Tunable asymmetric catalysis through ligand stacking in chiral rigid rods.

Matthieu Raynal, François Portier, Piet W. N. M. van Leeuwen and Laurent Bouteiller.*

SUPPORTING INFORMATION

General Procedures.

All manipulations for the synthesis and reactions were performed under argon using standard Schlenk–techniques unless otherwise stated. Solvents were obtained from commercial suppliers and dried with a solvent purification system (SPS) of IT–Inc. Triethylamine was distilled over CaH_2 and stored over 4Å molecular sieves. All other chemical were used as received from commercial suppliers. 3-diphenylphosphino aniline[1] and *N*-(ethyl)-1-(*S*)-methyl-heptylamine[2], $[Rh(cod)_2]BF_4$,[3] $[Rh(cod)_2]BAr_F$[4] and **^{H}BTA(*S*)**[5] were prepared according to published procedures. Dimethyl itaconate (**1**) and $[Rh(nbd)_2]BF_4$ were provided by Aldrich and Alfa Aesar respectively and used as received for the hydrogenation reactions. (*S*)-2-aminooctane and (*R*)-2-aminooctane were provided by Aldrich and Alfa Aesar respectively (ee>99% in both cases). The preparation and characterization of **^{H}BTA^{PPh2}(*S*)** will be described elsewhere.

All NMR spectra were obtained on a Bruker AVANCE 400 (^{1}H, 400 MHz; ^{13}C, 100.60 MHz; ^{31}P, 161.92 MHz) spectrometer and a Bruker AVANCE 300 (^{1}H, 300 MHz; ^{13}C, 75.43 MHz; ^{31}P, 121.44 MHz) spectrometer. Proton spectra are referenced to internal $Si(CH_3)_4$ (0 ppm) or residual $CHCl_3$ (7.27 ppm). $^{13}C\{^1H\}$ spectra are referenced to $CDCl_3$ (77.0 ppm). $^{31}P\{^1H\}$ spectra are referenced to 85 % H_3PO_4 as external standard. Assignments are based on DEPT135, COSY, HMQC, HMBC and $^1H\{^{31}P\}$ experiments. The aromatic protons are referred to as: (i) "BTA ring" (aromatic protons which belong to the benzene-1,3,5-tricarboxamide moiety), (ii) "CH arom." (protons belonging to the aryl amide moiety), and (iii) "PPh_2" (the aromatic protons which are not encompassed by the first two categories).

Mass spectra and high resolution mass spectra were obtained on a Bruker Autoflex MALDI–TOF Mass Spectrometer.

IR spectra were recorded on a Nicolet iS10 apparatus. For IR analysis performed in solution, cells with an optical pathlength of 0.3 cm were employed and spectroscopic grade solvents were employed. For IR analysis of solids, a small amount of the compound dissolved in CH_2Cl_2 was dropped and let evaporated on a KBr lens (s = strong, m = medium, br = broad, w = weak; only the more characteristic bands are reported).

Circular dichroism measurements were performed on a Jasco J-815 spectropolarimeter at 20 °C where the sensitivity, time constant and scan rate were chosen appropriately. Cells with an optimal path length of 0.1 cm or 0.5 cm were employed depending on the compound analyzed and spectroscopic grade solvents were employed. Solutions in decaline were prepared at room temperature under stirring at least 1 day prior to use. UV/Vis spectra were from a Varian UV/Vis spectrophotometer Cary-300 at 20 °C. Cells with an optimal path length of 0.5 cm and spectroscopic grade solvents were employed.

Small-angle neutron scattering measurements were made at the LLB (Saclay, France) on the Pace instrument, at two distance-wavelength combinations to cover the 4×10^{-3} to 0.2Å $^{-1}$ q-range, where the Scattering vector q is defined as usual, assuming elastic scattering, as $q=(4\pi/\lambda)\sin(\theta/2)$, where θ is the angle between incident and scattered beam. Data were corrected for the empty cell signal and the solute and solvent incoherent background. A light water standard was used to normalize the scattered intensities to cm^{-1} units.

Catalytic experiments.

General procedure for the asymmetric hydrogenation of dimethyl itaconate (1): All the solvents have been dried with a SPS of IT–Inc and stored over 4Å molecular sieves. All the stock solutions were prepared in CH_2Cl_2 since all the compounds investigated in this study are readily soluble in this solvent. The hydrogenation experiments were carried out in a HEL autoclave charged with an insert suitable for 24 reactions in glass vessels (including Teflon stirring bars) for conducting parallel reactions. In a typical experiment, the self-assembled precatalysts were prepared *in situ* in a glass tube mixing 2 equivalents of the phosphine-functionalized BTA (0.1 mL, 40 mM in CH_2Cl_2) and 1 equivalent of $[Rh(cod)_2]BAr_F$ (0.1 mL, 20 mM in CH_2Cl_2). The solution was stirred approximately for 5 minutes before mixing it with dimethyl itaconate (0.2 mL, 1 M in CH_2Cl_2). Alternatively, dimethyl itaconate can be added as a solid with no effect on the catalytic performance. For catalytic reactions performed in CH_2Cl_2: The glass tubes were transferred in a HEL autoclave, the H_2 pressure was adjusted to 3 bar without incubation. The mixtures were stirred for 12 h at room temperature. For catalytic reactions performed in other solvents: The CH_2Cl_2 catalytic solutions were stirred overnight and then evaporated under vacuum. 0.5 mL of the desired solvent was added and the glass tubes were put in an ultrasonic bath for 15 min. The glass tubes were transferred in a HEL autoclave, the H_2 pressure was adjusted to 3 bar without incubation. The mixtures were stirred for 12 h at room temperature. For catalytic reactions performed with **^{H}BTA(*S*)** as additive: The precatalysts were prepared by mixing 2 equivalents of the phosphine-functionalized BTA (0.1 mL, 40 mM in CH_2Cl_2), 2.5 equivalents of **^{H}BTA(*S*)** (0.25 mL, 20mM in CH_2Cl_2), 1 equivalent of $[Rh(cod)_2]BAr_F$ (0.1 mL, 20 mM in CH_2Cl_2), the solution was stirred approximately for 5 minutes before mixing it with dimethyl itaconate (0.2 mL, 1 M in CH_2Cl_2). The CH_2Cl_2 catalytic solutions were stirred overnight and then evaporated under vacuum. 0.5 mL of hexane was added and the glass tubes were put in an ultrasonic bath for 15 min. The glass tubes were transferred in a HEL autoclave, the H_2 pressure was adjusted to 3 bar without incubation. The mixtures were stirred for 12 h at room temperature. Determination of the conversion and the enantiomeric excess: The conversion was determined by ^{1}H NMR after evaporation of the catalytic solutions under vacuum. Ee were measured by chiral GC (Betadex 225, capillary 30.0mx250µmx0.25µm, Flow = 1.5mL/min, P_{He} = 17.6 psi, isotherm at 70°C (10 min) then 2°C/min until 95°C, t_r (*R*) = 24.1 min, t_r (*S*) = 24.7 min). Attribution of enantiomer was made according to published data.[6] Experiments were performed at least in triplicate except for the control experiments which gave low ee.

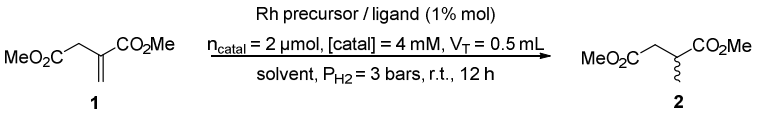


Table S.1. Screening of the catalytic conditions with ^{H}BTA^{PPh2}(*S*),(*S*)

entry	solvent	ligand:rhodium	BTA ligand	Rh precursor	conversion (%)	ee (%)
1	CH_2Cl_2	2:1	**^{H}BTA^{PPh2}(*S*),(*S*)**	$[Rh(cod)_2]BArF$	100	0
2	toluene	2:1	**^{H}BTA^{PPh2}(*S*),(*S*)**	$[Rh(cod)_2]BArF$	100	28
3	hexane	2:1	**^{H}BTA^{PPh2}(*S*),(*S*)**	$[Rh(cod)_2]BArF$	100	82
4	hexane	1:1	**^{H}BTA^{PPh2}(*S*),(*S*)**	$[Rh(cod)_2]BArF$	100	13
5	hexane	1.8:1	**^{H}BTA^{PPh2}(*S*),(*S*)**	$[Rh(cod)_2]BArF$	100	83
6	hexane	2.2:1	**^{H}BTA^{PPh2}(*S*),(*S*)**	$[Rh(cod)_2]BArF$	100	82
7	hexane	1:1	**^{H}BTA^{PPh2}(*S*),(*S*)**	$[Rh(nbd)_2]BF_4$	98	8
8	hexane	1:1	**^{H}BTA^{PPh2}(*S*),(*S*)**	$[Rh(cod)_2]BF_4$	90	32

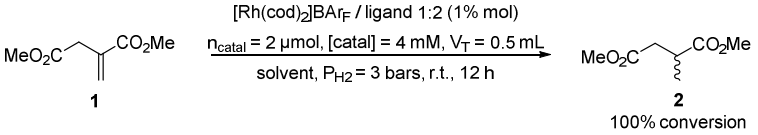


Table S.2. Influence of the solvent on the catalytic performance

entry	solvent	BTA ligand	ee (%)
1	CH_2Cl_2	^{H}BTA^{PPh2}(*S*),(*S*)	0
2	toluene	^{H}BTA^{PPh2}(*S*),(*S*)	28
3	toluene:hexane 1:1	^{H}BTA^{PPh2}(*S*),(*S*)	46
4	hexane	^{H}BTA^{PPh2}(*S*),(*S*)	82
5	CH_2Cl_2	^{H}BTA^{PPh2}(*R*),(*R*)	0
6	toluene	^{H}BTA^{PPh2}(*R*),(*R*)	-29
7	toluene:hexane 1:1	^{H}BTA^{PPh2}(*R*),(*R*)	-47
8	hexane	^{H}BTA^{PPh2}(*R*),(*R*)	-81
9	CH_2Cl_2	^{H}BTA^{PPh2}(*S*)	0
10	toluene	^{H}BTA^{PPh2}(*S*)	39
11	toluene:hexane 1:1	^{H}BTA^{PPh2}(*S*)	64
12	hexane	^{H}BTA^{PPh2}(*S*)	67

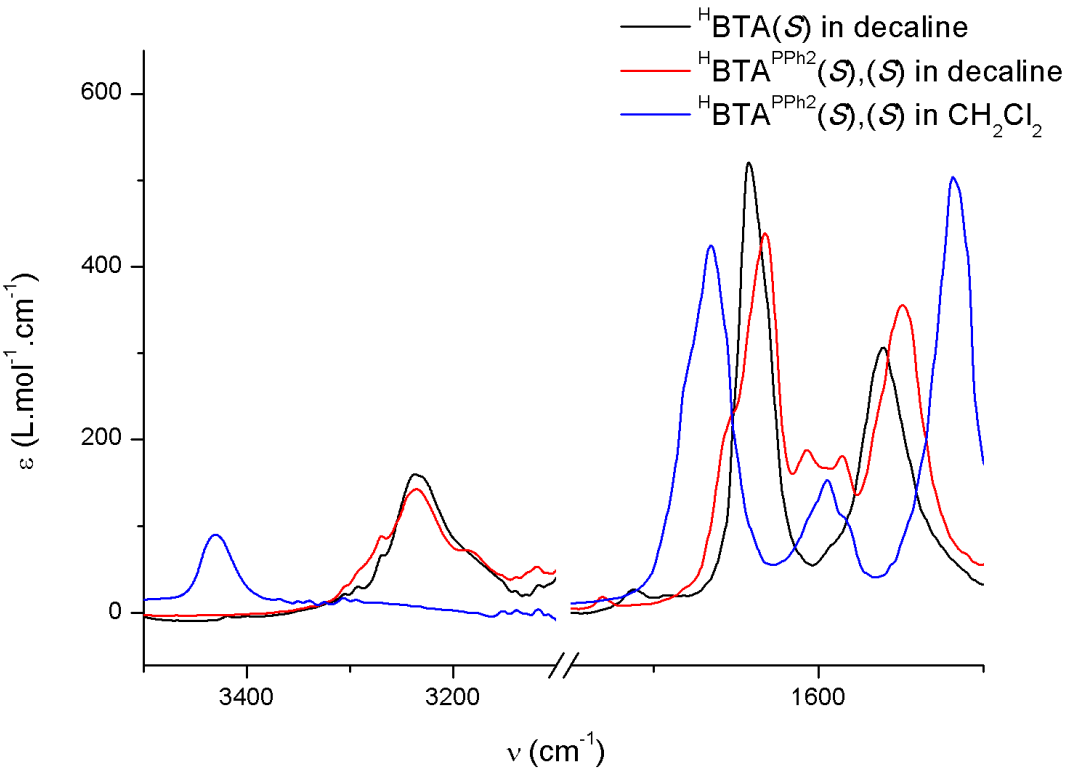


Figure S.1. IR spectra recorded in the N-H stretching region and the C=O stretching and amide II regions for **^{H}BTA(*S*)** in decaline and **^{H}BTA^{PPh2}(*S*),(*S*)** in decaline and CH_2Cl_2 at 4.0 mmol.L^{-1}**.**

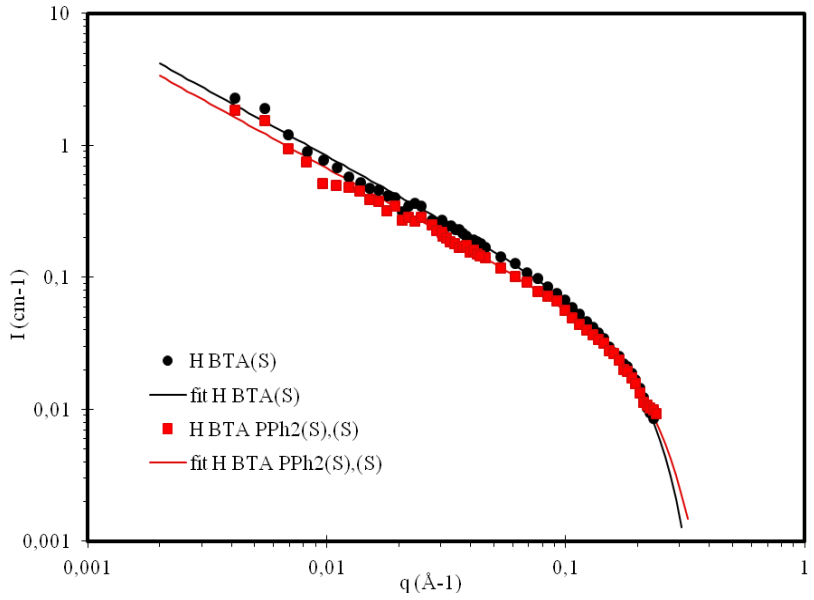


Figure S.2. SANS intensity versus scattering vector for solutions of **^{H}BTA(*S*)** (4 mmol.L^{-1}) and **^{H}BTA^{PPh2}(*S*),(*S*)** (3 mmol.L^{-1}) in deuterated cyclohexane. The curves are fitted according to a model for rigid and infinitely long cylindrical objects.[7]

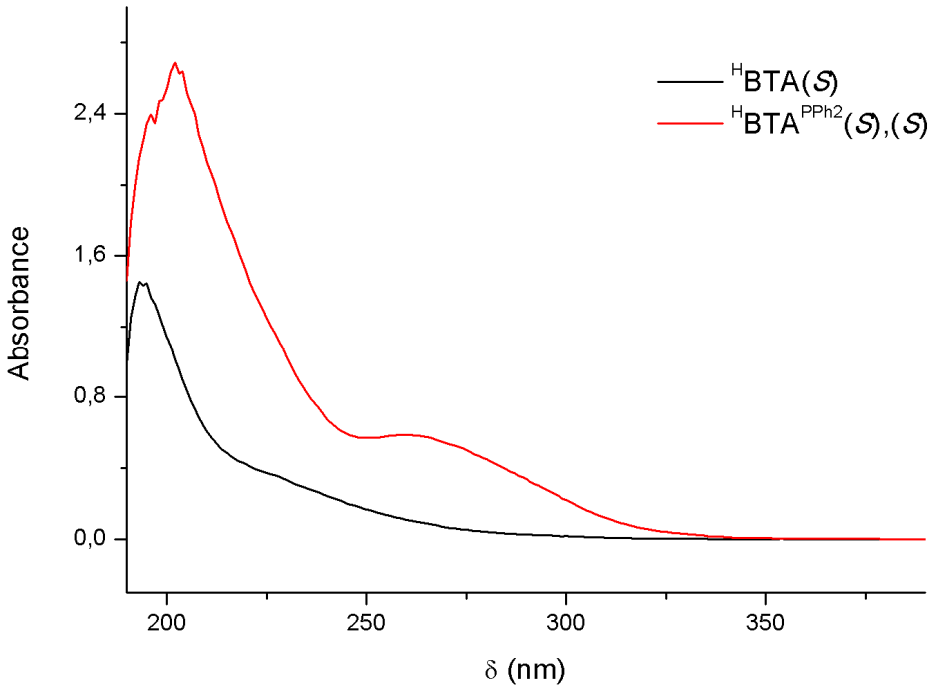
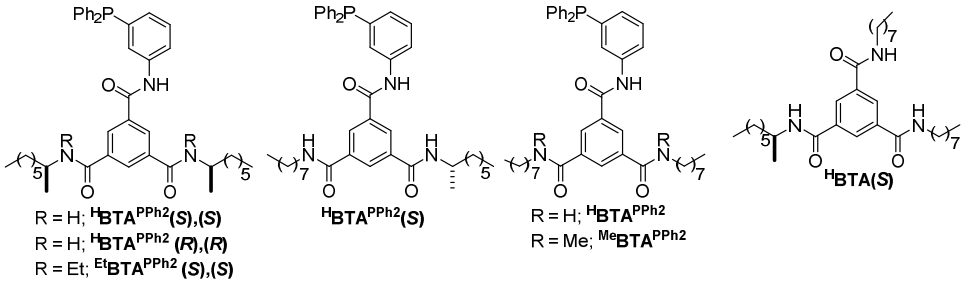


Figure S.3. UV-vis spectra of **^{H}BTA^{PPh2}(*S*),(*S*)** and **^{H}BTA(*S*)** in decaline (30 µmol.L^{-1}).

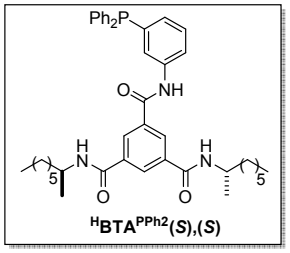
The UV-Vis spectrum of ^{H}BTA(*S*) is in accordance with the one reported previously by Nakano et al.[8]

Synthesis and characterization of the BTA derivatives.



Structure and nomenclature of the BTA derivatives studied in this paper.

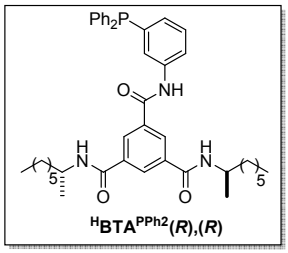
Synthesis of ^{H}BTA^{PPh2}(*S*),(*S*):



3-diphenylphosphinoaniline (0.744 g, 2.68 mmol, 0.95 equiv.) and NEt_3 (2 mL, 14.8 mmol, 5.23 equiv.) in 50 mL of CH_2Cl_2 were added dropwise to a cold solution (ice-water-salt bath) of benzene-1,3,5-tricarbonyl trichloride (0.73 g, 2.83 mmol, 1.00 equiv.) in 10 mL of dry CH_2Cl_2. The reaction mixture was stirred overnight. Then (*S*)-octan-2-amine (1.14 mL, 6.92 mmol, 2.45 equiv.) was added and the mixture was stirred further 12 h. Volatiles were removed and the resulting crude mixture was dissolved in CH_2Cl_2, washed with brine. Evaporation of the solvent led to a crude product which was purified twice by column chromatography (silica, CH_2Cl_2) yielding **^{H}BTA^{PPh2}(*S*),(*S*)** as a sticky colorless solid (0.180 g, 0.26 mmol, 9%). $^{31}P\{^1H\}$-NMR ($CDCl_3$): δ (ppm) = -1.75 (s). ^{1}H-NMR ($CDCl_3$): δ (ppm) = 0.87 (t, 6H, CH_3, J_{H-H} = 7.3 Hz), 1.23 (d, 6H, CHC*H*$_3$, J_{H-H} = 6.6 Hz), 1.24-1.39 (m, 16H, CH_2), 1.49-1.57 (m, 4H, CHC*H*$_2$), 4.13-4.22 (m, 2H, CH), 6.17 (d, 2H, N*H*CH, J_{H-H} = 8.5 Hz), 7.15 (tt, 1H, CH arom., J_{H-H} = 7.9, 1.2 Hz, J_{H-P} = 7.2 Hz), 7.30-7.36 (m, 10H, PPh_2), 7.37-7.41 (m, 2H, CH arom.), 7.84 (dd, 1H, CH arom., J_{H-H} = 8.5, 1.8 Hz), 8.21 (s, 1H, NHAr), 8.33 (t, 1H, BTA ring, J_{H-H} = 1.5 Hz), 8.38 (d, 2H, BTA ring, J_{H-H} = 8.5, 1.9 Hz). $^{13}C\{^1H\}$-NMR ($CDCl_3$): δ (ppm) = 14.2 (CH_2CH_3), 20.9 ($CHCH_3$), 22.7 (CH_2), 26.3 (CH_2), 29.3 (CH_2), 31.9 (CH_2), 37.0 (NHCHCH_2), 46.5 (NHCH), 121.1 (CH arom. *ortho*-NH), 125.3 (d, CH arom. *ortho*-NH, J_{C-P} = 21.1 Hz), 128.1 (CH BTA ring), 128.2 (CH BTA ring), 128.7 (d, PPh_2 *meta*, J_{C-P} = 7.0 Hz), 129.0 (PPh_2 *para*), 129.4 (d, CH arom. *meta*-NH, J_{C-P} = 7.5 Hz), 130.2 (d, CH arom. *para*-NH, J_{C-P} = 20.5 Hz), 134.0 (d, PPh_2 *ortho*, J_{C-P} = 19.5 Hz), 135.8 (C BTA ring), 137.0 (d, PPh_2 *ipso*, J_{C-P} = 10.8 Hz), 138.3 (d, C arom. *ipso*-NH, J_{C-P} = 8.1 Hz), 138.8 (d, C arom. *meta*-NH, J_{C-P} = 12.5 Hz), 164.8 (CO), 165.4 (CO). MS: (ESI, MeOH) m/z 692.4 $[M + H]^+$ corresponds to $C_{43}H_{55}N_3O_3P$; 714.4 $[M + Na]^+$ corresponds to $C_{43}H_{54}N_3O_3PNa$; 746.4 $[M + Na + CH_3OH]^+$ corresponds to $C_{44}H_{58}N_3O_4PNa$. HRMS (ESI, m/z): 714.3790 $[M + Na]^+$, 714.3795 calcd for $C_{43}H_{54}N_3O_3PNa$. IR (film layer, cm^{-1}): 1546 (s, C-

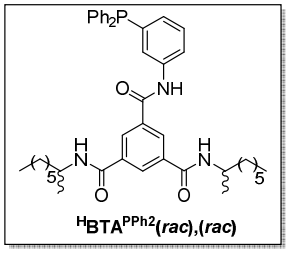
N), 1586 (m, C-N), 1606 (m, C-N), 1632 (s, C=O), 3234 (m br, N-H stretch). Enantiomeric excess > 99% (determined by chiral HPLC).

Synthesis of ^{H}BTA^{PPh2}(*R*),(*R*):



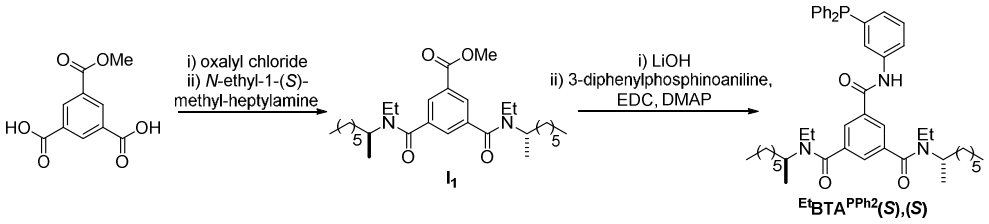
3-diphenylphosphinoaniline (0.957 g, 3.45 mmol, 1.22 equiv.) and NEt_3 (2.56 mL, 19.0 mmol, 6.70 equiv.) in 50 mL of CH_2Cl_2 were added dropwise to a cold solution (ice-water-salt bath) of benzene-1,3,5-tricarbonyl trichloride (0.73 g, 2.83 mmol, 1.00 equiv.) in 10 mL of dry CH_2Cl_2. The reaction mixture was stirred overnight. Then (*R*)-octan-2-amine (1.30 mL, 7.60 mmol, 2.70 equiv.) was added and the mixture was stirred further 12 h. Volatiles were removed and the resulting crude mixture was dissolved in CH_2Cl_2, washed with brine. Evaporation of the solvent led to a crude product which was purified two times by column chromatography (silica, CH_2Cl_2) yielding **^{H}BTA^{PPh2}(*R*),(*R*)** as a sticky colorless solid (0.160 g, 0.23 mmol, 8%). Analytical data are identical to **^{H}BTA^{PPh2}(*S*),(*S*)**. HRMS (ESI, m/z): 714.3797 $[M + Na]^+$, 714.3795 calcd for $C_{43}H_{54}N_3O_3PNa$. Enantiomeric excess > 99% (determined by chiral HPLC).

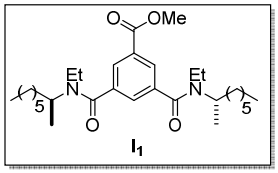
Synthesis of ^{H}BTA^{PPh2}(*rac*),(*rac*):



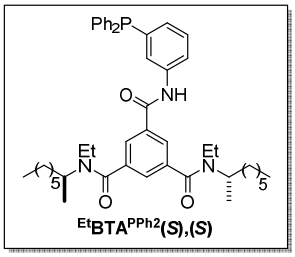
3-diphenylphosphinoaniline (0.957 g, 3.45 mmol, 1.22 equiv.) and NEt_3 (2.56 mL, 19.0 mmol, 6.70 equiv.) in 50 mL of CH_2Cl_2 were added dropwise to a cold solution (ice-water-salt bath) of benzene-1,3,5-tricarbonyl trichloride (0.73 g, 2.83 mmol, 1.00 equiv.) in 10 mL of dry CH_2Cl_2. The reaction mixture was stirred overnight. Then octan-2-amine (1.30 mL, 7.60 mmol, 2.70 equiv.) was added and the mixture was stirred further 12 h. Volatiles were removed and the resulting crude mixture was dissolved in CH_2Cl_2, washed with brine. Evaporation of the solvent led to a crude product which was purified two times by column chromatography (silica, CH_2Cl_2) yielding **^{H}BTA^{PPh2}(*rac*),(*rac*)** as a sticky colorless solid (0.210 g, 0.23 mmol, 11%). Analytical data are identical to **^{H}BTA^{PPh2}(*S*),(*S*)**. **^{H}BTA^{PPh2}(*rac*),(*rac*)** has been prepared for the purpose of determining the optical purity of **^{H}BTA^{PPh2}(*S*),(*S*)** and **^{H}BTA^{PPh2}(*R*),(*R*)**.

Synthesis of $^{Et}BTA^{PPh2}(S),(S)$:





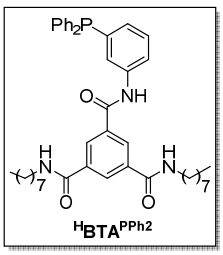
5-Methoxycarbonyl-benzene-1,3-dicarboxylic acid[9] (0.590 g, 2.92 mmol, 1.00 equiv.) was dissolved in dry THF (20 mL) under an argon atmosphere and two droplets of DMF was added. Oxalyl chloride (0.75 mL, 7.88 mmol, 2.70 equiv.) in THF (10 mL) was added dropwise to the solution and the reaction mixture was stirred for 2 h. The THF was removed in vacuo and a yellowish suspension was obtained. The excess of oxalyl chloride was removed by co-evaporation with toluene. The NMR analysis of the intermediate acyl chloride was consistent with published data.[9] The acyl chloride was dissolved in dry CH_2Cl_2 (20 mL) and a solution of *N*-ethyl-1-(*S*)-methyl-heptylamine (1.000 g, 6.37 mmol, 2.18 equiv.) and NEt_3 (1.57 mL, 11.60 mmol, 3.98 equiv.) in CH_2Cl_2 (20 mL) was added dropwise. The progress of the reaction was monitored by TLC (CH_2Cl_2/AcOEt 8:2). After 48 h, CH_2Cl_2 was removed under vacuum, THF (40 mL) was added and the reaction mixture was warmed at 45 °C for 30 min. The solution was cooled to room temperature and the solvent was evaporated under vacuum. The crude product was purified by column chromatography (silica, CH_2Cl_2/ AcOEt 8:2) yielding **I_1** as a colorless oil (0.250 g, 0.50 mmol, 17%).^{1}H-NMR ($CDCl_3$): 0.85 (t, 6H, CH_3, $J_{H\text{-}H}$ = 7.0 Hz), 0.97-1.41 (m, 28H, 8 × CH_2 + 4 × CH_3), 1.42-1.55 (m, 4H, CHCH_2), 3.08-3.38 (m, 3H, CH_3CH_2N + NCH), 3.39-3.77 (m, 2H, CH_3CH_2N), 3.93 (s, 3H, OCH_3), 4.30-4.57 (br s, 1H, NCH), 7.48 (br s, 1H, CH BTA ring), 8.04 (br s, 2H, CH BTA ring). $^{13}C\{^1H\}$-NMR ($CDCl_3$): δ (ppm) = 14.1 (CH_3), 14.6 (CH_3), 16.5 (CH_3), 19.3 (CH_3), 20.1 (CH_3), 22.7 (CH_2), 26.6 (CH_2), 27.0 (CH_2), 29.3 (CH_2), 31.8 (CH_2), 32.0 (CH_2), 34.7 (CH_2), 35.2 (CH_2), 35.8 (CH_2), 40.5 (CH_2), 51.5 (CH), 52.6 (CH), 55.3 (CH), 128.1 (CH BTA ring), 128.3 (CH BTA ring), 128.6 (CH BTA ring), 130.9 (C BTA ring), 138.5 (C BTA ring), 165.8 (CO), 170.0 (CO).



I_1 (0.225 g, 0.45 mmol, 1.00 equiv.) was dissolved in MeOH (10 mL). LiOH (0.021 g, 0.92 mmol, 2.00 equiv.) and a few drops of water were added to the solution. The solution was stirred at room temperature for 12 h and then warmed to 40 °C for 48 h. The solution was cooled to room temperature and HCl 4M in

dioxane (0.24 mL, 0.97 mmol, 2.12 equiv.) was added and the solution was stirred for 1 h. MeOH was removed in vacuo yielding a colorless oil that was dried under vacuum overnight. This oil corresponded to the expected mono-acid product with LiCl as a by-product. It was used for the next step without further purification. A round-bottom flask was charged with the mono-acid, DMAP (0.093 g, 0.77 mmol, 1.70 equiv.) and 3-diphenylphosphinoaniline (0.221 g, 0.77 mmol, 1.70 equiv.) and THF (20 mL). The solution was cooled with an ice-water-salt bath and 1-(3-dimethylpropyl)-3-ethylcarbodiimide hydrochloride (EDC, 0.13 mL, 0.77 mmol, 1.70 equiv.) in THF (10 mL) was quickly added to the solution. The mixture was refluxed and the progress of the reaction was monitored by TLC. After 48 h, the reaction mixture was cooled to room temperature and the THF was removed in vacuo. CH_2Cl_2 (50 mL) was added and the organic phase was washed with water (2 × 50 mL), dried over $MgSO_4$, filtered and evaporated in vacuo. The crude product was purified by column chromatography (SiO_2, CH_2Cl_2/AcOEt 8:2) yielding **^{Et}BTA^{PPh2}(*S*),(*S*)** (0.075 g, 0.10 mmol, 22%) as a colorless oil that crystallized upon standing. NMR analysis in $CDCl_3$ at room temperature indicated the presence of a mixture of isomers in a quite slow exchange.[10] ^{1}H-NMR analysis in d_8-toluene at 374 K is described since a single set of signals is present at this temperature. $^{31}P\{^1H\}$-NMR (d_8-toluene, 374 K): δ (ppm) = 0.35 (s). ^{1}H-NMR (d_8-toluene, 374 K): δ (ppm) = 0.85 (t, 6H, CH_3, J_{H-H} = 7.0 Hz), 1.01 (d, 6H, CHC*H*$_3$, J_{H-H} = 6.5 Hz), 1.09 (t, 6H, C*H*$_3$CH$_2$N, J_{H-H} = 6.8 Hz), 1.12-1.35 (m, 20H, CH_2), 3.02-3.10 (m, 2H, CH_3C*H*$_2$N), 3.17-3.25 (m, 2H, CH_3C*H*$_2$N), 3.84 (br s, 2H, NCH), 6.95 (br s, 1H, CH arom.), 7.02-7.13 (m, 7H, PPh_2 + 1 CH arom.), 7.34-7.41 (m, 4H, PPh_2), 7.53 (t, 1H, BTA ring, J_{H-H} = 1.5 Hz), 7.83 (dt, 1H, CH arom., J_{H-H} = 9.0, 1.5 Hz), 7.88 (d, 1H, CH arom., J_{H-H} = 8.0 Hz), 7.98 (d, 2H, BTA ring, J_{H-H} = 1.0 Hz), 8.62 (br s, 1H, NHAr). $^{13}C\{^1H\}$-NMR ($CDCl_3$, 298 K): δ (ppm) = 14.1 (CH_3), 14.6 (CH_3), 16.4 (CH_3), 19.1 (CH_3), 20.1 (CH_3), 22.7 (CH_2), 26.6 (CH_2), 27.1 (CH_2), 29.2 (CH_2), 29.8 (CH_2), 31.8 (CH_2), 34.7 (CH_2), 35.2 (CH_2), 35.9 (CH_2), 40.6 (CH_2), 51.7 (CH), 55.3 (CH), 121.0 (CH arom. *ortho*-NH), 125.2 (d, CH arom. *ortho*-NH, J_{C-P} = 22.4 Hz), 126.1 (CH BTA ring), 127.1 (CH BTA ring), 127.2 (CH BTA ring), 128.7 (d, PPh_2 *meta*, J_{C-P} = 6.8 Hz), 129.0 (PPh_2 *para*), 129.3 (d, CH arom. *meta*-NH, J_{C-P} = 7.0 Hz), 130.1 (d, CH arom. *para*-NH, J_{C-P} = 18.7 Hz), 133.9 (d, PPh_2 *ortho*, J_{C-P} = 19.7 Hz), 135.8 (C BTA ring), 137.0 (d, PPh_2 *ipso*, J_{C-P} = 11.7 Hz), 138.3 (d, C arom. *ipso*-NH, J_{C-P} = 8.5 Hz), 138.5 (C BTA ring), 138.7 (d, C arom. *meta*-NH, J_{C-P} = 12.9 Hz), 139.1 (C BTA ring), 164.4 (CO), 170.0 (CO). HRMS (ESI, m/z): 770.4418 $[M + Na]^+$, 770.4421 calcd for $C_{47}H_{62}N_3O_3PNa$. IR (film layer, cm^{-1}): 1541 (m, C-N), 1603 (s, C-N), 1633 (s, C=O), 3295 (w br, N-H stretch).

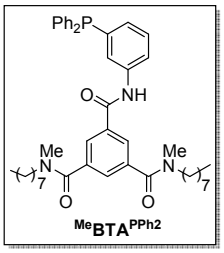
Synthesis of ^{H}BTA^{PPh2}:



3-diphenylphosphinoaniline (0.957 g, 3.45 mmol, 1.22 equiv.) and NEt_3 (2.56 mL, 19.0 mmol, 6.70 equiv.) in 50 mL of CH_2Cl_2 were added dropwise to a cold solution (ice-water-salt bath) of benzene-1,3,5-

tricarbonyl trichloride (0.73 g, 2.83 mmol, 1.00 equiv.) in 10 mL of dry CH_2Cl_2. The reaction mixture was stirred overnight. Then octylamine (1.40 mL, 8.50 mmol, 3.35 equiv.) was added and the mixture was stirred further 12 h. Volatiles were removed and the resulting crude mixture was dissolved in CH_2Cl_2, washed with brine. Evaporation of the solvent led to a crude product which was purified two times by column chromatography (silica, CH_2Cl_2) yielding **^{H}BTA^{PPh2}** as a sticky colorless solid (0.350 g, 0.51 mmol, 18%). $^{31}P\{^1H\}$-NMR ($CDCl_3$): δ (ppm) = -1.84 (s). ^{1}H-NMR ($CDCl_3$): δ (ppm) = 0.87 (t, 6H, CH_3, $J_{H–H}$ = 7.4 Hz), 1.20-1.40 (m, 20H, CH_2), 1.55 (quintet, 4H, NCH_2CH_2, $J_{H–H}$ = 7.3 Hz), 3.37 (q, 4H, NCH_2, $J_{H–H}$ = 6.6 Hz), 6.62 (br s, 2H, $NHCH_2$), 7.11 (tt, 1H, CH arom., $J_{H–H}$ = 7.6, 1.3 Hz, $J_{H–P}$ = 7.2 Hz), 7.29-7.35 (m, 11H, PPh_2 + 1 CH arom.), 7.43 (dt, 1H, CH arom., $J_{H–H}$ = 7.8, 1.3 Hz), 7.83 (dd, 1H, CH arom., $J_{H–H}$ = 8.2, 1.4 Hz), 8.20 (s, 1H, BTA ring), 8.27 (s, 2H, BTA ring), 8.75 (br s, 1H, NHAr). $^{13}C\{^1H\}$-NMR ($CDCl_3$): δ (ppm) = 14.2 (CH_3), 22.8 (CH_2), 27.2 (CH_2), 29.4 (CH_2), 29.6 (CH_2), 32.0 (CH_2), 40.5 (NCH_2), 121.1 (CH arom. *ortho*-NH), 125.4 (d, CH arom. *ortho*-NH, J_{C-P} = 21.7 Hz), 128.2 (CH BTA ring), 128.3 (CH BTA ring), 128.7 (d, PPh_2 *meta*, J_{C-P} = 7.0 Hz), 129.0 (PPh_2 *para*), 129.3 (d, CH arom. *meta*-NH, J_{C-P} = 7.0 Hz), 130.1 (d, CH arom. *para*-NH, J_{C-P} = 19.5 Hz), 133.9 (d, PPh_2 *ortho*, J_{C-P} = 19.5 Hz), 135.6 (C BTA ring), 135.9 (C BTA ring), 137.0 (d, PPh_2 *ipso*, J_{C-P} = 10.8 Hz), 138.5 (m, C arom. *ipso*-NH and *meta*-NH), 165.2 (CO), 166.5 (CO). MS: (ESI, MeOH) m/z 692.4 $[M + H]^+$ corresponds to $C_{43}H_{55}N_3O_3P$. HRMS (ESI, m/z): 714.3790 $[M + Na]^+$, 714.3795 calcd for $C_{43}H_{54}N_3O_3PNa$. IR (film layer, cm^{-1}): 1548 (s, C-N), 1584 (m, C-N), 1607 (m, C-N), 1634 (s, C=O), 3244 (m br, N-H stretch).

Synthesis of ^{Me}BTA^{PPh2}:



^{Me}BTA^{PPh2}

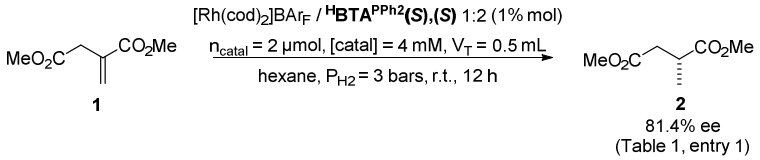
3-diphenylphosphinoaniline (1.270 g, 4.58 mmol, 1.22 equiv.) and NEt_3 (3.41 mL, 24.5 mmol, 6.50 equiv.) in 50 mL of CH_2Cl_2 were added dropwise to a cold solution (ice-water-salt bath) of benzene-1,3,5-tricarbonyl trichloride (1.000 g, 3.76 mmol, 1.00 equiv.) in 10 mL of dry CH_2Cl_2. The reaction mixture was stirred overnight. Then *N*-methyl-octylamine (2.28 mL, 12.60 mmol, 3.35 equiv.) was added and the mixture was stirred further 12 h. Volatiles were removed and the resulting crude mixture was dissolved in CH_2Cl_2, washed with brine. Evaporation of the solvent led to a crude product which was purified two times by column chromatography (silica, CH_2Cl_2) yielding **^{Me}BTA^{PPh2}** as a sticky colorless solid (0.210 g, 0.30 mmol, 8 %). NMR analysis in $CDCl_3$ at room temperature indicated the presence of a mixture of isomers in a quite slow exchange.[10] $^{31}P\{^1H\}$-NMR ($CDCl_3$): δ (ppm) = - 2.55 (br s). ^{1}H-NMR ($CDCl_3$): δ (ppm) = 0.86 (t, 6H, CH_3, J_{H-H} = 7.7 Hz), 1.15-1.40 (m, 20H, CH_2), 1.49-1.58 (m, 4H, NCH_2CH_2), 2.92 (br s, 3H, CH_3N, isomer 1), 3.06 (s, 3H, CH_3N, isomer 2), 3.21 (t, 2H, NCH_2, J_{H-H} = 6.9 Hz, isomer 2), 3.51 (t, 2H, NCH_2, J_{H-H} = 6.9 Hz, isomer 1), 7.13 (tt, 1H, CH arom., J_{H-H} = 7.5, 1.3 Hz, $J_{H–P}$ = 7.2 Hz), 7.29-7.39 (m, 10H, PPh_2), 7.43-7.59 (m, 2H, CH arom.), 7.67 (dd, 1H, CH arom., J_{H-H} = 12.0, 0.8 Hz),

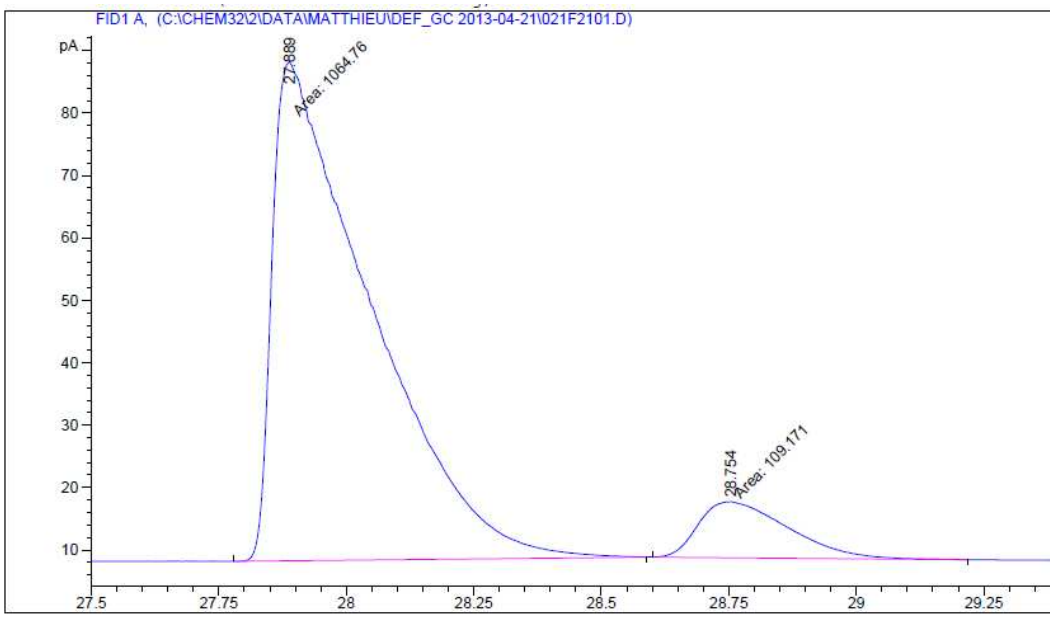
7.90 (s, 2H, BTA ring), 7.94 (d, 1H, CH BTA ring, $J_{H\text{-}H}$ = 1.5 Hz), 7.98 (br s, 1H, NHAr). $^{13}C\{^{1}H\}$-NMR ($CDCl_3$): δ (ppm) = 14.2 (CH_3), 22.8 (CH_2), 26.5 (CH_2), 27.0 (CH_2), 28.4 (CH_2), 29.2 (CH_2), 29.4 (CH_2), 29.5 (CH_2), 29.8 (CH_2), 31.8 (CH_2), 33.0 (CH_3N), 37.6 (CH_3N), 47.9 (NCH_2), 51.6 (NCH_2), 121.1 (CH arom.), 123.7 (d, CH arom., $J_{C\text{-}P}$ = 10.1 Hz), 124.3 (CH BTA ring), 125.4 (d, CH arom., $J_{C\text{-}P}$ = 23.6 Hz), 126.6 (CH BTA ring), 127.0 (CH BTA ring), 127.2 (CH BTA ring), 127.7 (d, CH arom., $J_{C\text{-}P}$ = 10.1 Hz), 128.7 (d, PPh_2, $J_{C\text{-}P}$ = 7.0 Hz), 128.9 (d, PPh_2, $J_{C\text{-}P}$ = 12.1 Hz),129.2 (d, CH arom., $J_{C\text{-}P}$ = 8.6 Hz), 129.8 (d, CH arom., $J_{C\text{-}P}$ = 17.6 Hz), 132.0 (PPh_2), 133.8 (d, PPh_2 *ortho*, $J_{C\text{-}P}$ = 20.0 Hz), 135.2 (C BTA ring), 135.5 (C BTA ring), 136.9 (d, PPh_2 *ipso*, $J_{C\text{-}P}$ = 10.8 Hz), 137.4 (C arom.), 138.4 (C arom.), 139.1 (C arom.), 164.5 (CO), 169.5 (CO), 170.0 (CO). HRMS (ESI, m/z): 742.4103 $[M + Na]^+$, 742.4108 calcd for $C_{45}H_{58}N_3O_3PNa$. IR (film layer, cm^{-1}): 1542 (s, C-N), 1620 (s, C-N), 1638 (s, C=O), 3294 (w br, N-H stretch).

References.

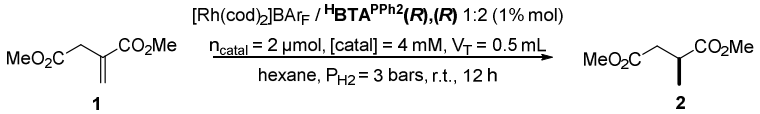
(1) van Leeuwen, P. W. N. M.; Rivillo, D.; Raynal, M.; Freixa, Z. *J. Am. Chem. Soc.* **2011**, *133*, 18562.
(2) Kabalka, G. W.; Mccollum, G. W.; Kunda, S. A. *J. Org. Chem.* **1984**, *49*, 1656.
(3) Qiu, H. B.; Inoue, Y.; Che, S. N. *Angew. Chem. Int. Ed.* **2009**, *48*, 3069.
(4) Neumann, E.; Pfaltz, A. *Organometallics* **2005**, *24*, 2008.
(5) Stals, P. J. M.; Smulders, M. M. J.; Martín-Rapún, R.; Palmans, A. R. A.; Meijer, E. W. *Chem. Eur. J.* **2009**, *15*, 2071.
(6) Fernandez-Perez, H.; Donald, S. M. A.; Munslow, I. J.; Benet-Buchholz, J.; Maseras, F.; Vidal-Ferran, A. *Chem. Eur. J.* **2010**, *16*, 6495.
(7) Lortie, F.; Boileau, S.; Bouteiller, L.; Chassenieux, C.; Deme, B.; Ducouret, G.; Jalabert, M.; Laupretre, F.; Terech, P. *Langmuir* **2002**, *18*, 7218.
(8) Nakano, Y.; Hirose, T.; Stals, P. J. M.; Meijer, E. W.; Palmans, A. R. A. *Chem. Sci.* **2012**, *3*, 148.
(9) Roosma, J.; Mes, T.; Leclere, P.; Palmans, A. R. A.; Meijer, E. W. *J. Am. Chem. Soc.* **2008**, *130*, 1120.
(10) Smulders, M. M. J.; Nieuwenhuizen, M. M. L.; Grossman, M.; Filot, I. A. W.; Lee, C. C.; de Greef, T. F. A.; Schenning, A. P. H. J.; Palmans, A. R. A.; Meijer, E. W. *Macromolecules* **2011**, *44*, 6581.

Determination of enantiomeric excesses by chiral GC

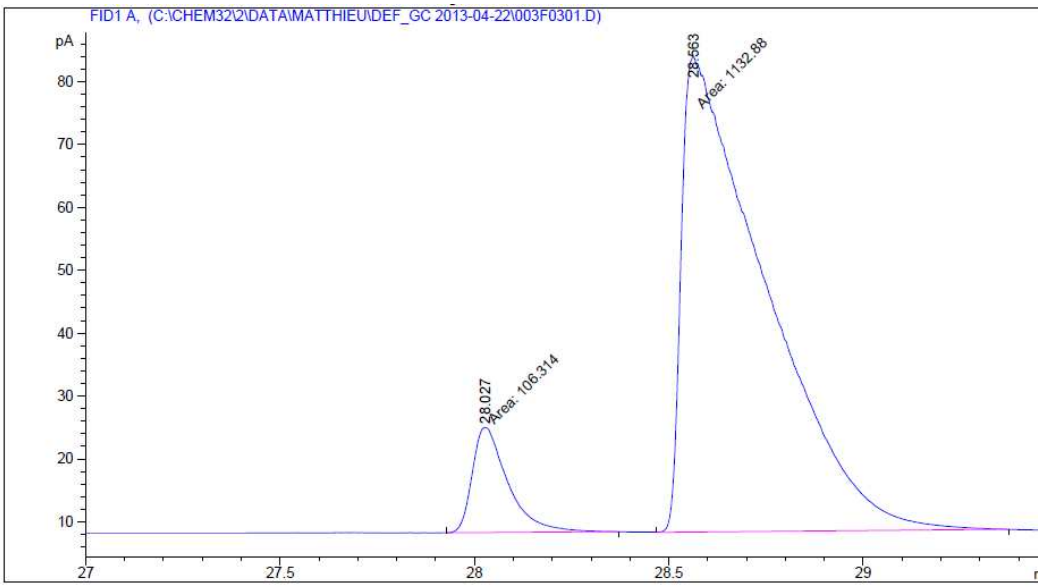




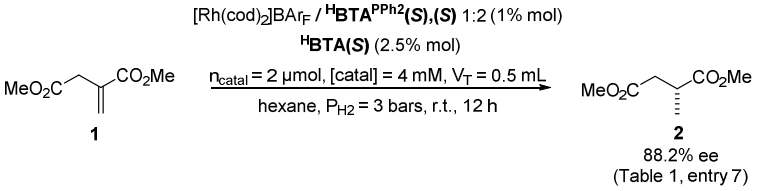

```
=====================================================================
                      Area Percent Report
=====================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Use Multiplier & Dilution Factor with ISTDs


Signal 1: FID1 A,

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [pA*s]      [pA]        %
----|-------|----|-------|----------|----------|--------|
   1  27.889 MM    0.2218 1064.76013   80.01595 90.70036
   2  28.754 MM    0.2019  109.17145    9.01170  9.29964

Totals :                  1173.93158   89.02766
```

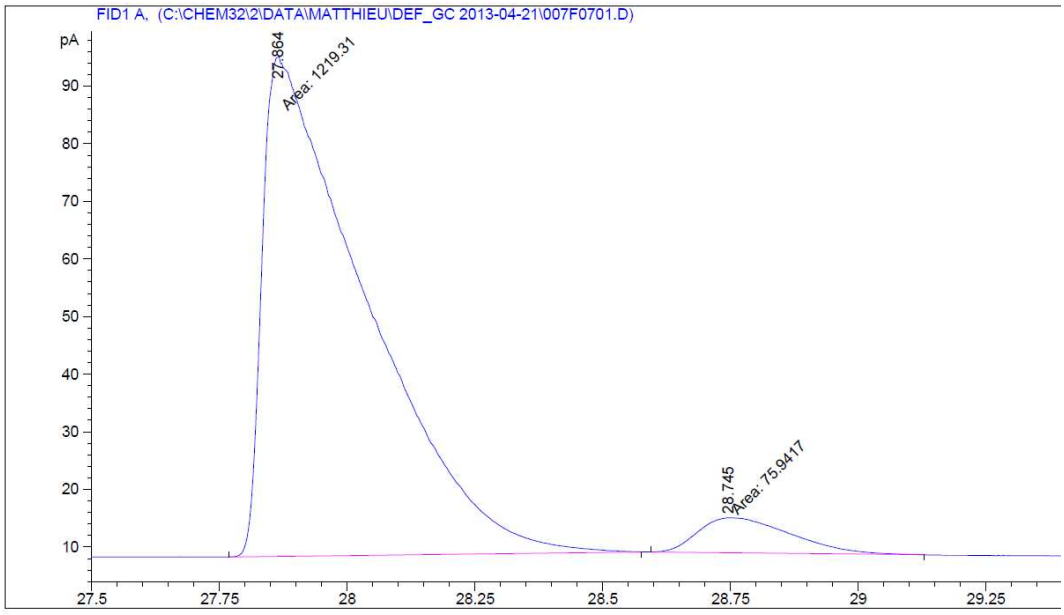


82.9% ee
(Table 1, entry 3)




```
=====================================================================
                      Area Percent Report
=====================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Use Multiplier & Dilution Factor with ISTDs


Signal 1: FID1 A,

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [pA*s]      [pA]        %
----|-------|----|-------|----------|----------|--------|
   1  28.027 MM    0.1060  106.31420   16.72118  8.57928
   2  28.563 MM    0.2499 1132.88245   75.54771 91.42072

Totals :                  1239.19665   92.26889
```

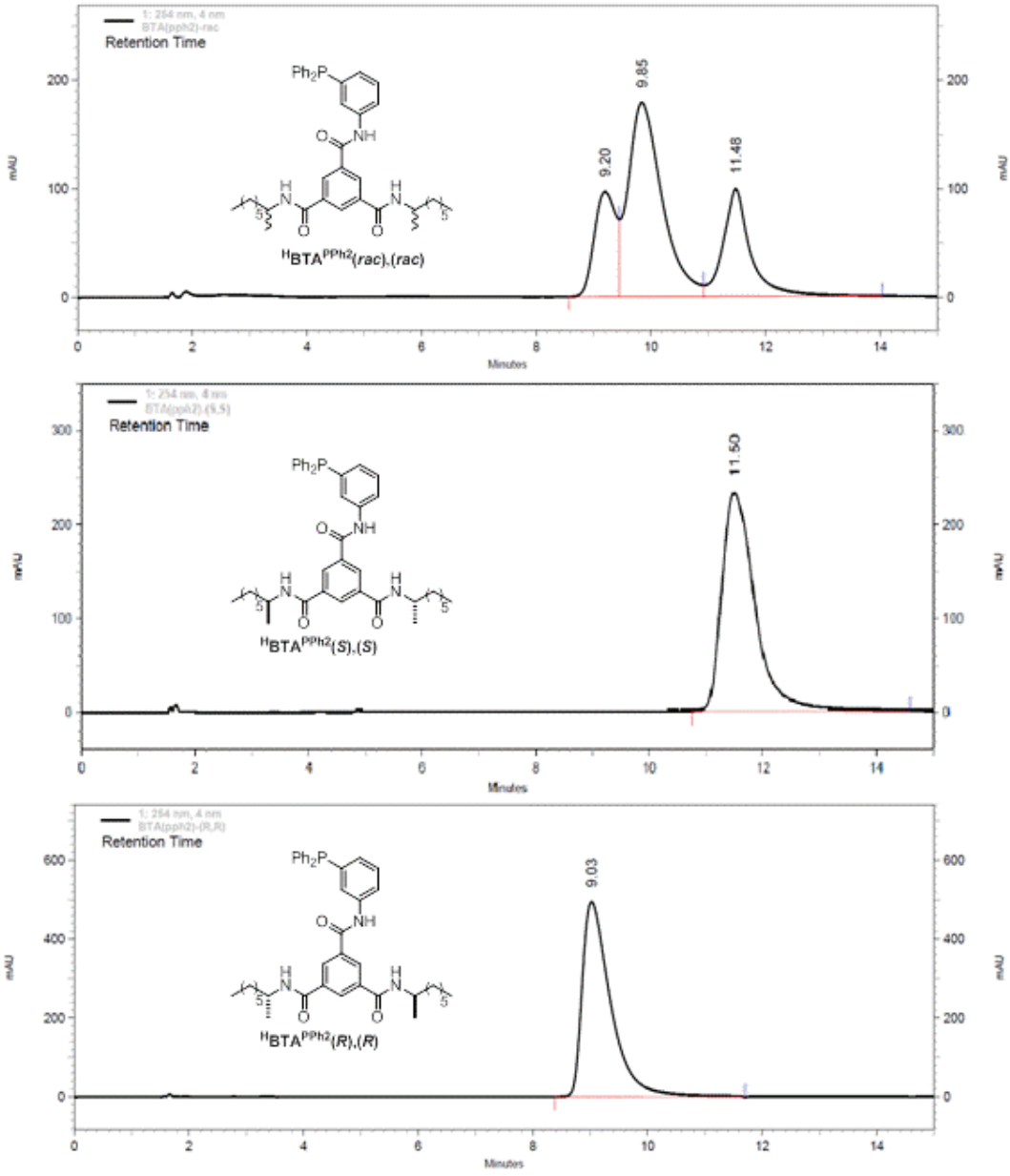




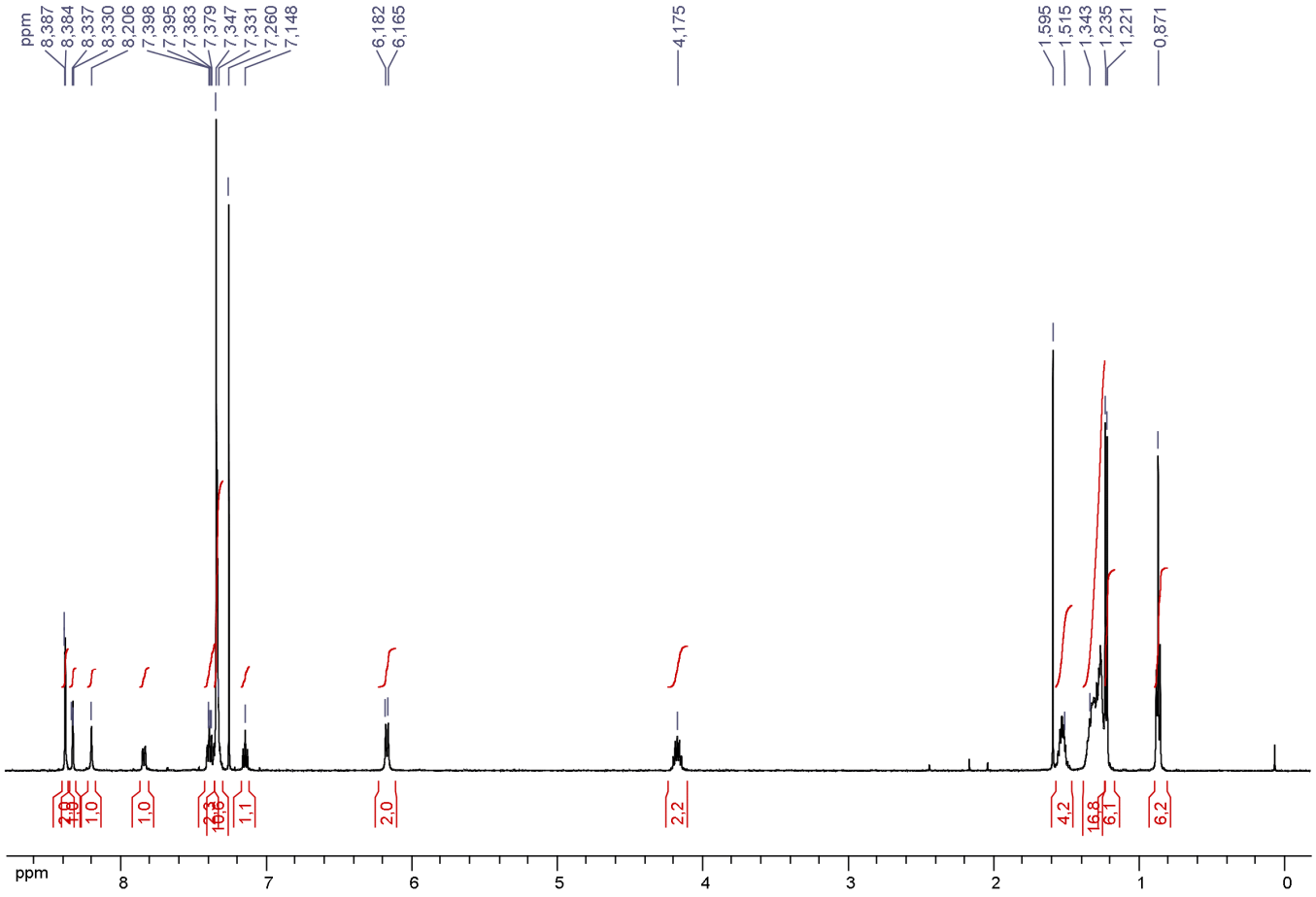

```
================================================================================
                          Area Percent Report
================================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Use Multiplier & Dilution Factor with ISTDs


Signal 1: FID1 A,

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [pA*s]      [pA]        %
----|-------|----|-------|----------|----------|--------|
   1  27.864 MM    0.2340 1219.30627   86.82724 94.13690
   2  28.745 MM    0.2079   75.94173    6.08656  5.86310

Totals :                  1295.24801   92.91380
```

Determination of the optical purity of $^{H}BTA^{PPh2}$(*S*),(*S*) and $^{H}BTA^{PPh2}$(*R*),(*R*) by chiral HPLC

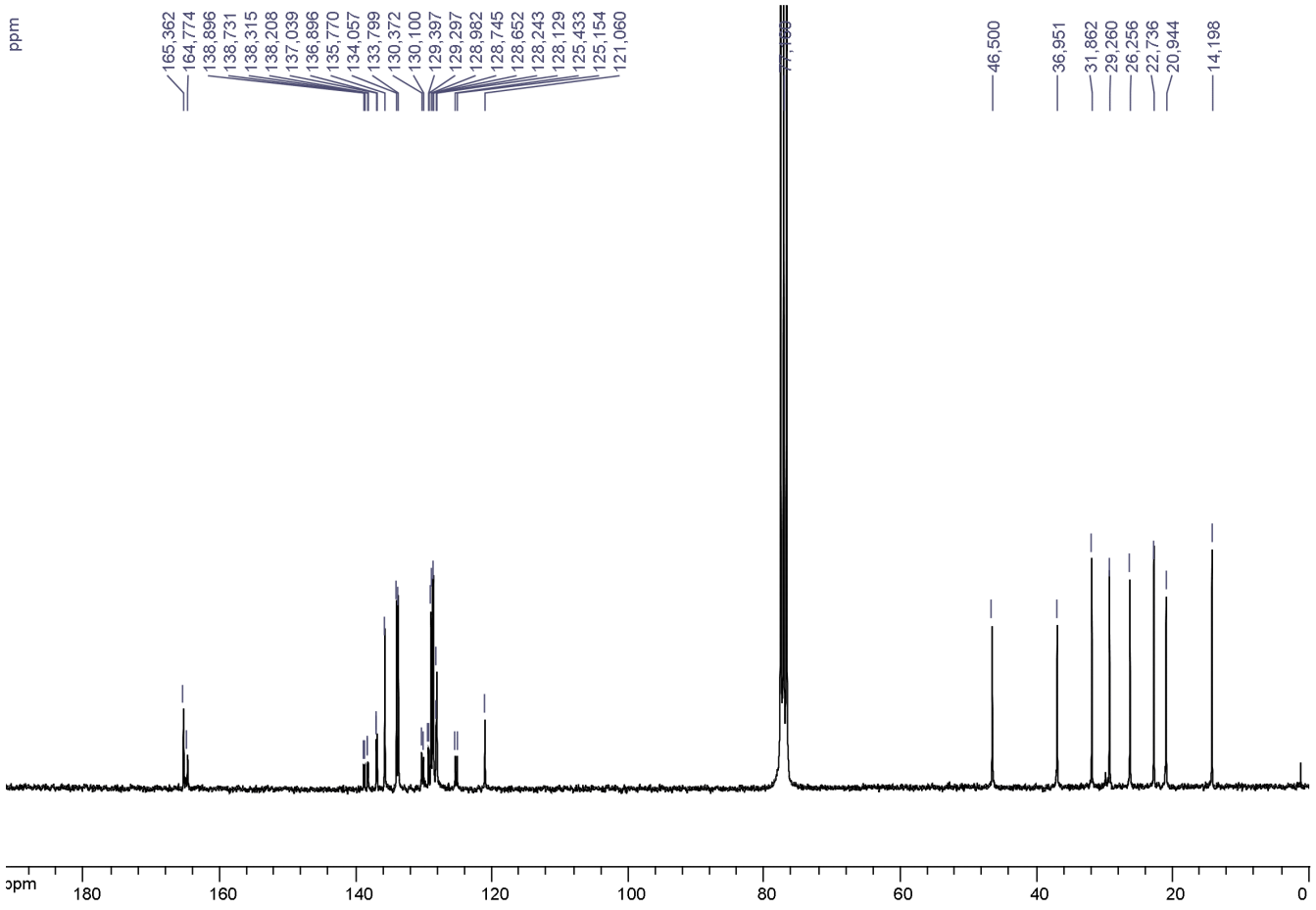
Method description: column = Chiralpak ID, hexane/ethanol 98/2, flow = 2 mL/min, detection at 254 nm.



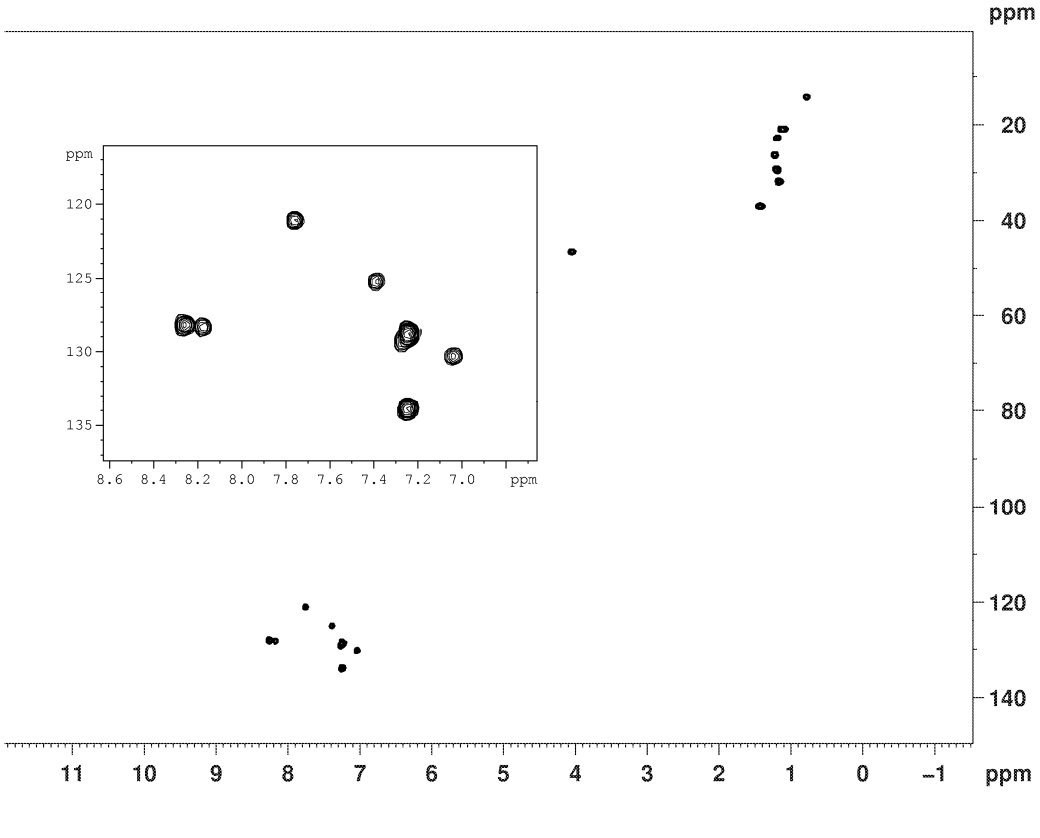
^{1}H-NMR ($CDCl_3$) ^{H}**BTA**^{PPh2}(***S***),(***S***)



$^{13}C\{^{1}H\}$-NMR ($CDCl_3$) **^{H}BTA^{PPh2}(*S*),(*S*)**

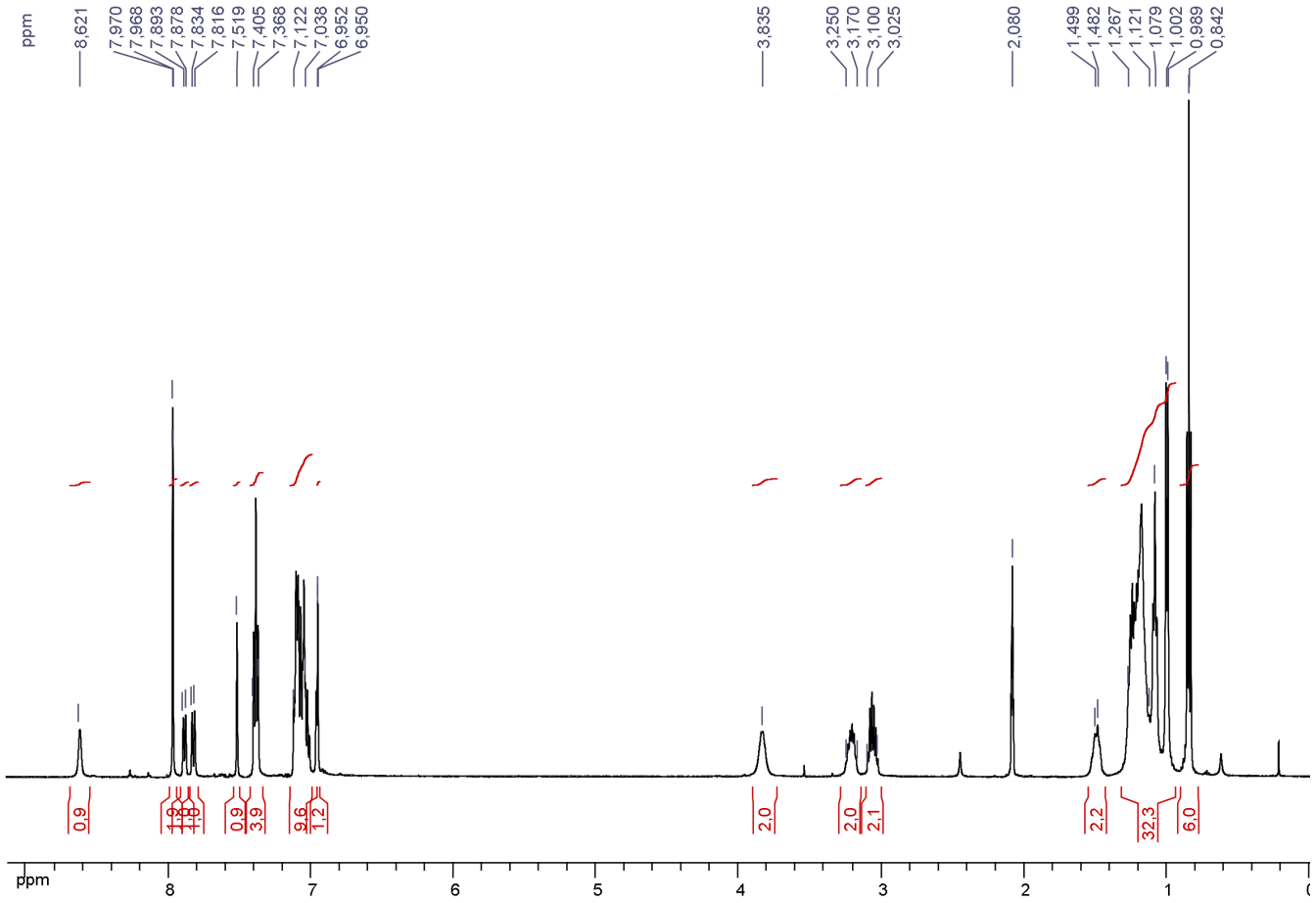


HSQC ($CDCl_3$) ^{H}**BTA**^{PPh2}(***S***),(***S***)

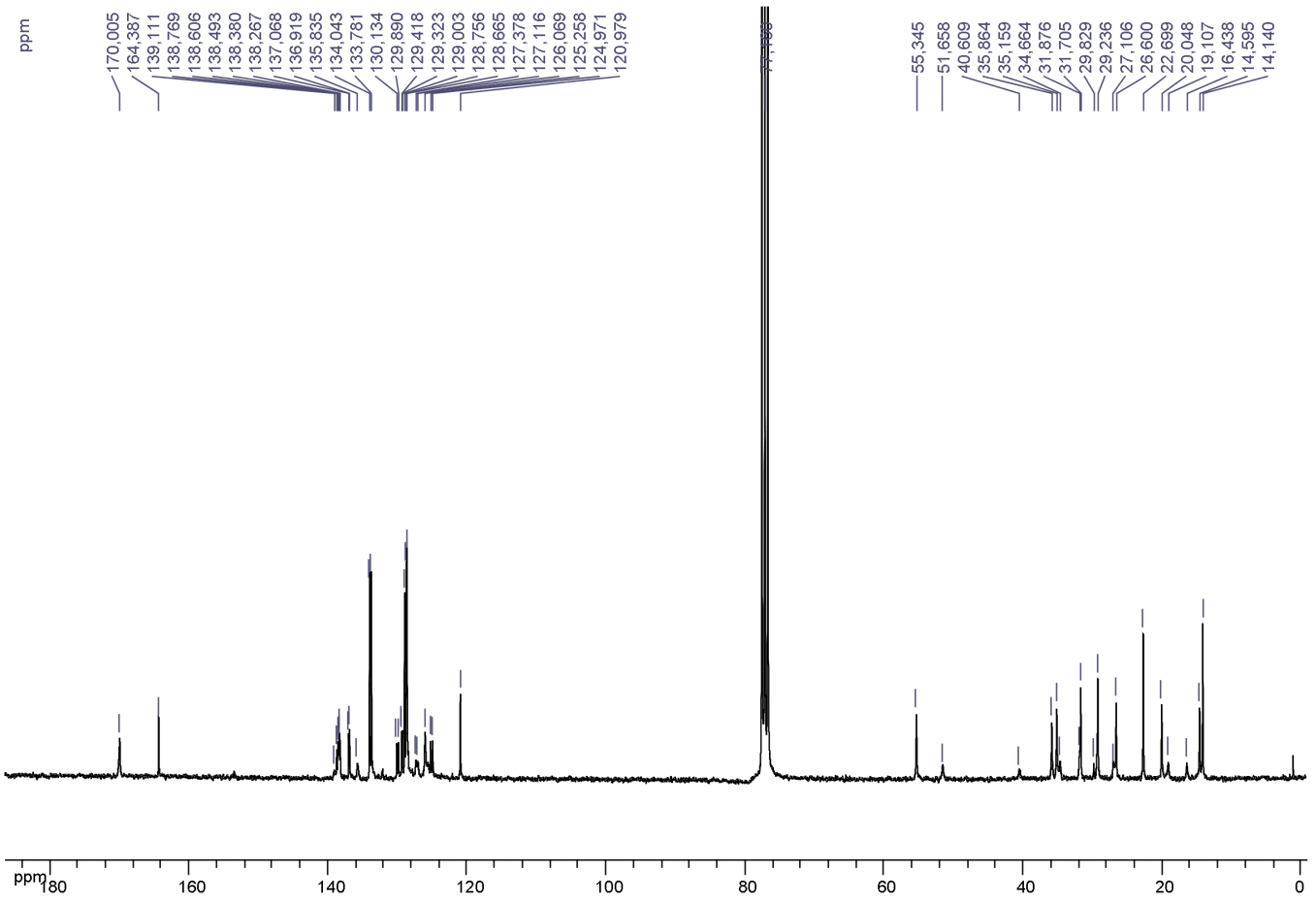



```
NAME        jb281b hsqc and 13C
EXPNO                        90
PROCNO                        1
Date_                  20130708
Time                      16.27
INSTRUM                    spect
PROBHD     5 mm PABBI 1H/
PULPROG                hsqcetgp
TD                         1024
SOLVENT                   CDCl3
NS                          168
DS                           16
SWH                  12500.000 Hz
FIDRES               12.207031 Hz
AQ                    0.0410100 sec
RG                         2050
DW                       40.000 usec
DE                        6.50 usec
TE                       300.9 K
CNST2               145.0000000
D0                    0.00000300 sec
D1                    1.50000000 sec
D4                    0.00172414 sec
D11                   0.03000000 sec
D13                   0.00000400 sec
D16                   0.00020000 sec
IN0                   0.00001815 sec
ZGOPTNS

======== CHANNEL f1 ========
NUC1                         1H
P1                        6.60 usec
P2                       13.20 usec
P28                    1000.00 usec
PL1                       1.50 dB
PL1W                19.56107330 W
SFO1                500.1620460 MHz

======== CHANNEL f2 ========
CPDPRG2                   garp
NUC2                        13C
P3                       14.00 usec
P4                       28.00 usec
PCPD2                    70.00 usec
PL2                      -1.20 dB
PL12                     12.78 dB
PL2W               129.80340576 W
PL12W                5.19141912 W
SFO2                125.7775820 MHz

------ GRADIENT CHANNEL -----
GPNAM1                SINE.100
GPNAM2                SINE.100
GPZ1                     80.00 %
GPZ2                     20.10 %
P16                    1000.00 usec
ND0                          2
TD                         256
SFO1                125.7776 MHz
FIDRES              107.598793 Hz
SW                      219.000 ppm
FnMODE          Echo-Antiecho
SI                        1024
SF                 500.1600450 MHz
WDW                       SINE
SSB                          2
LB                        0.00 Hz
GB                           0
PC                        4.00
SI                        1024
MC2             echo-antiecho
SF                 125.7653058 MHz
WDW                      QSINE
SSB                          2
```

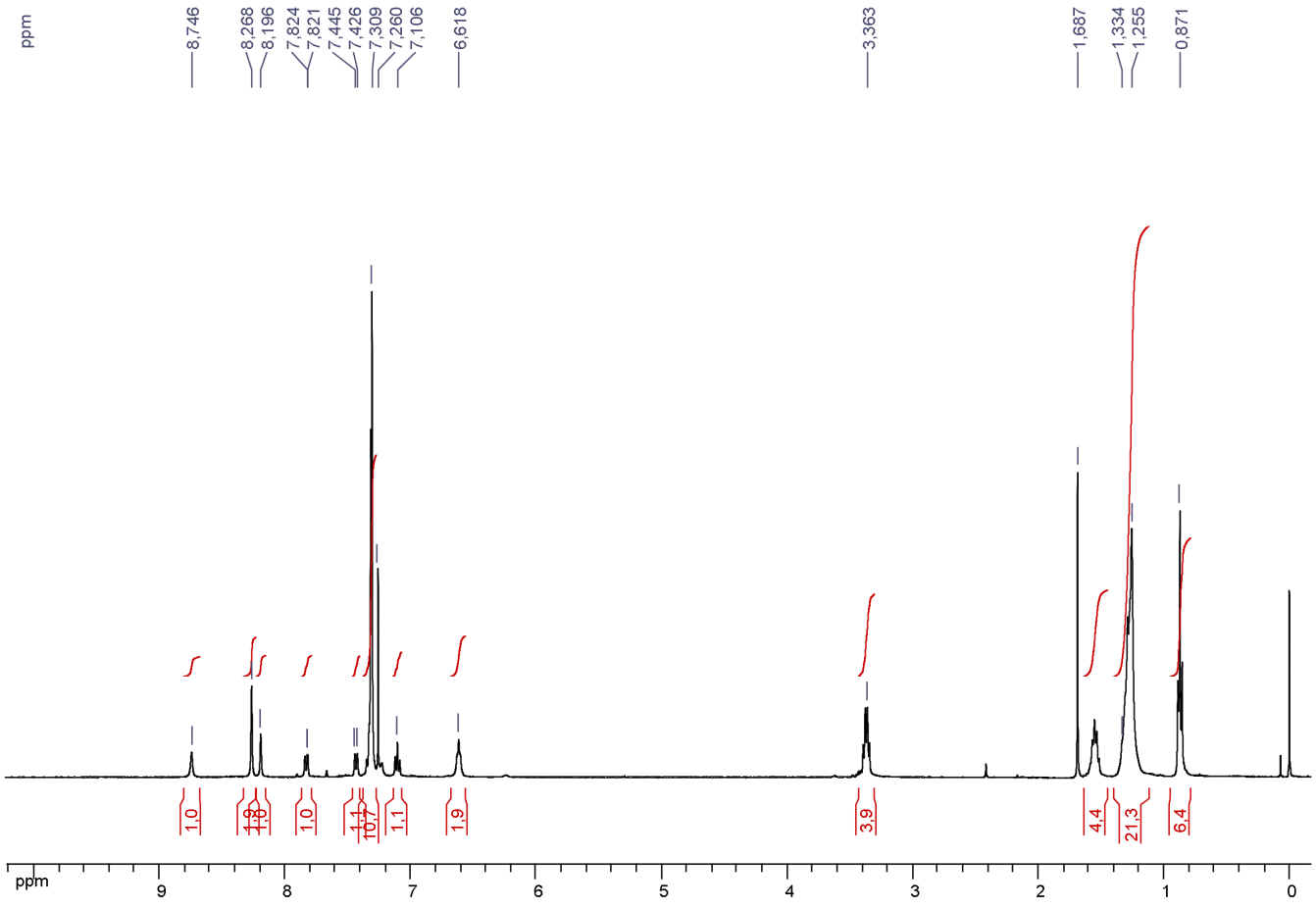
^{1}H-NMR (d_8-toluene, 374 K) **^{Et}BTA^{PPh2}(*S*),(*S*)**



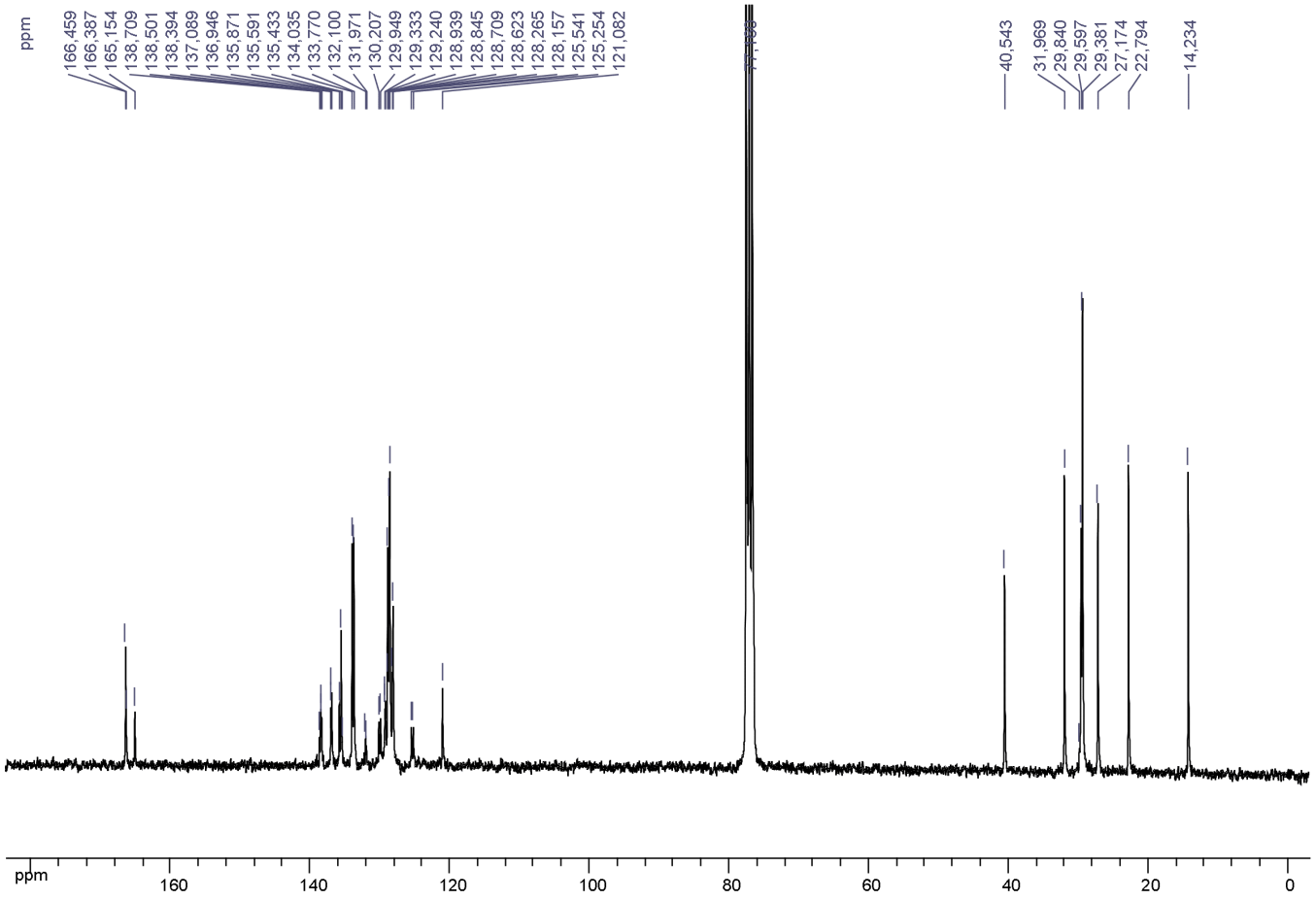
$^{13}C\{^{1}H\}$-NMR ($CDCl_3$, 298 K) **^{Et}BTA^{PPh2}(*S*),(*S*)**



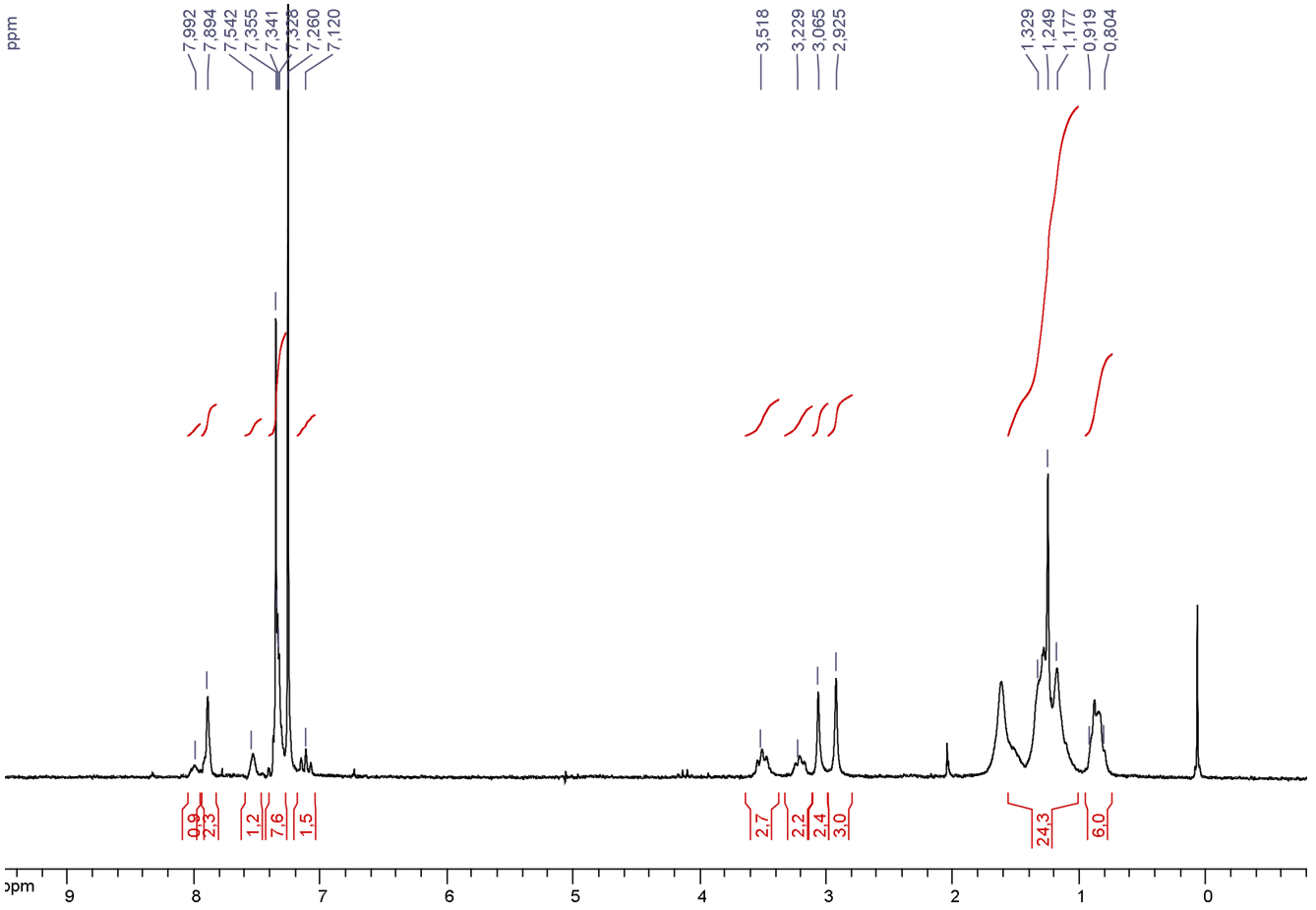
^{1}H-NMR ($CDCl_3$) **^{H}BTA^{PPh2}**



$^{13}C\{^{1}H\}$-NMR ($CDCl_3$) **^{H}BTA^{PPh2}**



^{1}H-NMR ($CDCl_3$) ^{Me}**BTA**^{PPh2}



$^{13}C\{^{1}H\}$-NMR ($CDCl_3$) **^{Me}BTA^{PPh2}**