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SUPPORTING INFORMATION

Catalytic Enantio- and Diastereoselective Mannich Reaction of α-Substituted Isocyanoacetates and Ketimines

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Contents

1 General experimental

All non-aqueous reactions were performed with magnetic stirring using oven-dried glassware under a positive pressure of nitrogen. Yields refer to spectroscopically pure compounds.

All reagents bought from commercial sources were used as received. Organic solvents were evaporated under reduced pressure using a Büchi rotary evaporator. All solvents were commercially supplied or dried by filtration through activated alumina (powder ~150 mesh, pore size 58 Å, basic, Sigma-Aldrich) columns. Petrol ether (PE) refers to distilled light petroleum of fraction 30 - 40 °C. Ethyl acetate used for the preparation of imidazolines was dried and stored over 4 Å MS.

All reactions were followed by thin-layer chromatography (TLC) when practical, using Merck Kieselgel 60 F_{254} fluorescent treated silica. Visualisation was accomplished under UV light (λ_{max}= 254 nm) and by staining with aqueous potassium permanganate alkaline solution or vanillin staining dip (prepared by adding 2.5 mL of concentrated H_2SO_4 to a solution of 15 g of vanillin in 250 mL EtOH 95%). Chromatographic purification was performed on VWR 60 silica gel 40-63 μm using HPLC grade solvents that were used as supplied.

Enantiomeric excesses were determined by analytical high performance liquid chromatography (HPLC) performed on an Agilent Technologies 1200 Series or 1260 Infinity Series systems using the chiral stationary phase column specified in the individual experiment and comparing the sample with the appropriate racemic mixture.
The enantiomeric excess of the imidazolines was measured after removal of the diphenylphosphinoyl (DPP) group.

Melting points were obtained on a Leica Galen III Hot-stage microscope apparatus equipped with a digital thermometer and are reported are uncorrected.

High resolution mass spectra (HRMS) were recorded by the University of Oxford mass spectrometry staff on a Bruker Daltonics MicroTOF mass spectrometer equipped with an ESI source or on a Micromass GCT equipped with an EI source unless otherwise specified.

Infrared absorption spectra (IR) were recorded on a Bruker Tensor 27 FT-IR spectrometer from a thin film (the sample was dissolved in $CHCl_3$ and the solvent evaporated) on a diamond ATR module. Only selected bands (ν_{max}) are reported in wavenumbers (cm^{-1}).

NMR spectra were recorded on Bruker spectrometers operating at 400 or 500 MHz (^1H resonance). Proton chemical shifts (δ) are given in parts per million (ppm) relative to tetramethylsilane (TMS) with the solvent resonance as internal standard:[1] $CDCl_3$, δ = 7.26 ppm; D_2O, δ = 4.79 ppm. The following abbreviations are used to describe spin multiplicity: s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, dt = doublet of triplets, m =

[1] G. R. Fulmer, A. J. M. Miller, N. H. Sherden, H. E. Gottlieb, A. Nudelman, B. M. Stoltz, J. E. Bercaw, K. I. Goldberg, *Organometallics* **2010**, *29*, 2176–2179.

multiplet, br = broad signal. Coupling constants (*J*) are given in Hertz (Hz). ^{13}C-NMR spectra were recorded with complete proton decoupling. Carbon chemical shifts are reported in ppm (δ) relative to TMS with the solvent resonance as internal standard:[1] $CDCl_3$, δ = 77.16 ppm; CD_2Cl_2, δ = 53.84 ppm. Two-dimensional NMR spectroscopy experiments (COSY, HSQC and HMBC) were used where appropriate to assist in the assignment of signals in ^{1}H and ^{13}C spectra and data are not reported. NOE ^{1}H-NMR spectra for imidazolines **5f**, **5o**, **5q** and **5v** were acquired to determine the relative stereochemistry (*trans*, see below for copies of spectra).

Optical rotations were recorded using a Schmidt Haensch UniPol polarimeter. $[\alpha]_D^T$ values, reported in 10^{-1} deg cm^2 g^{-1}, are calculated on the average value of ten consecutive readings. Concentrations (c) are quoted in g/100 mL with the appropriate number of significant figures; D refers to the D-line of sodium (589 nm); temperatures (T) are given in degrees Celsius (°C).

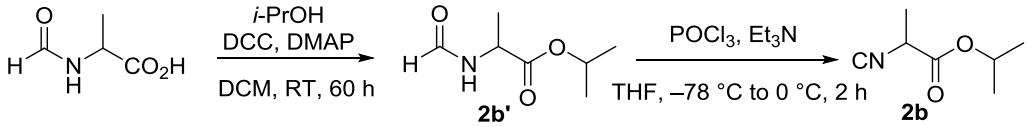
Single crystal X-ray diffraction data were collected at 150 K with an Oxford Diffraction SuperNova diffractometer and processed with CrysAlisPro as per the SI (CIF). The structure was solved with SIR92[16] and refined with CRYSTALS.[17] Full crystallographic data (in CIF format) is available as ESI and can be obtained from The Cambridge Crystallographic Data Centre at www.ccdc.cam.ac.uk/data_request/cif (reference number CCDC 1493438).

2 Practical experimental

2.1 Synthesis of starting materials and ligands

Ligands **1a**,[2] **1b**[2] and **1c**[3] were synthesized following literature procedures from quinine, quinidine and cinchonidine, respectively. The other ligands were prepared in a similar fashion (see below for procedure and full characterization).
Isocyanoacetates **2a** and **2d** were prepared by dehydration of the corresponding *N*-formyl precursor following literature procedures.[4] The other isocyanoacetates were prepared in a similar fashion (see below for procedure and full characterization).
N-Diphenylphosphinoyl imines **3a**-**3k** were prepared from the corresponding ketones *via* the oximes according to the literature.[5] The physical and spectroscopical data of ketimines **3a**,[6] **3b**,[7] **3c**,[8] **3d**,[9] **3e**,[7] **3f**,[6] **3g**,[6] **3h**,[8] **3i**,[6] **3j**[6] and **3k**[7] were in agreement with those reported.

2.1.1 Synthesis and characterization of isopropyl 2-isocyanopropanoate 2b



To a solution of isopropyl alcohol (0.67 mL, 8.8 mmol, 1 equiv) and *N*-formylalanine (1.30 g, 11.1 mmol, 1.2 equiv) in dry dichloromethane (80 mL) at 0 °C were added DCC (1.82 g, 8.80 mmol, 1 equiv) and DMAP (1.18 g, 9.65 mmol, 1.1 equiv). The mixture was warmed to room temperature and stirred for 60 hours. The mixture was filtered, washed with water (40 mL) and brine (40 mL), dried over anhydrous sodium sulphate, filtered again and concentrated under reduced pressure. The crude was purified by flash column chromatography using 4:6 PE:AcOEt, obtaining isopropyl *N*-formylalanine **2b'** as a colorless oil in 61% yield (856 mg).

IR (film) ν = 3294, 2983, 1734, 1661, 1525, 1454, 1377, 1204, 1106 cm^{-1}; **^{1}H-NMR** (400 MHz, $CDCl_3$) δ 8.13 (s, 1H, C**H**O), 6.95 (brs, 1H, N**H**), 5.00 (sept, *J* = 6.0 Hz, 1H, C**H**-$(CH_3)_2$), 4.56 (d, *J* = 7.2 Hz, 1H, C**H**-CH_3), 1.37 (d, *J* = 7.2 Hz, 3H, CH-C**H**$_3$), 1.22 (d, *J* = 6.0 Hz, 3H, CH-(C**H**$_3)_2$), 1.21 (d, *J* = 6.0 Hz, 3H, CH-(C**H**$_3)_2$); **^{13}C-NMR** (100 MHz, $CDCl_3$) δ 172.1 (**C**=O), 160.8 (**C**HO), 69.2 (**C**H-$(CH_3)_2$), 46.9 (**C**H-CH_3), 21.6 (CH-(**C**$H_3)_2$), 21.5 (CH-(**C**$H_3)_2$), 18.2 (CH-**C**H_3); **HRMS** (ESI): calcd. for $C_7H_{13}NNaO_3^+$ $[M+Na]^+$ 182.0788, found 182.0785.

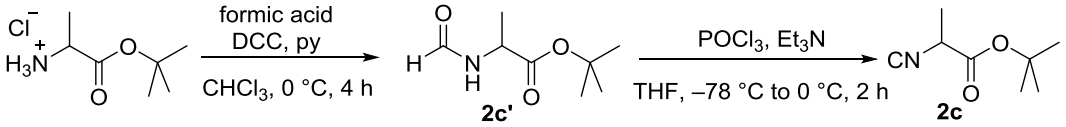
A solution of isopropyl *N*-formylalanine **2b'** (856 mg, 5.38 mmol, 1 equiv) in dry THF (8 mL) was cooled to −78 °C and Et_3N (3.7 mL, 26.9 mmol, 5 equiv) was added. Then, a solution of

[2] R. de la Campa, I. Ortín, D. J. Dixon, *Angew. Chem. Int. Ed.* **2014**, *54*, 4895–4898.
[3] F. Sladojevich, A. Trabocchi, A. Guarna, D. J. Dixon, *J. Am. Chem. Soc.*, **2011**, *133*, 1710–1713.
[4] (a) N. Elders, R. F. Schmitz, F. J. J. de Kanter, E. Ruijter, M. B. Groen, Romano V. A. Orru, *J. Org. Chem.* **2007**, *72*, 6135–6142; (b) J. Zhu, X. Wu, S. J. Danishefsky, *Tetrahedron Letters*, **2009**, *50*, 577–579.
[5] B. Krzyzanowska, W. J. Stec, *Synthesis* **1982**, 270.
[6] Y.-J. Chen, C. Chen, *Tetrahedron: Asymmetry*, **2008**, *19*, 2201–2209.
[7] S. Masumoto, H. Usuda, M. Suzuki, M. Kanai, M. Shibasaki, *J. Am. Chem. Soc.*, **2003**, *125*, 5634–5635.
[8] M. G. Núñez, A. J. M. Farley, D. J. Dixon, *J. Am. Chem. Soc.* **2013**, *135*, 16348–16351.
[9] I. Ortín, D. J. Dixon, *Angew. Chem. Int. Ed.* **2014**, *53*, 3462–3465.

$POCl_3$ (0.65 mL, 6.72 mmol, 1.25 equiv) in THF (8 mL) was added dropwise at −78 °C. The mixture was gently warmed to 0 °C, stirred for 2 hours, poured into cool water (10 mL) and extracted with diethyl ether (2 × 10 mL). The combined organic phases were washed with brine (10 mL), dried over anhydrous sodium sulphate, filtered and concentrated under reduced pressure. Compound **2b** was obtained as a yellow oil in 92% yield (695 mg) and was used without further purification.

IR (film) ν = 2983, 2936, 2144, 1743, 1677, 1454, 1212, 1105 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 5.07 (sept, *J* = 6.3 Hz, 1H, C**H**-$(CH_3)_2$), 4.27 (q, *J* = 7.1 Hz, 1H, C**H**), 1.62 (d, *J* = 7.1 Hz, 3H, C**H**$_3$), 1.29 (d, *J* = 6.3 Hz, 3H, CH-(C**H**$_3)_2$), 1.28 (d, *J* = 6.3 Hz, 3H, CH-(C**H**$_3)_2$); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 166.7 (**C**=O), 159.3 (**C**≡N), 70.8 (**C**H-$(CH_3)_2$), 52.0 (**C**H), 21.6 (CH-(**C**$H_3)_2$), 19.4 (**C**H_3); **HRMS** (ESI): calcd. for $C_7H_{11}NNaO_2^+$ $[M+Na]^+$ 164.0682, found 164.0688.

2.1.2 Synthesis and characterization of *tert*-butyl 2-isocyanopropanoate 2c[10]



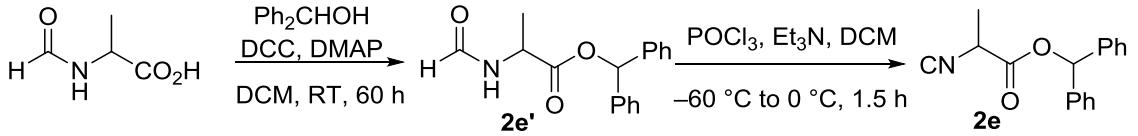
A 2 M solution of formic acid (3.77 mL in 12.5 mL of chloroform) was added dropwise to a stirred solution of DCC (2.57 g, 12.4 mmol, 2 equiv) in chloroform (15 mL) at 0 °C. The mixture was stirred at 0 °C for 5 minutes, then added over 30 minutes to a solution of alanine hydrochloride *tert*-butyl ester (1.13 g, 6.22 mmol, 1 equiv) in pyridine (15.5 mL) at 0 °C. The reaction mixtures was stirred at 0 °C for 4 hours, then volatiles were removed under vacuum. Diethyl ether is added to the residue and the suspension is filtered. The filtrate is concentrated under vacuum and purified by FCC (PE:EA 1:1) obtaining **2c'** as a colorless oil in 93% yield (999 mg, data in agreement with the literarure).[11]

A solution of *tert*-butyl *N*-formylalanine **2c'** (967 mg, 5.58 mmol, 1 equiv) in dry THF (7 mL) was cooled to −78 °C and Et_3N (3.9 mL, 27.9 mmol, 5 equiv) was added. Then, a solution of $POCl_3$ (0.68 mL, 6.98 mmol, 1.25 equiv) in THF (4 mL) was added dropwise at −78 °C. The mixture was gently warmed to 0 °C, stirred for 2 hours, poured into cool water (10 mL) and extracted with diethyl ether (2 × 10 mL). The combined organic phases were washed with brine (10 mL), dried over anhydrous sodium sulphate, filtered and concentrated under reduced pressure. Compound **2c** was obtained as a yellow oil in 92% yield (853 mg) and was used without further purification.

IR (film) ν = 2983, 2143, 1745, 1456, 1371, 1294, 1226, 1156, 1117, 1082, 1029, 850, 835 cm^{-1}; **^{1}H-NMR** (400 MHz, $CDCl_3$) δ 4.20 (q, *J* = 7.1 Hz, 1H, C**H**), 1.60 (d, *J* = 7.1 Hz, 3H, C**H**$_3$), 1.50 (s, 9H, C(C**H**$_3)_3$); **^{13}C-NMR** (100 MHz, $CDCl_3$) δ 166.2 (**C**=O), 158.9 (**C**≡N), 83.7 (**C**$(CH_3)_3$), 52.5 (t, *J* = 7.5 Hz, **C**H), 27.8 (C(**C**$H_3)_3$), 19.4 (**C**H_3); **HRMS** (ammonia CI): calcd. for $C_8H_{17}N_2O_2^+$ $[M+NH_4]^+$ 173.1285, found *m/z* 173.1286.

[10] Previously made by alkylation of *tert*-butyl isocyanoacetate, characterization not reported: U. Schöllkopf, D. Hoppe, R. Jentsch, *Angew. Chem.* **1971**, *83*, 357–358.
[11] Y. Zhang, M. L. Blackman, A. B. Leduc, T. F. Jamison, *Angew. Chem., Int. Ed.* **2013**, *52*, 4251–4255.

2.1.3 Synthesis and characterization of diphenylmethyl 2-isocyanopropanoate 2e



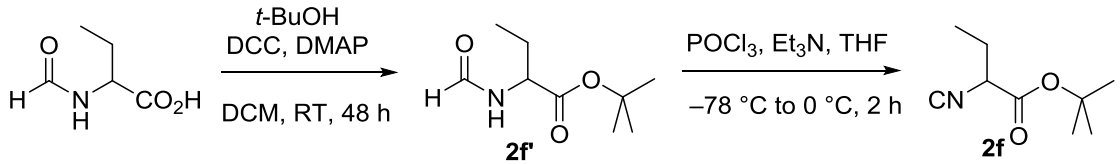
To a solution of diphenylmethanol (1.62 g, 8.80 mmol, 1 equiv) and *N*-formylalanine (1.30 g, 11.1 mmol, 1.26 equiv) in dry dichloromethane (80 mL) at 0 °C were added DCC (1.82 g, 8.80 mmol, 1 equiv) and DMAP (1.18 g, 9.65 mmol, 1.1 equiv). The mixture was warmed to room temperature and stirred for 60 hours. The mixture was filtered, washed with water (40 mL) and brine (40 mL), dried over anhydrous sodium sulphate, filtered again and concentrated under reduced pressure. The crude was purified by flash column chromatography using 1:1 PE:AcOEt, obtaining compound **2e'** as a white solid in 47% yield (1172 mg).

M.p. 73 – 74 °C; **IR** (film) ν = 3295, 3033, 1740, 1662, 1496, 1451, 1182, 1130, 738, 696 cm^{-1}; **^{1}H-NMR** (400 MHz, $CDCl_3$) δ 8.15 (s, 1H, C**H**O), 7.45 – 7.30 (m, 10H, Ar**H**), 6.96 (s, 1H, C**H**Ph_2), 6.85 (d, *J* = 7.1 Hz, 1H, N**H**), 4.87 (q, *J* = 7.1 Hz, 1H, C**H**-CH_3), 1.51 (d, *J* = 7.1 Hz, 3H, CH-C**H**$_3$); **^{13}C-NMR** (100 MHz, $CDCl_3$) δ 171.7 (**C**=O), 160.8 (**C**HO), 139.5 (**C**Ar), 139.3 (**C**Ar), 128.6 (**C**HAr), 128.6 (**C**HAr), 128.1 (**C**HAr), 127.0 (**C**HAr), 126.9 (**C**HAr), 78.1 (**C**HPh_2), 46.8 (**C**H-CH_3), 18.2 (CH-**C**H_3); **HRMS** (ESI): calcd. for $C_{17}H_{17}NNaO_3^+$ $[M+Na]^+$ 306.1101, found 306.1102.

A solution of diphenylmethyl *N*-formylalanine **2e'** (1.73 g, 6.11 mmol) in dry dichloromethane (20 mL) was cooled to –60 °C and Et_3N (2.04 mL, 14.6 mmol, 2.4 equiv) was added. Then, the $POCl_3$ (0.63 mL, 6.7 mmol, 1.1 equiv) was added dropwise at –60 ºC and the mixture was gently warmed to 0 °C and stirred for 1.5 hours. The reaction was quenched by adding a saturated solution of Na_2CO_3 (5 mL), washed with water (30 mL) and brine (20 mL), dried over anhydrous sodium sulphate, filtered and concentrated under reduced pressure. The crude was purified by flash column chromatography using 8:2 PE:AcOEt, affording compound **2e** as a pale yellow solid in 82% yield (1330 mg).

M.p. 57 – 58 °C; **IR** (film) ν = 2143, 1748, 1687, 1496, 1452, 1183, 1114, 743, 696 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.47 – 7.27 (m, 10H, CAr**H**), 6.94 (s, 1H, C**H**Ph_2), 4.42 (q, *J* = 7.1 Hz, 1H, C**H**), 1.67 (d, *J* = 7.1 Hz, 3H, C**H**$_3$); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 166.2 (**C**=O), 159.9 (**C**≡N), 139.1 (**C**Ar), 128.8 (**C**HAr), 128.5 (**C**HAr), 127.1 (**C**HAr), 79.2 (**C**HPh_2), 52.0 (**C**H), 19.4 (**C**H_3); **HRMS** (ESI): calcd. for $C_{17}H_{15}NNaO_2^+$ $[M+Na]^+$ 288.0995, found 288.0991.

2.1.4 Synthesis and characterization of *tert*-butyl 2-isocyanobutanoate 2f



To a solution of *tert*-butyl alcohol (0.58 mL, 6.05 mmol, 1.02 equiv) and 2-formamidobutanoic acid (780 mg, 5.95 mmol, 1 equiv) in dry dichloromethane (10 mL) at 0 °C were added DCC

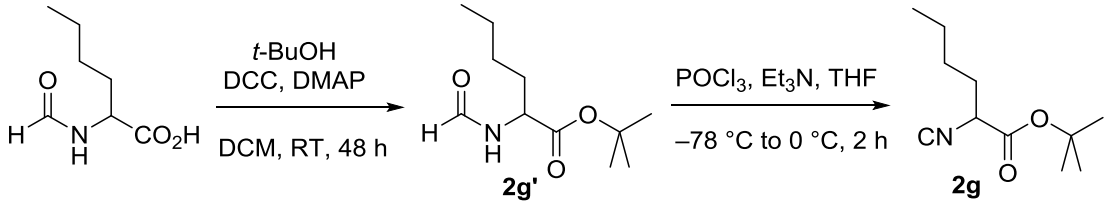
(1.37 g, 6.66 mmol, 1.13 equiv) and DMAP (743 mg, 6.05 mmol, 1.02 equiv). The mixture was warmed to room temperature and stirred for 48 hours. The solution was filtered, washed with water (10 mL) and brine (10 mL), dried over anhydrous sodium sulphate, filtered again and concentrated under reduced pressure. The crude was purified by flash column chromatography using 4:6 petroleum ether:ethyl acetate, affording compound **2f'** as a colorless oil in 22% yield (250 mg).

IR (film) ν = 3287, 2976, 1736, 1665, 1529, 1460, 1369, 1161 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 8.21 (s, 1H, C**H**O), 6.19 (brs, 1H, N**H**), 4.55 (dd, *J* = 13.6, 5.7 Hz, 1H, C**H**), 1.99 – 1.83 (m, 1H, C$\mathbf{H}_{2a}$), 1.81 – 1.64 (m, 1H, C$\mathbf{H}_{2b}$), 1.47 (s, 9H, C(C$\mathbf{H}_3$)$_3$), 0.91 (t, *J* = 7.5 Hz, 3H, C$\mathbf{H}_3$); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 171.3 (**C**=O), 160.6 (**C**HO), 82.5 (**C**$(CH_3)_3$), 52.5 (**C**H), 28.1 (C(**C**$H_3)_3$), 25.9 (**C**H_2), 9.2 (**C**H_3); **HRMS** (ESI): calcd. for $C_9H_{17}NNaO_3^+$ $[M+Na]^+$ 210.1101, found 210.1109.

A solution of compound **2f'** (217 mg, 1.16 mmol, 1 equiv) in dry THF (1.2 mL) was cooled to –78 °C and Et_3N (0.80 mL, 5.8 mmol, 5 equiv) was added. Then, a solution of $POCl_3$ (140 μL, 1.45 mmol, 1.25 equiv) in THF (1.2 mL) was added dropwise at –78 °C. The reaction mixture was gently warmed to 0 °C and stirred for 2 hours at 0 °C. The reaction mixture was poured into cool water (4 mL), extracted with diethyl ether (2 × 5 mL), washed with brine (4 mL), dried over anhydrous sodium sulphate, filtered and concentrated under reduced pressure. The crude was purified by flash column chromatography using 3:1 petroleum ether:ethyl acetate, obtaining compound **2f** as a yellow oil in 94% yield (185 mg).

IR (film): ν = 2980, 2147, 1747, 1370, 1253, 1155, 1126, 964, 839 cm^{-1}; **^{1}H-NMR** (400 MHz, $CDCl_3$): δ 4.11 (dd, *J* = 7.1, 5.1 Hz, 1H, C**H**), 2.00 – 1.86 (m, 2H, C$\mathbf{H}_2$), 1.49 (s, 9H, C(C$\mathbf{H}_3$)$_3$), 1.07 (t, *J* = 7.4 Hz, 3H, C$\mathbf{H}_3$); **^{13}C-NMR** (100 MHz, $CDCl_3$): δ 165.7 (**C**=O), 159.3 (**C**≡N), 83.7 (**C**$(CH_3)_3$), 58.7 (**C**H, t, $^{1}J_{CN}$ = 7.6 Hz), 27.9 (C(**C**$H_3)_3$), 26.5 (**C**H_2), 9.6 (**C**H_3); **HRMS** (ammonia CI): calcd. for $C_9H_{19}N_2O_2^+$ $[M+NH_4]^+$ 187.1441, found *m/z* 187.1443.

2.1.5 Synthesis and characterization of *tert*-butyl 2-isocyanohexanoate 2g

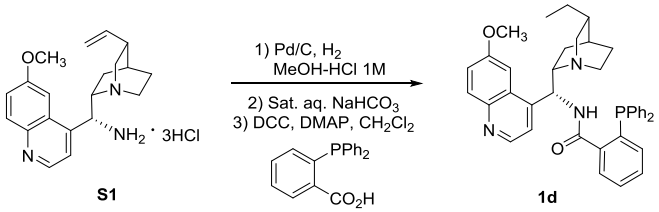


To a solution of *tert*-butyl alcohol (0.58 mL, 6.05 mmol, 1.04 equiv) and 2-formamidohexanoic acid (930 mg, 5.84 mmol, 1.0 equiv) in dry dichloromethane (10 mL) at 0 °C were added DCC (1.37 g, 6.66 mmol, 1.13 equiv) and DMAP (743 mg, 6.05 mmol, 1.04 equiv). The mixture was warmed to room temperature and stirred for 48 hours. The solution was filtered, washed with water (10 mL) and brine (10 mL), dried over anhydrous sodium sulphate, filtered again and concentrated under reduced pressure. The crude was purified by flash column chromatography using 4:6 petroleum ether:ethyl acetate, affording compound **2g'** as a colorless oil in 69% yield (871 mg). A solution of *tert*-butyl 2-formamidohexanoate **2g'** (249 mg, 1.16 mmol, 1 equiv) in dry THF (1.2 mL) was cooled to –78 °C and Et_3N (0.80 mL, 5.8 mmol, 5 equiv) was added.

Then, $POCl_3$ (140 μL, 1.45 mmol, 1.25 equiv) in THF (1.2 mL) was added dropwise at −78 ºC. The reaction mixture was gently warmed to 0 °C and stirred for 2 hours. The reaction mixture was poured into cool water (4 mL), extracted with diethyl ether (2 × 5 mL) washed with brine (4 mL), dried over anhydrous sodium sulphate, filtered and concentrated under reduced pressure. The crude was purified by flash column chromatography using 3:1 petroleum ether:ethyl acetate, affording compound **2g** as a yellow oil in 96% yield (219 mg).

IR (film): ν = 2961, 2147, 1748, 1156 cm^{-1}; **^{1}H-NMR** (400 MHz, $CDCl_3$): δ 4.09 – 4.04 (m, 1H, C**H**), 1.83 – 1.78 (m, 2H, CHC**H**$_2$), 1.43 (s, 9H, C(C**H**$_3$)$_3$), 1.41 – 1.14 (m, 4H, C**H**$_2$C**H**$_2$CH$_3$), 0.87 (t, *J* = 8.0 Hz, 3H, C**H**$_3$); **^{13}C-NMR** (100 MHz, $CDCl_3$): δ 165.8 (**C**=O), 159.1 (**C**≡N), 83.6 (**C**(CH$_3$)$_3$), 57.4 (**C**H), 32.4 (**C**H$_2$), 27.8 (C(**C**H$_3$)$_3$), 27.2 (**C**H$_2$), 21.8 (**C**H$_2$), 13.8 (**C**H$_3$); **HRMS** (ESI): calcd. for $C_{11}H_{19}NO_2Na^+$ $[M+Na]^+$ 220.1308, found *m/z* 220.1309.

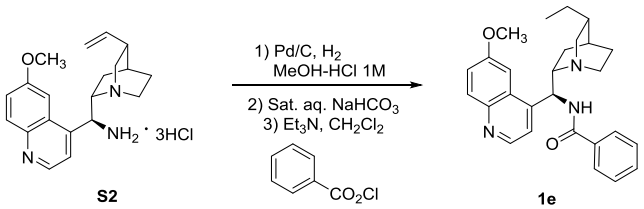
2.1.6 Synthesis and characterization of ligand 1d



S1 (585 g, 1.35 mmol) was dissolved in 8 mL of 2:1 MeOH/HCl 1M and 10% Pd/C (59 mg) was added. The reaction mixture was stirred under hydrogen (1 atm) for 7 h at room temperature and then filtered through Celite washing with water and MeOH. The filtrate was concentrated under reduced pressure and neutralized with sat. $NaHCO_3$. The resultant solution was extracted several times with CH_2Cl_2. The combined CH_2Cl_2 extracts were dried over Na_2SO_4 and concentrated under reduced pressure to yield a colorless oil (400 mg, 1.23 mmol, 91% yield) which was dissolved in 12 mL of dry CH_2Cl_2. 2-(Diphenylphosphino)benzoic acid (452 mg, 1.47 mmol) and 4-dimethylaminopyridine (18 mg, 0.15 mmol) were added. The mixture was cooled to 0 ºC, dicyclohexyl carbodiimide (280 mg, 1.35 mmol) was added and then the ice bath was removed and the resultant solution was stirred at room temperature for 12 h. After filtration, CH_2Cl_2 was evaporated under reduced pressure and the residue was dissolved in EtOAc and washed with water, brine and dried over Na_2SO_4. The organic phase was concentrated under reduced pressure. Purification by flash column chromatography using EtOAc:MeOH 95:5 afforded product **1d** as a white solid in 46% yield (338 mg).

$[\alpha]_D^{25}$ = + 52 (*c* = 0.5 in $CHCl_3$). **M.p.** 155 – 156 °C; **IR** (film) ν = 3210, 2954, 1647, 1620, 1509, 1472, 1327, 1244, 1230, 1027, 846, 744, 697 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 8.67 (d, *J* = 4.6 Hz, 1H, C**H**Ar), 7.97 (d, *J* = 9.2 Hz, 1H, C**H**Ar), 7.64 (d, *J* = 2.5 Hz, 1H, C**H**Ar), 7.59 – 7.47 (m, 1H, C**H**Ar), 7.38 – 7.30 (m, 2H, C**H**Ar), 7.30 – 7.25 (m, 2H, C**H**Ar), 7.25 – 7.15 (m, 5H, C**H**Ar), 7.12 (d, *J* = 3.4 Hz, 1H, C**H**Ar), 7.00 (dd, *J* = 11.8, 4.2 Hz, 2H, C**H**Ar), 6.94 (dd, *J* = 11.8, 4.2 Hz, 2H, C**H**Ar), 6.84 (ddd, *J* = 7.7, 4.2, 0.9 Hz, 1H, C**H**Ar), 6.07 (t, *J* = 10.1 Hz, 1H, C**H**), 3.95 (s, 3H, OC$\mathbf{H}_3$), 3.25 (dd, *J* = 17.2, 9.1 Hz, 1H, C**H**), 3.07 (dd, *J* = 13.4, 9.1 Hz, 1H, C$\mathbf{H}_{2a}$), 2.89 – 2.72 (m, 1H, C$\mathbf{H}_{2b}$), 2.55 – 2.43 (m, 1H, C$\mathbf{H}_{2b'}$), 2.40 (d, *J* = 13.4 Hz, 1H, C$\mathbf{H}_{2a'}$), 1.94 – 1.81 (m, 1H, C$\mathbf{H}_{2c}$), 1.81 – 1.64 (m, 2H, C**H** and C$\mathbf{H}_{2d}$), 1.53 (dd, *J* = 13.4, 7.1 Hz, 1H, C$\mathbf{H}_{2c'}$), 1.47 – 1.31 (m, 4H, C**H**, C$\mathbf{H}_{2d'}$, C$\mathbf{H}_{2e}$ and C$\mathbf{H}_{2e'}$), 0.93 (t, *J* = 7.1 Hz, 3H, $CH_2C\mathbf{H}_3$); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 168.8 (**C**=O), 158.2 (**C**-OCH_3), 147.6 (**C**HAr), 145.1 (**C**Ar), 143.9 (**C**Ar), 141.3 (d, *J* = 26.9 Hz, **C**Ar), 136.4 (d, *J* = 10.8 Hz, **C**Ar), 136.2 (d, *J* = 11.0 Hz, **C**Ar), 134.9 (d, *J* = 20.7 Hz, **C**Ar), 134.3 (**C**HAr), 133.7 (d, *J* = 16.7 Hz, **C**HAr), 133.6 (d, *J* = 16.6 Hz, **C**HAr), 131.5 (**C**HAr), 130.6 (**C**HAr), 129.1 (**C**HAr), 129.0 (d, *J* = 8.9 Hz, **C**HAr), 128.8 (d, *J* = 7.1 Hz, **C**HAr), 128.7 (d, *J* = 7.2 Hz, **C**HAr), 128.7 (**C**HAr), 128.6 (**C**HAr), 122.4 (**C**HAr), 119.1 (**C**HAr), 101.8 (**C**HAr), 57.8 (**C**H), 57.7 ($\mathbf{C}H_2$), 56.0 (O$\mathbf{C}H_3$), 50.1 (**C**H), 41.6 ($\mathbf{C}H_2$), 37.5 (**C**H), 28.2 ($\mathbf{C}H_2$), 27.9 ($\mathbf{C}H_2$), 25.5 (**C**H and $\mathbf{C}H_2$), 12.4 ($\mathbf{C}H_3$); **^{31}P-NMR** (162 MHz, $CDCl_3$) δ −10.5 (brs). **HRMS** (ESI): calcd. for $C_{39}H_{41}N_3O_2P^+$ $[M+H]^+$ 614.2931, found *m/z* 614.2933.

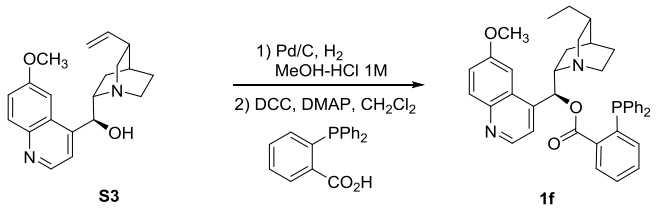
2.1.7 Synthesis and characterization of ligand 1e



S2 (850 mg, 1.96 mmol) was dissolved in 10 mL of 2:1 MeOH/HCl 1M and 10% Pd/C (85 mg) was added. The reaction mixture was stirred under hydrogen (1 atm) for 7 h at room temperature and then filtered through Celite washing with water and MeOH. The filtrate was concentrated under reduced pressure and neutralized with sat. $NaHCO_3$. The resultant solution was extracted several times with CH_2Cl_2. The combined CH_2Cl_2 extracts were dried over Na_2SO_4 and concentrated under reduced pressure to yield a colorless oil (509 mg, 1.56 mmol, 80% yield) which was dissolved in 16 mL of dry CH_2Cl_2. Triethylamine (0.26 mL, 1.87 mmol) and benzoyl chloride (0.2 mL, 1.72 mmol) were added. The mixture was stirred at room temperature for 12 h. CH_2Cl_2 was removed under reduced pressure. Purification by flash column chromatography using EtOAc:MeOH 8:2 afforded the product **1e** as a pale yellow solid in 46% yield (436 mg).

$[\alpha]_D^{25}$ = –145 (*c* = 0.5 in $CHCl_3$). **M.p.** 90 – 91 °C; **IR** (film) ν = 2930, 2962, 1621, 1509, 1475, 1262, 1230 1029, 852, 829, 713 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 8.73 (d, *J* = 4.6 Hz, 1H, C**H**Ar), 8.03 (d, *J* = 9.2 Hz, 1H, C**H**Ar), 7.87 – 7.77 (m, 2H, C**H**Ar), 7.73 (d, *J* = 2.6 Hz, 1H, C**H**Ar), 7.59 – 7.33 (m, 5H, C**H**Ar), 5.37 (s, 1H, C**H**), 3.98 (s, 3H, OC$\mathbf{H}_3$), 3.27 (dd, *J* = 13.6, 9.9 Hz, 1H, C$\mathbf{H}_{2a}$), 3.14 (dd, *J* = 20.5, 10.6 Hz, 2H, C**H** and C$\mathbf{H}_{2b}$), 2.79 – 2.62 (m, 1H, C$\mathbf{H}_{2b'}$), 2.47 (ddd, *J* = 13.6, 5.0, 2.2 Hz, 1H, C$\mathbf{H}_{2a'}$), 1.64 (dd, *J* = 15.9, 4.3 Hz, 2H, C**H** and C$\mathbf{H}_{2c}$), 1.59 – 1.49 (m, 1H, C$\mathbf{H}_{2c'}$), 1.49 – 1.43 (m, 1H, C**H**), 1.43 – 1.33 (m, 1H, C$\mathbf{H}_{2d}$), 1.33 – 1.15 (m, 2H, C$\mathbf{H}_{2e}$ and C$\mathbf{H}_{2e'}$), 1.04 (dd, *J* = 13.6, 6.7 Hz, 1H, C$\mathbf{H}_{2d'}$), 0.81 (t, *J* = 7.4 Hz, 3H, $CH_2C\mathbf{H}_3$); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 167.3 (**C**=O), 157.9 (**C**-OCH_3), 147.8 (**C**HAr), 145.0 (**C**Ar), 134.1 (**C**Ar), 132.0 (**C**HAr), 131.8 (**C**HAr), 128.6 (**C**HAr), 127.3 (**C**HAr), 121.6 (**C**HAr), 102.1 (**C**HAr), 60.3 (**C**H), 57.9 (**C**H_2), 55.8 (O**C**H_3), 53.6 (**C**H), 41.1 (**C**H_2), 37.4 (**C**H), 28.7 (**C**H_2), 27.5 (**C**H_2), 26.1 (**C**H_2), 25.2 (**C**H), 12.1 (**C**H_3); **HRMS** (ESI): calcd. for $C_{27}H_{32}N_3O_2^+$ $[M+H]^+$ 430.2489, found *m/z* 430.2482.

2.1.8 Synthesis and characterization of ligand 1f

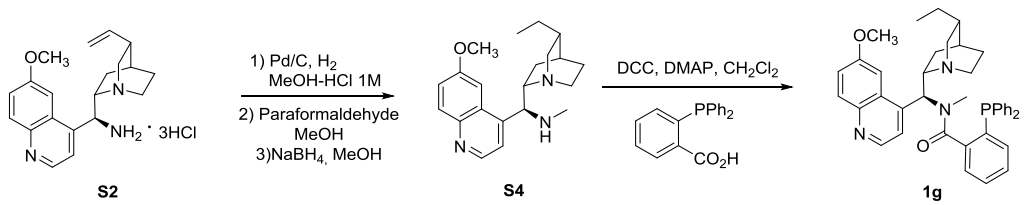


S3 (425 mg, 1.31 mmol) was dissolved in 5 mL of 2:1 MeOH/HCl 1M and 10% Pd/C (43 mg) was added. The reaction mixture was stirred under hydrogen (1 atm) for 7 h at room temperature and then filtered through Celite washing with water and MeOH. The filtrate was concentrated under reduced pressure and neutralized with sat. $NaHCO_3$. The resultant solution

was extracted several times with CH_2Cl_2. The combined CH_2Cl_2 extracts were dried over Na_2SO_4 and concentrated under reduced pressure to yield a colorless oil (375 mg, 1.15 mmol, 88% yield) which was dissolved in 8 mL of dry CH_2Cl_2. 2-(diphenylphosphino)benzoic acid (423 mg, 1.38 mmol) and 4-dimethylaminopyridine (17 mg, 0.14 mmol) were added. The mixture was cooled to 0 ºC, dicyclohexyl carbodiimide (261 mg, 1.27 mmol) was added and then the ice bath was removed and the resultant solution was stirred at room temperature for 12 h. After filtration, CH_2Cl_2 was removed under reduced pressure and the residue was dissolved in EtOAc and washed with water, brine and dried over Na_2SO_4. The organic phase was concentrated under reduced pressure. Purification by flash column chromatography using EtOAc:MeOH 9:1 afforded the product **1f** as a white solid in 65% yield (460 mg).

$[\alpha]_D^{25}$ = –70 (*c* = 0.5 in $CHCl_3$). **M.p.** 85 – 86 °C; **IR** (film) ν = 2930, 2863, 1712, 1621, 1508, 1476, 1434, 1251, 1139, 1105, 1055, 744, 697 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 8.69 (d, *J* = 4.5 Hz, 1H, C**H**Ar), 8.16 (s, 1H, C**H**Ar), 8.01 (d, *J* = 9.2 Hz, 1H, C**H**Ar), 7.58 (d, *J* = 1.9 Hz, 1H, C**H**Ar), 7.41 – 7.34 (m, 2H, C**H**Ar), 7.34 – 7.26 (m, 5H, C**H**Ar), 7.21 (td, *J* = 7.8, 1.5 Hz, 2H, C**H**Ar), 7.16 – 7.00 (m, 5H, C**H**Ar), 6.85 (ddd, *J* = 7.6, 4.0, 1.0 Hz, 1H, C**H**Ar), 6.57 (d, *J* = 9.8 Hz, 1H, C**H**), 3.94 (s, 3H, OC**H**$_3$), 3.53 – 3.44 (m, 1H, C**H**), 3.19 (dd, *J* = 9.0, 4.4 Hz, 2H, C**H**$_{2a}$ and C**H**$_{2b}$), 2.62 (t, *J* = 10.1 Hz, 1H, C**H**$_{2a}$´), 2.47 (d, *J* = 13.0 Hz, 1H, C**H**$_{2b}$´), 1.60 (s, 1H, C**H**), 1.52 (s, 1H, C**H**$_{2c}$), 1.43 (m, 2H, C**H**$_{2c´}$ and C**H**), 1.37 – 1.24 (m, 3H, C**H**$_{2d}$, C**H**$_{2d´}$ and C**H**$_{2e}$), 0.84 (t, *J* = 7.3 Hz, 3H, $CH_2C\mathbf{H}_3$), 0.79 – 0.58 (m, 1H, C**H**$_{2e´}$); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 165.9 (d, *J* = 2.4 Hz, **C**=O), 157.9 (**C**-OCH_3), 147.3 (**C**HAr), 144.8 (**C**Ar), 141.4 (**C**Ar),140.6 (d, *J* = 27.8 Hz, **C**Ar), 138.0 (d, *J* = 12.4 Hz, **C**Ar), 137.7 (d, *J* = 11.6 Hz, **C**Ar), 134.1 (**C**HAr), 134.0 (d, *J* = 20.7 Hz, **C**HAr), 133.6 (d, *J* = 20.7 Hz, **C**HAr), 132.0 (**C**HAr), 131.6 (**C**HAr), 131.0 (**C**HAr), 128.5 (**C**HAr), 128.4 (**C**HAr), 128.4 (**C**HAr), 128.3 (**C**HAr), 128.1 (**C**HAr), 128.1 (**C**HAr), 128.0 (**C**HAr), 127.9 (**C**HAr), 122.0 (**C**HAr), 120.7 (**C**HAr), 101.8 (**C**HAr), 71.8 (**C**H), 58.8 (**C**H), 57.7 (**C**H_2), 55.7 (O**C**H_3), 41.4 (**C**H_2), 37.4 (**C**H), 28.5 (**C**H_2), 27.6 (**C**H_2), 25.1 (**C**H), 25.0 (**C**H_2), 12.1 (**C**H_3); **^{31}P-NMR** (162 MHz, $CDCl_3$) δ –3.2 (brs); **HRMS** (ESI): calcd. for $C_{39}H_{40}N_2O_3P^+$ $[M+H]^+$ 615.2771, found *m/z* 615.2783.

2.1.9 Synthesis and characterization of ligand 1g



S2 (1.22 g, 2.82 mmol) was dissolved in 13 mL of 2:1 MeOH/HCl 1M and 10% Pd/C (122 mg) was added. The reaction mixture was stirred under hydrogen (1 atm) for 7 h at room temperature and then filtered through Celite washing with water and MeOH. The filtrate was concentrated under reduced pressure and neutralized with sat. $NaHCO_3$. The resultant solution was extracted several times with CH_2Cl_2. The combined CH_2Cl_2 extracts were dried over Na_2SO_4 and concentrated under reduced pressure to yield a colorless oil (662 mg, 1.97 mmol,

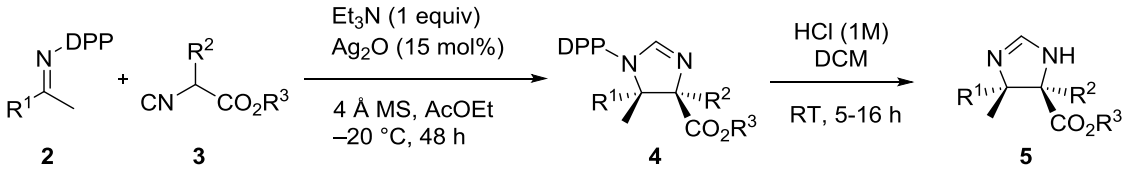
70% yield) which was dissolved in 12 mL of MeOH. NaOMe (111.7 mg, 2.07 mmol) and paraformaldehyde (207.4 mg, 6.9 mmol) were added and the reaction mixture was stirred at room temperature for 4 h. Then the mixture was cooled to 0 ºC and $NaBH_4$ (261 mg, 6.9 mmol) was added in small portions. The mixture was stirred for 30 minutes and the reaction was quenched by addition of water (6 mL), extracted with EtOAc (3 × 50 mL), washed with water, brine and dried over Na_2SO_4. The organic phase was concentrated under reduced pressure. Purification by flash column chromatography using EtOAc:MeOH:Et_3N 100:20:3 afforded the product **S4** as a colorless oil in 30% yield (200 mg).

$[\alpha]_D^{25}$ = –79 (*c* = 0.26 in $CHCl_3$). **IR** (film) ν = 2934, 2862, 1620, 1588, 1507, 1472, 1432, 1229, 1033, 856, 831 cm^{-1}; **HRMS** (ESI): calcd. for $C_{21}H_{30}N_3O^+$ $[M+H]^+$ 340.2383, found *m/z* 340.2383 (compound **S4** has not been fully characterized due to the poor resolution of broad signals in NMR).

The amine **S4** (172 mg, 0.51 mmol) was dissolved in 3 mL of CH_2Cl_2. 2-(diphenylphosphino)benzoic acid (186 mg, 0.61 mmol) and 4-dimethylaminopyridine (7.5 mg, 0.06 mmol) were added. The mixture was cooled to 0 ºC, dicyclohexyl carbodiimide (115 mg, 0.56 mmol) was added and then the ice bath was removed and the resultant solution was stirred at room temperature for 12 h. After filtration, CH_2Cl_2 was removed under reduced pressure and the residue was dissolved in EtOAc and washed with water, brine and dried over Na_2SO_4. The organic phase was concentrated under vacuum. Purification by flash column chromatography using EtOAc:MeOH 9:1 afforded the product **1g** as a colorless oil in 17% yield (55 mg).

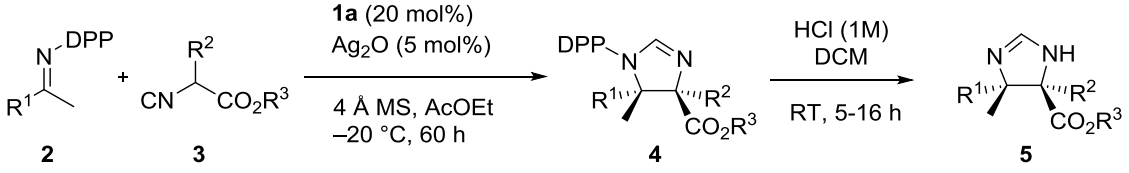
$[\alpha]_D^{25}$ = –22 (*c* = 1.0 in $CHCl_3$). **IR** (film) ν = 2927, 1621, 1509, 1476, 1435, 1324, 1242, 1047, 908, 729, 696 cm^{-1}; **^{1}H-NMR** (400 MHz, $CDCl_3$) δ 8.64 (d, *J* = 4.5 Hz, 1H, C**H**Ar), 8.27 (s, 1H, C**H**Ar), 7.98 (d, *J* = 9.1 Hz, 1H, C**H**Ar), 7.34 (dd, *J* = 9.1, 2.7 Hz, 1H, C**H**Ar), 7.29 – 7.11 (m, 7H, C**H**Ar), 7.05 (d, *J* = 4.6 Hz, 1H, C**H**Ar), 6.94 (m, 4H, C**H**Ar), 6.77 (d, *J* = 6.4 Hz, 2H, C**H**Ar), 6.50 (s, 1H, C**H**Ar), 6.45 (d, *J* = 11.4 Hz, 1H, C**H**), 3.91 (s, 3H, OC$\mathbf{H}_3$), 3.55 – 3.32 (m, 2H, C**H** and C$\mathbf{H}_{2a}$), 3.22 (dd, *J* = 13.2, 9.1 Hz, 1H, C$\mathbf{H}_{2b}$), 2.75 – 2.52 (m, 1H, C$\mathbf{H}_{2a'}$), 2.40 (d, *J* = 13.5 Hz, 1H, C$\mathbf{H}_{2b'}$), 1.90 (s, 3H, N-C$\mathbf{H}_3$), 1.73 (dd, *J* = 12.7, 9.9 Hz, 1H, C$\mathbf{H}_{2c}$), 1.57 (d, *J* = 21.0 Hz, 2H, C**H** and C$\mathbf{H}_{2c'}$), 1.47 – 1.22 (m, 4H, C$\mathbf{H}_{2d}$, C$\mathbf{H}_{2d'}$, C**H** and C$\mathbf{H}_{2e}$), 0.84 (t, *J* = 7.1 Hz, 3H, C$\mathbf{H}_3$), 0.63 (dd, *J* = 13.0, 7.4 Hz, 1H, C$\mathbf{H}_{2e'}$); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 170.9 (**C**=O), 158.6 (**C**-OCH_3), 146.5 (**C**HAr), 145.1 (**C**Ar), 144.0 (d, *J* = 34.9 Hz, **C**Ar), 140.6 (**C**Ar), 136.6 (d, *J* = 12.0 Hz, **C**Ar), 134.6 (**C**Ar), 134.4 (d, *J* = 21.0 Hz, **C**HAr), 133.2 (d, *J* = 14.8 Hz, **C**Ar), 133.9 (**C**HAr), 133.2 (d, *J* = 18.7 Hz, **C**HAr), 131.1 (**C**HAr), 130.2 (**C**HAr), 129.2 (**C**HAr), 128.7 (d, *J* = 5.3 Hz, **C**HAr), 128.4 (d, *J* = 6.1 Hz, **C**HAr), 128.2 (**C**HAr), 128.0 (d, *J* = 7.5 Hz, **C**HAr), 126.6 (d, *J* = 7.6 Hz, **C**HAr), 123.1 (**C**HAr), 120.2 (**C**HAr), 103.7 (**C**HAr), 58.8 (**C**H_2), 56.2 (O**C**H_3), 56.1 (**C**H), 53.5 (**C**H), 42.0 (**C**H_2), 37.7 (N-**C**H_3), 30.8 (**C**H), 28.6 (**C**H_2), 28.1 (**C**H_2), 27.7 (**C**H_2), 25.4 (**C**H), 12.3 (**C**H_3); **^{31}P-NMR** (162 MHz, $CDCl_3$) δ –14.6 (brs); **HRMS** (ESI): calcd. for $C_{40}H_{42}N_3NaO_2P^+$ $[M+Na]^+$ 650.2907, found *m/z* 650.2901.

2.2 General procedure for the synthesis of racemic imidazolines 5



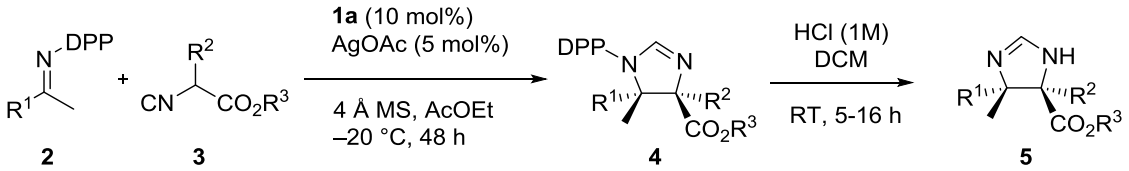
A heterogeneous mixture of isocyanoacetate **3** (0.16 mmol, 1.0 equiv), *N*-diphenylphosphinoyl imine **2** (0.176 mmol, 1.1 equiv), Ag_2O (5.6 mg, 0.024 mmol, 0.15 equiv), powdered 4 Å molecular sieves (60 mg), Et_3N (22 μL, 0.16 mmol, 1.0 equivalent) in ethyl acetate (0.09 M) was stirred at **–**20 °C for 48 hours. The reaction mixture was filtered throught a short pad of celite washing with AcOEt. The filtrate was concentrated under reduced pressure and purified through a short pad of silica eluting with PE:EtOAc 1:9 to obtain compound **4**. Due to its instability, compound **4** was used directly in the following step. The *N*-diphenylphosphinoyl imidazoline **4** (1.0 equiv) was dissolved in dichloromethane (10 mL/mmol), then 1.0 M HCl (10 mL/mmol) was added and the mixture was stirred for 5-16 hours (followed by MS). The reaction was quenched with a solution of sodium bicarbonate to pH ca 7, then extracted with dichloromethane (2 × 6 mL), washed with water (5 mL) and brine (5 mL), dried over anhydrous sodium sulphate, filtered and concentrated under reduced pressure. The crude was purified by flash column chromatography using EtOAc:MeOH 9:1 to obtain compound **5**.

2.3 General procedure A for the enantioselective synthesis of imidazolines 5



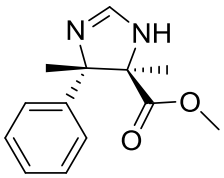
To a mixture of precatalyst **1a** (0.20 equiv), Ag_2O (0.05 equiv), powdered 4 Å molecular sieves (60 mg/0.16 mmol) and *N*-diphenylphosphinoyl imine **2** (1.1 equiv), ethyl acetate (1 mL/0.16 mmol) was added. The reaction mixture was cooled to **–**20 °C under nitrogen atmosphere and a cold solution of isocyanoacetate **3** (1.0 equiv in 1 mL/0.16 mmol of EtOAc) was added. The heterogeneous mixture was stirred at **–**20 °C for 60 hours. The reaction mixture was purified throught a short path of silica gel using AcOEt to obtain compound **4**. Due to its instability, compound **4** was used directly in the following step. The *N*-diphenylphosphinoyl imidazoline **4** (1.0 equiv) was dissolved in dichloromethane (6 mL/mmol), then 1.0 M HCl (6 mL/mmol) was added and the mixture was stirred for 5-16 hours (followed by MS). The reaction was quenched with a solution of sodium bicarbonate to pH ca 7, then extracted with dichloromethane (2 × 6 mL), washed with water (5 mL) and brine (5 mL), dried over anhydrous sodium sulphate, filtered and concentrated under reduced pressure. The crude was purified by flash column chromatography using EtOAc:MeOH 9:1 to obtain compound **5**.

2.4 General procedure B for the enantioselective synthesis of imidazolines 5



To a mixture of precatalyst **1a** (9.8 mg, 0.016 mmol, 0.10 equiv), AgOAc (1.3 mg, 0.008 mmol, 0.05 equiv), powdered 4 Å molecular sieves (60 mg) and *N*-diphenylphosphinoyl imine **2** (0.176 mmol, 1.1 equiv), ethyl acetate (1 mL) was added. The reaction mixture was cooled to –20 °C under nitrogen atmosphere and a cold solution of isocyanoacetate **3** (0.16 mmol, 1.0 equiv in 1 mL of EtOAc) was added. The heterogeneous mixture was stirred at –20 °C for 48 hours. The reaction mixture was purified throught a short path of silica gel using PE:EtOAc 1:9 to obtain compound **4**. Due to its instability, compound **4** was used directly in the following step. The *N*-diphenylphosphinoyl imidazoline **4** (1.0 equiv) was dissolved in dichloromethane (10 mL/mmol), then 1.0 M HCl (10 mL/mmol) was added and the mixture was stirred for 5-16 hours (followed by MS). The reaction was quenched with a solution of sodium bicarbonate to pH ca 7, then extracted with dichloromethane (2 × 6 mL), washed with water (5 mL) and brine (5 mL), dried over anhydrous sodium sulphate, filtered and concentrated under reduced pressure. The crude was purified by flash column chromatography using EtOAc:MeOH 9:1 to obtain compound **5**.

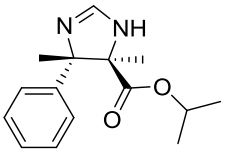
2.4.1 Synthesis and characterization of (4*S*,5*R*)-methyl-4,5-dimethyl-4-phenyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5a



According to general procedure A, using methyl 2-isocyanopropanoate **2a** (40 mg, 0.35 mmol) and *P*,*P*-diphenyl-*N*-(1-phenylethylidene)phosphinic amide **3a** (124.2 mg, 0.39 mmol), ligand **1a** (42 mg, 0.07 mmol), Ag_2O (4.1 mg, 0.017 mmol) as starting materials and ethyl acetate (4 mL) as solvent, imidazoline **4a** was obtained in 63% yield (96 mg, *trans:cis* = 98:2). Deprotection of imidazoline *trans*-**4a** (95 mg, 0.219 mmol) using dichloromethane (1.0 mL) as solvent according to general procedure A gave imidazoline **5a** as a white solid in 93% yield (47 mg, 59% yield over two steps). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 90:10, λ 230 nm, 1 mL/min]: t (minor) = 7.3 min; t (major) = 8.2 min (89% ee).

$[\alpha]_D^{25}$ = +236 (*c* = 0.5 in $CHCl_3$). **M.p.** 104 – 105 °C; **IR** (film) ν = 3087, 1728, 1604, 1446, 1276, 1134, 763, 734 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.59 – 7.54 (m, 2H, C**H**Ar), 7.34 (t, *J* = 7.5 Hz, 2H, C**H**Ar), 7.30 – 7.25 (m, 1H, C**H**Ar), 7.22 (s, 1H, C**H**=N), 4.17 (s, 1H, N**H**), 3.83 (s, 3H, OC**H$_3$**), 1.50 (s, 3H, C**H$_3$**-C-Ar), 0.89 (s, 3H, C**H$_3$**-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 174.1 (**C**=O), 151.7 (**C**H=N), 141.8 (**C**Ar), 128.0 **C**HAr), 127.4 (**C**HAr), 127.0 (**C**HAr), 74.9 (**C**-CO), 73.5 (**C**-Ar), 52.4 (O**C**H$_3$), 25.9 (**C**H$_3$-C-Ar), 24.4 (**C**H$_3$-C-CO); **HRMS** (ESI): calcd. for $C_{13}H_{17}N_2O_2^+$ $[M+H]^+$ 233.1285, found *m/z* 233.1284.

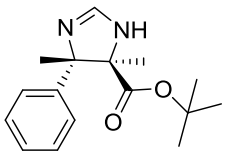
2.4.2 Synthesis and characterization of (4*S*,5*R*)-isopropyl-4,5-dimethyl-4-phenyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5b



According to general procedure A, using isopropyl 2-isocyanopropanoate **2b** (23 mg, 0.16 mmol) and *P*,*P*-diphenyl-*N*-(1-phenylethylidene)phosphinic amide **3a** (56.5 mg, 0.18 mmol), ligand **1a** (19.7 mg, 0.032 mmol), Ag_2O (1.9 mg, 0.008 mmol) as starting materials and ethyl acetate (2 mL) as solvent, imidazoline **4b** was obtained in 87% yield (71 mg, *trans:cis* = 98:2). Deprotection of imidazoline *trans*-**4b** (60 mg, 0.13 mmol) using dichloromethane (0.8 mL) as solvent according to general procedure A gave imidazoline **5b** as a colorless oil in 88% yield (30 mg, 77% yield over two steps). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 80:20, λ 230 nm, 1 mL/min]: t (minor) = 4.1 min; t (major) = 4.6 min (80% ee).

$[\alpha]_D^{25}$ = +150 (*c* = 0.5 in $CHCl_3$). **IR** (film) ν = 2979, 1719, 1603, 1447, 1274, 1145, 1101, 700 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.64 – 7.58 (m, 2H, C**H**Ar), 7.34 (t, *J* = 7.5 Hz, 2H, C**H**Ar), 7.30 – 7.24 (m, 1H, C**H**Ar), 7.19 (s, 1H, C**H**=N), 5.17 (hept, *J* = 6.3 Hz, 1H, C**H**-$(CH_3)_2$), 1.53 (s, 3H, C**H$_3$**-C-Ar), 1.39 (d, *J* = 6.3 Hz, 3H, CH-(C**H$_3$**)$_2$), 1.31 (d, *J* = 6.3 Hz, 3H, CH-(C**H$_3$**)$_2$), 0.88 (s, 3H, C**H$_3$**-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 173.1 (**C**=O), 151.3 (**C**H=N), 142.1 (**C**Ar), 127.9 (**C**HAr), 127.2 (**C**HAr), 74.3 (**C**-Ar), 73.7 (**C**-CO), 69.3 (**C**H-$(CH_3)_2$), 25.8 (**C**H$_3$-C-Ar), 24.6 (**C**H$_3$-C-CO), 22.0 (CH-(**C**H$_3$)$_2$), 21.9 (CH-(**C**H$_3$)$_2$); **HRMS** (ESI): calcd. for $C_{15}H_{21}N_2O_2^+$ $[M+H]^+$ 261.1598, found *m/z* 261.1605.

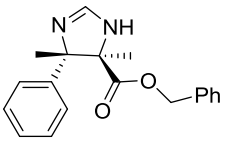
2.4.3 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-4,5-dimethyl-4-phenyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5c



The general procedure B was followed. The desired product was obtained as a colorless oil in 90% yield (40 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 95:5, λ 220 nm, 1 mL/min]: t (minor) = 9.4 min, t (major) = 11.6 min (89% ee).

$[\alpha]_D^{25}$ = +197 (*c* = 0.5 in $CHCl_3$). **IR** (film) ν = 2976, 2931, 1729, 1606, 1448, 1393, 1292, 701 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.63 – 7.58 (m, 2H, C**H**Ar), 7.33 (t, *J* = 7.5 Hz, 2H, C**H**Ar), 7.29 – 7.24 (m, 1H, C**H**Ar), 7.17 (s, 1H, C**H**=N), 4.35 (br s, 1H, N**H**), 1.56 (s, 12H, C**H$_3$**-C-CAr and C(C**H$_3$**)$_3$), 0.86 (s, 3H, C**H$_3$**-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.7 (**C**=O), 151.1 (**C**H=N), 142.3 (**C**Ar), 127.8 (**C**HAr), 127.3 (**C**HAr), 127.2 (**C**HAr), 82.3 (**C**$(CH_3)_3$), 74.6 (**C**-CAr), 73.6 (**C**-CO), 28.2 (C(**C**H$_3$)$_3$), 25.8 (**C**H$_3$-C-CAr), 24.8 (**C**H$_3$-C-CO); **HRMS** (ESI): calcd. for $C_{16}H_{23}N_2O_2^+$ $[M+H]^+$ 275.1754, found *m/z* 275.1757.

2.4.4 Synthesis and characterization of (4*S*,5*R*)-benzyl-4,5-dimethyl-4-phenyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5d

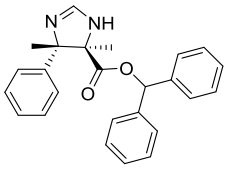


According to general procedure A, using benzyl 2-isocyanopropanoate **2d** (30 mg, 0.16 mmol) and *P*,*P*-diphenyl-*N*-(1-phenylethylidene)phosphinic amide **3a** (57.5 mg, 0.17 mmol), ligand **1a** (19.4 mg, 0.032 mmol), Ag_2O

(1.9 mg, 0.008 mmol) as starting materials and ethyl acetate (2 mL) as solvent, imidazoline **4d** was obtained in 85% yield (69 mg, *trans:cis* = 97:3). Deprotection of imidazoline *trans*-**4d** (66 mg, 0.13 mmol) using dichloromethane (0.8 mL) as solvent according to general procedure A gave imidazoline **5d** as a colorless oil in 91% yield (36 mg, 77% yield over two steps). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 80:20, λ 230 nm, 1 mL/min]: t (minor) = 5.4 min; t (major) = 6.3 min (83% ee).

$[\alpha]_D^{25}$ = +154 (*c* = 0.5 in $CHCl_3$). **IR** (film) ν = 3064, 1729, 1605, 1495, 1270, 1131, 699 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.54 – 7.49 (m, 2H, C**H**Ar), 7.46 – 7.33 (m, 5H, C**H**Ar), 7.33 – 7.23 (m, 3H, C**H**Ar), 7.21 (s, 1H, C**H**=N), 5.31 (d, *J* = 12.2 Hz, 1H, C**H$_{2a}$**), 5.26 (d, *J* = 12.2 Hz, 1H, C**H$_{2b}$**), 1.44 (s, 3H, C**H$_3$**-C-Ar), 0.92 (s, 3H, C**H$_3$**-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 173.3 (**C**=O), 151.5 (**C**H=N), 141.7 (**C**Ar), 135.5 (**C**Ar), 128.8 (**C**HAr), 128.8 (**C**HAr), 128.7 (**C**HAr), 127.9 (**C**HAr), 127.3 (**C**HAr), 127. (**C**HAr), 74.4 (**C**-CO), 74.1 (**C**-Ar), 67.4 (**C**H_2), 25.8 (**C**H_3-C-Ar), 24.4 (**C**H_3-C-CO); **HRMS** (ESI): calcd. for $C_{19}H_{21}N_2O_2^+$ $[M+H]^+$ 309.1598, found *m/z* 309.1598.

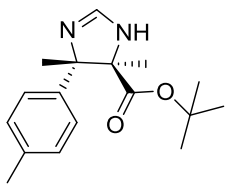
2.4.5 Synthesis and characterization of (4*S*,5*R*)-diphenylmethyl-4,5-dimethyl-4-phenyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5e



According to general procedure A, using diphenylmethyl 2-isocyanopropanoate **2e** (40 mg, 0.16 mmol) and *P*,*P*-diphenyl-*N*-(1-phenylethylidene)phosphinic amide **3a** (0.17 mmol, 53.0 mg), precatalyst **1a** (17.6 mg, 0.03 mmol), Ag_2O (1.8 mg, 0.0076 mmol) as starting materials and ethyl acetate (2 mL) as solvent, imidazoline **4e** was obtained in 76% yield (67 mg, *trans:cis* ≥ 99:1). Deprotection of imidazoline *trans*-**4e** (65 mg, 0.111 mmol) using dichloromethane (0.7 mL) as solvent according to general procedure A gave imidazoline **5e** as a white solid in 82% yield (35 mg, 62% yield over two steps). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 80:20, λ 240 nm, 1 mL/min]: t (minor) = 6.3 min; t (major) = 11.2 min (84% ee).

$[\alpha]_D^{25}$ = +111 (*c* = 0.5 in $CHCl_3$). **M.p.** 176 – 177 °C; **IR** (film) ν = 3062, 1734, 1605, 1449, 1264, 1127, 698 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.48 – 7.43 (m, 4H, C**H**Ar), 7.40 (t, *J* = 7.4 Hz, 2H, C**H**Ar), 7.38 – 7.30 (m, 5H, C**H**Ar), 7.31 – 7.24 (m, 4H, C**H**Ar), 7.23 (s, 1H, C**H**=N), 7.05 (s, 1H, C**H**-$(Ph)_2$), 3.91 (s, 1H. N**H**), 1.32 (s, 3H, C**H$_3$**-C-Ar), 0.97 (s, 3H, C**H$_3$**-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.3 (**C**=O), 151.6 (**C**H=N), 141.5 (**C**Ar), 139.8 (**C**Ar), 139.6 (**C**Ar), 128.8 (**C**HAr), 128.7 (**C**HAr), 128.6 (**C**HAr), 128.1 (**C**HAr), 128.1 (**C**HAr), 127.9 (**C**HAr), 127.4 (**C**HAr), 127.3 (**C**HAr), 126.8 (**C**HAr), 78.2 (**C**H-$(Ph)_2$), 74.3 (**C**-CH_3), 74.2 (**C**-CH_3), 25.4 (**C**H_3-C-Ar), 24.4 (**C**H_3-C-CO); **HRMS** (ESI): calcd. for $C_{25}H_{25}N_2O_2^+$ $[M+H]^+$ 385.1911, found *m/z* 385.1917.

2.4.6 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-4,5-dimethyl-4-(*p*-tolyl)-4,5-dihydro-1*H*-imidazole-5-carboxylate 5f

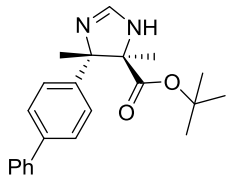


The general procedure B was followed. The desired product was obtained as a colorless oil in 71% yield (33 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-

propanol 95:5, λ 220 nm, 1 mL/min]: t (minor) = 13.7 min, t (major) = 16.4 min (89% ee).

[α]$_D^{25}$ = +148 (*c* = 1.0 in $CHCl_3$). **IR** (film) ν = 2976, 2929, 1732, 1606, 1513, 1451, 1393, 1368, 1291, 1259, 1133, 848, 807 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.48 (d, *J* = 7.1 Hz, 2H, C**H**Ar), 7.21 (s, 1H, C**H**=N), 7.13 (d, *J* = 7.1 Hz, 2H, C**H**Ar), 4.50 (br s, 1H, N**H**), 2.34 (s, 3H, CH_3-CAr) 1.55 (s, 9H, C(C**H**$_3$)$_3$), 1.54 (s, 3H, C**H$_3$**-C-CAr), 0.86 (s, 3H, C**H$_3$**-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.6 (**C**=O), 151.2 (**C**H=N), 139.2 (**C**Ar), 136.8 (**C**Ar), 128.5 (**C**HAr), 127.2 (**C**HAr), 82.3 (**C**(CH$_3$)$_3$), 74.3 (**C**-CAr), 73.7 (**C**-CO), 28.2 (C(**C**H$_3$)$_3$), 25.8 (**CH$_3$**-C-CAr), 24.8 (**CH$_3$**-C-CO), 21.2 (**CH$_3$**-CAr); **HRMS** (ESI): calcd. for $C_{17}H_{25}N_2O_2^+$ $[M+H]^+$ 289.1911, found *m/z* 289.1913.

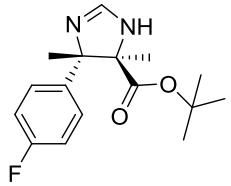
2.4.7 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-4-([1,1'-biphenyl]-4-yl)-4,5-dimethyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5g



The general procedure B was followed. The desired product was obtained as a pale yellow solid in 87% yield (49 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 95:5, λ 220 nm, 1 mL/min] t (minor) = 16.7 min, t (major) = 21.8 min (88% ee).

[α]$_D^{25}$ = +60 (*c* = 0.53 in $CHCl_3$). **M.p.** 70 – 71 °C; **IR** (film) ν = 2976, 2931, 1730, 1605, 1487, 1449, 1369, 1291, 1135, 734 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.68 (d, *J* = 8.5 Hz, 2H, C**H**Ar), 7.62 (dd, *J* = 8.3, 1.2 Hz, 2H, C**H**Ar), 7.57 (d, *J* = 8.5 Hz, 2H, C**H**Ar), 7.43 (t, *J* = 7.7 Hz, 2H, C**H**Ar), 7.36 – 7.29 (m, 1H, C**H**Ar), 7.21 (s, 1H, C**H**=N), 4.10 (br s, 1H, N**H**), 1.59 (s, 3H, C**H$_3$**-C-CAr), 1.58 (s, 9H, C(C**H**$_3$)$_3$), 0.92 (s, 3H, C**H$_3$**-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.6 (**C**=O), 151.2 (**C**H=N), 141.4 (**C**Ar), 140.9 (**C**Ar), 139.9 (**C**Ar), 128.9 (**C**HAr), 127.8 (**C**HAr), 127.3 (**C**HAr), 127.1 (**C**HAr), 126.4 (**C**HAr), 82.4 (**C**(CH$_3$)$_3$), 74.5 (**C**-CAr), 73.6 (**C**-CO), 28.2 (C(**C**H$_3$)$_3$), 25.8 (**C**H$_3$-C-CAr), 24.9 (**C**H$_3$-C-CO); **HRMS** (ESI): calcd. for $C_{22}H_{27}N_2O_2^+$ $[M+H]^+$ 351.2067, found *m/z* 351.2056.

2.4.8 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-4-(4-fluorophenyl)-4,5-dimethyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5h

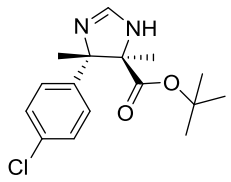


The general procedure B was followed. The desired product was obtained as a pale yellow solid in 89% yield (42 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD-H column [hexane/*iso*-propanol 90:10, λ 220 nm, 1 mL/min] t (minor) = 5.0 min, t (major) = 5.8 min (90% ee).

[α]$_D^{25}$ = +175 (*c* = 0.5 in $CHCl_3$). **M.p.** 38 – 39°C; **IR** (film) ν = 2977, 1730, 1608, 1509, 1369, 1133, 840 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.58 (dd, *J* = 8.8, 5.5 Hz, 2H, C**H**Ar), 7.12 (s, 1H, C**H**=N), 6.99 (t, *J* = 8.8 Hz, 2H, C**H**Ar), 4.27 (br s, 1H, N**H**), 1.54 (s, 9H, C(C**H**$_3$)$_3$), 1.51 (s, 3H, C**H$_3$**-C-CAr), 0.83 (s, 3H, C**H$_3$**-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.6 (**C**=O), 162.0 (d, *J* = 245.4 Hz, **C**-F), 151.0 (**C**H=N), 138.2 (d, *J* = 3.1 Hz, **C**Ar), 129.0 (d, *J* = 7.8 Hz, **C**HAr), 114.4 (d, *J* = 21.0 Hz, **C**HAr), 82.4 (**C**(CH$_3$)$_3$), 74.6 (**C**-CAr), 73.1 (**C**-CO), 28.2 (C(**C**H$_3$)$_3$),

25.8 (**C**H_3-C-CAr), 24.9 (**C**H_3-C-CO); **HRMS** (ESI): calcd. for $C_{16}H_{22}FN_2O_2^+$ $[M+H]^+$ 293.1660, found *m/z* 293.1667.

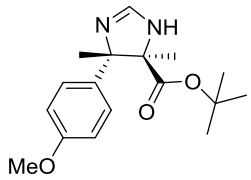
2.4.9 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-4-(4-chlorophenyl)-4,5-dimethyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5i



The general procedure B was followed. The desired product was obtained as a white solid in 80% yield (39 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 95:5, λ 220 nm, 1 mL/min]: t (minor) = 20.0 min, t (major) = 23.3 min (89% ee).

$[\alpha]_D^{25}$ = +105 (*c* = 0.61 in $CHCl_3$). **M.p.** 41 – 42 °C; **IR** (film) ν = 2977, 1730, 1606, 1492, 1452, 1394, 1291, 1132, 1094, 836 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.56 (d, *J* = 8.8 Hz, 2H, C**H**Ar), 7.28 (d, *J* = 8.8 Hz, 2H, C**H**Ar), 7.13 (s, 1H, C**H**=N), 4.20 (br s, 1H, N**H**), 1.54 (s, 9H, C(C**H**$_3$)$_3$), 1.51 (s, 3H, C**H**$_3$-C-CAr), 0.84 (s, 3H, C**H**$_3$-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.5 (**C**=O), 151.1 (**C**H=N), 141.0 (**C**Ar), 133.0 (**C**Ar), 128.9 (**C**HAr), 127.9 (**C**HAr), 82.5 (**C**(CH$_3$)$_3$), 74.7 (**C**-CAr), 73.0 (**C**-CO), 28.2 (C(**C**H$_3$)$_3$), 25.7 (**C**H$_3$-C-CAr), 24.9 (**C**H$_3$-C-CO); **HRMS** (ESI): calcd. for $C_{16}H_{22}ClN_2O_2^+$ $[M+H]^+$ 309.1364, found *m/z* 309.1366.

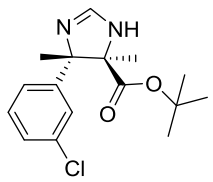
2.4.10 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-4-(4-methoxyphenyl)-4,5-dimethyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5j



The general procedure B was followed. The desired product was obtained as a colorless oil in 80% yield (39 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 85:15, λ 280 nm, 1 mL/min] t (minor) = 5.2 min, t (major) = 6.0 min (90% ee).

$[\alpha]_D^{25}$ = +120 (*c* = 0.8 in $CHCl_3$). **IR** (film) ν = 2976, 1729, 1612, 1512, 1455, 1298, 1248, 1180, 1134 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.51 (d, *J* = 8.9 Hz, 2H, C**H**Ar), 7.13 (s, 1H, C**H**=N), 6.85 (d, *J* = 8.9 Hz, 2H, C**H**Ar), 4.12 (br s, 1H, N**H**), 3.80 (s, 3H, OC**H**$_3$), 1.54 (s, 9H, C(C**H**$_3$)$_3$), 1.52 (s, 3H, C**H**$_3$-C-CAr), 0.84 (s, 3H, C**H**$_3$-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.8 (**C**=O), 158.7 (**C**-OCH$_3$), 151.0 (**C**H=N), 134.5 (**C**Ar), 128.4 (**C**HAr), 113.0 (**C**HAr), 82.2 (**C**(CH$_3$)$_3$), 74.2 (**C**-CAr), 73.6 (**C**-CO), 55.3 (O**C**H$_3$), 28.2 (C(**C**H$_3$)$_3$), 25.8 (**C**H$_3$-C-CAr), 24.8 (**C**H$_3$-C-CO); **HRMS** (ESI): calcd. for $C_{17}H_{25}N_2O_3^+$ $[M+H]^+$ 305.1860, found *m/z* 305.1858.

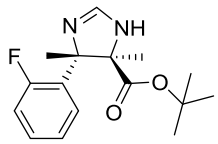
2.4.11 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-4-(3-chlorophenyl)-4,5-dimethyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5k



The general procedure B was followed. The desired product was obtained as a colorless oil in 65% yield (32 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak OD-H column [hexane/*iso*-propanol 95:5, λ 220 nm, 1 mL/min] t (minor) = 13.7 min, t (major) = 29.4 min (87% ee).

$[\alpha]_D^{25}$ = +113 (*c* = 1.50 in $CHCl_3$). **IR** (film) ν = 2977, 1729, 1596, 1360, 1131, 785, 729, 698 cm^{-1}; **^{1}H-NMR** (400 MHz, $CDCl_3$) δ 7.58 (m, 1H, C**H**Ar), 7.47 (m, 1H, C**H**Ar), 7.19 (m, 2H, C**H**Ar), 7.06 (s, 1H, C**H**=N), 1.50 (s, 9H, C(C**H$_3$**)$_3$), 1.46 (s, 3H, C**H$_3$**-C-CAr), 0.81 (s, 3H, C**H$_3$**-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.4 (**C**=O), 151.0 (**C**H=N), 144.7 (**C**Ar), 133.9 (**C**Ar), 129.0 (**C**HAr), 127.7 (**C**HAr), 127.3 (**C**HAr), 125.7 (**C**HAr), 82.6 (**C**(CH$_3$)$_3$), 74.8 (**C**-CAr), 73.0 (**C**-CO), 28.2 (C(**C**H$_3$)$_3$), 25.7 (**C**H$_3$-C-CAr), 24.9 (**C**H$_3$-C-CO); **HRMS** (ESI): calcd. for $C_{16}H_{22}N_2O_2Cl^+$ $[M+H]^+$ 309.1364, found *m/z* 309.1362.

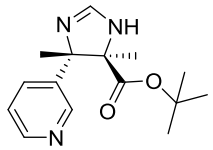
2.4.12 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-4-(2-fluorophenyl)-4,5-dimethyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5l



The general procedure B was followed. The desired product was obtained as a yellow oil in 63% yield (29 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak OD-H column [hexane/*iso*-propanol 95:5, λ 210 nm, 1 mL/min] t (minor) = 36.5 min, t (major) = 50.8 min (90% ee).

$[\alpha]_D^{25}$ = +71 (*c* = 0.5 in $CHCl_3$). **M.p.** 64 – 65 °C; **IR** (film) ν = 2978, 1724, 1610, 1486, 1446, 1368, 1280, 1209, 786 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.55 (td, *J* = 8.0, 1.8 Hz, 1H, C**H**Ar), 7.29 – 7.22 (m, 1H, C**H**Ar), 7.16 (s, 1H, C**H**=N), 7.09 (td, *J* = 7.7, 1.2 Hz, 1H, C**H**Ar), 7.03 (ddd, *J* = 12.1, 8.0, 1.2 Hz, 1H, C**H**Ar), 1.69 (d, *J* = 1.9 Hz, 3H, C**H$_3$**-C-Ar), 1.52 (s, 9H, C(C**H$_3$**)$_3$), 1.00 (s, 3H, C**H$_3$**-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.6 (**C**=O), 160.8 (d, *J* = 248.2 Hz, **C**-F), 151.1 (**C**H=N), 130.1 (d, *J* = 4.4 Hz, **C**HAr), 129.5 (d, *J* = 12.3 Hz, **C**Ar), 129.3 (d, *J* = 8.5 Hz, **C**HAr), 123.7 (d, *J* = 3.3 Hz, **C**HAr), 116.2 (d, *J* = 24.1 Hz, **C**HAr), 82.3 (**C**(CH$_3$)$_3$), 75.4 (**C**-Ar), 72.4 (**C**-CO), 28.0 (C(**C**H$_3$)$_3$), 25.4 (d, *J* = 7.2 Hz, **C**H$_3$-C-Ar), 24.0 (**C**H$_3$-C-CO); **HRMS** (ESI): calcd. for $C_{16}H_{22}FN_2O_2^+$ $[M+H]^+$ 293.1660, found *m/z* 293.1669.

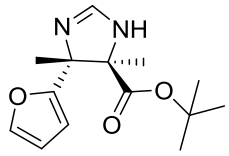
2.4.13 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-4,5-dimethyl-4-(pyridin-3-yl)-4,5-dihydro-1*H*-imidazole-5-carboxylate 5m



The general procedure B was followed. The desired product was obtained as a pale yellow solid in 80% yield (35 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 90:10, λ 220 nm, 1 mL/min] t (minor) = 8.9 min, t (major) = 11.1 min (87% ee).

$[\alpha]_D^{25}$ = +127 (*c* = 0.6 in $CHCl_3$). **IR** (film) ν = 2977, 1729, 1607, 1369, 1289, 1129, 715 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 8.85 (d, *J* = 1.6 Hz, 1H, C**H**Ar), 8.50 (dd, *J* = 4.7, 1.6 Hz, 1H, C**H**Ar), 7.94 (dt, *J* = 7.8, 2.0 Hz, 1H, C**H**Ar), 7.27 (s, 1H, C**H**=N), 7.24 (m, 1H, C**H**Ar), 5.11 (br s, 1H, N**H**), 1.55 (s, 3H, C**H$_3$**-C-CAr), 1.54 (s, 9H, C(C**H$_3$**)$_3$), 0.86 (s, 3H, C**H$_3$**-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.0 (**C**=O), 151.6 (**C**H=N), 148.9 (**C**HAr), 148.5 (**C**HAr), 137.7 (**C**Ar), 135.0 (**C**HAr), 122.8 (**C**HAr), 82.9 (**C**(CH$_3$)$_3$), 73.6 (**C**-CAr), 73.0 (**C**-CO), 28.1 (C(**C**H$_3$)$_3$), 25.3 (**C**H$_3$-C-CAr), 25.0 (**C**H$_3$-C-CO); **HRMS** (ESI): calcd. for $C_{15}H_{22}N_3O_2^+$ $[M+H]^+$ 276.1707, found *m/z* 276.1711.

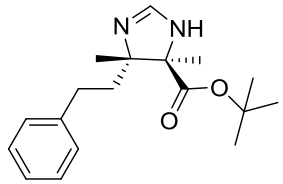
2.4.14 Synthesis and characterization of *tert*-butyl (4*R*,5*R*)-4-(furan-2-yl)-4,5-dimethyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5n



The general procedure B was followed. The desired product was obtained as a pale yellow solid in 83% yield (35 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 95:5, λ 220 nm, 1 mL/min] t (minor) = 12.9 min, t (major) = 18.5 min (91% ee).

$[\alpha]_D^{25}$ = +47 (*c* = 0.5 in $CHCl_3$). **IR** (film) ν = 2978, 1725, 1604, 1451, 1368, 1288, 1135, 733 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.38 (s, 1H, C**H**Ar), 7.18 (s, 1H, C**H**=N), 6.35 – 6.30 (m, 1H, C**H**Ar), 6.29 (d, *J* = 3.2 Hz, 1H, C**H**Ar), 4.36 (s, 1H, N**H**), 1.55 (s, 3H, C**H$_3$**-C-CAr), 1.51 (s, 9H, C(C**H$_3$**)$_3$), 1.05 (s, 3H, C**H$_3$**-C-CO); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.1 (**C**=O), 155.8 (**C**Ar), 152.6 (**C**H=N), 141.9 (**C**HAr), 110.3 (**C**HAr), 107.5 (**C**HAr), 82.3 (**C**$(CH_3)_3$), 73.6 (**C**-CH_3), 72.0 (**C**-CH_3), 28.1 (C(**C**H_3)$_3$), 23.2 (**C**H_3-C-CAr), 22.8 (**C**H_3-C-CO); **HRMS** (ESI): calcd. for $C_{14}H_{21}N_2O_3^+$ $[M+H]^+$ 265.1547, found *m/z* 265.1554.

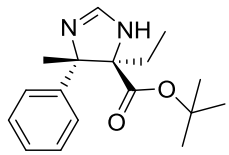
2.4.15 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-4,5-dimethyl-4-phenethyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5o



The general procedure B was followed. The asymmetric reaction affords **4o** as a 5:1 mixture of *trans* and *cis* diastereomers. (determined by 1H-NMR analysis of the crude reaction mixture). The desired product **5o** was obtained as a clear oil in 48% yield (23 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak OD-H column [hexane/*iso*-propanol 90:10, λ 220 nm, 0.5 mL/min] t (minor) = 22.0 min, t (major) = 28.5 min (87% ee).

$[\alpha]_D^{25}$ = +21 (*c* = 0.65 in $CHCl_3$). **IR** (film) ν = 2973, 1731, 1601, 1454, 1368, 1138, 701 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.32 (m, 2H, C**H**Ar), 7.27 (m, 2H, C**H**Ar), 7.22 (t, *J* = 7.3 Hz, 1H, C**H**Ar), 7.05 (s, 1H, C**H**=N), 3.99 (br s, 1H, N**H**), 2.85 (app dd, *J* = 7.0, 10.1 Hz, 2H, C**H$_2$**Ph), 2.00 (m, 2H, C**H$_2$**CH_2Ph), 1.52 (s, 9H, C(C**H$_3$**)$_3$), 1.34 (s, 3H, CO-C-C**H$_3$**), 1.25 (s, 3H, CH_2-C-C**H$_3$**); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.6 (**C**=O), 151.3 (**C**H=N), 142.9 (**C**Ar), 128.6 (**C**HAr, **C**HAr), 125.9 (**C**HAr), 82.0 (**C**$(CH_3)_3$), 73.2 (**C**-CO), 70.5 (**C**-CH_2), 38.0 (**C**H_2-CH_2Ph), 31.4 (**C**H_2Ph), 28.1 (C(**C**H_3)$_3$), 21.7 (CH_2-C-**C**H_3), 21.5 (CO-C-**C**H_3); **HRMS** (ESI): calcd. for $C_{18}H_{27}N_2O_2^+$ $[M+H]^+$ 303.20670, found *m/z* 303.20584.

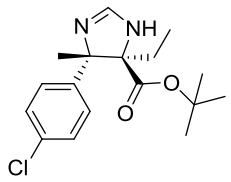
2.4.16 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-5-ethyl-4-methyl-4-phenyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5p



The general procedure B was followed. The desired product was obtained as a pale yellow solid in 62% yield (29 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 95:5, λ 220 nm, 1 mL/min] t (minor) = 8.5 min, t (major) = 10.1 min (90% ee).

[α]$_D^{25}$ = +155 (*c* = 0.5 in $CHCl_3$). **M.p.** 170 – 171°C; **IR** (film) ν = 3088, 2976, 2933, 1732, 1604, 1369, 1250, 1137, 763, 701 cm^{-1}; **^{1}H-NMR** (500 MHz, $CDCl_3$) δ 7.59 (d, *J* = 7.2 Hz, 2H, C**H**Ar), 7.32 (t, *J* = 7.5 Hz, 2H, C**H**Ar), 7.28 – 7.22 (m, 1H, C**H**Ar), 7.13 (s, 1H, C**H**=N), 4.65 (br s, 1H, N**H**), 1.57 (s, 9H, C(C**H**$_3$)$_3$), 1.54 (s, 3H, C**H**$_3$), 1.18 (dq, *J* = 14.6, 7.4 Hz, 1H, C**H$_{2a}$**-CH_3), 0.94 (dt, *J* = 14.6, 7.4 Hz, 1H, C**H$_{2a'}$**-CH_3), 0.68 (t, *J* = 7.4 Hz, 3H, CH_2-C**H$_3$**); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.1 (**C**=O), 151.0 (**C**H=N), 142.5 (**C**Ar), 127.6 (**C**HAr), 127.6 (**C**HAr), 127.0 (**C**HAr), 82.4 (**C**(CH$_3$)$_3$), 76.5 (**C**-CO), 76.0 (**C**-CAr), 30.7 (**C**H$_2$-CH$_3$), 28.2 (C(**C**H$_3$)$_3$), 26.2 (**C**H$_3$), 8.7 (CH_2-**C**H$_3$); **HRMS** (ESI): calcd. for $C_{17}H_{25}N_2O_2^+$ $[M+H]^+$ 289.1911, found *m/z* 289.1913.

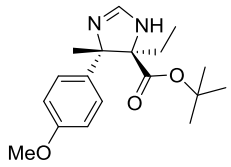
2.4.17 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-4-(4-chlorophenyl)-5-ethyl-4-methyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5q



The general procedure B was followed. The desired product was obtained as a white solid in 81% yield (42 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 95:5, λ 220 nm, 1 mL/min] t (minor) = 7.7 min, t (major) = 8.2 min (89% ee).

[α]$_D^{25}$ = +99 (*c* = 5.2 in $CHCl_3$). **M.p.** 130 – 135 °C; **^{1}H-NMR** (400 MHz, $CDCl_3$) δ 7.48 (d, *J* = 8.0 Hz, 2H, C**H**Ar), 7.21 (d, *J* = 8.0 Hz, 2H, C**H**Ar), 7.04 (s, 1H, C**H**=N), 1.50 (s, 9H, C(C**H**$_3$)$_3$), 1.43 (s, 3H, C**H**$_3$), 1.12 – 1.07 (m, 1H, C**H$_{2a}$**-CH_3), 0.88 – 0.82 (m, 1H, C**H$_{2a'}$**-CH_3), 0.61 (t, *J* = 7.4 Hz, 3H, CH_2-C**H$_3$**); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 171.8 (**C**=O), 150.9 (**C**H=N), 141.1 (**C**Ar), 132.7 (**C**Ar), 129.0 (**C**HAr), 127.6 (**C**HAr), 82.5 (**C**(CH$_3$)$_3$), 75.8 (**C**-CAr or **C**-CO, one quaternary C obscured by solvent resonance), 30.6 (**C**H$_{2a}$-CH$_3$), 28.1 (C(**C**H$_3$)$_3$), 26.0 (**C**H$_3$), 8.5 (CH_2-**C**H$_3$); **HRMS** (ESI): calcd. for $C_{17}H_{24}N_2O_2Cl^+$ $[M+H]^+$ 323.1521, found *m/z* 323.1520.

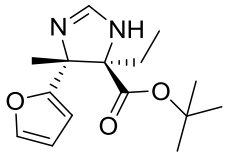
2.4.18 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-5-ethyl-4-(4-methoxyphenyl)-4-methyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5r



The general procedure B was followed. The desired product was obtained as an off-white solid in 79% yield (40 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 95:5, λ 220 nm, 1 mL/min] t (minor) = 9.4 min, t (major) = 11.2 min (92% ee).

[α]$_D^{25}$ = +109 (*c* = 11.3 in $CHCl_3$). **M.p.** 125 – 128 °C; **IR** (film) ν = 2978, 1731, 1512, 1247, 1137; **^{1}H-NMR** (400 MHz, $CDCl_3$) δ 7.44 (d, *J* = 12.0 Hz, 2H, C**H**Ar), 7.05 (s, 1H, C**H**=N), 6.79 (d, *J* = 12.0 Hz, 2H, C**H**Ar), 3.47 (s, 1H, OC**H**$_3$), 1.50 (s, 9H, C(C**H**$_3$)$_3$), 1.44 (s, 3H, C**H**$_3$), 1.14 – 1.09 (m, 1H, C**H$_{2a}$**-CH_3), 0.90 – 0.86 (m, 1H, C**H$_{2a'}$**-CH_3), 0.61 (t, *J* = 8.0 Hz, 3H, CH_2-C**H$_3$**); **^{13}C-NMR** (125 MHz, CD_2Cl_2) δ 171.8 (**C**=O), 158.5 (**C**Ar), 150.7 (**C**H=N), 134.7 (**C**Ar), 128.6 (**C**HAr), 112.6 (**C**HAr), 82.0 (**C**(CH$_3$)$_3$), 76.5 (**C**-CO), 75.3 (**C**-CAr), 55.1 (O**C**H$_3$), 30.5 (**C**H$_2$-CH$_3$), 27.8 (C(**C**H$_3$)$_3$), 25.9 (**C**H$_3$), 8.3 (CH_2-**C**H$_3$); **HRMS** (ESI): calcd. for $C_{18}H_{27}N_2O_3^+$ $[M+H]^+$ 319.2016, found *m/z* 319.2015.

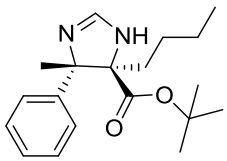
2.4.19 Synthesis and characterization of *tert*-butyl (4*R*,5*R*)-5-ethyl-4-(furan-2-yl)-4-methyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5s



The general procedure B was followed. The desired product was obtained as a colorless oil in 84% yield (37 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 90:10, λ 220 nm, 1 mL/min]: t (minor) = 8.2 min, t (major) = 10.3 min (93% ee).

$[\alpha]_D^{25}$ = +21.1 (*c* = 15.1 in $CHCl_3$). **IR** (film) ν = 2980, 1737, 1247, 1141; **^{1}H-NMR** (400 MHz, $CDCl_3$) δ 7.32 (dd, *J* = 1.7, 0.8 Hz, 1H, C**H**Ar), 7.08 (s, 1H, C**H**=N), 6.27 (dd, *J* = 3.2, 1.7 Hz, 1H, C**H**Ar), 6.21 (dd, *J* = 3.2, 0.8 Hz, 1H, C**H**Ar), 1.48 (s, 3H, C-C**H**$_3$), 1.46 (s, 9H, C(C**H**$_3$)$_3$), 1.40 – 1.30 (m, 1H, C**H**$_{2a}$-CH$_3$), 1.19 – 1.11 (m, 1H, C**H**$_{2a'}$-CH$_3$), 0.68 (t, *J* = 8.0 Hz, 3H, CH$_2$-C**H**$_3$); **^{13}C-NMR** (125 MHz, CD_2Cl_2) δ 171.1 (**C**=O), 156.0 (**C**Ar), 152.9 (**C**H=N), 141.8 (**C**HAr), 110.2 (**C**HAr), 107.6 (**C**HAr), 82.3 (**C**(CH$_3$)$_3$), 77.1 (**C**-CO), 72.8 (**C**-CAr), 28.7 (**C**H$_2$-CH$_3$), 27.8 (C(**C**H$_3$)$_3$), 23.5 (**C**H$_3$), 8.7 (CH$_2$-**C**H$_3$); **HRMS** (ESI): calcd. for $C_{15}H_{23}N_2O_3^+$ $[M+H]^+$ 279.1703, found *m/z* 279.1702.

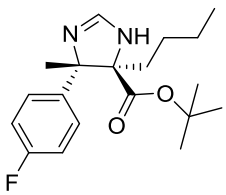
2.4.20 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-5-butyl-4-methyl-4-phenyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5t



The general procedure B was followed. The desired product was obtained as a colorless oil in in 85% yield (43 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 95:5, λ 220 nm, 1 mL/min]: t (minor) = 12.5 min, t (major) = 18.4 min (91% ee).

$[\alpha]_D^{25}$ = +131 (*c* = 14.3 in $CHCl_3$). **IR** (film) ν = 2970, 1730, 1579, 1356 cm^{-1}; **^{1}H-NMR** (400 MHz, $CDCl_3$) δ 7.53 – 7.51 (m, 2H, C**H**Ar), 7.27 – 7.17 (m, 3H, C**H**Ar), 7.07 (s, 1H, C**H**=N), 1.50 (s, 9H, C(C**H**$_3$)$_3$), 1.46 (s, 3H, C**H**$_3$), 1.08 – 0.97 (m, 4H, C**H**$_2$), 0.88 – 0.83 (m, 2H, C**H**$_2$), 0.65 (t, *J* = 8.0 Hz, 3H, CH$_2$-C**H**$_3$); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.2 (**C**=O), 150.9 (**C**H=N), 142.3 (**C**Ar), 127.6 (**C**HAr), 127.5 (**C**HAr), 126.9 (**C**HAr), 82.3 (**C**(CH$_3$)$_3$), 76.0 (**C**-CAr or **C**-CO, one quaternary C obscured by solvent resonance), 37.1 (**C**H$_2$), 28.1 (C(**C**H$_3$)$_3$), 26.6 (**C**H$_2$), 26.2 (**C**H$_3$), 22.8 (C-**C**H$_3$), 13.9 (CH$_2$-**C**H$_3$); **HRMS** (ESI): calcd. for $C_{19}H_{29}N_2O_2^+$ $[M+H]^+$ 317.2224, found *m/z* 317.2225.

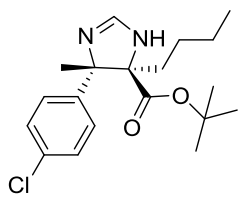
2.4.21 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-5-butyl-4-(4-fluorophenyl)-4-methyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5u



The general procedure B was followed. The desired product was obtained as an off-white solid in in 83% yield (44 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 90:10, λ 220 nm, 1 mL/min] t (minor) = 4.6 min, t (major) = 5.9 min (90% ee).

$[\alpha]_D^{25}$ = +140 (*c* = 15.1 in $CHCl_3$). **M.p.** 117 – 119 °C; **IR** (film) ν = 2960, 1731, 1509, 1136 cm^{-1}; **^{1}H-NMR** (400 MHz, $CDCl_3$) δ 7.56 (d, 2H, *J* = 9.0, 5.5 Hz, C**H**Ar), 7.12 (s, 1H, C**H**=N), 6.99 (t, 2H, *J* = 8.8 Hz, C**H**Ar), 1.55 (s, 9H, C(C**H**$_3$)$_3$), 1.49 (s, 3H, C**H**$_3$), 1.15 – 1.01 (m, 4H, C**H**$_2$), 0.97 – 0.83 (m, 2H, **CH**$_2$), 0.66 (t, *J* = 7.0 Hz, CH_2-C**H**$_3$); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.2 (**C**=O), 162.0 (d, $J_{C,F}$ = 303.7 Hz, **C**FAr), 151 (**C**H=N), 138.2 (d, $J_{C,F}$ = 3.7 Hz, **C**Ar), 129.2 (d, $J_{C,F}$ = 10.0 Hz, **C**HAr), 114.4 (d, $J_{C,F}$ = 26.2 Hz, **C**HAr), 82.6 (**C**(CH$_3$)$_3$), 75.7 (**C**-CAr or **C**-CO, one quaternary C obscured by solvent resonance), 37.3 (**C**H$_2$), 28.2 (C(**C**H$_3$)$_3$), 26.6 (**C**H$_2$), 26.3 (C-**C**H$_3$), 22.8 (**C**H$_2$), 14.0 (CH_2**C**H$_3$); **HRMS** (ESI): calcd. for $C_{19}H_{28}N_2O_2F^+$ $[M+H]^+$ 335.2129, found *m/z* 335.2126.

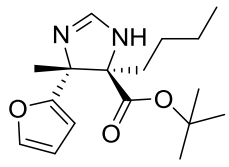
2.4.22 Synthesis and characterization of *tert*-butyl (4*S*,5*R*)-5-butyl-4-(4-chlorophenyl)-4-methyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5v



The general procedure B was followed. The desired product was obtained as an off-white solid in 80% yield (45 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 90:10, λ 220 nm, 1 mL/min] t (minor) = 7.8 min, t (major) = 9.1 min (88% ee).

$[\alpha]_D^{25}$ = +155 (*c* = 1.0 in $CHCl_3$). **M.p.** 130 – 140 °C; **IR** (film) ν = 2959, 1731, 1606, 1136 cm^{-1}; **^{1}H-NMR** (400 MHz, $CDCl_3$) δ 7.48 (d, *J* = 8.0 Hz, 2H, C**H**Ar), 7.22 (d, *J* = 8.0 Hz, 2H, C**H**Ar), 7.05 (s, 1H, C**H**=N), 1.49 (s, 9H, C(C**H**$_3$)$_3$), 1.42 (s, 3H, C**H**$_3$), 1.06 – 1.00 (m, 4H, C**H$_2$**), 0.86 – 0.82 (m, 2H, C**H$_2$**), 0.67 (t, *J* = 8.0 Hz, 3H, C**H**$_3$); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 172.0 (**C**=O), 151.1 (**C**H=N), 141.0 (**C**Ar), 132.9 (**C**Ar), 129.1 (**C**HAr), 127.8 (**C**HAr), 82.6 (**C**(CH$_3$)$_3$), 75.8 (**C**), 75.7 (**C**), 37.3 (**C**H$_2$), 28.2 (C(**C**H$_3$)$_3$), 26.6 (**C**H$_2$) 26.2 (**C**H$_3$), 22.8 (**C**H$_2$), 14.0 (CH_2-**C**H$_3$); **HRMS** (ESI): calcd. for $C_{19}H_{28}N_2O_2Cl^+$ $[M+H]^+$ 351.1834, found *m/z* 351.1830.

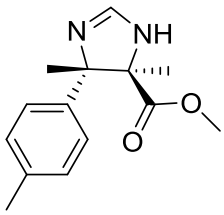
2.4.23 Synthesis and characterization of *tert*-butyl (4*R*,5*R*)-5-butyl-4-(furan-2-yl)-4-methyl-4,5-dihydro-1*H*-imidazole-5-carboxylate 5w



The general procedure B was followed. The desired product was obtained as a colorless oil in 83% yield (41 mg, *trans* diastereoisomeronly). The ee was determined by HPLC using a Chiralpak AD column [hexane/*iso*-propanol 95:5, λ 220 nm, 1 mL/min]: t (minor) = 14.7 min, t (major) = 26.2 min (93% ee).

$[\alpha]_D^{25}$ = +11 (*c* = 2.0 in $CHCl_3$). **IR** (film) ν = 2980, 1728, 1605, 1142 cm^{-1}; **^{1}H-NMR** (400 MHz, $CDCl_3$) δ 7.37 (dd, *J* = 1.7, 0.8 Hz, 1H, C**H**Ar), 7.14 (s, 1H, C**H**=N), 6.32 (dd, *J* = 3.2, 1.8 Hz, 1H, C**H**Ar), 6.26 (dd, *J* = 3.2, 0.8 Hz, 1H, C**H**Ar), 1.53 (s, 3H, C-C**H**$_3$), 1.51 (s, 9H, C(C**H**$_3$)$_3$), 1.43 – 1.30 (m, 1H, C**H$_2$**), 1.23 – 1.07 (m, 4H, C**H$_2$**), 1.05 – 0.93 (m, 1H, C**H$_2$**), 0.73 (t, *J* = 7.3 Hz, 3H, C**H**$_3$); **^{13}C-NMR** (125 MHz, $CDCl_3$) δ 171.7 (**C**=O), 155.8 (**C**Ar), 152.5 (**C**H=N), 141.6 (**C**HAr), 110.1 (**C**HAr), 107.4 (**C**HAr), 82.2 (**C**(CH$_3$)$_3$), 35.1 (**C**H$_{2a}$-CH$_2$), 28.0 (C(**C**H$_3$)$_3$), 26.9 (**C**H$_{2a}$-CH$_2$) 23.5 (**C**H$_3$), 22.8 (**C**H$_{2a}$-CH$_3$), 13.8 (CH$_{2a}$-**C**H$_3$); **HRMS** (ESI): calcd. for $C_{17}H_{27}N_2O_3^+$ $[M+H]^+$ 307.2016, found *m/z* 307.2013.

2.4.24 Synthesis and characterization of methyl (4*S*,5*R*)-4,5-dimethyl-4-(*p*-tolyl)-4,5-dihydro-1*H*-imidazole-5-carboxylate 5y



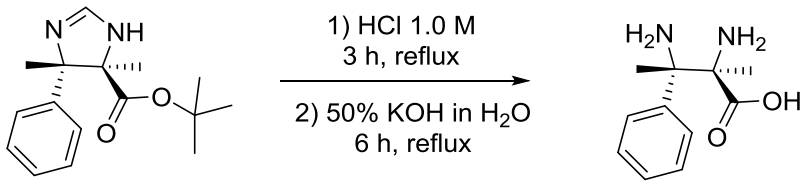
The general procedure B was followed. The desired product was obtained as a white solid in 28% yield (11 mg, *trans* diastereoisomer only). The ee was determined by HPLC using a Chiralpak OJ column [hexane/*iso*-propanol 90:10, λ 220 nm, 1 mL/min]: t (major) = 8.9 min, t (minor) = 15.6 min (87% ee).

$[\alpha]_D^{25}$ = +166 (*c* = 0.69 in $CHCl_3$). Lit. for the enantiomer:[12] $[\alpha]_D^{20.7}$ = −173.6 (*c* = 0.76 in $CHCl_3$). **M.p.**: 107 – 111 °C; **^{1}H-NMR** (400 MHz, $CDCl_3$) δ 7.44 (d, *J* = 8.3 Hz, 2H, C**H**Ar), 7.26 (s, 1H, C**H**=N), 7.15 (d, *J* = 8.1 Hz, 2H, C**H**Ar), 3.97 (br s, 1H, N**H**), 3.83 (s, 1H, $CO_2C\mathbf{H}_3$), 2.35 (s, 3H, C$\mathbf{H}_3$-CAr), 1.49 (s, 3H, C$\mathbf{H_3}$-C-CAr), 0.91 (s, 3H, C$\mathbf{H_3}$-C-CO); **^{13}C-NMR** (75 MHz, $CDCl_3$) δ 174.1 (**C**=O), 151.7 (**C**H=N), 138.8 (**C**Ar), 137.1 (**C**Ar), 128.8 (**C**HAr), 126.9 (**C**HAr), 74.9 (**C**-CAr), 73.5 (**C**-CO), 52.4 ($CO_2\mathbf{C}H_3$), 26.1 (**C**H_3-C-CAr), 24.4 (**C**H_3-C-CO), 21.1 (**C**H_3-CAr). Spectroscopical data are in agreement with the reported ones;[12] the chemical shift of the C**H** on the imidazoline moves in the range 7.3 – 7.0 ppm depending on sample concentration, presumably because of H-bonding interactions.

[12] G. Lu, T. Yoshino, H. Morimoto, S. Matsunaga, M. Shibasaki, *Angew. Chem. Int. Ed*. **2011**, *50*, 4382–4385.

2.5 Synthesis of imidazoline derivatives

2.5.1 Synthesis of (2*R*,3*S*)- 2,3-diamino-2-methyl-3-phenylbutanoic acid 6c



5c **6c**

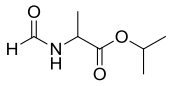
Imidazoline **5c** (15 mg, 0.055 mmol) was dissolved in HCl 1.0 M (0.3 mL). The resultant solution was refluxed for 3 hours. After solvent evaporation the residue was dissolved in aqueous 50%(w/w) KOH solution (0.3 mL) and refluxed for 6 hours. The reaction mixture was cooled to 0 ºC and neutralized with 1.0 M aqueous HCl. The solvents were removed in vacuo and the remaining residue was loaded on a Dowex H^+ ion exchange resin. The column was flushed with water, dioxane, more water and eluted with 2.0 M aqueous ammonia. The ammoniacal fraction was evaporated to afford diaminoacid **6c** as a white solid in 69% yield (8 mg).

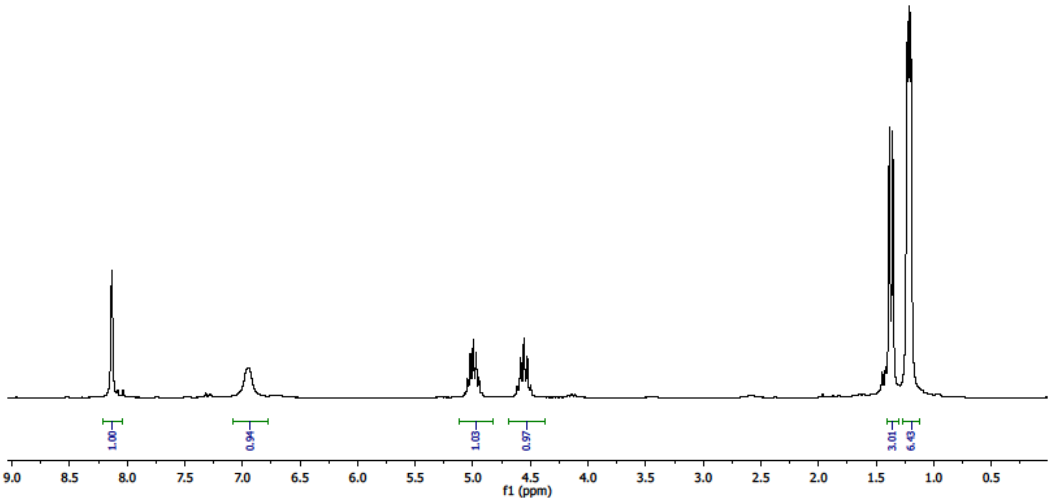
$[\alpha]_D^{20}$: + 20 (*c* = 0.75 in MeOH); **m.p.** 160 – 161 °C; **IR** (film): ν = 3345, 2973, 1600, 1447, 1390, 1359, 700 cm^{-1}; **^{1}H-NMR** (500 MHz, D_2O): δ 7.47 (s, 5H, C_{Ar}**H**), 1.79 (s, 3H, C**H$_3$**CC_{Ar}), 1.44 (s, 3H, C**H$_3$**CCO_2H); **^{13}C-NMR** (125 MHz, D_2O) δ 178.8 (**C**OOH), 139.0 (**C**$_{Ar}$), 129.1 (**C**$_{Ar}$H), 128.9 (**C**$_{Ar}$H), 126.7 (**C**$_{Ar}$H), 64.5 (**C**COOH), 60.5 (**C**C_{Ar}), 21.3 (**C**H_3CC_{Ar}), 20.5 (**C**H_3CCO_2H); **HRMS** (ESI): calcd. for $C_{11}H_{16}N_2NaO_2^+$ $[M+Na]^+$ 231.1104, found *m/z* 231.1109.

3 ^{1}H-NMR and ^{13}C-NMR of starting materials and ligands

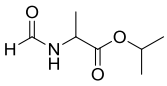
3.1 ^{1}H-NMR and ^{13}C-NMR of isopropyl *N*-formylalanine 2b'

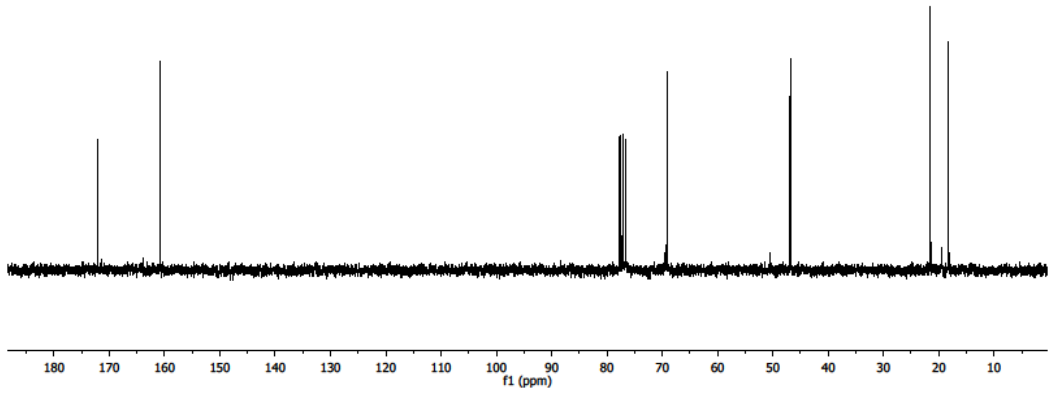
^{1}H-NMR





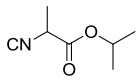
^{13}C-NMR

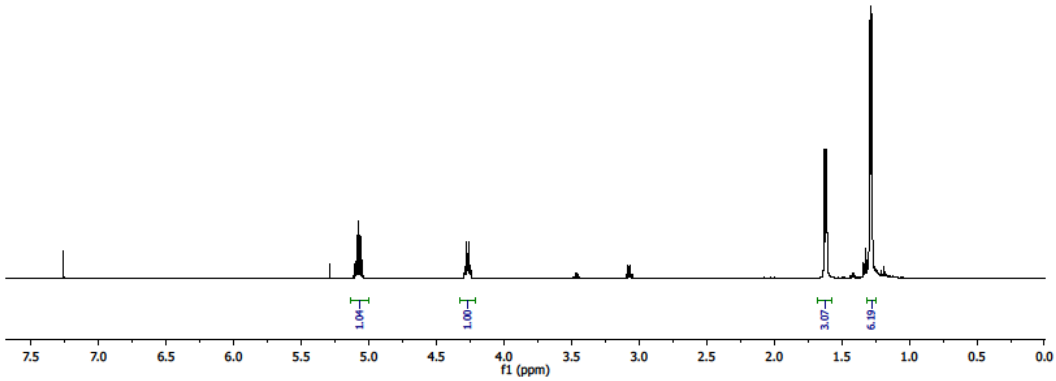




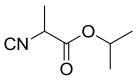
3.2 ^{1}H-NMR and ^{13}C-NMR of isopropyl 2-isocyanopropanoate 2b

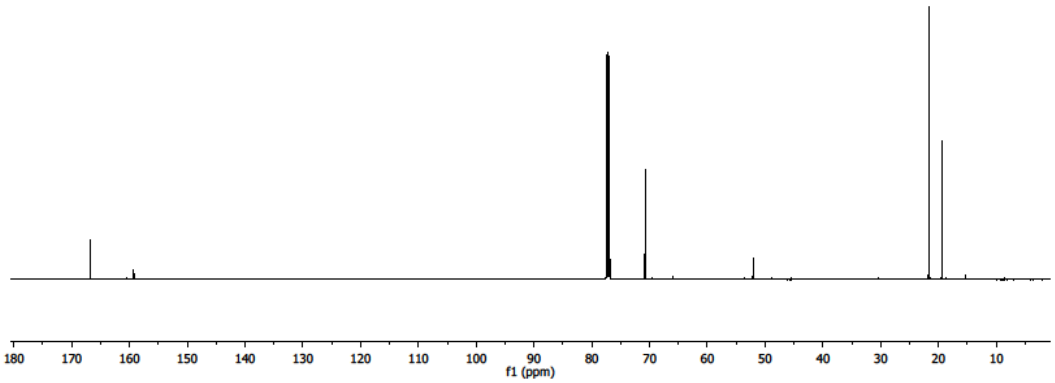
^{1}H-NMR





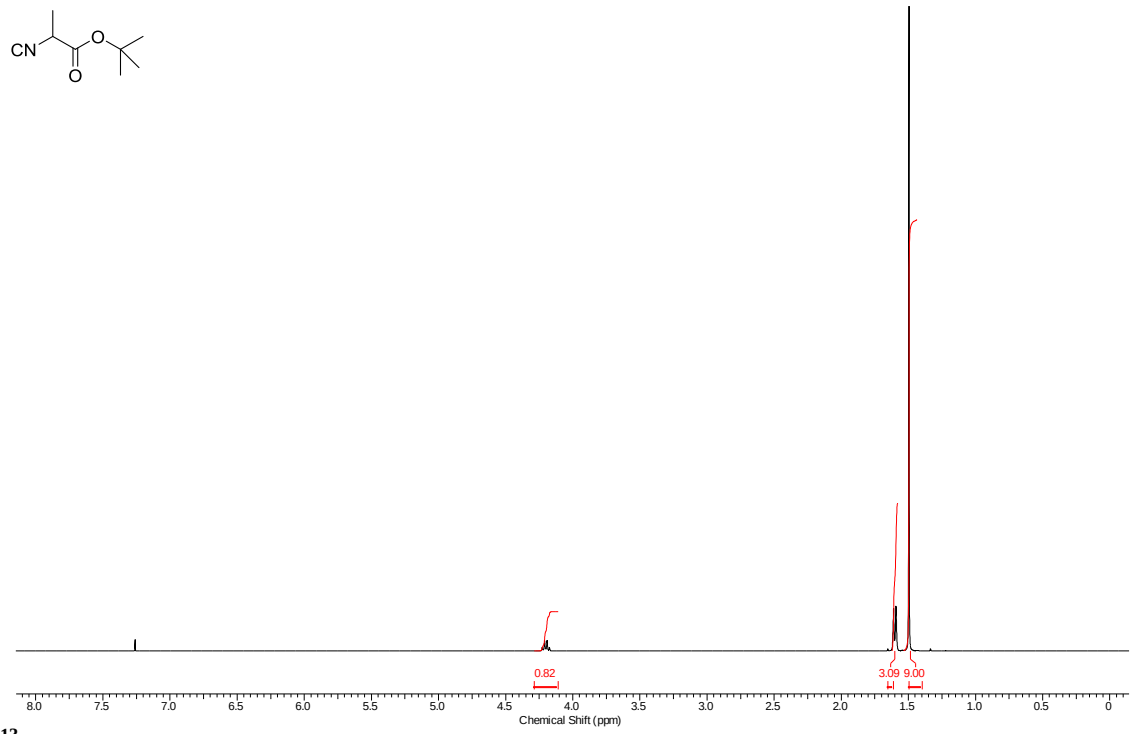
^{13}C-NMR



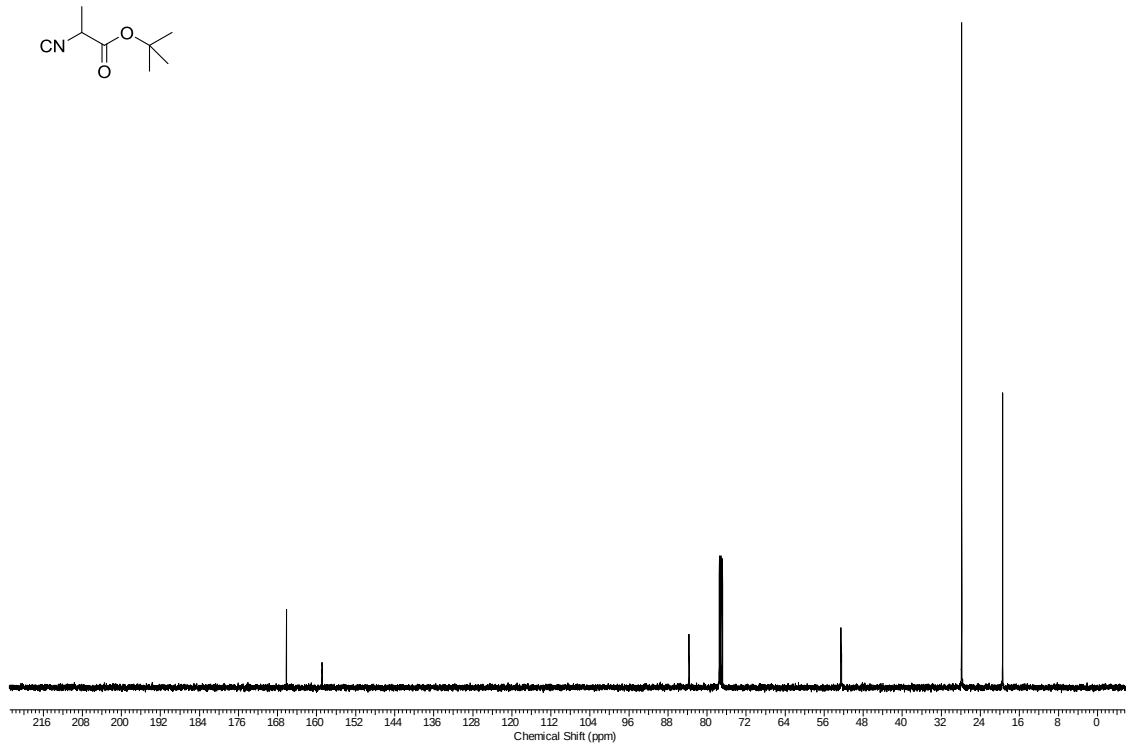


3.3 ^{1}H-NMR and ^{13}C-NMR of *tert*-butyl 2-isocyanopropanoate 2c

^{1}H-NMR

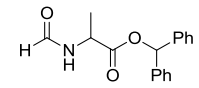


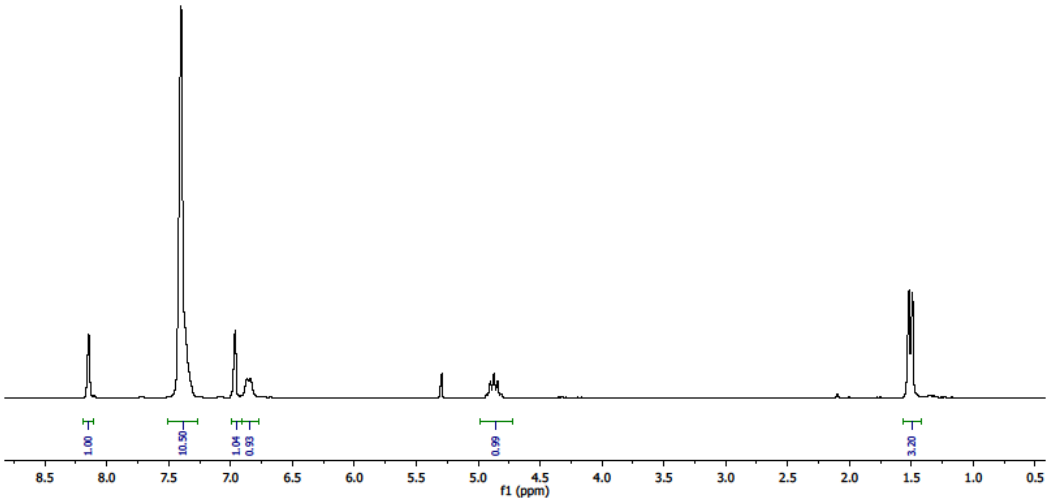
^{13}C-NMR



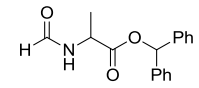
3.4 ^{1}H-NMR and ^{13}C-NMR of diphenylmethyl *N*-formylalanine 2e'

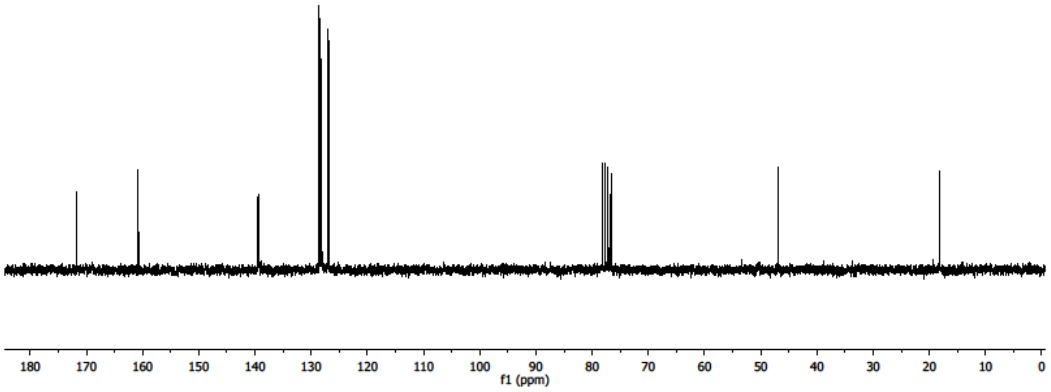
^{1}H-NMR





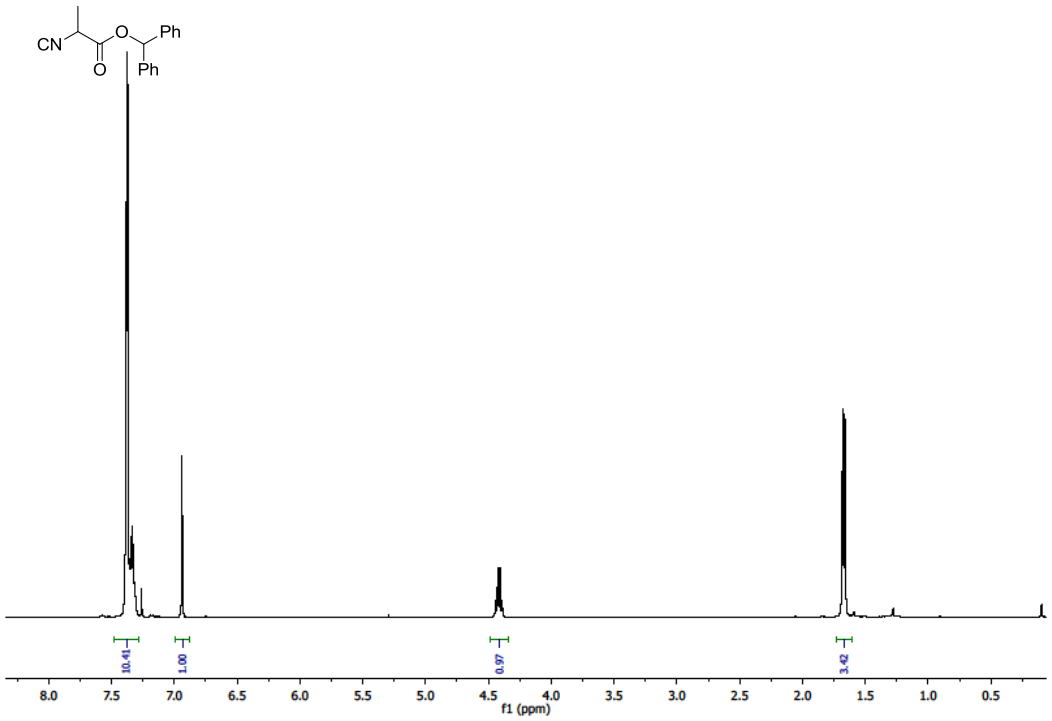
^{13}C-NMR



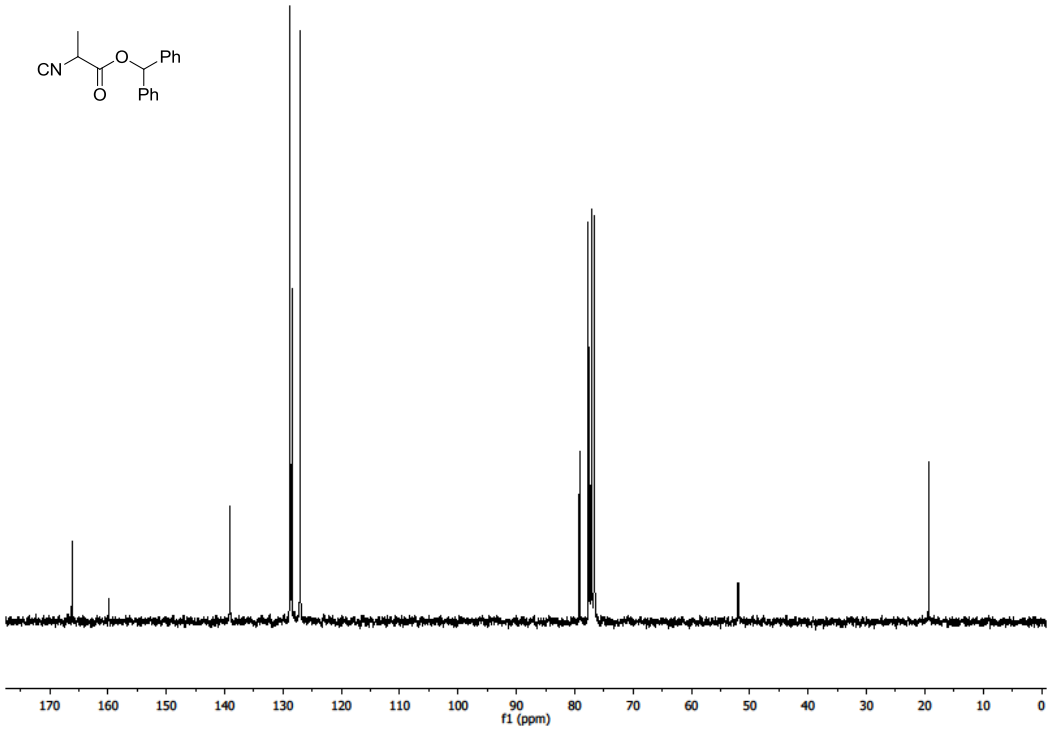


3.5 ^{1}H-NMR and ^{13}C-NMR of diphenylmethyl 2-isocyanopropanoate 2e

^{1}H-NMR

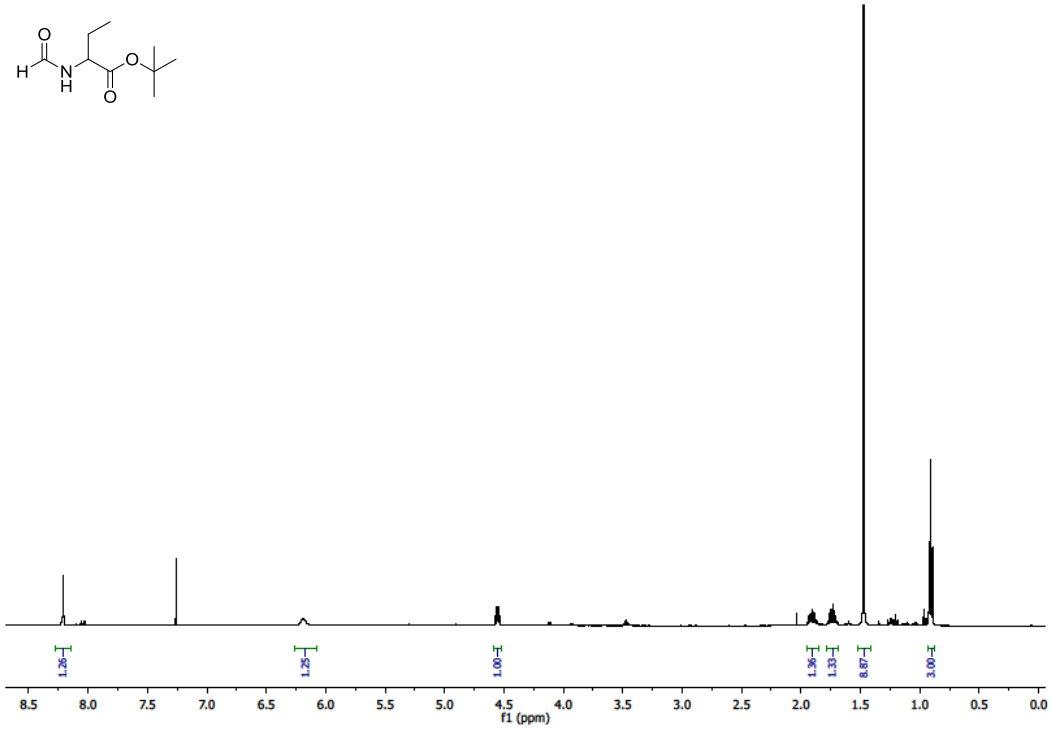


^{13}C-NMR

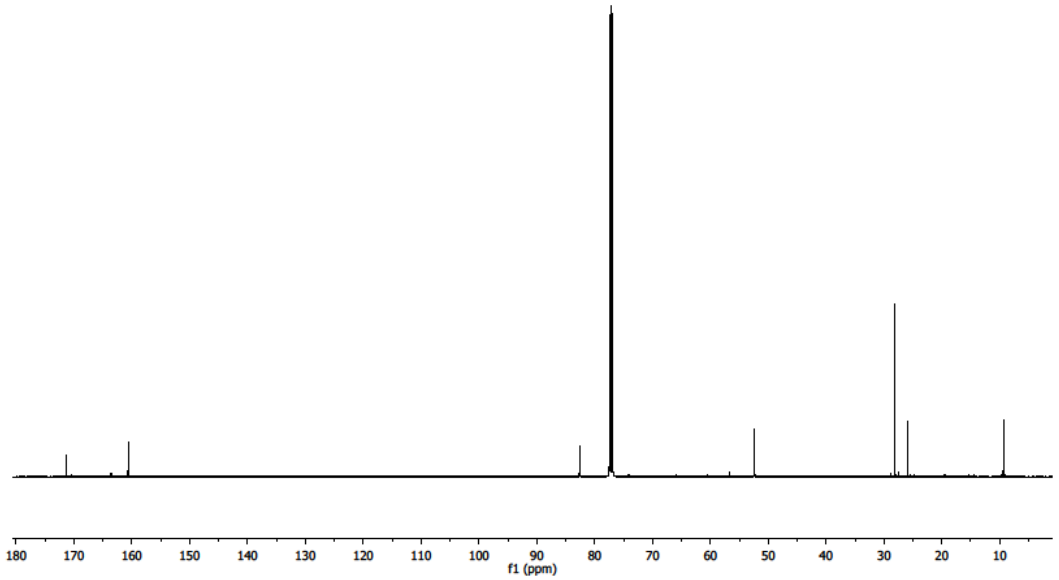


3.6 ^{1}H-NMR and ^{13}C-NMR of *tert*-butyl 2-formamidobutanoate 2f'

^{1}H-NMR

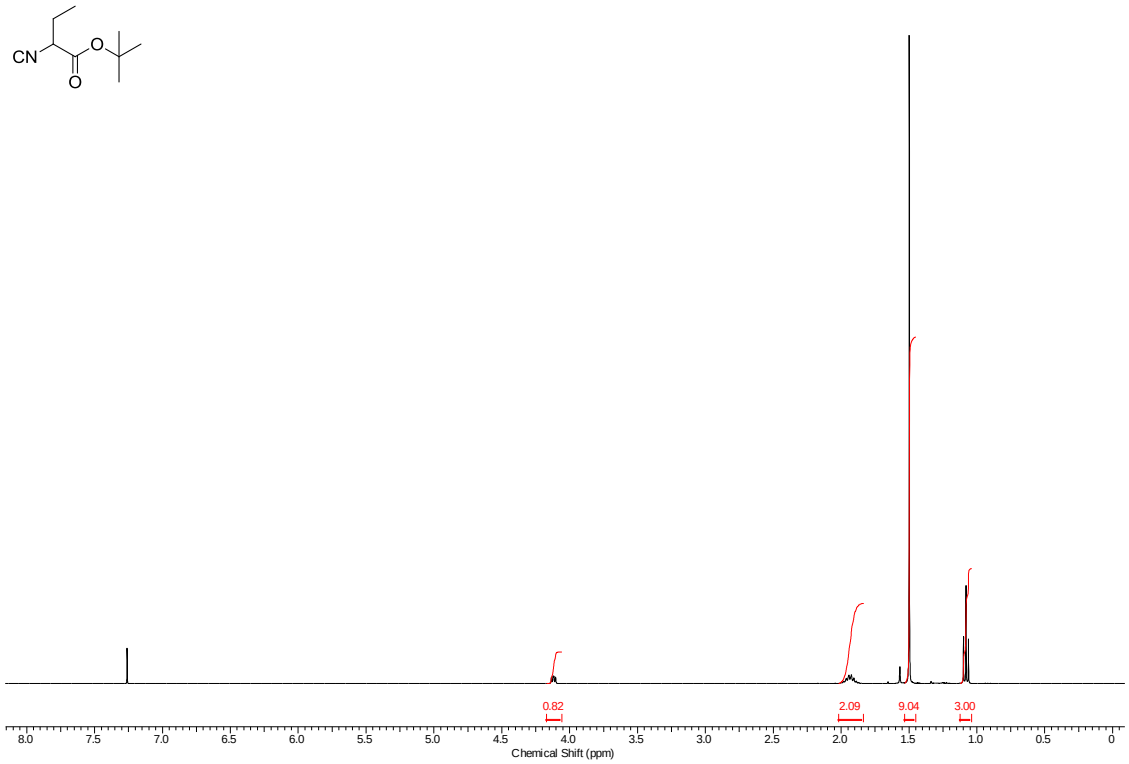


^{13}C-NMR

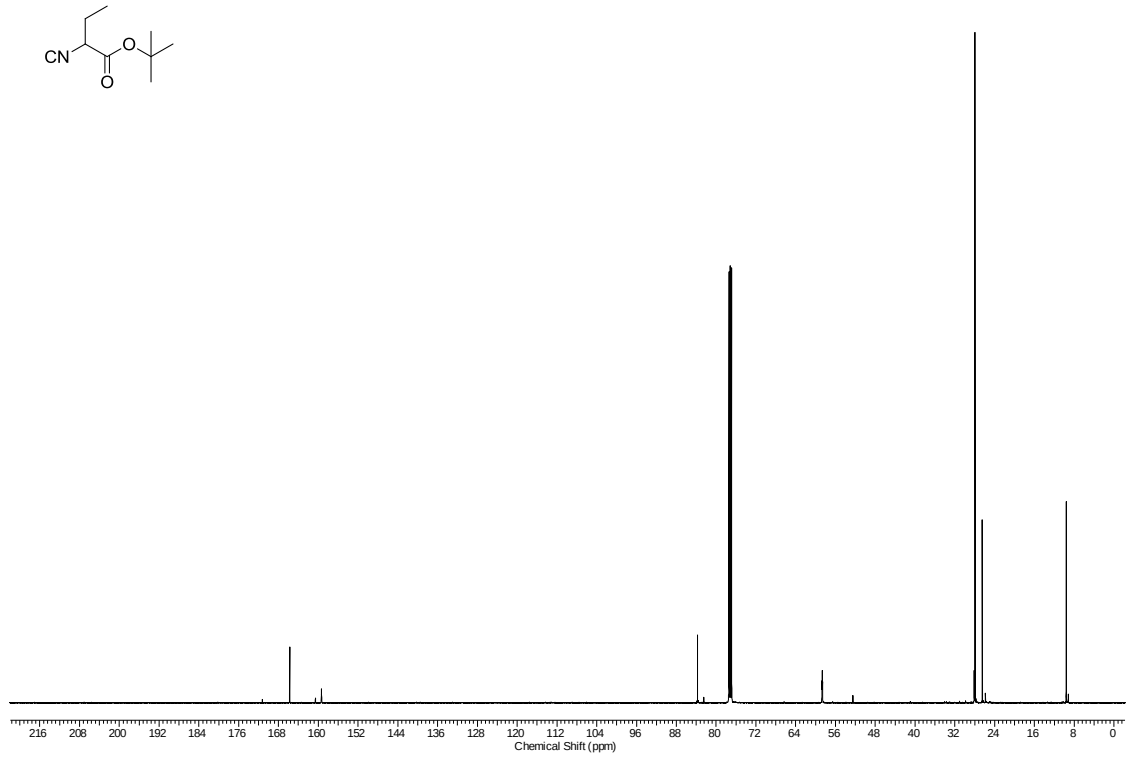


3.7 ^{1}H-NMR and ^{13}C-NMR of *tert*-butyl 2-isocyanobutanoate 2f

^{1}H-NMR

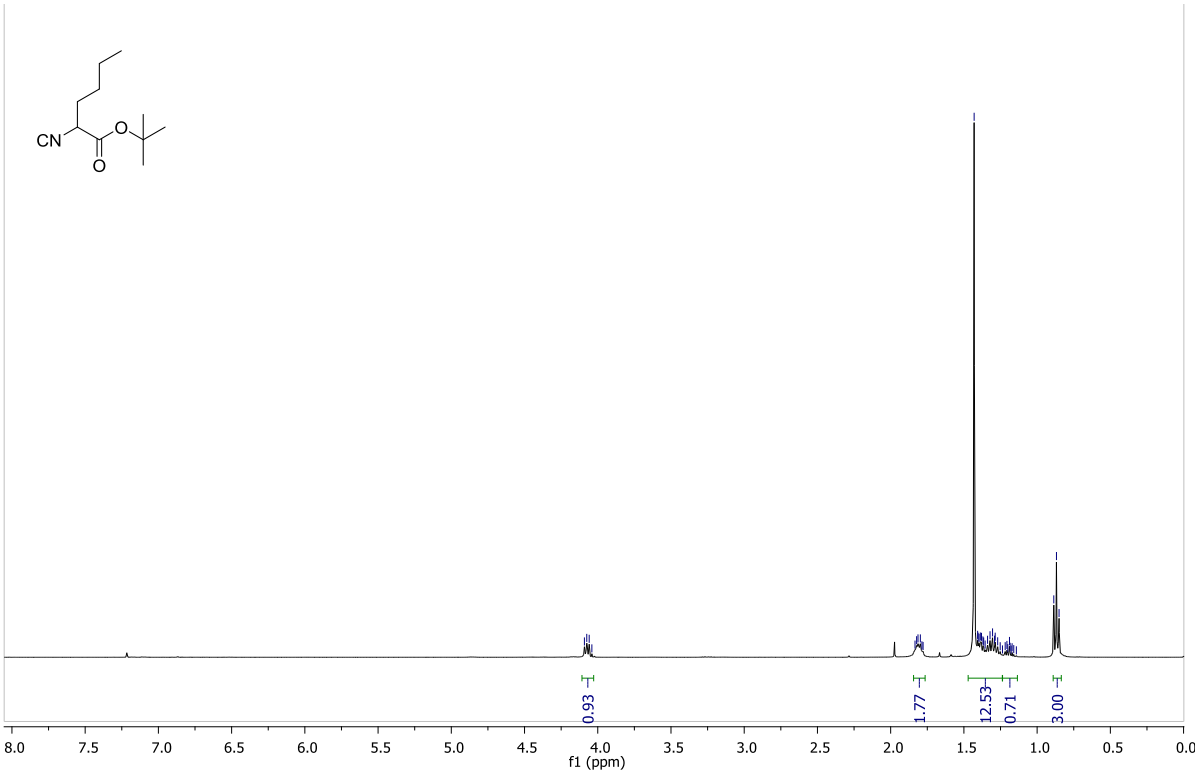


^{13}C-NMR

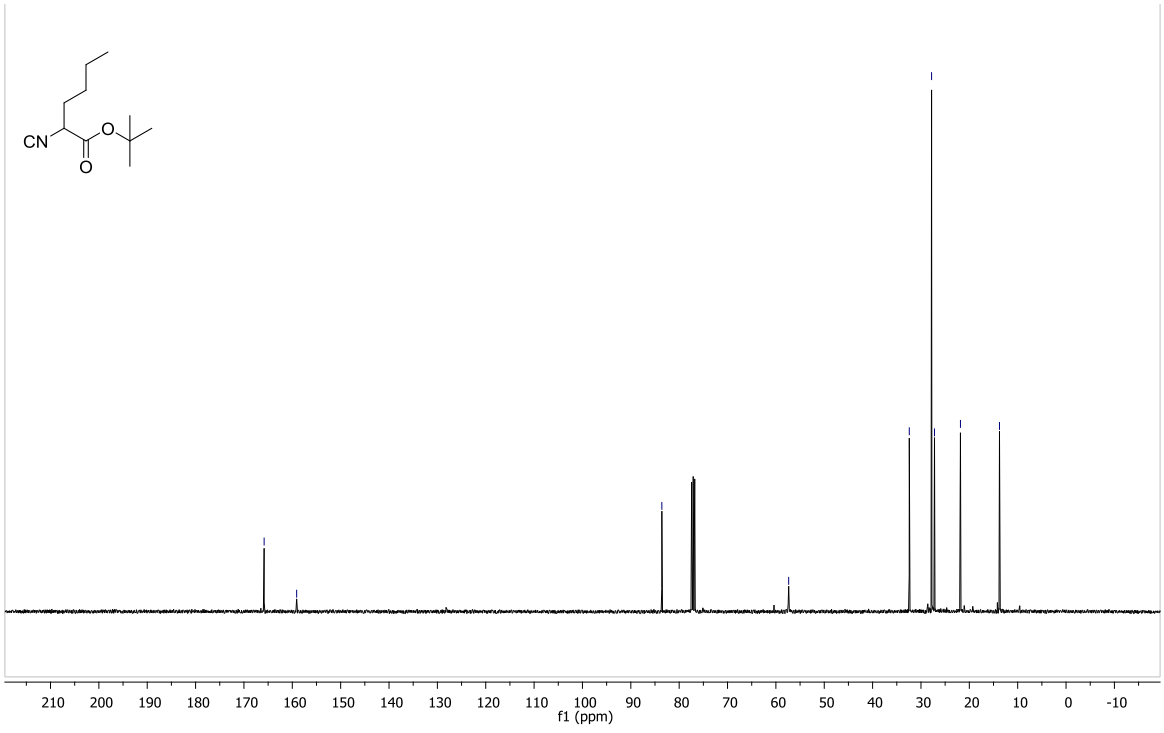


3.8 ^{1}H-NMR and ^{13}C-NMR of *ter-t*butyl 2-isocyanohaxanoate 2g

^{1}H-NMR

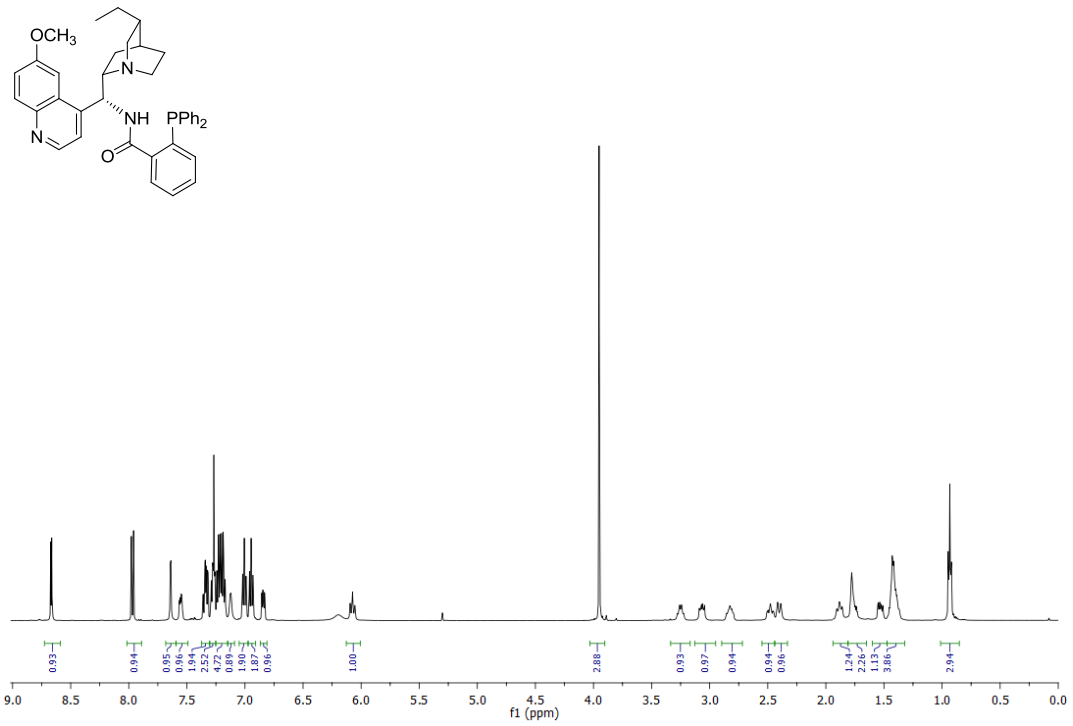


^{13}C-NMR

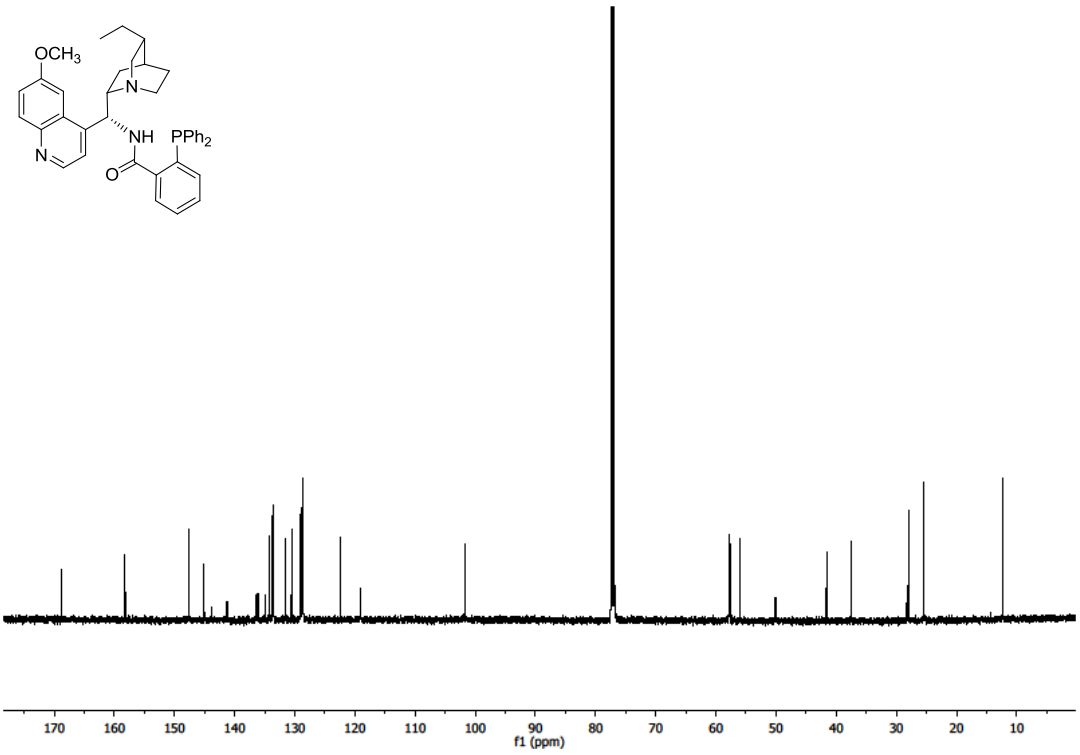


3.9 ^{1}H-NMR and ^{13}C-NMR of ligand 1d

^{1}H-NMR

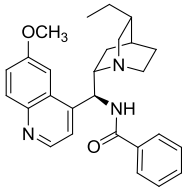


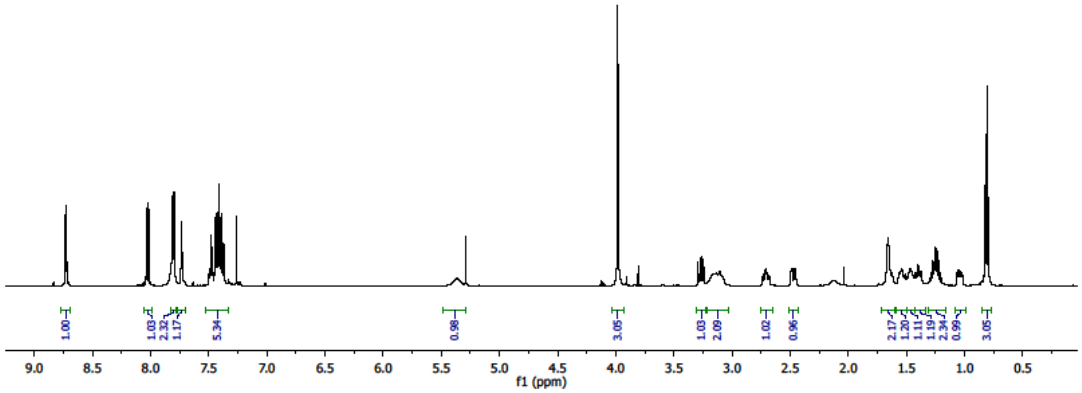
^{13}C-NMR



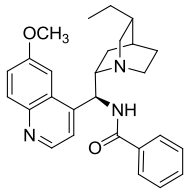
3.10 ^{1}H-NMR and ^{13}C-NMR of ligand 1e

^{1}H-NMR



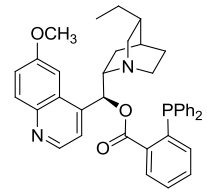


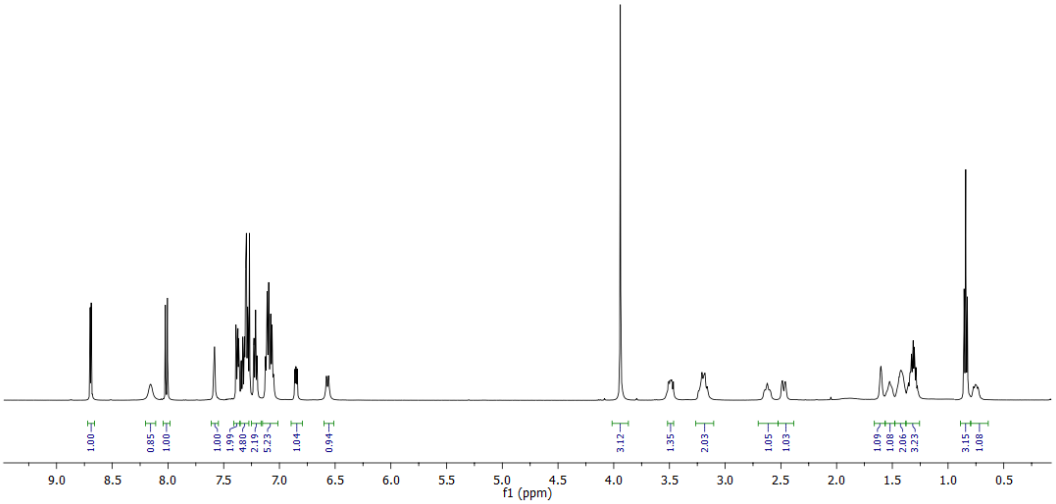
^{13}C-NMR



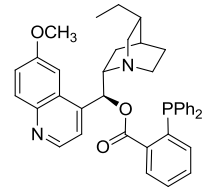
3.11 ^{1}H-NMR and ^{13}C-NMR of ligand 1f

^{1}H-NMR



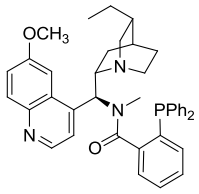


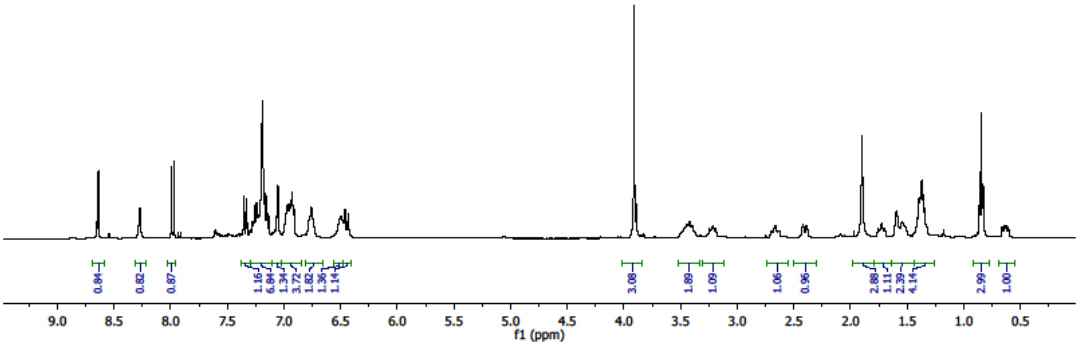
^{13}C-NMR



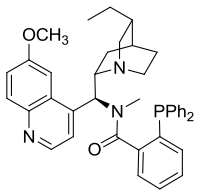
3.12 ^{1}H-NMR and ^{13}C-NMR of ligand 1g

^{1}H-NMR





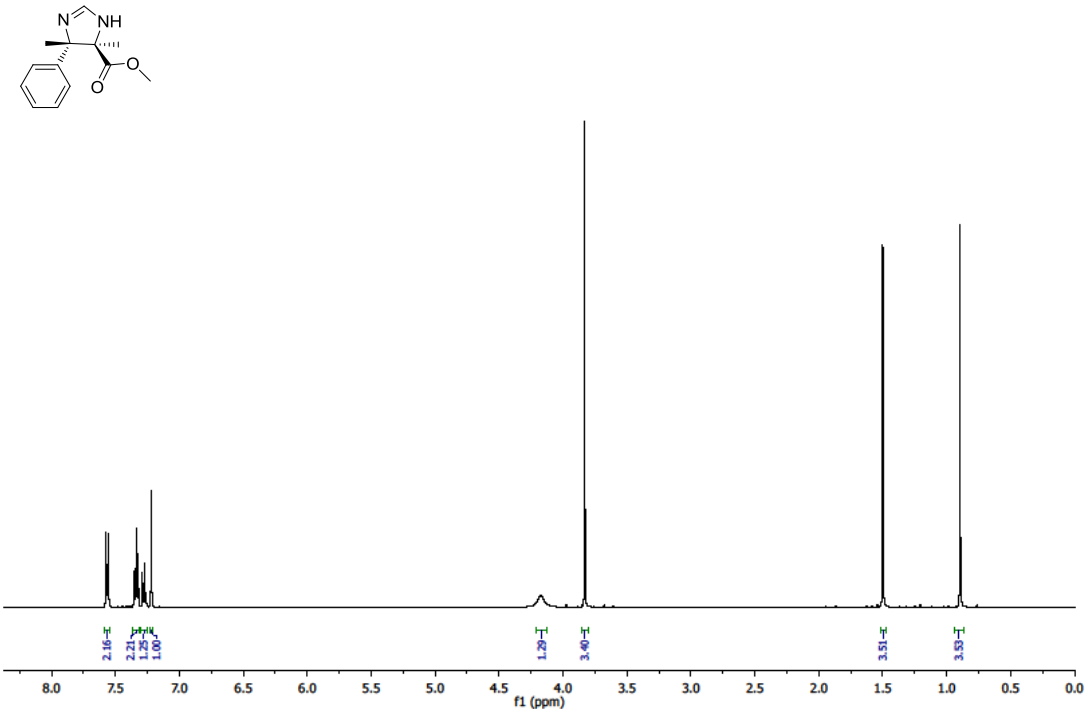
^{13}C-NMR



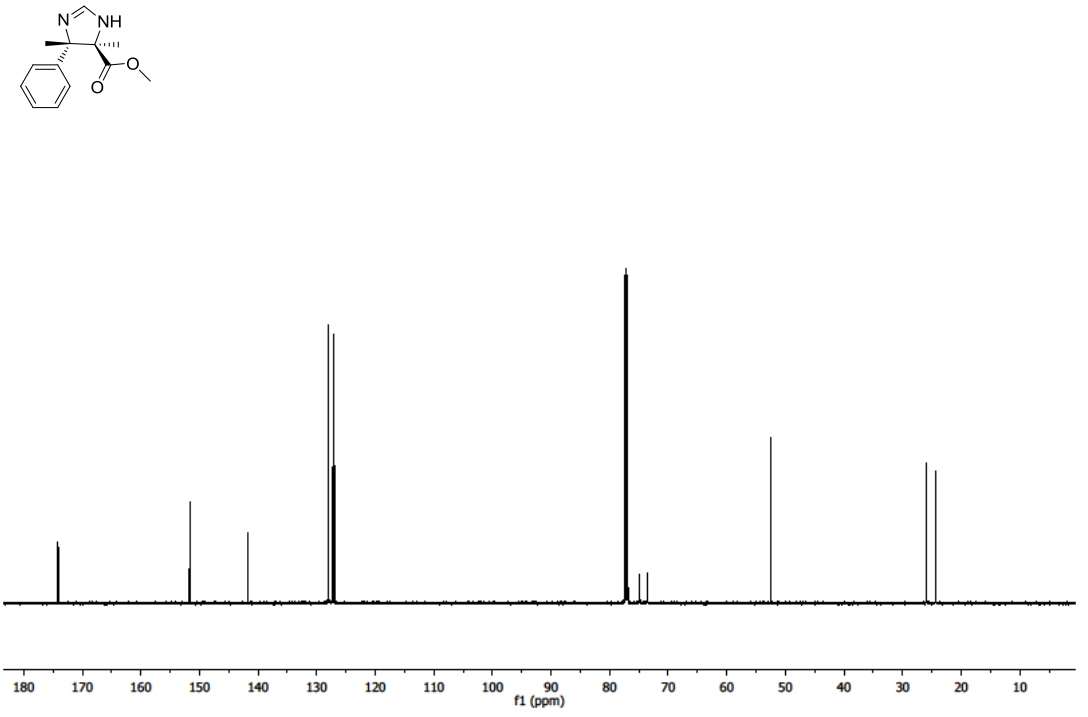
4 ^{1}H-NMR, ^{13}C-NMR, NOE and HPLC traces of imidazolines 5

4.1 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5a

^{1}H-NMR

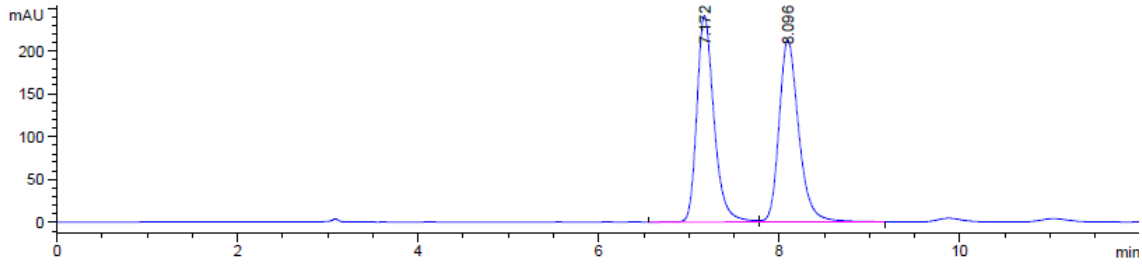


^{13}C-NMR



HPLC traces of imidazoline 5a

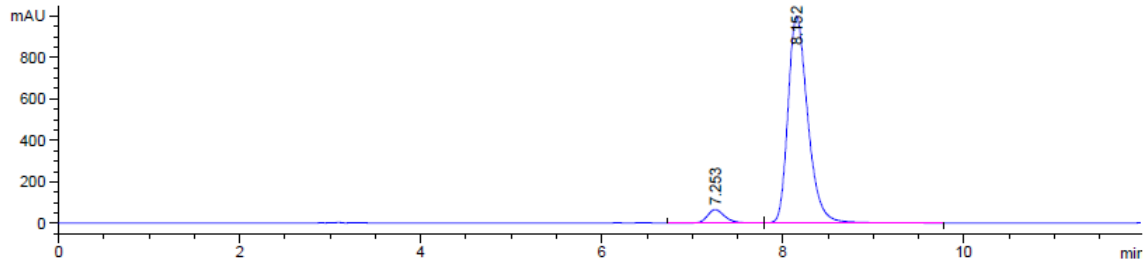
Racemic



Signal 2: DAD1 B, Sig=230,16 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.172	VV	0.2024	3192.17114	241.26320	49.7568
2	8.096	VB	0.2331	3223.37402	212.39865	50.2432
Totals :				6415.54517	453.66185	

Enanatioenriched

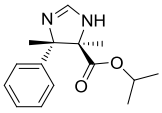


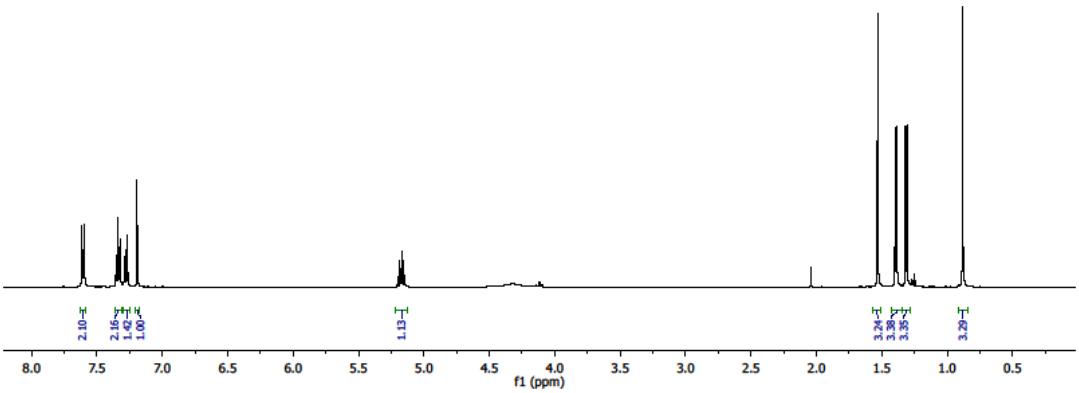
Signal 2: DAD1 B, Sig=230,16 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.253	VV	0.2098	905.01654	65.24442	5.6049
2	8.152	VB	0.2341	1.52420e4	998.40479	94.3951
Totals :				1.61470e4	1063.64921	

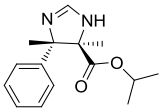
4.2 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5b

^{1}H-NMR



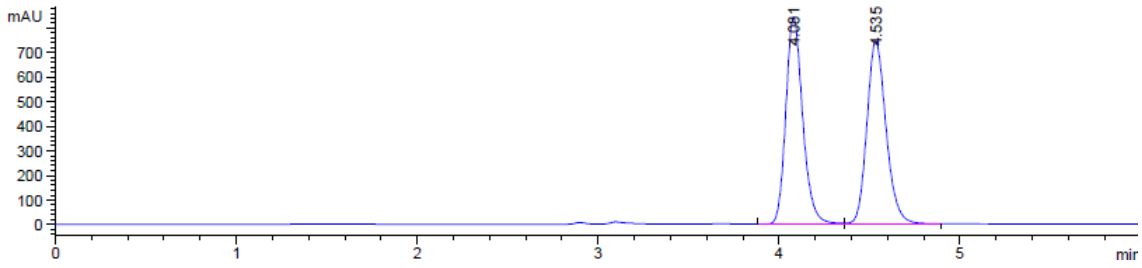


^{13}C-NMR



HPLC traces of imidazoline 5b

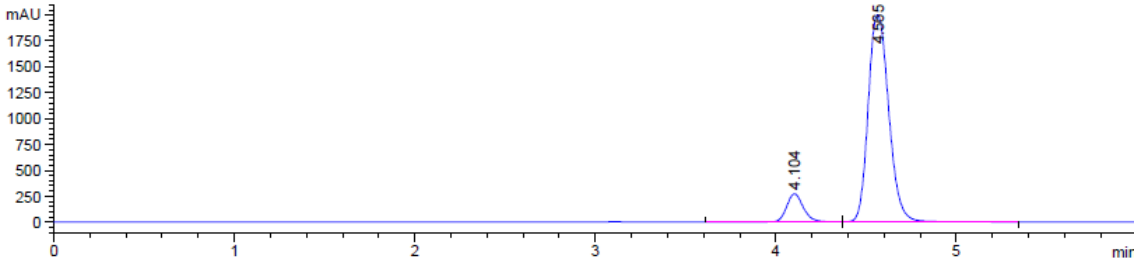
Racemic



Signal 2: DAD1 B, Sig=230,16 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.081	VV	0.1001	5508.81689	844.99323	48.8619
2	4.535	VV	0.1148	5561.21484	747.09430	51.1381
Totals :				1.10700e4	1592.08753	

Enantioenriched

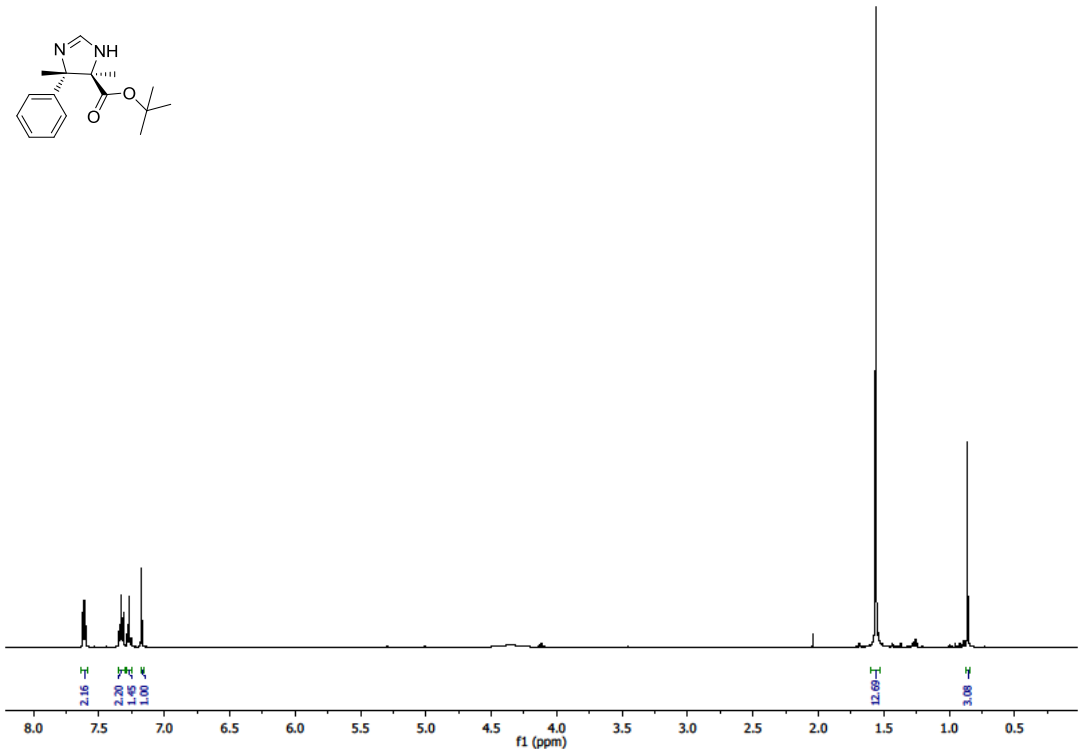


Signal 2: DAD1 B, Sig=230,16 Ref=360,100

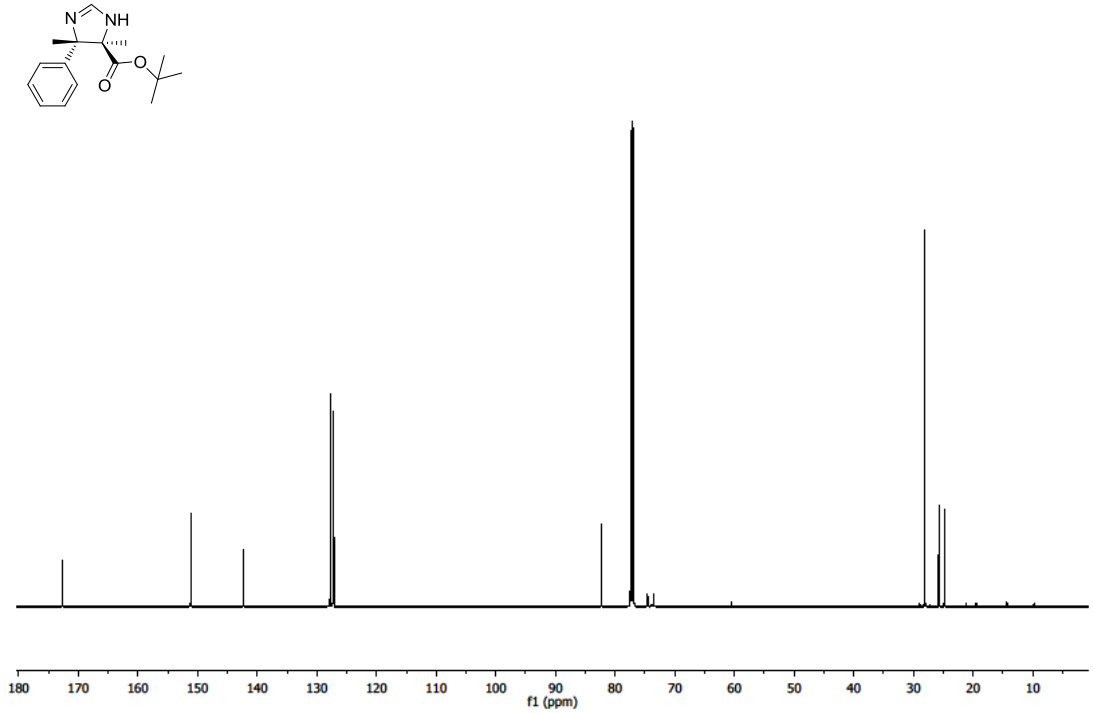
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.104	VV	0.1016	1822.99377	273.94739	10.2690
2	4.565	VV	0.1249	1.59295e4	2001.39014	89.7310
Totals :				1.77525e4	2275.33752	

4.3 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5c

^{1}H-NMR

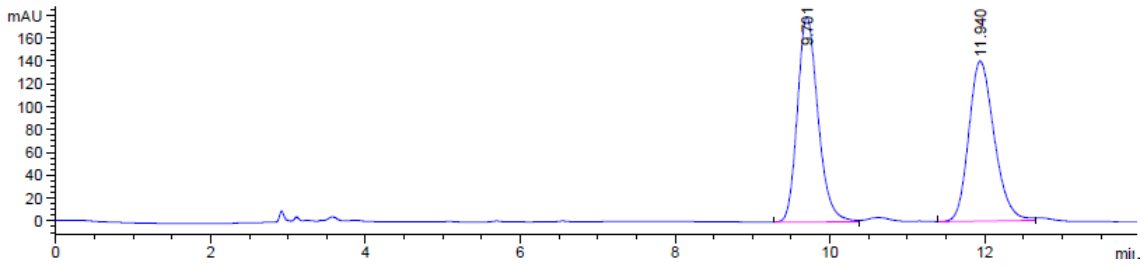


^{13}C-NMR



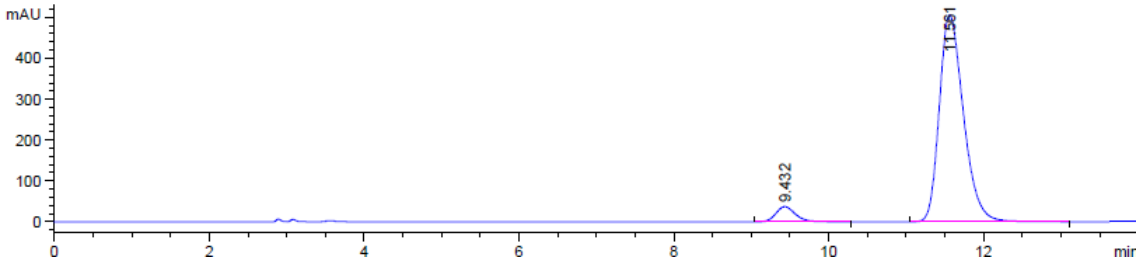
HPLC traces of imidazoline 5c

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.701	BV	0.2858	3326.81274	179.85448	50.9161
2	11.940	VB	0.3527	3207.09741	140.27768	49.0839

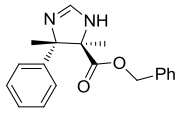
Enantioenriched

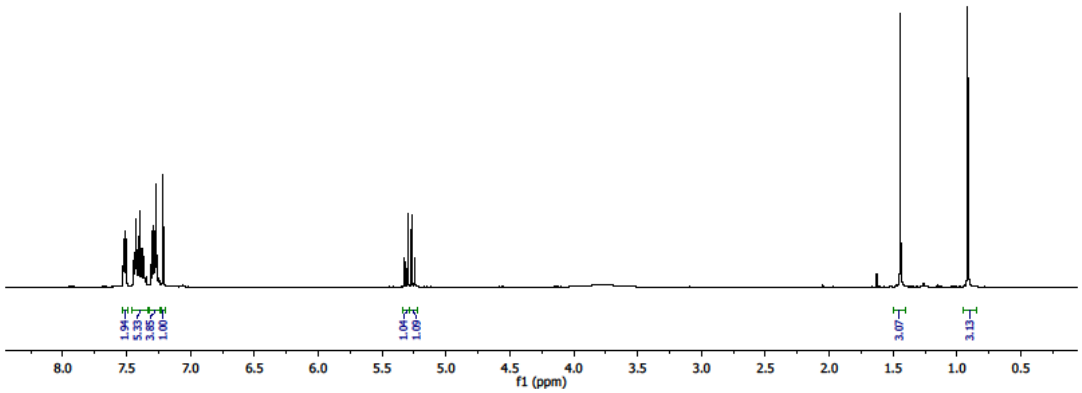


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.432	BB	0.2682	646.78839	36.94935	5.5873
2	11.561	BB	0.3322	1.09293e4	505.66959	94.4127

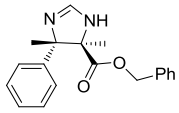
4.4 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5d

^{1}H-NMR



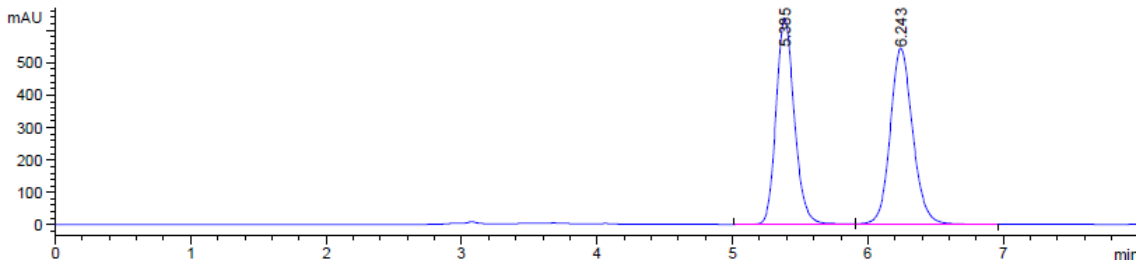


^{13}C-NMR



HPLC traces of imidazoline 5d

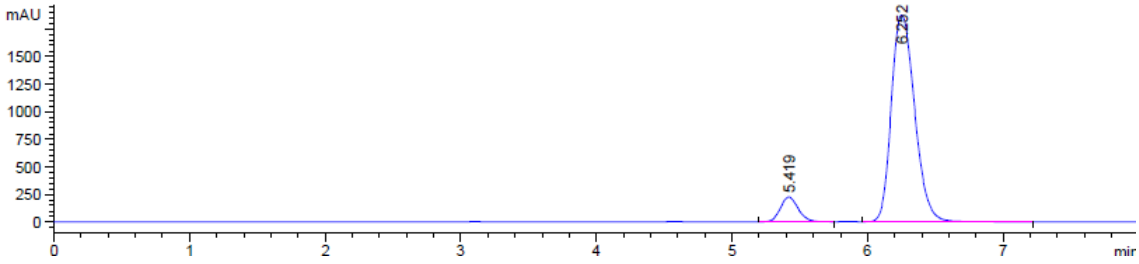
Racemic



Signal 2: DAD1 B, Sig=230,16 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.385	BV	0.1461	6011.99170	636.97437	48.8733
2	6.243	VB	0.1780	6289.17480	543.43011	51.1267
Totals :				1.23012e4	1180.40448	

Enantioenriched

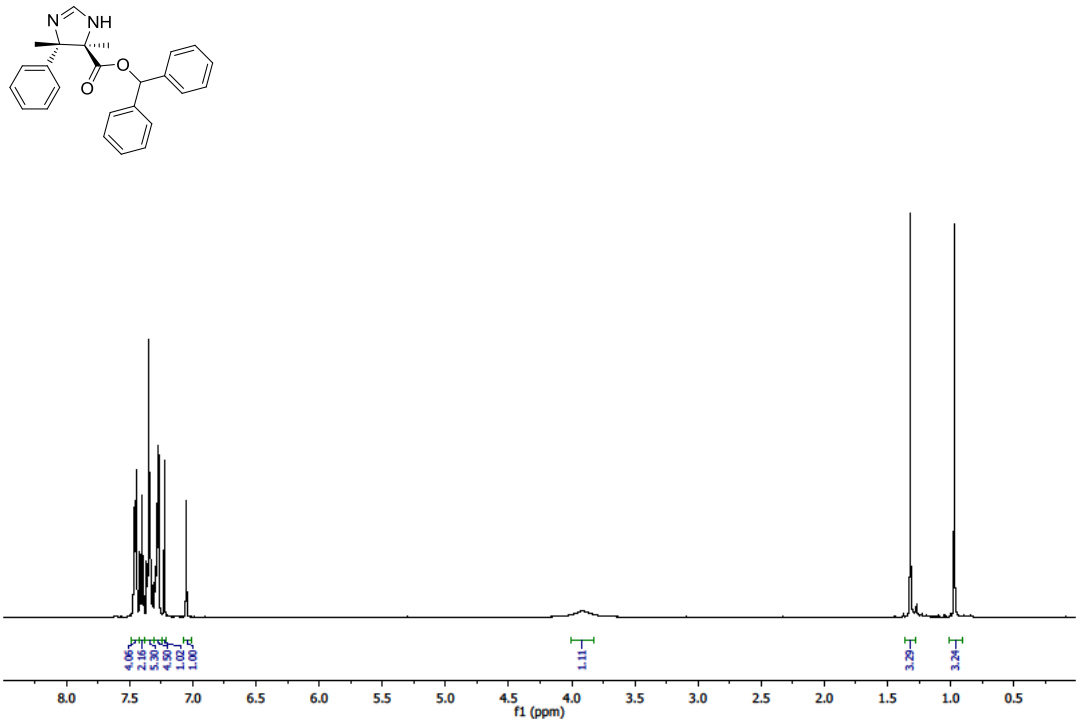


Signal 2: DAD1 B, Sig=230,16 Ref=360,100

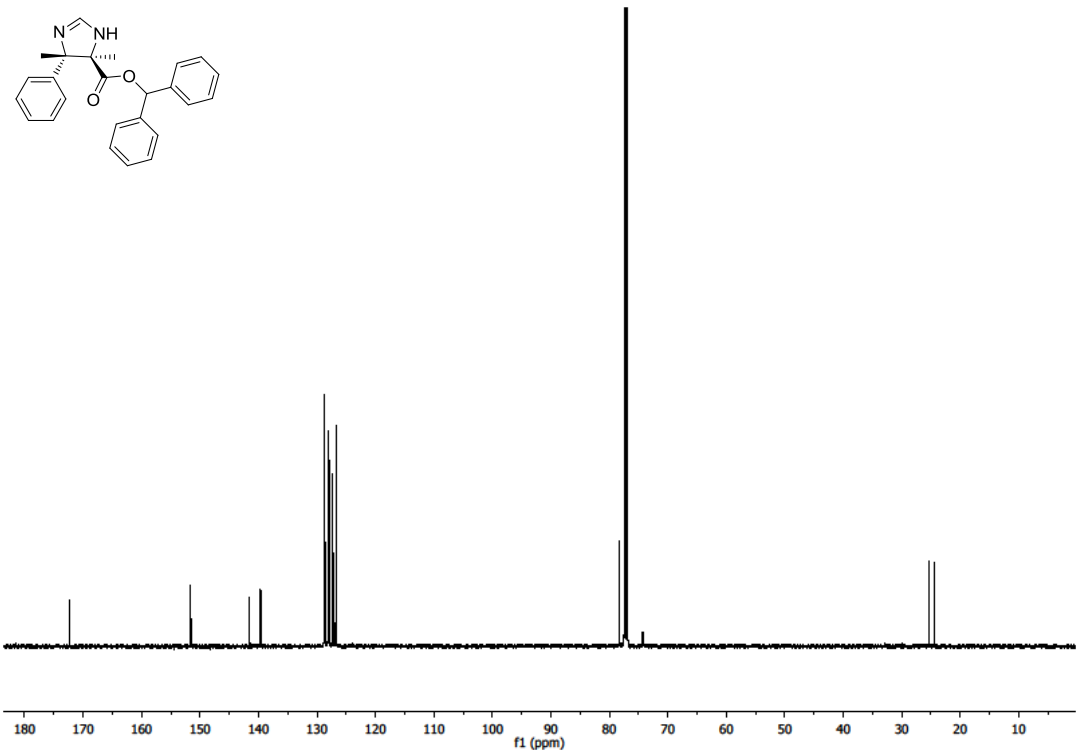
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.419	VV	0.1453	2113.89160	225.63458	8.5841
2	6.252	VV	0.1881	2.25119e4	1874.10986	91.4159
Totals :				2.46258e4	2099.74445	

4.5 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5e

^{1}H-NMR

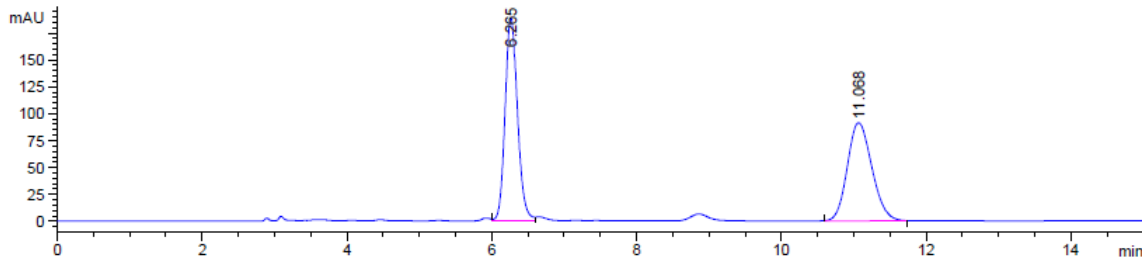


^{13}C-NMR



HPLC traces of racemic imidazoline 5e

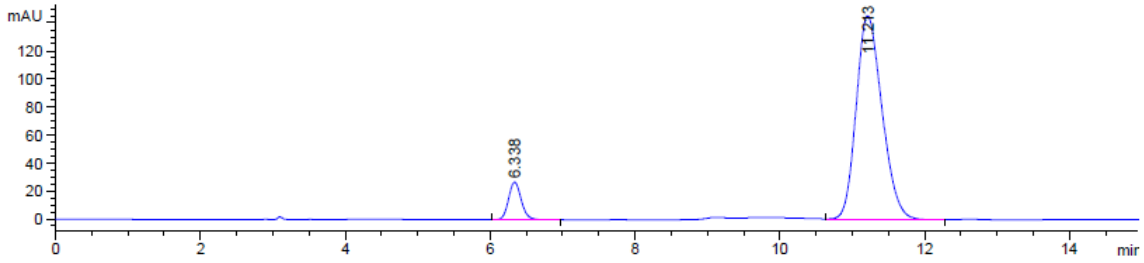
Racemic



Signal 5: DAD1 E, Sig=240,16 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.265	VV	0.1819	2233.90015	188.94266	50.1657
2	11.068	BB	0.3646	2145.96167	91.18897	49.8343
Totals :				4379.86182	280.13163	

Enantioenriched

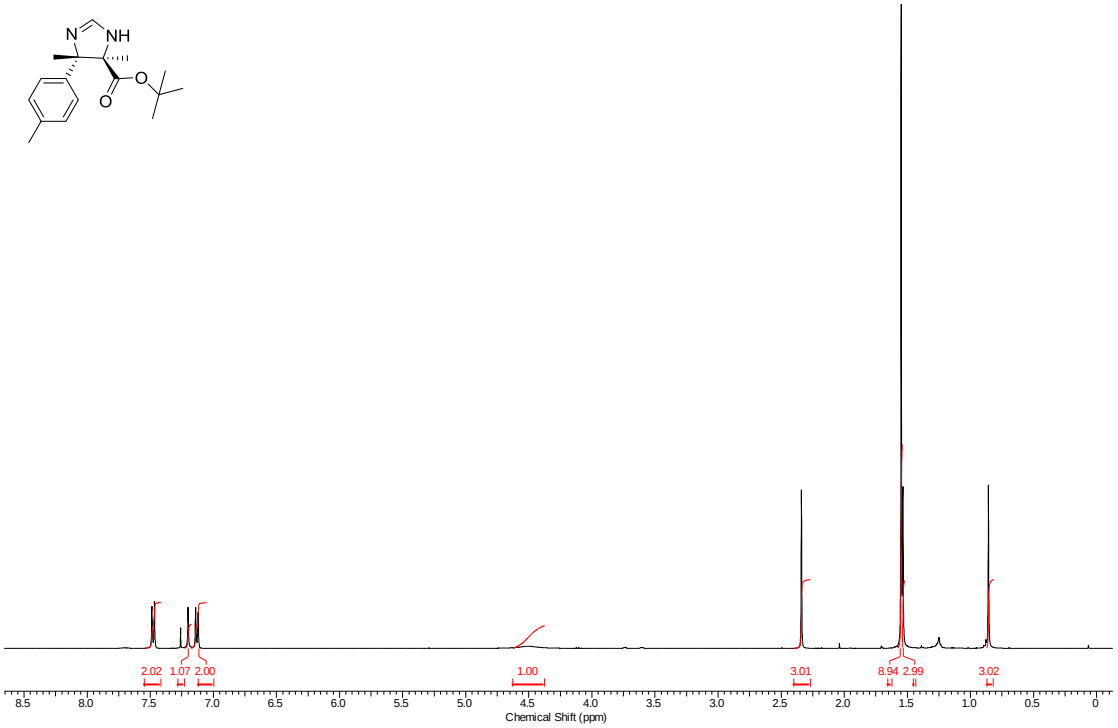


Signal 5: DAD1 E, Sig=240,16 Ref=360,100

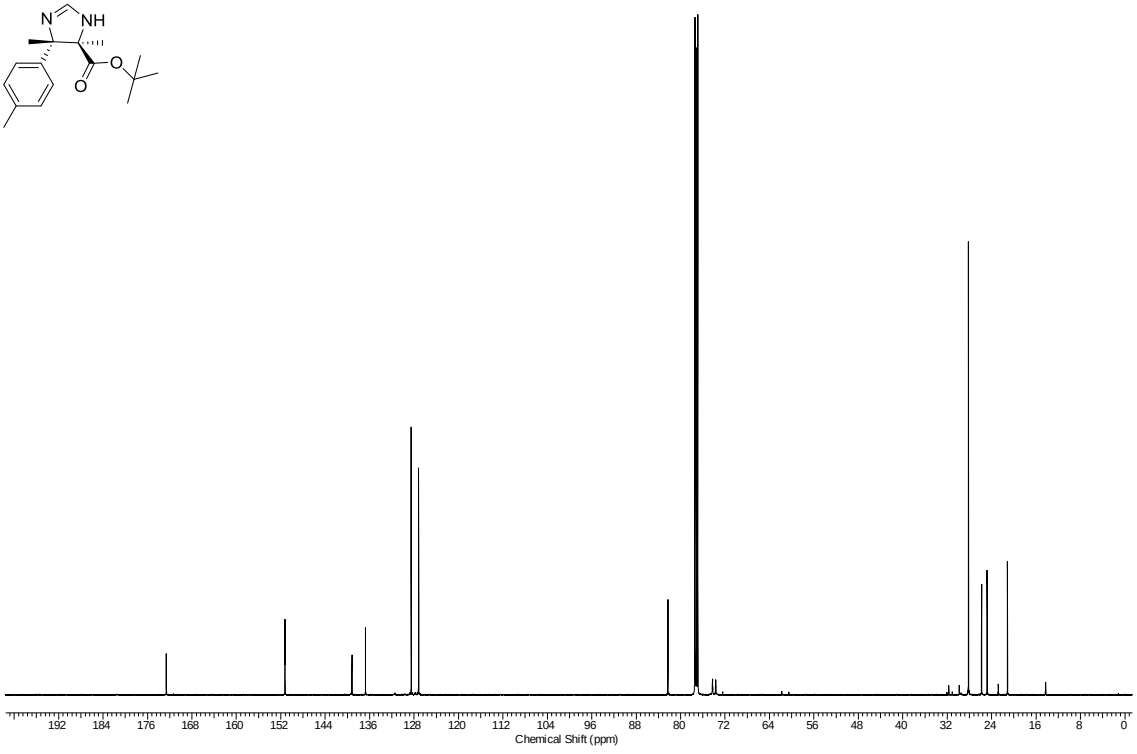
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.338	BB	0.1854	324.71451	26.79047	8.1917
2	11.213	VB	0.3875	3639.22949	145.66898	91.8083
Totals :				3963.94400	172.45945	

4.6 ^{1}H-NMR, ^{13}C-NMR, NOE and HPLC traces of imidazoline 5f

^{1}H-NMR

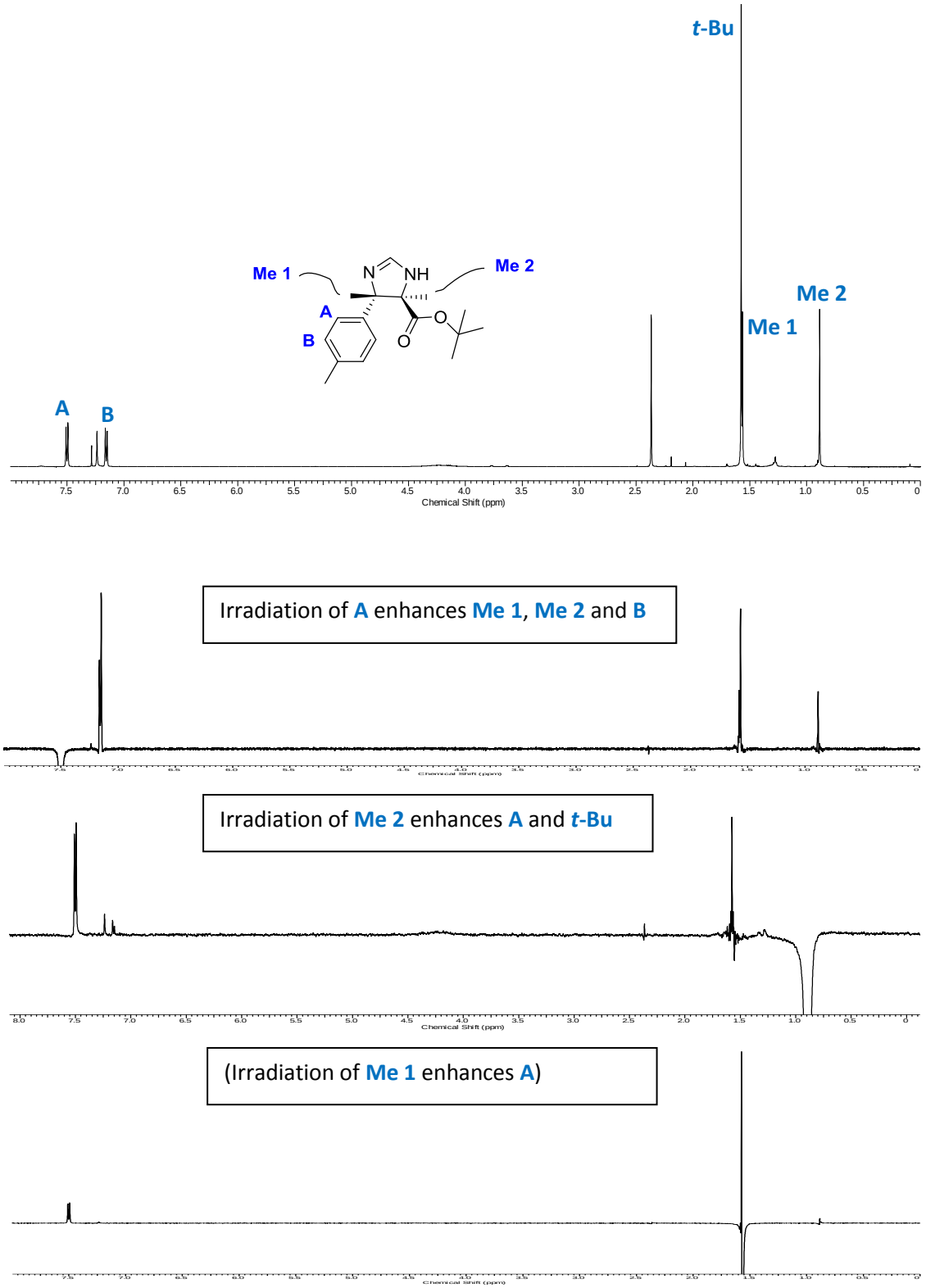


^{13}C-NMR



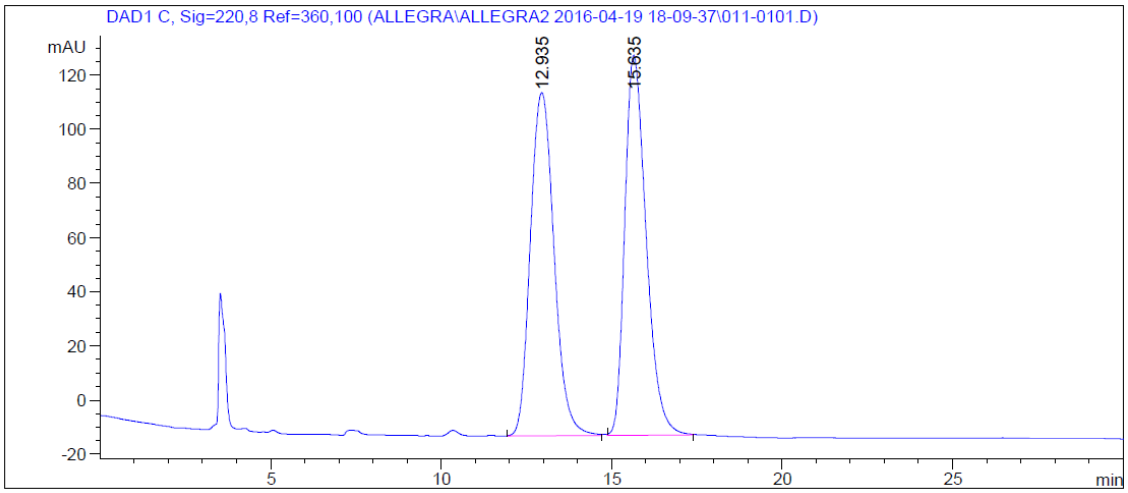
nOe in the ^{1}H-NMR of imidazoline 5f

$CDCl_3$, 400 MHz, Tmix 800 ms



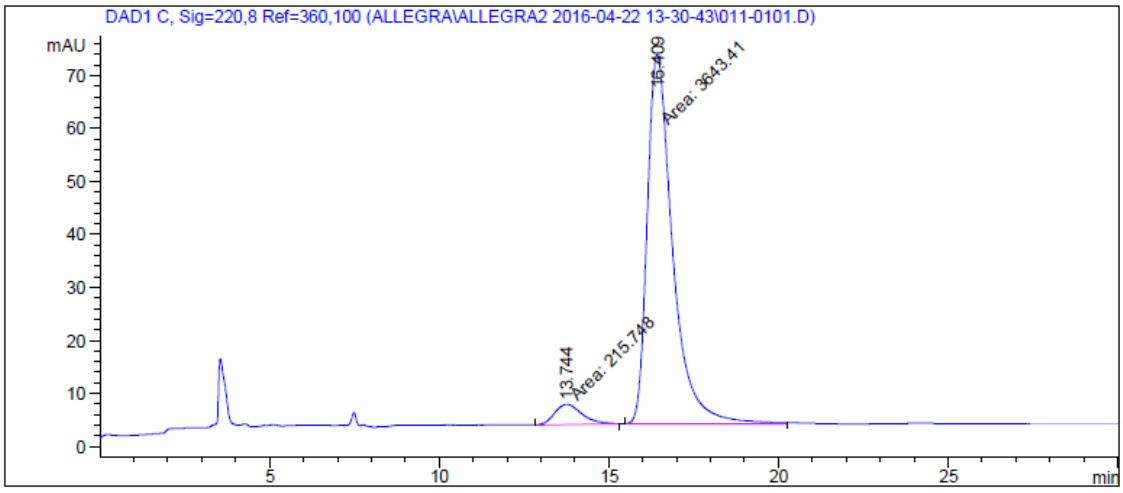
HPLC traces of imidazoline 5f

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.935	BB	0.7647	6132.23438	126.69684	50.0277
2	15.635	BB	0.6732	6125.45068	140.33130	49.9723

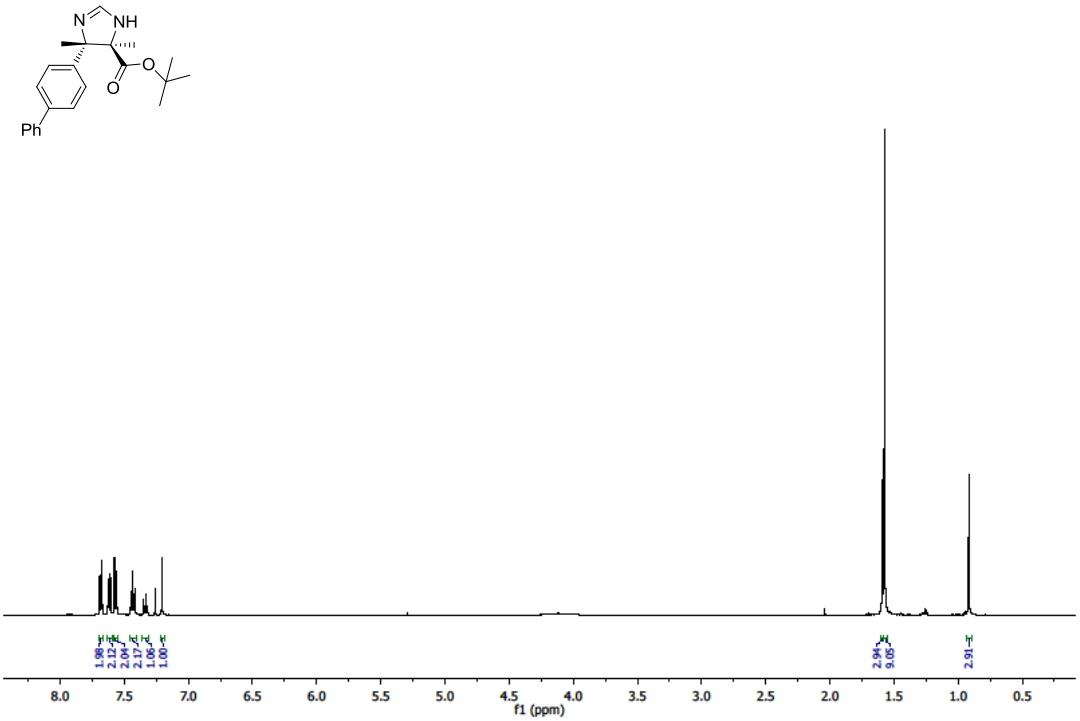
Enantioenriched



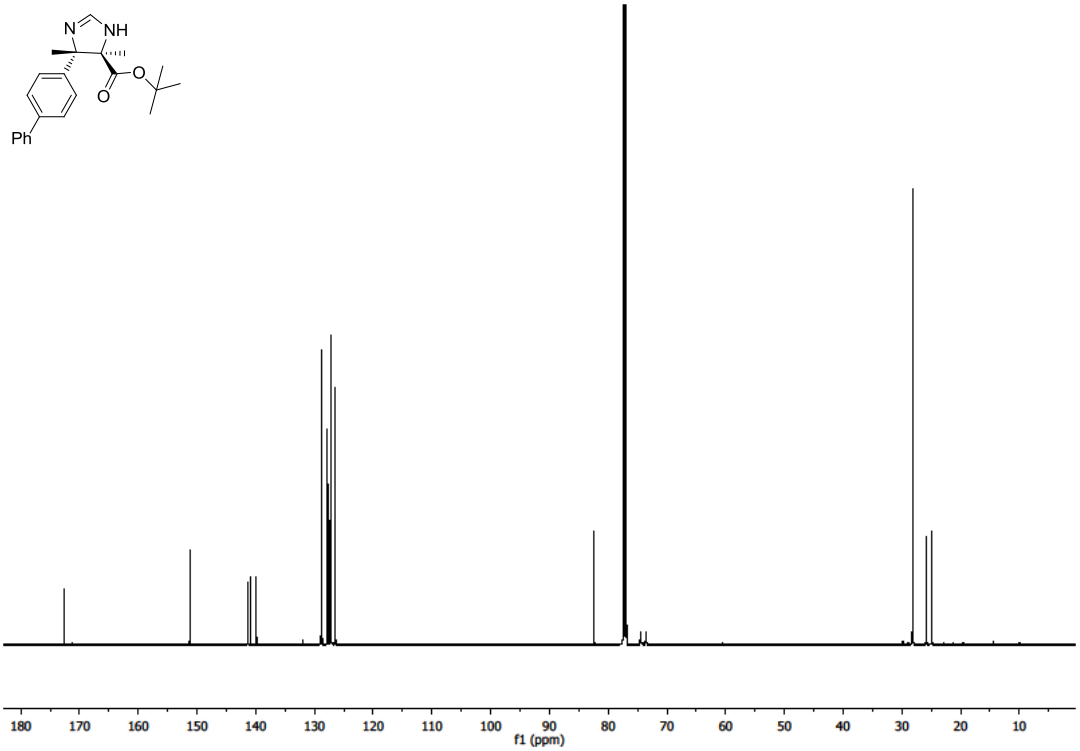
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	13.744	MM	0.9428	215.74811	3.81394	5.5906
2	16.409	MM	0.8710	3643.40576	69.71594	94.4094

4.7 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5g

^{1}H-NMR

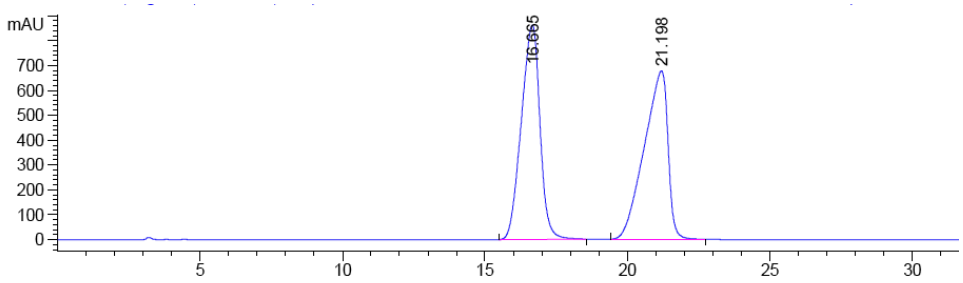


^{13}C-NMR



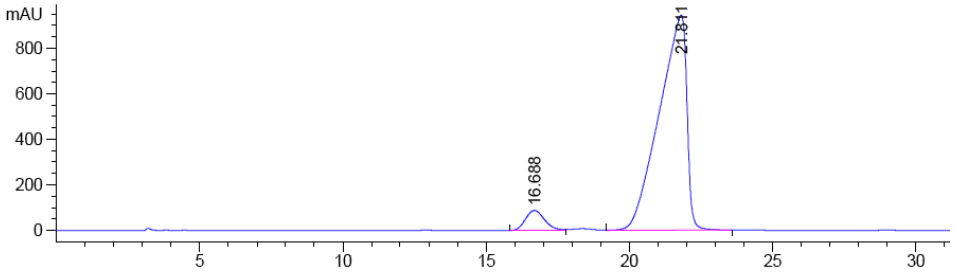
HPLC traces of imidazoline 5g

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	16.665	BB	0.7179	3.92650e4	861.20380	50.0310
2	21.198	BB	0.8553	3.92164e4	677.56262	49.9690

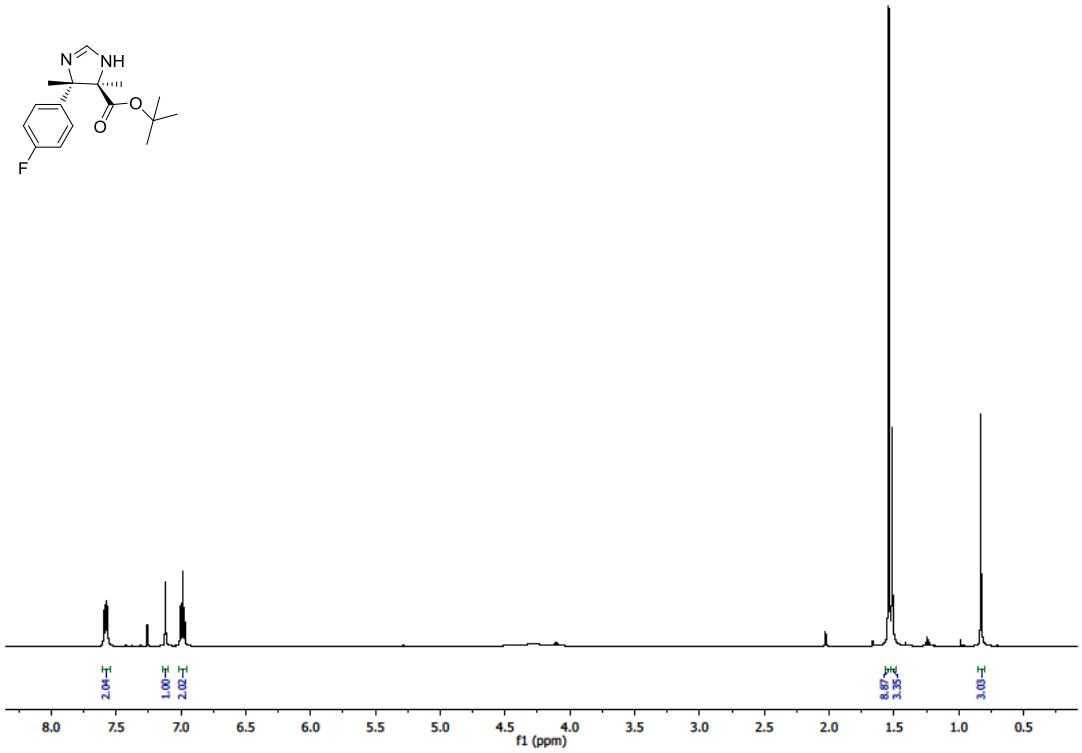
Enantioenriched



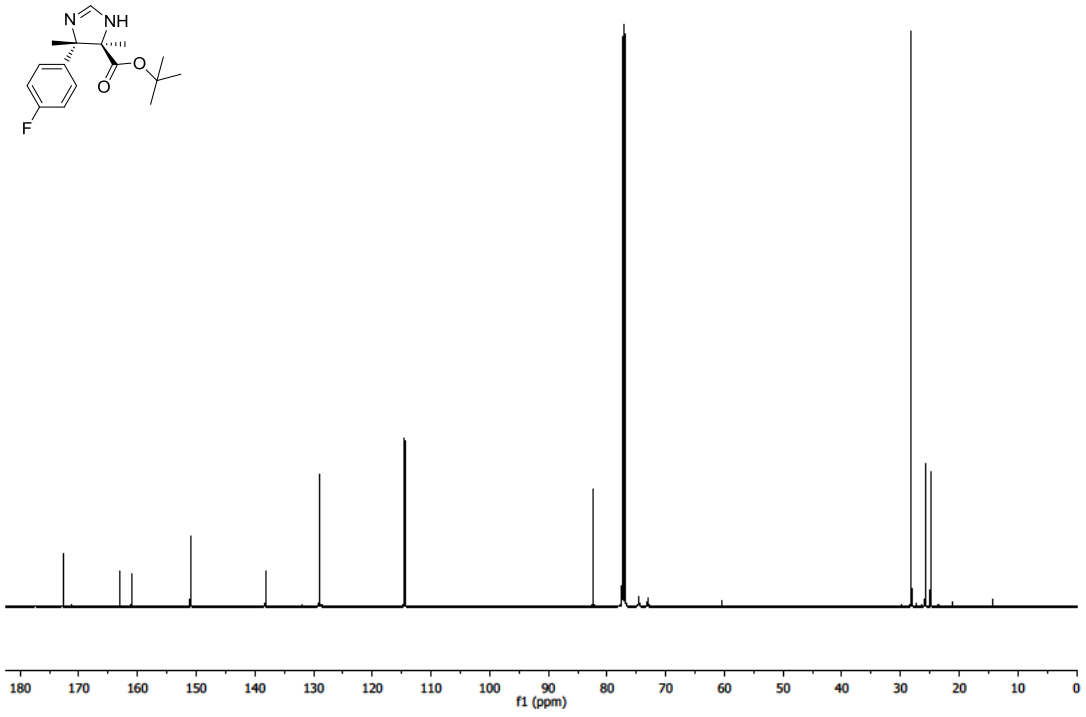
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	16.688	BV	0.7172	4027.33057	87.13321	6.0059
2	21.811	VB	0.9568	6.30288e4	944.23627	93.9941

4.8 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5h

^{1}H-NMR

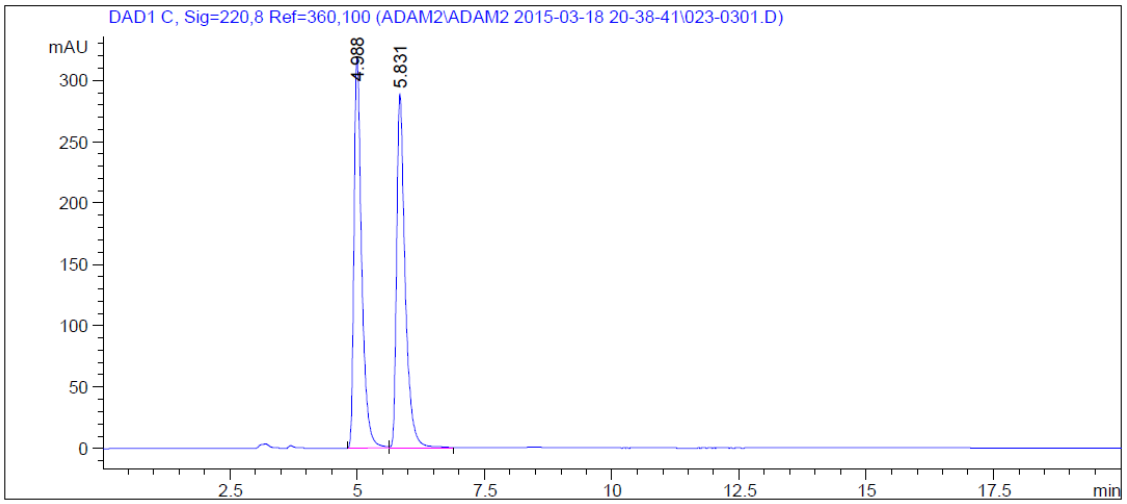


^{13}C-NMR



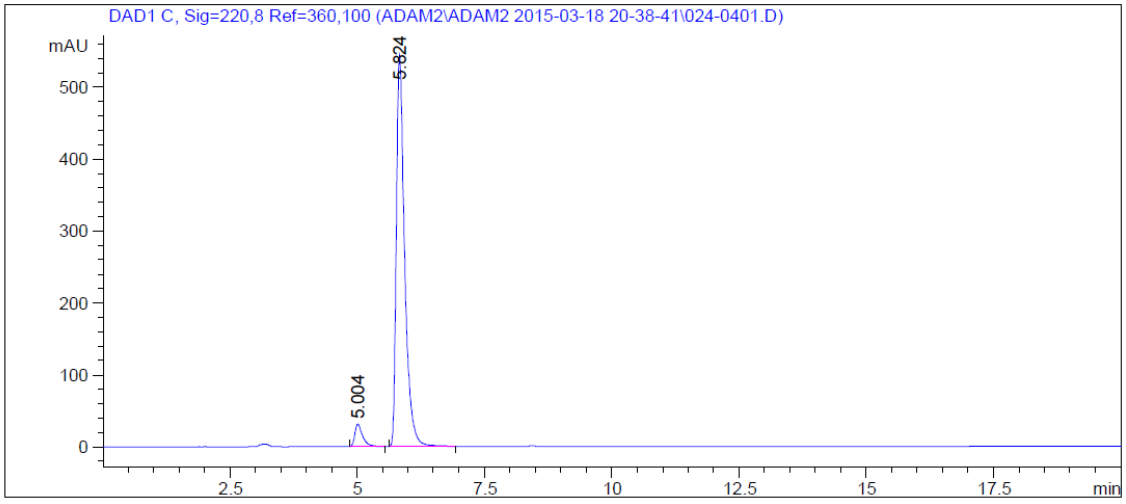
HPLC traces of imidazoline 5h

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.988	BV	0.1577	3336.00659	319.67346	49.8075
2	5.831	VB	0.1736	3361.79028	289.13434	50.1925

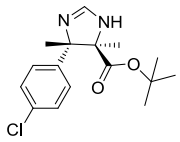
Enantioenriched

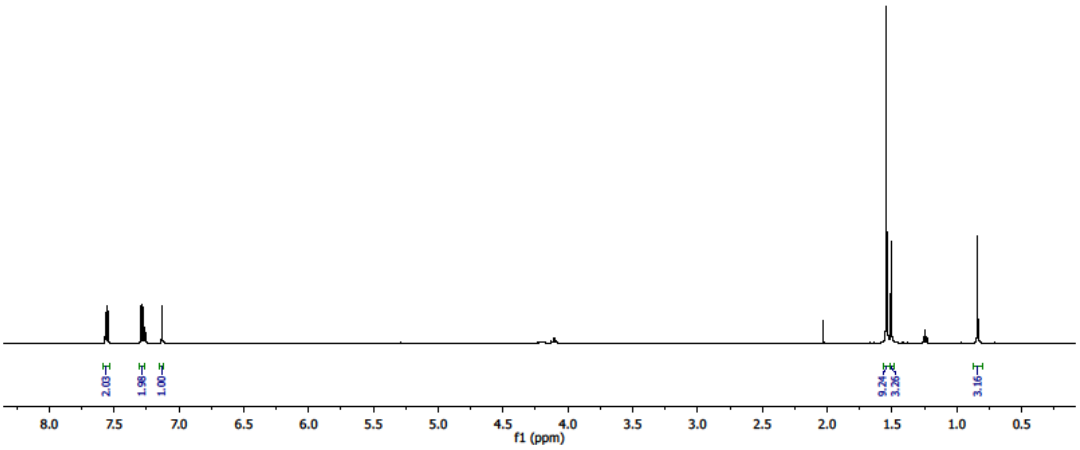


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.004	BB	0.1581	331.86877	31.18900	5.0889
2	5.824	BB	0.1705	6189.50488	544.78314	94.9111

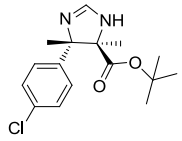
4.9 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5i

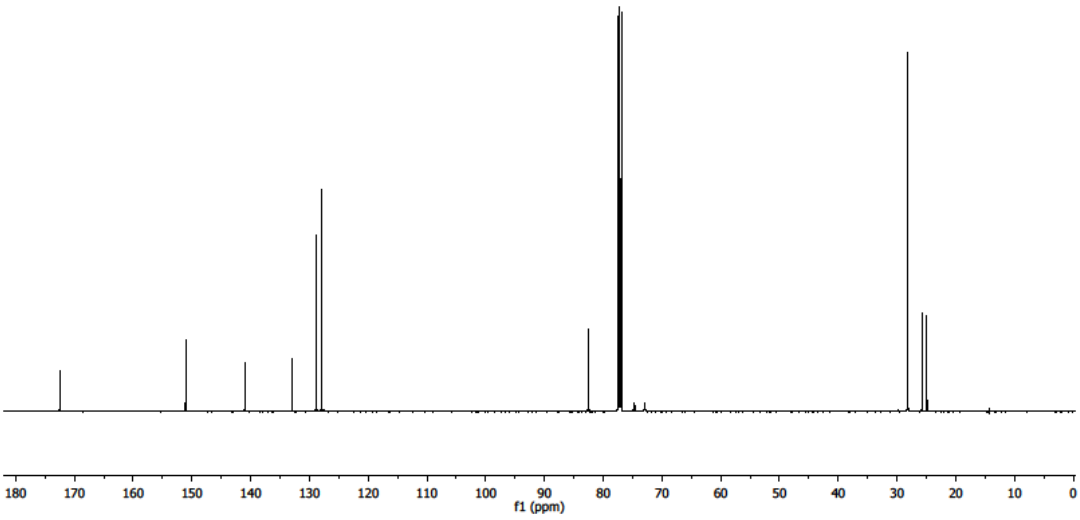
^{1}H-NMR





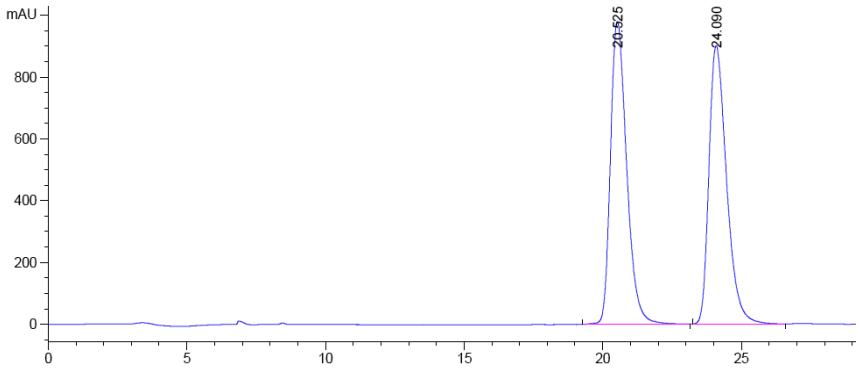
^{13}C-NMR





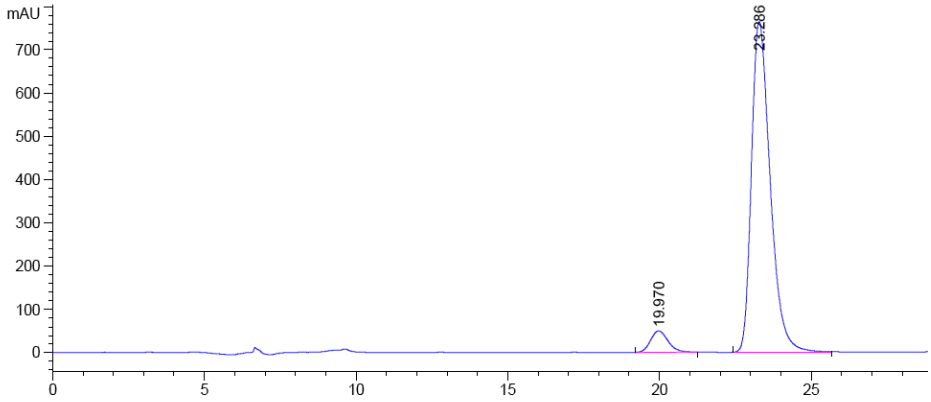
HPLC traces of imidazoline 5i

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	20.525	BB	0.6288	4.00605e4	980.26593	50.0240
2	24.090	BB	0.6821	4.00220e4	901.15967	49.9760

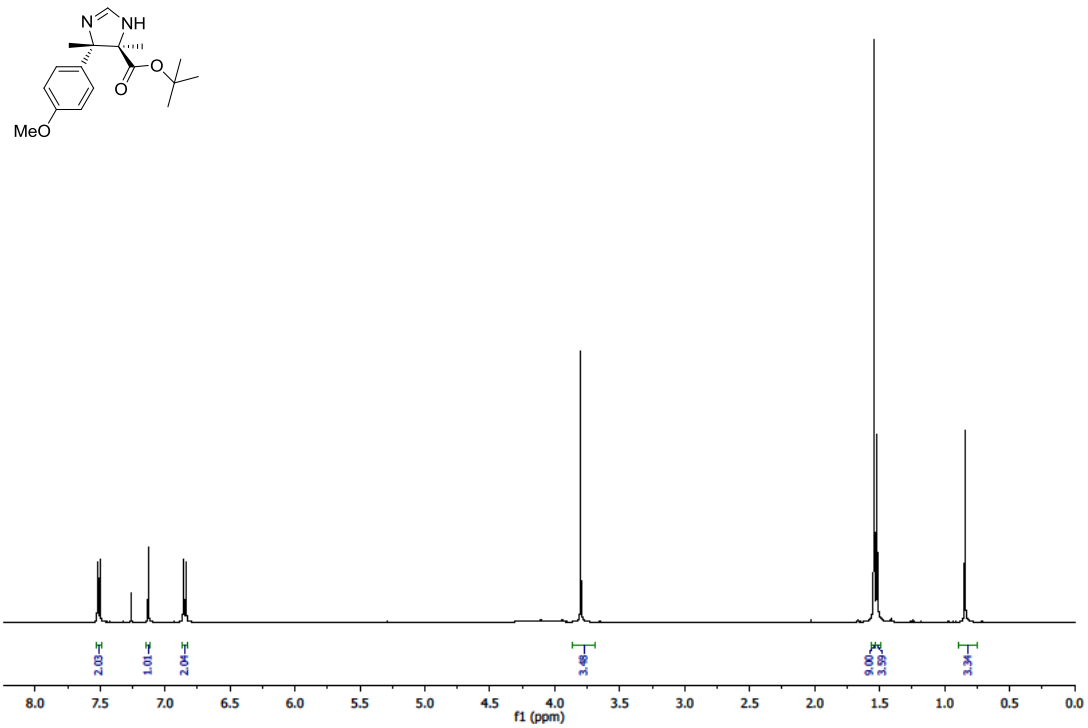
Enantioenriched



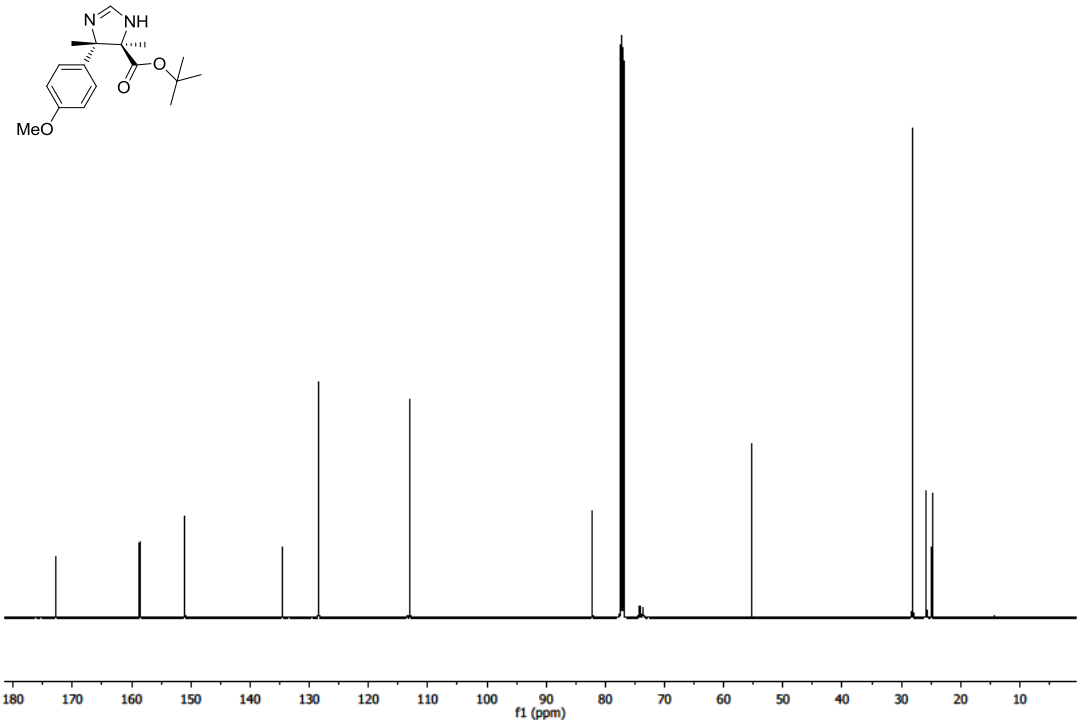
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	19.970	BB	0.6259	1989.75378	49.40577	5.7243
2	23.286	BB	0.6606	3.27701e4	763.68127	94.2757

4.10 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5j

^{1}H-NMR

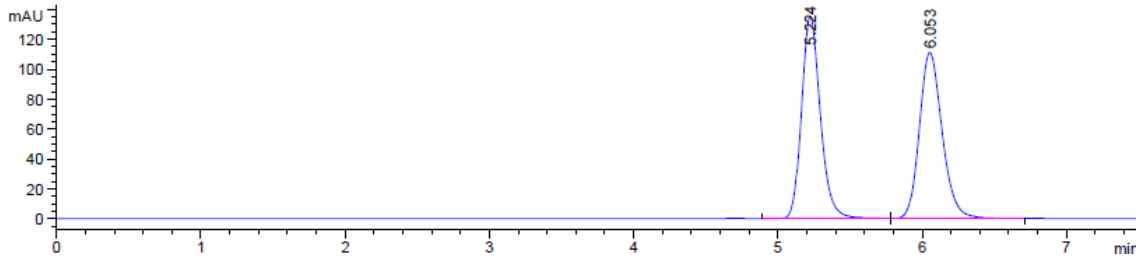


^{13}C-NMR



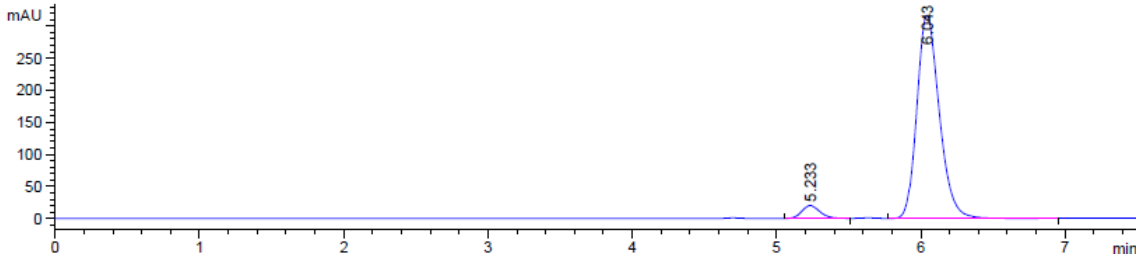
HPLC traces of imidazoline 5j

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.224	VV	0.1384	1233.69507	135.21347	50.1078
2	6.053	VB	0.1692	1228.38745	110.94753	49.8922

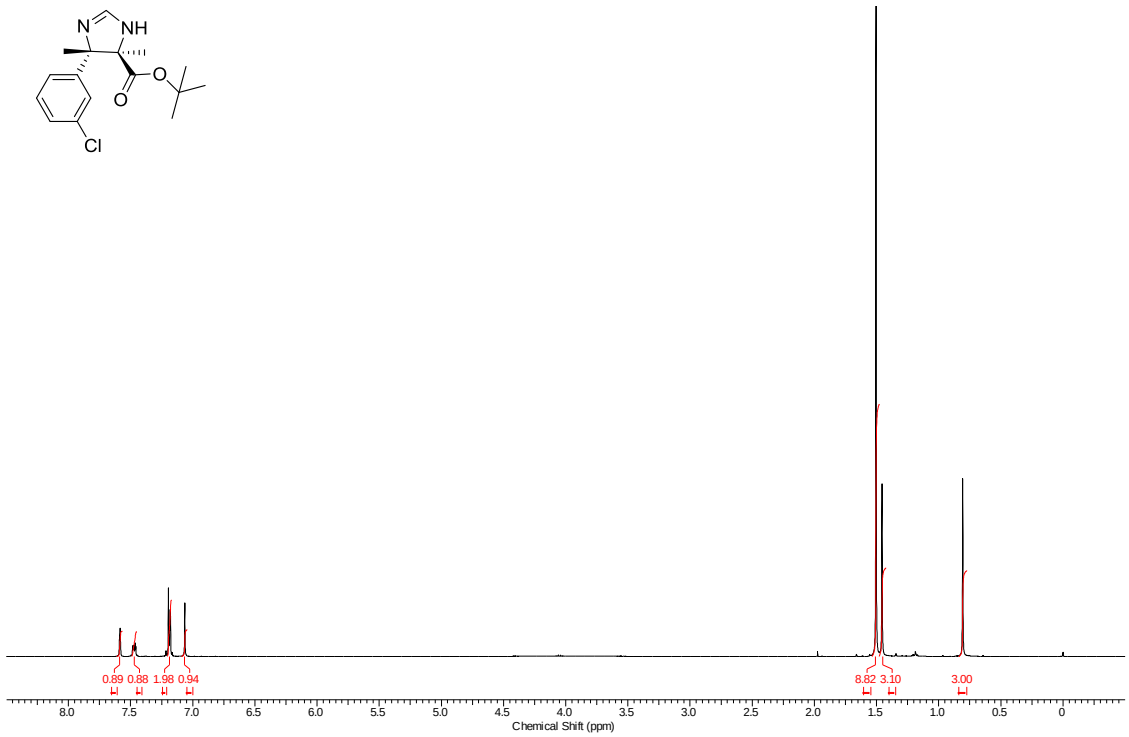
Enantioenriched



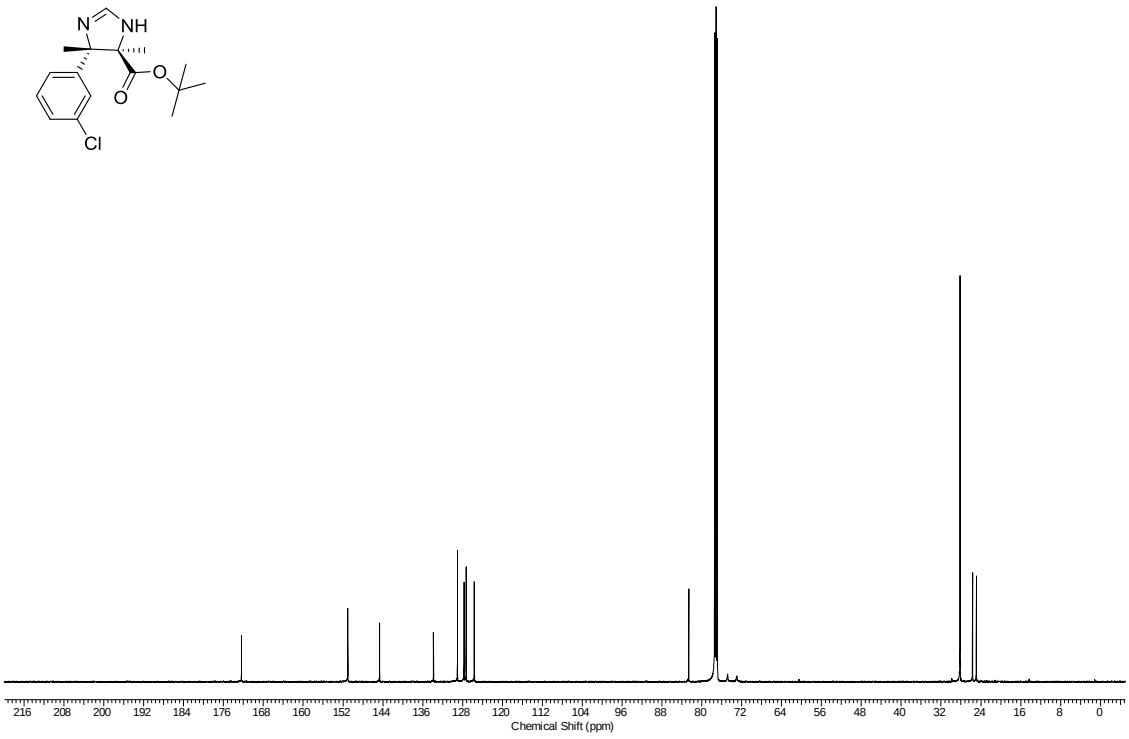
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.233	BV	0.1423	184.96959	20.29319	5.0898
2	6.043	VB	0.1673	3449.18726	316.20911	94.9102

4.11 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5k

^{1}H-NMR

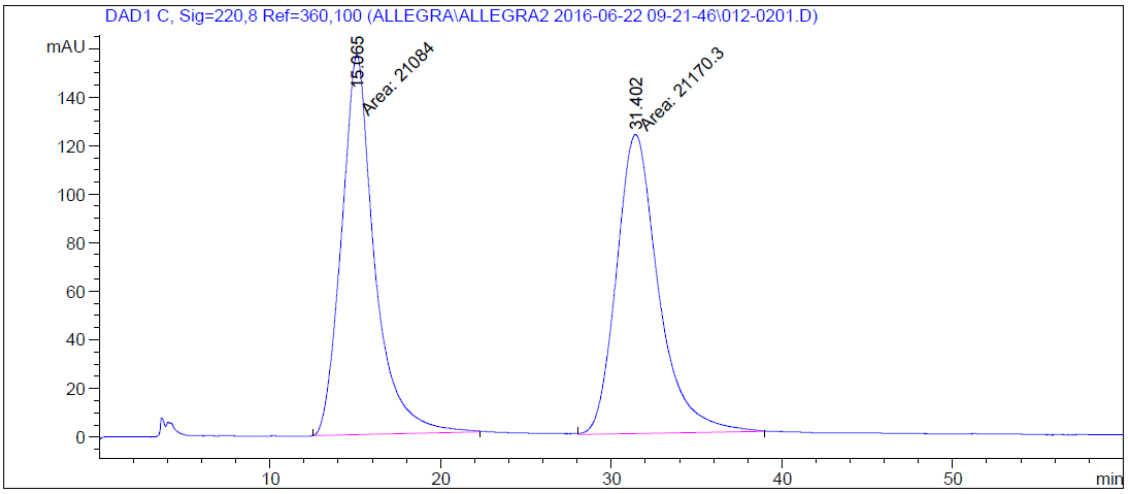


^{13}C-NMR



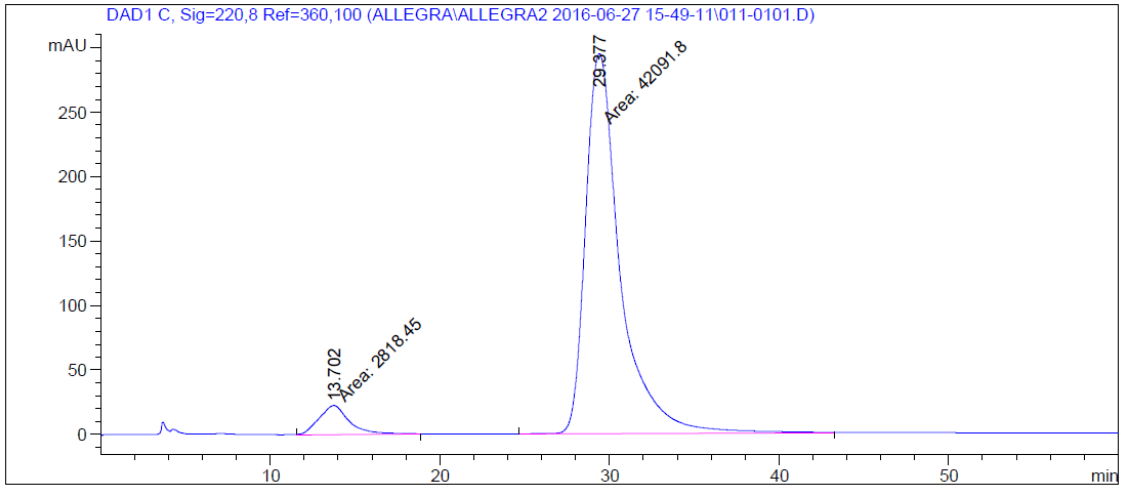
HPLC traces of imidazoline 5k

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	15.065	MM	2.2439	2.10840e4	156.60271	49.8978
2	31.402	MM	2.8613	2.11703e4	123.31413	50.1022

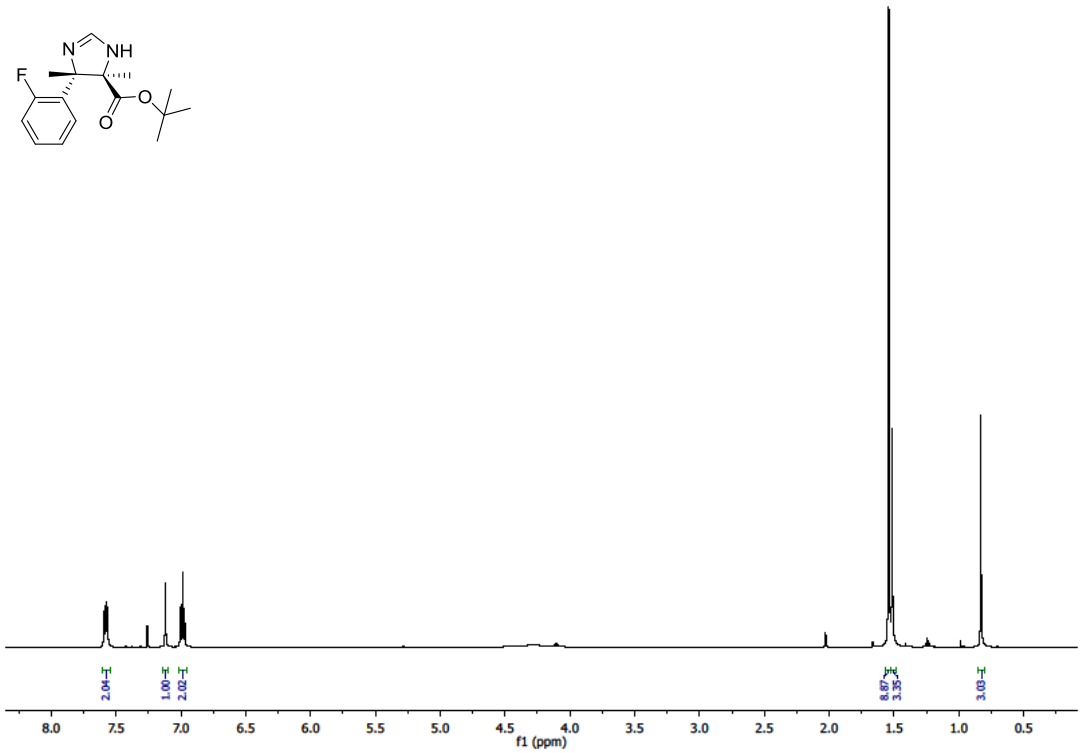
Enantioenriched



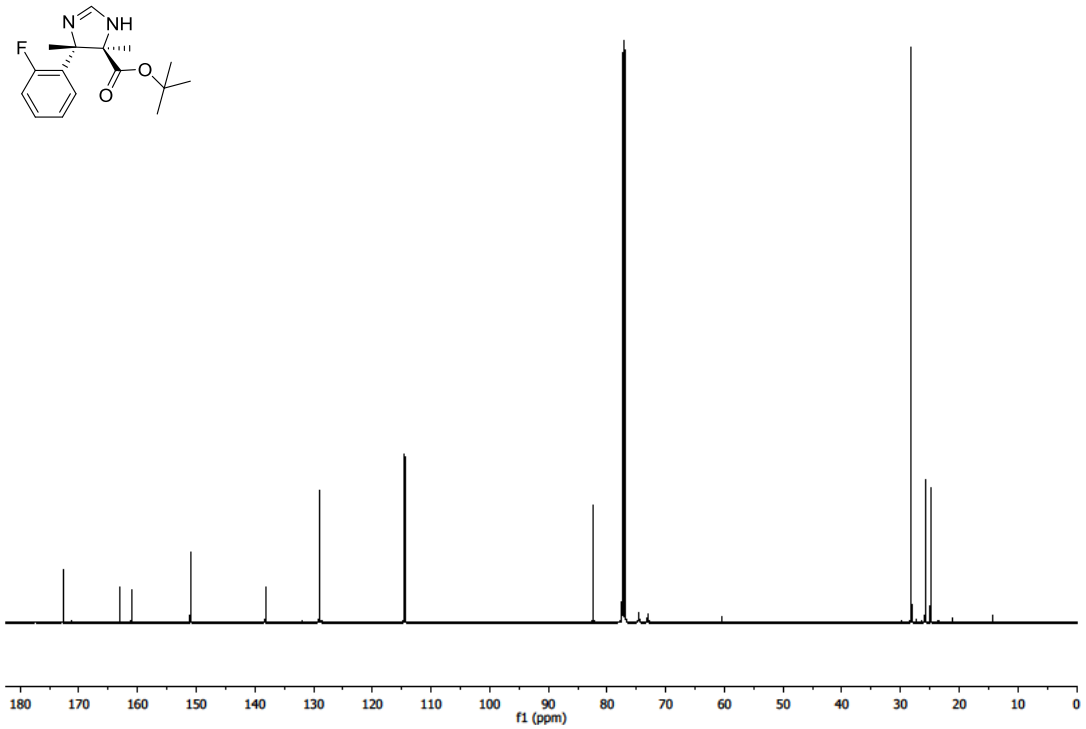
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	13.702	MM	2.0823	2818.44775	22.55852	6.2757
2	29.377	MM	2.3783	4.20918e4	294.97662	93.7243

4.12 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5l

^{1}H-NMR

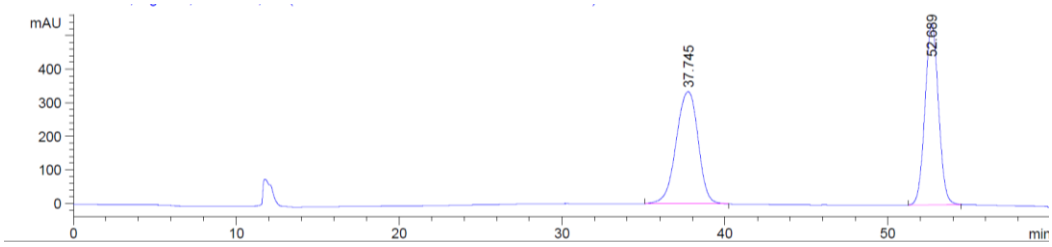


^{13}C-NMR



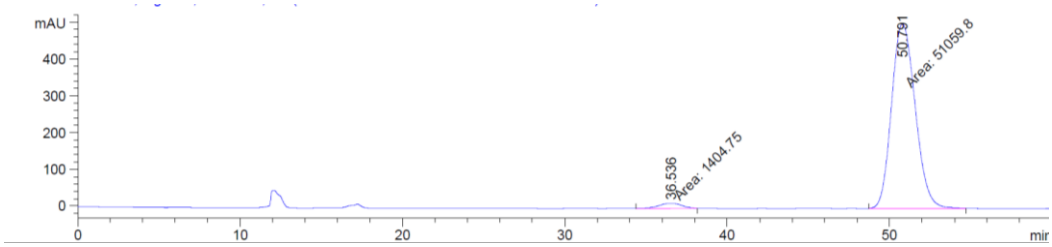
HPLC traces of imidazoline 5l

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	37.745	BB	1.1874	3.14818e4	334.68719	50.3278
2	52.689	BB	0.7855	3.10717e4	540.66876	49.6722

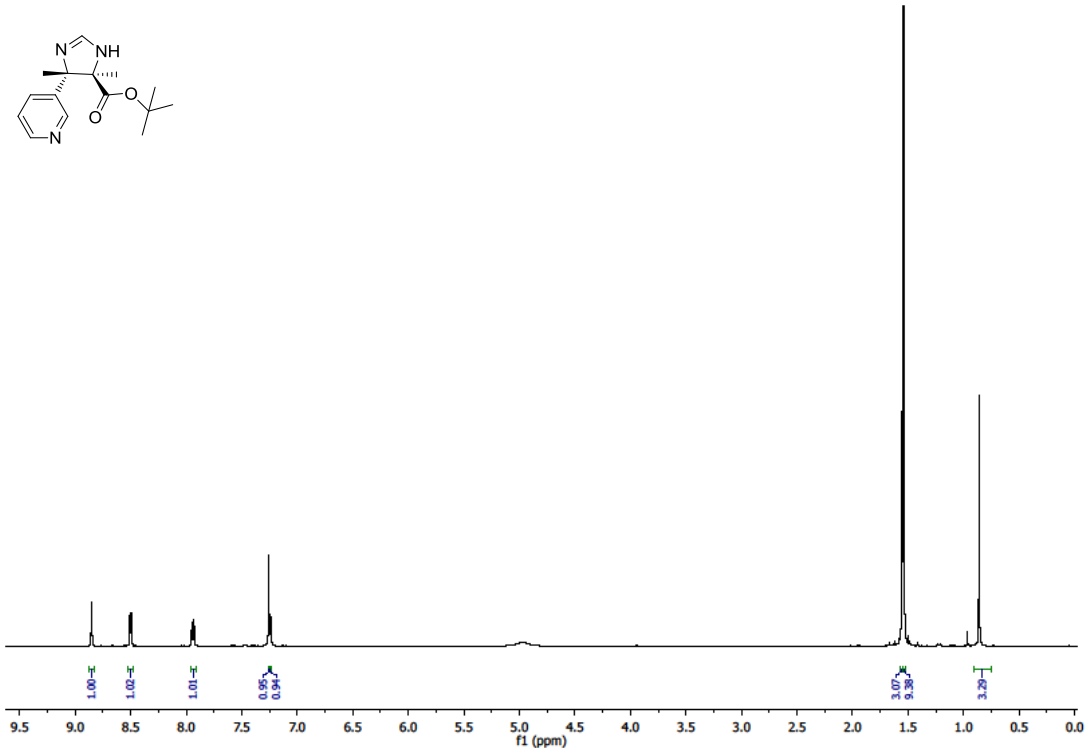
Enantioenriched



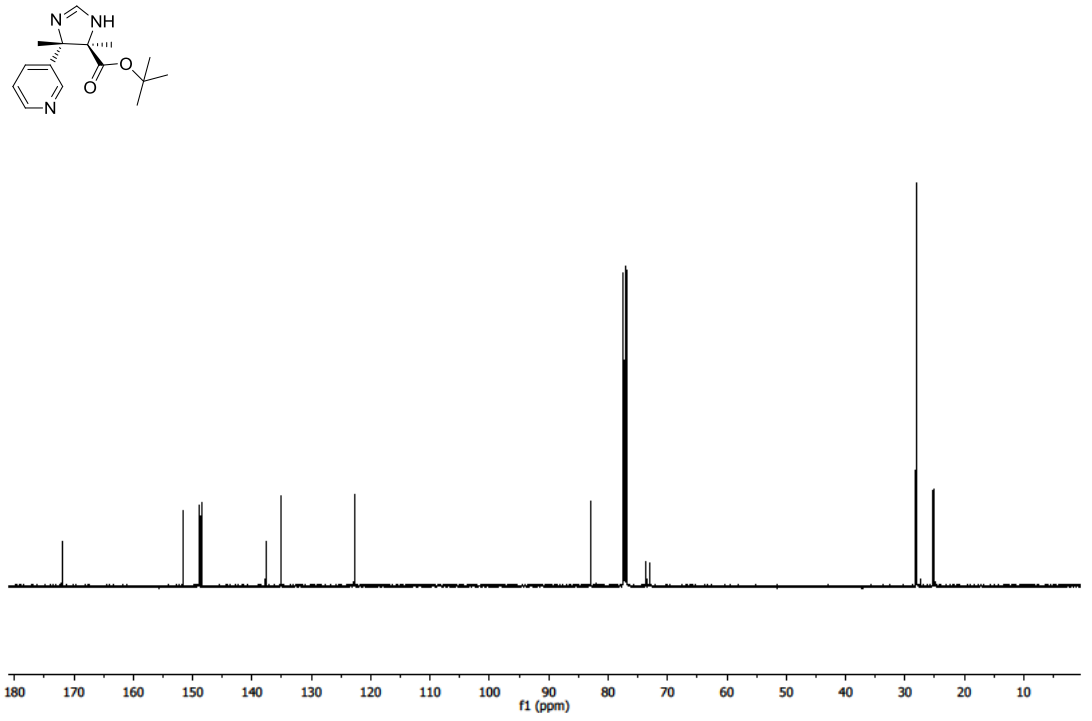
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	36.536	MM	1.6726	1404.74902	13.99772	2.6775
2	50.791	MM	1.6899	5.10598e4	503.58163	97.3225

4.13 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5m

^{1}H-NMR

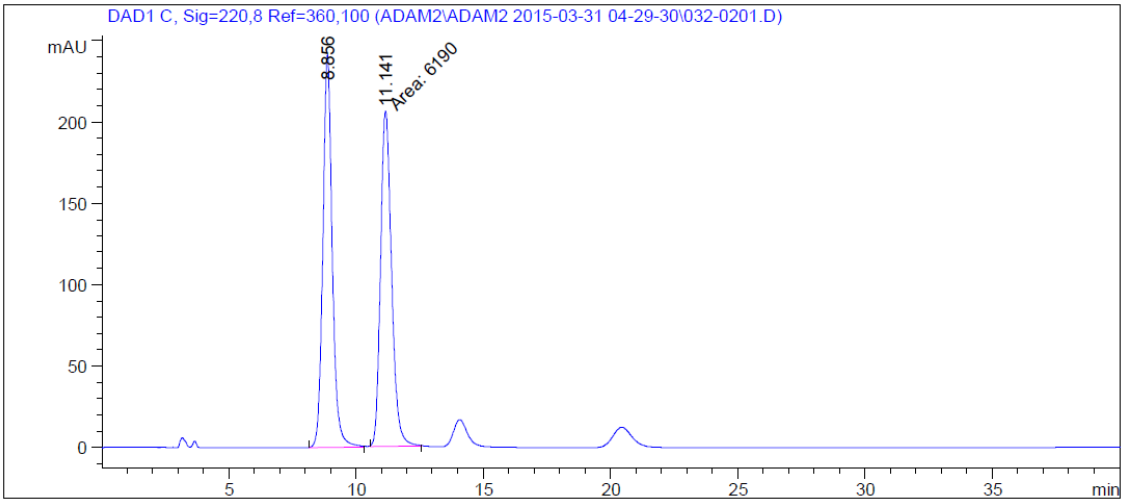


^{13}C-NMR



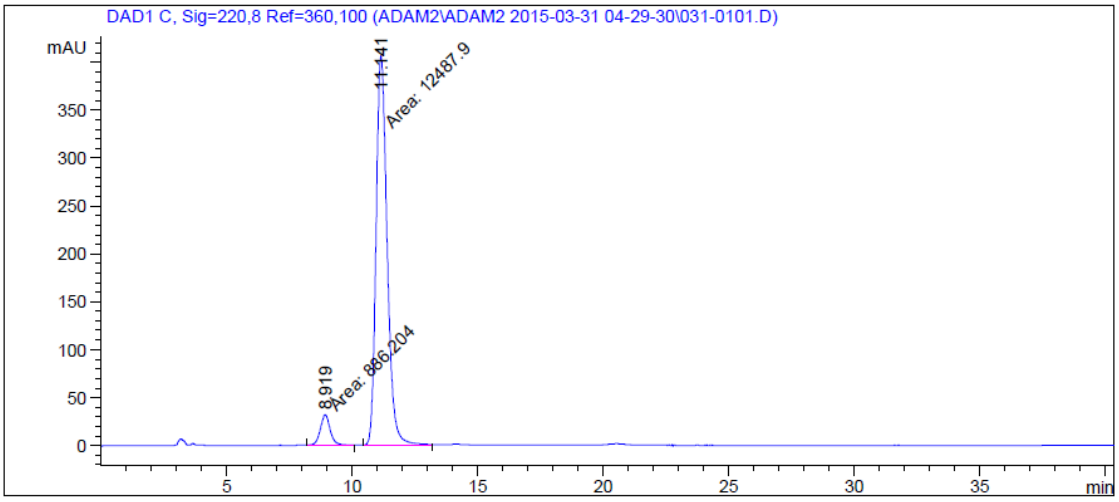
HPLC traces of imidazoline 5m

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.856	BB	0.3888	6212.50488	240.96596	50.0907
2	11.141	MM	0.5011	6189.99805	205.88304	49.9093

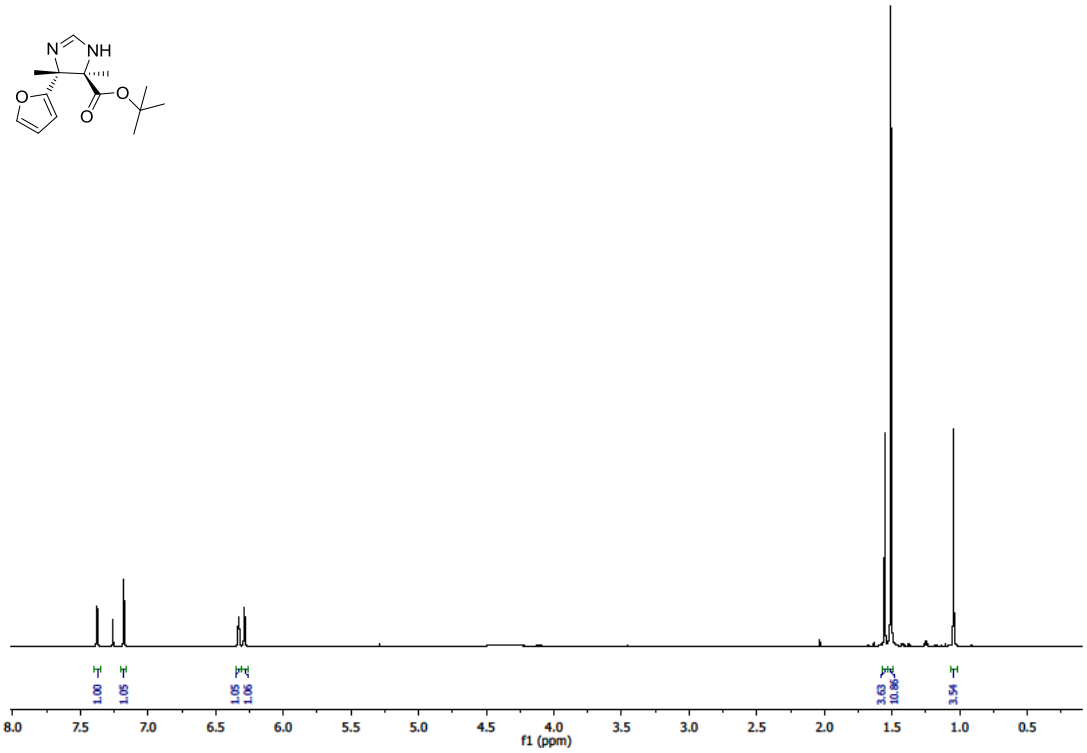
Enantioenriched



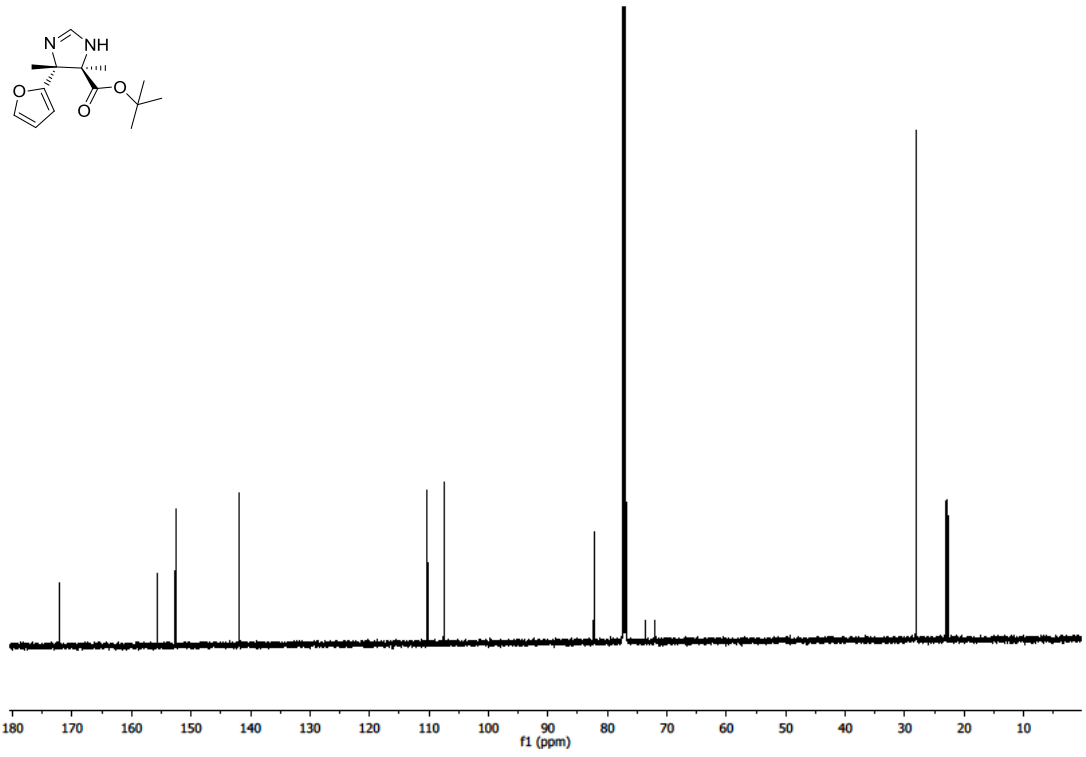
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.919	MM	0.4619	886.20422	31.97665	6.6263
2	11.141	MM	0.5120	1.24879e4	406.51300	93.3737

4.14 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5n

^{1}H-NMR

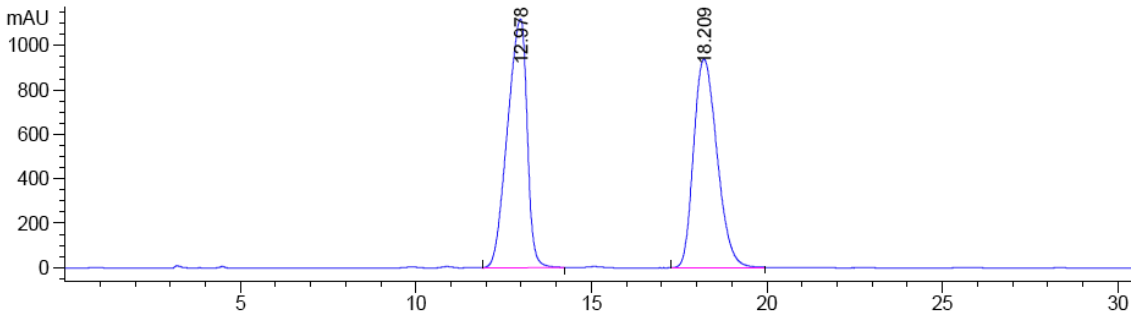


^{13}C-NMR



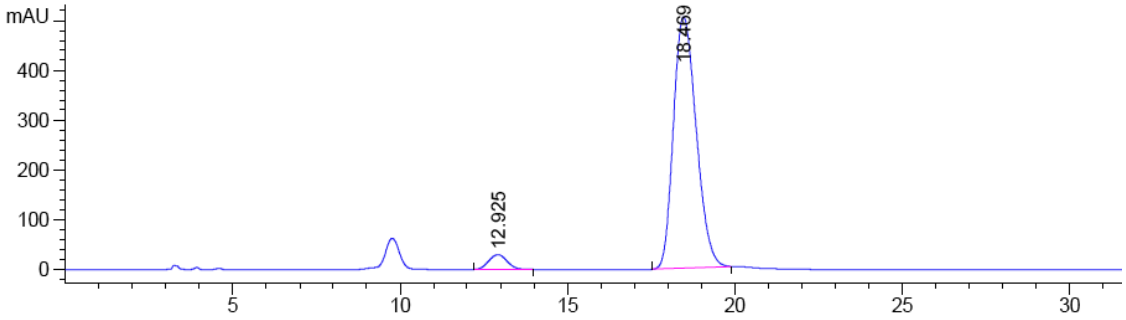
HPLC traces of imidazoline 5n

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.978	VB	0.6315	4.34602e4	1118.15540	49.9540
2	18.209	BB	0.7276	4.35403e4	937.90662	50.0460

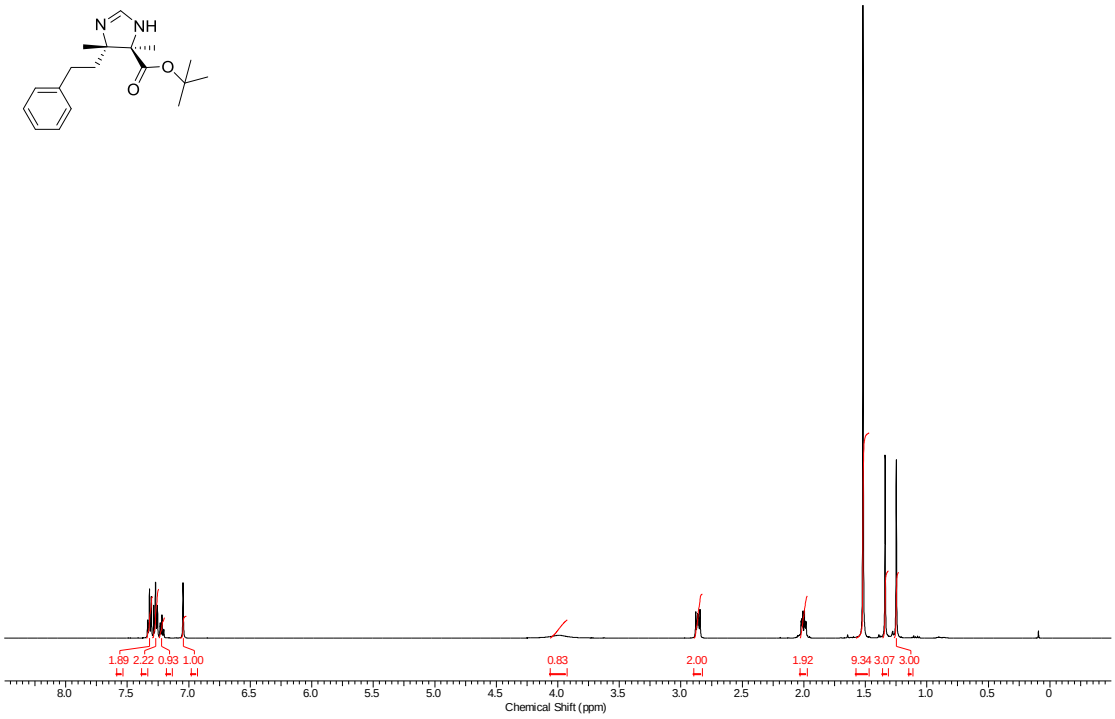
Enantioenriched



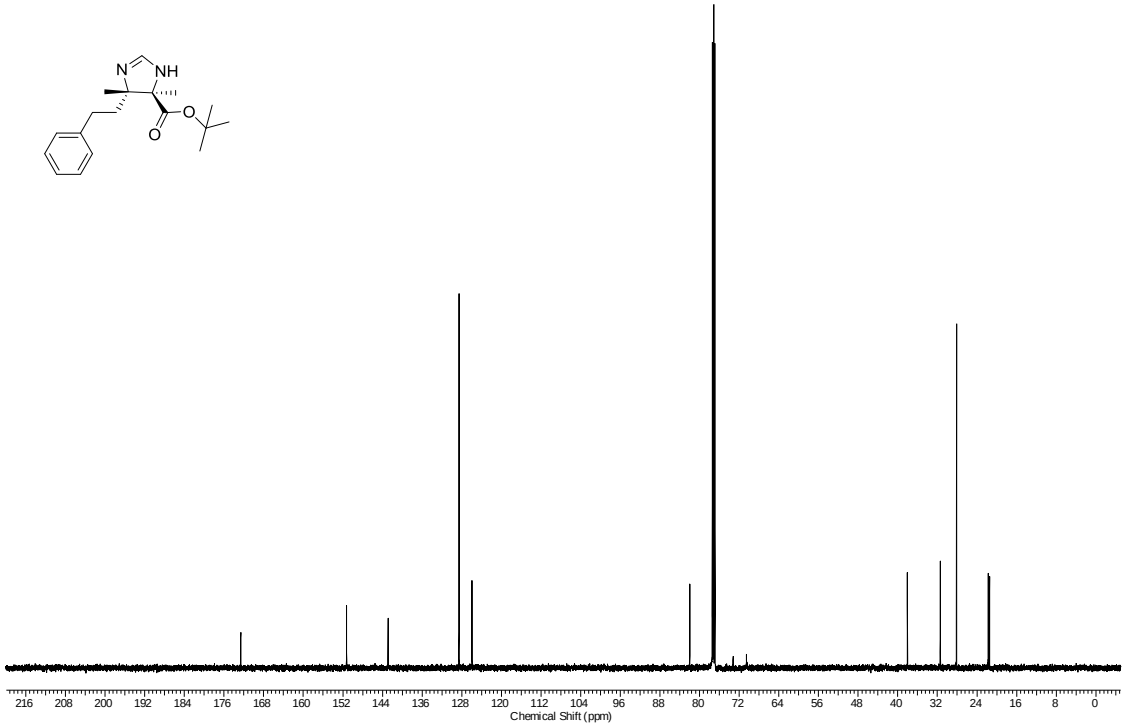
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.925	BB	0.6056	1808.98987	47.14923	4.5045
2	18.469	BB	0.7474	3.83507e4	808.50659	95.4955

4.15 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5o

^{1}H-NMR

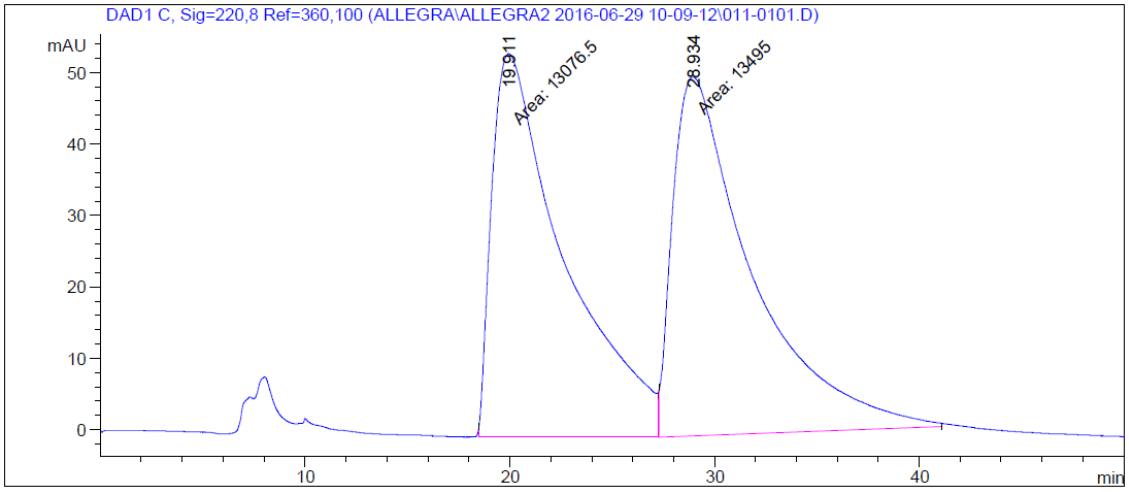


^{13}C-NMR



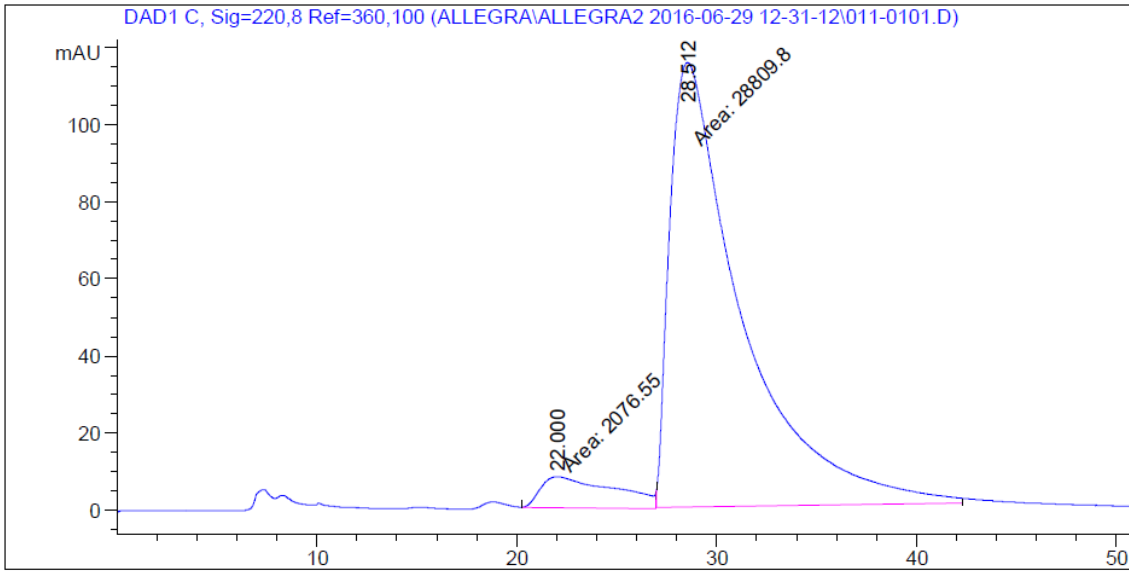
HPLC traces of imidazoline 5o

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	19.911	MM	4.0629	1.30765e4	53.64240	49.2124
2	28.934	MM	4.4768	1.34950e4	50.24086	50.7876

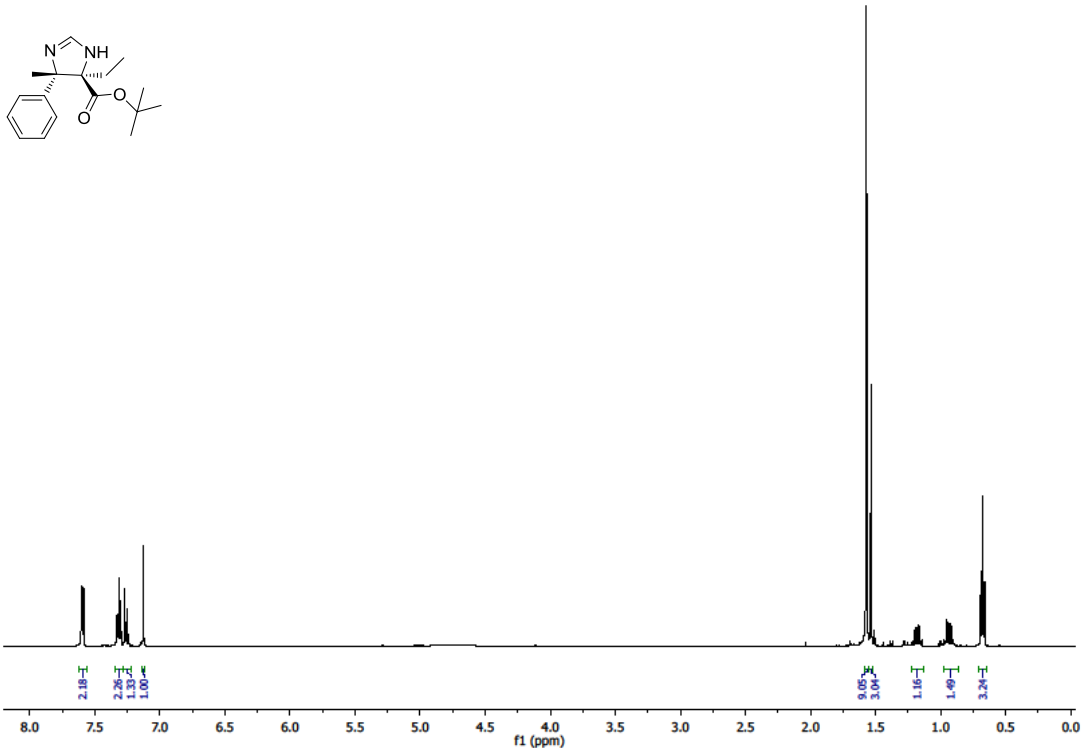
Enantioenriched



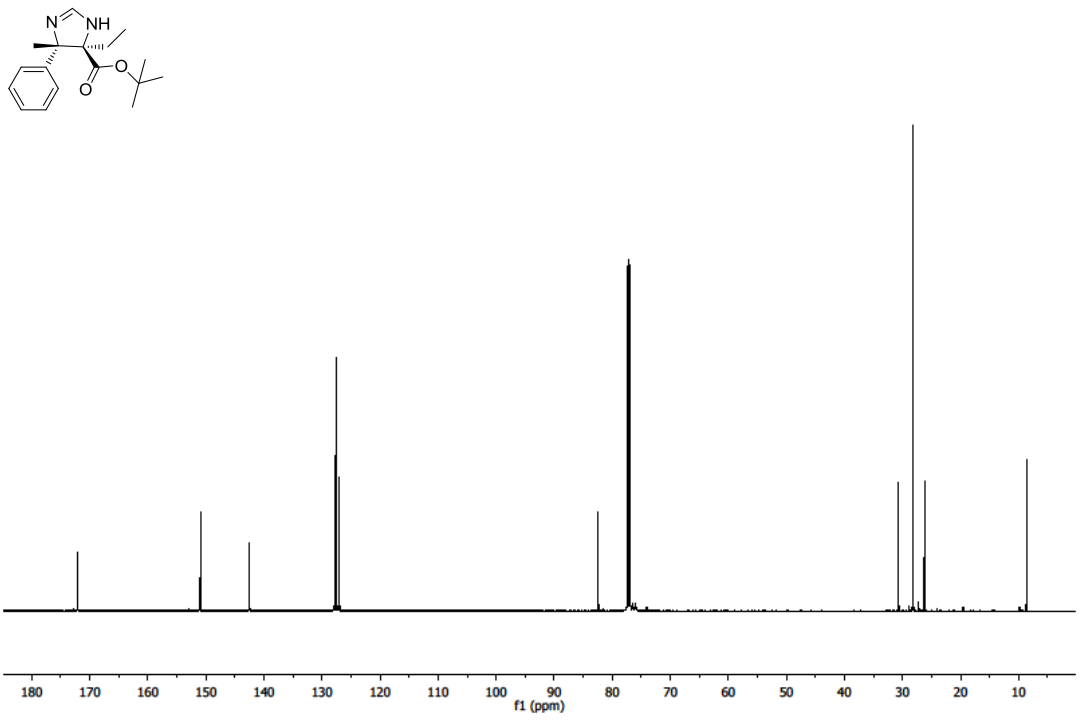
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	22.000	MM	4.3210	2076.55469	8.00961	6.7232
2	28.512	MM	4.1655	2.88098e4	115.27138	93.2768

4.16 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5p

^{1}H-NMR

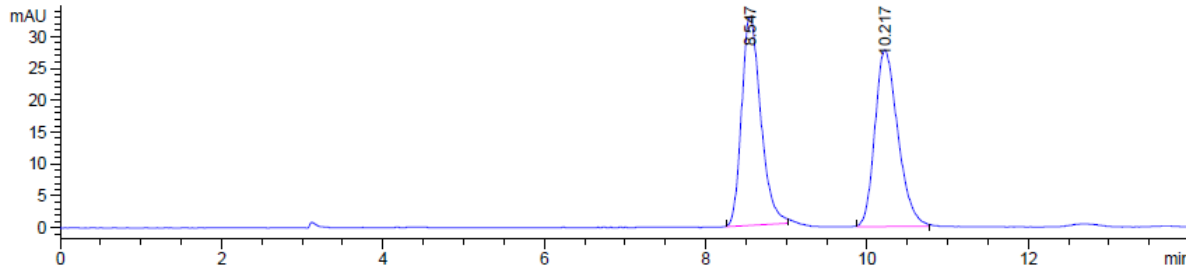


^{13}C-NMR



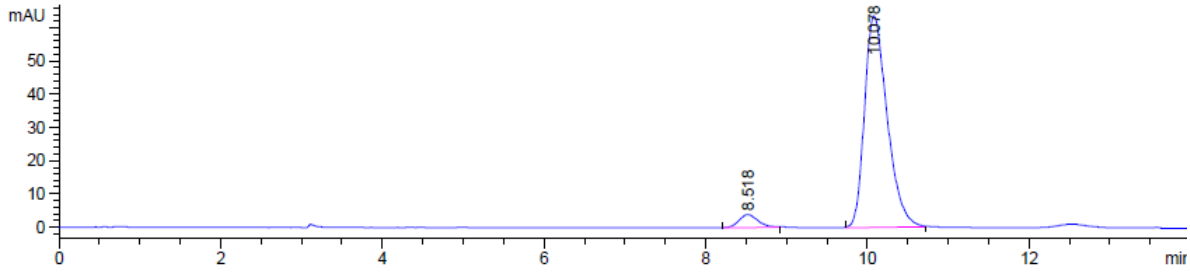
HPLC traces of imidazoline 5p

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.547	BB	0.2520	539.70135	32.78625	49.6545
2	10.217	BB	0.3046	547.21179	27.68389	50.3455
Totals :				1086.91315	60.47013	

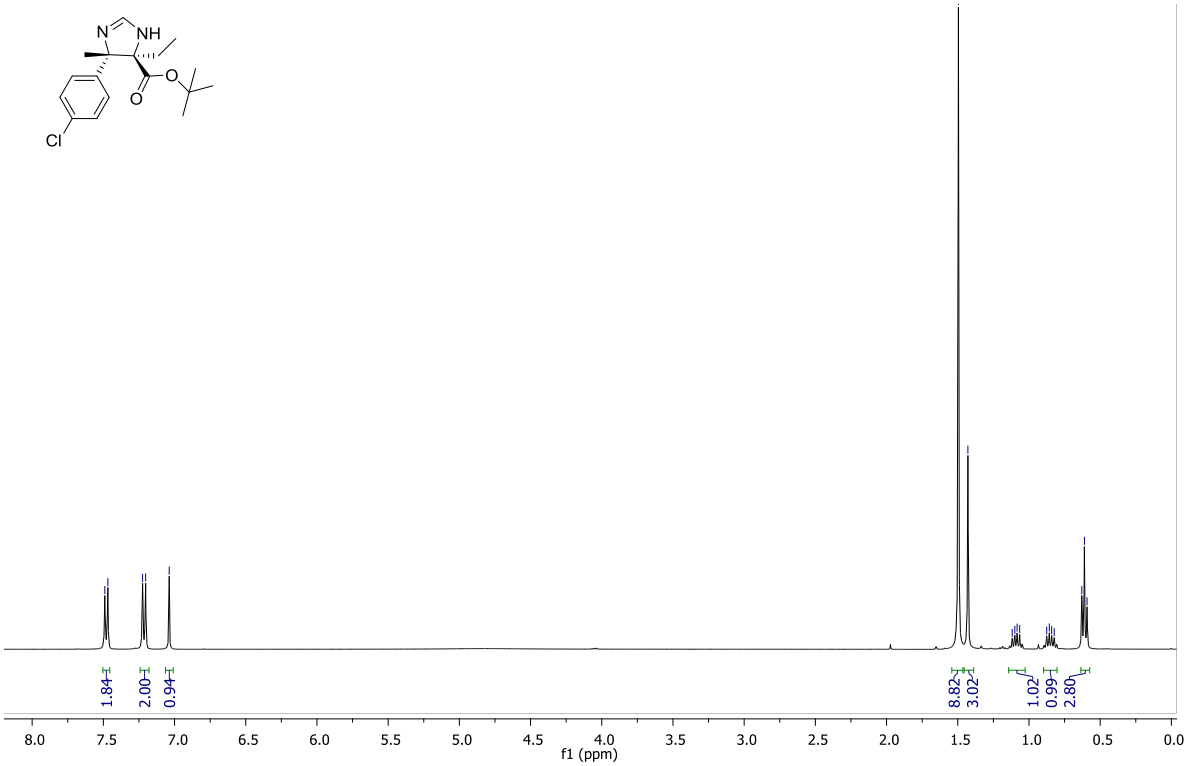
Enantioenriched



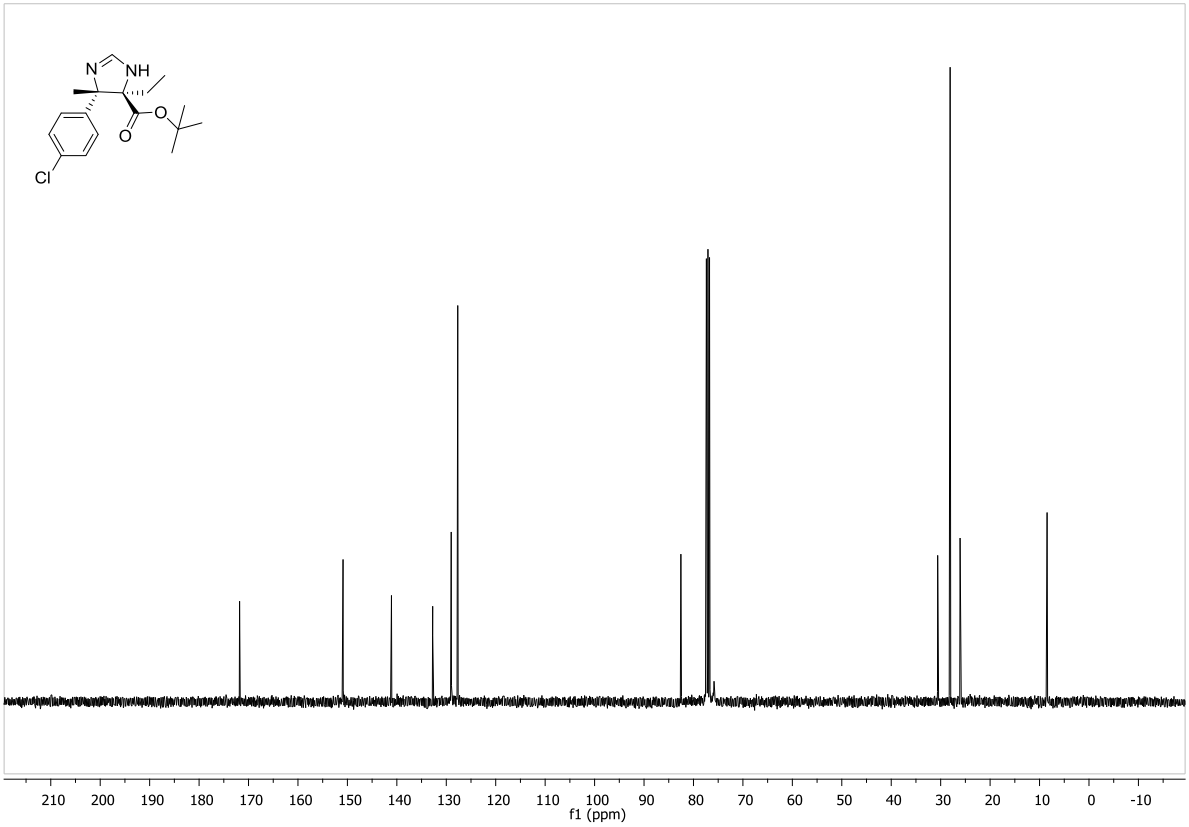
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.518	BB	0.2512	63.61702	3.88254	4.8731
2	10.078	BB	0.2995	1241.85059	63.69743	95.1269
Totals :				1305.46760	67.57997	

4.17 ^{1}H-NMR, ^{13}C-NMR, NOE and HPLC traces of imidazoline 5q

^{1}H-NMR

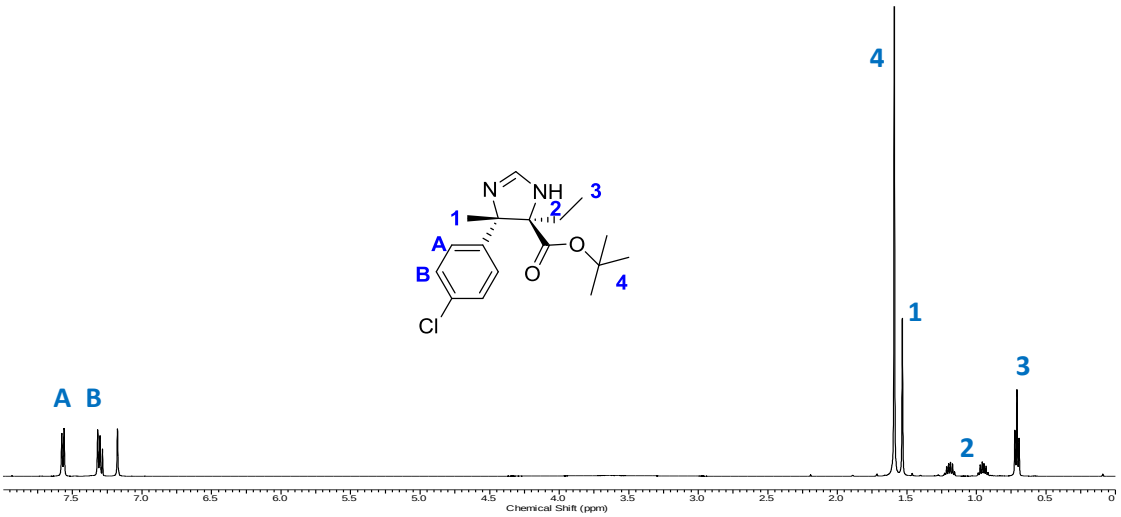


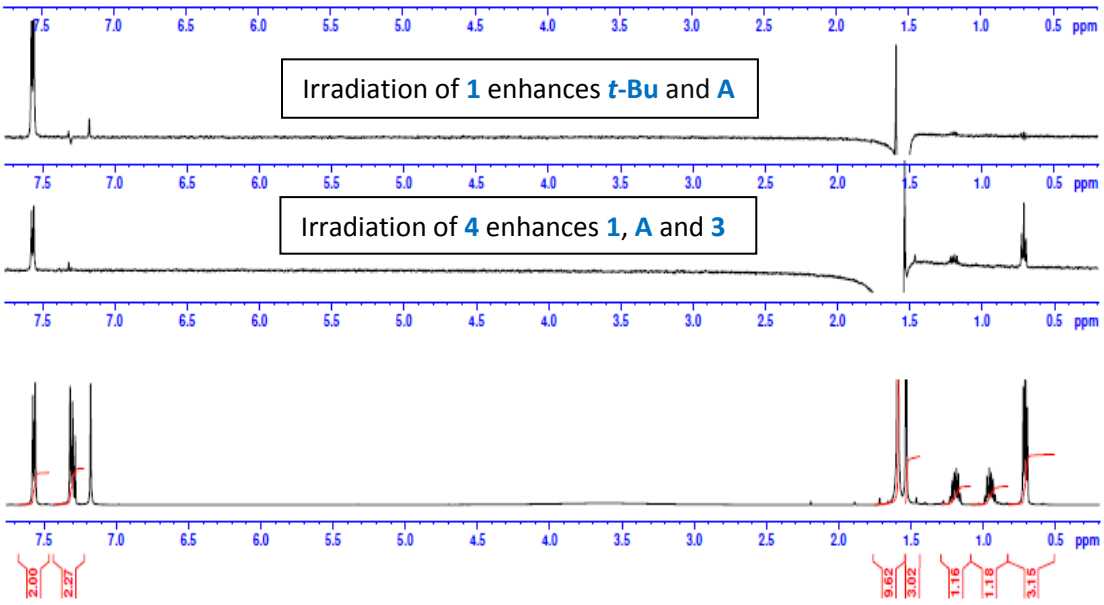
^{13}C-NMR



nOe in the ^{1}H-NMR of imidazoline 5q

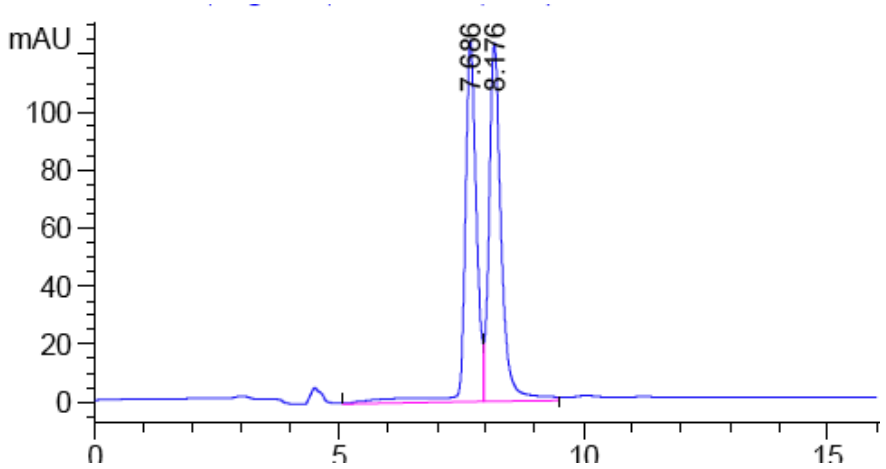
$CDCl_3$, 400 MHz, Tmix 800 ms





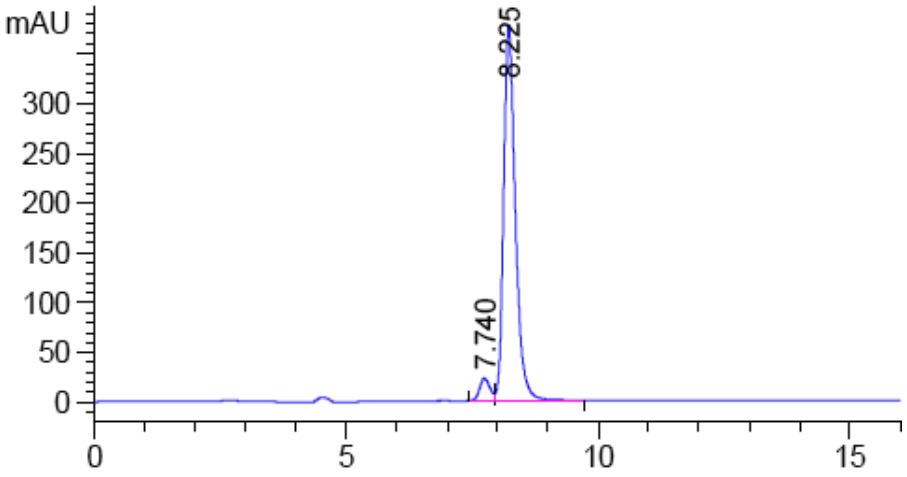
HPLC traces of imidazoline 5q

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.686	VV	0.2443	2051.85498	124.48985	48.7914
2	8.176	VB	0.2601	2153.50586	123.09373	51.2086

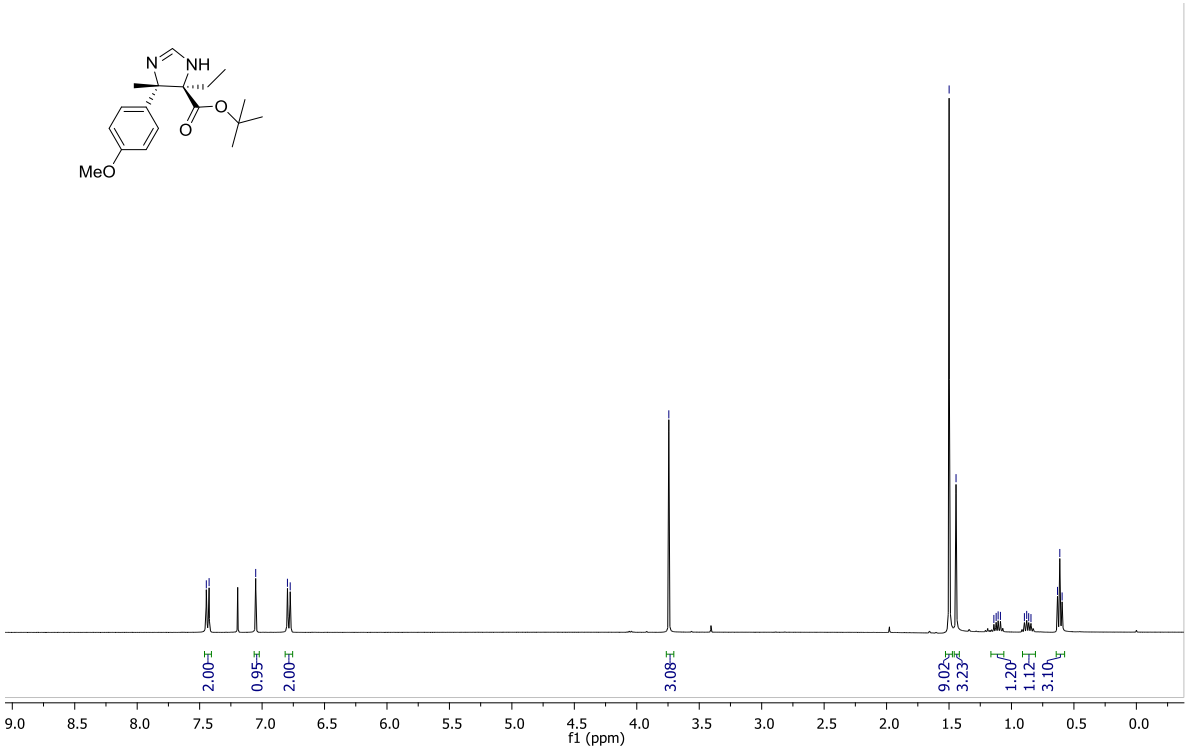
Enantioenriched



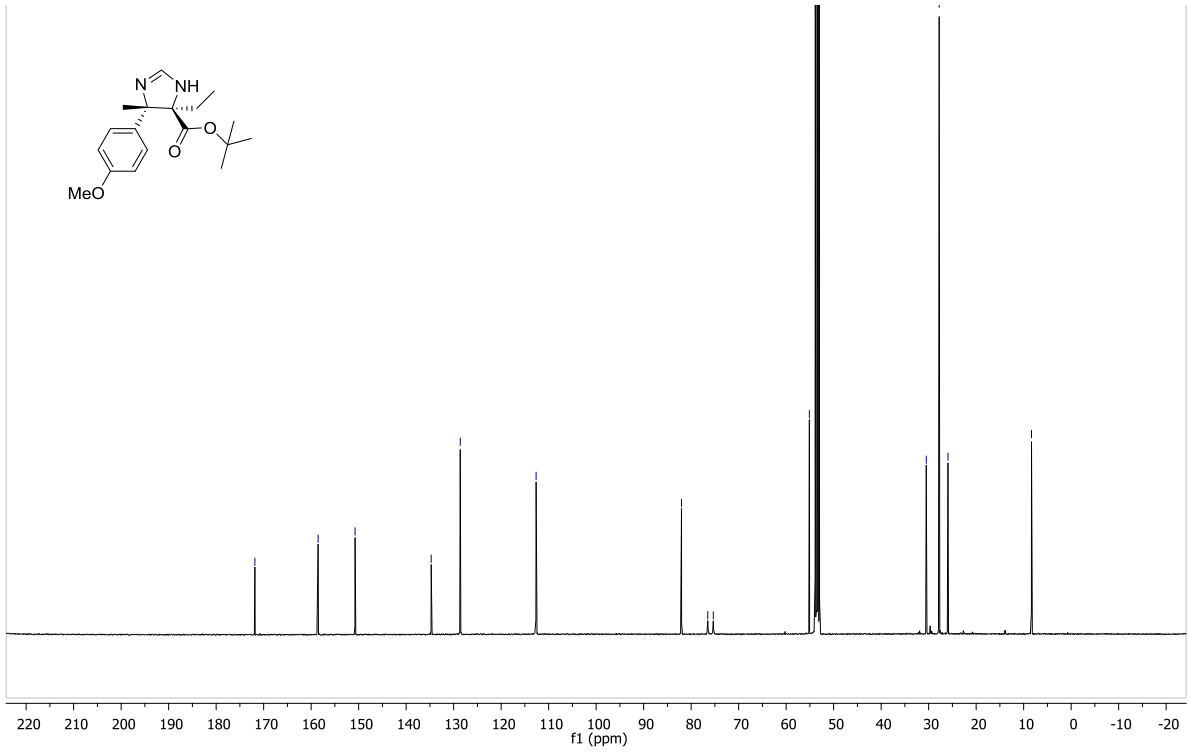
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.740	BV	0.2257	349.47983	23.47752	5.3510
2	8.225	VB	0.2465	6181.67236	378.53668	94.6490

4.18 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5r

^{1}H-NMR

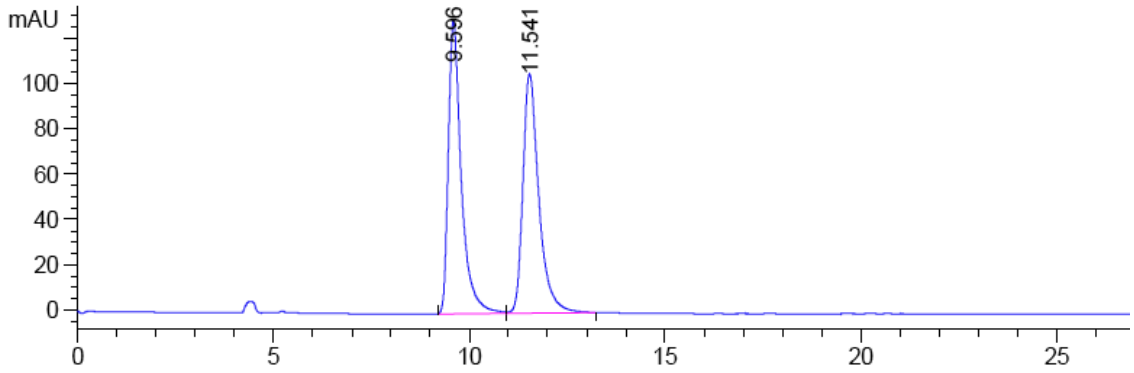


^{13}C-NMR



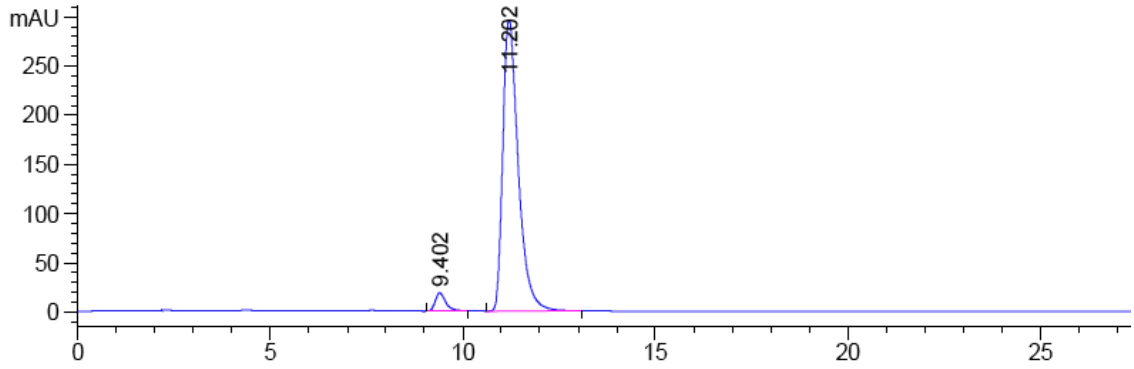
HPLC traces of imidazoline 5r

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.596	BV	0.3443	2978.76978	129.54291	49.8505
2	11.541	VB	0.4229	2996.63232	105.65739	50.1495

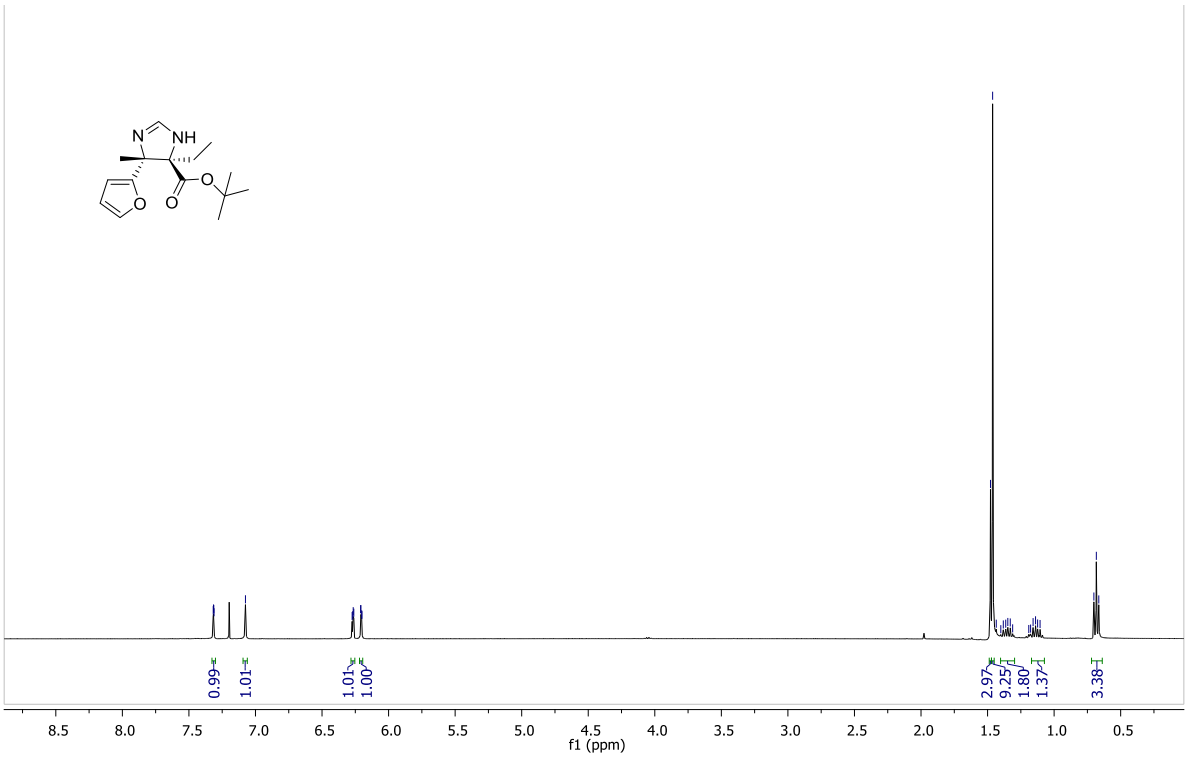
Enantioenriched



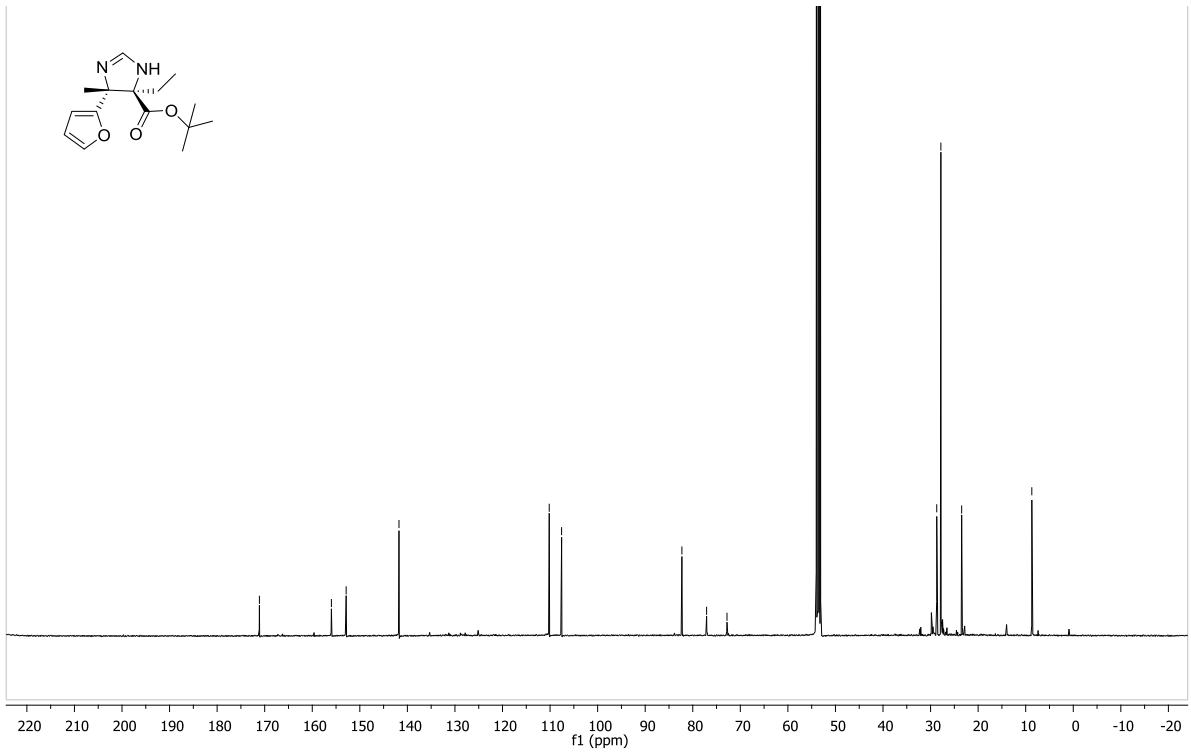
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.402	VV	0.2860	1628.91064	85.60803	4.1329
2	11.202	VB	0.4340	3.77839e4	1335.86658	95.8671

4.19 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5s

^{1}H-NMR

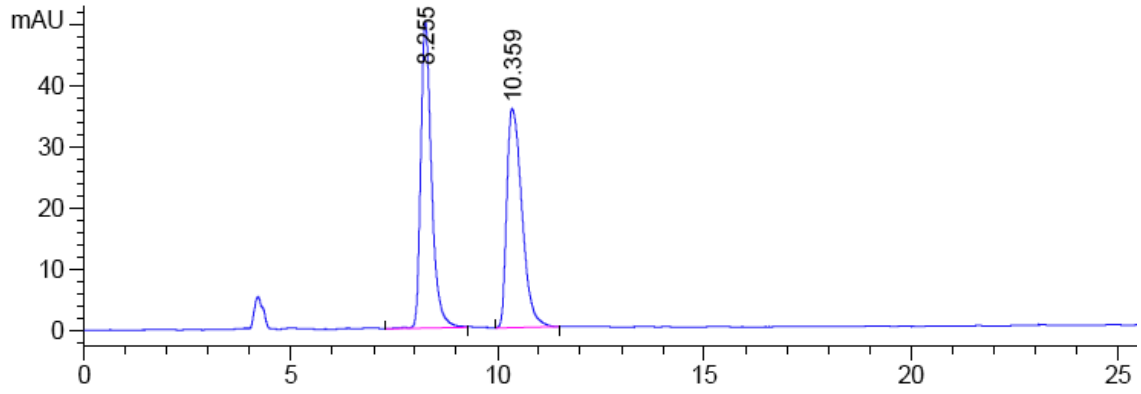


^{13}C-NMR



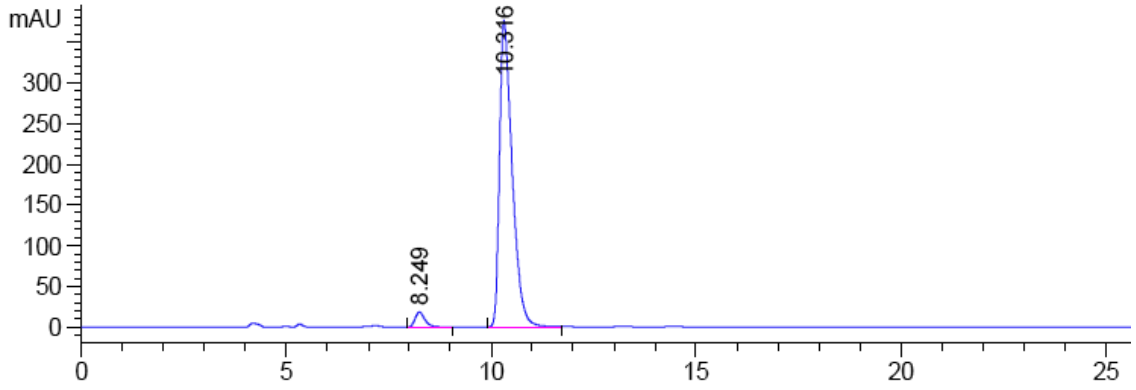
HPLC traces of imidazoline 5s

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.255	VB	0.2759	908.65033	50.01686	49.8919
2	10.359	BB	0.4068	912.58704	35.62939	50.1081

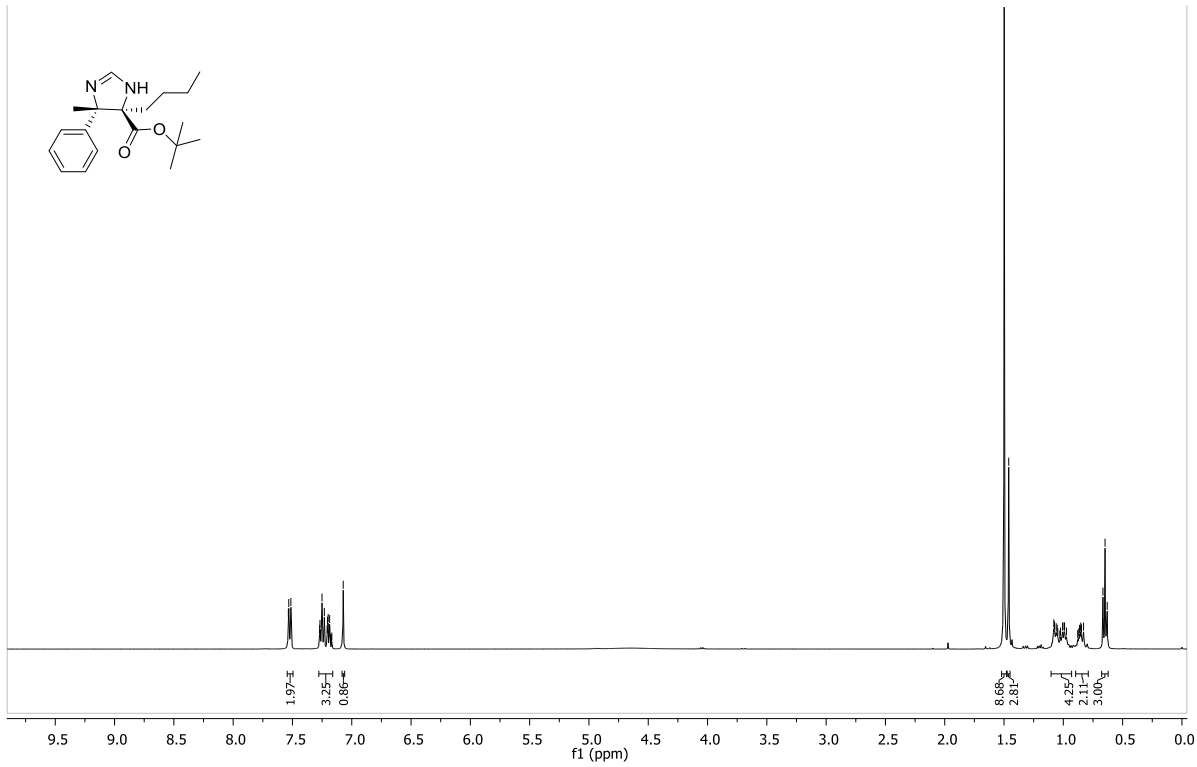
Enantioenriched



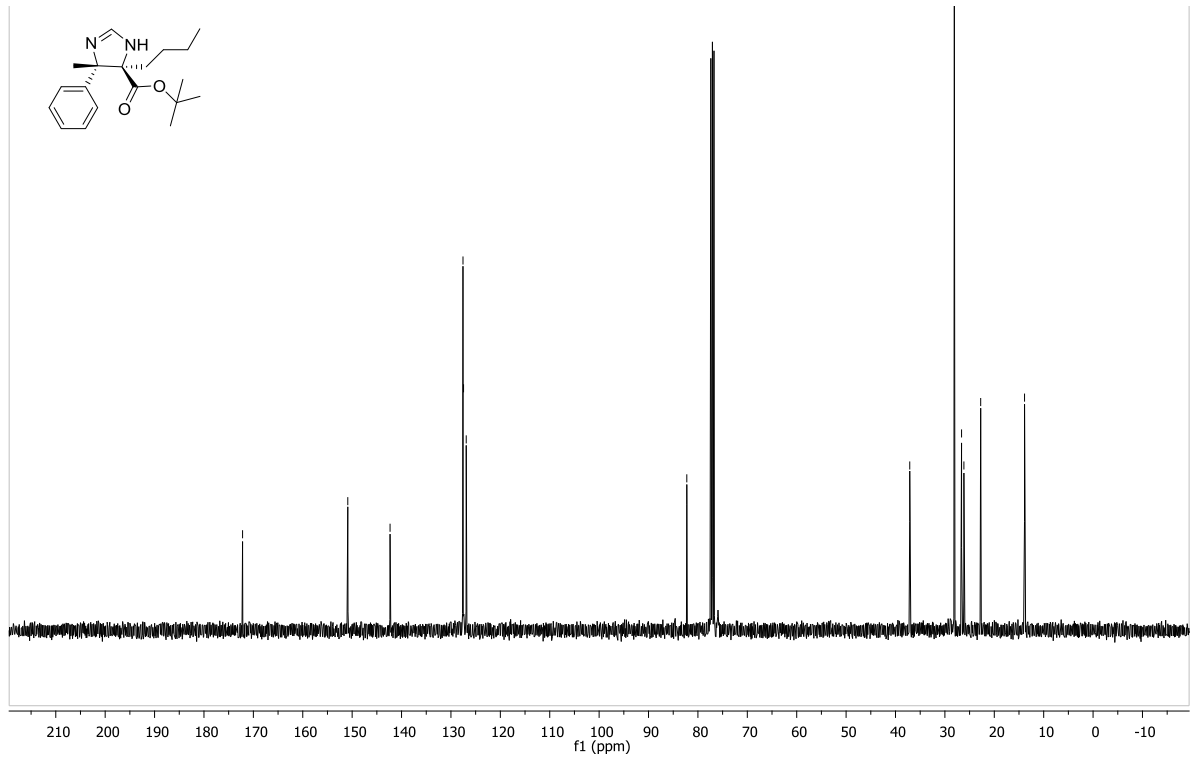
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.249	BB	0.2566	312.27069	18.53080	3.7400
2	10.316	BB	0.3132	8037.21729	376.33499	96.2600

4.20 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5t

^{1}H-NMR

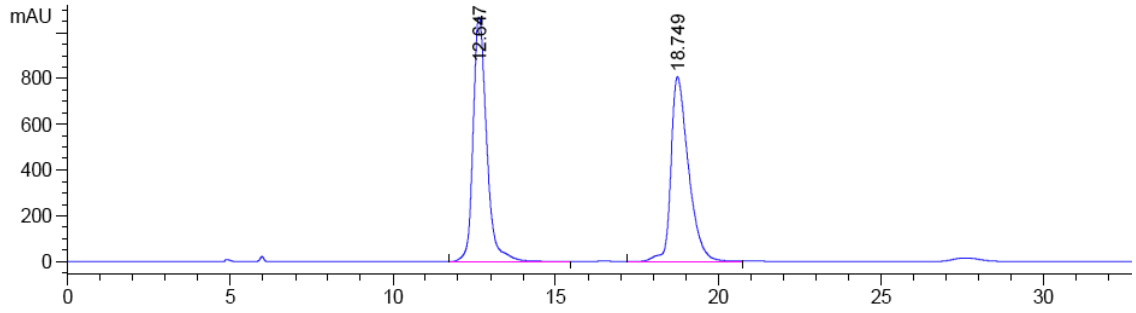


^{13}C-NMR



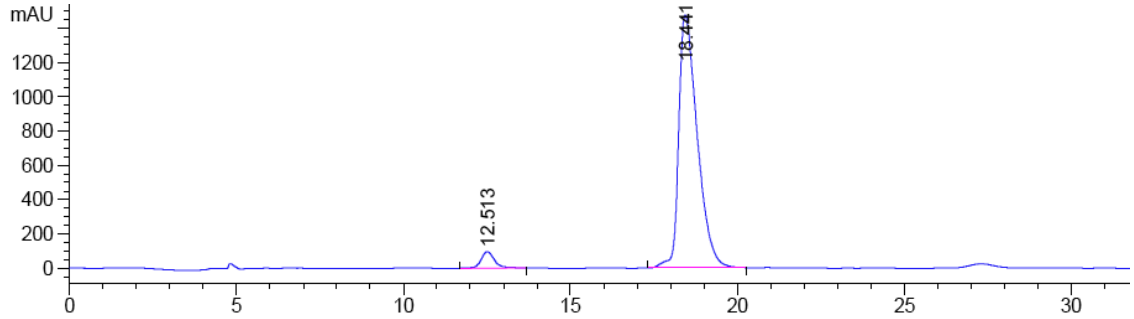
HPLC traces of imidazoline 5t

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.647	BB	0.4422	3.09712e4	1068.35327	50.5255
2	18.749	VB	0.5580	3.03271e4	807.86121	49.4745

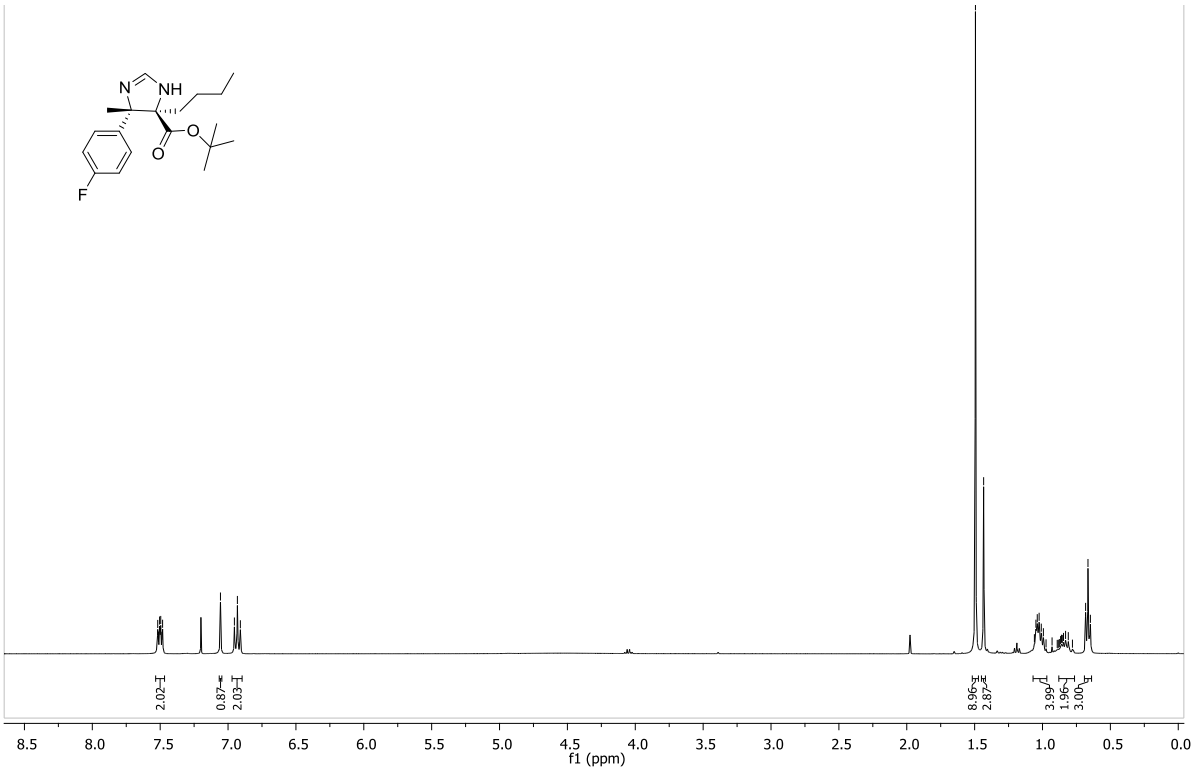
Enantioenriched



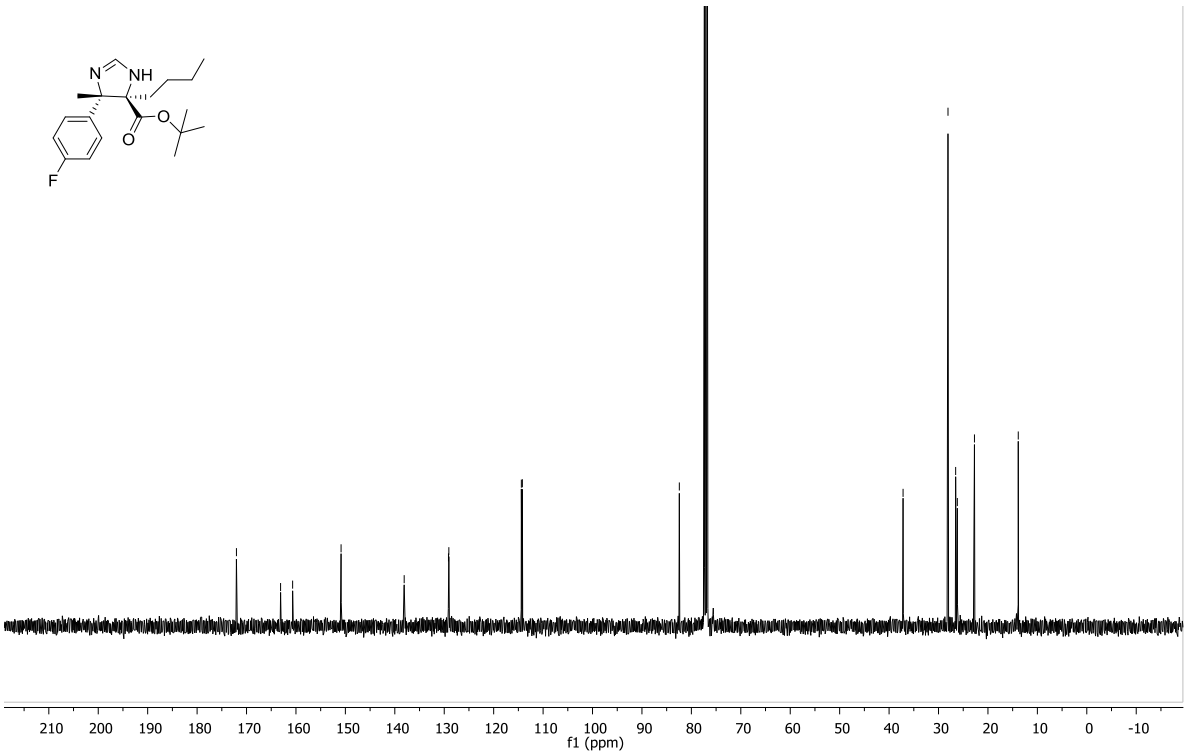
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.513	BB	0.4215	2708.96924	95.35264	4.5378
2	18.441	BB	0.5618	5.69885e4	1471.47949	95.4622

4.21 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5u

^{1}H-NMR

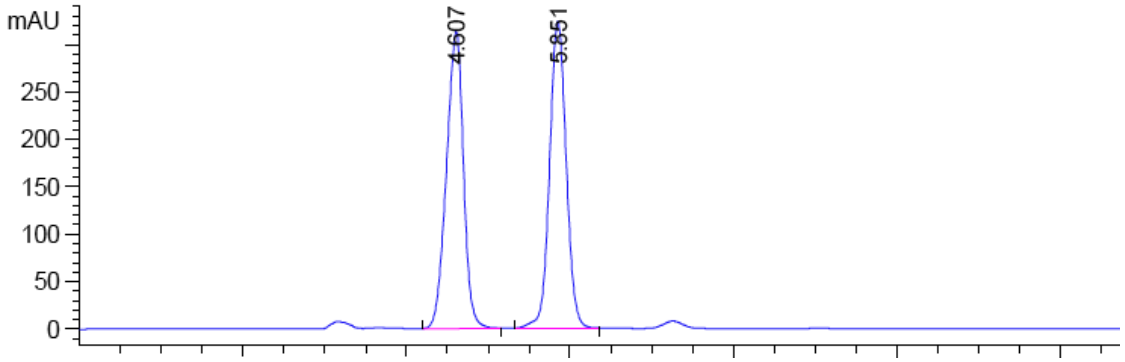


^{13}C-NMR



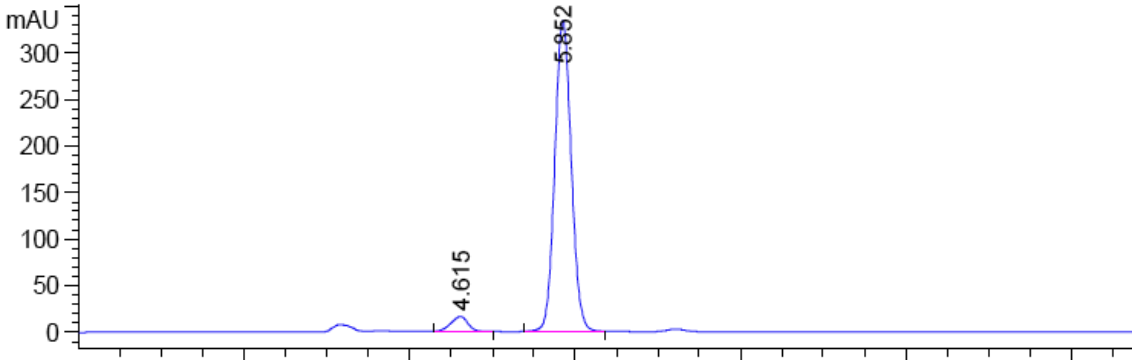
HPLC traces of imidazoline 5u

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.607	BB	0.2232	2502.23291	172.52979	49.8825
2	5.851	BB	0.2185	2514.02148	178.28250	50.1175

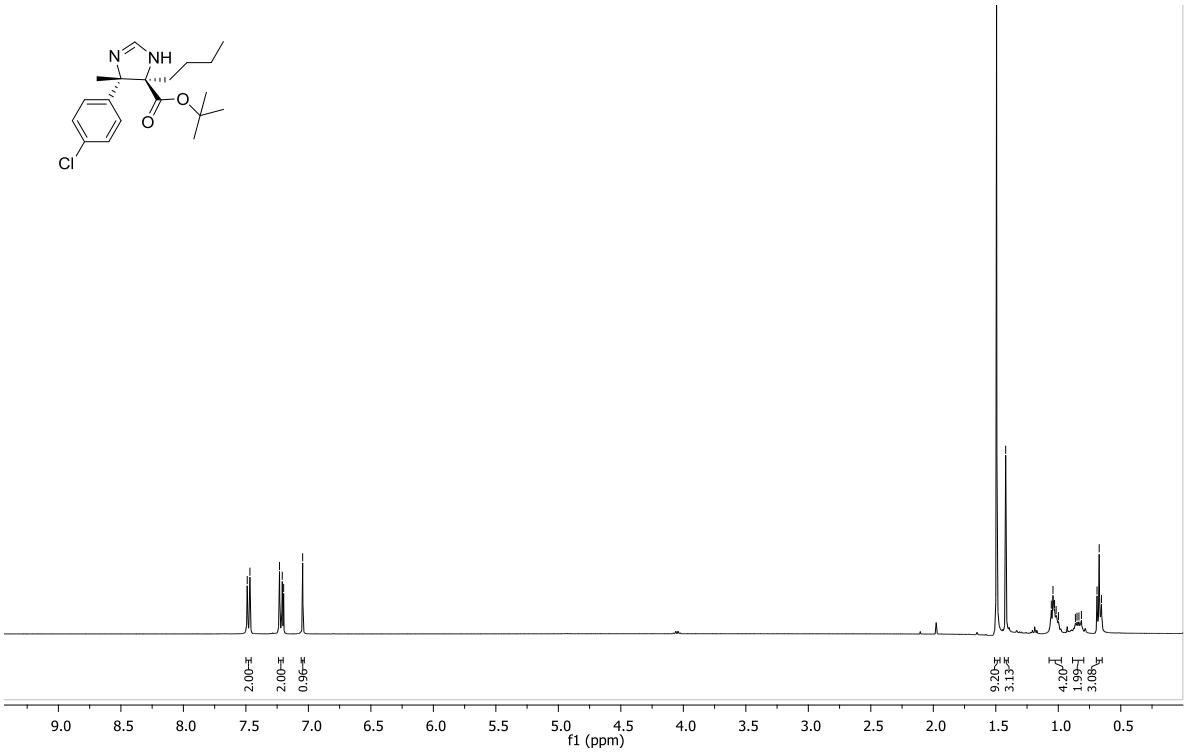
Enantioenriched



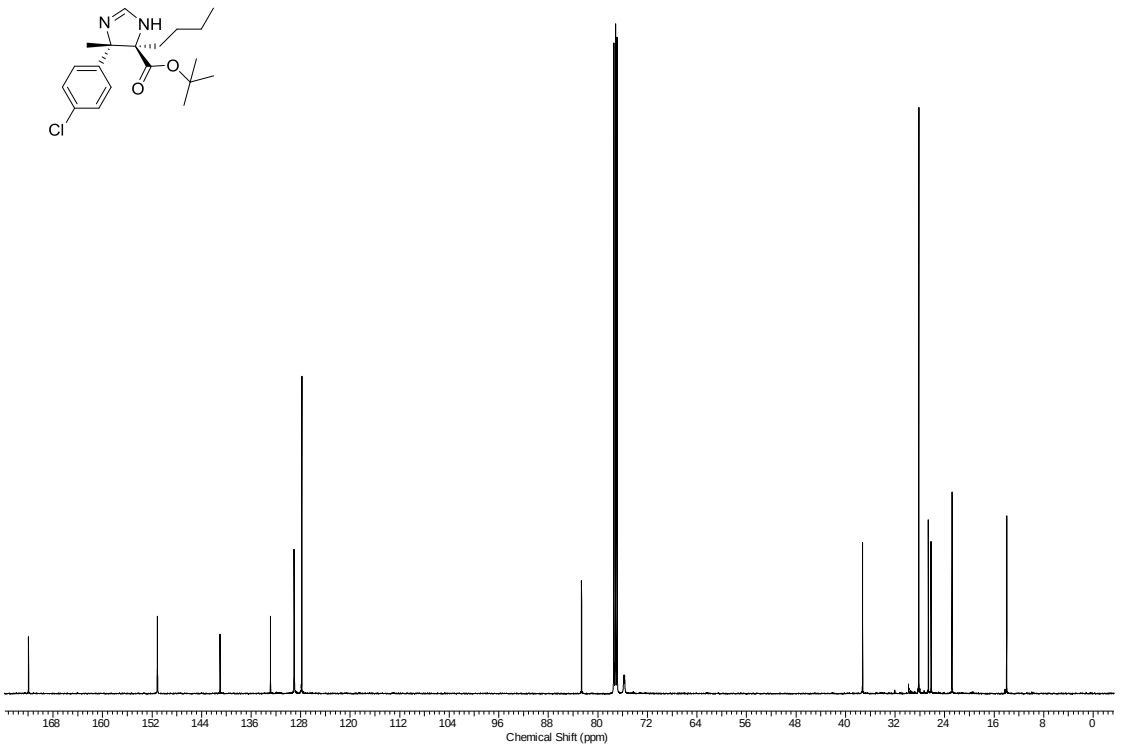
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.615	BB	0.2226	237.77773	16.25991	4.8839
2	5.852	BB	0.2178	4630.81934	333.90622	95.1161

4.22 ^{1}H-NMR, ^{13}C-NMR, NOE and HPLC traces of imidazoline 5v

^{1}H-NMR

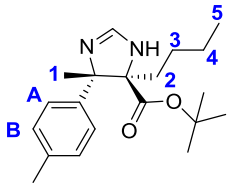


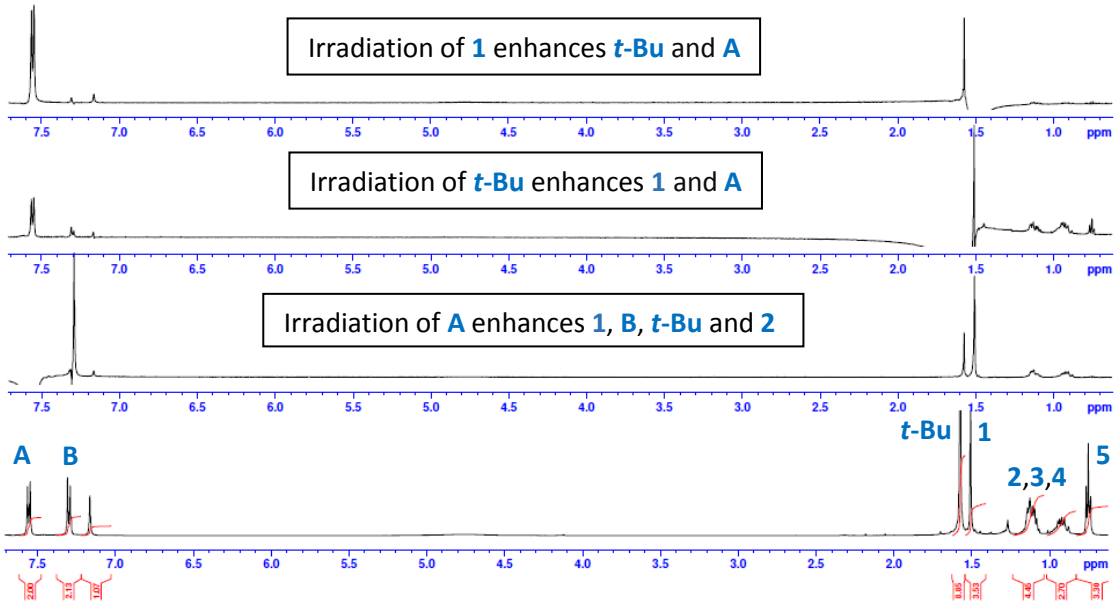
^{13}C-NMR



nOe in the ^{1}H-NMR of imidazoline 5v

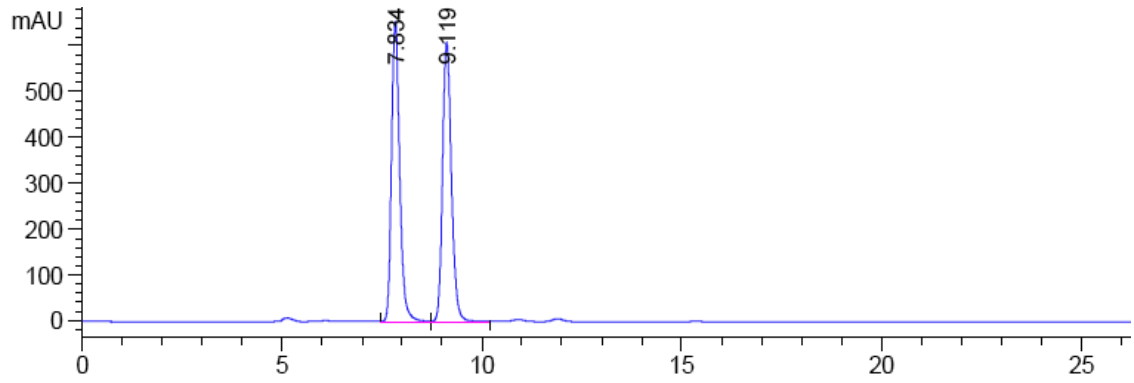
$CDCl_3$, 400 MHz, Tmix 800 ms





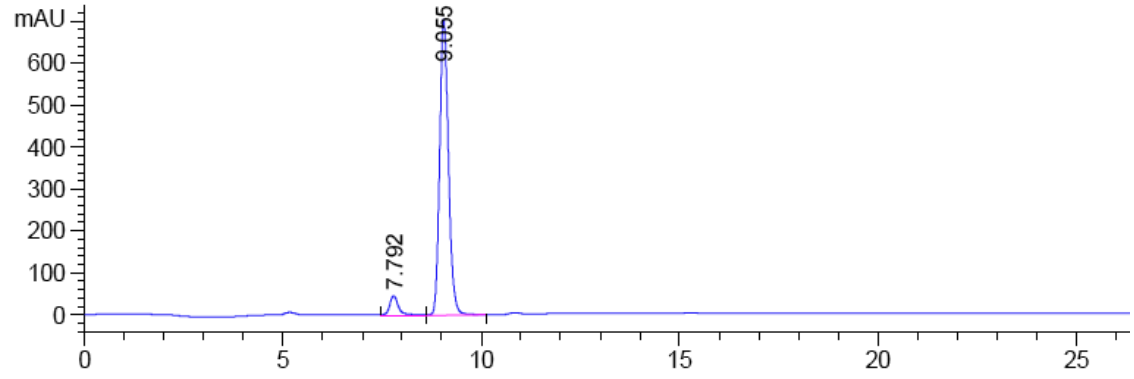
HPLC traces of imidazoline 5v

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.834	BV	0.2187	9340.56738	653.65997	49.7834
2	9.119	VV	0.2368	9421.85938	607.96771	50.2166

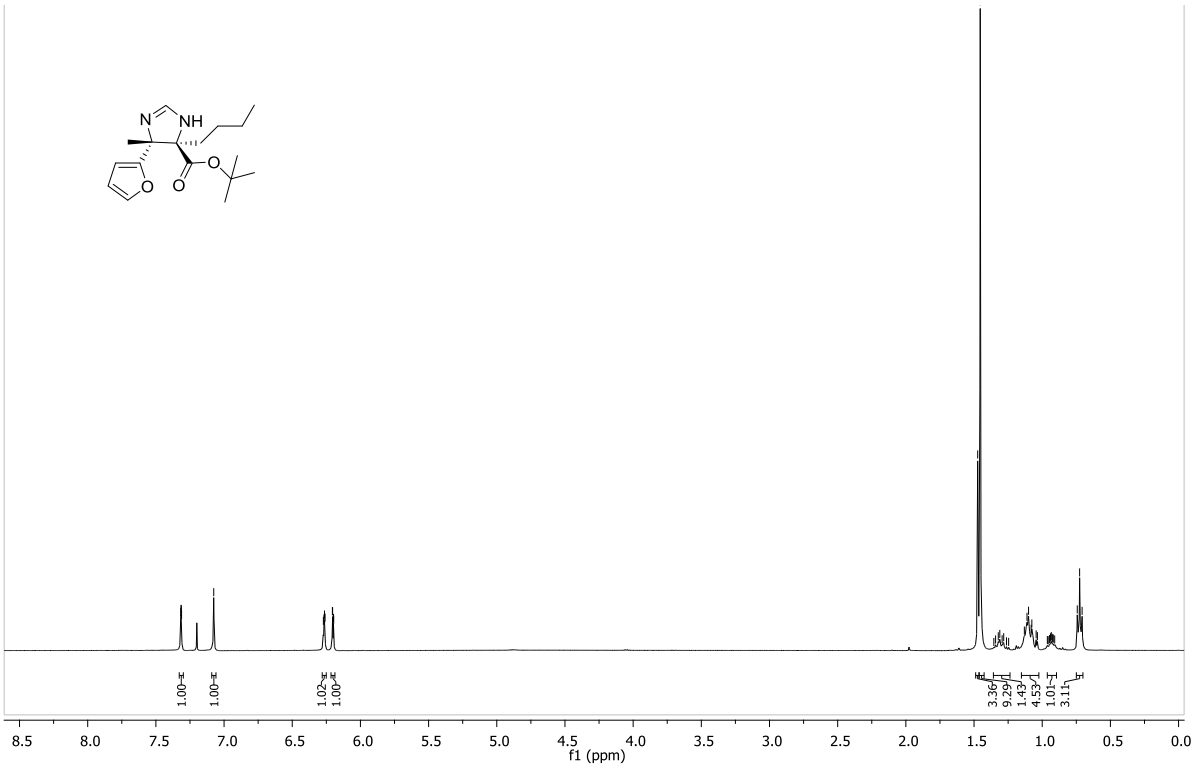
Enantioenriched



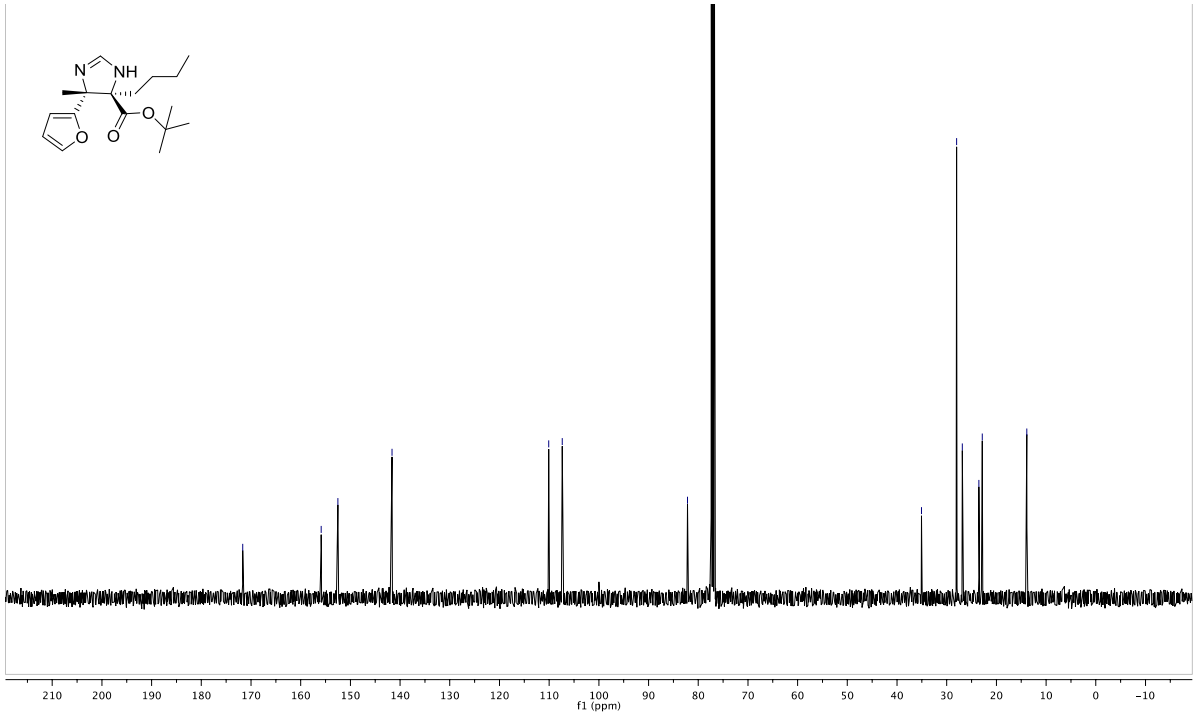
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.793	BB	0.2247	579.14594	39.58824	5.7568
2	9.054	BB	0.2351	9481.12500	617.69049	94.2432

4.23 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5w

^{1}H-NMR

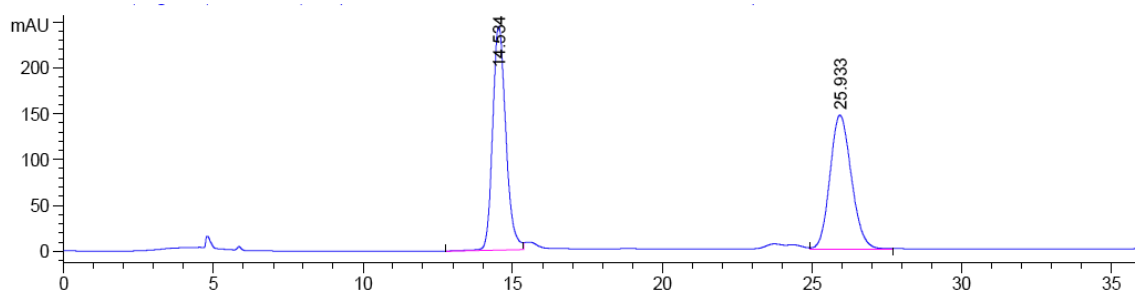


^{13}C-NMR



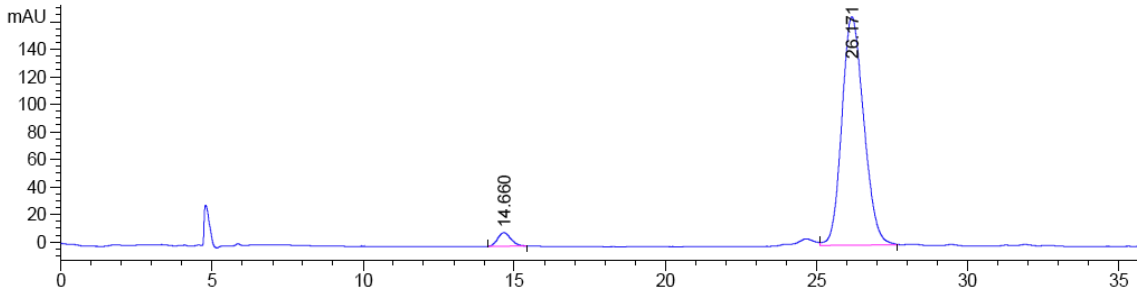
HPLC traces of imidazoline 5w

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	14.534	BV	0.4700	7489.09424	244.06279	50.8220
2	25.933	VB	0.7672	7246.82715	145.96376	49.1780

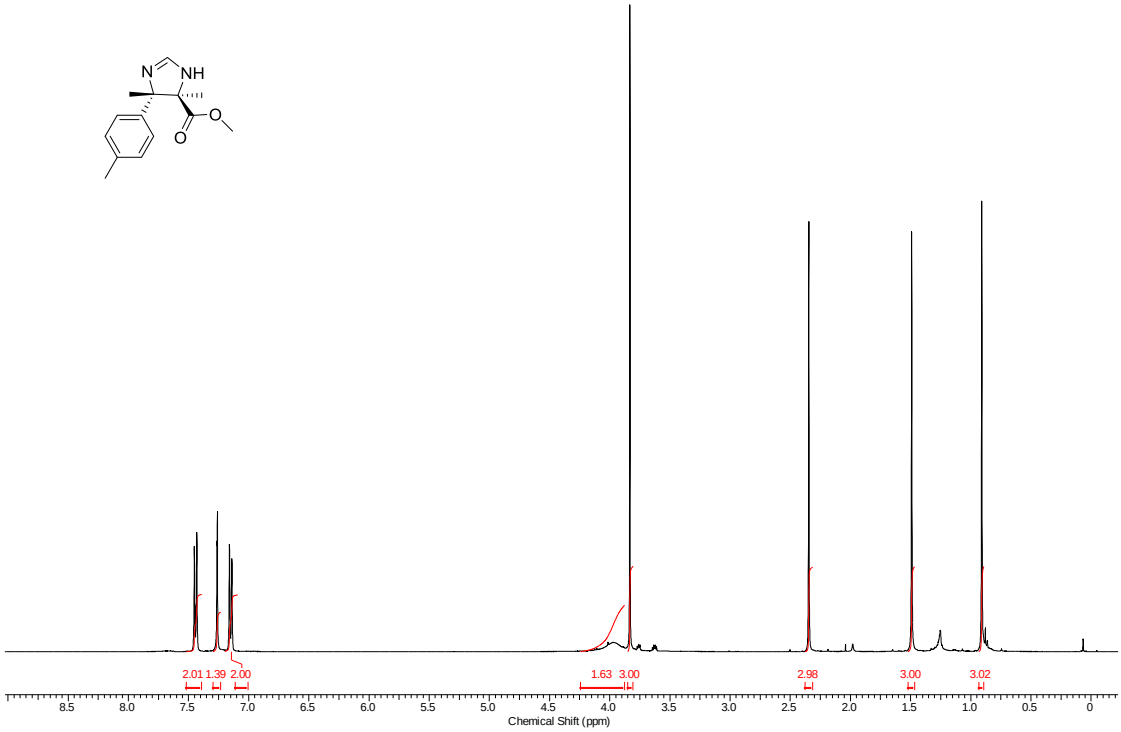
Enantioenriched



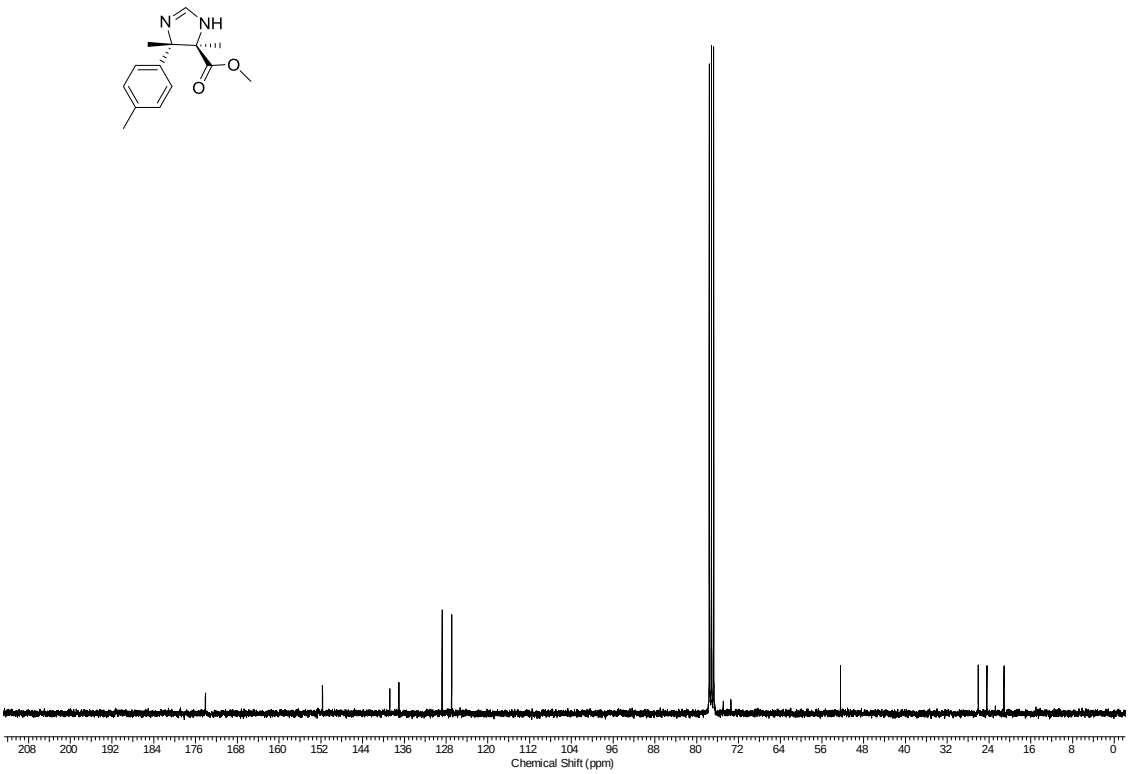
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	14.660	BB	0.4377	298.53610	9.84651	3.4401
2	26.171	VB	0.7436	8379.67383	165.80602	96.5599

4.24 ^{1}H-NMR, ^{13}C-NMR and HPLC traces of imidazoline 5y

^{1}H-NMR

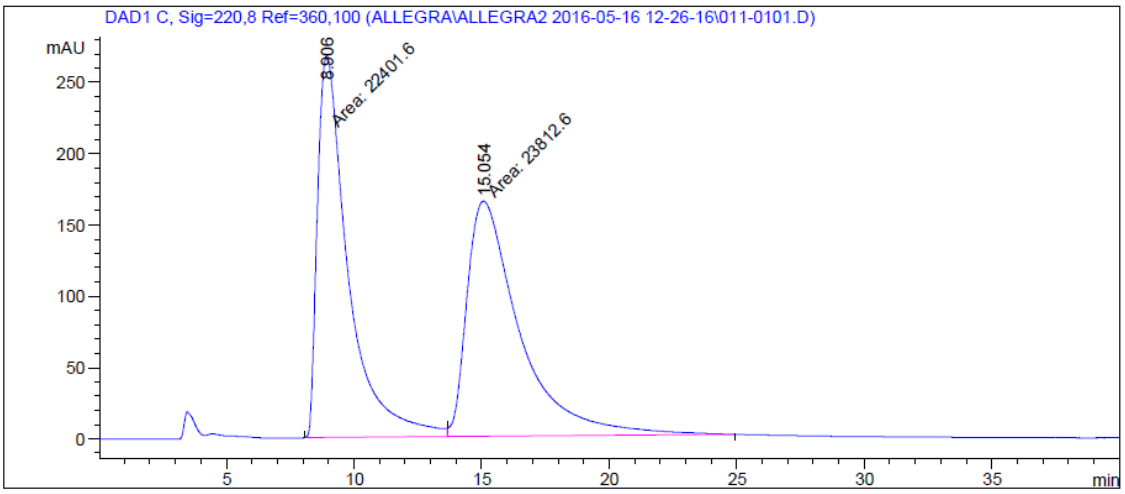


^{13}C-NMR



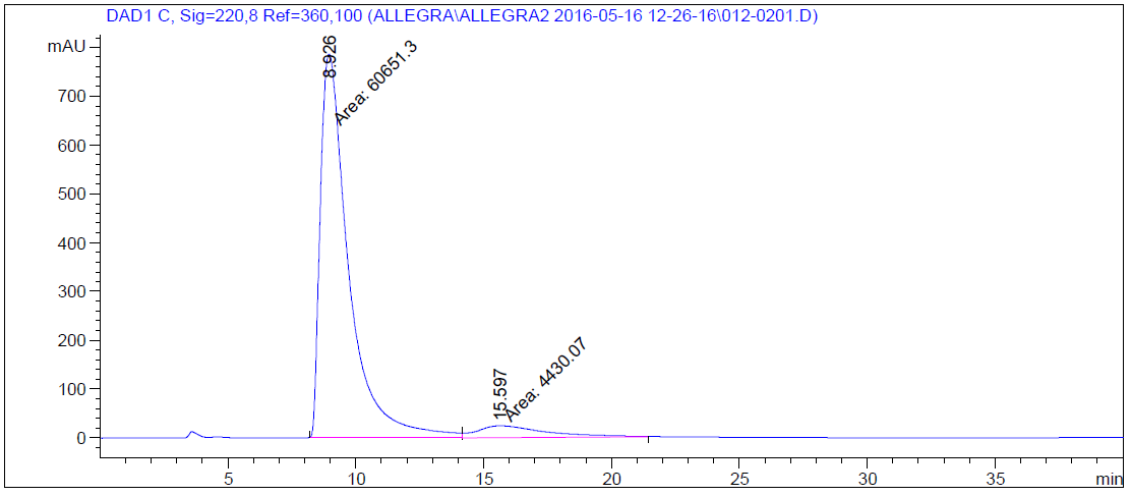
HPLC traces of imidazoline 5y

Racemic



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.906	MF	1.3956	2.24016e4	267.52496	48.4734
2	15.054	FM	2.4066	2.38126e4	164.91110	51.5266

Enantioenriched

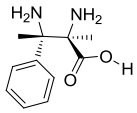


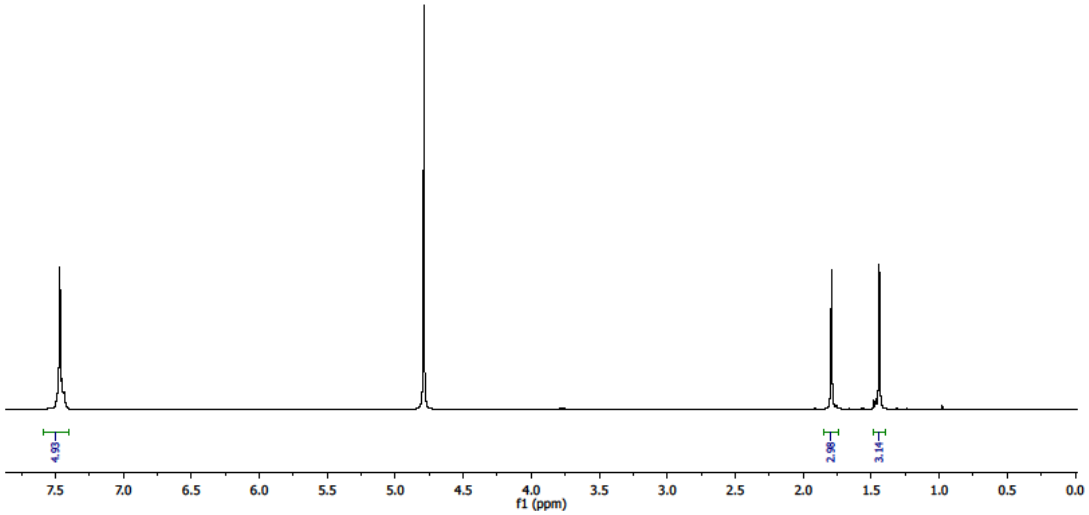
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.926	MF	1.2861	6.06513e4	785.98505	93.1930
2	15.597	MM	3.0714	4430.06934	24.03913	6.8070

5 ^{1}H-NMR and ^{13}C-NMR of imidazoline derivatives

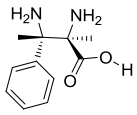
5.1 ^{1}H-NMR and ^{13}C-NMR of 6c

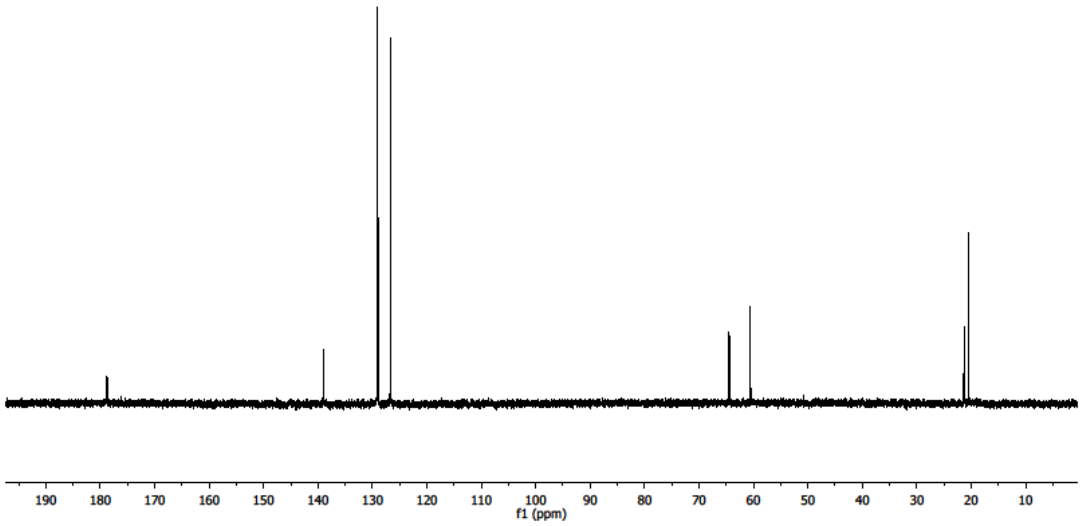
^{1}H-NMR





^{13}C-NMR



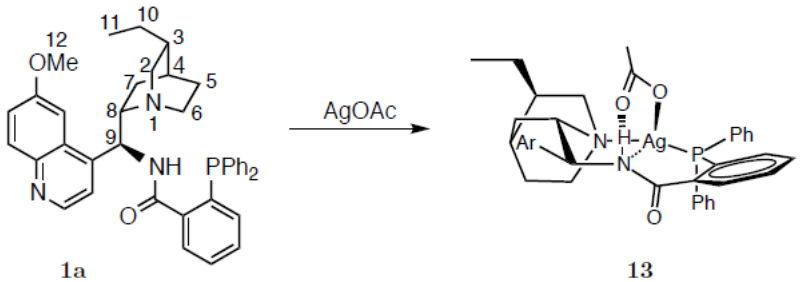


6 NMR studies of 1a·AgOAc complex

6.1 ^{1}H-NMR spectra

Low temperature ^{1}H NMR experiments were also performed. On complexation of **1a** with silver acetate the NMR spectrum of the complex appears more resolved. In particular H–9 and H–8, which appear as very broad multiplets in the free ligand (inset 2, Figure 1.4) are resolved as a triplet and sharper multiplet respectively in **1a**·AgOAc. This is indicative of more rigidity about the C-9 amide centre which would arise from complexation with silver. Secondly there is a general downfield shift of the proton signals on complexation with silver but this more prominent in some protons signals with respect to others. Assignment of the ^{1}H NMR spectrum of both **1a** and **1a**·AgOAc was done and the change in chemical shift calculated (Table 1.4).

Table 1.4: δ_H of the aliphatic protons in **1a** and **1a**·AgOAc with $\Delta\delta_H$ calculated for complexation.

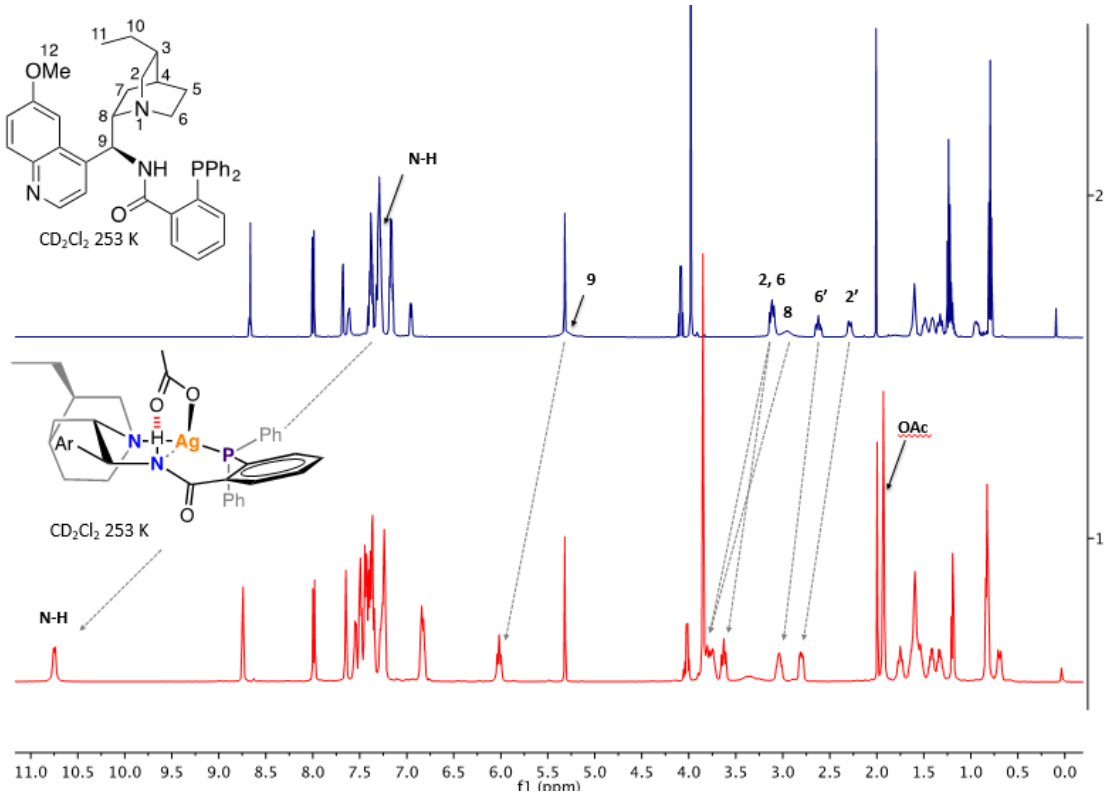


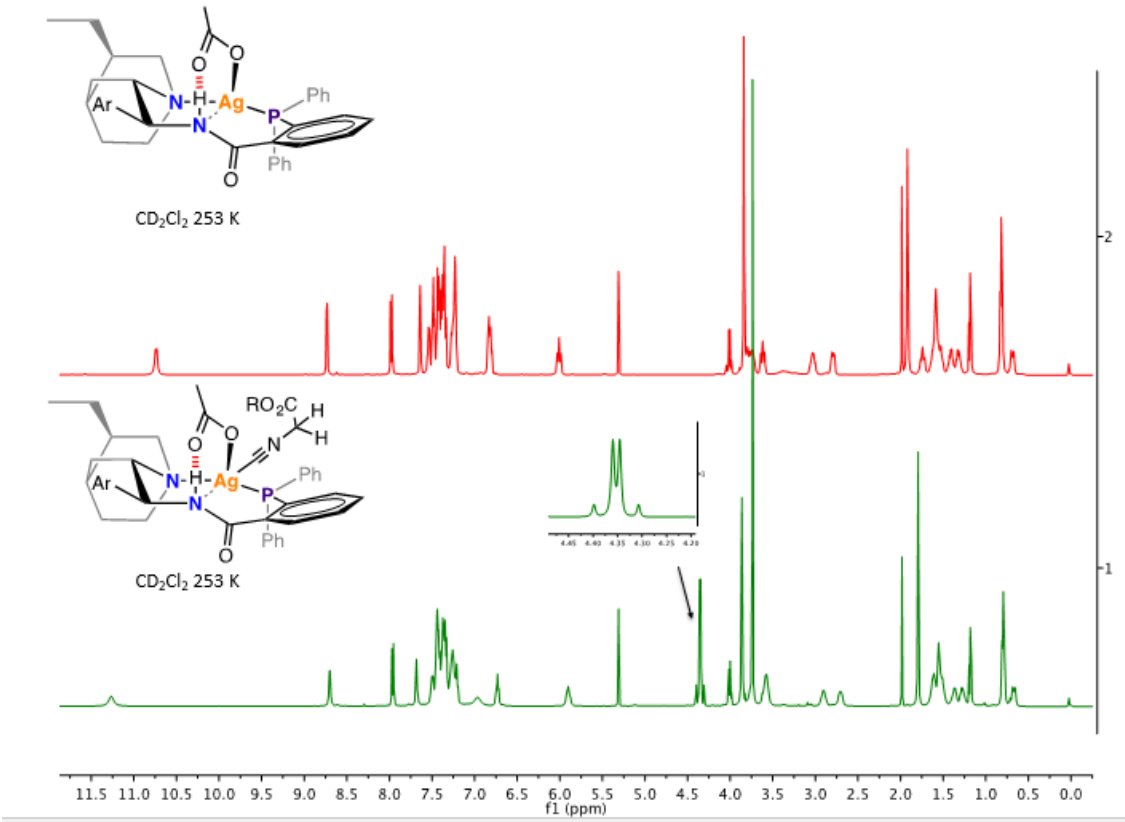
1a **13**

	H-2$_a$	H-2$_b$	H-3	H-4	H-5$_a$	H-5$_b$	H-6$_a$	H-6$_b$
δ_H[a]	3.12	2.29	1.4	1.61	1.61	1.49	3.12	2.62
δ_H [a]	3.67	2.85	1.63	1.63	1.79	1.66	3.85	3.08
$\Delta\delta_H$	0.55	0.56	0.23	0.02	0.18	0.05	0.73	0.46

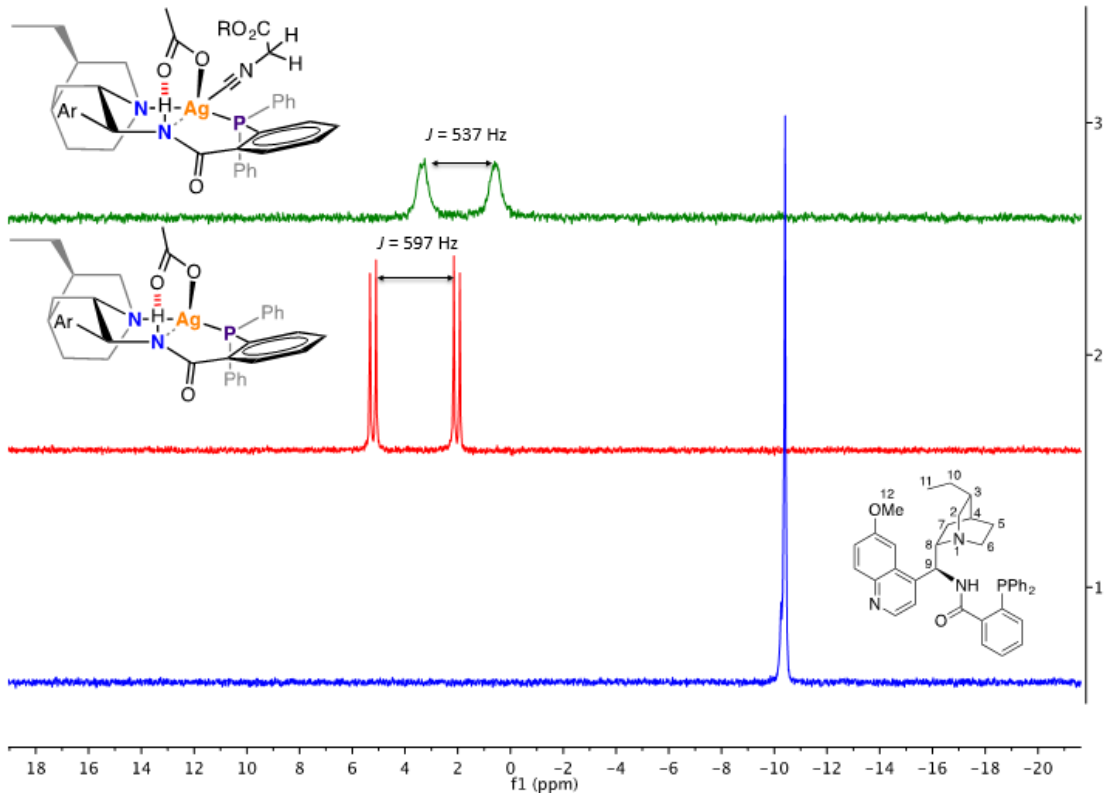
	H-7$_a$	H-7$_b$	H-8	H-9	H-10	H-11	H-12	N–H
δ_H	1.33	0.95	2.96	5.3	1.26	0.79	3.98	7.3
δ_H	1.58	0.75	3.79	6.06	1.42	0.87	3.89	10.7
$\Delta\delta_H$	0.25	-0.20	0.83	0.76	0.16	0.08	-0.09	≈3.4

[a] δ_H for overlapping signals were obtained from the HSQC


OMe
NH
PPh2
CD2Cl2 253 K
N-H
9
2, 6
8
6'
2'
OAc
Ar
Ag
Ph
CD2Cl2 253 K
N-H
f1 (ppm)


Ar
Ag
Ph
CD2Cl2 253 K
RO2C
CD2Cl2 253 K
f1 (ppm)

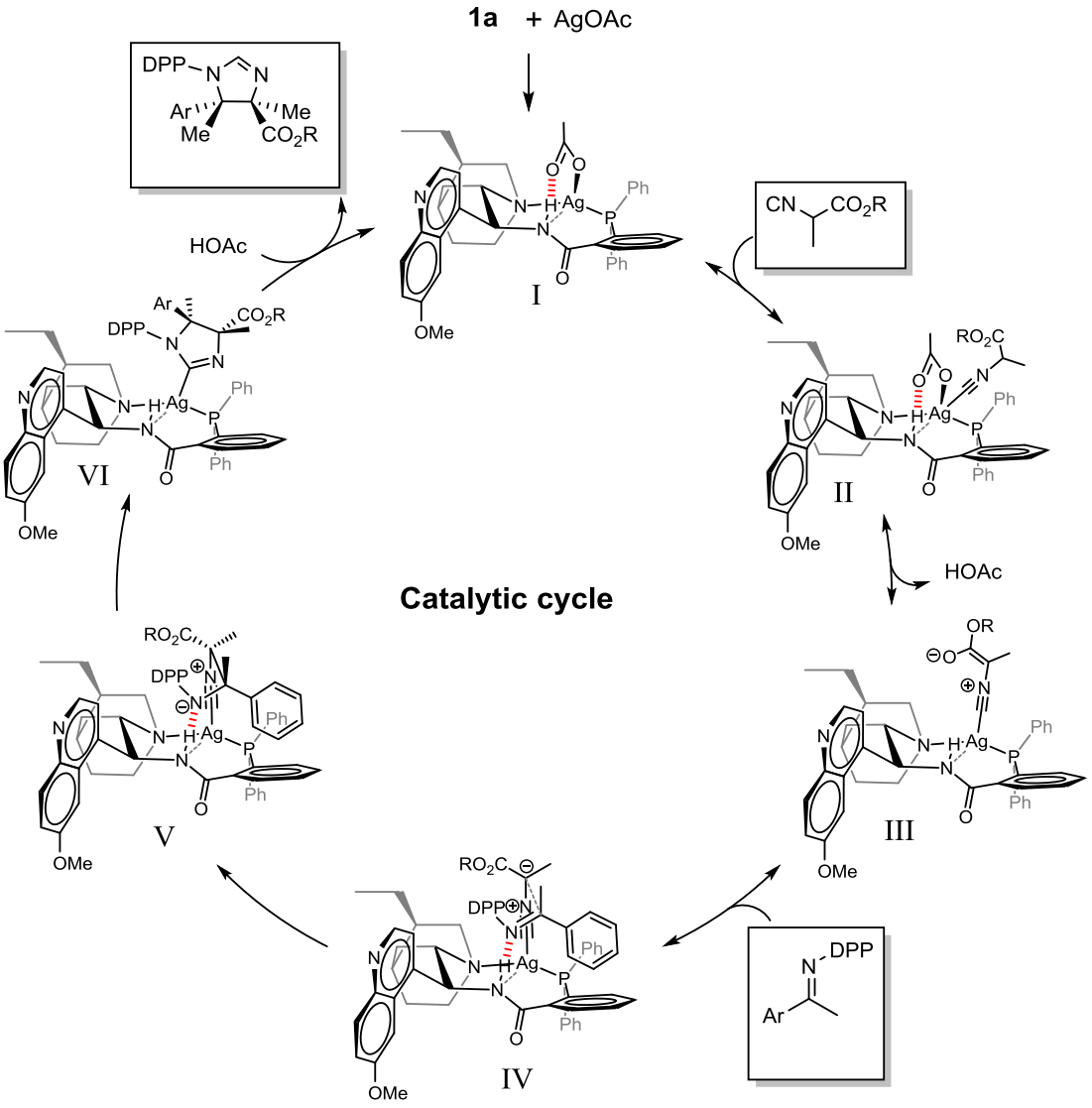
6.2 ^{31}P-NMR spectra



^{31}P NMR at 253 K (including proposed binding mode) of 1) Free ligand **1a**: $\delta^{31}P$ = -10.4; 2) **1a**·AgOAc: $\delta^{31}P$ = 3.6, $^{1}J^{107}Ag^{31}P$ = 597 Hz; 3) Ligand 1 +1 eq of AgOAc + 1 eq. of methylisocyanoacetate: $\delta^{31}P$ = 2.0, $^{1}J^{107}Ag^{31}P$ = 537 Hz.

^{31}P NMR experiments indicated that when **1a** and AgOAc are mixed in a 1:1 ratio, quantitatively binding the silver(I) in solution at –20 °C is observed represented by a downfield shift of the phosphorous signal which is split by ^{1}J coupling to the two silver isotopes which have marginally different gyromagnetic ratios and exist in roughly equal natural abundance ($^{1}J^{107}Ag^{31}P$ = 597 Hz & $^{1}J^{109}Ag^{31}P$ = 690 Hz) resulting in an apparent double doublet (inset 2, Figure 1.3). Subsequent addition of methyl isocyanoacetate saw a second shift, upfield, with significant broadening of the ^{31}P signal whilst still indicating the phosphorous was bound to silver (inset 3, Figure 1.3). This may be as a result of the isonitrile unit binding to silver and concomitantly creating a more dynamic species which is not resolvable on the NMR timescale at that temperature. At –50 °C it was possible to marginally sharpen the phosphorous signals but resolution of the two $^{1}J^{107/109}Ag^{31}P$ couplings was not achieved.

7 Proposed reaction mechanism



8 X-Ray data for the crystal of complex 1a·AgOAc (CCDC 1493438)

Crystal growing of complex 1a·AgOAc

A 1:1 mixture of amino phosphine **1a** and AgOAc was dissolved in degassed CH_2Cl_2 and filtered through a microfilter to remove residual silver source. This mixture was added to a vial with a small hole in the lid to allow slow diffusion. This vial was placed within a Schlenk tube, hexane was added between the vial and the Schlenk tube, and the Schlenk tube was evacuated and purged with Argon three times. After 4 weeks in the dark at room temperature, several brown crystals of X-ray quality were present on the surface of the glass.

Single crystal X-ray diffraction data were collected at 150 K with an Oxford Diffraction SuperNova diffractometer and processed with CrysAlisPro as per the SI (CIF). The structure was solved with SIR92[16] and refined with CRYSTALS.[17] Full crystallographic data (in CIF format) is available as ESI and can be obtained from The Cambridge Crystallographic Data Centre at www.ccdc.cam.ac.uk/data_request/cif (reference number CCDC 1493438).

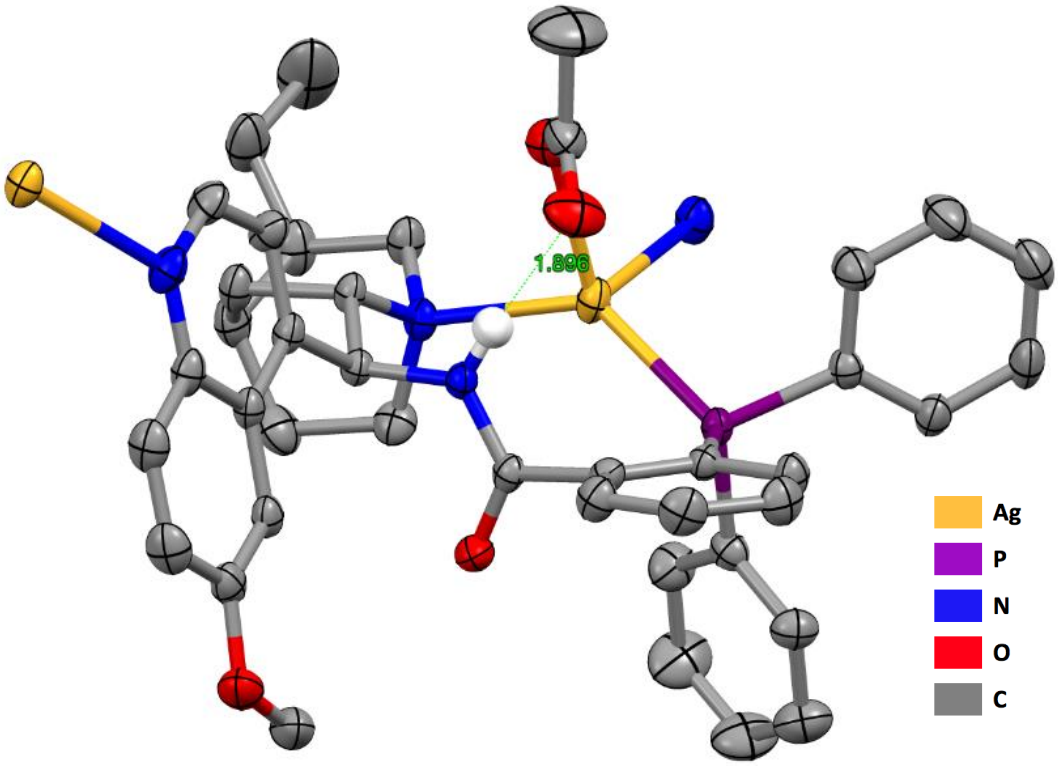


Figure S1. Crystal structure of complex **1a**·AgOAc with highlighted intramolecular H-bond.

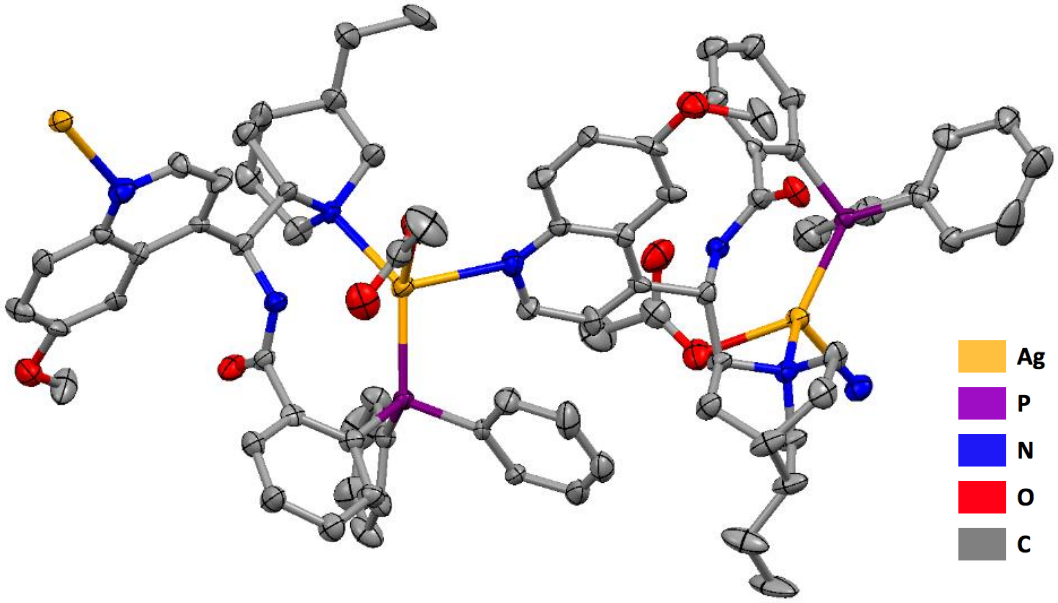


Figure S2. Crystal structure of complex **1a**·AgOAc (dimer indicating the polymeric chain structure in the solid state).

Table 1. Crystal data and structure refinement for 6531.

Identification code	6531	
Empirical formula	C42.98 H46.96 Ag1 Cl3.96 N3 O4 P1	
Formula weight	948.89	
Temperature	150 K	
Wavelength	1.54180 Å	
Crystal system	Orthorhombic	
Space group	P 21 21 21	
Unit cell dimensions	a = 14.0180(1) Å	α= 90°.
	b = 17.0222(1) Å	β= 90°.
	c = 19.3743(1) Å	γ = 90°.
Volume	4623.04(5) $Å^3$	
Z	4	
Density (calculated)	1.363 Mg/m^3	
Absorption coefficient	6.267 mm^{-1}	
F(000)	1948.787	
Crystal size	0.38 x 0.15 x 0.10 mm^3	
Theta range for data collection	3.456 to 76.352°.	
Index ranges	-17<=h<=17, -21<=k<=21, -23<=l<=24	
Reflections collected	124114	
Independent reflections	9674 [R(int) = 0.051]	
Completeness to theta = 76.352°	99.9 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.53 and 0.30	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	9636 / 73 / 547	
Goodness-of-fit on F^2	1.0014	
Final R indices [I>2sigma(I)]	R1 = 0.0270, wR2 = 0.0709	
R indices (all data)	R1 = 0.0276, wR2 = 0.0715	
Absolute structure parameter	-0.017(4)	
Largest diff. peak and hole	0.69 and -0.48 e.$Å^{-3}$	

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for 6531. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
Ag(1)	7055(1)	4725(1)	5248(1)	28
P(1)	6063(1)	3643(1)	4918(1)	22
C(1)	6315(2)	5246(1)	6952(1)	22
C(2)	6628(2)	5165(1)	7705(1)	25
C(3)	7558(2)	5265(2)	7902(1)	30
C(4)	7820(2)	5156(2)	8599(1)	33
N(5)	7226(2)	4957(1)	9091(1)	32
C(6)	6295(2)	4833(1)	8907(1)	29
C(7)	5642(2)	4588(2)	9424(1)	35
C(8)	4713(2)	4439(2)	9267(1)	37
C(9)	4385(2)	4537(1)	8583(1)	30
C(10)	4984(2)	4776(1)	8069(1)	26
C(11)	5959(2)	4925(1)	8217(1)	24
O(12)	3429(1)	4394(1)	8492(1)	38
C(13)	3051(2)	4554(2)	7826(2)	46
N(14)	6676(1)	5900(1)	5815(1)	24
C(15)	6923(2)	5847(1)	6561(1)	23
C(16)	6829(2)	6664(1)	6909(1)	30
C(17)	6431(2)	7254(2)	6383(1)	35
C(18)	7115(2)	7340(1)	5775(1)	37
C(19)	7320(2)	6495(1)	5504(1)	31
C(20)	5676(2)	6171(2)	5717(1)	32
C(21)	5480(2)	6941(2)	6124(2)	41
C(22)	8021(3)	7782(2)	5948(2)	55
C(23)	8646(4)	7930(3)	5317(3)	85
N(24)	6325(1)	4452(1)	6660(1)	22
C(25)	5527(2)	4088(1)	6447(1)	22
O(26)	4735(1)	4395(1)	6417(1)	33
C(27)	5827(2)	2947(1)	5618(1)	23
C(28)	5646(2)	3227(1)	6284(1)	23
C(29)	5504(2)	2702(2)	6826(1)	32

C(30)	5518(2)	1903(2)	6707(1)	36
C(31)	5675(2)	1616(2)	6045(2)	35
C(32)	5841(2)	2135(1)	5508(1)	29
C(33)	4891(2)	3804(1)	4537(1)	27
C(34)	4622(2)	4569(2)	4383(2)	38
C(35)	3743(3)	4716(2)	4087(2)	58
C(36)	3126(2)	4108(2)	3940(2)	55
C(37)	3388(2)	3342(2)	4087(2)	44
C(38)	4264(2)	3192(2)	4391(1)	33
C(39)	6709(2)	3045(1)	4295(1)	24
C(40)	6339(2)	2759(2)	3678(1)	31
C(41)	6911(2)	2309(2)	3248(1)	39
C(42)	7843(2)	2158(2)	3414(2)	43
C(43)	8215(2)	2442(2)	4022(2)	47
C(44)	7662(2)	2889(2)	4457(1)	37
C(45)	8646(2)	4095(2)	6237(2)	38
O(46)	8520(1)	4664(1)	5848(1)	43
O(47)	8012(2)	3654(1)	6468(1)	50
C(48)	9662(3)	3916(3)	6479(3)	78
C(51)	4858(3)	4051(2)	1394(2)	69
Cl(52)	5127(2)	3829(2)	2231(1)	122
Cl(53)	4648(3)	3308(2)	865(2)	74
Cl(54)	3676(3)	4182(4)	1189(3)	97
C(55)	2088(2)	5060(4)	787(4)	76
Cl(56)	3183(1)	5398(2)	525(2)	96
Cl(57)	2066(2)	4219(1)	1280(1)	75
C(58)	3219(4)	2074(4)	1990(2)	120
Cl(59)	2169(2)	2064(1)	1585(1)	116
Cl(60)	4147(2)	1624(2)	1590(2)	187

Table 3. Bond lengths [Å] and angles [°] for 6531.

Ag(1)-N(5)#1	2.5164(19)	N(14)-C(19)	1.486(3)
Ag(1)-P(1)	2.3944(6)	N(14)-C(20)	1.488(3)
Ag(1)-N(14)	2.3419(19)	C(15)-C(16)	1.553(3)
Ag(1)-N(24)	2.9571(18)	C(15)-H(151)	0.967
Ag(1)-O(46)	2.361(2)	C(16)-C(17)	1.536(4)
P(1)-C(27)	1.831(2)	C(16)-H(161)	0.976
P(1)-C(33)	1.823(2)	C(16)-H(162)	0.960
P(1)-C(39)	1.820(2)	C(17)-C(18)	1.526(4)
C(1)-C(2)	1.528(3)	C(17)-C(21)	1.520(4)
C(1)-C(15)	1.532(3)	C(17)-H(171)	0.977
C(1)-N(24)	1.466(3)	C(18)-C(19)	1.558(3)
C(1)-H(11)	0.966	C(18)-C(22)	1.513(5)
C(2)-C(3)	1.370(3)	C(18)-H(181)	0.981
C(2)-C(11)	1.425(3)	C(19)-H(191)	0.969
C(3)-C(4)	1.410(3)	C(19)-H(192)	0.998
C(3)-H(31)	0.908	C(20)-C(21)	1.554(4)
C(4)-N(5)	1.311(3)	C(20)-H(201)	0.979
C(4)-H(41)	0.949	C(20)-H(202)	0.945
N(5)-C(6)	1.370(3)	C(21)-H(211)	0.959
C(6)-C(7)	1.418(3)	C(21)-H(212)	0.936
C(6)-C(11)	1.425(3)	C(22)-C(23)	1.525(5)
C(7)-C(8)	1.362(4)	C(22)-H(221)	0.995
C(7)-H(71)	0.941	C(22)-H(222)	0.972
C(8)-C(9)	1.412(4)	C(23)-H(233)	0.957
C(8)-H(81)	0.907	C(23)-H(232)	0.954
C(9)-C(10)	1.365(3)	C(23)-H(231)	0.976
C(9)-O(12)	1.373(3)	N(24)-C(25)	1.343(3)
C(10)-C(11)	1.420(3)	N(24)-H(241)	0.861
C(10)-H(101)	0.927	C(25)-O(26)	1.229(3)
O(12)-C(13)	1.423(4)	C(25)-C(28)	1.509(3)
C(13)-H(133)	0.959	C(27)-C(28)	1.399(3)
C(13)-H(132)	0.971	C(27)-C(32)	1.398(3)
C(13)-H(131)	0.952	C(28)-C(29)	1.393(3)
N(14)-C(15)	1.490(3)	C(29)-C(30)	1.379(4)

C(29)-H(291)	0.946	C(51)-H(511)	0.950
C(30)-C(31)	1.390(4)	C(51)-H(512)	0.950
C(30)-H(301)	0.934	C(51)-Cl(54)	1.719(5)
C(31)-C(32)	1.384(4)	C(51)-H(513)	0.950
C(31)-H(311)	0.940	C(51)-H(514)	0.950
C(32)-H(321)	0.930	C(55)-Cl(56)	1.716(5)
C(33)-C(34)	1.389(3)	C(55)-Cl(57)	1.721(5)
C(33)-C(38)	1.391(4)	C(55)-H(551)	0.950
C(34)-C(35)	1.382(4)	C(55)-H(552)	0.950
C(34)-H(341)	0.940	C(58)-Cl(59)	1.668(5)
C(35)-C(36)	1.379(5)	C(58)-Cl(60)	1.696(5)
C(35)-H(351)	0.950	C(58)-H(581)	0.950
C(36)-C(37)	1.384(5)	C(58)-H(582)	0.950
C(36)-H(361)	0.914		
C(37)-C(38)	1.386(4)	N(5)#1-Ag(1)-P(1)	99.22(5)
C(37)-H(371)	0.934	N(5)#1-Ag(1)-N(14)	108.93(7)
C(38)-H(381)	0.939	P(1)-Ag(1)-N(14)	130.51(5)
C(39)-C(40)	1.392(3)	N(5)#1-Ag(1)-N(24)	175.06(6)
C(39)-C(44)	1.399(4)	P(1)-Ag(1)-N(24)	85.69(4)
C(40)-C(41)	1.388(4)	N(14)-Ag(1)-N(24)	67.81(6)
C(40)-H(401)	0.958	N(5)#1-Ag(1)-O(46)	95.73(7)
C(41)-C(42)	1.369(5)	P(1)-Ag(1)-O(46)	127.05(6)
C(41)-H(411)	0.944	N(14)-Ag(1)-O(46)	90.27(7)
C(42)-C(43)	1.377(5)	N(24)-Ag(1)-O(46)	80.74(6)
C(42)-H(421)	0.917	Ag(1)-P(1)-C(27)	113.94(7)
C(43)-C(44)	1.374(4)	Ag(1)-P(1)-C(33)	121.09(8)
C(43)-H(431)	0.931	C(27)-P(1)-C(33)	103.55(10)
C(44)-H(441)	0.935	Ag(1)-P(1)-C(39)	108.57(8)
C(45)-O(46)	1.240(4)	C(27)-P(1)-C(39)	102.63(10)
C(45)-O(47)	1.248(4)	C(33)-P(1)-C(39)	105.24(11)
C(45)-C(48)	1.529(4)	C(2)-C(1)-C(15)	111.92(18)
C(48)-H(482)	0.973	C(2)-C(1)-N(24)	106.40(18)
C(48)-H(481)	0.972	C(15)-C(1)-N(24)	114.76(17)
C(48)-H(483)	0.953	C(2)-C(1)-H(11)	108.9
C(51)-Cl(52)	1.706(3)	C(15)-C(1)-H(11)	108.0
C(51)-Cl(53)	1.655(4)	N(24)-C(1)-H(11)	106.6

C(1)-C(2)-C(3)	121.9(2)	H(132)-C(13)-H(131)	109.1
C(1)-C(2)-C(11)	120.1(2)	Ag(1)-N(14)-C(15)	110.48(13)
C(3)-C(2)-C(11)	117.8(2)	Ag(1)-N(14)-C(19)	104.75(14)
C(2)-C(3)-C(4)	119.9(2)	C(15)-N(14)-C(19)	107.05(18)
C(2)-C(3)-H(31)	121.0	Ag(1)-N(14)-C(20)	114.81(15)
C(4)-C(3)-H(31)	119.1	C(15)-N(14)-C(20)	111.23(18)
C(3)-C(4)-N(5)	124.5(2)	C(19)-N(14)-C(20)	108.00(19)
C(3)-C(4)-H(41)	119.5	C(1)-C(15)-N(14)	113.05(17)
N(5)-C(4)-H(41)	116.0	C(1)-C(15)-C(16)	109.62(18)
Ag(1)#2-N(5)-C(4)	109.83(16)	N(14)-C(15)-C(16)	110.31(18)
Ag(1)#2-N(5)-C(6)	130.28(16)	C(1)-C(15)-H(151)	106.8
C(4)-N(5)-C(6)	117.0(2)	N(14)-C(15)-H(151)	103.8
N(5)-C(6)-C(7)	118.4(2)	C(16)-C(15)-H(151)	113.2
N(5)-C(6)-C(11)	122.8(2)	C(15)-C(16)-C(17)	109.21(19)
C(7)-C(6)-C(11)	118.8(2)	C(15)-C(16)-H(161)	109.5
C(6)-C(7)-C(8)	121.0(2)	C(17)-C(16)-H(161)	110.5
C(6)-C(7)-H(71)	117.5	C(15)-C(16)-H(162)	109.5
C(8)-C(7)-H(71)	121.5	C(17)-C(16)-H(162)	109.7
C(7)-C(8)-C(9)	119.9(2)	H(161)-C(16)-H(162)	108.4
C(7)-C(8)-H(81)	120.5	C(16)-C(17)-C(18)	110.3(2)
C(9)-C(8)-H(81)	119.6	C(16)-C(17)-C(21)	108.0(2)
C(8)-C(9)-C(10)	121.3(2)	C(18)-C(17)-C(21)	109.3(2)
C(8)-C(9)-O(12)	114.7(2)	C(16)-C(17)-H(171)	109.3
C(10)-C(9)-O(12)	124.0(2)	C(18)-C(17)-H(171)	109.8
C(9)-C(10)-C(11)	119.9(2)	C(21)-C(17)-H(171)	110.2
C(9)-C(10)-H(101)	119.4	C(17)-C(18)-C(19)	106.71(19)
C(11)-C(10)-H(101)	120.7	C(17)-C(18)-C(22)	113.8(2)
C(6)-C(11)-C(2)	117.9(2)	C(19)-C(18)-C(22)	112.3(3)
C(6)-C(11)-C(10)	119.2(2)	C(17)-C(18)-H(181)	107.6
C(2)-C(11)-C(10)	122.9(2)	C(19)-C(18)-H(181)	108.9
C(9)-O(12)-C(13)	116.6(2)	C(22)-C(18)-H(181)	107.3
O(12)-C(13)-H(133)	107.8	C(18)-C(19)-N(14)	112.4(2)
O(12)-C(13)-H(132)	110.7	C(18)-C(19)-H(191)	110.0
H(133)-C(13)-H(132)	107.5	N(14)-C(19)-H(191)	106.3
O(12)-C(13)-H(131)	112.0	C(18)-C(19)-H(192)	110.2
H(133)-C(13)-H(131)	109.6	N(14)-C(19)-H(192)	108.9

H(191)-C(19)-H(192)	109.0	C(28)-C(27)-C(32)	118.7(2)
N(14)-C(20)-C(21)	111.3(2)	C(25)-C(28)-C(27)	123.0(2)
N(14)-C(20)-H(201)	109.2	C(25)-C(28)-C(29)	116.7(2)
C(21)-C(20)-H(201)	110.6	C(27)-C(28)-C(29)	120.2(2)
N(14)-C(20)-H(202)	107.1	C(28)-C(29)-C(30)	120.3(2)
C(21)-C(20)-H(202)	111.2	C(28)-C(29)-H(291)	118.8
H(201)-C(20)-H(202)	107.3	C(30)-C(29)-H(291)	120.9
C(20)-C(21)-C(17)	108.0(2)	C(29)-C(30)-C(31)	120.2(2)
C(20)-C(21)-H(211)	110.9	C(29)-C(30)-H(301)	120.9
C(17)-C(21)-H(211)	111.7	C(31)-C(30)-H(301)	118.8
C(20)-C(21)-H(212)	109.3	C(30)-C(31)-C(32)	119.7(2)
C(17)-C(21)-H(212)	108.7	C(30)-C(31)-H(311)	120.3
H(211)-C(21)-H(212)	108.3	C(32)-C(31)-H(311)	120.0
C(18)-C(22)-C(23)	112.7(3)	C(27)-C(32)-C(31)	120.9(2)
C(18)-C(22)-H(221)	109.4	C(27)-C(32)-H(321)	119.9
C(23)-C(22)-H(221)	108.4	C(31)-C(32)-H(321)	119.2
C(18)-C(22)-H(222)	107.0	P(1)-C(33)-C(34)	118.2(2)
C(23)-C(22)-H(222)	110.7	P(1)-C(33)-C(38)	122.64(19)
H(221)-C(22)-H(222)	108.5	C(34)-C(33)-C(38)	119.1(2)
C(22)-C(23)-H(233)	107.5	C(33)-C(34)-C(35)	120.1(3)
C(22)-C(23)-H(232)	111.1	C(33)-C(34)-H(341)	119.1
H(233)-C(23)-H(232)	109.1	C(35)-C(34)-H(341)	120.8
C(22)-C(23)-H(231)	110.9	C(34)-C(35)-C(36)	120.6(3)
H(233)-C(23)-H(231)	107.8	C(34)-C(35)-H(351)	120.7
H(232)-C(23)-H(231)	110.3	C(36)-C(35)-H(351)	118.7
C(1)-N(24)-Ag(1)	102.46(12)	C(35)-C(36)-C(37)	120.0(3)
C(1)-N(24)-C(25)	122.44(19)	C(35)-C(36)-H(361)	120.0
Ag(1)-N(24)-C(25)	94.42(13)	C(37)-C(36)-H(361)	120.0
C(1)-N(24)-H(241)	118.8	C(36)-C(37)-C(38)	119.6(3)
Ag(1)-N(24)-H(241)	74.7	C(36)-C(37)-H(371)	120.0
C(25)-N(24)-H(241)	118.7	C(38)-C(37)-H(371)	120.3
N(24)-C(25)-O(26)	124.8(2)	C(33)-C(38)-C(37)	120.6(3)
N(24)-C(25)-C(28)	114.87(19)	C(33)-C(38)-H(381)	119.1
O(26)-C(25)-C(28)	120.2(2)	C(37)-C(38)-H(381)	120.2
P(1)-C(27)-C(28)	119.62(17)	P(1)-C(39)-C(40)	125.48(19)
P(1)-C(27)-C(32)	121.67(18)	P(1)-C(39)-C(44)	115.64(19)

C(40)-C(39)-C(44)	118.9(2)	H(482)-C(48)-H(481)	109.4
C(39)-C(40)-C(41)	119.5(3)	C(45)-C(48)-H(483)	109.5
C(39)-C(40)-H(401)	119.2	H(482)-C(48)-H(483)	108.2
C(41)-C(40)-H(401)	121.2	H(481)-C(48)-H(483)	108.0
C(40)-C(41)-C(42)	120.9(3)	Cl(53)-C(51)-H(511)	107.7
C(40)-C(41)-H(411)	119.2	Cl(53)-C(51)-H(512)	107.3
C(42)-C(41)-H(411)	119.9	H(511)-C(51)-H(512)	109.5
C(41)-C(42)-C(43)	119.8(3)	Cl(54)-C(51)-H(513)	107.7
C(41)-C(42)-H(421)	119.9	Cl(54)-C(51)-H(514)	107.3
C(43)-C(42)-H(421)	120.2	H(513)-C(51)-H(514)	109.5
C(42)-C(43)-C(44)	120.4(3)	Cl(56)-C(55)-Cl(57)	117.36(7)
C(42)-C(43)-H(431)	120.9	Cl(56)-C(55)-H(551)	107.5
C(44)-C(43)-H(431)	118.8	Cl(57)-C(55)-H(551)	107.5
C(39)-C(44)-C(43)	120.4(3)	Cl(56)-C(55)-H(552)	107.5
C(39)-C(44)-H(441)	118.8	Cl(57)-C(55)-H(552)	107.5
C(43)-C(44)-H(441)	120.7	H(551)-C(55)-H(552)	109.5
O(46)-C(45)-O(47)	125.9(3)	Cl(59)-C(58)-Cl(60)	117.20(7)
O(46)-C(45)-C(48)	118.4(3)	Cl(59)-C(58)-H(581)	107.5
O(47)-C(45)-C(48)	115.7(3)	Cl(60)-C(58)-H(581)	107.5
Ag(1)-O(46)-C(45)	117.24(19)	Cl(59)-C(58)-H(582)	107.5
C(45)-C(48)-H(482)	112.8	Cl(60)-C(58)-H(582)	107.5
C(45)-C(48)-H(481)	108.8	H(581)-C(58)-H(582)	109.5

Symmetry transformations used to generate equivalent atoms:

#1 -x+3/2,-y+1,z-1/2 #2 -x+3/2,-y+1,z+1/2

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for 6531. The anisotropic displacement factor exponent takes the form: $-2\pi^2[\ h^2\ a^{*2}U^{11} + \ldots + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
Ag(1)	39(1)	25(1)	20(1)	-2(1)	2(1)	-6(1)
P(1)	26(1)	20(1)	19(1)	-1(1)	2(1)	0(1)
C(1)	26(1)	21(1)	20(1)	-2(1)	0(1)	-1(1)
C(2)	33(1)	23(1)	19(1)	-4(1)	1(1)	-4(1)
C(3)	32(1)	38(1)	21(1)	0(1)	1(1)	-10(1)
C(4)	38(1)	38(1)	24(1)	-3(1)	-6(1)	-6(1)
N(5)	42(1)	33(1)	21(1)	0(1)	-5(1)	-6(1)
C(6)	42(1)	21(1)	23(1)	-1(1)	1(1)	-4(1)
C(7)	50(1)	30(1)	23(1)	3(1)	4(1)	-5(1)
C(8)	49(2)	31(1)	31(1)	6(1)	12(1)	-4(1)
C(9)	33(1)	21(1)	36(1)	-4(1)	7(1)	-3(1)
C(10)	33(1)	19(1)	25(1)	-4(1)	4(1)	-2(1)
C(11)	33(1)	19(1)	21(1)	-3(1)	3(1)	-2(1)
O(12)	32(1)	38(1)	44(1)	-4(1)	9(1)	-7(1)
C(13)	33(1)	60(2)	46(2)	-18(1)	5(1)	-8(1)
N(14)	33(1)	22(1)	19(1)	1(1)	1(1)	-2(1)
C(15)	30(1)	21(1)	18(1)	-2(1)	0(1)	-3(1)
C(16)	42(1)	23(1)	26(1)	-4(1)	5(1)	-7(1)
C(17)	47(2)	23(1)	36(1)	-4(1)	7(1)	1(1)
C(18)	56(2)	22(1)	33(1)	2(1)	8(1)	-3(1)
C(19)	44(1)	23(1)	25(1)	0(1)	6(1)	-7(1)
C(20)	37(1)	31(1)	29(1)	3(1)	-6(1)	3(1)
C(21)	43(2)	36(1)	46(2)	-2(1)	2(1)	12(1)
C(22)	70(2)	41(2)	56(2)	-15(1)	23(2)	-25(2)
C(23)	100(3)	76(3)	80(3)	-14(2)	44(3)	-50(3)
N(24)	24(1)	21(1)	19(1)	-2(1)	1(1)	-1(1)
C(25)	28(1)	23(1)	16(1)	-1(1)	1(1)	-3(1)
O(26)	25(1)	35(1)	39(1)	-10(1)	-4(1)	1(1)
C(27)	24(1)	22(1)	24(1)	-2(1)	1(1)	-1(1)
C(28)	23(1)	25(1)	22(1)	0(1)	-2(1)	-4(1)
C(29)	38(1)	32(1)	25(1)	1(1)	1(1)	-5(1)

C(30)	44(1)	31(1)	32(1)	10(1)	4(1)	-6(1)
C(31)	43(1)	22(1)	39(1)	3(1)	2(1)	-2(1)
C(32)	36(1)	20(1)	30(1)	-3(1)	3(1)	-2(1)
C(33)	28(1)	30(1)	23(1)	2(1)	3(1)	2(1)
C(34)	42(1)	28(1)	45(2)	5(1)	-8(1)	3(1)
C(35)	60(2)	40(2)	74(2)	14(2)	-21(2)	12(2)
C(36)	41(2)	56(2)	67(2)	18(2)	-17(2)	5(1)
C(37)	35(1)	49(2)	49(2)	10(1)	-5(1)	-7(1)
C(38)	30(1)	32(1)	37(1)	6(1)	0(1)	-1(1)
C(39)	29(1)	22(1)	21(1)	0(1)	4(1)	-1(1)
C(40)	35(1)	30(1)	28(1)	-6(1)	4(1)	-7(1)
C(41)	54(2)	35(1)	29(1)	-11(1)	10(1)	-10(1)
C(42)	46(2)	39(1)	44(2)	-7(1)	17(1)	6(1)
C(43)	36(2)	57(2)	47(2)	-6(1)	5(1)	14(1)
C(44)	34(1)	46(2)	31(1)	-5(1)	0(1)	6(1)
C(45)	33(1)	39(1)	41(2)	-8(1)	1(1)	9(1)
O(46)	41(1)	50(1)	38(1)	5(1)	1(1)	-1(1)
O(47)	40(1)	42(1)	69(1)	14(1)	1(1)	9(1)
C(48)	40(2)	78(3)	115(4)	13(3)	-14(2)	15(2)
C(51)	63(3)	79(4)	66(3)	18(2)	-7(3)	-13(3)
Cl(52)	132(2)	151(3)	83(1)	48(2)	-49(1)	-86(2)
Cl(53)	94(2)	59(2)	69(2)	17(1)	16(2)	-6(1)
Cl(54)	62(2)	130(5)	100(4)	45(3)	-9(2)	-21(2)
C(55)	53(3)	109(5)	66(4)	17(4)	15(4)	9(3)
Cl(56)	51(1)	97(2)	139(2)	27(2)	10(1)	6(1)
Cl(57)	71(1)	69(1)	85(1)	-5(1)	2(1)	9(1)
C(58)	170(4)	115(5)	76(4)	31(4)	11(3)	-34(4)
Cl(59)	162(2)	106(1)	80(1)	-17(1)	16(1)	-35(1)
Cl(60)	151(2)	261(4)	150(2)	-55(2)	65(2)	-90(2)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for 6531.

	x	y	z	U(eq)
H(11)	5660	5423	6940	27
H(31)	8010	5412	7593	37
H(41)	8467	5219	8731	39
H(71)	5872	4547	9879	42
H(81)	4298	4287	9600	43
H(101)	4750	4831	7624	31
H(133)	2388	4414	7830	68
H(132)	3091	5111	7722	68
H(131)	3371	4267	7474	69
H(151)	7569	5648	6560	26
H(161)	7452	6835	7076	37
H(162)	6404	6627	7296	38
H(171)	6342	7763	6607	42
H(181)	6784	7638	5414	45
H(191)	7963	6339	5626	36
H(192)	7251	6478	4991	37
H(201)	5238	5755	5864	38
H(202)	5584	6246	5238	38
H(211)	5043	6849	6496	51
H(212)	5210	7314	5827	50
H(221)	7854	8298	6157	66
H(222)	8362	7472	6290	66
H(233)	9186	8229	5466	128
H(232)	8309	8220	4974	128
H(231)	8879	7436	5125	128
H(291)	5382	2904	7272	38
H(301)	5398	1547	7063	43
H(311)	5668	1072	5961	41
H(321)	5970	1938	5070	34
H(341)	5039	4983	4492	47

H(351)	3542	5239	3996	70
H(361)	2548	4209	3741	66
H(371)	2976	2928	3979	53
H(381)	4437	2677	4510	40
H(401)	5699	2893	3550	38
H(411)	6655	2113	2831	47
H(421)	8211	1858	3126	53
H(431)	8844	2337	4147	56
H(441)	7918	3098	4863	44
H(482)	9758	3364	6589	117
H(481)	9799	4234	6884	117
H(483)	10103	4058	6126	117
H(241)	6858	4201	6640	26
H(511)	5376	4343	1210	83
H(512)	4302	4369	1399	83
H(513)	5187	4521	1278	83
H(514)	5090	3632	1117	83
H(551)	1796	5466	1050	92
H(552)	1720	4962	385	92
H(581)	3392	2608	2058	145
H(582)	3134	1826	2424	145

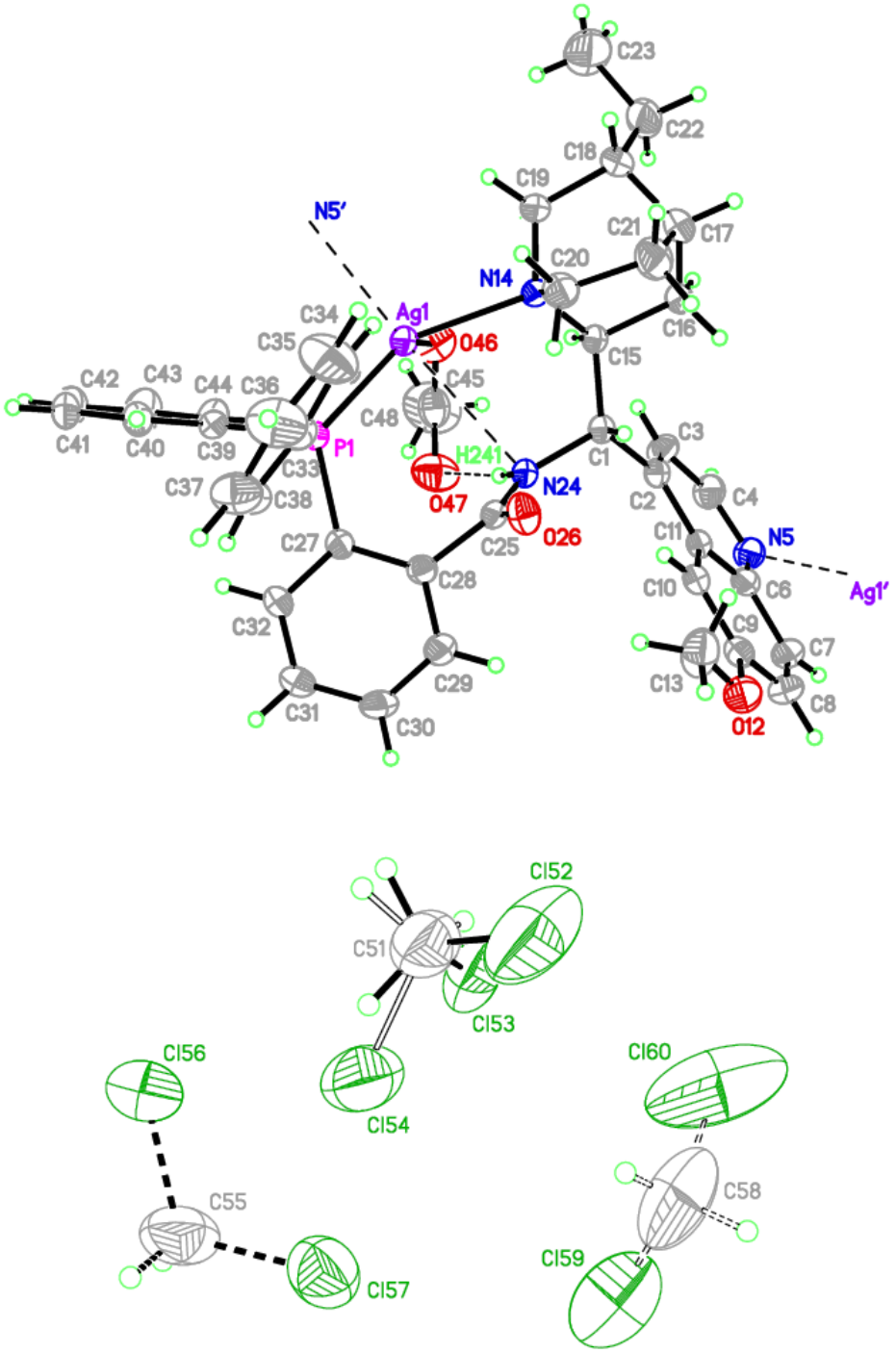
Table 6. Hydrogen bonds for 6531 [Å and °].

D-H...A	d(D-H)	d(H...A)	d(D...A)	<(DHA)
C(7)-H(71)...O(46)#2	0.94	2.46	3.258(4)	142
C(10)-H(101)...O(26)	0.93	2.45	3.284(4)	149
C(15)-H(151)...O(46)	0.97	2.55	3.312(4)	136
N(24)-H(241)...O(47)	0.86	1.90	2.752(4)	172
C(51)-H(511)...O(46)#1	0.95	2.40	3.328(4)	167
C(51)-H(513)...O(46)#1	0.95	2.43	3.328(4)	157
C(55)-H(551)...O(26)#3	0.95	2.27	2.980(4)	131
C(58)-H(582)...O(47)#4	0.95	2.30	3.248(4)	174

Symmetry transformations used to generate equivalent atoms:

#1 -x+3/2,-y+1,z-1/2 #2 -x+3/2,-y+1,z+1/2 #3 -x+1/2,-y+1,z-1/2

#4 x-1/2,-y+1/2,-z+1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C22
C18
C19
N5'
C21
C17
C20
N14
Ag1
C34
C35
046
C16
C15
C42
C43
C44
C36
C45
C48
C41
C40
C39
P1
H241
C1
C3
C33
N24
C2
C4
C37
C38
047
026
C25
C11
N5
C27
C10
C6
Ag1'
C28
C32
C9
C7
C29
C13
C8
C31
C30
012
Cl52
C51
Cl53
Cl56
Cl54
Cl60
C58
C55
Cl59
Cl57