MHz) stacked spectra of enantiomerically-pure *R*-/*S*-**3** (blue) and *rac*-**3** (red). While for the enantiomerically-pure *R*-/*S*-**3** only one dimer (*RR* or *SS*) is formed, additional signals are observed for *rac*-**3** due to the presence of the *RS* dimer. Out of the resonances (H^3, $CHCH_3$ and Py-CH_3) for which this splitting is resolved, the 6-*Me*-Py signal is the most obvious reporter group.

Note: a very small amount of dimer *RS* was found in the crystalline sample, which comes from the commercially-supplied chiral 2-butanol; easily observed by the two characteristic Me-Py singlets at 2.49 and 2.39 ppm.

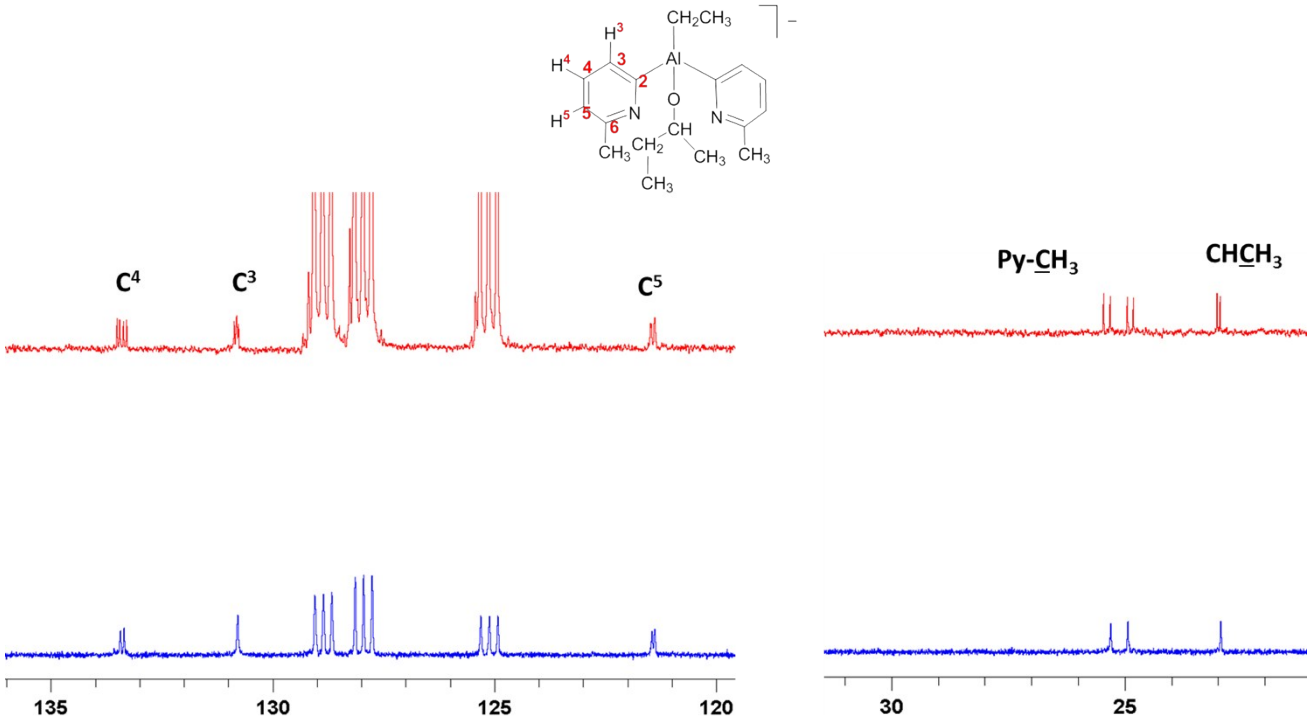


Figure S4. $^{13}C\{^{1}H\}$ NMR (298K, d_8-toluene, 100.6 MHz) stacked spectra of enantiomerically-pure *R*-/*S*-**3** (blue) and *rac*-**3** (red).

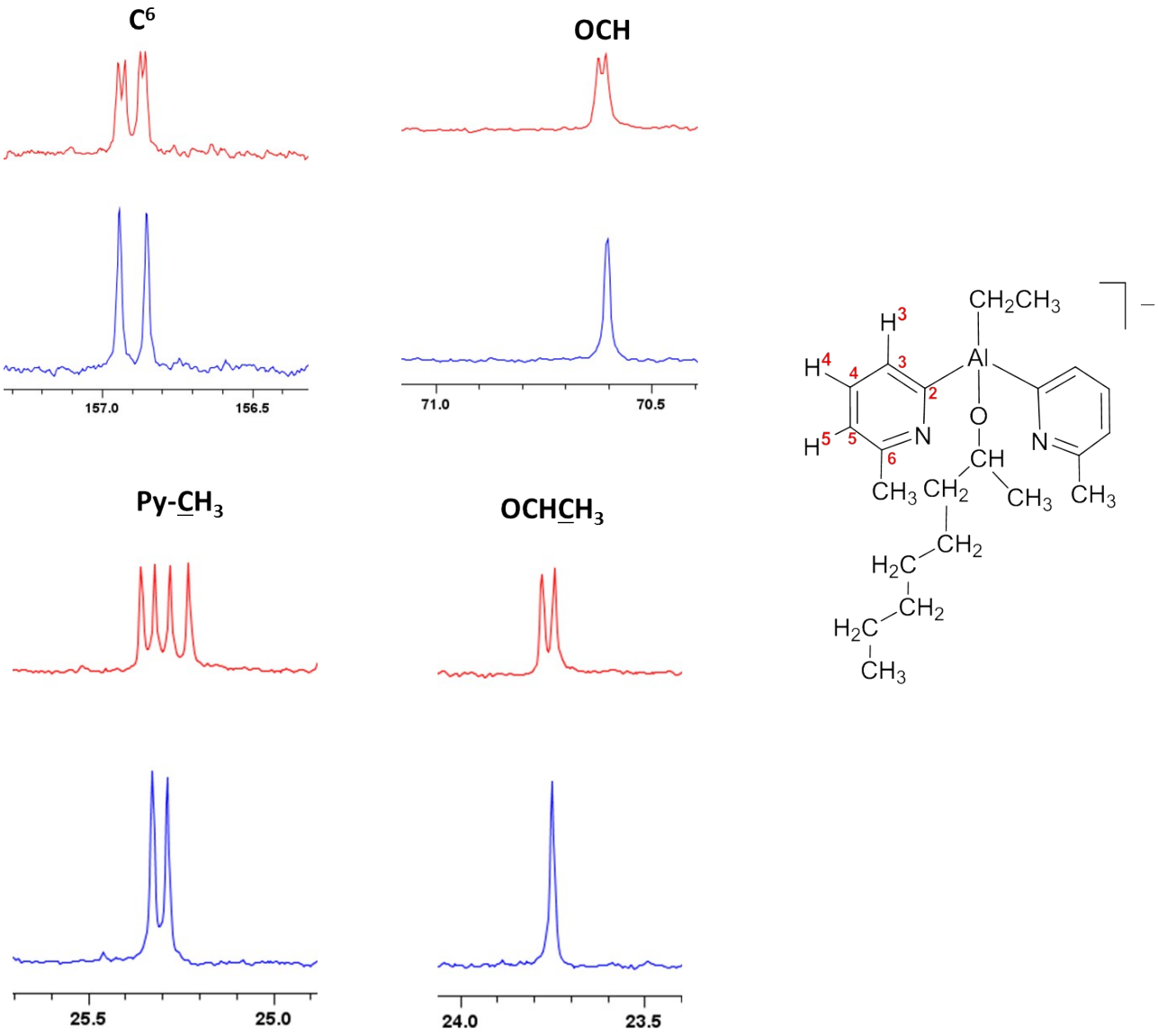


Figure S5. $^{13}C\{^{1}H\}$ NMR (298K, d_8-toluene, 100.6 MHz) stacked spectra of enantiomerically pure *R*-/*S*-**4** (blue) and racemic *rac*-**4** (red). While for the enantiomerically-pure **4** only one dimer (*RR* or *SS*) is formed, additional signals are observed for *rac*-**4** due to the additional formation of heterochiral *RS* dimer. Shown in the figure are the ^{13}C signals for which this splitting is resolved.

In the case of the ^{1}H NMR spectra, splitting of the signals was only observed for the Py-CH_3 signal (which acts as a reporter group, see Figure 1 in the main text).

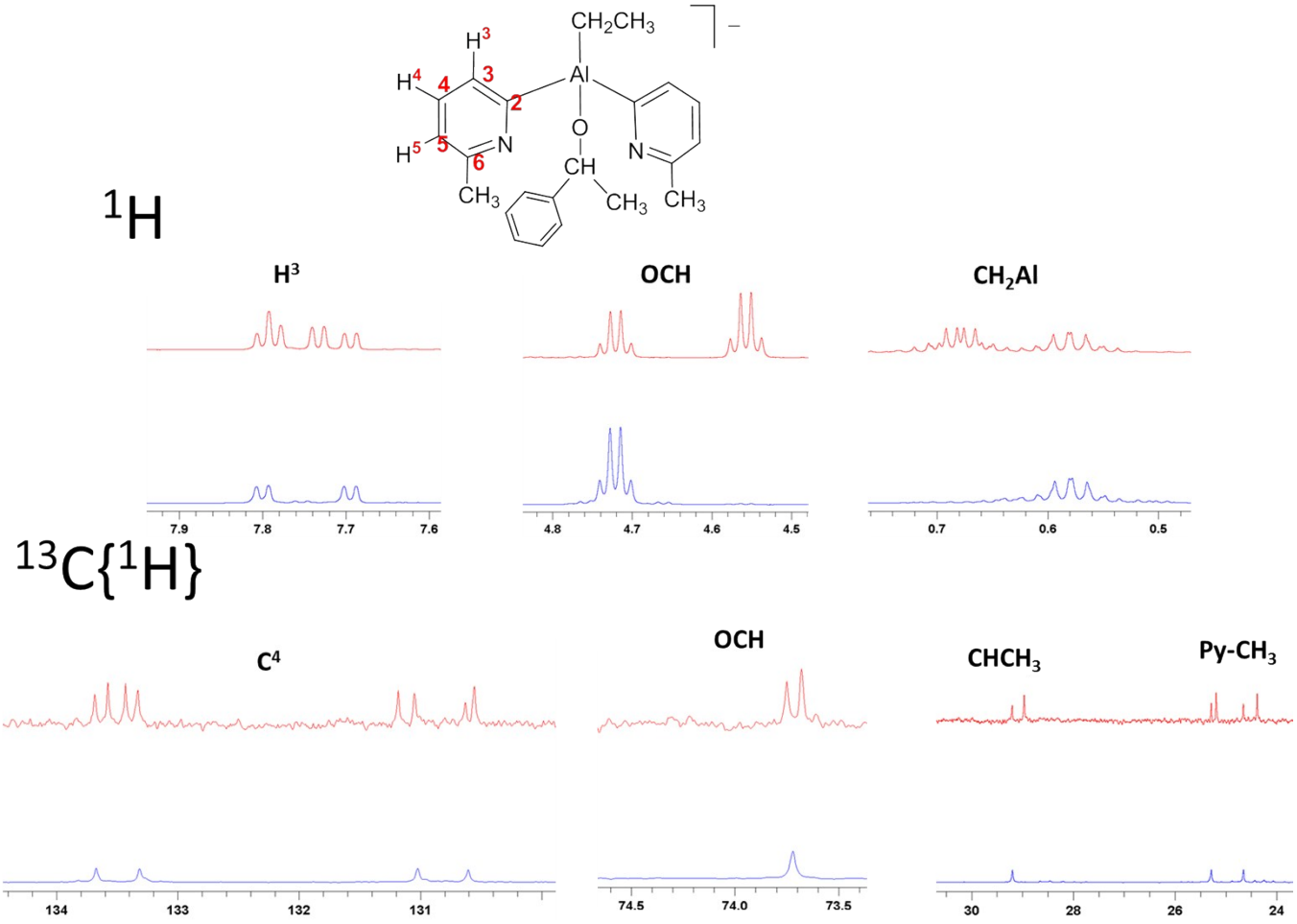


Figure S6. ^{1}H and ^{13}C{^{1}H} NMR (298K, d_8-toluene, 100.6 MHz) stacked spectra of enantiomerically pure *R*-/*S*-**5** (blue) and *rac*-**4** (red). While for the enantiomerically-pure **5** only one dimer (*RR* or *SS*) is formed, additional signals are observed for *rac*-**5** due to the additional presence of *RS* dimer. See also Fig 1 and 3 in the main text: ^{1}HNMR spectra, 6-CH_3-Py region and ^{7}Li spectra respectively.

Symmetry of the complexes

The {[Al(6-CH_3-2-py)$_2$(O)Li]}$_2$ core of the dimeric complex has effective C_{2h} point symmetry, with the C_2 axis passing through the two Li atoms, and the mirror plane passing through the two Al atoms and the two O atoms. In the crystal structures, this symmetry is reduced by the fixed orientations of the Et groups on Al. In solution, however, these Et groups undergo free rotation, and do not influence the apparent symmetry. Excluding the Et groups on Al, the C_{2h} symmetry is clearly illustrated by the complex in the crystal structure of **2** (Fig. S2). According to the C_{2h} symmetry, both Li atoms are equivalent, and all 6-CH_3 groups are equivalent.

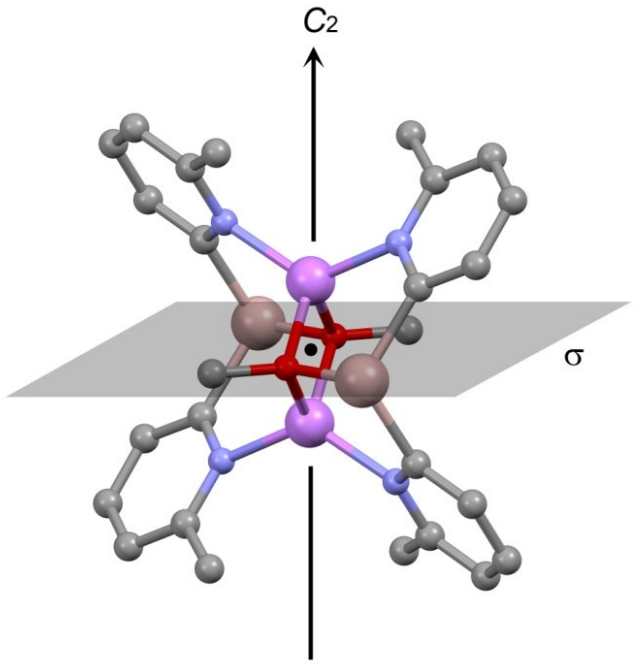


Figure S7. Complex taken from the crystal structure of **2**, showing the symmetry elements of the approximate point group C_{2h}. H atoms and the Et groups bound to Al are excluded. There are two crystallographically independent complexes in **2**, with identical geometry (RMS deviation for overlay of **all** atoms= 0.09 Å).

Introducing 2-butanol (or 1-phenylethanol) in place of methanol lowers the symmetry. For the homochiral **3**-*SS* (or **3**-*RR*), the C_2 axis of C_{2h} is retained, but the inversion centre and mirror plane are lost. Thus, the effective symmetry is reduced to point group C_2. In the crystal structure, the 2-fold

symmetry is local rather than crystallographic. According to the C_2 symmetry, there are two distinct Li atoms lying on the 2-fold axis, and two distinct 6-CH_3 environments.

For the heterochiral **3**-*RS* complex, the inversion centre of C_{2h} is retained, but the C_2 axis and mirror plane are lost. The effective symmetry is reduced to point group C_i. In the crystal structure, the inversion symmetry is local rather than crystallographic. According to the C_i symmetry, both Li atoms are equivalent, but there are two distinct 6-CH_3 environments.

Overall: the effective C_{2h} symmetry of the methanol complex **2** shows only one resonance for the 6-Me group in ^{1}H NMR and one resonance in ^{7}Li NMR. The effective C_2 symmetry of **3**-*SS* or **3**-RR shows two resonances for the 6-Me group in ^{1}H NMR and two resonances in the ^{7}Li NMR (because the distinct Li atoms lie on the 2-fold axis). The effective C_i symmetry of **3**-*RS* shows two resonances for the 6-Me group in ^{1}H NMR and one resonance in the ^{7}Li NMR, as clearly observed for 1 phenylethanol (**5**), for which RR/SS- and RS-dimers can be easily distinguished by ^{7}Li NMR

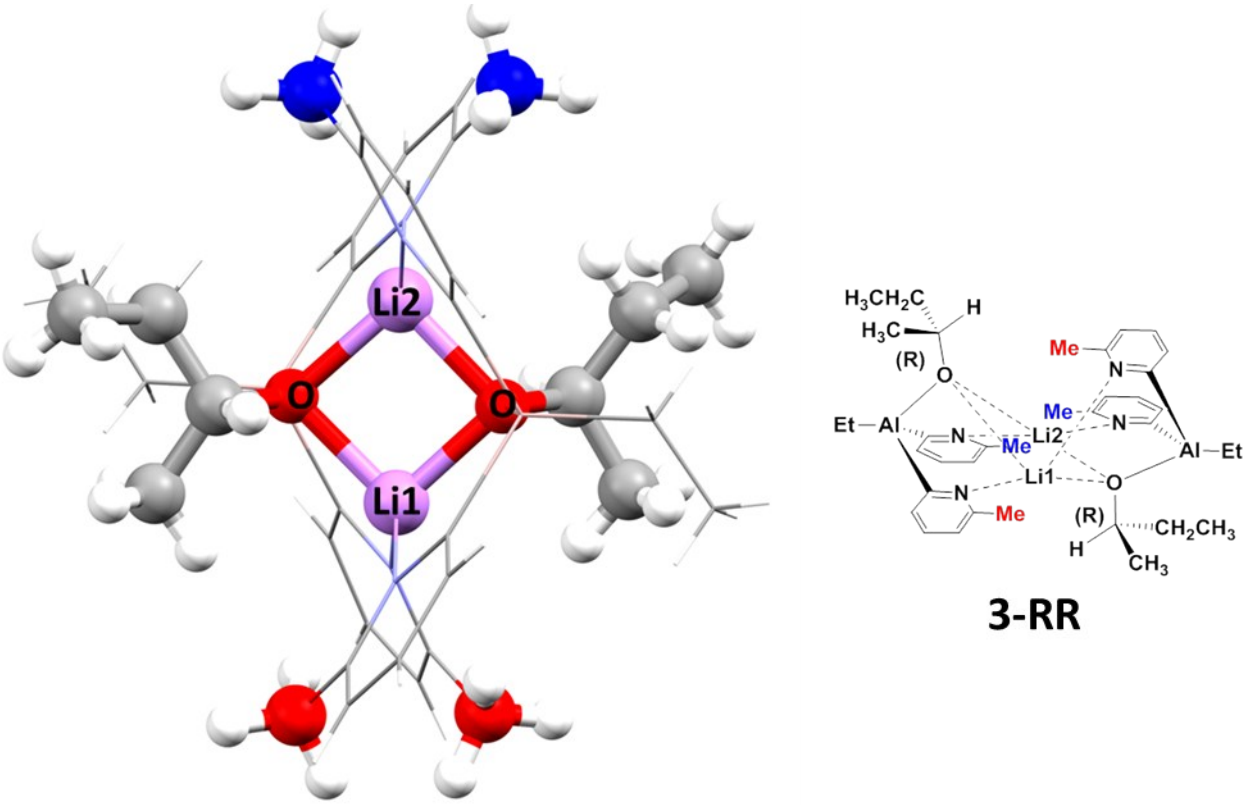


Figure S8. Single-crystal X-ray structure of **3**-*RR* showing that there are two different 6-Me-Py environments, two facing the alkoxide Me group (6-Me-Py groups in blue) and two facing the alkoxide Et group (6-Me-Py groups in red). Also both Li atoms are equivalent (in contrast to the heterochiral dimer *RS*. See discussion on page S15 for more details). Figure S9 shows a comparison of all of the possible dimers of *R*-/S- and *rac*-**3**.

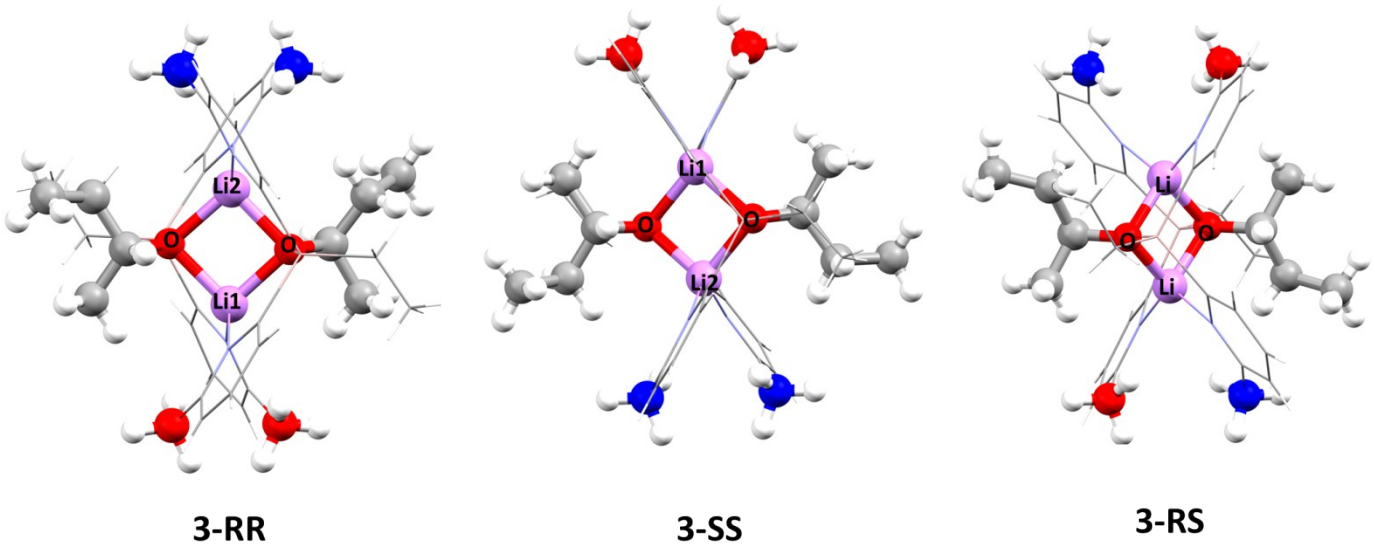


Figure S9 Single-crystal X-ray structures for all of the possible dimers **3**-*SS*, **3**-*RR* and **3**-*RS*. Each dimer has two different 6-Me-Py environments. The structures explain the presence of two singlets in the ^{7}Li NMR spectra of the homochiral dimers *RR* and *SS* (which are enantiomers) as there are two different environments for the Li atoms. See discussion on page S15 for more details.

Note: 3-*RR* and 3-*SS* are enantiomer*s*, but they do not have the same crystal structure. They are polytypes: they have consistent 2-D layers in the *ab* planes but different stacking sequences along *c* (see section "X-ray Crystallographic Studies" on page S51 and Fig S41).

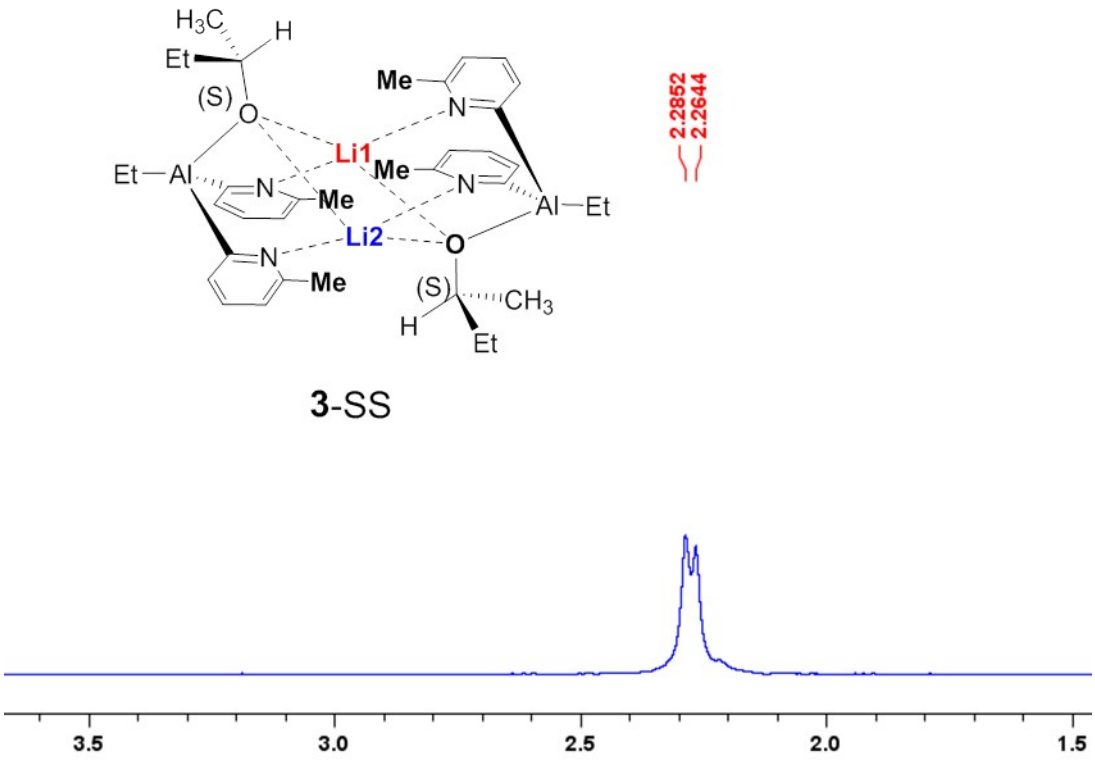


Figure S10. ^{7}Li NMR (298K, d_8-toluene, 194.4 MHz,) spectrum of *S*-**3**. Two singlets are observed due to fact that the dimer **3**-*SS* is retained in solution and the Li atoms in the dimer have different environments (See discussion on page S15 for more details).

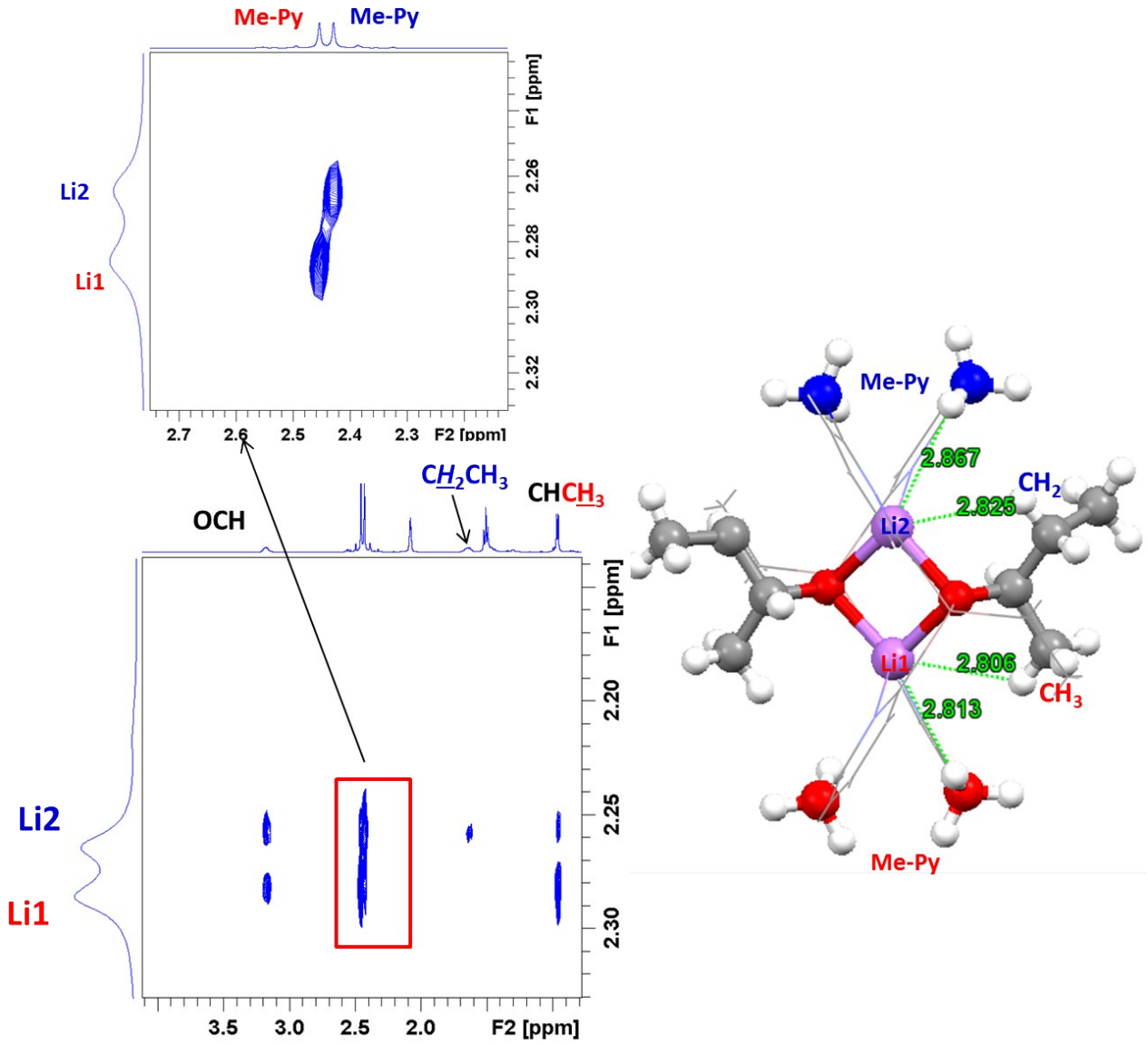


Figure S11. ^{1}H-^{7}Li HOESY (298K, d_8-toluene, 500 MHz, mixing time of 100 ms) spectrum of *R*-**3**. The ^{1}H-^{7}Li HOESY experiment can be used to assess the spatial proximity between ^{7}Li and ^{1}H nuclei (see section on page S24 for more details). The experiment shows crosspeaks between both ^{7}Li resonances and the CH resonance of the 2-butoxy group, indicating that both Li atoms are spatially close to the CH group. Each of the two singlets for the Py-CH_3 groups showed a crosspeak with only one of the ^{7}Li signals (which has been represented by using the same color code, blue or red, see the insert of the region highlighted in red), since for each of these two Py-CH_3 groups only one of the two Li nuclei is close in space, as found in the X-ray structure of *RR*-**3** (which is shown at the left of the Figure). The assignment of the ^{7}Li resonances as Li1 and Li2 has been done on the basis of the ^{1}H-^{7}Li HOESY experiment. While Li1 showed an intense crosspeak with the CH_3 protons, Li2 showed a weaker cross peak with the CH_3 protons and, additionally a cross peak with the CH_2 protons. This agrees with the X-ray structure (at the left of the figure) which shows that the arrangement of the 2-butoxy group is such that one of the Li nuclei is closer to the CH_2CH_3 fragment while the other Li nuclei is closer to the CH_3 group. These data revealed that the *RR*-dimer found in solid state is retained in toluene solution.

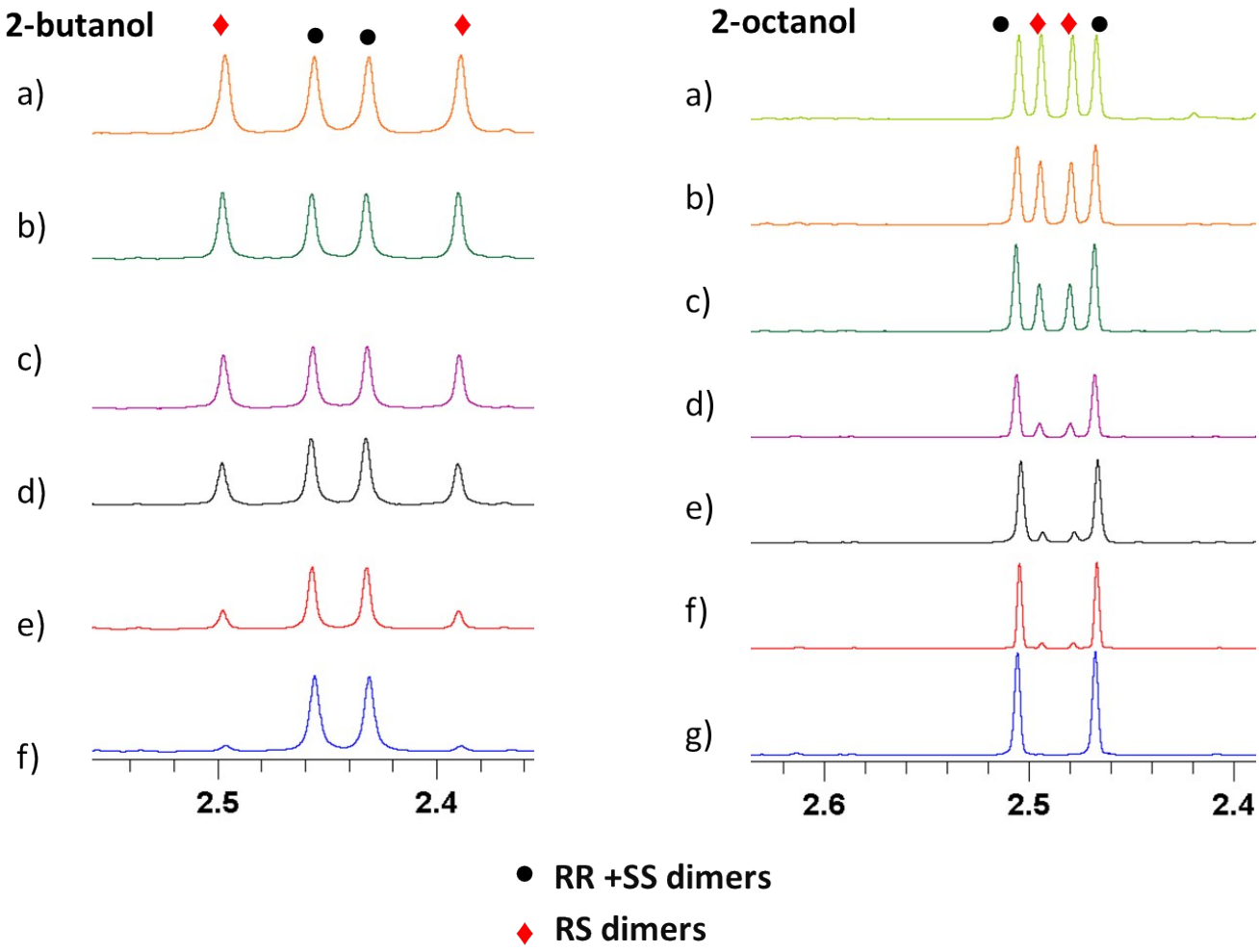


Figure S12. ^{1}H NMR (298K, d_8-toluene, 500 MHz) stacked spectra (6-*Me*-Py region) of the *in situ* reaction of **1** with butanol (left) and octanol(right) containing different *ee*'s. For butanol: a) racemic; b) 11% (80µl of *S* + 100µL of *R*); c) 33.3% (50µl of *S* + 100µL of *R*); d) 54% (30µl of *S* + 100µL of R); e) 82% (10µl of *S* + 100µL of *R*); and f) enantiomerically-pure R-2-butanol. In the latter case, the ^{1}H NMR spectrum (f, at the left) shows a small amount of the *RS* dimer and the sample was determined to contain 93.0% *ee* by integration of these signals (see also SI, section "Analysis of Enantiomeric Purity of R-/S-2-Butanol Samples" on page S55). For octanol: a) racemic, b) 33.3% (50µl of *R* + 100µL of *S*), c) 53.8% (30µl of *R* + 100µL of *S*), d) 81.8% (10µl of *R*+ 100µL of *S*); e) 90.5% (5µl of *R* + 100µL of *S*); f) 95.12 (5µl of *R* + 200µL of *S*); % and g) enantiomerically-pure *S*-2-octanol.

Note:2 octanol spectra were processed using a Gaussian function (lb = -0.5Hz)

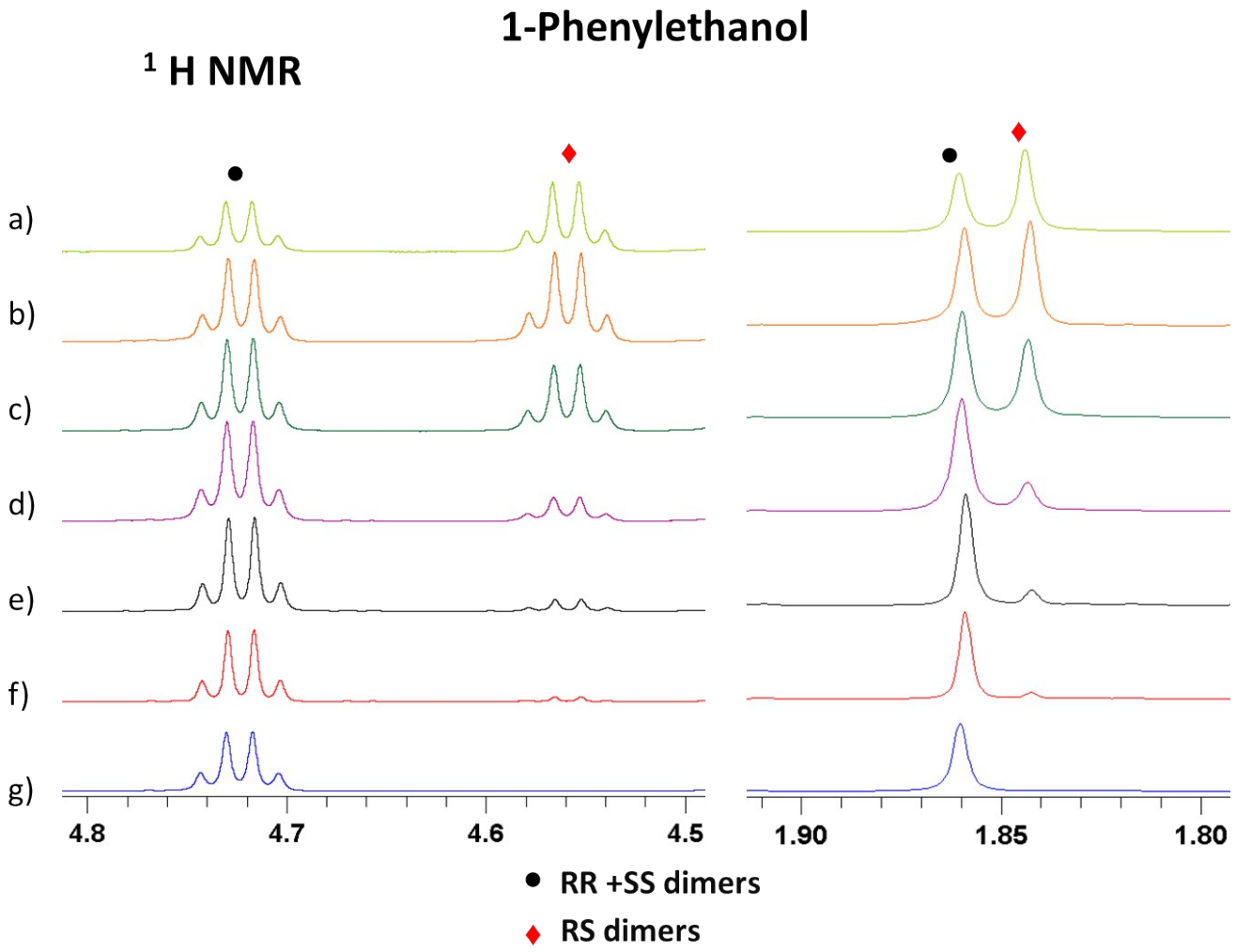


Figure S13. ^{1}H NMR (298K, d_8-toluene, 500 MHz) stacked spectra of the *in situ* reaction of **1** with 1-phenylethanol (**5**) containing different *ee*'s for the OCH region (left) and one of the 6-*Me*-Py regions (right). a) racemic; b) 33.3% (50µl of *R* + 100µL of *S*); c) 54%(30µl of *R* + 100µL of *S*); d) 82% (10µl of *R* + 100µL of *S*); e) 90.5% (10µl of *R* + 200µL of *S*); f) 95.12% (5µl of *R* + 200µL of *S*); and g) enantiomerically pure *S*-**5**.

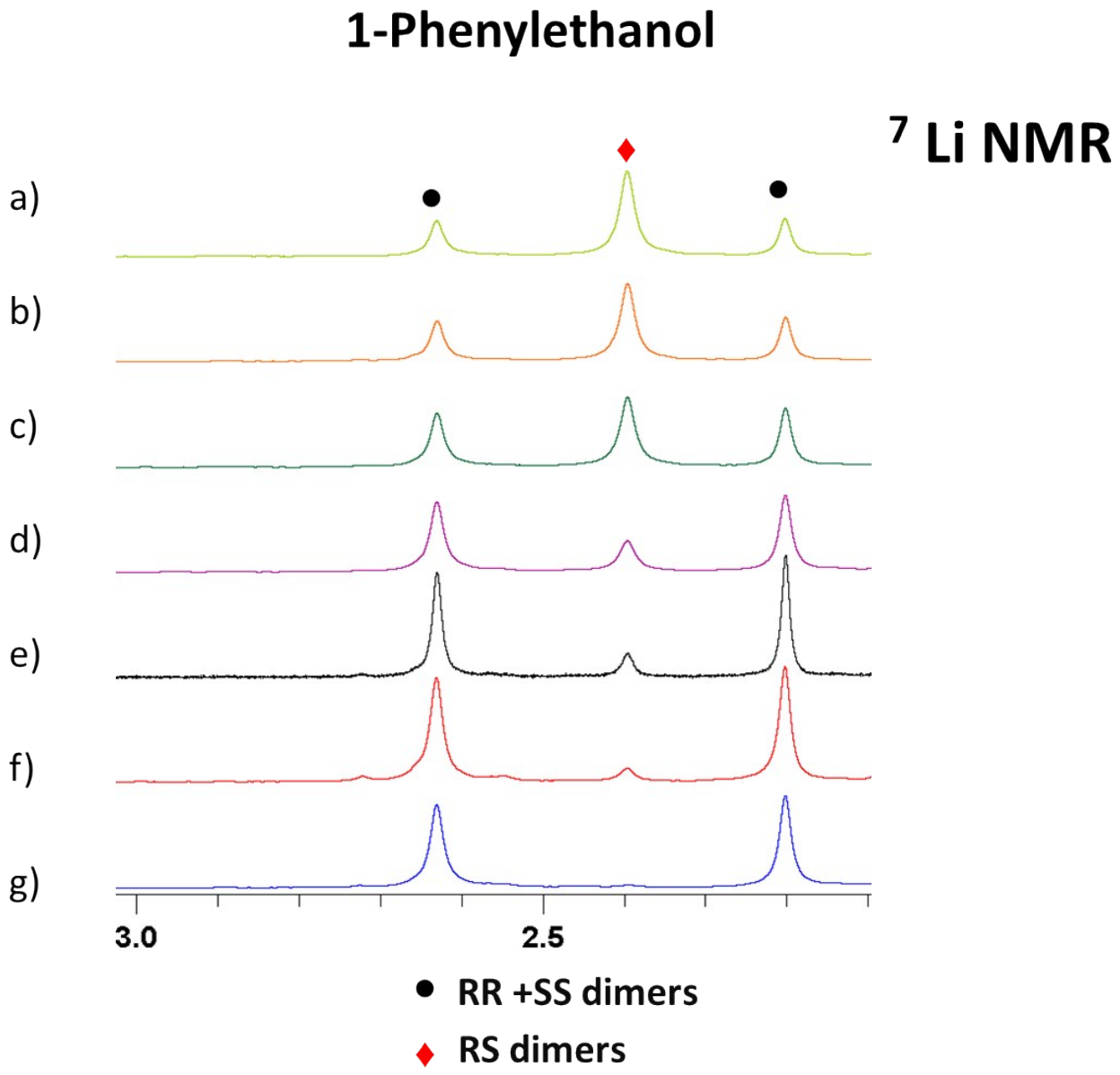


Figure S14. ^{7}Li NMR (298K, d_8-toluene, 500 MHz) stacked spectra of the *in situ* reaction of **1** with 1-phenylethanol containing different *ee*'s a) racemic; b) 33.3% (50µl of *R* + 100µL of *S*); c) 54% (30µl of *R* + 100µL of *S*); d) 82% (10µl of *R* + 100µL of *S*); e) 90.48% (10µl of *R* + 200µL of *S*); f) 95.12% (5µl of *R* + 200µL of *S*); and g) enantiomerically-pure S-**5**.

^{1}H-^{1}H NOESY and ^{1}H-^{7}Li HOESY NMR experiments of enantiomerically pure and racemic mixtures of 3-5

The different environments that result from the association of the chiral aluminates into robust dimers can be conveniently studied through NMR experiments. In particular, the correct assignation of the different environments for the lithium atoms and the 6-*Me*-Py groups for each type of dimer observed in the ^{7}Li and ^{1}H NMR spectra can be achieved through ^{1}H-^{7}Li HOESY and ^{1}H-^{1}H NOESY experiments . As shown previously, the different environments result from the fact that in these dimers the Li atoms and 6-*Me*-Py groups are orientated differently. The ^{1}H-^{7}Li HOESY experiment can be used to assess the spatial proximity between ^{7}Li and ^{1}H nuclei in a similar manner to how the^{1}H-^{1}H NOESY experiment is employed to correlate protons that are close in space.

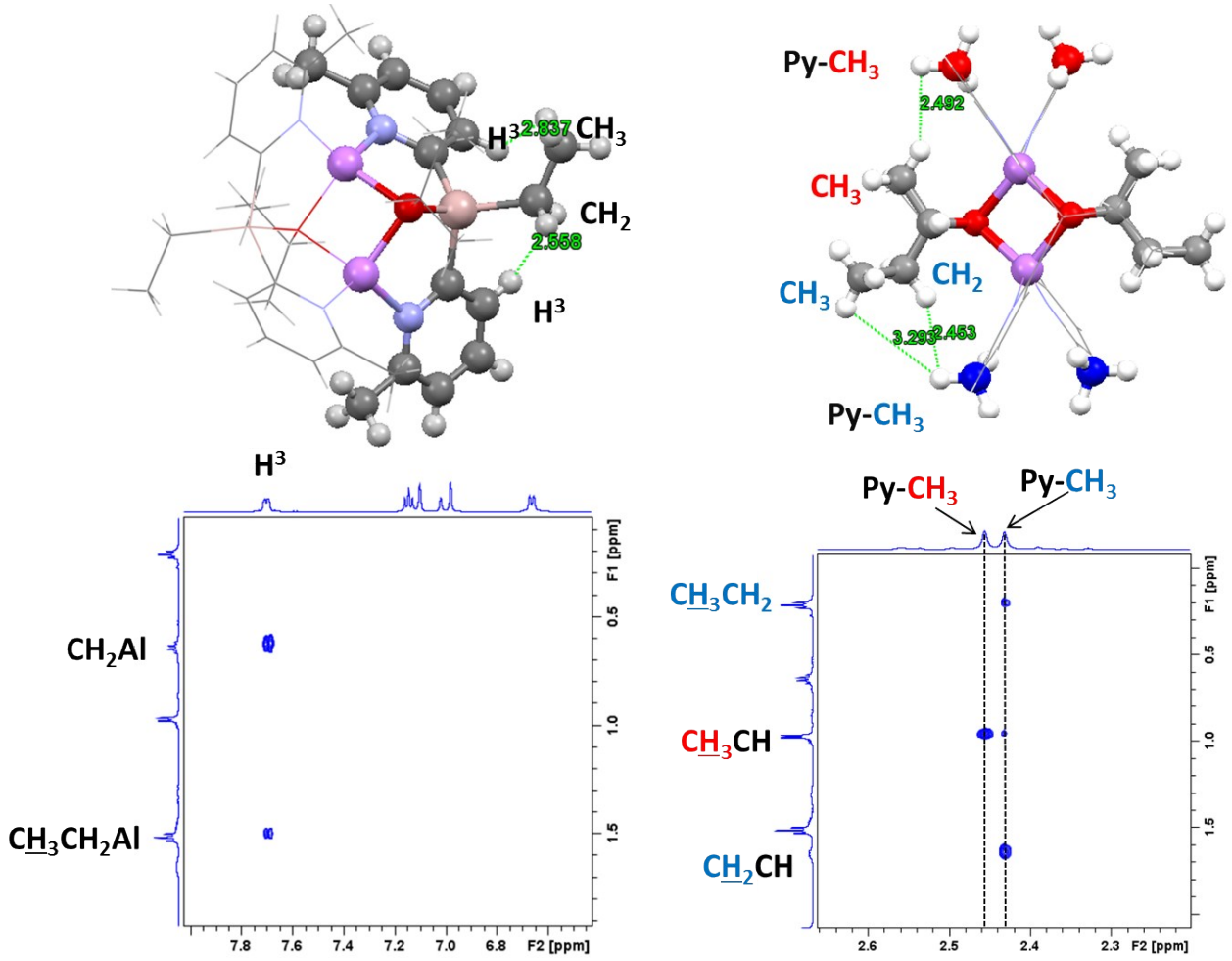


Figure S15. ^{1}H-^{1}H NOESY (298K, d_8-toluene, 400 MHz, mixing time of 600 ms) selected regions of spectrum of *S*-**3**. (Left) shows the crosspeaks between H^3 and the protons of Al-CH_2CH_3, confirming the presence of an Et−Al-Py linkage and the correct assignment of the pyridyl resonance as H^3. (Right), the two different 6-*Me*-Py environments in the homochiral dimer **3**-*SS*. As the ^{1}H-^{1}H NOESY experiment shows, two of the Me-6-Py groups are closer to the alkoxide Me group (singlet at 2.45 ppm, labeled in blue) than the other two of the Me-6-Py groups which are closer to the alkoxide ethyl group (singlet at 2.43 ppm, labeled in red). Dashed lines are given as guides to the eye. The corresponding distances from the X-ray structure are also given (above).

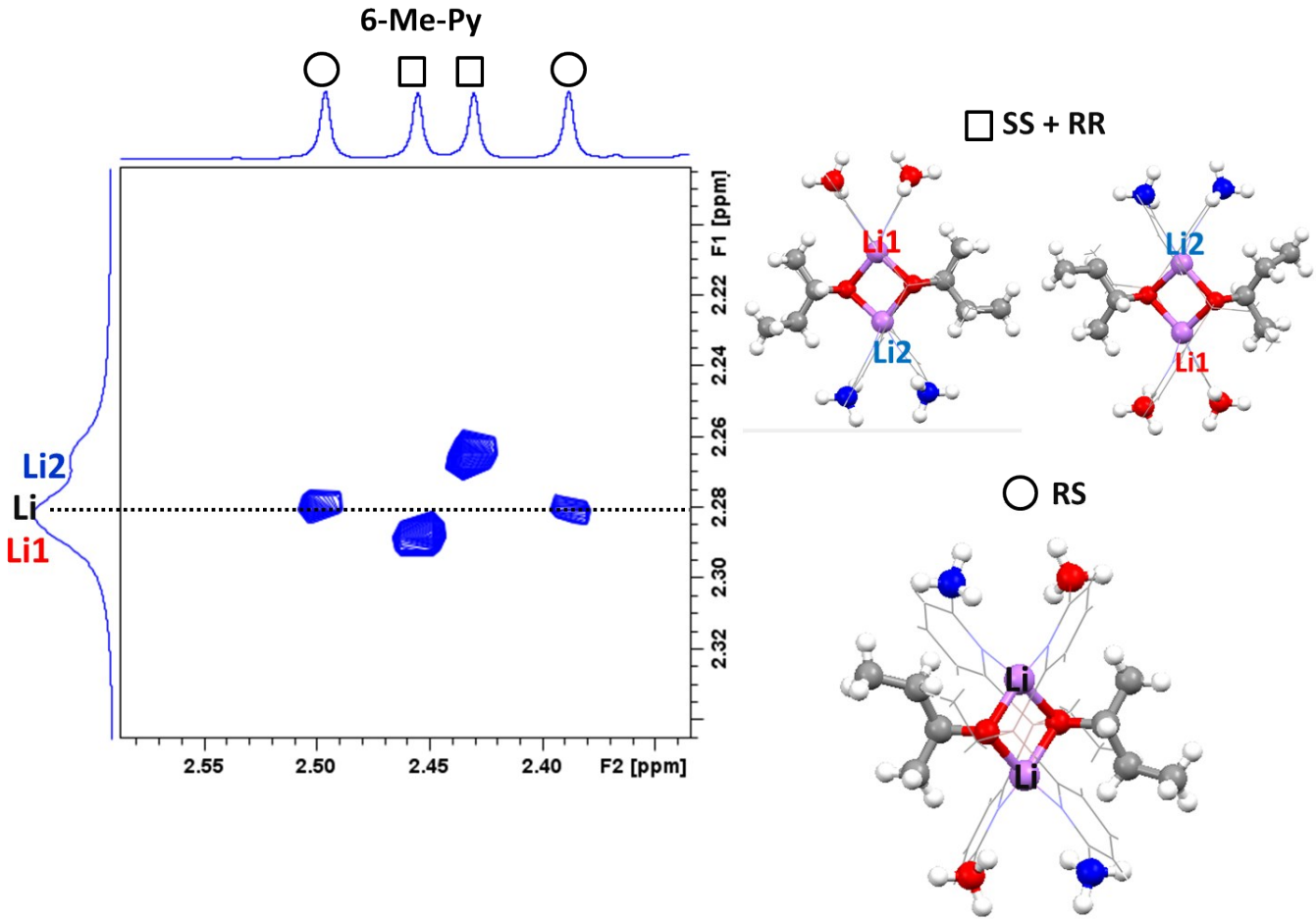


Figure S16. ^{1}H-^{7}Li HOESY (298K, d_8-toluene, 500 MHz, mixing time of 100 ms) spectrum of *rac*-**3**). The ^{1}H-^{7}Li HOESY experiment shows that the multiplet observed in the ^{7}Li NMR spectrum results from the overlap of the three signals: two singlets observed in enantiomerically pure *R*-/*S*-**3** (see for instance Fig. S10 and section" Symmetry of the complexes" on page S15 for details) with an additional singlet due to the *RS* dimer. The X-ray structure of the homochiral **3**-*SS*/**3**-*RR* (a pair of enantiomers) and heterochiral **3**-*RS* dimers are shown on the right.

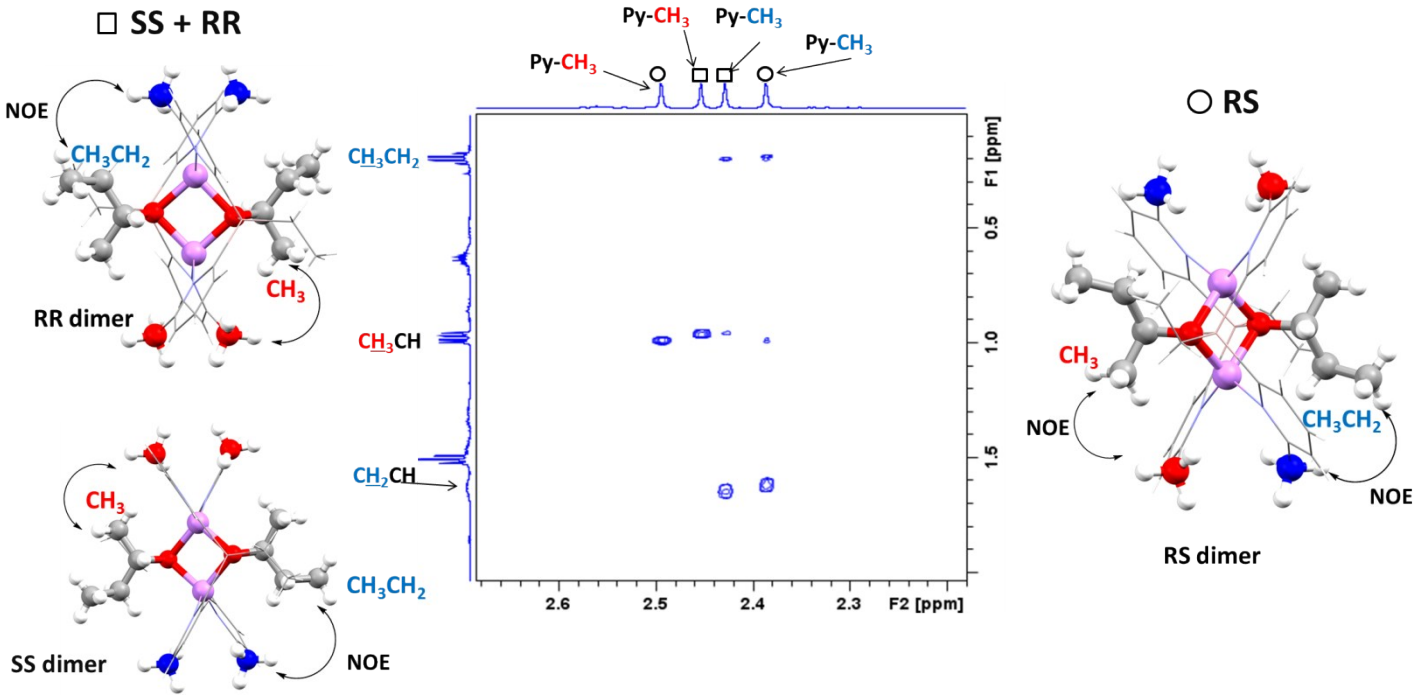


Figure S17. ^{1}H-^{1}H NOESY (298K, d_8-toluene, 500 MHz, mixing time of 600 ms) selected 6-*Me*-Py region of the spectrum of racemic-[EtAl(OCH(CH_3)CH_2CH_3)(6-Me-2-py)2Li]$_2$ (rac-**3**). Four distinct resonances in the 6-*Me*-Py region are observed consisting of those for **3**-*SS*/**3**-*RR* (two resonances for each, blue and red, that are coincident, since they are present as a pair of enantiomers) and **3**-*RS* (two resonances, red and blue). The solid state structure of *all* of the possible dimers of **3**: **3**-*SS*, **3**-*RR* and **3**-*RS* is also shown along with the NOE cross peaks observed. See also see FigS18.

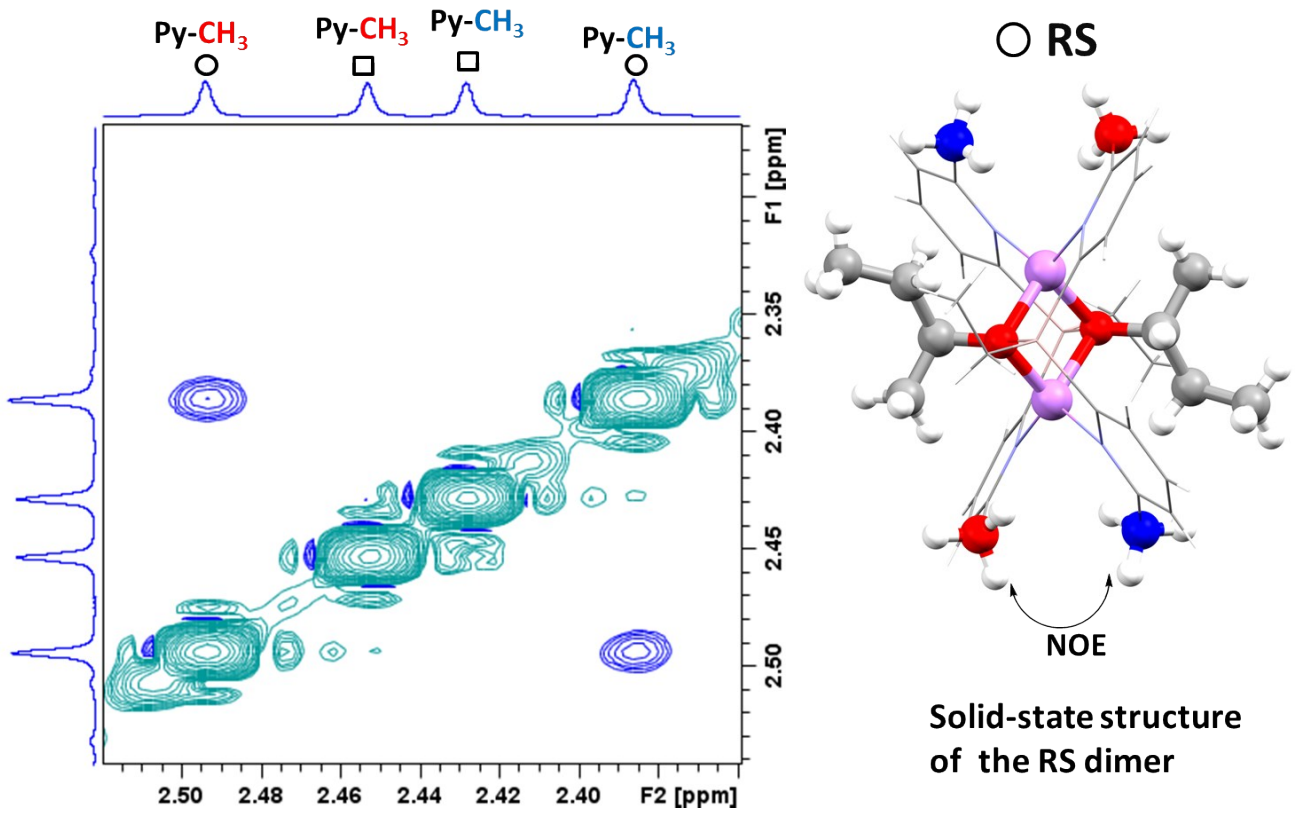


Figure S18. ^{1}H-^{1}H NOESY (298K, d_8-toluene, 500 MHz, mixing time of 600 ms) selected 6-CH_3-Py region of the spectrum of *rac*-**3**. The two different 6-Me groups of the *RS* dimer are in close spatial proximity in the solid -state structure (2.55 Å), right, resulting in the crosspeaks observed in the NOESY experiment.

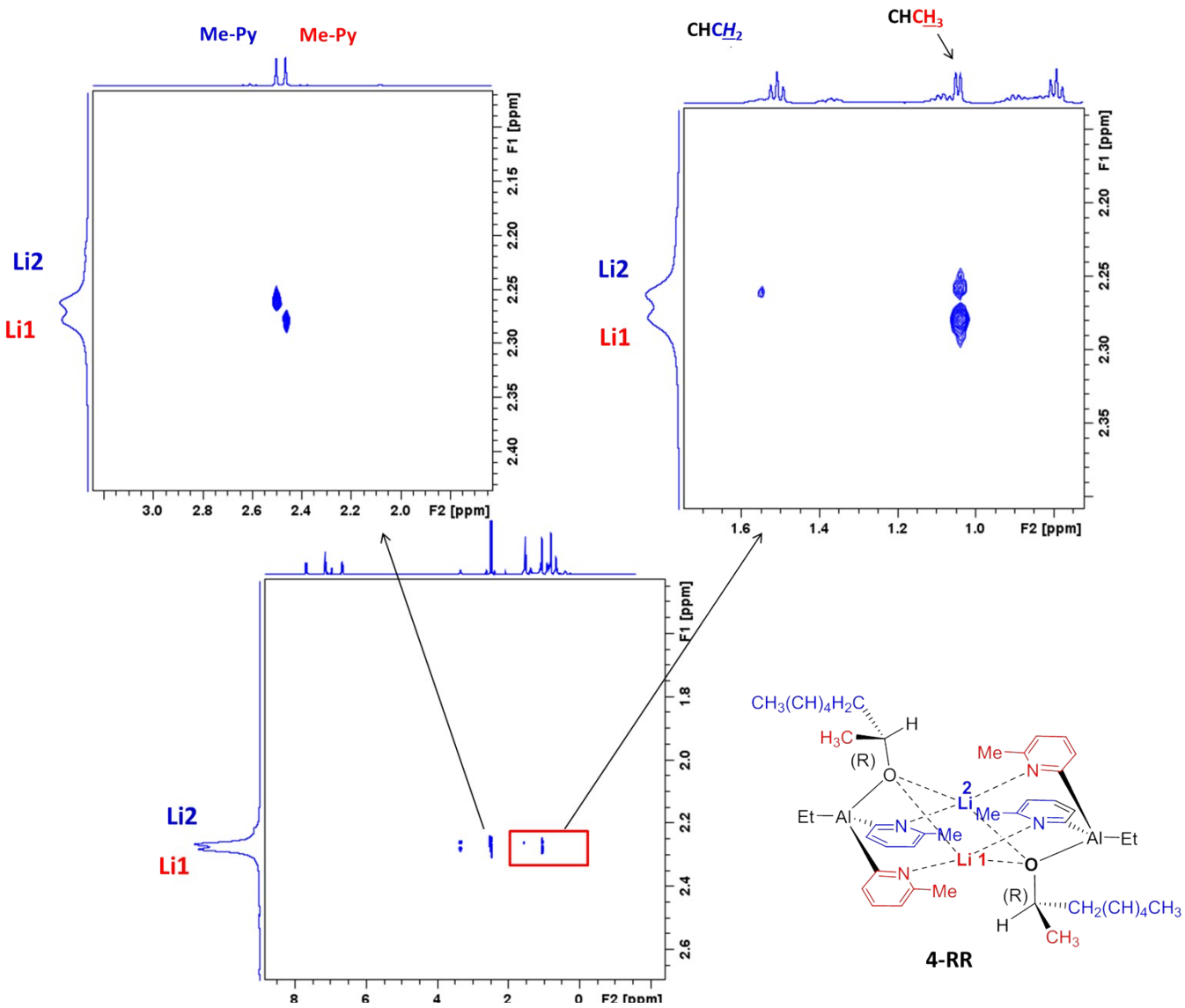


Figure S19. ^{1}H-^{7}Li HOESY (298K, d_8-toluene, 500 MHz, mixing time of 100 ms) spectrum of *R*-**4**. The experiment shows crosspeaks between both ^{7}Li resonances and the CH resonance of the 2-octyloxy group, indicating that both Li atoms are spatially close to the CH group. Each of the two singlets for the Py-CH_3 groups showed a crosspeak with only one of the ^{7}Li signals (which has been represented by using the same color code, blue or red, see the insert of the region highlighted in red), since for each of these two Py-CH_3 groups only one of the two Li nuclei is close in space. The assignment of the ^{7}Li resonances as Li1 and Li2 has been done on the basis of the ^{1}H-^{7}Li HOESY experiment. While Li1 showed an intense crosspeak with the CH_3 protons, Li2 showed a weaker crosspeak with the CH_3 protons and, additionally a crosspeak with the CH_2 protons. This agrees with a dimeric structure in solution (toluene) shown on the right,which shows that the arrangement of the 2-octyloxy group is such that one of the Li nuclei is closer to the $(CH_2)_5CH_3$ fragment while the other Li is closer to the CH_3 group.

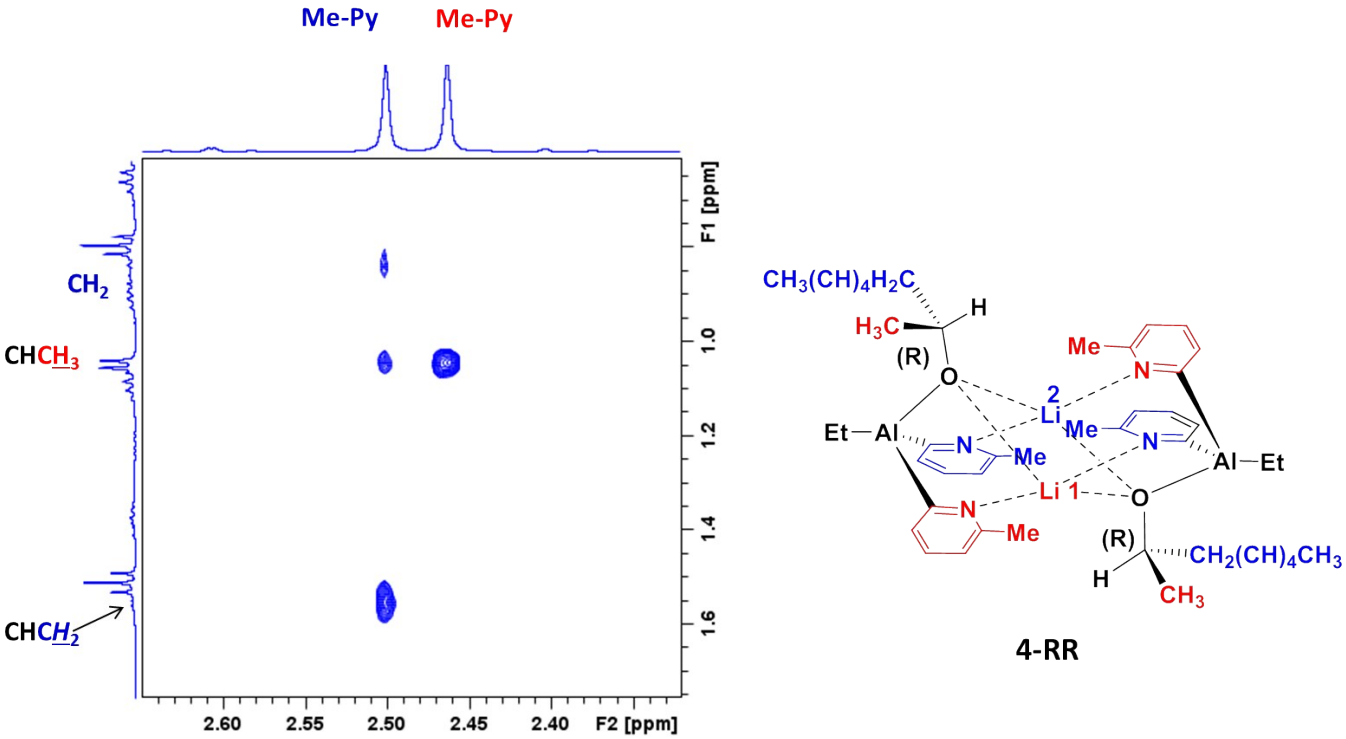


Figure S20. ^{1}H-^{1}H NOESY (298K, d_8-toluene, 400 MHz, mixing time of 600 ms) showing the two different 6-Me-Py environments (red and blue) in the homochiral dimer **4**-*RR* of the spectrum of *R*-**4**.The ^{1}H-^{1}H NOESY experiment shows that two of the *Me*-6-Py groups (singlet at 2.46 ppm, labeled in red) are spatially closer the alkoxide Me group, OCH$\underline{CH_3}$, (labeled in red) than the other two *Me*-6-Py groups (singlet at 2.50 ppm, labeled in blue), which are closer to the $(CH_2)_5CH_3$ chain (labeled in blue).

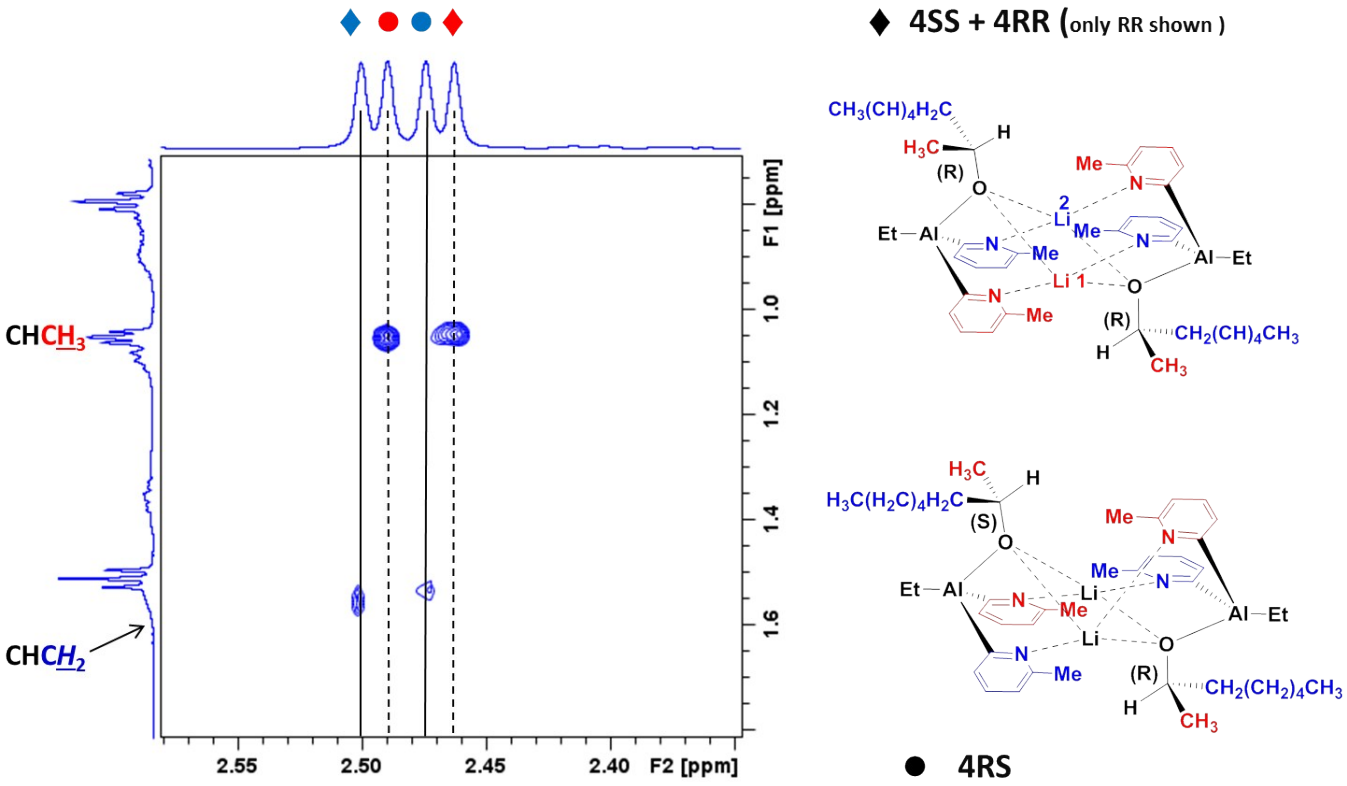


Figure S21. ^{1}H-^{1}H NOESY (298K, d_8-toluene, 400 MHz, mixing time of 600 ms) of the 6-*Me*-Py region of spectrum of *rac*-**4**. Two type of dimers are formed: homochiral *RR*, *SS* and heterochiral *RS* (centrosymmetric, achiral). Each dimer gives two different environments for the 6-*Me*-Py resonances, since the Me groups can face the CH_3 (singlets at 2.49 for *RS* dimers and 2.46 for *RR* + *SS* dimers) or $(CH_2)_5CH_3$ alkoxide groups (singlets at 2.50 for *RR* + *SS* dimers and 2.47 for *RS* dimers). See line-drawing on the right.

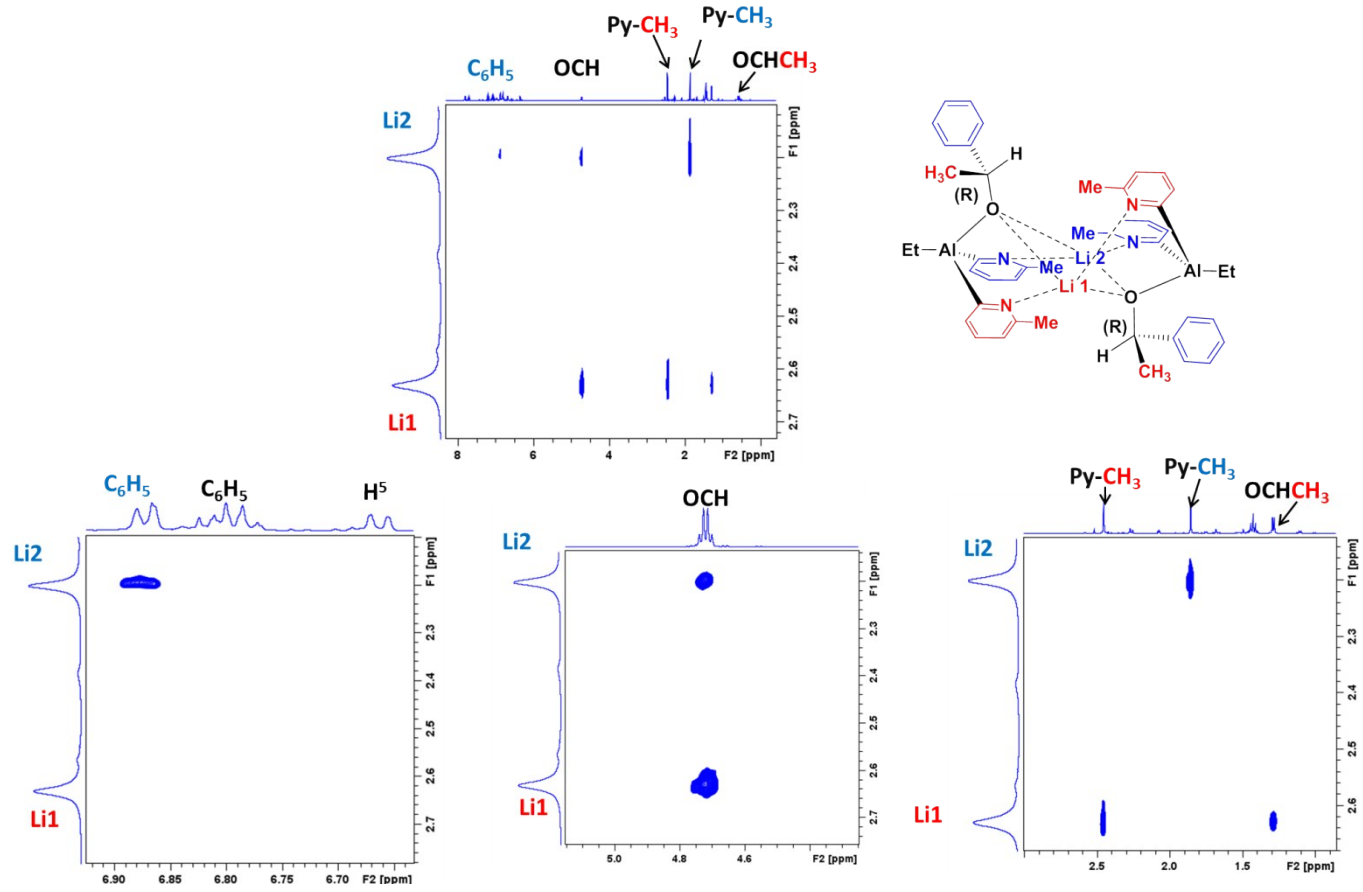


Figure S22. ^{1}H-^{7}Li HOESY (298K, d_8-toluene, 500 MHz, mixing time of 100 ms) (above) spectrum of *R*-**5** and (below) selected regions. The experiment shows crosspeaks between both ^{7}Li resonances and the OC*H* resonance, indicating that both Li atoms are spatially close to the CH group. Each of the two singlets for the Py-CH_3 groups showed a crosspeak with only one of the ^{7}Li signals (which has been represented by using the same color code, blue or red, see the line drawing on the top right). While Li1 showed a crosspeak with the CH_3 protons (indicating close proximity of these nuclei), Li2 showed a crosspek with the C_6H_5 ortho-protons. The results of the experiment agree with a dimeric structure in solution as shown in the line drawing.

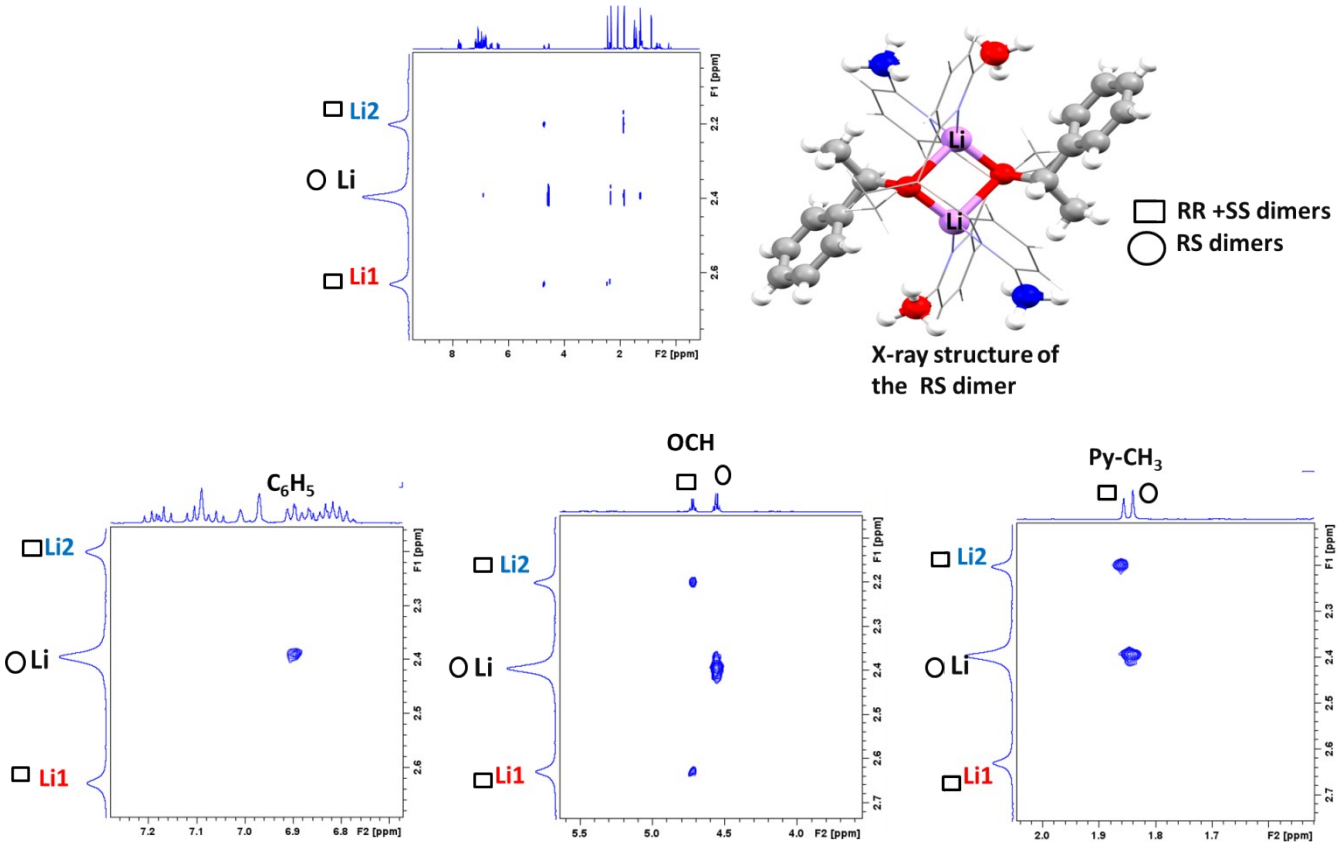


Figure S23. ^{1}H-^{7}Li HOESY (298K, d_8-toluene, 500 MHz, mixing time of 100 ms) (above) spectrum of *rac*-**5**) and (below) selected regions. Three singlets are observed in the ^{7}Li NMR spectrum, a central resonance, resulting from the single magnetic environment of **5**-*RS* (which is centrosymmetric), which is flanked by the resonances for **5**-*SS* and **5**-*RR,* two resonances for each that are coincident (see also section "Symmetry of the complexes" on page S15).

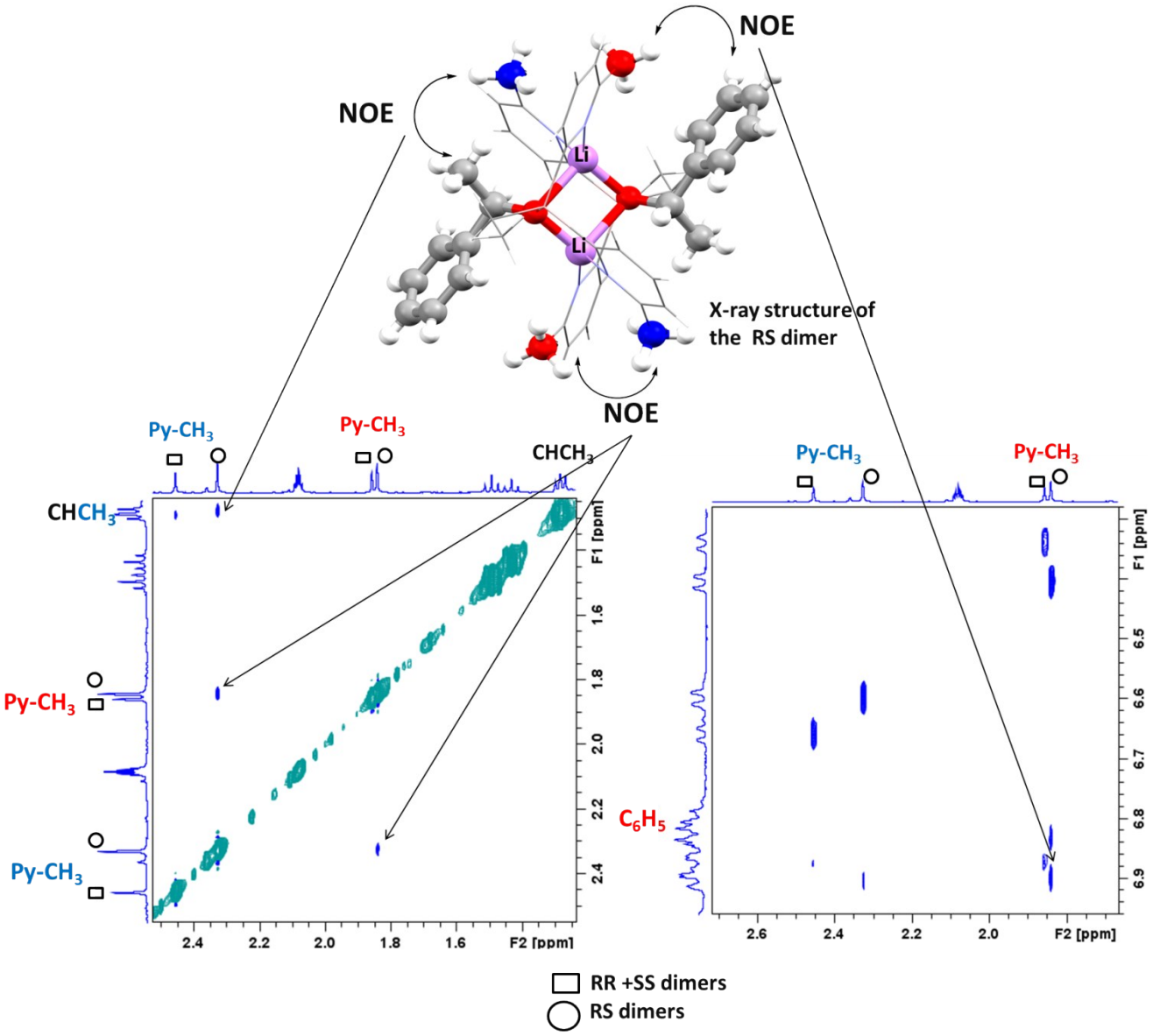


Figure S24. ^{1}H-^{1}H NOESY (298K, d_8-toluene, 500 MHz, mixing time of 600 ms) 6-*CH*$_3$-Py region of the spectrum of *rac*-**5**. The solid-state structures of heterochiral **5**-*RS* is shown above. The crosspeaks observed in the NOESY experiment show that the dimeric structure found for **5**-*RS* is retained in solution.

Representative NMR spectra for 2-5

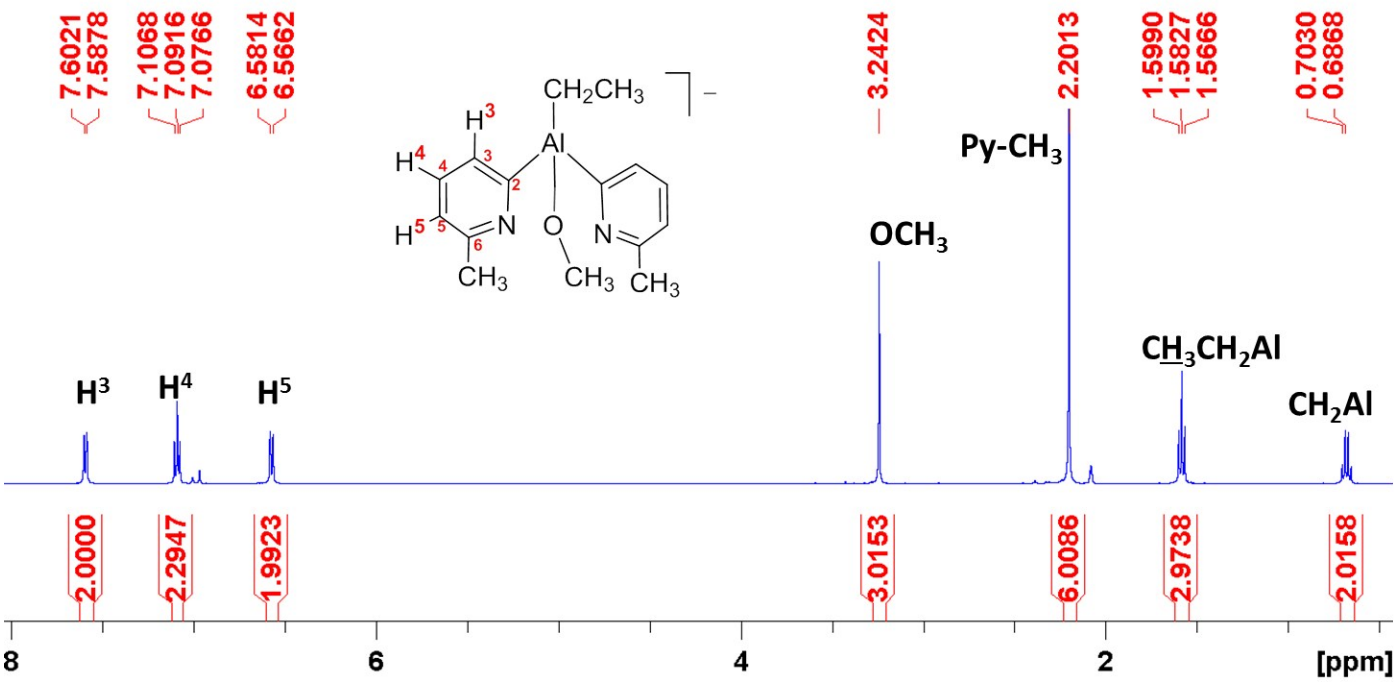


Figure S25. ^{1}H NMR (298K, d_8-toluene, 500 MHz) spectrum of $[EtAl(OMe)(6\text{-}Me\text{-}2\text{-}py)_2Li]_2$ (**2**). The H4 resonance partially overlaps with residual toluene-d_8 signal

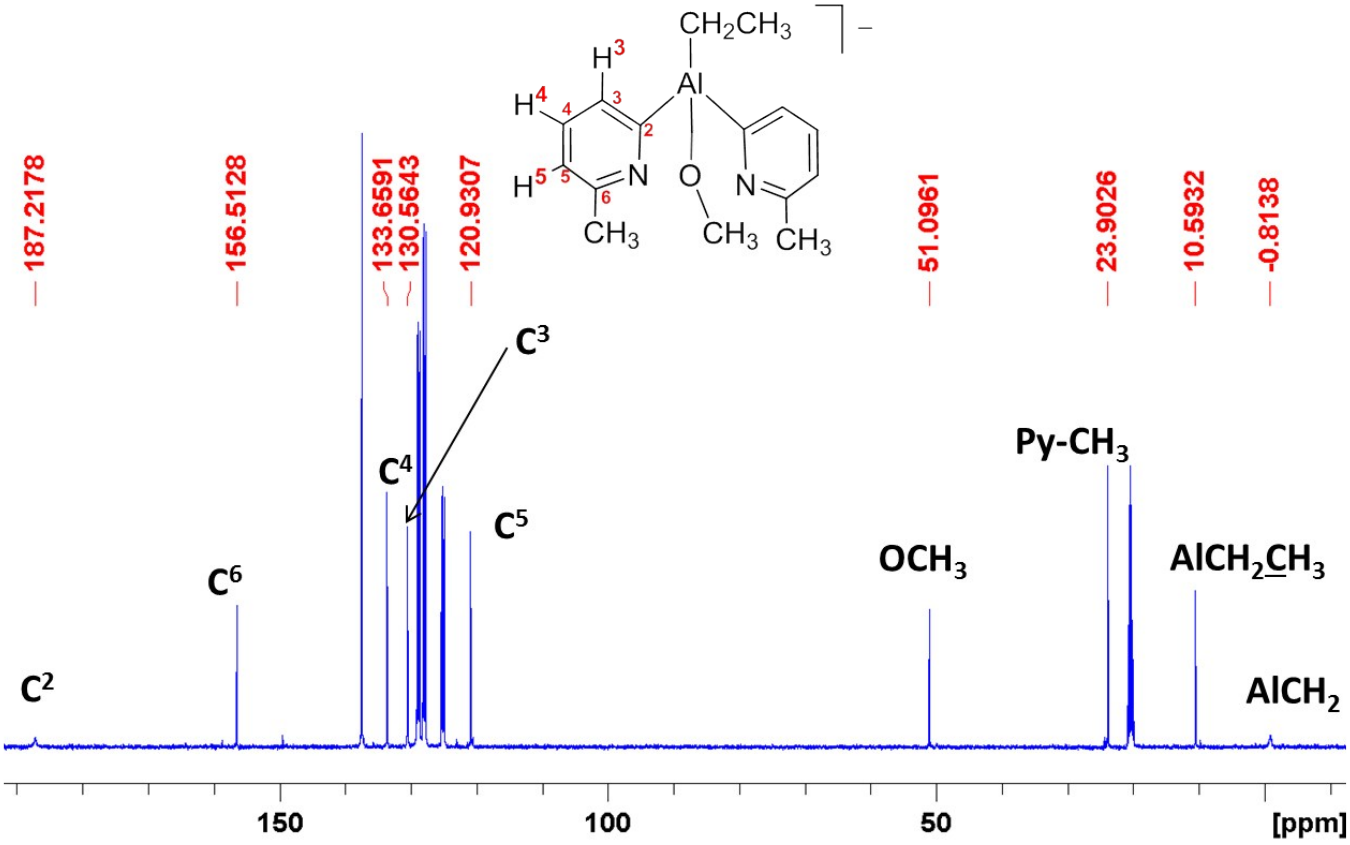


Figure S26. $^{13}C\{^{1}H\}$ NMR (298K, d_8-toluene, 100.6 MHz) spectrum of **2**. Note that despite the low-intensity broad resonances of Al-bonded C atoms at 187.2 (br, C^2 py) and -0.81 (br, Al–CH_2) ppm these resonances are observed through ^{1}H-^{13}C HMBC and ^{1}H-^{13}C HMQC experiments.

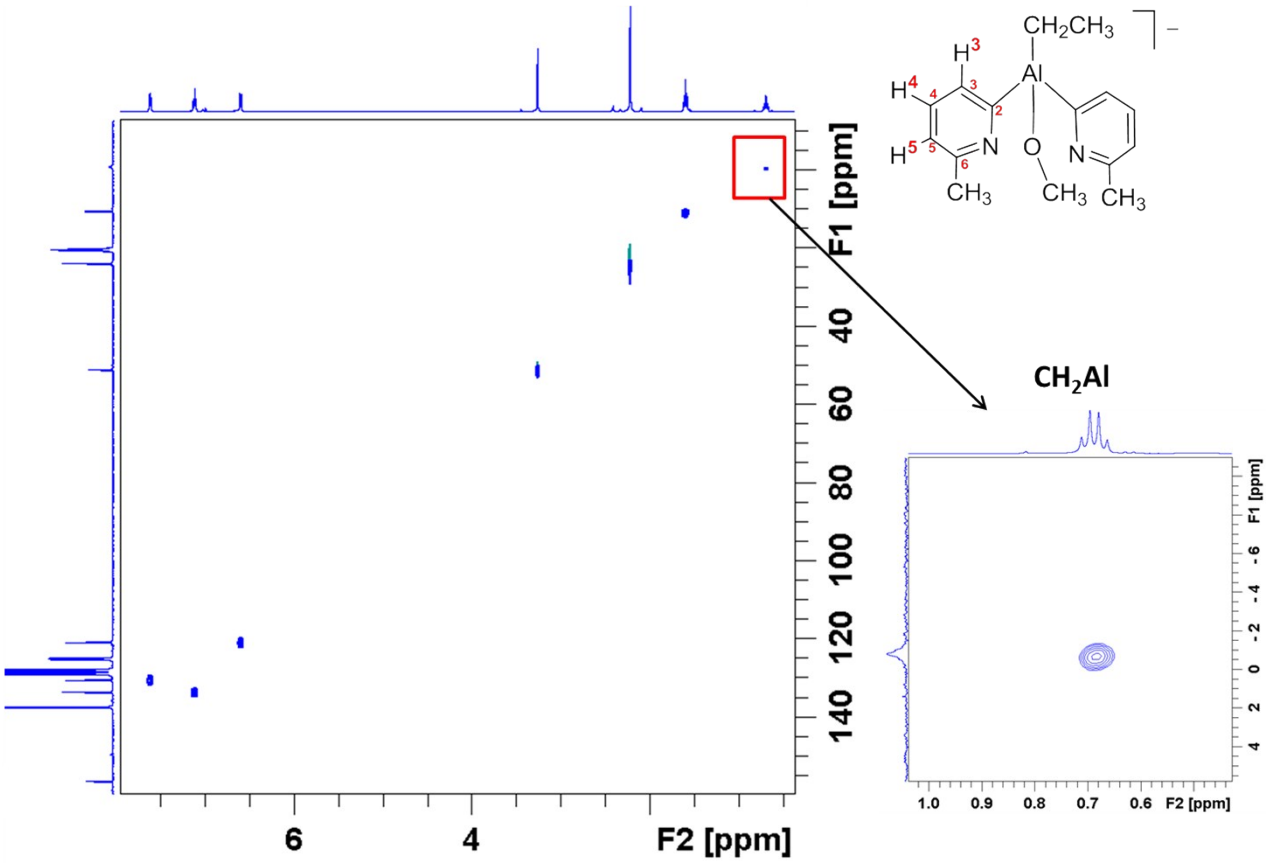


Figure S27. ^{1}H-^{13}C HMQC (298K, d_8-toluene, 500 MHz) spectrum of **2**. The correlation between the $AlCH_2$ protons and the broad carbon resonance is highlighted in red. Note: 1D $^{13}C\{^{1}H\}$ NMR spectrum processed with a line broadening (lb) of 5Hz is shown in the 'external projection'

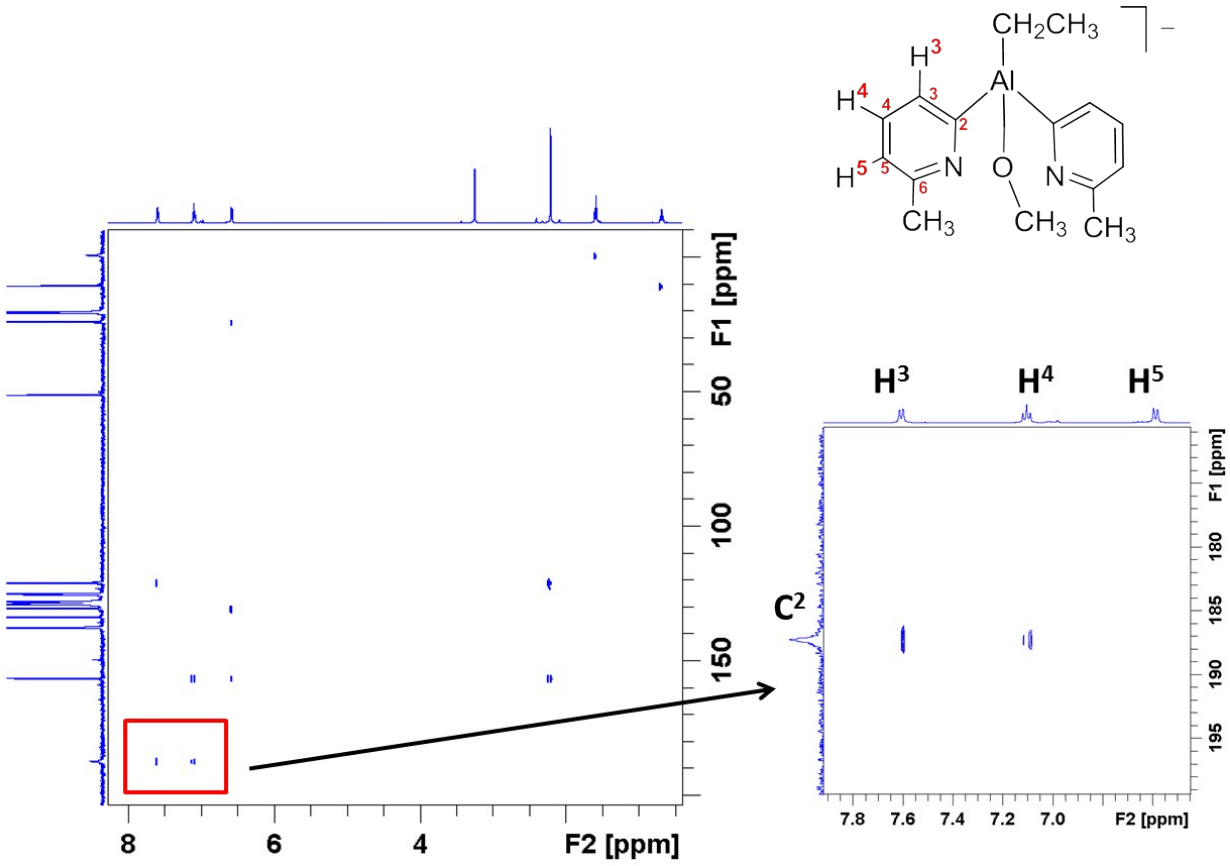


Figure S28. ^{1}H-^{13}C HMBC (298K, d_8-toluene, 500 MHz) spectrum of **2**. The correlation between the broad carbon resonance of Al-C^2 py and H^3py and H^4 py is highlighted in red. (the correlation of H^5 and CH_3Py is also).

Note: 1D $^{13}C\{^{1}H\}$ NMR spectrum processed with a line broadening (lb) of 5Hz is shown in the 'external projection'.

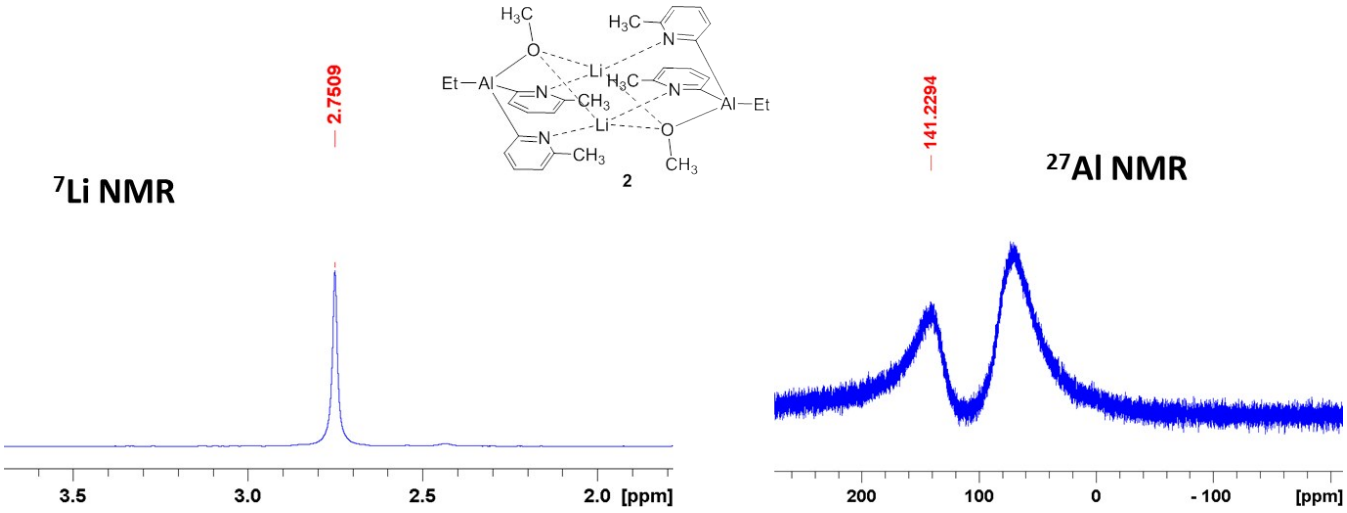


Figure S29. ^{7}Li NMR (298K, d_8-toluene, 194.4 MHz, referenced to a solution of LiCl/D_2O) (left) and ^{27}Al NMR (130.3 MHz, 298K, d_8-toluene, referenced to a solution of $AlCl_3.6H_2O/D_2O$) (right) spectra of **2**.

Note: The broad signal at around 65 ppm in the ^{27}Al NMR spectrum arises from the probe background.

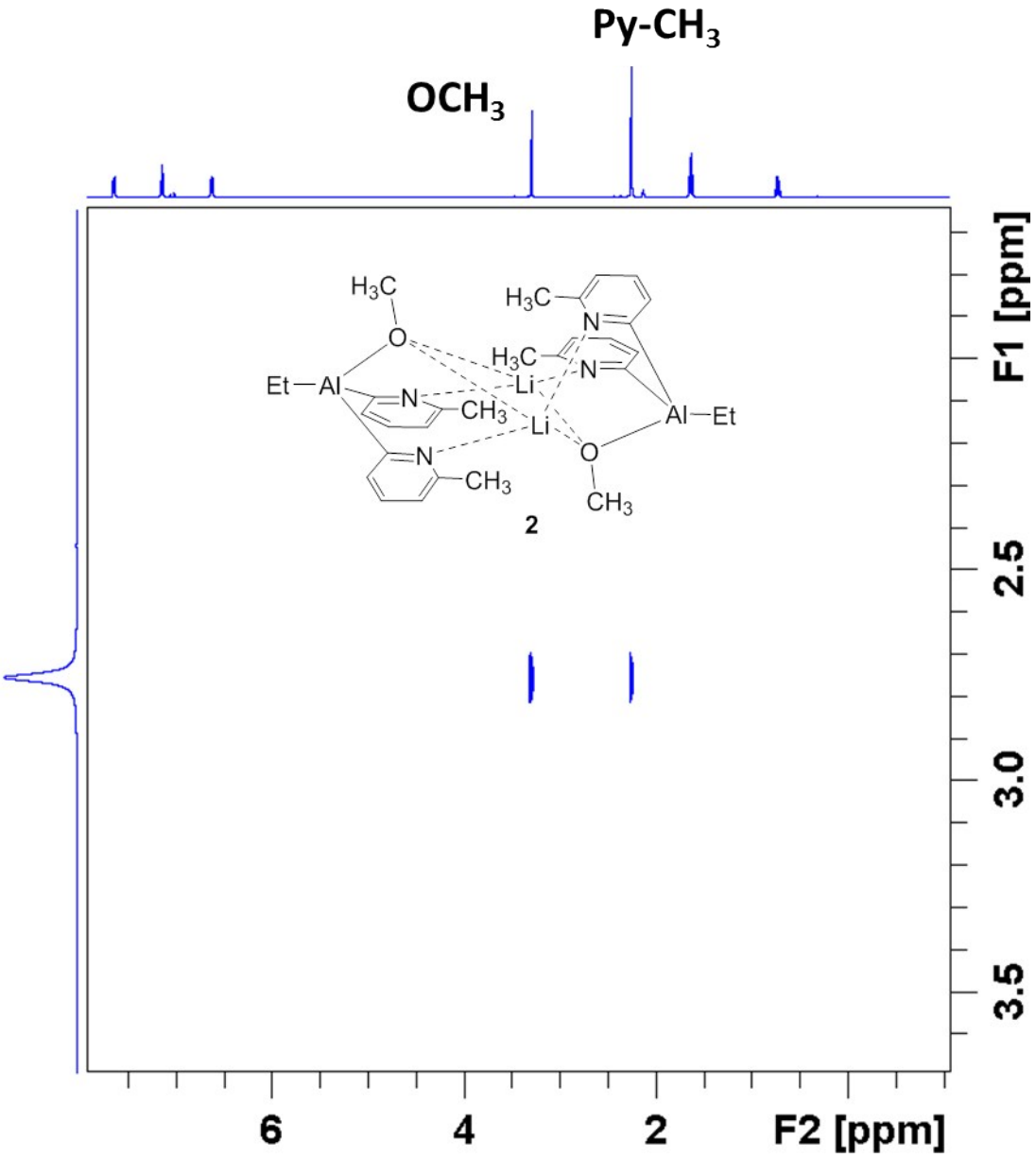


Figure S39. ^{1}H-^{7}Li HOESY (298K, d_8-toluene) spectrum of **2**.

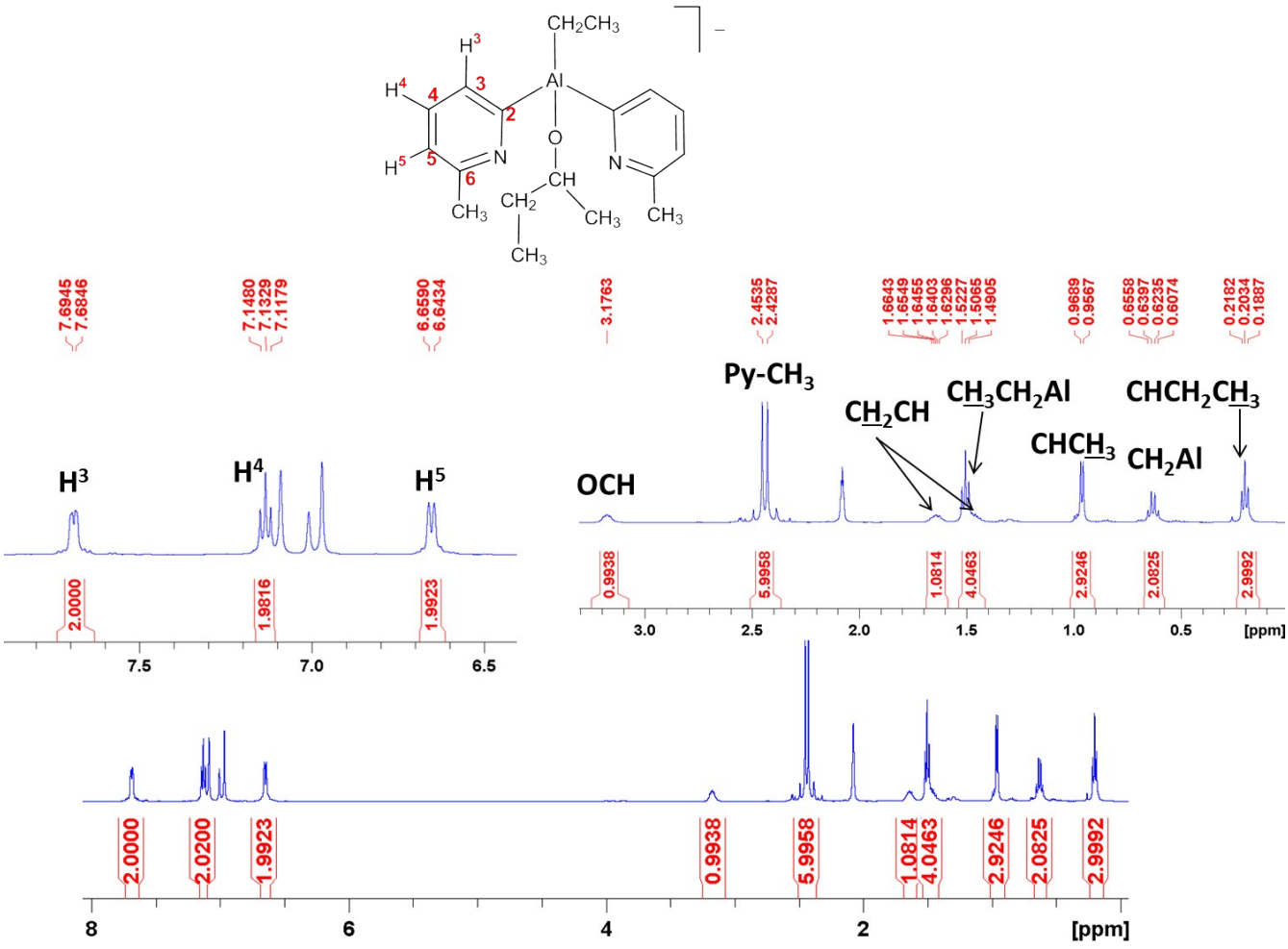


Figure S31. ^{1}H NMR (298K, d_8-toluene, 500 MHz) spectrum of crystals *S*-[EtAl(OCH(CH_3)CH_2CH_3)(6-Me-2-py)$_2$Li]$_2$ (**S-3**).

Note: a very small amount of dimer *RS* was found in this sample easily observed by the two characteristic Me-Py singlets at 2.49 and 2.39 ppm, which comes from the commercially-supplied chiral 2-S-butanol;

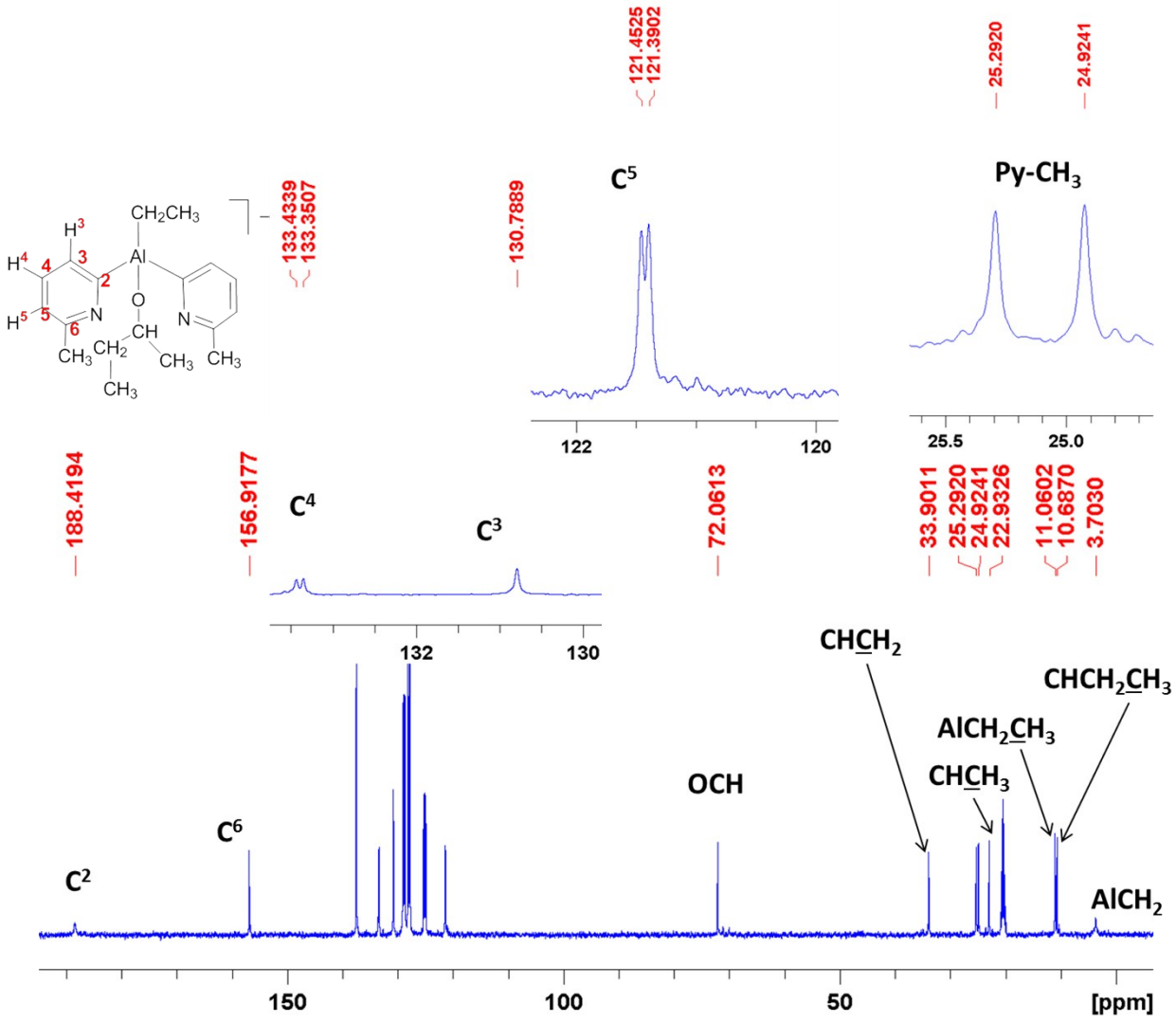


Figure S32. $^{13}C\{^{1}H\}$ NMR (298K, d_8-toluene, 100.6 MHz) spectrum of **S-3**. Note that despite the low-intensity broad resonances of Al-bonded C atoms at 187.2 (br, C^2 py) and -0.81 (br, Al–CH_2) ppm these resonances are observed through ^{1}H-^{13}C HMBC and ^{1}H-^{13}C HMQC experiments.

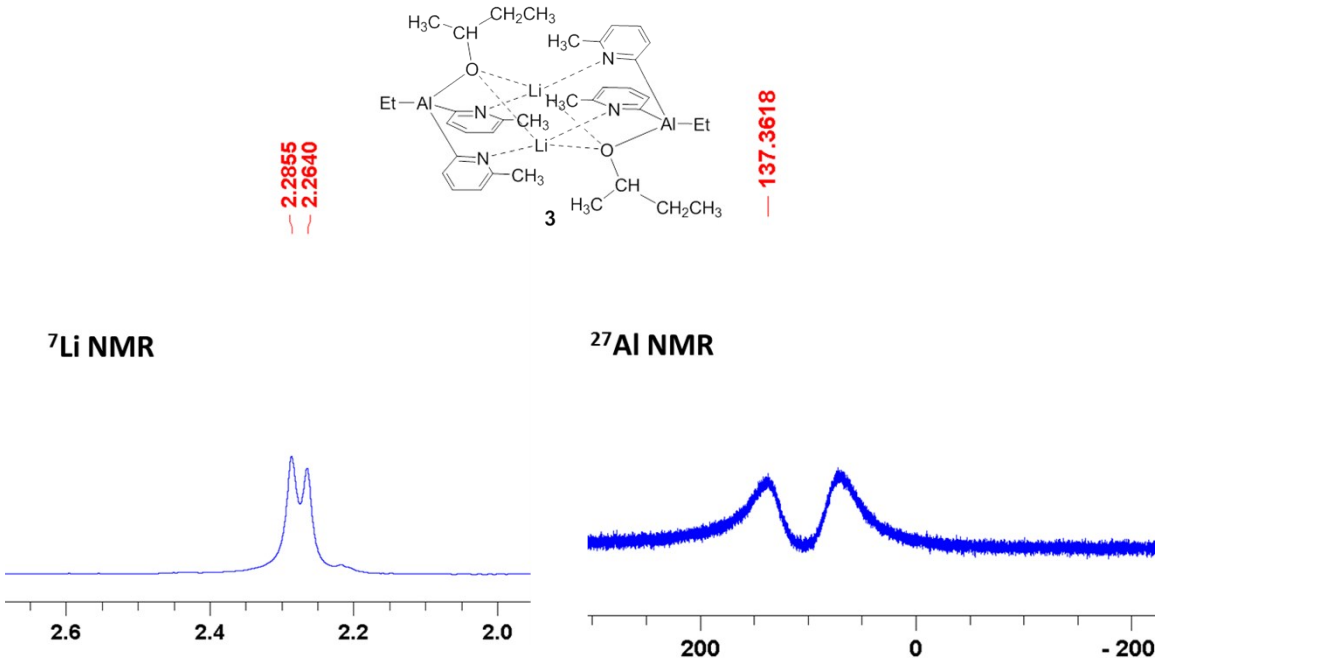


Figure S33. ^{7}Li NMR (298K, d_8-toluene, 194.4 MHz, referenced to a solution of LiCl/D_2O) (left) and ^{27}Al NMR (130.3 MHz, 298K, , d_8-toluene, referenced to a solution of $AlCl_3.6H_2O/D_2O$) (right) spectra of **S-3**.

Note: The broad signal at around 65ppm in the ^{27}Al NMR spectrum arises from the probe background.

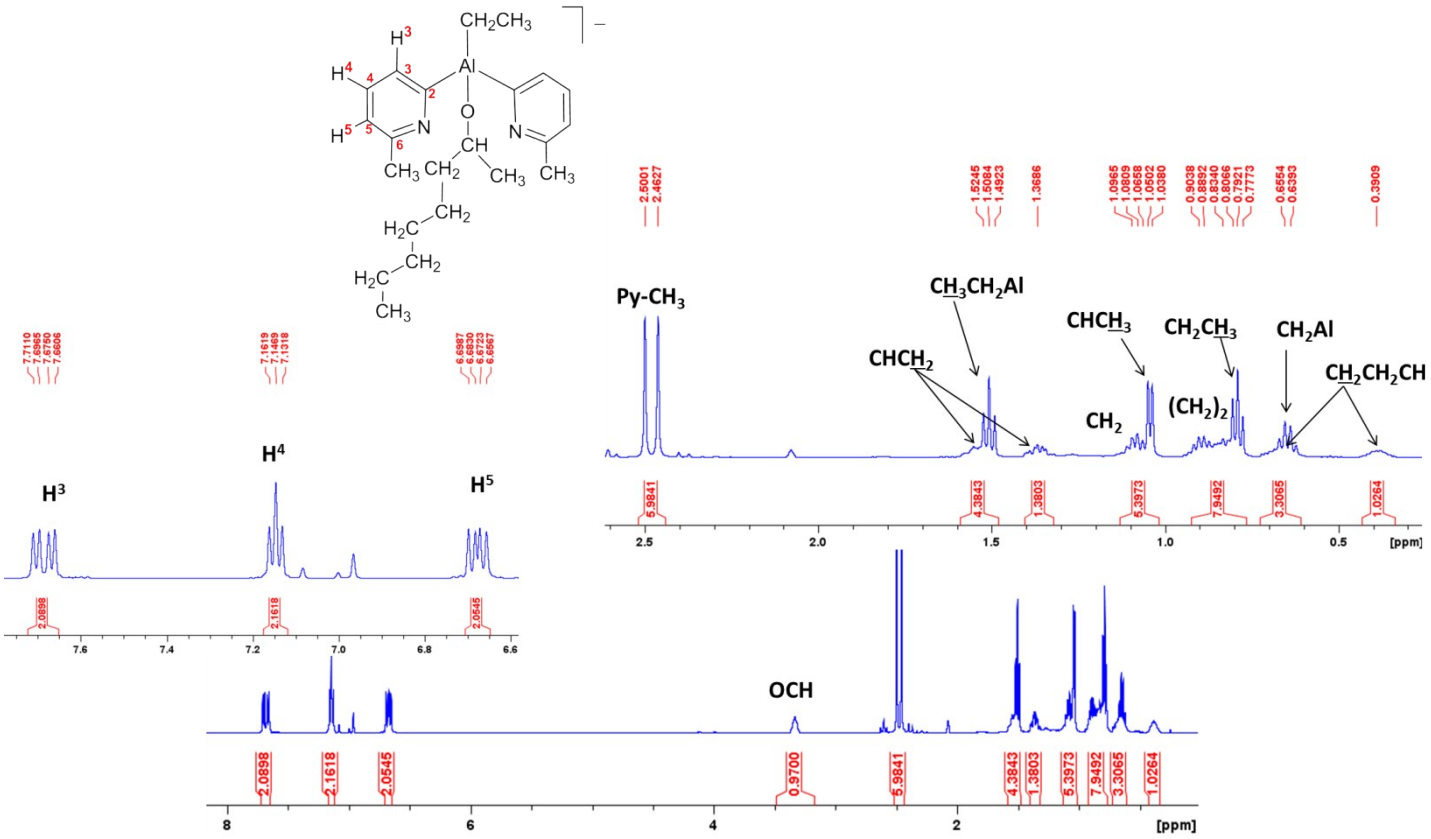


Figure S34. ^{1}H NMR (298K, d_8-toluene, 500 MHz) spectrum of *R*-**4**.

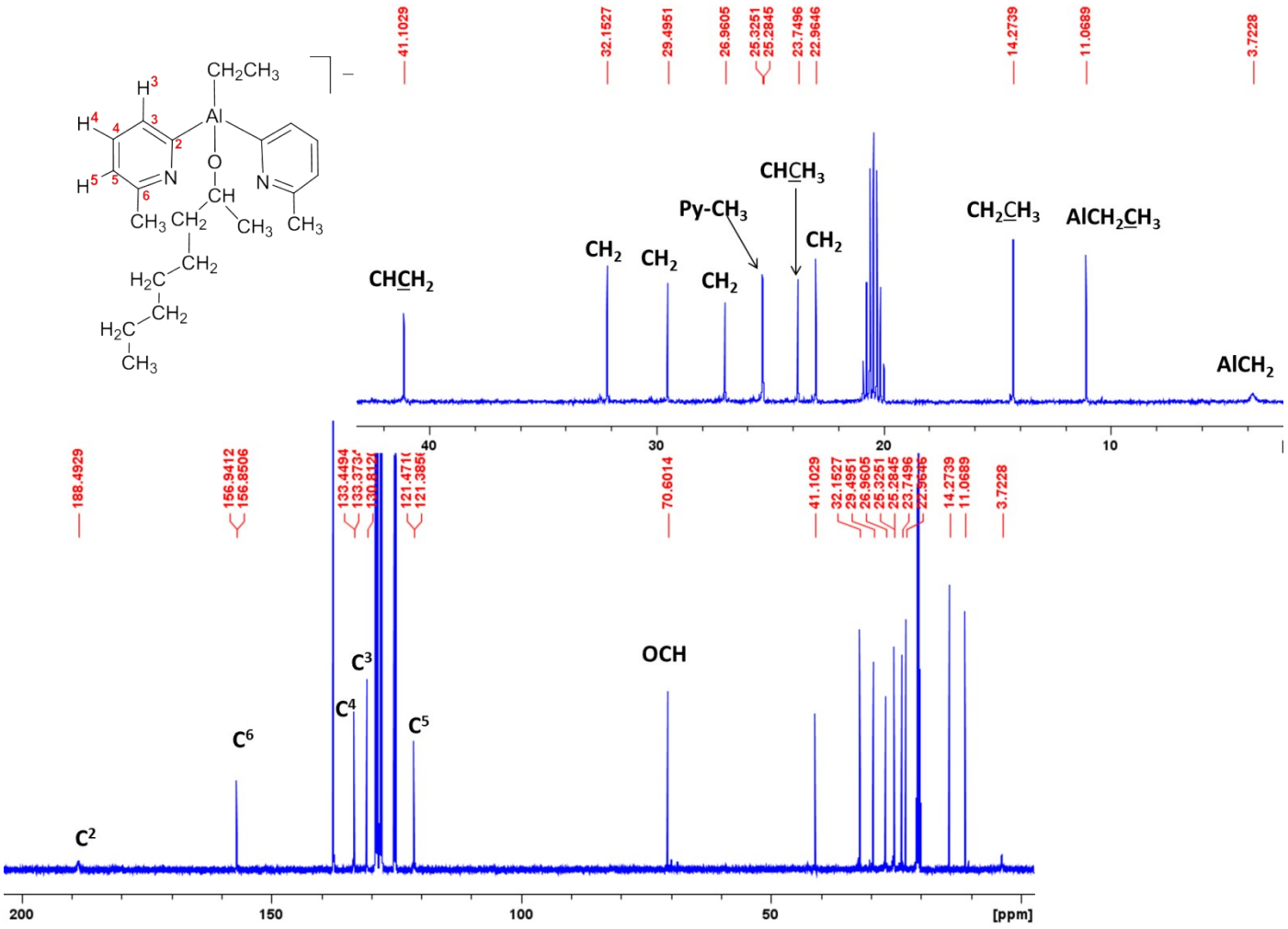


Figure S35. $^{13}C\{^{1}H\}$ NMR (298K, d_8-toluene, 100.6 MHz) spectrum of *R*-**4**. Note that despite the low-intensity broad resonances of Al-bonded C atoms (br, C^2 py and Al–CH_2) these resonances are easily observed through ^{1}H-^{13}C HMBC and ^{1}H-^{13}C HMQC experiments (see Figures S36-S37).

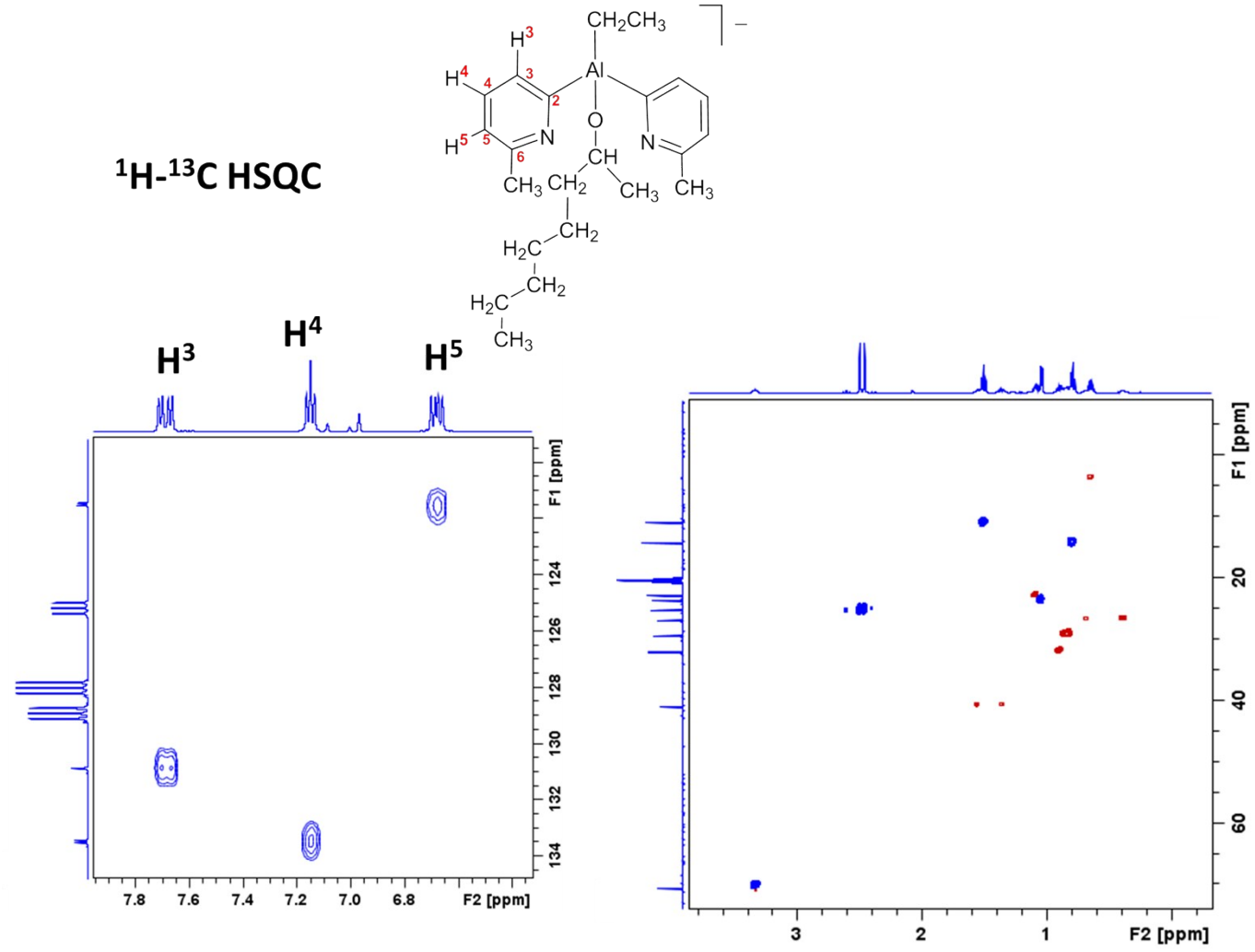


Figure S36. ^{1}H-^{13}C HSQC spectrum (298K, d_8-toluene) of *R*-**4**.

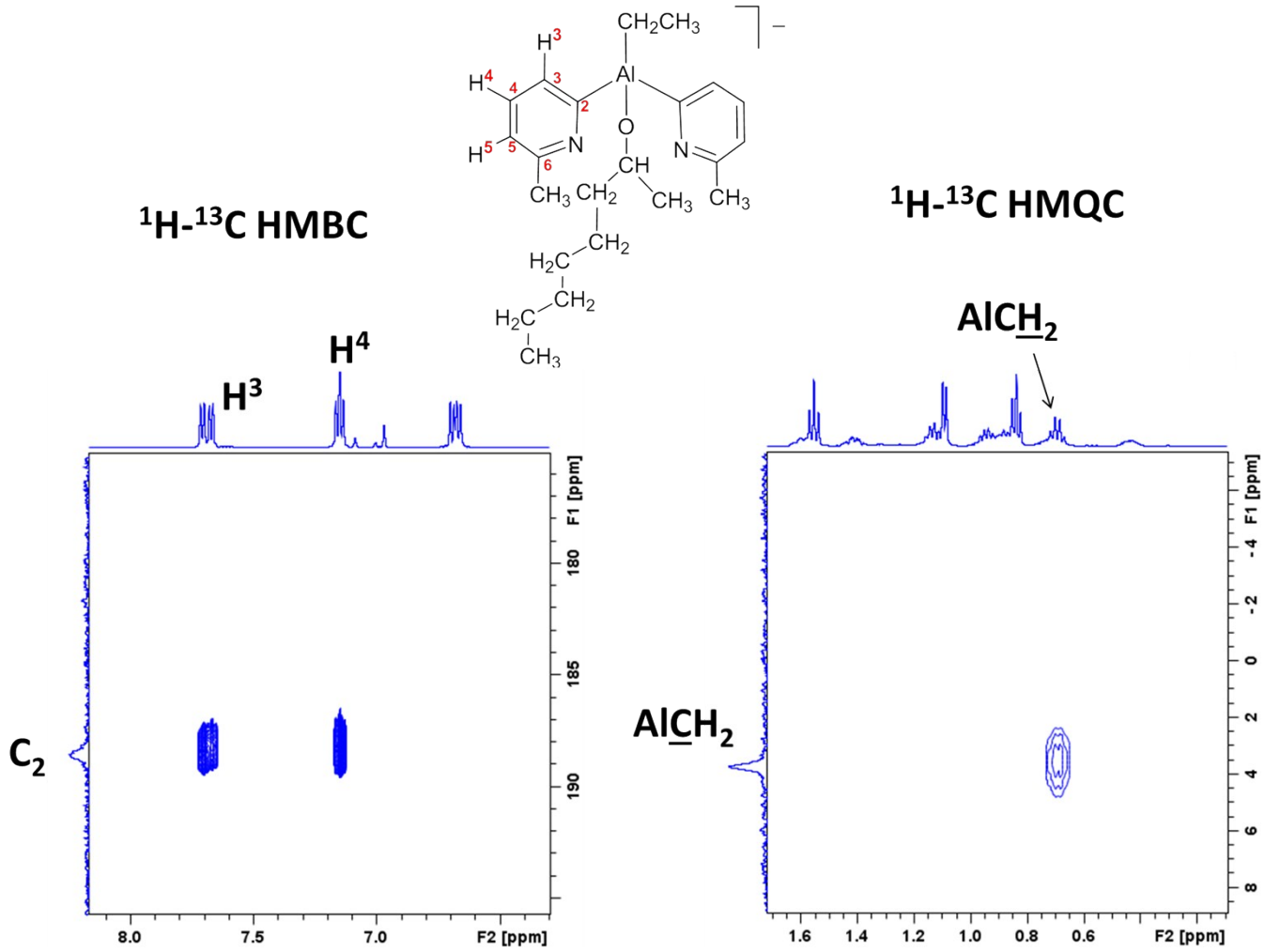


Figure S37. ^{1}H-^{13}C HMBC (left) and ^{1}H-^{13}C HMQC (right) spectra (298K, d_8-toluene) of *R*-**4** showing that the broad resonances for C^2 py and Al–CH_2 directly bonded to the Al atom, are easily observed through ^{1}H-^{13}C HMBC and ^{1}H-^{13}C HMQC experiments.

Note: 1D ^{13}C{^{1}H} NMR spectrum processed with a line broadening (lb) of 5 Hz is shown as the 'external projection'.

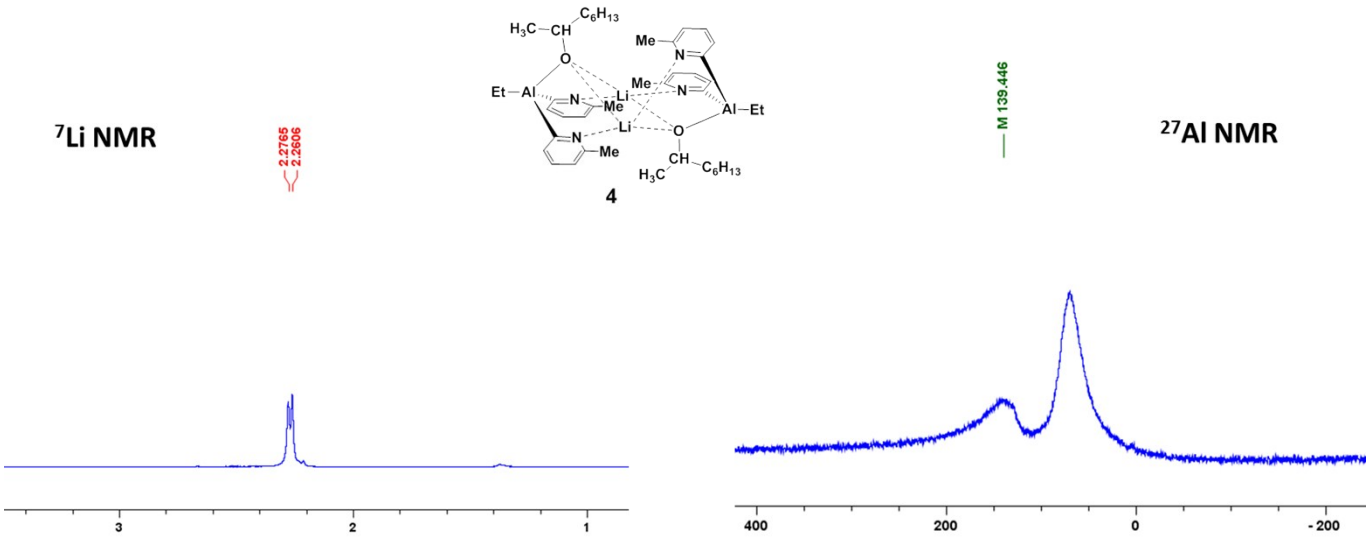


Figure S38. ^{7}Li NMR (298K, d_8-toluene, 194.4 MHz, referenced to a solution of $LiCl/D_2O$) (left) and ^{27}Al NMR (130.3 MHz, 298K, , d_8-toluene, referenced to a solution of $AlCl_3.6H_2O/D_2O$) (right) spectra of **R-4**.

Note: The broad signal at around 65ppm in the ^{27}Al NMR spectrum arises from the probe background

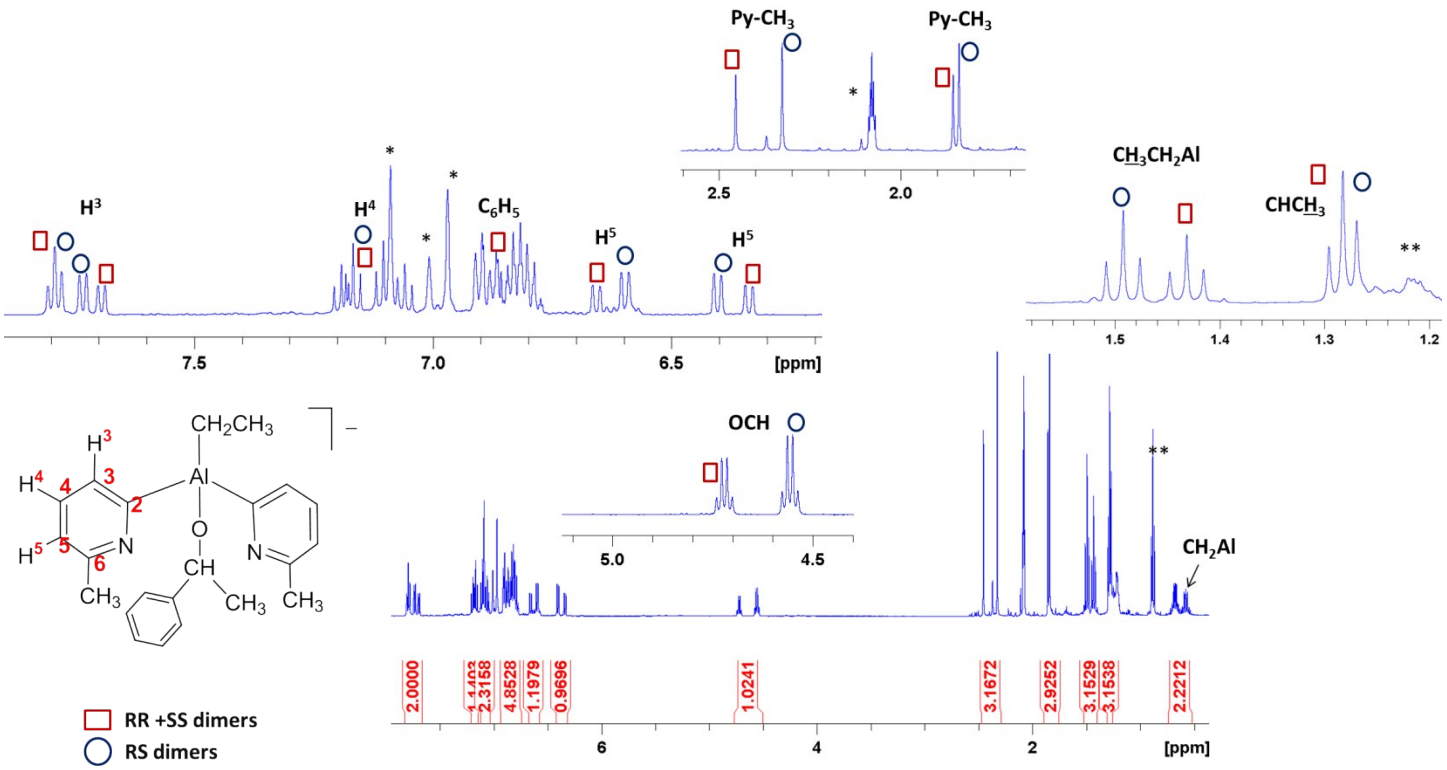


Figure S39. ^{1}H NMR (298K, d_8-toluene, 500 MHz) spectrum of racemic-[EtAl(OCH(CH_3)C_6H_5)(6-Me-2-py)$_2$Li]$_2$ (*rac*-**5**). Two set of signals are observed corresponding to the heterochiral dimer (*RS*) and the enantiomeric pair of homochiral dimers (*RR*+*SS*) in a ratio 58% and 42%, respectively. Note: the ratio found in crystals of *rac*-**5** was the same and remained constant for at least 1 week. Residual toluene-d_8/toluene (*). The spectrum contained hexane (**) from crystallization as evidenced by resonances at 0.88 and 1.22 ppm and also in ^{13}C signals 32.06, 23.12 and 14.35 ppm) and a very small amount of free Py-CH_3 (4%) from hydrolysis (singlet at 2.37 ppm).

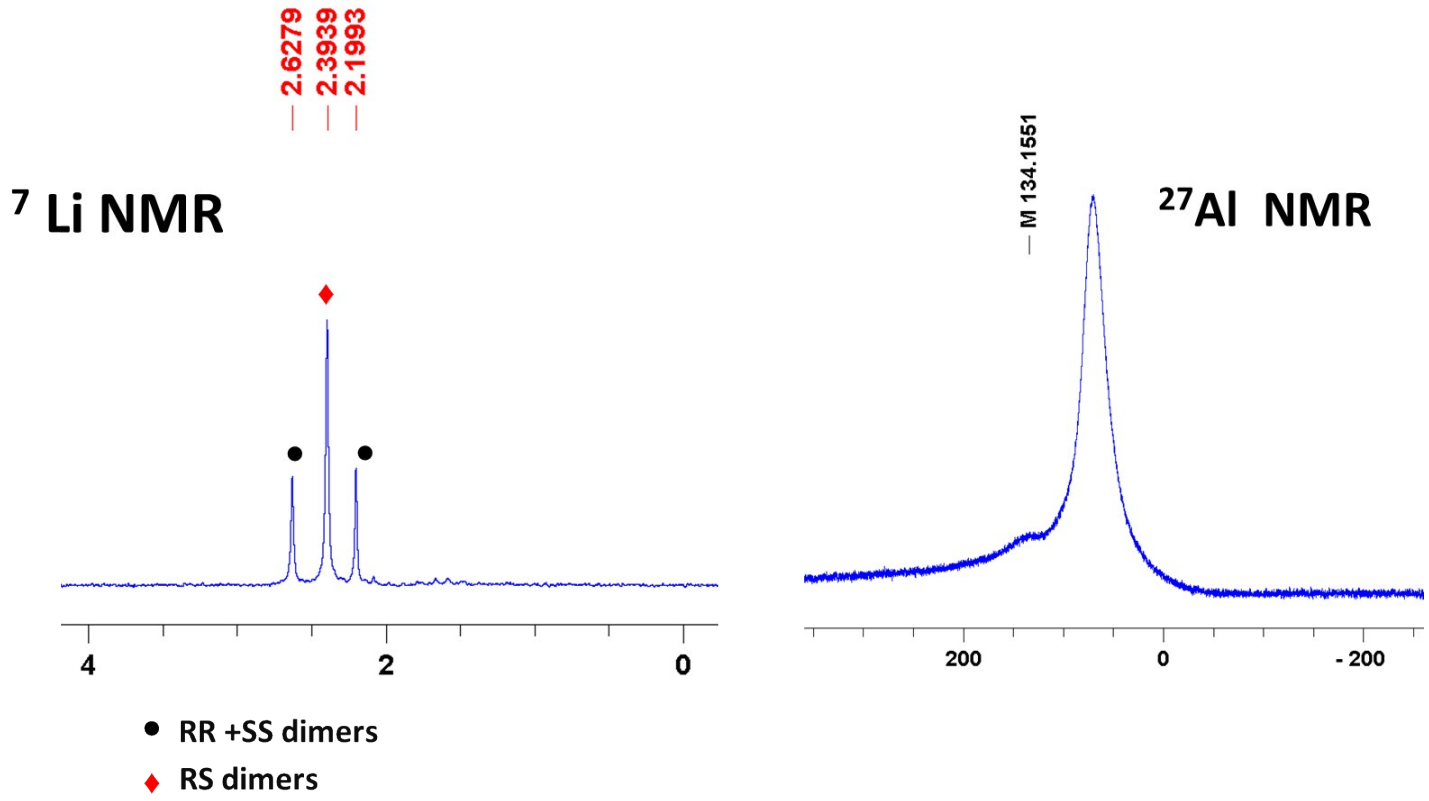


Figure S40. ^{7}Li NMR (298K, d_8-toluene, 194.4 MHz, referenced to a solution of LiCl/D_2O) (left) and ^{27}Al NMR (130.3 MHz, 298K, d_8-toluene, referenced to a solution of $AlCl_3.6H_2O/D_2O$) (right) spectra of racemic *rac*-**5**. See also Figure 3 in the main text for ^{7}Li of enantiomerically pure *R*-/*S*-**5**.

Note: The broad signal at around 65ppm in the ^{27}Al NMR spectrum arises from the probe background.

X-ray Crystallographic Studies

Data were collected on a Bruker D8 QUEST diffractometer with an Incoatec IμS Cu microfocus source. Crystals were mounted directly from their mother liquor using perfluorohydrocarbon oil to prevent atmospheric oxidation, hydrolysis, and solvent loss, and the temperature was held at 180(2) K using an Oxford Cryosystems N_2 cryostat. Data were collected and processed using the Bruker APEX3 software package, structures were solved using SHELXT (Sheldrick, 2015) and refined using SHELXL (Sheldrick, 2015). For the non-centrosymmetric structures **3**-*RR* and **3**-*SS*, the absolute structure was established using the quotients method of Parsons.

	5-*RS*	**3**-*RR*	**3**-*SS*	**3**-*RS*	**2**
CCDC No.	1503079	1503080	1503081	1503082	1503083
Formula	$C_{44}H_{52}Al_2Li_2N_4O_2$	$C_{36}H_{52}Al_2Li_2N_4O_2$	$C_{36}H_{52}Al_2Li_2N_4O_2$	$C_{36}H_{52}Al_2Li_2N_4O_2$, $2(C_7H_8)$	$C_{30}H_{40}Al_2Li_2N_4O_2$, C_7H_8
Formula weight	736.73	640.65	640.65	824.92	648.63
Crystal dimensions (mm)	0.35 x 0.25 x 0.15	0.11 x 0.09 x 0.08	0.21 x 0.20 x 0.11	0.23 x 0.10 x 0.08	0.22 x 0.18 x 0.14
Crystal system	Monoclinic	Triclinic	Triclinic	Monoclinic	Triclinic
Space group	$P2_1/c$	$P\bar{1}$	$P\bar{1}$	$P2_1/n$	$P\bar{1}$
a (Å)	10.9319(2)	10.0524(3)	9.9938(3)	9.7021(2)	10.1776(3)
b (Å)	12.8579(2)	10.2219(3)	10.2452(3)	22.8975(5)	11.8188(3)
c (Å)	15.7558(3)	18.3853(5)	19.3556(6)	22.1511(5)	17.6040(4)
α (°)	90	87.4066(15)	75.1082(13)	90	101.361(1)
β (°)	110.243(1)	86.1584(14)	77.7169(13)	95.061(1)	103.470(1)
γ (°)	90	84.2038(15)	84.5937(13)	90	104.633(1)
V (Å^3)	2077.86(6)	1873.88(9)	1869.74(10)	4901.77(18)	1917.43(9)
Z	2	2	2	4	2
ρ_{calcd} (g cm^{-3})	1.178	1.135	1.138	1.118	1.123
μ (mm^{-1})	0.938	0.963	0.965	0.840	0.950
λ (Å)	1.5418	1.5418	1.5418	1.5418	1.5418
T (K)	180(2)	180(2)	180(2)	180(2)	180(2)
$2\theta_{max}$ (°)	132.9	132.3	133.4	133.1	133.1
Measured data	22969	36625	55196	72167	61133
Unique data	3663	12730	12837	8689	6764
R_{int}	0.046	0.070	0.031	0.087	0.031
$R1$ [$I>2\sigma(I)$]	0.058	0.058	0.045	0.073	0.038
$wR2$ (all data)	0.162	0.141	0.119	0.195	0.103
Goodness of fit, S	1.07	1.03	1.03	1.04	1.04
Residual electron density (e Å^{-3})	–0.314, 0.237	–0.259, 0.321	–0.313, 0.404	–0.419, 0.951	–0.232, 0.277
Flack parameter		0.00(4)	–0.03(2)		

APEX3: Bruker (2015). *APEX3*. Ver.2016.1–0. Bruker AXS Inc., Madison, Wisconsin, USA.

SHELXT: Sheldrick, G. M. (2015). *Acta Cryst.* A**71**, 3-8.

SHELXL: Sheldrick, G. M. (2015). *Acta Cryst.* C**71**, 3-8.

Absolute structure: Parsons, S., Flack, H. D. & Wagner, T. *Acta Cryst.* (2013). B**69**, 249-259.

The crystal structures obtained for **3**-*RR* and **3**-*SS* are not identical: they are polytypes, having identical layers in the *ab* plane, but different stacking arrangements along *c*. **3**-*RR* can be approximately transformed to **3**-*SS* using the transformation matrix: 1 0 0 / 0 1 0 / ½ ½ 1.

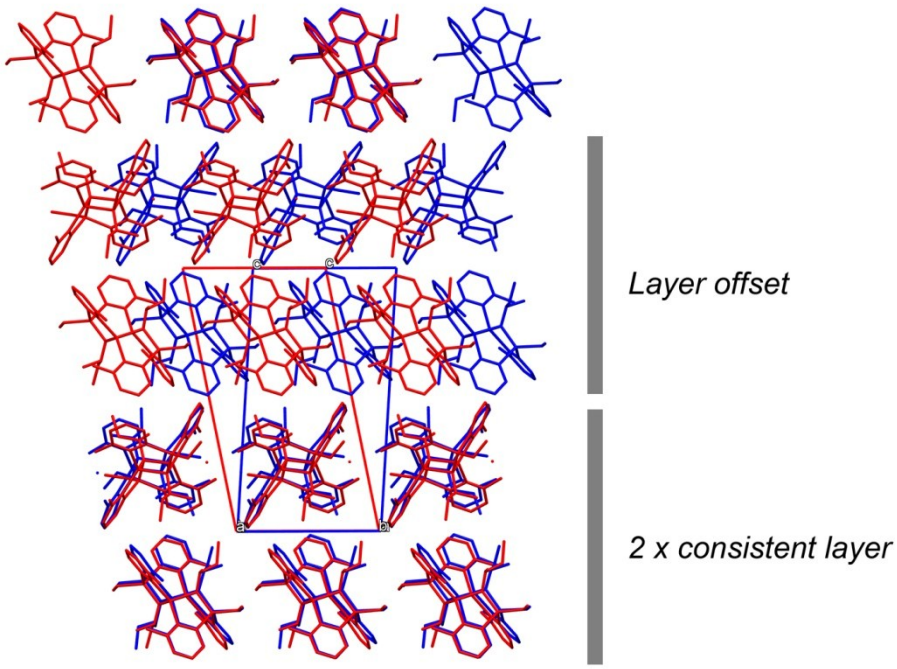


Figure S41. Overlay of the polytypic crystal structures of 3-SS (red) and 3-RR (blue), showing consistent layers in the *ab* plane (horizontal), but different stacking sequences along *c*.

Determination of Enantiomeric Excess (*ee*)

If the distribution of the *RR*-, *SS*- and *RS*-dimers is purely statistical, the enantiomeric excess present in the alcohol, *ee* (%), can be calculated by:

$$ee(\%) = \sqrt{\frac{r-1}{r+1}} \times 100$$ eq 1 (see derivation below, on page S56)

Where *r* is the ratio between homochiral (*RR* + *SS*) and heterochiral (*RS*) dimers, and can be extracted directly by NMR by integrating their signals:

$$r = \frac{Homochiral\ dimers}{Heterochiral\ dimers} = \frac{RR+SS}{RS}$$

The reaction of the chiral alcohol with non-chiral aluminate (**1**) is irreversible and produces the corresponding *RR* or *SS* aluminates that are associated into robust dimers in solution. This formula is equivalent to Horeau's formula[2] to calculate enatiomeric purity for coupling reactions of chiral species.

If the distribution of these dimers diverges from a statistical the situation due to the preferential formation of a particular dimer (diasteroselectivity) can be corrected by equ. 2,

$$ee(\%) = \sqrt{\frac{r-d'}{r+d'}} \times 100$$ eq. 2 (see derivation section, on page S56)

Where d′ is the ratio between homo and heterochiral dimers for a racemic mixture of the alcohol and therefore easily determined experimentally by NMR:

$d' = [(SS + RR)/RS]_{\text{racemic}}$

If there is no diasteroselectivity, then the ratio of homo and heterochiral dimers is the same for a racemic mixture (the amount of *RS* is equal to *RR* + *SS*, i.e., statistical distribution). Therefore d′ = 1 and eq. 2 transforms into eq. 1.

If a new alcohol that induces diasteroselectivity is studied with this methodology at least two measurements are needed, one containing the unknown proportion of alcohol from which the %*ee* can be determined and the other with a racemic composition of the alcohol in order to determine d′. We note that this methodology avoids the use of a calibration curve. However we also note that for high % *ee* a good approximation is achieved with eq 1 since the procedure is very sensitive at high enantiomeric purities where the effects of diasteroselectivity are negligible, and the presence of the small amount of the minority enantiomer is effectively amplified by the formation of the heterochiral dimer. Under these conditions determination of d' is not necessary, avoiding second measurement involving the racemic mixture of the alcohol.

Analysis of Enantiomeric Purity of *R*-/*S*-2-Butanol Samples

R-2-butanol 99% Aldrich, Batch Number: SHBD0787V. The *ee* was calculated to be 93.0±0.5% (Table 1 in the main manuscript, last entry for 2-butanol). For this particular batch $[\alpha]_{20}^{D}$ (neat) = -13.0 from which %(*ee*) was calculated to be $[\alpha]_{20}^{D}$ (neat) of lot / $[\alpha]_{20}^{D}$(neat) x 100% = -13.0/-13.9% = 93.5%, by optical rotation.

S-2-butanol 99% Aldrich, Batch Number: SHBB6867V. The *ee* was calculated to be 89.2±0.5%. For this particular batch: $[\alpha]_{20}^{D}$ (neat) of lot / $[\alpha]_{20}^{D}$(neat) x 100% = 12.4/13.9% = 89.2%.

Derivation of the Formula to Calculate Enantiomeric Excess (*ee*)

The enantiomeric excess (*ee*) is the absolute difference between the mole fraction of each enantiomer, $ee = \frac{|R - S|}{R + S}$ which is normally expressed as percentage (%), % *ee* = *ee*×100. For convenience in the following discussion we will call *ee* = P, so % *ee* = P ×100.

If the initial reacting alcohol is present as a mixture of *R* and *S* enantiomers with fractions *R* = x and *S* = 1-x, we can express the fraction of each enantiomer in terms of enantiomeric excess as: *R* = x = (P+1)/2 and *S* = 1-x = (1- P)/2. The reaction of the chiral alcohol with non-chiral aluminate **1** is irreversible and quantitative and the initial reaction with each enantiomer proceeds with the same reaction rate to produce the corresponding *R* and *S* aluminates that form robust dimers in solution. If there is no preference for the formation of any dimer (*RR*, *SS* or *RS*), then a purely statistical distribution of the dimers is expected.

Probability (*RR*) = x^2, Probability(*SS*) = $(1-x)^2$ and Probability(*RS*)= $1-x^2-(1-x)^2 = 2x(1-x)$.

Therefore the amount of each dimer will be proportional to the probability of forming each dimer:

RR = $k'x^2$, *SS* = $k'(1-x)^2$ and *RS* = $2k'x(1-x)$ (see Appendix 1)

Since we will be working with ratios the discussion can be only focused on their relative proportions (probabilities) and k′ can be ignored (see eq 1).

Since the fraction of each enantiomer is *R* = x = (P+1)/2 and *S* = 1-x = (1- P)/2 we can express the above equations as:

RR = $k' x^2 = k' [(P+1)/2]^2 = k' (1+P^2 + 2P)/4$

$SS = k' (1-x)^2 = k' [(1-P)/2]^2 = k' (1+P^2 - 2P)/4$

$RS = k' 2x(1-x) = k' (P+1)(1-P)/2 = k' (1-P^2)/2$

Homochiral (*RR* and *SS*) and heterochiral dimers are distinguishable by NMR and their ratio: r = (*RR* + *SS*)/ *RS* can be easily determined by integration of their signals and from this ratio the enantiomeric excess of the alcohol (% *ee* = P ×100) can be easily extracted. Combining with the previous:

$$r = \frac{Homochiral\ dimers}{Heterochiral\ dimers} = \frac{RR + SS}{RS} = \frac{k'(1 + P^2)/2}{k'(1 - P^2)/2} = \frac{1 + P^2}{1 - P^2} \qquad \text{eq 3}$$

from which ; $P^2 = \frac{r - 1}{r + 1}$; $P = \sqrt{\frac{r - 1}{r + 1}}$ eq 4

Since % *ee* = P ×100, eq 4 can be transformed into eq 1.

We note that this formula is based on a statistical distribution of the dimers and it is valid if there is no preference for any of the dimers. In this case, for a racemic mixture (P = 0, 0% *ee*), we would expect the same proportion of homo and heterochiral dimers, *r* = 1 since *RS* = *RR*+*SS*. However, if there is preference for the formation of the homo- or the heterochiral dimers (i.e., diasteroselectivity), for a racemic mixture (P = 0) r ≠ 1.

To take into account diasteroselectivity we define d = $[RS/(RR+SS+RS)]_{racemic}$ which is the fraction of *RS* dimer when R and S are present at 50% (racemic mixture, P = 0) and a value that can be extracted experimentally. This value is extracted directly by the integration of the signal corresponding for the RS dimer when a racemic alcohol is used. If no diasteroselectivity is present d′ = 0.5 since the fraction of *RS* and homochiral dimers (*RR* and *SS*) is the same (i.e., no preference for the formation of dimers) and their ratio is *r* = 1 for a racemic mixture (P = 0). In this case eq. 1 describes the system.

If there is diasteroselectivity, then d ≠ 0.5, due to the preferential formation of homochiral dimer (d< 0.5) or the hereochiral one (d > 0.5). eq 1 must be corrected to take into account the preferential formation of homo or hetero dimers. The deviation from a purely statistical distribution is corrected by adjusting the ratio *r* multiplying eq.3 by (1-d)/d, i.e., the ratio of the dimers (r) is adjusted by multiplying each term by their fraction observed in a racemic mixture (P=0).

$$r = \frac{(1-d)}{d} \times \frac{RR+SS}{RS} = \frac{(1-d)(1+P^2)}{d(1-P^2)} \quad \text{eq. 3}$$

Equation 3 can be solved for P (see appendix 2) to give eq. 6, that makes possible the calculation of *ee*:

$$P = \sqrt{\frac{rd+d-1}{rd-d+1}} \quad \text{eq. 6}$$

A simpler equation can be obtained if we define d′= [(*SS*+*RR*)/*RS*] $_{\text{racemic}}$, i.e., the ratio between homo and heterochiral dimers for a racemic mixture (P=0, 0% *ee*) , Introducing d′ instead of d in eq. 6, we obtain (see appendix 3):

$$P = \sqrt{\frac{r-d'}{r+d'}} \quad \text{eq. 7}$$

From which eq. 2 is obtained taking into account that % *ee* = P ×100.

Appendix 1

The alcohol reacts quantitatively and irreversibly with the aluminate so no free alcohol is present in the sample. We assume that the resulting chiral aluminate, [EtAl(6-Me-2-Py)$_3$(OR)], is only present in solution forming dimers that are distributed statistically (i.e., no disateroselectivity). Therefore from the statistical distribution of dimers (*RR*, *SS* and *RS*) that is determined by NMR as a ratio homo/heterochiral dimer, the initial enantiomeric excess of the alcohol can be in principle extracted.

We define k as the total number of molecules of alcohol present initially and k′ the total number of dimers formed.

$k = R+S$

$k' = RR+SS+RS$

Probability(R) = R/k = x; R = kx. We note that in this formalism the probability of R, probability(R) = x, is equivalent to the fraction of alcohol R defined as x (or molar fraction if k is expressed as moles). Similarly for S:

Probability(S) = S/k = 1-x; S=k(1-x)

If we consider that only dimeric aluminates exist in solution and that the formation of this dimer is merely statistical, the probability of forming dimers is given by:

Probability(*RR*)=R/k×(R-1)/(k-1) ≈ $R^2/k^2 = x^2$. This approximation is valid due to the large number of elements (molecules) present.

Probability(*RR*) = *RR*/k′

Combining both expressions we obtain $RR = k'x^2$; i.e., the amount of dimer *RR* is proportional to the probability (x^2).

Similarly:

Probability(*SS*) ≈ $(1-x)^2$ and probabilty(*SS*) = *SS*/k′ and combining both expressions $SS = k' (1-x)^2$

Probability(*RR*) + Probability(*SS*) + Probability(*RS*) = 1 and Probability(*RS*) = *RS*/k′ and combining both expressions *RS* = k′2x(1-x)

P is defined as the difference between the fraction of R and S and %(*ee*) = P×100

We can express the fractions of alcohols as: x = (P+1)/2 ad 1-x = (1-P)/2 and the number of dimers (elements *RR*, *SS* and *RS*) as:

$RR = k'x^2 = k'[(P+1)/2]^2 = k' (1+P^2 + 2P)/4$

$SS = k'(1-x)^2 = k' [(1-P)/2]^2 = k' (1+P^2 - 2P)/4$

$RS = k'2x(1-x) = k' (P+1)(1-P)/2 = k' (1-P^2)/2$

The ratio of dimers, which is directly obtained from NMR data, is given by $r = (RR+SS)/RS = 1+P^2/(1-P^2)$ from which the enantiomeric excess, %(*ee*) = P × 100, can be determined.

Appendix 2

$$r = \frac{(1-d)(1+P^2)}{d(1-P^2)} \quad \text{eq. 5.}$$

if we define c = (1-d)/d

$$r = c\frac{(1+P^2)}{(1-P^2)} \; ; \quad r/c = \frac{(1+P^2)}{(1-P^2)}$$

And if we define a = r/c, we obtain a similar expression to eq. 3, which can be solved for P:

$$a = \frac{(1+P^2)}{(1-P^2)} \; ; \quad P = \sqrt{\frac{a-1}{a+1}} \quad \text{where a = r/c = rd/(1-d)}$$

$$P = \sqrt{\frac{rd+d-1}{rd-d+1}} \qquad \text{eq. 6}$$

Appendix 3

We have defined d = $[RS/(RR+SS+RS)]_{racemic}$ and d ′=$[(SS+RR)/RS]_{racemic}$. Both can be easily determinate by NMR and are related through:

$$d = \frac{RS}{RR + SS + RS} = \frac{RS/RS}{RR/RS + SS/RS + RS/RS} = \frac{1}{1 + d'}$$

Substituting this relationship in eq. 6 we obtain eq. 7, which is a much simpler equation:

$$P = \sqrt{\frac{rd + d - 1}{rd - d + 1}} = \sqrt{\frac{d(r+1) - 1}{d(r-1) + 1}} = \sqrt{\frac{\frac{1}{1+d'}(r+1) - 1}{\frac{1}{1+d'}(r-1) + 1}} = \sqrt{\frac{r + 1 - 1 - d'}{r - 1 + 1 + d'}} = \sqrt{\frac{r - d'}{r + d'}}$$

References

1) R. Garcia-Rodriguez, D. S. Wright, *Chem. - Eur. J*. **2015**, 21, 14949-14957.

2) J. P. Vigneron, M. Dhaenens, A. Horeau, *Tetrahedron* 1**973**, *29*, 1055