Supporting Information for:

Regulation of Orthogonal Functions in a Dual Catalyst System. Subservient Role of a Non-chiral Lewis Acid in an Asymmetric Catalytic Heteroatom Diels-Alder Reaction.

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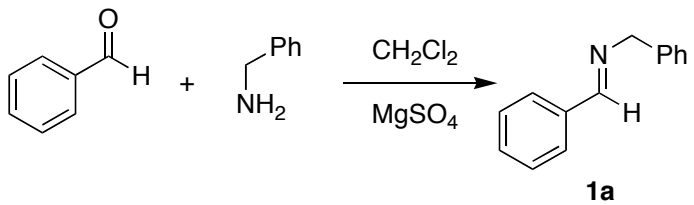
General Information

Unless otherwise indicated, all common reagents and solvents were used as obtained from commercial suppliers without further purification. Prior to use, tetrahydrofuran was distilled from Na/benzophenone ketyl, carbon tetrachloride and dichloromethane were distilled from calcium hydride and toluene was distilled from sodium. Routine NMR spectra were recorded on a 300 MHz INOVA instrument. Infrared spectra were recorded on a Nicolet IR/42 spectrometer and low resolution mass spectra were obtained on a GCMS, VARIAN Chrompack Saturn 2000R chromatograph/Saturn 2000R mass spectrometer. Enantiomeric excesses were all obtained using VARIAN ProStar HPLC. The special glassware was prepared by the Michigan State University glass blowing facility.

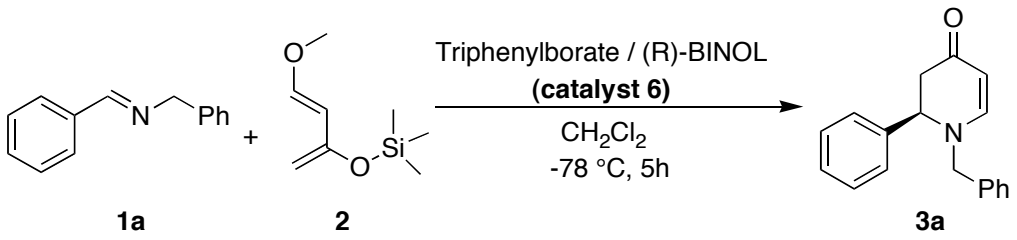
Preparation of imine 1a



1a

To a flame dried round bottom flask equipped with a magnetic stir bar was added benzaldehyde (5.23 g, 49.2 mmol) followed by $MgSO_4$ (7.5 g) and dichloromethane (100 mL). To this solution was then added benzylamine (5.20 g, 49.2 mmol). The resulting solution was then allowed to stir at room temperature for 5.5 hours. At the end of the reaction time, the solution was filtered to remove the $MgSO_4$, and the solvent was removed under reduced pressure. The resulting imine was an oil which was purified by bulb to bulb distillation (bp 133 °C, 3 mm Hg) yielding **1a** (6.24 g, 67% yield). The spectral data matched those reported in the literature[1]. ^{1}H-NMR ($CDCl_3$) δ 4.86 (s, 2H), 7.28-7.47 (m, 8H), 7.81-7.84 (m, 2H), 8.41 (s, 1H); ^{13}C-NMR ($CDCl_3$) δ 64.76, 126.70, 127.70, 128.00, 128.22, 128.32, 130.48, 135.93, 139.07, 161.65.

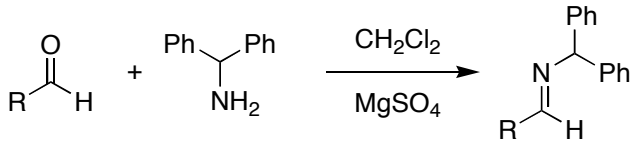
Preparation of 1-benzyl-2,3-dihydro-2-phenylpyridin-4(1*H*)-one (3a)



To a flame dried round bottom flask equipped with a magnetic stir bar was added 4 Å molecular sieves (1.0 g), triphenylborate (101 mg, 0.35 mmol) and (*R*)-BINOL (100 mg, 0.35 mmol). To this was added dichlormethane (10 mL) and the reaction mixture was allowed to stir for one hour at room temperature. The reaction was then cooled to 0 °C at which time the imine **1a** (68 mg, 0.35 mmol) was added in dichloromethane (1.0 mL). This was allowed to stir for 5 minutes at which time the reaction mixture was cooled to – 78 °C and the diene (**2**) (84 μL, 0.42 mmol) was added in dichloromethane (1.0 mL) dropwise over about 3 minutes. The reaction was then allowed to stir at —78 °C for an additional 5 hours. The reaction was then suction filtered to remove the molecular sieves. The resulting mixture was then washed once with water (30 mL) and once with sodium bicarbonate (sat.) (50 mL). The organic layers were then dried with magnesium sulfate, filtered and the solvent was removed under reduced pressure. The product was purified via flash column chromatography (36 cm x 2 cm), R_f = 0.06 (hexanes/ethyl acetate 2:1), yielding **3a** (62.3 mg, 68% yield). Spectral data were collected and were found to be identical to those in the literature.[8] The enantiomers could be separated by HPLC analysis on Chiralcel OJ-H (80:20 hexane/isopropanol, 1mL/min). Retention times: 26.15 and 31.81 min. The product **3a** obtained from the reaction was determined to be 85.5% ee (major peak = 26.15 min).

The same reaction was accomplished following the exact procedure except that 10 mol% (*R*)-BINOL (10 mg, 0.035 mmol) and 100 mol% (101 mg, 0.35 mmol) of $B(OPh)_3$ was used. This reaction yielded **3a** (38 mg, 41% yield) which was determined to be 40% ee (major peak = 26.15 min).

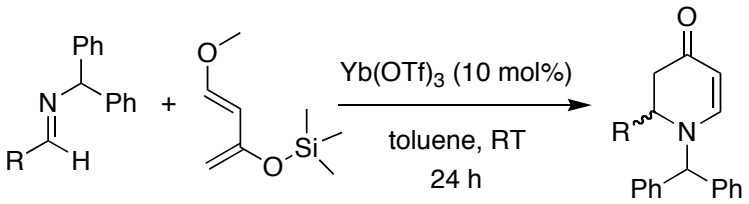
Preparation of imines 1b-1n



1b-n

All imines were prepared using the following general protocol and spectral data matched that published in the literature.[2-6] To a flame dried round bottom flask equipped with a magnetic stir bar was added the aldehyde (1.0 equivalent) followed by $MgSO_4$ (0.15g/mmol) and dichloromethane (1.5mL/mL). To this solution was then added the desired benzhydrylamine (1.0 equivalent). The resulting solution was then allowed to stir at room temperature overnight (18-25 hrs). At the end of the reaction time, the solution is filtered to remove the $MgSO_4$, and the solvent is removed under reduced pressure. If the resulting imine is a solid, then it is purified by recrystallization (hexane/dichloromethane). If the resulting imine is an oil, it is simply used as the crude oil.

General Protocol for the Preparation of Racemic 3b-3n

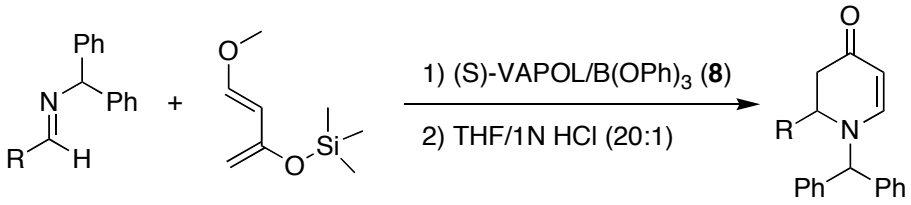


1b-n **2** **3b-n**

To a flame dried round bottom flask equipped with a magnetic stir bar was added the imine (**1b-n**) (1 mmol) and Ytterbium triflate (62 mg, 0.1 mmol). To the contents of the flask were then added toluene (10 mL) followed by Danishefsky's diene (**2**) (1.1 mmol). The reaction was then allowed to stir for 24 hours at which time the reaction was quenched with a mixture of THF and 1N HCl (20:1) and stirred for one hour. The contents were then transferred to a separatory funnel and extracted with dichloromethane (3 x 50 mL). The organic layers were then combined and dried over magnesium sulfate,

filtered, and the solvent was removed under reduced pressure. The racemic compounds (**3b-n**) were then purified via flash column chromatography.

Protocol for the aza-Diels-Alder reaction



1b-n **2** **3b-n**

Condition A. To a flame dried, argon purged single-necked flask that had its 14/20 joint replaced with a threaded Teflon high-vacuum T-shaped stop-cock equipped with a stir bar was added triphenylborate (**5**) (0.3125g, 1.0 mmol) and (S)-VAPOL (**7**) (27mg, 0.05 mmol). To this was added dichloromethane (2 mL) and then the flask was sealed with the stopcock and heated to 55 °C for one hour. After one hour, the solvent was removed via high vacuum and left under high vacuum at 55 °C for 0.5 hours yielding catalyst **8**. After cooling the stopcock was removed and replaced with a rubber septum. The catalyst was dissolved by the injection via syringe of 2.0 mL of a 1:1 mixture of toluene and CH_2Cl_2 (in two portions). The catalyst solution was transferred by syringe to a solution of the imine prepared as immediately below.

To a flame dried, argon purged homemade flask with a cold addition coil (see below) equipped with a stir bar was added the imine (**1b-n**) (1.0 mmol). The flask was topped with two rubber septa and the catalyst (**8**) was added in two 1.0 mL portions of toluene/dichloromethane (1:1) directly to the bottom of the flask by a syringe equipped with a long needle. This was allowed to stir for 5-10 minutes at room temperature and then cooled to –45 °C. Meanwhile, in a separate flame dried 5 or 10 mL round bottom flask purged with argon was added Danishefsky's diene (**2**) (0.38 mL, 2.0 mmol) and toluene/dichloromethane (1:1) (3.0 mL). The diene was taken up in a syringe and added over 3.0 hours via syringe pump through the cold addition coil. The reaction was then allowed to stir at –45 °C for the duration of the reaction (for reaction times see Table 3). After completion of the reaction, saturated sodium bicarbonate (~20 mL) was added to the reaction flask at –45 °C. This was then transferred to a separatory funnel and diluted with distilled water (25 mL) and extracted with three or four 30-40 mL portions of dichloromethane. TLC analysis of the organic layer after extraction showed a small amount of two compounds in addition to the dihydropyridinone. The crude ^{1}H-NMR confirmed that only a small amount of other products were present. Isolation gave small amounts of materials that had very complicated ^{1}H NMR spectra with broad peaks and assignment of structure was not made. These compounds were not observable by TLC after treatment of the reaction mixture

with 1N HCl diluted with THF. Therefore, the combined organic layers were placed in a 250 mL round bottom flask and the solvent was then removed via rotary evaporation. The flask was then equipped with a stir bar and cooled in an ice bath. To this was then added a previously cooled (0 °C) 20:1 mixture of THF and 1N HCl (50 mL) at which time the flask was removed from the ice bath and allowed to stir (monitored by TLC) until the undesired spots close to the desired product disappeared (usually less than one hour). This was then transferred to a separatory funnel containing water (75-100 mL) followed by extraction of the crude product with four 50 mL portions of dichloromethane. The combined organic layers were then dried with magnesium sulfate, filtered, and solvent was removed via rotary evaporation. The product (**3b-n)** was then purified via flash column chromatography (36 cm x 2 cm). The enantiomeric excess was determined by chiral HPLC analysis with the aid of an authentic sample of the racemic product. The absolute configurations of the products **3** were assigned as the (*S*)-enantiomers based on the reduction of **3h** to the known piperidinone **9** (see below). The primary product of the reaction should be an enol silane but several attempts to detect this compound in the crude reaction mixture failed. This included workup of reaction with pH 7 buffer rather than HCl and examining the crude ^{1}H NMR. The reaction quenched with buffer was also carefully chromatographed with careful collection of all the small bands that could be seen by TLC but no evidence for the enol silane product could be found.

Condition B. The exact same protocol was followed only 0.1 mmol (10 mol%) of (*S*)-VAPOL (**7**) was used during the preparation of the catalyst.

Condition C. The exact protocol was followed as described above for conditions B only a normal 25 mL round bottom flask was used in place of the special glassware containing the cold addition coil. Danishefsky's diene (**2**) was added by syringe pump through the septum.

Condition D. The exact protocol was followed as described above for conditions A only Danishefsky's diene (**2**) was added in 3 mL solvent dropwise over 5 minutes rather than over three hours.

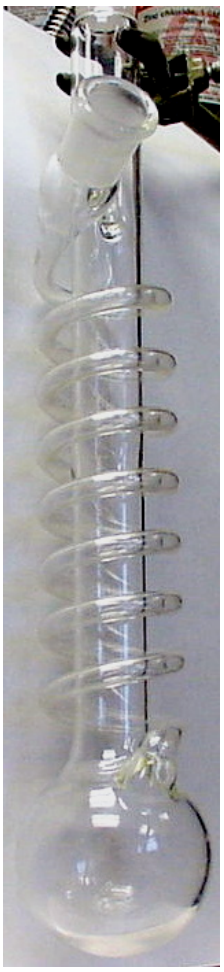
Condition E. The exact protocol was followed as described above for conditions A except that the catalyst was prepared with 30 mol% $B(OPh)_3$ and that an additional portion of $B(OPh)_3$ (100 mol %) was added along with the imine to the cold addition flask prior to the transfer of the catalyst.

Condition F. The exact protocol was followed as described above for conditions A except that the catalyst was prepared from 130 mol% $B(OPh)_3$ and also that 50 mol% phenol was added to the cold addition flask along with the imine prior to the transfer of the catalyst.

Condition G. The exact protocol was followed as described above for conditions A only a normal 25 mL round bottom flask was used in place of the special glassware containing the cold addition coil. Danishefsky's diene (**2**) was added by syringe pump through the septum.

Condition H. The exact protocol was followed as described above for conditions A only a normal 25 mL round bottom flask was used in place of the special glassware containing the cold addition coil. Danishefsky's diene (**2**) was added in 3 mL solvent dropwise over 5 minutes rather than over three hours..

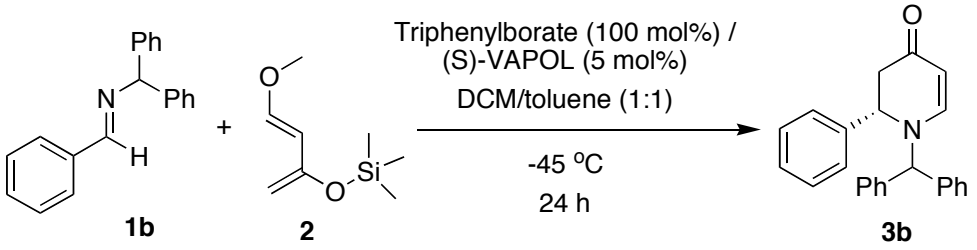
Cold Addition Flask



View 1

View 2

Preparation of (*S*)-1-benzhydryl-2,3-dihydro-2-phenylpyridin-4(1*H*)-one (3b)



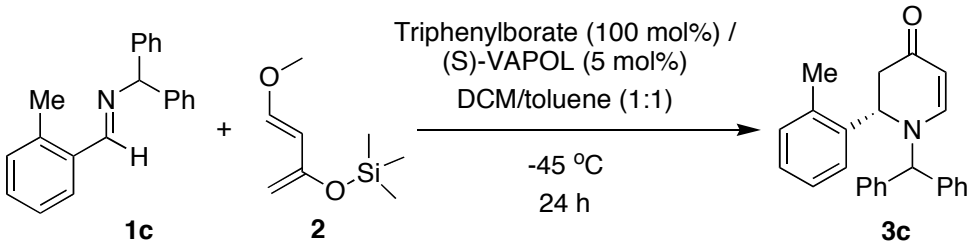
According to the general protocol described above (Condition A), **1b** (0.271g, 1 mmol) was treated with 5 mol% catalyst (**8**) and reacted with Danishefsky's diene (**2**) (0.38 mL, 2 mmol) at –45 °C for 24 hours. The product was purified via flash column chromatography (36 cm x 2 cm), R_f = 0.08 (2:1 hexane/EtOAc), yielding **3b** (0.288 g, 85% yield). A sample of racemic **3b** was prepared in 32% yield by the general procedure described above with the racemic catalyst $Yb(OTf)_3$. The enantiomers could be separated by HPLC analysis on Chiralcel OJ-H (75:25 hexane/isopropanol, 1mL/min). Retention times: 8.55 and 17.61 min. The **3b** obtained from the reaction was determined to be 90% ee (major peak = 17.61 min). Spectral data for **3b**: ^{1}H NMR ($CDCl_3$) δ 2.77-2.96 (m, 2H), 4.59 (t, 1H, *J* = 7.1 Hz), 5.06 (d, 1H, *J* = 8 Hz), 5.46 (s, 1H), 7.46-7.06 (m, 16H); ^{13}C NMR ($CDCl_3$) δ 43.51, 62.01, 67.67, 98.60, 127.04, 127.39, 128.01, 128.18, 128.32, 128.68, 128.82, 128.95, 129.36, 137.94, 138.11, 138.74, 151.30, 190.15; IR ($CDCl_3$) 3031m, 2959m, 2926m, 1645vs, 1591vs, 1570m cm^{-1}; mass spectrum *m/z* (% rel intensity) 339 M^+ (5), 338 (13), 168 (14), 167 (100), 165 (31), 152 (17), 104 (12), 103 (10), 77 (8), 51 (5), 50 (3). White solid, mp 136-138 °C. Optical rotation taken on 90% ee sample, $[\alpha]^{20}_D$ +106.2 (c 1.90, CH_2Cl_2)

If conditions C were employed the reaction gave **3b** in 90% yield and 86% enantiomeric excess. If conditions D were employed the reaction gave **3b** in 83% yield and 88% enantiomeric excess. If conditions E were employed the reaction gave **3b** in 96% yield and 84% ee. If conditions F were employed the reaction gave **3b** in 97% yield and 77% ee. If conditions G were employed the reaction gave **3b** in 85% yield and 88% ee. If conditions H were employed the reaction gave **3b** in 90% yield and 86% ee.

A series of reactions were also performed on imine **1b** with Danishefsky's diene with 5 mol % VAPOL with Conditions A except that the amount of $B(OPh)_3$ was varied between 5 mol % and 500 mol %. The data from these reactions are summarized in the Table below.

Entry	B-(OPh)3 (mol%)	(S)-VAPOL (mol%)	yield (%)	ee (%)
1	5	5	49.9	64.7
2	10	5	52.1	84.4
3	15	5	59	89.4
4	30	5	66.9	90.4
5	60	5	71.3	89.6
6	100	5	85	90
7	150	5	95.8	91.9
8	500	5	98	83

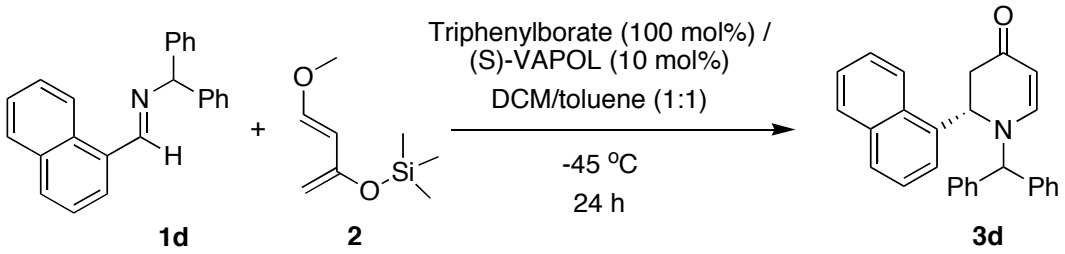
Preparation of (*S*)-1-benzhydryl-2,3-dihydro-2-*o*-tolylpyridin-4(1*H*)-one (3c)



According to the general protocol described above (Condition A), **1c** (0.285 g, 1 mmol) was treated with 5 mol% catalyst (**8**) and reacted with Danishefsky's diene (**2**) (0.38 mL, 2 mmol) at –45 °C for 24 hours. The product was purified via flash column chromatography (36 cm x 2 cm), R_f 0.09 (hexanes/ethyl acetate 2:1), yielding **3c** (0.237 g, 83% yield). A sample of racemic **3c** was prepared in 46% yield by the general procedure described above with the racemic catalyst $Yb(OTf)_3$. The enantiomers could be separated by HPLC analysis on Chiralcel OD (98:2 hexane/isopropanol, 1 mL/min). Retention times: 47.09 and 51.34 min. The product **3c** obtained from the reaction was determined to be 90% ee (major peak = 51.34 min). Recrystallization from hexanes/dichloromethane gave material that is 99.9% ee. Spectral data for **3c**: ^{1}H NMR ($CDCl_3$) δ 1.83 (s, 3H), 2.63-2.79 (m, 2H), 4.77 (t, 1H, *J* = 8.8 Hz), 5.05 (d, 1H, *J* = 8 Hz), 5.20 (s, 1H), 7.03-7.40 (m, 14H), 7.59 (d, 1H, *J* = 7.7 Hz); ^{13}C NMR ($CDCl_3$) δ 18.35, 42.83, 57.93, 67.13, 98.71, 126.33, 126.59, 127.46, 127.81, 127.93, 128.00, 128.55, 128.75, 129.26, 130.90, 135.55, 136.49, 137.55, 137.91, 152.06, 190.38; IR ($CDCl_3$) 3027s, 2953m, 2938m, 2909m, 1642vs,

1582vs cm^{-1}; mass spectrum *m/z* (% rel intensity) M^+ 353 (42), 281 (14), 267 (4), 249 (3), 225 (15), 209 (15), 207 (27), 182 (13), 168 (16), 167 (100), 166 (12), 165 (34), 152 (20), 133 (5), 117 (7), 115 (9), 104 (7), 103 (7), 91 (10), 77 (9), 73 (10), 51 (5). Anal calcd for $C_{25}H_{23}NO$: C, 84.95; H, 6.56; N, 3.96. Found: C, 84.96; H, 6.47; N, 3.89. White solid, mp 174-175 °C,. Optical rotation taken on 99.9% ee material, $[\alpha]^{20}_D$ +91.5 (c 1.25, CH_2Cl_2).

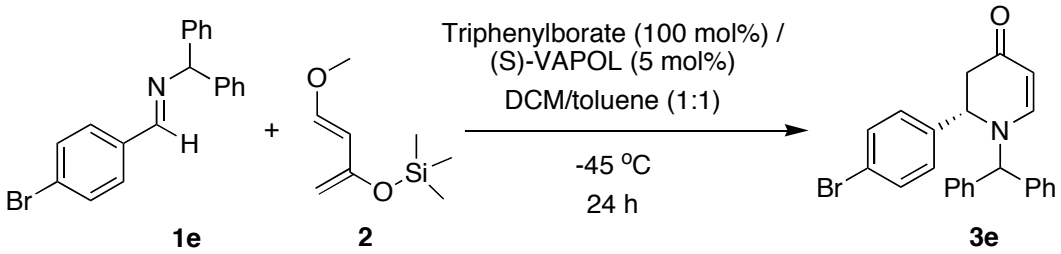
Preparation of (*S*)-1-benzhydryl-2,3-dihydro-2-(naphthalen-4-yl)pyridin-4(1*H*)-one (3d)



1d **2** **3d**

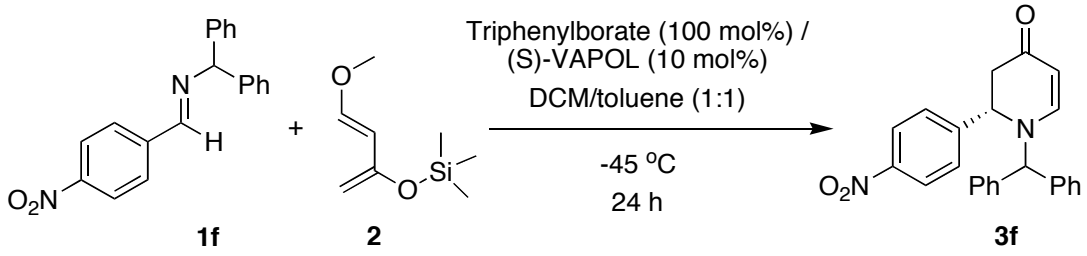
According to the general protocol described above (Condition B), **1d** (0.321 g, 1 mmol) was treated with 10 mol% catalyst (**8**) and reacted with Danishefsky's diene (**2**) (0.38 mL, 2 mmol) at –45 °C for 24 hours. The product was purified via flash column chromatography (36 cm x 2 cm), R_f 0.14 (2:1 hexanes/ethyl acetate), yielding **3d** (0.251 g, 78% yield). A sample of racemic **3d** was prepared in 52% yield by the general procedure described above with the racemic catalyst $Yb(OTf)_3$. The enantiomers could be separated by HPLC analysis on Chiralcel OJ-H (95:5 hexane/isopropanol, 2 mL/min). Retention times: 39.53 and 58.78 min. The product **3d** obtained from the reaction was determined to be 90% ee (major peak = 58.78 min). Spectral data for **3d**: ^{1}H NMR ($CDCl_3$) δ 2.96 (br s, 2H), 5.15 (d, 1H, *J* = 8 Hz), 5.29 (br s, 1H), 5.45 (s, 1H), 7.02-7.52 (m, 15H), 7.84-7.93 (m, 3H); ^{13}C NMR ($CDCl_3$) δ 42.09, 68.07, 98.30, 122.46, 125.12, 125.67, 126.17, 127.27, 127.94, 128.14, 128.63, 128.72, 128.97, 129.20, 129.43, 130.10, 132.95, 134.15, 137.62, 138.16, 151.30, 190.02 (two aromatic carbons not located); IR($CDCl_3$) 3061s, 3031s, 2901m, 1649vs, 1593vs, 1510s, 1449m, 1389s, 1240m, 1028m, 911m cm^{-1}; mass spectrum *m/z* (% rel intensity) M^+ 389 (33), 308 (8), 281 (5), 248 (4), 222 (6), 207 (12), 182 (12), 167 (100), 166 (11), 165 (37), 152 (32), 128 (4), 115 (6), 77 (5), 51 (4). Yellow solid, mp 73-81 °C. Optical rotation taken on 90% ee material $[\alpha]^{20}_D$ —3.9 (c 2.80, CH_2Cl_2).

Preparation of (*S*)-1-benzhydryl-2-(4-bromophenyl)-2,3-dihydropyridin-4(1*H*)-one (3e)



According to the general protocol described above (Condition A), **1e** (0.350 g, 1 mmol) was treated with 5 mol% catalyst (**8**) and reacted with Danishefsky's diene (**2**) (0.38 mL, 2 mmol) at –45 °C for 24 hours. The product was purified via flash column chromatography (36 cm x 2 cm), R_f = 0.07 (hexane/ethyl acetate 2:1), yielding **3e** (0.294 g, 84% yield). A sample of racemic **3e** was prepared in 48% yield by the general procedure described above with the racemic catalyst $Yb(OTf)_3$. The enantiomers could be separated by HPLC analysis on Chiralcel OJ-H (80:20 hexanes/isopropanol, 1mL/min). Retention times: 16.36 and 28.10 min. The **3e** obtained from the reaction was determined to be 89% ee (major peak = 28.10 min). Spectral data for **3e**: ^{1}H NMR ($CDCl_3$) δ 2.62 (dd, 1H, *J* = 16.5, 8.4 Hz), 2.81 (dd, 1H, *J* = 16.5, 6.9 Hz), 4.47 (t, 1H, *J* = 7.5 Hz), 4.96 (d, 1H, *J*= 7.8 Hz), 5.34 (s, 1H), 6.98-7.52 (m, 15H); ^{13}C NMR ($CDCl_3$) δ 43.19, 61.20, 67.90, 98.76, 122.07, 127.24, 128.05, 128.22, 128.63, 128.69, 128.82, 129.23, 132.01, 137.53, 137.76, 137.84, 150.95, 189.51; IR ($CDCl_3$) 3028m, 1653vs, 1578vs, 1487s, 1449s, 1221s, 1140s cm^{-1}; mass spectrum *m/z* (% rel intensity) 419 M^+ (18, ^{81}Br), 417 M^+ (19, ^{79}Br), 182 (12), 168 (15), 167 (100), 166 (9), 165 (31), 152 (15), 103 (7), 102 (7), 77 (6), 51 (4), 50 (4). Anal calcd for $C_{24}H_{20}BrNO$: C, 68.91; H, 4.82; N, 3.35. Found: C, 68.97; H, 4.60; N, 3.26. White solid, mp141-142 °C. Optical rotation taken on 90% ee sample, $[\alpha]^{20}_D$ +117.2 (c 1.285, CH_2Cl_2).

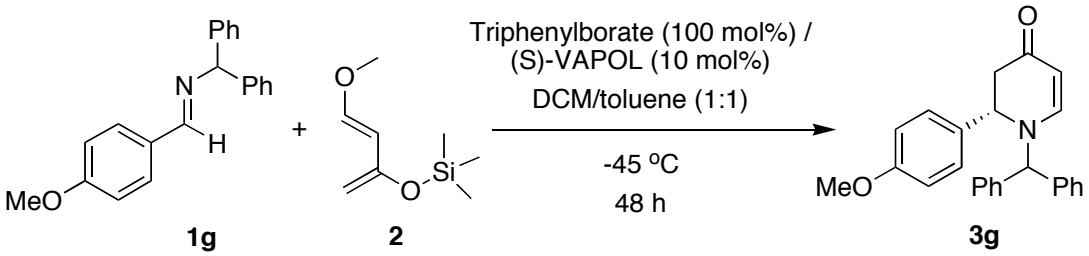
Preparation of (*S*)-1-benzhydryl-2,3-dihydro-2-(4-nitrophenyl)pyridin-4(1*H*)-one (3f)



According to the general protocol described above (Condition B), **1f** (0.316 g, 1 mmol) was treated with 10 mol% catalyst (**8**) and reacted with Danishefsky's diene (**2**) (0.38 mL, 2 mmol) at –45 °C for 24 hours. The product was purified via flash column chromatography (36 cm x 2 cm), R_f 0.04 (hexanes/ethyl acetate 2:1), yielding **3f** (0.218 g, 69% yield). A sample of racemic **3f** was prepared in 28% yield by the general procedure described above with the racemic catalyst $Yb(OTf)_3$. The

enantiomers could be separated by HPLC analysis on Chiralpak AD (75:25 hexane/isopropanol, 1 mL/min). Retention times: 6.31 and 12.46 min. The product **3f** obtained from the reaction was determined to be 73% ee (major peak = 6.31 min). When the solvent was removed from a solution of hexanes/ethyl acetate a waxy material deposited on the sides of the flask. This was found to be pure **3f** which was 99.9% optically pure by HPLC. Spectral data for **3f**: ^{1}H NMR ($CDCl_3$) δ 2.61 (dd, 1H, *J* = 16.5, 6.6 Hz), 2.98 (dd, 1H, *J* = 16.5, 7.1 Hz), 4.69 (t, 1H, *J* = 6.9 Hz), 5.02 (d, 1H, *J*=8 Hz), 5.39 (s, 1H), 7.00-7.48 (m, 13H), 8.21 (d, 2H, *J* = 2 Hz); ^{13}C NMR ($CDCl_3$) δ 42.65, 60.83, 68.86, 99.05, 124.07, 127.18, 127.68, 128.23, 128.44, 128.84, 128.90, 129.14, 137.08, 137.75, 146.09, 147.49, 150.66, 188.60; IR ($CDCl_3$) 3061w, 2910w, 1644s, 1590vs, 1578vs, 1520s, 1346vs, 1219m, 1138m cm^{-1}; mass spectrum *m/z* (% rel intensity) 286 M+2 (2), 285 M+1 (1), 384 M$^+$ (2), 355 (20), 341 (11), 327 (9), 281 (54), 267 (17), 251 (7), 227 (18), 226 (14), 225 (45), 224 (19), 223 (13), 211 (20), 210 (14), 209 (67), 208 (42), 207 (100), 194 (19), 191 (19), 177 (10), 149 (13), 147 (13), 135 (16), 133 (18), 119 (8), 105 (9), 103 (9), 91 (13), 77 (16), 75 (17), 73 (43), 51 (6). Light yellow solid, mp 192-197°C. Optical rotation taken on 99.9 % ee sample, $[\alpha]^{20}_{D}$ +106.5 (c 3.835, CH_2Cl_2).

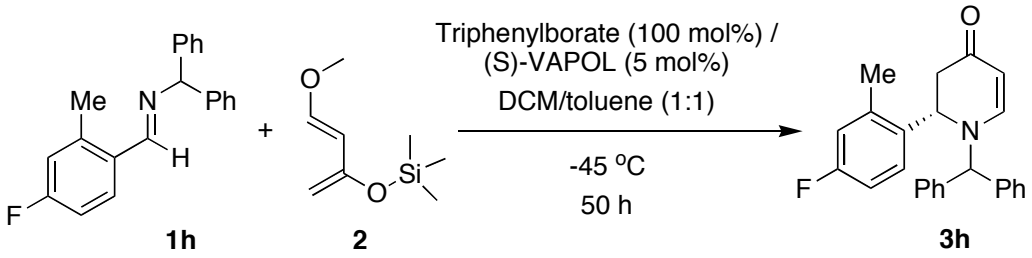
Preparation of (*S*)-1-benzhydryl-2,3-dihydro-2-(4-methoxyphenyl)pyridin-4(1*H*)-one (3g)



According to the general protocol described above (Condition B), **1g** (0.301 g, 1 mmol) was treated with 10 mol% catalyst (**8**) and reacted with Danishefsky's diene (**2**) (0.38 mL, 2 mmol) at –45 °C for 48 hours. The product was purified via flash column chromatography (36 cm x 2 cm), R_f 0.04 (hexanes/ethyl acetate 2:1), yielding **3g** (0.214 g, 71% yield). A sample of racemic **3g** was prepared in 40% yield by the general procedure described above with the racemic catalyst $Yb(OTf)_3$. The enantiomers could be separated by HPLC analysis on Chiralcel OJ-H (90:10 hexane/isopropanol, 2 mL/min). Retention times: 17.38 and 33.63 min. The product **3g** obtained from the reaction was determined to be 90% ee (major peak = 33.63 min). Spectral data for **3g**: ^{1}H NMR ($CDCl_3$) δ 2.67-2.82 (m, 2H), 3.75 (s, 3H), 4.43 (t, 1H *J* = 8.3 Hz), 4.98 (d, 1H, *J* = 7.4 Hz), 5.39 (s, 1H), 6.85 (d, 1H, *J* = 8 Hz), 6.84-7.37 (m, 14H); ^{13}C NMR ($CDCl_3$) δ 43.65, 54.97, 61.42, 67.19, 98.42, 114.15, 127.32, 127.84, 127.97, 128.25, 128.53, 128.69, 129.22, 130.54, 137.99, 138.03, 151.21, 159.34, 190.26; IR ($CDCl_3$) 3042w, 2965w, 2816w, 1645vs, 1581vs, 1578vs, 1513s, 1250s cm^{-1}; mass spectrum *m/z* (% rel intensity) 371 M+2 (10), 369 M$^+$ (2), 355 (20), 341 (12), 327 (9), 281 (52), 267 (17), 265 (10), 225 (46), 224 (14), 223 (8), 211 (18), 209 (60), 207 (100), 167 (86),

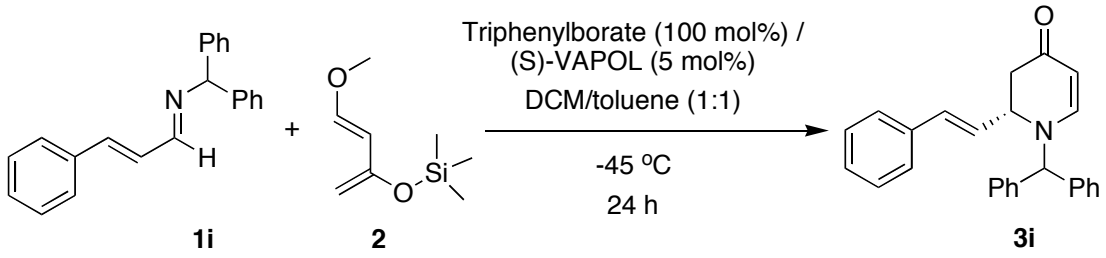
152 (24), 133 (31), 104 (21), 91 (30), 73 (41), 51 (19). White solid, mp 56-60 °C. Optical rotation taken on an 82% ee sample, $[\alpha]^{20}_{D}$ +147.4 (c 0.95, CH_2Cl_2,).

Preparation of (*S*)-1-benzhydryl-2-(4-fluoro-2-methylphenyl)-2,3-dihydropyridin-4(1*H*)-one (3h)



According to the general protocol described above (Condition A), **1h** (0.303 g, 1 mmol) was treated with 5 mol% catalyst (**8**) and reacted with Danishefsky's diene (**2**) (0.38 mL, 2 mmol) at –45 °C for 50 hours. The product was purified via flash column chromatography (36 cm x 2 cm), R_f 0.08 (hexanes/ethyl acetate 2:1), yielding **3h** (0.255 g, 89% yield). A sample of racemic **3h** was prepared in 34% yield by the general procedure described above with the racemic catalyst $Yb(OTf)_3$. The enantiomers could be separated by HPLC analysis on Chiralcel OD (with guard column) (98:2 hexane/isopropanol, 1 mL/min). Retention times: 55.03 and 63.06 min. The product **3h** obtained from the reaction was determined to be 89% ee (major peak = 63.06 min). Spectral data for **3h**: ^{1}H NMR ($CDCl_3$) δ 1.83 (s, 3H), 2.63-2.79 (m, 2H), 4.77 (t, 1H, *J* = 8.7 Hz), 5.05 (d, 1H, *J* = 7.7 Hz), 5.40 (s, 1H), 7.03-7.38 (m, 13H), 7.58 (d, 1H, *J* = 7.4 Hz); ^{13}C NMR ($CDCl_3$) δ 18.35, 42.82, 57.93, 67.13, 98.70, 126.33, 126.58, 127.46, 127.81, 127.93, 128.00, 128.55, 128.75, 129.25, 130.89, 135.55, 136.47, 137.55, 137.91, 152.07, 190.35; IR ($CDCl_3$) 3027w, 1645vs, 1578vs, 1443m, 1238s cm^{-1}; mass spectrum *m/z* (% rel intensity) 371 M^+ (91), 342 (1), 294 (1), 262 (7), 248 (8), 206 (9), 182 (25), 168 (13), 167 (100), 166 (14), 165 (40), 152 (8), 133 (10), 115 (9), 77 (6), 51 (5). White solid, 55-59 °C. Optical rotation taken on 88% ee sample, $[\alpha]^{20}_{D}$ +56.9 (c 2.185, CH_2Cl_2).

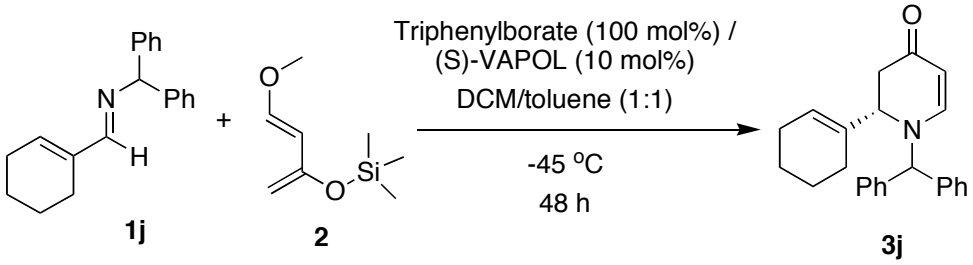
Preparation of (*S*)-1-benzhydryl-2,3-dihydro-2-styrylpyridin-4(1*H*)-one (3i)



According to the general protocol described above (Condition A), **1i** (0.297 g, 1 mmol) was treated with 5 mol% catalyst (**8**) and reacted with Danishefsky's diene (**2**) (0.38 mL, 2 mmol) at –45 °C for 24 hours. The product was purified via

flash column chromatography (36 cm x 2 cm), R_f = 0.05 (hexanes/ethyl acetate 2:1), yielding **3i** (0.033 g, 11% yield). A sample of racemic **3i** was prepared in 7% yield by the general procedure described above with the racemic catalyst $Yb(OTf)_3$. The enantiomers could be separated by HPLC analysis on Chiralcel OD (with guard column) (75:25 hexane/isopropanol, 1mL/min). Retention times: 10.82 and 19.13 min. The product **3i** obtained from the reaction was determined to be 0% ee. Spectral data for **3i**: ^{1}H NMR ($CDCl_3$) δ 2.52 (dd, 1H, *J* = 16.2, 6.0 Hz), 2.86 (dd, 1H, *J* = 16.5, 6.6 Hz), 4.14-4.20 (m, 1H), 4.96 (d, 1H, *J* = 7.7 Hz), 5.67 (s, 1H), 6.29-47 (m, 2H), 6.87 (d, 1H, *J* = 7.7 Hz), 7.09 (d, 2H, *J* = 6.0 Hz), 7.24-7.45 (m, 13H); ^{13}C NMR ($CDCl_3$) δ 41.28, 60.60, 68.25, 97.89, 124.19, 126.38, 127.29, 127.93, 128.02, 128.15, 128.40, 128.70, 128.761, 129.28, 133.75, 135.49, 137.87, 138.63, 150.19, 190.11; IR ($CDCl_3$) 3031m, 2926m, 1642vs, 1576vs, 1449m, 1223m, 1140m; mass spectrum *m/z* (% rel intensity) 365 M^+ (54), 363 (11), 288 (7), 207 (11), 198 (11), 168 (34), 167 (100), 166 (12), 365 (35), 152 (27), 115 (10), 102 (7), 101 (7), 91 (14), 76 (8), 64 (6). White solid, mp 148-151 °C.

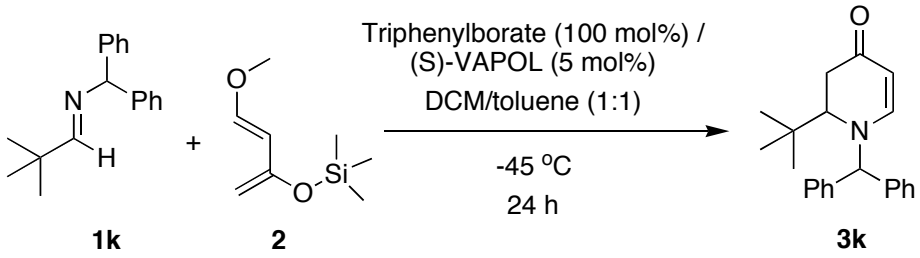
Preparation of (*S*)-1-benzhydryl-2-cyclohexenyl-2,3-dihydropyridin-4(1*H*)-one (3j)



According to the general protocol described above (Condition B), **1j** (0.275 g, 1 mmol) was treated with 10 mol% catalyst (**8**) and reacted with Danishefsky's diene (**2**) (0.38 mL, 2 mmol) at –45 °C for 48 hours. The product was purified via flash column chromatography (36 cm x 2 cm), R_f 0.07 (hexanes/ethyl acetate 2:1), yielding **3j** (0.124 g, 45% yield). A sample of racemic **3j** was prepared in 30% yield by the general procedure described above with the racemic catalyst $Yb(OTf)_3$. The enantiomers could be separated by HPLC analysis on Chiralcel OJ-H (90:10 hexane/isopropanol, 1mL/min). Retention times: 11.77 and 15.97 min. The product **3j** obtained from the reaction was determined to be 93% ee (major peak = 15.97 min). Crystallization from CH_2Cl_2/hexanes gave **3j** that was 98% ee. Spectral data for **3j**: ^{1}H NMR ($CDCl_3$) δ 1.53-1.79 (m, 4H), 2.04-2.15 (m, 4H), 2.56-2.69 (m, 2H), 3.88 (t, 1H, *J* = 7.7 Hz), 4.87 (d, 1H, *J* = 7.7 Hz), 5.50 (s, 1H), 5.57 (s, 1H), 6.93 (d, 1H, *J* = 7.7 Hz), 7.04-7.42 (m, 10H); ^{13}C NMR ($CDCl_3$) δ 21.84, 22.81, 23.87, 24.80, 39.78, 64.26, 67.10, 97.45, 127.17, 127.34, 127.70, 127.96, 128.58, 129.25, 134.01, 138.25, 128.58, 151.19, 190.82 (one aromatic carbon not located); IR ($CDCl_3$) 3028w, 2928m, 1643vs, 1589vs, 1578vs, 1449m, 1235m, 1219m, 1142m cm^{-1}; mass spectrum *m/z* (% rel intensity) M^+ 343 (42), 326 (2), 281 (10), 267 (3), 225 (10), 209 (13), 208 (10), 207 (22), 193 (11), 168 (15), 167 (100), 166 (11), 165 (34), 152 (21), 133

(5), 115 (5), 91 (10), 77 (12), 73 (9), 51 (6). White solid, mp 189-191 °C. Optical rotation taken on a 98% ee sample, $[\alpha]^{20}_{D}$ +137.2 (c 1.055, CH_2Cl_2).

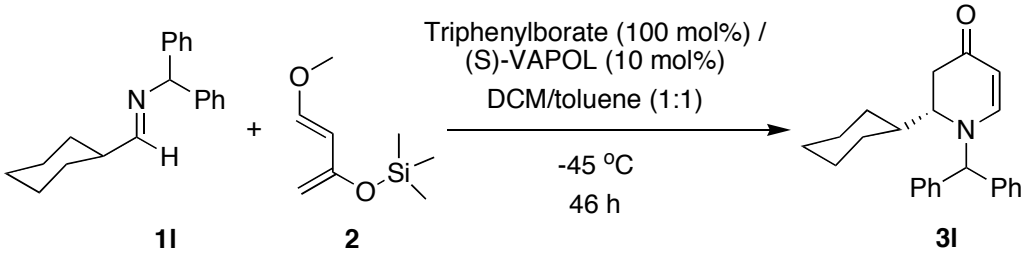
Preparation of 2-*tert*-butyl-1-benzhydryl-2,3-dihydropyridin-4(1*H*)-one (3k)



1k **2** **3k**

According to the general protocol described above (Condition A), **1k** (0.251 g, 1 mmol) was treated with 5 mol% catalyst (**8**)) and reacted with Danishefsky's diene (**2**) (0.38 mL, 2 mmol) at –45 °C for 24 hours. The reaction resulted in no product. Preparation of racemic **3k** was attempted using the general procedure described above with the racemic catalyst $Yb(OTf)_3$ but no product was formed.

Preparation of (*S*)-1-benzhydryl-2-cyclohexyl-2,3-dihydropyridin-4(1*H*)-one (3l)

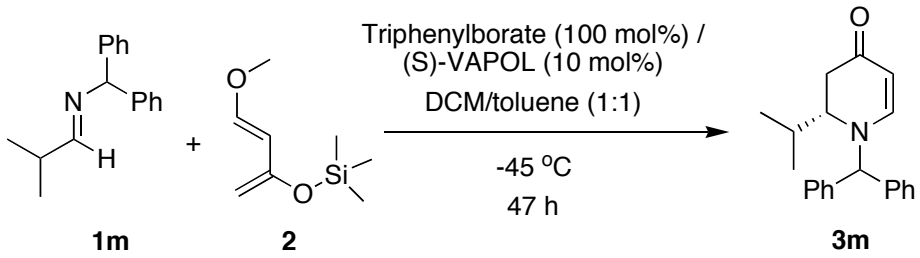


1l **2** **3l**

According to the general protocol described above (Condition B), **1l** (0.277 g, 1 mmol) was treated with 10 mol% catalyst (**8**) \and reacted with Danishefsky's diene (**2**) (0.38 mL, 2 mmol) at –45 °C for 46 hours. The product was purified via flash column chromatography (36 cm x 2 cm) R_f = 0.09 (hexane/ethyl acetate 2:1) yielding **3l** (0.250 g, 90% yield). A sample of racemic **3l** was prepared in 41% yield by the general procedure described above with the racemic catalyst $Yb(OTf)_3$. The enantiomers could be separated by HPLC analysis on Chiralcel OJ-H (90:10 hexanes/isopropanol, 1mL/min). Retention times: 8.98 and 13.85 min. The product **3l** obtained from the reaction was determined to be 93% ee (major peak = 13.85 min). Spectral data for **3l**: ^{1}H NMR ($CDCl_3$) δ 0.96-1.20 (m, 5H), 1.59-1.95 (m, 6H), 2.35 (d, 1H, *J*=16.8 Hz), 2.67 (dd, 1H, *J* = 17.1, 8.1 Hz), 3.27 (br t, 1H, *J* = 1.9 Hz), 4.76 (d, 1H, *J* = 7.5 Hz), 5.68 (s, 1H), 6.82 (d, 1H, *J* = 7.8 Hz), 7.04 (d, 2H, *J* = 7.5 Hz)**,** 7.19-7.37 (m, 8H); ^{13}C NMR ($CDCl_3$) δ 25.76, 26.00, 26.06, 28.08, 29.43, 36.05, 40.51, 61.78, 69.56, 96.71, 126.99, 127.93, 128.17, 128.66, 128.69, 129.31, 137.61, 139.45, 150.21, 190.70; IR ($CDCl_3$) 3063w, 3030w, 2928vs, 2853vs, 1638vs,

1576vs, 1449s, 1223s, 1143s cm^{-1}; mass spectrum *m/z* (% rel intensity) 345 M^+ (63), 346 (19), 344 (9), 262 (12), 208 (4), 182 (16), 168 (15), 167 (100), 166 (9), 165 (31), 152 (19), 115 (5), 91 (4), 77 (6), 51 (4). Anal calcd for $C_{24}H_{27}NO$: C, 83.44; H, 7.88; N, 4.05. Found: C, 83.03; H, 8.11; N, 4.09. White solid, mp 132-134 °C. Optical rotation taken on 93% ee sample, $[\alpha]^{20}_D$ –127.2 (c 1.13, CH_2Cl_2, 93% ee).

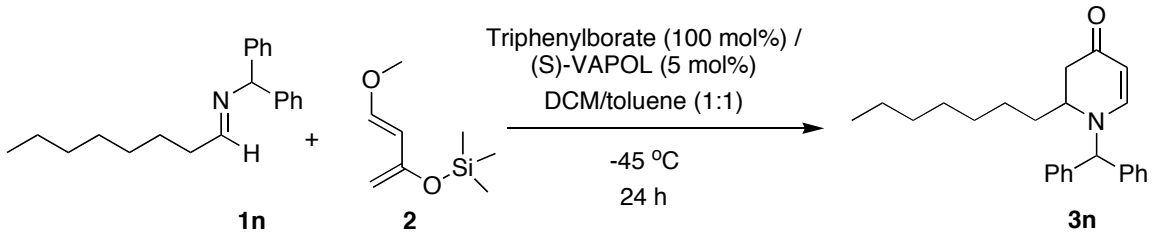
Preparation of (*S*)-1-benzhydryl-2,3-dihydro-2-isopropylpyridin-4(1*H*)-one (3m)



1m **2** **3m**

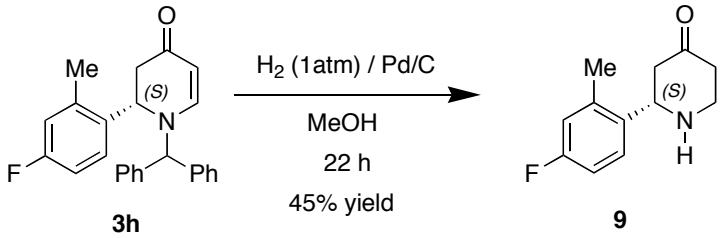
According to the general protocol described above (Condition B), **1m** (0.237 g, 1 mmol) was treated with 10 mol% catalyst (**8**) and reacted with Danishefsky's diene (**2**) (0.38 mL, 2 mmol) at –45 °C for 47 hours. The product was purified via flash column chromatography (36 cm x 2 cm), R_f = 0.06 (hexanes/ethyl acetate 2:1), yielding **3m** (0.152 g, 64% yield). A sample of racemic **3m** was prepared in 48% yield by the general procedure described above with the racemic catalyst $Yb(OTf)_3$. The enantiomers could be separated by HPLC analysis on Chiralpak AS (70:30 hexanes/isopropanol, 1mL/min). Retention times: 14.82 and 32.15 min. The product **3m** obtained from the reaction was determined to be 90% ee (major peak = 14.82 min). Spectral data for **3m**: ^{1}H NMR ($CDCl_3$) δ 0.98 (d, 6H, *J* = 9.3 Hz), 2.34 (d, 1H, *J* = 16.5 Hz), 2.34-2.41 (m, 1H), 2.64 (dd, 1H, *J* = 17.1, 8.1 Hz), 3.28-3.33 (br m, 1H), 4.78 (d, 1H, *J* = 7.2 Hz), 5.70 (s, 1H), 6.83 (d, 1H, *J* = 7.8 Hz), 7.05 (d, 2H, *J* = 7.5 Hz), 7.24-7.43 (m, 8H); ^{13}C NMR ($CDCl_3$) δ 17.44, 19.32, 29.90, 35.23, 62.06, 69.18, 96.83, 126.99, 127.93, 128.15, 128.64, 128.70, 129.34, 137.66, 139.28, 150.24, 190.77; IR ($CDCl_3$) 2965s, 2932m, 2899m, 2876m, 1640vs, 1578vs, 1449s, 1227s, 1144s; mass spectrum *m/z* (% rel intensity) M+1 306 (19), 305 M^+ (75), 304 (13), 262 (37), 228 (10), 191 (9), 168 (15), 167 (100), 166 (9), 165 (34), 152 (18), 105 (5), 77 (8), 50 (5). Light yellow solid, mp 139-142 °C. Optical rotation taken a a 84% ee sample, $[\alpha]^{20}_D$ –155.2 (c 0.93, CH_2Cl_2).

Preparation of 1-benzhydryl-2-heptyl-2,3-dihydropyridin-4(1*H*)-one (3n)



According to the general protocol described above (Condition A), **1n** (0.294 g, 1 mmol) was treated with 5 mol% catalyst (**8**) and reacted with Danishefsky's diene (**2**) (0.38 mL, 2 mmol) at –45 °C for 24 hours. The product was purified via flash column chromatography (36 cm x 2 cm), R_f = 0.10 (hexanes/ethyl acetate 2:1), yielding **3n** (0.098 g, 41% yield). A sample of racemic **3n** was prepared in 65% yield by the general procedure described above with the racemic catalyst $Yb(OTf)_3$. The enantiomers could be separated by HPLC analysis on Chiralpak AD (95:5 hexane/isopropanol, 1mL/min). Retention times: 13.25 and 16.32 min. The product **3n** obtained from the reaction was determined to be 0% ee. A control was performed to determined the non-chiral background reaction which involved 100 mol% B(OPh)3. When this reaction was carried out under the same conditions the racemic product **3n** was obtained in 40% yield. Spectral data for **3n**: ^{1}H NMR ($CDCl_3$) δ 0.85 (t, 3H, *J* = 6.9 Hz), 1.25-1.39 (br m, 10H), 1.68-1.71 (br m, 1H), 1.84-1.94 (br m, 1H), 2.31 (d, 1H, *J* = 16.5 Hz), 2.75 (dd, 1H, *J* = 16.5, 6.9 Hz), 3.46 (br s, 1H), 4.83 (d, 1H, *J* = 7.4 Hz), 5.63 (s, 1H), 6.72 (d, 1H, *J* = 6.9 Hz), 7.06 (d, 2H, *J* = 9.0 Hz), 7.24-7.43 (m, 8H); ^{13}C NMR ($CDCl_3$) δ 13.75, 22.25, 25.16, 28.79, 29.16, 31.37, 38.44, 57.28, 69.21, 96.50, 126.85, 127.06, 127.91, 128.17, 128.46, 128.67, 129.23, 137.53, 139.26, 149.22, 190.24; IR ($CDCl_3$) 3063w, 3030w, 2928vs, 2857vs, 1645vs, 1576vs, 1456s, 1145s cm^{-1}; mass spectrum *m/z* (% rel intensity) 362 M+1 (54), 361 M$^+$ (100), 304 (4), 276 (3), 262 (7), 206 (3), 182 (16), 167 (75), 165 (30), 152 (14), 77 (3). Light yellow solid, mp 115-117 °C.

Preparation of (*S*)-2-(4-fluoro-2-methylphenyl)piperidin-4-one (9)



To a flame dried argon purged round bottom flask equipped with a magnetic stir bar was added **3h** (89% ee as determined by HPLC) (50 mg, 0.135 mmol) and 10% palladium on carbon (28.7 mg, 0.027 mmol) and methanol (2.5 mL). The reaction flask was then flushed with hydrogen gas and kept under 1 atm hydrogen for 22 hours. The reaction mixture was then filtered through Celite and the Celite pad was flushed with ether (200 mL). The solvent was then removed under reduced pressure. Purification was accomplished via flash column chromatography (hexanes/ethyl acetate 1:1, R_f = 0.08) yielding **9** (12.7 mg, 45% yield). ^{1}H-NMR was recorded and was identical to that reported in the literature[6]. The absolute configuration was then determined by comparison of the optical rotation reported in the literature for a sample of the (*R*)-enantiomer of **9** that was 97% ee, (lit. $[\alpha]^{20}_D$ +77.4 (c 0.18, DMSO).[7] The configuration of **9** obtained above is thus assigned as the (*S*)-enantiomer based on the optical rotation obtained on material that was 89% ee: $[\alpha]^{20}_D$ –77.0 (c 0.18, DMSO).

NMR Titration Experiment with Catalyst 8 and Imine 1b.

To a flame dried, argon purged single-necked flask that had its 14/20 joint replaced with a threaded Teflon high-vacuum T-shaped stop-cock equipped with a stir bar was added (*R*)-VAPOL (0.0.957 g, 1.77 mmol) and phenol (0.333g, 3.54 mmol). To this was added dichloromethane (15 mL) followed by $BH_3{\cdot}SMe_2$ (1.77 mL, 3.54 mmol, 2 M solution in toluene) and water (0.031 mL, 1.77 mmol). The flask was sealed with the stopcock and heated to 75 °C for one hour. After one hour, the solvent was removed via high vacuum and heated to 100°C and left under high vacuum for 0.5 hours yielding catalyst **8**. After cooling the stopcock was removed and replaced with a rubber septum. The catalyst was dissolved by the injection via syringe of 5 mL of a $CDCl_3$ (stored over 4Å M.S.) to make a 0.35 M solution. Meanwhile, 50 mg (0.184 mmol) of imine **1b** was added to 10 separate flame dried argon purged 2 mL volumetric flasks. To each volumetric flask was then transferred via syringe a different amount of the catalyst **8** solution (see table below). After the addition of the catalyst, the solutions were diluted to the 2 mL mark on the volumetric flask to ensure the concentration of the imine was maintained. One separate flask was prepared using only the imine with no catalyst. This was used as the reference sample. Approximately 0.8 mL of each volumetric flask was then transferred via syringe to a clean and dry NMR tube and capped immediately to ensure no air was introduced to the system. The ^{1}H-NMR's were then taken for each of the different catalyst/imine ratios. Recorded in the table are the exact concentrations of imine **1b** and catalyst **8**, and the observed chemical shifts for the complexed species for the benzhydryl proton (H^1) and the imine sp^2 C-H (H^2).

NMR	[imine **1b**] (M)	[catalyst **8**] (M)	Obs Chem Shift (H^1, ppm)	Obs Chem Shift (H^2, ppm)
1	0.092	0.0046	under aromatic	under aromatic
2	0.092	0.00575	6.142	under aromatic
3	0.092	0.00775	6.035	8.163
4	0.092	0.0115	5.926	8.255
5	0.092	0.023	5.852	8.317
6	0.092	0.03075	5.791	8.37
7	0.092	0.046	5.735	8.405
8	0.092	0.069	5.713	8.428
9	0.092	0.092	5.7	8.44
10	0.092	0.1505	5.694	8.447

NMR Titration Experiment with Catalyst 8 and the Product 3b.

To a flame dried, argon purged single-necked flask that had its 14/20 joint replaced with a threaded Teflon high-vacuum T-shaped stop-cock equipped with a stir bar was added (*S*)-VAPOL (0.0.957 g, 1.77 mmol) and phenol (0.333g, 3.54 mmol). To this was added dichloromethane (15 mL) followed by $BH_3{\cdot}SMe_2$ (1.77 mL, 3.54 mmol, 2 M solution in toluene) and water (0.031 mL, 1.77 mmol). The flask was sealed with the stopcock and heated to 75 °C for one hour. After one hour, the solvent was removed via high vacuum and heated to 100°C and left under high vacuum for 0.5 hours yielding catalyst **8**. After cooling the stopcock was removed and replaced with a rubber septum. The catalyst was dissolved by the injection via syringe of 5 mL of a $CDCl_3$ (stored over 4Å M.S.) to make a 0.35 M solution. Meanwhile, 62.5 mg (0.184 mmol) of product **3b** was added to 10 separate flame dried argon purged 2 mL volumetric flasks. To each volumetric flask was then transferred via syringe a different amount of the catalyst **8** solution (see table below). After the addition of the catalyst, the solutions were diluted to the 2 mL mark on the volumetric flask to ensure the concentration of the imine was maintained. One separate flask was prepared using only the imine with no catalyst. This was used as the reference sample. Approximately 0.8 mL of each volumetric flask was then transferred via syringe to a clean and dry NMR tube and capped immediately to ensure no air was introduced to the system. The ^{1}H-NMR's were then taken for each of the different catalyst/imine ratios. Recorded in the table are the exact concentrations of product **3b** and catalyst **8**, and the observed chemical shifts for the complexed species for the vinylic proton adjacent to the carbonyl.

NMR	[product **3b**] (M)	[catalyst **8**] (M)	Obs Chem Shift (ppm)
1	0.092	0.0046	5.338
2	0.092	0.00575	5.337
3	0.092	0.00775	5.335
4	0.092	0.0115	5.331
5	0.092	0.023	5.321
6	0.092	0.03075	5.314
7	0.092	0.046	5.301
8	0.092	0.069	5.292
9	0.092	0.092	5.288

NMR Titration Experiment with Triphenylborate and Imine 1b.

50 mg (0.184 mmol) of imine **1b** was added to 10 separate flame dried argon purged 2 mL volumetric flasks. To each volumetric flask was then transferred via syringe a different amount of a 0.35 M solution of triphenylborate **5** (see table below) prepared using triphenylborate that had been distilled immediately before use. After the addition of the triphenylborate, the solutions were diluted to the 2 mL mark on the volumetric flask to ensure the concentration of the imine was maintained. One separate flask was prepared using only the imine with no catalyst. This was used as the reference sample. Approximately 0.8 mL of each volumetric flask was then transferred via syringe to a clean and dry NMR tube and capped immediately to ensure no air was introduced to the system. The ^{1}H-NMR's were then taken for each of the different catalyst/imine ratios. Recorded in the table are the exact concentrations of imine **1b** and triphenylborate, and the observed chemical shifts for the complexed species for the benzhydryl proton (H^1) and the imine sp^2 C-H (H^2).

NMR	[imine **1b**] (M)	[$B(OPh)_3$] (M)	Obs Chem Shift (H^1, ppm)	Obs Chem Shift (H^2, ppm)
1	0.092	0.0046	5.518	8.331
2	0.092	0.00575	5.517	8.329
3	0.092	0.00775	5.52	8.332
4	0.092	0.0115	5.522	8.334
5	0.092	0.023	5.526	8.338
6	0.092	0.03075	5.53	8.342
7	0.092	0.046	5.536	8.347
8	0.092	0.069	5.544	8.353
9	0.092	0.092	5.556	8.364
10	0.092	0.1505	5.59	8.392

NMR Titration Experiment with Triphenylborate and the Product 3b.

62.5 mg (0.184 mmol) of product **3b** was added to 10 separate flame dried argon purged 2 mL volumetric flasks. To each volumetric flask was then transferred via syringe a different amount of a 0.35 M solution of triphenylborate **5** (see table below) prepared using triphenylborate that had been distilled immediately before use. After the addition of the triphenylborate, the solutions were diluted to the 2 mL mark on the volumetric flask to ensure the concentration of the imine was maintained. One separate flask was prepared using only the imine with no catalyst. This was used as the reference sample. Approximately 0.8 mL of each volumetric flask was then transferred via syringe to a clean and dry NMR tube and capped immediately to ensure no air was introduced to the system. The ^{1}H-NMR's were then taken for each of the different catalyst/imine ratios. Recorded in the table are the exact concentrations of product **3b** and catalyst **8**, and the observed chemical shifts for the complexed species for the vinylic proton adjacent to the carbonyl.

NMR	[product **3b**] (M)	[$B(OPh)_3$] (M)	Obs Chem Shift (ppm)
1	0.092	0.0046	5.344
2	0.092	0.00575	5.348
3	0.092	0.00775	5.348
4	0.092	0.0115	5.351
5	0.092	0.023	5.354
6	0.092	0.03075	5.359
7	0.092	0.046	5.365
8	0.092	0.069	5.374
9	0.092	0.092	5.383
10	0.092	0.1505	5.408

NMR data analysis

The stability constant comes from the NMR titration data by fitting the data to the two site model (9). This assumes a 1:1 stoichiometery and fast exchange between the bound and non bound forms of the NMR observed species. In the present case titrations were configured so that the chemical shifts of reporter protons on the starting imine or the product amine (both termed ligand in the following discussion), were followed as a function of varying catalyst concentration.

Any observed ^{1}H chemical shift is the mole fraction weighted average of the shifts observed in the free and complexed molecule.

$$\delta_{obs} = X_L \, \delta_L + X_{LCat} \, \delta_{LCat} \qquad (1)$$

where X_L and X_{LCat} are the mole fractions of ligand that are free and bound to catalyst and δ_L and δ_{LCat} are the chemical shifts of the reporter protons in the free and bound states.

For the formation of a 1:1 complex the following relationships describe the equilibrium conditions.

$$[L] + [LCat] = [L]_o \quad (2)$$

$$[Cat] + [LCat] = [Cat]_o \quad (3)$$

$$K_a = [LCat]/[L][Cat] \quad (4)$$

$[L]_o$ and $[Cat]_o$ are the known solution compositions, and [L], [Cat] and [LCat] are the equilibrium concentration of ligand, catalyst and complex respectively. The following quadratic equation relates the equilibrium conditions to the known total concentrations

$$[LCat] = (a - b^{1/2})/2K_a \quad (5)$$

where

$$a = K_a[L]_o + K_a[Cat]_o + 1 \quad (6)$$

$$b = (K_a[L]_o - K_a[Cat]_o)^2 + 2K_a[L]_o + 2K_a[Cat]_o + 1 \quad (7)$$

This now allows solutions of equation (1) so that δ_{obs} can be calculated for any desired solution composition and K_a.

K_a is obtained from the NMR data by calculating a titration curve and matching it to the experimental data by adjusting K_a and δ_{Lcat}. This is accomplished within an Excel spreadsheet, and using the 'Solver' tool to minimize the global error between the experimental data and the calculated curve.

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