

Design of a well-defined, silica-supported chiral Zn scaffold for enantioselective catalysis.

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A. Experimental Details.

General considerations. Manipulations were carried out under an argon atmosphere in glove-box or by using Schlenk techniques. Solvents were dried using conventional reagents and stored in the glove-box over 3A molecular sieves. *N,N*-Dimethylaniline-*N*-oxide (**3**) was synthesized according to known literature procedure.¹ Liquid-state NMR analyses were run on Bruker Avance 300 and on Avance 400 spectrometers. Solid-state MAS NMR spectra were recorded on Bruker Avance 400 (¹H: 400.1 MHz, ¹³C: 100.6 MHz) and on a Avance II 800 spectrometers (¹H: 800.13 MHz, ¹³C: 201.21 MHz). For ¹H experiments, the spinning frequency was 20 kHz, the recycle delay was 5 s and 16 scans were collected using a 90° pulse excitation of 2.6 μs. The ¹H-¹³C CP experiments were obtained at a spinning frequency of 10 kHz, with a recycle delay of 5 s. For the CP step, a ramped radio frequency (RF) field centered at 50 kHz was applied on protons, while the carbon RF field was matched to obtain optimal signal. The contact time was set to 1.5 ms. Chemical shifts were given with respect to TMS for ¹H and ¹³C. Diffuse reflectance infrared spectra were collected using a Harrick cell on a Nicolet Avatar spectrometer fitted with a MCT detector. Elemental analyses were carried out at the Service Central d'Analyse du CNRS (Zn), and in the Service d'Analyse Élémentaire, ICMUB, Université de Bourgogne (C, H, N). Aerosil 380 silica (Degussa, specific area 380 m² g⁻¹ prior heat-treatment) was subjected to heating under secondary vacuum (10⁻⁶ mmHg) at 500 °C over 15 hours followed by 4 hours of heating at 800°C, and stored in a glove-box. Gas chromatography analyses were performed on a Shimadzu GC-2014 gas chromatograph under N₂ flow with a ChirasilDexCB column (25 m length, 0.25 mm diameter).

Synthesis of 1. To a solution of (*S,S*)-*i*Pr-pybox (0.371 g, 1.23 mmol) in toluene (5 mL) was slowly added ZnEt₂ (1.01 g, 15 wt% solution in hexane, 1.23 mmol) at room temperature. The reaction mixture was stirred for 2 h. After evaporation of volatiles under vacuum, the residue was recrystallized from a saturated hexane solution at room temperature to give colorless crystals of **1** (0.470 g, 90%). A suitable crystal was selected for X-ray diffraction analysis. ¹H NMR (300 MHz, C₆D₆): 7.68 (d, ³*J* = 7.9 Hz, 2H,

CH_{meta} pyr.), 6.82 (t, ³J= 7.9 Hz, 1H, CH_{para} pyr.), 3.9 (m, 6H, CH₂CH), 1.7 (m, 2H, CH *i*Pr), 1.60 (t, ³J= 8.0 Hz, 6H, ZnCH₂CH₃), 1.01 (d, ³J= 6.7 Hz, 6H, CH₃ *i*Pr), 0.78 (d, ³J= 6.8 Hz, 6H, CH₃ *i*Pr), 0.67 (m, 4H, ZnCH₂CH₃). ¹³C NMR (75 MHz, C₆D₆): 161.42 (C=N oxazol.), 145.85 (C_{ortho} pyr.), 137.78 (C_{para} pyr.), 125.48 (C_{meta} pyr.), 73.14 CH₂CH oxazol.), 32.88 (CH *i*Pr), 9.15 (CH₃ *i*Pr), 18.60 (CH₃ *i*Pr), 14.72 (ZnCH₂CH₃), 3.29 (ZnCH₂CH₃). IR (DRIFTS, cm⁻¹): 3072 (w), 3015(w), 2960 (s), 2934 (s), 2872 (s), 2836 (s), 2789 (m), 2704 (w), 2009 (vw), 1932 (vw), 1855 (vw), 1670 (s), 1663 (s), 1640 (m), 1583 (s), 1471 (s), 1459 (s), 1414 (w), 1378 (s), 1360 (s), 1317 (s), 1307 (s), 1265 (s), 1177 (s), 1154 (s), 1100 (s), 1086 (s), 1072 (s), 1040 (m), 1021 (m), 996 (m), 979 (s), 963 (s), 905 (m), 832 (s), 758 (m), 750 (s), 707 (m), 661 (s). Elemental analysis: Anal. Calcd for C₂₁H₃₃N₃O₂Zn (%): C, 59.36; H, 7.83; N, 9.89. Found (%): C, 59.68; H, 7.69; N, 9.97.

Synthesis of 2. In the glove-box, a double-Schlenk apparatus was loaded with Zn[(*S,S*)-pybox]Et₂ (**1**, 550 mg, 1.3 10⁻³ mol) dissolved in 20 mL toluene in one compartment, and with silica dehydroxylated at 800 °C (2.150 g) suspended in 30 mL toluene in the other compartment. The complex solution was added to the toluene-suspended support by filtering through the sintered glass separating the two Schlenk tubes, and the reaction mixture was stirred for 15 hours at room temperature. The supernatant liquid was then separated by filtration into the other compartment, from which toluene was gas-phase transferred by trap-to-trap distillation back into the compartment containing the modified support in order to wash away the residual molecular precursor. This operation was repeated twice until colorless washing fractions were obtained. In the glove-box, 20 mL of pentane were added in the double-Schlenk vessel, and the material was washed twice by successive vacuum transfers of the solvent. The resulting pale orange powder **2** was then dried under secondary vacuum (3.10⁻⁶ mmHg) at 40°C for 6 hours. Elemental analysis (%): Zn, 2.18; C, 7.775; H, 0.849; N, 1.37. ¹H MAS NMR (800.13 MHz): 8.1, 4.2, 1.8 (shoulder), 1.0, 0.2 (shoulder). ¹³C CP MAS (201.21 MHz): 160.6, 143.2, 123.8, 72.5, 31.7, 17.0, 9.9, -1.8. IR (DRIFTS, cm⁻¹): 3089 (w), 2965 (m), 2936 (m), 2891 (m), 2855 (m), 2810 (w), 1662 (m), 1591 (m), 1482 (m), 1470 (m), 1446 (m), 1362 (m), 1310 (w).

Typical procedure for the catalytic trimethylsilylcyanation of benzaldehyde. To a stirred solution of the aldehyde (0.2 mmol), catalyst **1** (0.01 mmol), Lewis base **3** (0.05 mmol) and mesitylene (20 mg, internal standard) in dry THF (2ml) under an argon atmosphere was added trimethylsilylcyanide (0.4 mmol). The reaction mixture was stirred for 2 h, and a 0.05 mL aliquot was used for conversion and enantiomeric excess determination by gas chromatography (ChirasilDexCB, 110°C isotherm, retention time of *S* isomer = 27.0 min., retention time of *R* isomer = 27.6 min.). Determination of the major enantiomer chirality was done by comparison to literature.²

B. Additional spectroscopic data.

Figure S1. Variable temperature ^1H NMR spectra of **1** (400 MHz, d^8 -tol, *S*: solvent's residual H peaks).

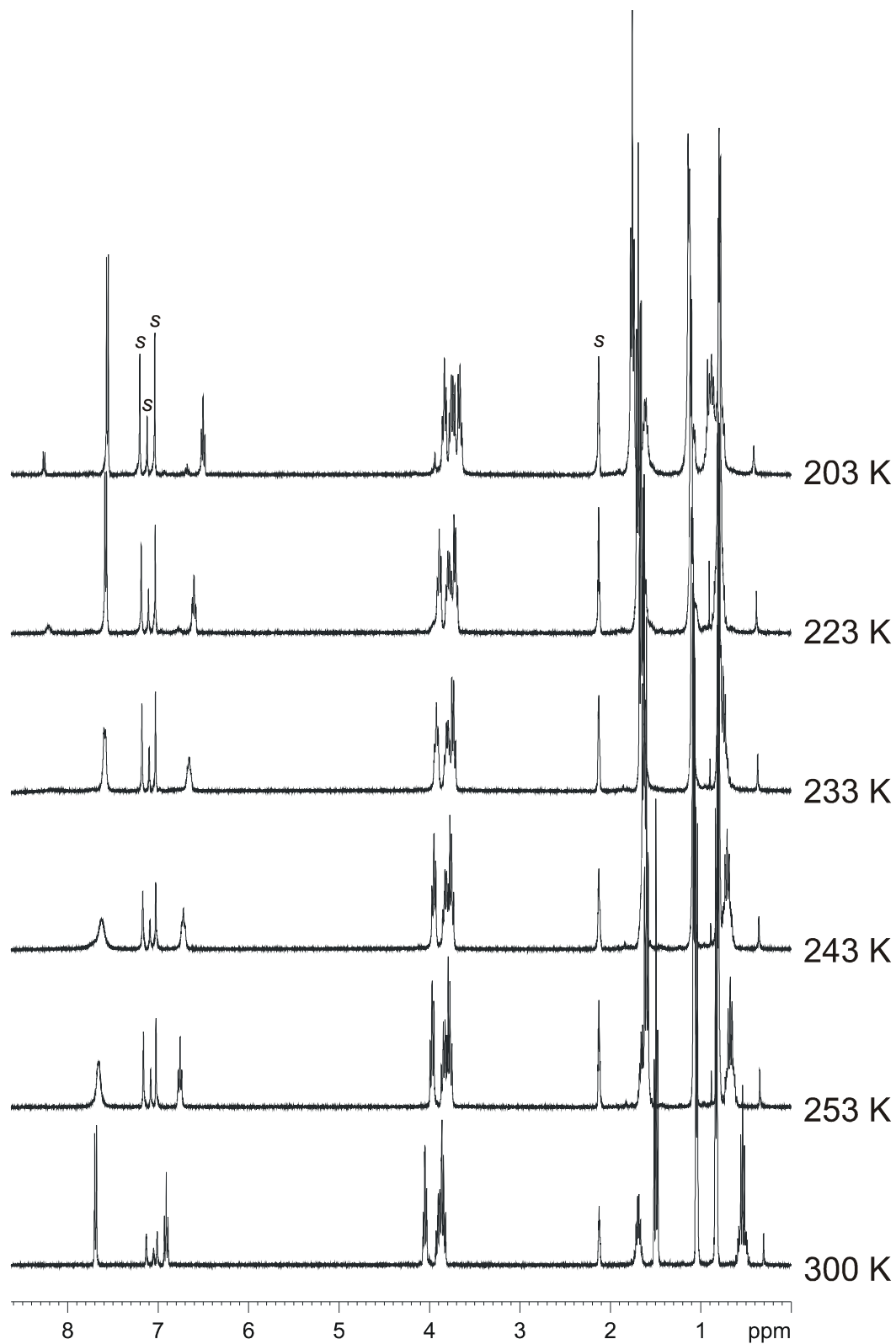


Figure S2. Variable temperature ^1H NMR spectra of **1** (400 MHz, d^8 -tol, *S*: solvent's residual H peaks).

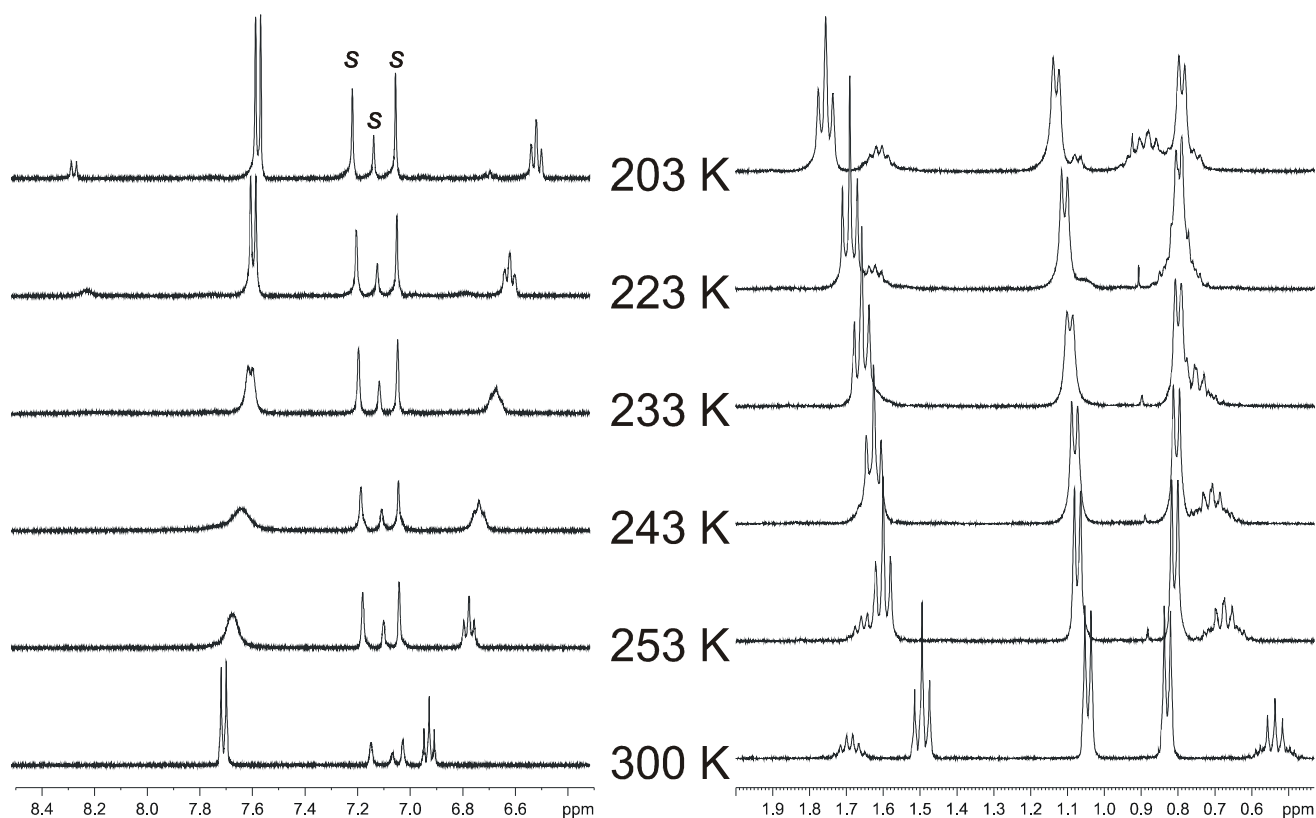


Figure S3. DRIFT spectra of a) SiO_2 -800, b) **1** and c) **2**.

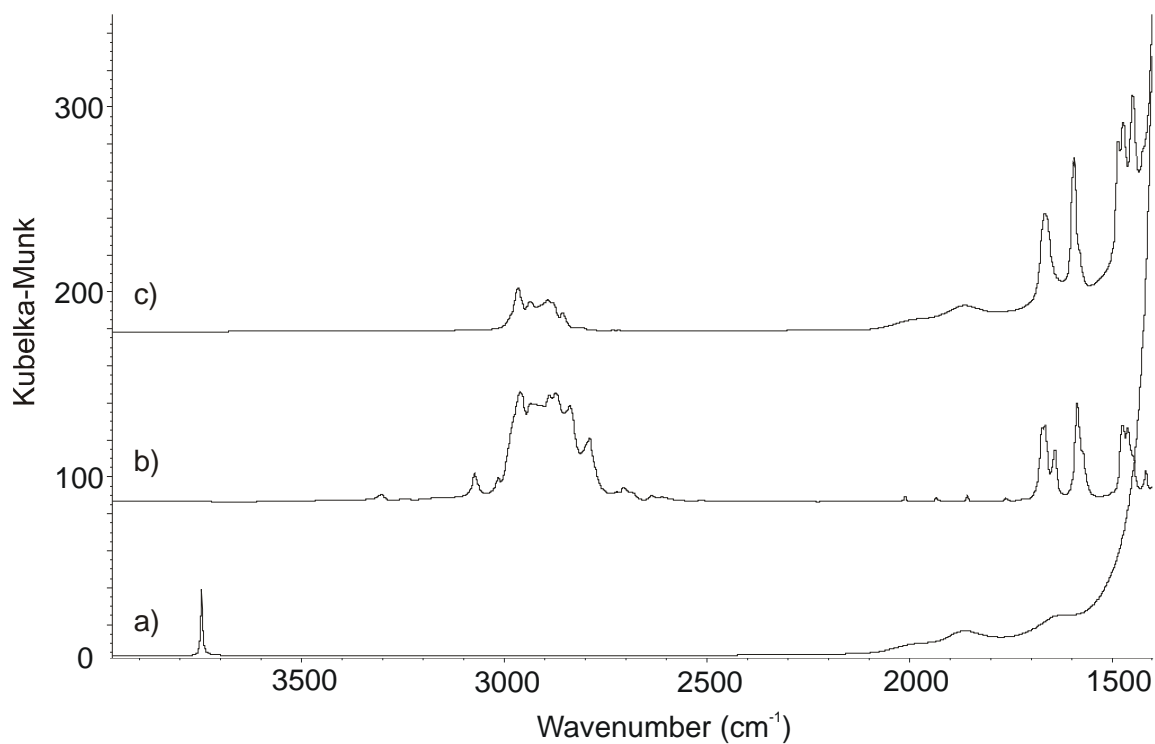


Figure S4. Compared ^1H MAS spectra of **1** (a) and **2** (b) (800.13 MHz, 20 KHz spinning speed, recycle delay 5s, 16 (**1**) and 32 (**2**) transients)

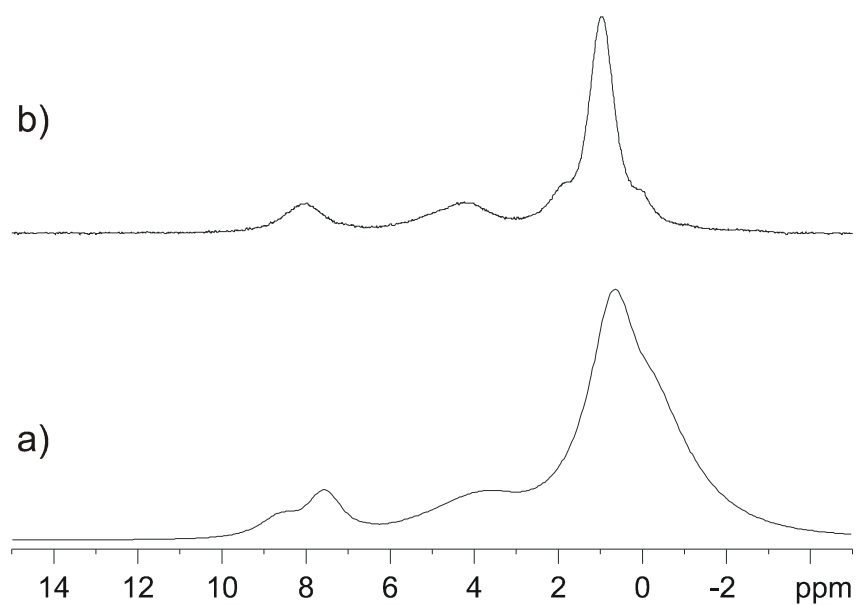


Figure S5. ^{13}C CP MAS NMR spectrum of **2** (201.21 MHz, 10 kHz spinning speed, 8618 transients, with a relaxation delay of 5s; The contact time was set to 1.5 msec, at a radio-frequency field of 50 kHz. ^1H decoupling at 85 kHz was applied during the acquisition; *: rotation peaks)

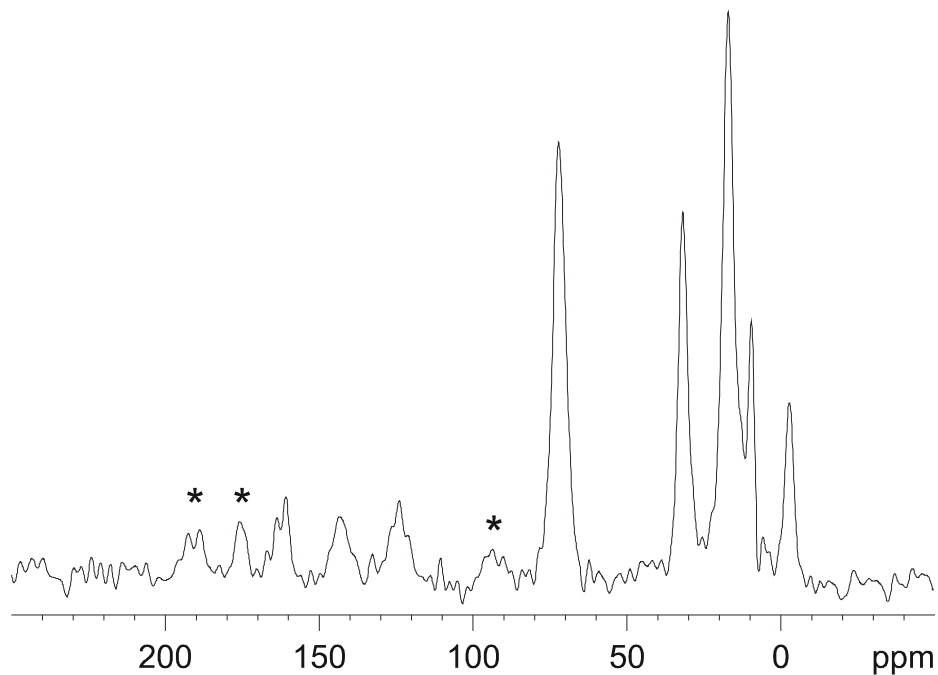
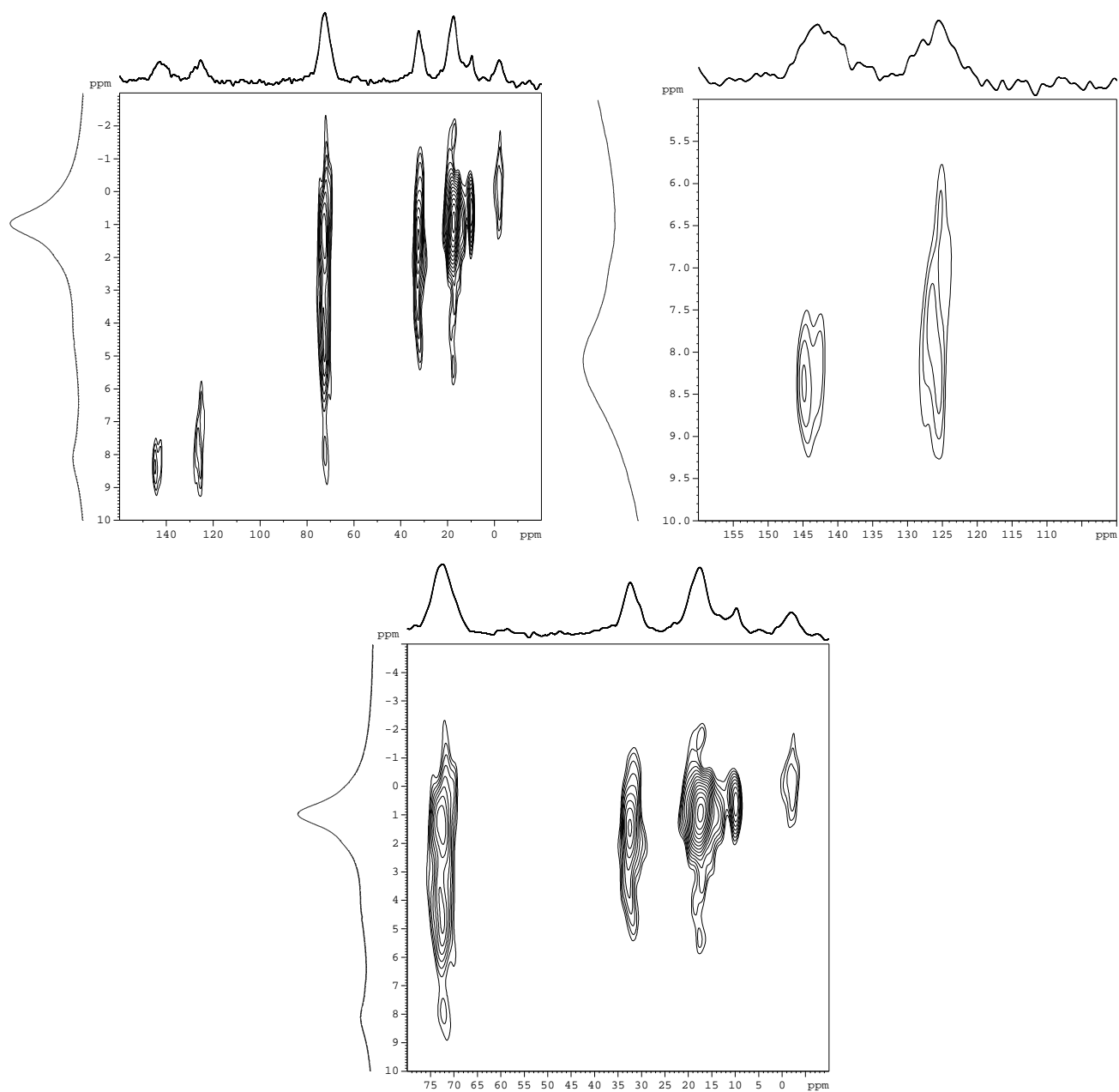


Figure S6. ^{13}C - ^1H CP-HETCOR spectrum of **2** at 9.4 T (^1H : 400.16 MHz, ^{13}C : 102.70MHz).



C. Asymmetric Silylcyanation Studies

Table S1. Benzaldehyde trimethylsilylcyanation catalyzed by **1** and **2**^a

Run	Cat.	Lewis Base/Cat. (mol/mol) ^b	Conversion % ^c 2h (16 h)	Enantiomeric excess (%) (Config.) ^b
1	1	0	0.5 (5)	0
2	1	0.5	3(20)	17.6 (S)
3	1	1	5(25)	11.8 (S)
4	2	0.5	20 (40)	66.3 (S)

^a) Conditions: 0.01 mmol catalyst, 0.2 mmol PhCHO, 0.4 mmol Me₃SiCN, 2 mL THF, 21°C. ^b)

Lewis base: N-oxide dimethylamine; ^c) determined by chiral gas chromatography.

D. Solid State Structure Determination of Complex 1. A suitable single crystal of **1** was mounted onto a glass fiber using the “oil-drop” method. Diffraction data were collected at 100 K using an APEXII, Bruker-AXS diffractometer with graphite monochromatized MoK α radiation ($\lambda = 0.71073 \text{ \AA}$). The structure was solved by direct methods using the SIR97 program,³ and then refined with full-matrix least-square methods based on F² (SHELX-97)⁴ with the aid of the WINGX⁵ program. All non-hydrogen atoms were refined with anisotropic thermal parameters. H atoms were finally included in their calculated positions. A final refinement on F² with 4844 unique intensities and 245 parameters converged at $\omega R(F^2) = 0.053$ ($R(F) = 0.0314$) for 4300 observed reflections with $I > 2\sigma(I)$. Crystal data and details of data collection and structure refinement are given in Table S2.

Table S2. Summary of crystallographic data for 1.

Empirical formula	C ₂₁ H ₃₃ N ₃ O ₂ Zn
Formula weight	424.87
Temperature	100(2) K
Wavelength	0.71073 Å
Crystal system, space group	trigonal, P 31
Unit cell dimensions	a = 8.9918(3) Å, alpha = 90 °
	b = 8.9918(3) Å, beta = 90 °
	c = 22.6476(10) Å, gamma = 120 °
Volume	1585.79(10) Å ³
Z, Calculated density	3, 1.335 (g.cm ⁻³)
Absorption coefficient	1.182 mm ⁻¹
F(000)	678
Crystal size	0.25 x 0.2 x 0.04 mm
Theta range for data collection	3.6 to 27.47 °
h_min, h_max	-11, 11
k_min, k_max	-11, 11
l_min, l_max	-29, 29
Reflections collected / unique	27955 / 4844 [R(int) = 0.0627]
Completeness to theta_max	0.998
Absorption correction type	multi-scan
Max. and min. transmission	0.954, 0.741
Refinement method	Full-matrix least-squares on F ²
Data / restraints / parameters	4844 / 1 / 245
Goodness-of-fit	0.995
Final R indices [I > 2sigma(I)]	R1 = 0.0314, wR2 = 0.053
R indices (all data)	R1 = 0.0426, wR2 = 0.0559
Largest diff. peak and hole	0.289 and -0.252 e.Å ⁻³

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