EFFICIENT and PRACTICAL Ag-CATALYZED CYCLOADDITIONS BETWEEN ARYLIMINES AND THE DANISHEFSKY DIENE

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SUPPORTING INFORMATION

General. Infrared (IR) spectra were recorded on a Perkin Elmer 781 spectrophotometer, $\nu_{\max}$ in cm^{-1} . Bands are characterized as broad (br), strong (s), medium (m), or weak (w). ^1H NMR spectra were recorded on a Varian Unity INOVA 400 (400 MHz) spectrometer. Chemical shifts are reported in ppm from tetramethylsilane with the solvent resonance resulting from incomplete deuteration as the internal standard (CDCl_3 : 7.26). Data are reported as follows: chemical shift, integration, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, br = broad, m = multiplet), and coupling constants in Hz. ^{13}C NMR spectra were recorded on a Varian Unity INOVA 400 (100MHz) with complete proton decoupling. Chemical shifts are reported in ppm from tetramethylsilane with the solvent resonance as the internal standard (CDCl_3 : 77.16). Enantiomeric ratios were determined by high-performance liquid chromatography (HPLC) by a Shimadzu chromatograph and chiralpak AD, OD and OJ column (4.6 mm x 250 mm chiral column by Chiral Technologies) in comparison with authentic racemic materials. Elemental analyses were performed by Robertson Microlit Laboratories (Madison, New Jersey). High-resolution mass spectrometry was performed by the University of Illinois Mass Spectrometry Laboratories (Urbana, Illinois) and at Boston College (on a Micromass LCT ESI-MS (positive mode). Optical rotation values were recorded on a Rudolph Research Analytical Autopol IV polarimeter.

Unless otherwise stated, all reactions were conducted in oven- (135 °C) and flame dried glassware under an inert atmosphere of nitrogen. THF was purified under a positive pressure of dry argon by a modified Advanced ChemTech purification system through two alumina columns. 2-Propanol was purified by passage through a plug of activated alumina. Danishefsky's diene was purchased from Aldrich or Acros and distilled prior to use. Silver acetate (99%), 2-(diphenylphosphino)-benzaldehyde, *p*-anisidine and all commercially available aldehydes (for imines) were purchased from Aldrich and used without further purification. Boc-Isoleucine, EDC (1-(3-dimethylaminopropyl)-3-ethyl-carbodiimide hydrochloride) and HOBt (*N*-hydroxybenzotriazole) were purchased from Advanced ChemTech and used without further purification. *O*-anisidyl imines were synthesized according to literature procedure¹.

Representative procedure for the asymmetric Aza-Diels-Alder reaction: Ligand **3a** (6.0 mg, 12 μmol) and AgOAc (2.0 mg, 12 μmol) were weighed into a 16 x 150 mm test tube in an N_2 atmosphere glovebox. The contents were dissolved in 0.5 mL of THF and allowed to stirred for 15 min at 22 °C. Imine **2c** (325 mg, 1.20 mmol) was added immediately followed by 1.5 mL

¹ a) Saito, S; Hatanaka, K.; Yamamoto, H. *Org. Lett.* **2000**, 2, 1891-1894. (b) Adrian, Jr., J.C.; Barkin, J.L.; Hassib, L. *Tetrahedron Lett.* **1999**, 40, 2457-2460.

of THF and 100 μ L *i*-PrOH (1.25 mmol). The test tube was capped with a septum, sealed with parafilm, removed from the glovebox, and allowed to stir in a cold room at 4 °C for 15 min. Danishefsky's diene **3** (360 μ L, 1.80 mmol) was added by syringe and the reaction mixture was allowed to stir at 4 °C for 12 h. The reaction was quenched upon addition of 2 mL of 10 % aqueous HCl followed by vigorous stirring for 5 min. 5 mL of CH₂Cl₂ was added to the test tube and the reaction was stirred vigorously for 1 min. The layers were allowed to separate, and the bottom layer (CH₂Cl₂) was removed by using a pipette and placed into a round-bottom flask. The aqueous layer was washed with 2 x 5mL portions of CH₂Cl₂ as stated above. The combined organic layers were concentrated *invacuo* (without drying) and purified by silica gel chromatography (7:3 EtOAc:hexanes) in most cases (3-pyridyl substrate was chromatographed with 9:1 EtOAc:MeOH), to deliver 395 mg (1.11 mmol; 99% yield) of the desired product **4c** as a viscous yellow solid. Enantiomeric excess of the products were determined by chiral HPLC.

(+)-2-[(2-Diphenylphosphanylbenzylidene)-amino]-3-methylpentanoic acid (4-methoxyphenyl)-amide (3a):

A 250 mL round bottom flask was charged with Boc-Ile (5 g, 20 mmol), EDC (4.2 g, 22 mmol), and HOBT (3.4 g, 22 mmol) were dissolved in 100 mL of CH₂Cl₂. The reaction was cooled to 0 °C followed by addition of *p*-anisidine (7.4 g, 60 mmol), warmed to 22 °C and was allowed to stir for 4 h. The reaction was quenched upon addition of 15 mL of 15% citric acid. The organic layer was separated and washed with 3 x 100 mL of 15% citric acid and 200 mL of NaHCO₃. The organic layer was dried over MgSO₄, filtered and concentrated to yield a light brown solid. This solid was dissolved in a minimum amount of trifluoroacetic acid (upon which vigorous bubbling occurred) and allowed to stir at 22 °C for 45 min. H₂O and CH₂Cl₂ (20 mL of each) were added and the solution was cooled to 0 °C. To this vigorously stirred solution was added 1M NaOH dropwise through an addition funnel until the solution reached a pH of ~10. This mixture was washed with 3 x 50 mL of ethyl acetate, dried over MgSO₄ and concentrated to afford 4.30 g (18.0 mmol, 91% yield) of the free amine as a red-brown oil. The resulting amine (2.75g, 11.6 mmol) was dissolved in 15 mL of CH₂Cl₂, followed by addition of 3.40 g (11.6 mmol) of 2-(diphenylphosphino)benzaldehyde and ~100 mg of MgSO₄. The reaction was allowed to stir at 22 °C for 16 h after which time it was filtered and concentrated. This oil was purified by silica gel chromatography (3:2 hexanes:EtOAc) to give 4.1 g (8.1 mmol, 70% yield) of a light tan solid that smells like brown sugar. IR (neat, NaCl): 3255 (br), 2957 (m), 1674 (s), 1512 (s), 1438 (m), 1246 (s), 1301 (m), 824 (m), 750 (s), 693 (m). ¹H NMR (CDCl₃, 400 MHz): δ 9.55 (1H, d, *J* = 5.1), 8.41 (1H, d, *J* = 2.7), 7.74-7.66 (3H, m), 7.47 (1H, dt, *J* = 1.1, 7.5), 7.37-7.23 (9H, m), 7.18-7.14 (2H, m), 6.92 (1H, dd, *J* = 4.6, 7.7), 6.85 (2H, dd, *J* = 2.2, 6.8), 3.77 (3H, s), 3.73 (1H, dd, *J* = 2.0, 4.3), 1.91 (1H, ddd, *J* = 3.7, 7.1, 14.1), 1.1 (1H, dddd, *J* = 4.2, 7.5, 14.8, 18.8), 0.65 (3H, d, *J* = 6.9), 0.57 (3H, t, *J* = 7.3), 0.31 (1H, dddd, *J* = 6.9, 14.3, 17.2, 18.9). ¹³C NMR (CDCl₃, 100 MHz): δ 170.3, 162.5, 156.3, 138.45, 138.1, 138.0, 137.0, 136.8, 135.0, 134.8, 133.3, 133.1, 132.4, 132.4, 132.0, 130.7, 129.3, 129.0, 129.0, 128.9, 128.7, 128.7, 128.6, 121.5, 121.4, 114.3, 81.2, 55.5, 39.6, 23.8, 15.8, 12.0. HRMS (ES) Calcd for C₃₂H₃₄N₂O₃P (M + H⁺): 509.2359; Found: 509.2358. Anal Calcd for C₃₂H₃₃N₂O₃P: C, 75.57, H, 6.54; Found: C, 75.50, H, 6.33. [α]_D²⁰ +104.1° (*c* = 1.520, CHCl₃).

(-)-1-(2-Methoxyphenyl)-2-phenyl-2,3-dihydro-1H-pyridin-4-one (4a): IR (neat, NaCl), 2837 (w), 2358 (w), 1644 (s), 1575 (s), 1501 (s), 1271 (m), 1209 (m), 1022 (m), 755 (s), 693 (s). ¹H NMR (CDCl₃, 400 MHz): δ 7.25-7.08 (7H, m), 6.94 (1H, dd, *J* = 1.7, 7.7 Hz), 6.82-6.75 (2H, m), 5.19-5.15 (2H, m), 3.78 (3H, s), 3.05 (1H, dd, *J* = 6.4, 16.4), 2.80 (1H, dd, *J* = 7.9, 16.5). ¹³C NMR (CDCl₃, 100 MHz): δ 191.2, 154.2, 153.7, 139.2, 133.6, 128.6, 128.3, 128.0, 127.4, 127.1, 121.0, 112.1, 100.0, 63.1, 55.8, 44.0. HRMS (ES) Calcd for C₁₈H₁₇NO₂: 279.1259; Found: 279.1259. Anal Calcd for C₁₈H₁₇NO₂: C, 77.40, H, 6.13; Found: C, 77.14, H, 6.36. [α]_D²⁰ -114.8° (*c* = 1.353, CHCl₃) for a 93% ee sample.

The optical purity of the Aza-Diels-Alder product was established by chiral HPLC analysis (OJ column, 90/10 hexanes/ *i*-PrOH eluent, 0.9 mL/min and a lamp setting of 254 nm); chromatograms are shown below:

(+)-1-(2-Methoxyphenyl)-2-naphthalen-1-yl-2,3-dihydro-1H-pyridin-4-one (4b): IR (neat, NaCl), 3053 (w), 2225 (w), 1639 (s), 1571 (s), 1502 (s), 1278 (m), 1016 (m), 742 (m), 717 (m). ¹H NMR (CDCl₃, 400 MHz): δ 7.98 (1H, brd, *J* = 7.5), 7.79 (1H, d, *J* = 7.7), 7.68 (1H, d, *J* = 8.0), 7.61 (1H, d, *J* = 7.1), 7.49-7.41 (3H, m), 7.34 (1H, t, *J* = 7.7), 7.05-6.98 (2H, m), 6.76 (1H, d, *J* = 8.2), 6.69 (1H, t, *J* = 7.5), 6.07 (1H, dd, *J* = 7.3, 7.3), 5.24 (1H, d, *J* = 7.9), 3.75 (3H, s), 3.19 (1H, dd, *J* = 6.6, 16.1), 3.0 (1H, brm). ¹³C NMR (CDCl₃, 100 MHz): δ 191.1, 154.5, 153.9, 134.3, 133.9, 133.7, 130.3, 129.4, 128.6, 128.0, 126.4, 126.3, 125.7, 125.3, 122.7, 121.0, 112.1, 99.9, 60.1, 55.8, 43.4. HRMS (ES) Calcd for C₂₂H₁₉NO₂: 329.1414; Found: 329.1416. Anal Calcd for C₂₂H₁₉NO₂: C, 80.22, H, 5.81; Found: C, 79.94, H, 5.88. [α]_D²⁰ +32.2° (*c* = 1.167, CHCl₃) for a 90% ee sample.

The optical purity of the Aza-Diels-Alder product was established by chiral HPLC analysis (OD column, 90/10 hexanes/ *i*-PrOH eluent, 1 mL/min and a lamp setting of 254 nm); chromatograms are shown below:

(-)-1-(2-Methoxyphenyl)-2-naphthalen-2-yl-2,3-dihydro-1H-pyridin-4-one (4c): IR (neat, NaCl), 3050 (br), 2358 (m), 2334 (m), 1636 (s), 1568 (s), 1501 (s), 1275 (s), 1017 (m), 742 (s).

¹H NMR (CDCl₃, 400 MHz): δ 7.75-7.67 (4H, m), 7.44-7.30 (4H, m), 7.08 (1H, t, J = 7.8), 7.00 (1H, dd, J = 7.8), 6.81-6.73 (2H, m), 5.37 (1H, dd, J = 7.1, 7.1), 5.22 (1H, d, J = 7.7), 3.82 (3H, s), 3.12 (1H, dd, J = 6.6, 16.3), 2.92 (1H, dd, J = 7.9, 16.4). ¹³C NMR (CDCl₃, 100 MHz): δ 191.1, 154.1, 153.8, 136.7, 133.6, 133.3, 133.1, 128.5, 128.3, 128.1, 127.8, 127.0, 126.4, 126.2, 125.1, 121.1, 112.1, 100.1, 63.3, 55.8, 44.0. HRMS (ES) Calcd for C₂₂H₂₀NO₂ (M + H⁺), 330.1495; found, 330.1494. Anal Calcd for C₂₂H₁₉NO₂: C, 80.22; H, 5.81; N, 4.25; Found: C, 80.05; H, 5.77; N, 4.19.

[α]_D²⁰ -131.2° (c = 0.8933, CHCl₃) for a 96% ee sample.

The optical purity of the Aza-Diels-Alder product was established by chiral HPLC analysis (OD column, 80/20 hexanes/*i*-PrOH eluent, 1 mL/min and a lamp setting of 254 nm); chromatograms are shown below:

(-)-2-(4-Methoxyphenyl)-1-(2-methoxyphenyl)-2,3-dihydro-1H-pyridin-4-one (4d): IR (neat, NaCl), 2955 (w), 1644 (s), 1575 (s), 1501 (s), 1463 (m), 1252 (s), 1209 (m), 1028 (m), 749 (s). ¹H NMR (CDCl₃, 400 MHz): δ 7.20

(1H, d, $J = 7.7$), 7.13- 7.08 (3H, m), 6.91 (1H, dd, $J = 1.6, 7.7$), 6.82-6.75 (2H, m), 6.71-6.68 (2H, m), 5.15-5.10 (2H, m), 3.78 (3H, s), 3.69 (3H, s), 2.99 (1H, dd, $J = 6.4, 16.5$), 2.78 (1H, dd, $J = 8.2, 16.4$). ^{13}C NMR (CDCl_3 , 100 MHz): δ 191.6, 159.3, 154.3, 153.8, 133.6, 131.3, 128.6, 128.4, 128.3, 127.3, 121.0, 113.9, 112.1, 99.8, 62.6, 55.8, 55.4, 44.1. HRMS (ES) Calcd for $\text{C}_{19}\text{H}_{20}\text{NO}_3$ ($\text{M} + \text{H}^+$): 310.1444; Found: 310.1442. Anal Calcd for $\text{C}_{19}\text{H}_{19}\text{NO}_3$: C, 73.77, H, 6.19; Found: C, 73.56, H, 6.07. $[\alpha]_D^{20}$ -154.9° ($c = 1.920$, CHCl_3) for a 91% ee sample.

The optical purity of the Aza-Diels-Alder product was established by chiral HPLC analysis (OJ column, 90/10 hexanes/ *i*-PrOH eluent, 1 mL/min and a lamp setting nM); chromatograms are shown below:

(-)-2-(4-Chlorophenyl)-1-(2-methoxyphenyl)-2,3-dihydro-1H-pyridin-4-one (4e): IR (neat, NaCl), 2968 (w), 1644 (s), 1575 (s), 1494 (s), 1271 (m), 1209 (m), 755 (s). ^1H NMR (CDCl_3 , 400 MHz): δ 7.25 (1H, d, $J = 7.7$), 7.17 (5H, m), 6.96 (1H, dd, $J = 1.6, 7.8$), 6.86-6.81 (2H, m), 5.18 (2H, m), 3.81 (3H, s), 3.06 (1H, dd, $J = 6.6, 16.3$), 2.77 (1H, dd, $J = 7.9, 16.4$). ^{13}C NMR (CDCl_3 , 100 MHz): δ 190.9, 154.1, 153.6, 137.8, 133.8, 133.3, 128.8, 128.7, 128.5, 127.1, 121.2, 112.2, 100.2, 62.5, 55.8, 43.8. HRMS (ES) Calcd for $\text{C}_{18}\text{H}_{17}\text{ClNO}_2$ ($\text{M} + \text{H}^+$): 314.0948; Found: 314.0947. Anal Calcd for $\text{C}_{18}\text{H}_{16}\text{ClNO}_2$: C, 68.90, H, 5.14; Found: C, 68.98, H, 5.18. $[\alpha]_D^{20}$ -120.2° ($c = 1.620$, CHCl_3) for a 90% ee sample.

The optical purity of the Aza-Diels-Alder product was established by chiral HPLC analysis (OJ column, 90/10 hexanes/ *i*-PrOH eluent, 0.9 mL/min and a lamp setting of 254 nM); chromatograms are shown below:

(-)-2-(2-Bromophenyl)-1-(2-methoxyphenyl)-2,3-dihydro-1H-pyridin-4-one (4f): IR (neat, NaCl), 3005 (w), 2359 (w), 1644 (s), 1582 (s), 1501 (s), 1271 (s), 1209 (s), 1022 (s), 749 (s), cm^{-1} . ^1H NMR (CDCl_3 , 400 MHz): δ 7.54 (1H, d, $J = 7.9$), 7.44 (1H, d, $J = 7.9$), 7.37 (1H, d, $J = 7.7$), 7.19-7.10 (2H, m), 7.04-6.99 (2H, m), 6.86-6.79 (2H, m), 5.72 (1H, dd, $J = 7.1, 7.1$), 5.20 (1H, d, $J = 7.7$), 3.81 (3H, s), 3.08 (1H, dd, $J = 7.0, 16.5$), 2.76 (1H, dd, $J = 7.2, 16.5$). ^{13}C NMR (CDCl_3 , 100 MHz): δ 190.6, 154.2, 153.8, 138.2, 133.4, 129.4, 128.6, 128.2, 127.7, 126.1, 122.6, 121.1, 112.3, 100.3, 61.9, 55.9, 42.4. HRMS (ES) Calcd for $\text{C}_{18}\text{H}_{17}\text{BrNO}_2$, ($\text{M} + \text{H}^+$): 358.0443; Found: 358.0442. Anal Calcd for $\text{C}_{18}\text{H}_{16}\text{BrNO}_2$: C, 60.35, H, 4.50; Found: C, 60.60, H, 4.57. $[\alpha]_{\text{D}}^{20}$ -24.3°

($c = 1.780$, CHCl_3) for a 89% ee sample.

The optical purity of the Aza-Diels-Alder product was established by chiral HPLC analysis (OJ column, 90/10 hexanes/ *i*-PrOH eluent, 0.8 mL/min and a lamp setting of 254 nm); chromatograms are shown below:

A crystal structure of **4f** is shown at the end of this supporting information. The absolute stereochemistry was determined by X-ray crystallography of **4f** indicating an *R* configuration. All other absolute stereochemical assignments are inferred.

(-)-1-(2-Methoxyphenyl)-2-(3-nitrophenyl)-2,3-dihydro-1H-pyridin-4-one (4g): IR (neat, NaCl), 3067 (w), 2358 (w), 1644 (s), 1575 (s), 1526 (s), 1495 (s), 1352 (s), 1209 (m), 1022 (m), 749 (m). ^1H NMR (CDCl_3 , 400 MHz): δ 8.14 (1H, t, $J = 1.8$), 7.99 (1H, d, $J = 8.4$), 7.58 (1H, d, $J = 7.7$), 7.38 (1H, t, $J = 7.8$), 7.30 (1H, d, $J = 7.7$), 7.12 (1H, dt, $J = 1.6, 7.6$), 7.00 (1H, dd, $J = 1.5, 7.7$), 6.82-6.79 (2H, m), 5.32 (1H, dd, $J = 7.0, 7.0$), 5.17 (1H, d, $J = 7.7$), 3.79 (3H, s), 3.11 (1H, dd, $J = 6.6, 16.3$), 2.75 (1H, dd, $J = 7.1, 16.3$). ^{13}C NMR (CDCl_3 , 100 MHz): δ 190.1, 153.9, 153.5, 148.4, 141.4, 133.4, 132.9, 129.8, 128.8, 126.8, 123.0, 122.3, 121.3, 112.3, 100.8, 62.3, 55.9, 43.6. HRMS (ES) Calcd for $\text{C}_{18}\text{H}_{17}\text{N}_2\text{O}_4$ ($\text{M} + \text{H}^+$): 325.1189; Found: 325.1188. Anal Calcd for $\text{C}_{18}\text{H}_{16}\text{N}_2\text{O}_4$: C, 66.66, H, 4.97; Found: C, 66.81, H, 4.92. $[\alpha]_{\text{D}}^{20}$ -67.8° ($c = 1.480$, CHCl_3) for a 91% ee sample.

The optical purity of the Aza-Diels-Alder product was established by chiral HPLC analysis (OJ column, 90/10 hexanes/ *i*-PrOH eluent, 0.9 mL/min and a lamp setting of 254 nm); chromatograms are shown below:

(-)-1-(2-Methoxyphenyl)-2-(4-nitrophenyl)-2,3-dihydro-1H-pyridin-4-one (4h): IR (neat, NaCl), 3074 (m), 2967 (m), 1646 (s), 1583 (s), 1513 (s), 1463 (m), 1350 (s), 1211 (s), 1023 (s), 846 (s), 758 (s), 695 (m), 632 (m). ¹H NMR (CDCl₃, 400 MHz): δ 8.02 (2H, d, *J* = 8.4), 7.40 (2H, d, *J* = 8.6), 7.26 (1H, d, *J* = 7.7), 7.12 (1H, t, *J* = 7.7), 6.96 (1H, d, *J* = 7.7), 6.83-6.78 (2H, m), 5.30 (1H, dd, *J* = 7.0, 7.0), 5.16 (1H, d, *J* = 7.7), 3.76 (3H, s), 3.09 (1H, dd, *J* = 6.6, 16.4), 2.71 (1H, dd, *J* = 7.1, 16.4). ¹³C NMR (CDCl₃, 100 MHz): δ 190.0, 153.8, 153.4, 147.5, 146.7, 133.0, 128.7, 128.2, 126.7, 123.9, 121.3, 112.3, 100.8, 62.4, 55.8, 43.4. HRMS (ES) Calcd for C₁₈H₁₇N₂O₄ (M + H⁺): 325.1190 Found: 325.1191. [α]_D²⁰ -154.9° (*c* = 1.920, CHCl₃) for a 92% ee sample.

The optical purity of the Aza-Diels-Alder product was established by chiral HPLC analysis (AD column, 80/20 hexanes/ *i*-PrOH eluent, 1 mL/min and a lamp setting of 254 nm); chromatograms are shown below:

(-)-2-Furan-2-yl-1-(2-methoxyphenyl)-2,3-dihydro-1H-pyridin-4-one (4i): IR (neat, NaCl), 3458(wbr), 2965 (w), 2835 (w), 2355 (w), 1639 (s), 1576 (s), 1502 (s), 1464 (m), 1433 (m), 1277 (s), 1215 (s), 1178 (s), 1022 (s), 754 (s). ¹H NMR (CDCl₃, 400 MHz): δ 7.18 (2H, t, *J* = 0.9), 7.04 (1H, d, *J* = 7.7),

6.97 (1H, dd, $J = 1.7, 7.8$), 6.88-6.80 (2H, m), 6.14-6.09 (2H, m), 5.12 (1H, dd, $J = 6.0, 6.0$), 5.07 (1H, d, $J = 7.7$), 3.79 (3H, s), 3.02 (1H, dd, $J = 6.6, 16.3$), 2.80 (1H, dd, $J = 5.7, 16.3$). ^{13}C NMR (CDCl_3 , 100 MHz): 191.0, 154.3, 152.4, 151.8, 142.4, 133.5, 128.7, 127.3, 121.2, 112.1, 110.3, 108.4, 99.8, 56.4, 55.9, 40.2. HRMS (ES) Calcd $\text{C}_{16}\text{H}_{15}\text{NO}_3$: 269.1045; Found: 269.1038. Anal Calcd for $\text{C}_{16}\text{H}_{15}\text{NO}_3$: C, 71.36, H, 5.61; Found: C, 71.09, H, 5.48. $[\alpha]_{\text{D}}^{20} - 155.9^\circ$ ($c = 1.520$, CHCl_3), for a 92% ee sample.

The optical purity of the Aza-Diels-Alder product was established by chiral HPLC analysis (OJ column, 92/8 hexanes/ *i*-PrOH eluent, 0.35 mL/min and a lamp setting of 254 nm); chromatograms are shown below:

PK#	Ret Time	Name	Amount	Amount%	Area	Area%	Type	Width	Height	Height%
1	90.938		0.0000	0.000	657487.9	46.636	BV	4.342	2523.84	50.324
2	97.780		0.0000	0.000	752343.1	53.364	BV	5.033	2491.35	49.676

PK#	Ret Time	Name	Amount	Amount%	Area	Area%	Type	Width	Height	Height%
1	89.037		0.0000	0.000	5902175.0	96.305	SBB	4.624	21273.95	94.783
2	94.933		0.0000	0.000	226440.6	3.695	TVD	3.223	1170.95	5.217

(-)-1-(2-Methoxyphenyl)-2,3-dihydro-1H-[2,3']bipyridinyl-4-one (4j): IR (neat, NaCl), 3037 (w), 1639 (s), 1576 (s), 1495 (s), 1425 (m), 1293 (m), 1268 (m), 1023 (m), 758 (m), 708 (m). ^1H NMR (CDCl_3 , 400 MHz): δ 8.37 (2H, brs), 7.57 (1H, d, $J = 7.9$), 7.20 (1H, dd, $J = 1.1, 7.8$), 7.10 (2H, t, $J = 7.3$), 6.92 (1H, d, $J = 7.5$), 6.79-6.75 (2H, m), 5.19 (1H, dd, $J = 7.3, 7.3$), 5.15 (1H, d, $J = 1.1$), 3.72 (3H, s), 3.01 (1H, dd, $J = 6.6, 16.8$), 2.72 (1H, dd, $J = 7.9, 16.8$). ^{13}C NMR (CDCl_3 , 100 MHz): 190.6, 154.0, 153.6, 149.4, 148.9, 134.9, 134.8, 132.9, 128.8, 127.2, 123.5, 121.2, 112.2, 100.4, 60.7, 55.8, 43.4. HRMS (ES) Calcd $\text{C}_{16}\text{H}_{17}\text{NO}_3$ ($M + H$): 281.1285; Found: 281.1290. $[\alpha]_{\text{D}}^{20} - 105.6^\circ$ ($c = 4.000$, CHCl_3), for a 84% ee sample.

The optical purity of the Aza-Diels-Alder product was established by chiral HPLC analysis (OD column, 80/20 hexanes/ *i*-PrOH eluent, 1 mL/min and a lamp setting of 254 nm); chromatograms are shown below:

(-)-1-(2-Methoxyphenyl)-2-phenylpiperidin-4-ol (6a): To a 50 mL round bottom flask charged with 275 mg (0.98 mmol) of **4a** in 10 mL of THF cooled to -78°C was added 110 mg

(3.0 mmol) of solid LAH. The reaction was allowed to stir for 2 h after which time it was warmed to 22°C and allowed to stir for 4 h. The reaction was then cooled to 0°C and MeOH was slowly added to quench the reaction so as to avoid vigorous gas evolution. After the excess LAH was quenched 25 mL of 10% sodium potassium tartrate was added and the solution was allowed to stir for 30 min. The organic layer was separated and the aqueous layer was washed with 2 x 15 mL EtOAc. The combined organic layers were washed with 15 mL of brine dried over MgSO_4 and

concentrated to give a pale yellow oil. This oil was directly dissolved in 10 mL of THF and cooled to -78°C . To this solution was added 110 mg (3.0 mmol) of LAH and the reaction was allowed to stir for 2 hours before quenching as above. The aqueous layer was washed with 2 x 15 mL EtOAc, and the combined organic layers were washed with 15 mL of brine dried over MgSO_4 and concentrated to give a light yellow oil. This oil was purified by silica gel chromatography (3:2 hexanes:EtOAc) to give 188 mg (0.66 mmol, 68% yield for 2 steps) of the amino alcohol **6a** as a 9:1 mixture of diastereomers. IR (neat, NaCl): 3361 (br), 2939 (m), 2833 (w), 1500 (s), 1450 (m), 1245 (s), 1028 (s), 749 (s), 700 (s). ^1H NMR (CDCl_3 , 400 MHz): δ 7.22 (2H, d, $J = 7.3$), 7.13 (2H, t, $J = 7.5$), 7.04 (1H, tt, $J = 1.5, 7.3$), 6.90-6.82 (2H, m), 6.75 (1H, dd, $J = 1.3, 8.2$), 6.63 (1H, dt, $J = 1.3, 7.2$), 4.20 (1H, dd, $J = 2.8, 11.2$), 3.89-3.80 (4H, m), 3.49 (1H, dt, $J = 3.7, 11.9$), 2.74 (1H, dt, $J = 2.6, 12.3$), 2.19 (1H, dddd, $J = 2.8, 2.8, 5.3, 7.1$), 2.05 (1H, dddd, $J = 2.7, 2.7, 5.3, 7.1$), 1.98 (1H, brs), 1.87 (1H, ddd, $J = 4.4, 12.3, 15.4$), 1.74 (1H, q, $J = 12.3$), 1.29 (1H, m). ^{13}C NMR (CDCl_3 , 100 MHz): 144.1, 140.2, 128.3, 127.5, 127.4, 126.7, 125.4, 124.6, 120.5, 111.8, 69.8, 63.0, 55.7, 52.7, 46.5, 35.9. HRMS (ES) Calcd $\text{C}_{18}\text{H}_{21}\text{NO}_2\text{Na}$ ($\text{M} + \text{Na}$): 306.1470; Found: 306.1480. $[\alpha]_D^{20} -79.2^{\circ}$ ($c = 4.00$, CHCl_3). The stereochemical relationship of the major product was shown to be 1-(2-Methoxy-phenyl)-2-(*R*)-phenyl-piperidin-4-(*S*)-ol by nOe studies.

(-)-4-(tert-Butyldimethylsilyloxy)-1-(2-methoxyphenyl)-2-phenylpiperidine (6): In a 25 mL round bottom flask charged with 175 mg (0.62 mmol) of **6a** dissolved in 5 mL of DMF was added 16 mg (1.1 mmol) of TBSCl followed by 90 mg (1.3 mmol) of imidazole and the reaction was allowed to stir at 23 °C for 12 h. 25 mL of a saturated solution of NH₄Cl was added followed by 10 mL of Et₂O and the organic layer was separated. The aqueous layer was washed with 2 x 10 mL of Et₂O, and the combined organic layers were washed with 15 mL of brine, dried over MgSO₄ and concentrated. The yellow oil was purified by silica gel chromatography (6:1 hexanes:EtOAc) to yield 243 mg (0.61 mmol, >98% yield) of **6** as a yellow oil. IR (neat, NaCl): 2948 (s), 2923 (s), 2854 (s), 1595 (m), 1495 (s), 1457 (m), 1362 (w), 1249 (s), 1104 (s), 865 (m), 834 (s), 777 (m), 702 (m). ¹H NMR (CDCl₃, 400 MHz): 7.22 (2H, d, *J* = 7.0), 7.10 (2H, t, *J* = 7.1), 7.02 (1H, dt, *J* = 1.5, 7.1), 6.87-6.80 (2H, m), 6.72 (1H, dd, *J* = 1.5, 8.1), 6.61 (1H, dt, *J* = 1.5, 7.3), 4.16, (1H, dd, *J* = 2.7, 11.3), 3.84-3.78 (4H, m), 3.42 (1H, dt, *J* = 3.4, 11.7), 2.70 (1H, m), 2.06-2.01 (1H, m), 1.90 (2H, ddd, *J* = 3.5, 5.3, 8.7), 1.76 (1H, q, *J* = 11.2), 0.87 (6H, s), 0.13 (9H, s). ¹³C NMR (CDCl₃, 100 MHz): 144.3, 140.5, 128.2, 128.1, 127.4, 126.6, 125.5, 124.5, 120.5, 111.9, 70.4, 63.1, 55.7, 52.9, 46.8, 36.4, 26.1, 26.0. HRMS (ES) Calcd C₂₄H₃₆NO₂Si (M + H): 398.2525; Found: 398.2515. [α]_D²⁰ -63.6° (*c* = 0.800, CHCl₃).

(-)-1-(2-Methoxyphenylamino)-7-methyl-1-phenyl-oct-4-en-3-one (7a): A 100 mL round bottom flask was charged with 184 mg (2.1 mmol) of CuCN and 25 mL of THF and cooled to -78 °C. To this slurry was added *i*-BuMgCl (1.0 mL, 2.1 mmol, 2M solution, Aldrich) by syringe over 20 min. The resulting reaction was stirred at -78 °C for 1.5 h at which time freshly distilled BF₃•Et₂O (156 μL, 1.23 mmol) was added by syringe over five min. A solution of **4a** (230 mg, 0.82 mmol in 7 mL of THF, 94% ee) was added dropwise by syringe over 15 min followed by washing the flask with 2 x 2 mL of THF which was added to the reaction slowly. This reaction was allowed to stir at -78 °C for 1 h or upon completion of the reaction by TLC analysis (4:1 hexanes-EtOAc). The reaction was quenched at -78 °C upon slow addition of 5 mL of 10% AcOH in MeOH followed by slowly warming the solution to 22 °C. H₂O was added (50 mL), the organic layer was separated and the aqueous layer was washed with 2 x 25 mL of EtOAc. The combined organic layers were washed with 50 mL of brine, dried over MgSO₄ and concentrated. The resulting oil was purified by silica gel chromatography (4:1 hexanes-EtOAc) to give 274 mg (8.1 mmol, 98% yield) of product as a yellow oil. IR (neat, NaCl): 3408 (w), 2955 (m), 2357 (m), 1665 (m), 1602 (s), 1513 (s), 1457 (m), 1224 (m), 1029 (m), 735 (m), 700 (m). ¹H NMR (CDCl₃, 400 MHz): δ 7.38 (2H, d, *J* = 7.1), 7.29 (2H, t, *J* = 7.1), 7.20 (1H, t, *J* = 7.1), 6.77-6.67 (3H, m), 6.60 (1H, dt, *J* = 1.7, 7.6), 6.40 (1H, dd, *J* = 1.5, 7.8), 6.03 (1H, d, *J* = 15.8), 4.94 (1H, bs), 4.88 (1H, t, *J* = 6.4), 3.85 (3H, s), 3.06 (2H, t, *J* = 7.0), 2.05 (2H, dt, *J* = 1.5, 6.9), 1.71 (1H, septet, *J* = 6.8), 0.88 (6H, d, *J* =

6.6). ^{13}C NMR (CDCl_3 , 100 MHz): 198.3, 147.7, 147.2, 143.3, 137.0, 131.8, 128.9, 127.4, 126.6, 121.3, 117.0, 111.5, 109.6, 55.7, 54.8, 48.1, 41.9, 28.1, 22.6. HRMS (ES) Calcd $\text{C}_{22}\text{H}_{27}\text{NO}_2\text{Na}$ ($\text{M} + \text{Na}$): 360.1933; Found: 360.1939. $[\alpha]_{\text{D}}^{20}$ -22.2° ($c = 2.00$, CHCl_3).

(-)-1-(2-Methoxyphenylamino)-7-methyl-1-phenyl-oct-4-en-3-ol (7b): A 50 mL round bottom flask was charged with **7a** (100 mg, 0.3 mmol), dissolved in 10 mL of THF and cooled to -40°C . To this solution was added 2.0 mL (0.73M solution, 1.5 mmol) of $\text{Zn}(\text{BH}_4)_2^2$ dropwise over 5 min. This reaction was allowed to stir at -40°C for 2 h followed by slow warming to 0°C . The reaction was quenched at 0°C upon addition of 5 mL of MeOH and 20 mL of a saturated aqueous solution of

NaHCO_3 . The organic layer was separated and the aqueous layer was washed 2 x 10 mL of EtOAc. The combined organic layers were washed with 15 mL of brine, dried over MgSO_4 and concentrated. The resulting yellow oil was purified by silica gel chromatography with (4:1 hexanes:EtOAc) to yield 100 mg (2.9 mmol, 97% yield) of a yellow oil. Diastereoselectivity was determined by 400 MHz ^1H NMR, (10:1 syn:anti). Major isomer is syn by comparison with literature data^{2b}. IR (neat, NaCl): 3419 (br), 2951 (s), 2862 (m), 1600 (s), 1511 (s), 1452 (s), 1422 (m), 1233 (s), 1031 (m), 736 (s), 700 (m). ^1H NMR (CDCl_3 , 400 MHz): δ 7.36-7.28 (4H, m), 7.21 (1H, dt, $J = 1.7, 7.0$), 6.75 (1H, dd, $J = 1.5, 7.8$), 6.73 (2H, ddd, $J = 1.5, 7.9, 16.7$), 6.46 (1H, dd, $J = 1.5, 7.8$), 5.67-5.59 (1H, m), 5.50 (1H, dd, $J = 6.6, 15.3$), 4.99 (1H, bs), 4.57 (1H, dd, $J = 5.5, 8.5$), 4.25 (1H, ddd, $J = 5.4, 8.3, 14.8$), 3.87 (3H, s), 2.43 (1H, bs), 2.12-1.87 (4H, m), 1.60 (1H, septet, $J = 6.6$), 0.87 (6H, d, $J = 6.6$). ^{13}C NMR (CDCl_3 , 100 MHz): 147.4, 144.1, 137.1, 128.8, 127.2, 126.5, 121.3, 117.2, 112.1, 109.7, 72.0, 57.0, 55.7, 46.3, 41.8, 28.4, 22.5, 22.4. HRMS (ES) Calcd $\text{C}_{22}\text{H}_{30}\text{NO}_2$ ($\text{M} + \text{H}$): 340.2265; Found: 340.2277. $[\alpha]_{\text{D}}^{20}$ -13.0° ($c = 2.000$, CHCl_3).

(-)-1-Amino-7-methyl-1-phenyloct-4-en-3-ol (7): A 25 mL round bottom flask equipped with a reflux condenser was charged with 70 mg (0.2 mmol) of **7b** dissolved in 7 mL of a 5:2 mixture of MeCN: H_2O and warmed to 60°C . AgNO_2 (12 mg, 0.07 mmol) was added followed by 330 mg (1.4 mmol) of $(\text{NH}_4)_2\text{S}_2\text{O}_8$ in 3 batches over 15 min. The reaction was allowed to stir at 60°C for 4 h. The reaction was cooled to 22°C followed by addition of 10 mL of 10% aqueous HCl. The organic layer was separated and the aqueous layer was washed 2 x 10 mL of 10% aqueous HCl. The combined

aqueous layers were washed with 2 x 15 mL of Et_2O followed by neutralizing with sodium carbonate. The aqueous solution was washed with 3 x 15 mL of EtOAc, and the combined organic layers were washed with 50 mL of brine, dried over MgSO_4 and concentrated. This red solid was purified by silica gel chromatography (9:1 CH_2Cl_2 :MeOH) to give 40 mg of **7** (0.2 mmol, 82% yield) as a red viscous solid. IR (neat, NaCl): 3307 (br), 2948 (s), 2923 (m), 1570 (m), 1495 (s), 1457 (s), 1362 (m), 1029 (m), 966 (m), 752 (s), 702 (s). ^1H NMR (CDCl_3 , 400 MHz): 7.46-7.25 (5H, m), 5.58 (1H, quatet, $J = 7.9$), 5.33 (1H, dd, $J = 5.3, 16.3$), 4.29-3.73 (2H, m), 1.92-1.82 (4H, m), 1.56 (1H, septet, $J = 6.8$), 0.85 (6H, m). ^{13}C NMR (CDCl_3 , 100 MHz): 129.2, 129.1, 128.8, 128.4, 126.8, 28.4, 22.5, 22.4. HRMS (ES) Calcd $\text{C}_{15}\text{H}_{24}\text{NO}$ ($\text{M} + \text{H}$): 234.1858 Found: 234.1869. $[\alpha]_{\text{D}}^{20}$ -6.6° ($c = 0.3333$, CHCl_3).

² a) Narasimhan, S.; Madhave, S.; Ganeshwar Prasad, K. *J. Org. Chem.* **1995**, *60*, 5314-5315. b) Pilli, R.A.; Russowsky, D.; Dias, L. C. *J. Chem Soc. Perkin Trans. I* **1990**, 1213-1214.

Ligand Screening Data

All solid phase reactions were performed in Bio-Spin Chromatography Columns (2 mL capacity, from Bio-Rad, cat.# 732-6008). 100-200 mesh Aminomethyl resin LS, 1% DVB (0.5 mmol/g) was purchased from Advanced ChemTech. Sequencing grade DMF was purchased from Fisher Scientific and purified by bubbling dry N₂ through for 24 h, then stored over 4Å molecular sieves. CH₂Cl₂ and EtOAc were used as reagent grade, undistilled. Piperidine and all Fmoc-protected amino acids were purchased from Advanced ChemTech and used without purification.

Scheme 1. General procedure for ligand synthesis on solid support

Multiple ligands for screening were prepared according to the general synthetic sequence shown in Scheme 1. Aminomethyl resin (100 mg, 0.6 mmol/g, 0.06 mmol) was added to a Bio-Spin column and swelled with 1.5 mL of DMF for at least 6 h. In separate round bottom flasks 3.7 g (9.6 mmol) of Fmoc-Phe-OH was dissolved in 60 mL of DMF and 1.9 g (12.4 mmol) of HOBt was dissolved in 10 mL of DMF. After swelling the resin 1.5 mL (0.24 mmol) of the Fmoc-Phe-OH solution, 250 μ L (0.31 mmol) of the HOBt solution and 50 μ L (0.31 mmol) of DIC was added to the 36 different Bio-Spin tubes containing resin, followed by rotation/agitation for 4 h. The solvent was then removed by filtration and the resin was washed with DMF (7 x 2 mL). Deprotection was achieved by addition of 1.5 mL of 20% piperidine/DMF solution to each reaction tube and rotated/agitated for 45 min. The resin was washed with DMF (10 x 2 mL). To each reaction tube was weighed 0.24 mmol of different Fmoc-protected amino acids followed by 250 μ L (0.3 mmol) of an HOBt solution (described above) and 50 μ L (0.3 mmol) of DIC followed by rotation/agitation for 4 h. The resin was washed with DMF (7 x 2 mL) and 1.5 mL of 20% piperidine/DMF was added to the tubes followed by rotation/agitation for 45 min. The resin was then washed with DMF (7 x 2 mL) and 1.5 mL (0.16M, 2.8 g in 60 mL DMF) of 2-(diphenylphosphino)-benzaldehyde was added to the tubes followed by rotation/agitation for 16

h. The resin was washed with DMF (10 x 2 mL), CH₂Cl₂ (3 x 2 mL) and Et₂O (3 x 2 mL) followed by drying in vacuo.

Ligand Screening Results: The reactions were run with the ligand on the solid support³ using 20 mol% catalysts loading. Amino acid 1 (AA1) screen was carried out first with AA2 = L-Phe and the inclusion of D-Val and D-Phe to check that L,D ligands (as opposed to the usual L,L ligands) are not more selective ligands for the reaction. The results are shown in Chart 1. In this case it can be seen that the absolute stereochemistry for the product is dependent upon the absolute stereochemistry of AA1. It is apparent that for high enantioselectivities branching, α on the R group of AA1 is required (for example Val, Ile, Thr). With Ile giving the best results.

Solid Supported Catalyst: A Bio-Spin Chromatography Column was loaded with 50 mg of solid-supported ligand (synthesized from aminomethyl resin, 0.5mmol/g, as outlined above) on the bench top, sealed and the resin was swelled with 1.5 mL of THF (undistilled) for 6 h at 23 °C. AgOAc (4 mg, 0.024 mmol) was added, followed by 125 mg (0.5 mmol) of imine **2c** and 40 μ L of i-PrOH (50 mmol). The column was resealed and allowed to rotate/agitate at 4 °C for 15 min after which time 115 μ L (0.58 mmol) of **3a** was added and the reaction was allowed to rotate/agitate for 12 h at 4 °C. The solution was filtered through the columns frit disk into a 16 x 150 mm test tube loaded with 2 mL of 10% aqueous HCl in water. CH₂Cl₂ was added (1 mL)

³ Shimizu, K.D.; Cole, B.M.; Krueger, C.A.; Kuntz, K.W.; Snapper, M.L.; Hoveyda, A.H. *Angew. Chem. Int., Ed. Engl.* **1997**, *36*, 1703-1707. Cole, B.M.; Shimizu, K.D.; Krueger, C.A.; Harrity, J.P.A.; Snapper, M.L.; Hoveyda, A.H. *Angew. Chem Int., Ed. Engl.* **1996**, *35*, 1668-1671.

followed by vigorous stirring for 1 min. The organic layer was separated and the water layer was washed with 3 x 3 mL of CH₂Cl₂. The combined wet organic layers were concentrated and purified by silica gel chromatography (7:3 EtOAc:hexanes) to give the product **4C** as a viscous yellow solid in 86% ee and 96% yield. The product was spectroscopically identical to that obtained with solution phase ligand.

After the first cycle of the reaction the solid supported ligand turned brown. This however did not affect its activity. For subsequent reactions with this recycled solid supported ligand fresh AgOAc was required to be added (4 mg in this case).

Table . Ag-Catalyzed Enantioselective Cycloadditions with Supported Chiral Ligand

cycle	yield (%)	ee (%)
1	96	86
2	98	82
3	91	76
4	78	72
5	77	72

Crystal structure of **4f**:

Table 1. Crystal data and structure refinement for NSJt.

Identification code	nsjt
Empirical formula	C ₁₈ H ₁₆ Br N O ₂
Formula weight	358.23
Temperature	273(2) K
Wavelength	0.71073 Å

Crystal system	Orthorhombic	
Space group	P2(1)2(1)2(1)	
Unit cell dimensions	a = 8.4877(5) Å	$\alpha = 90^\circ$
	b = 11.1363(6) Å	$\beta = 90^\circ$
	c = 16.6361(9) Å	$\gamma = 90^\circ$
Volume	1572.47(15) Å ³	
Z	4	
Density (calculated)	1.513 Mg/m ³	
Absorption coefficient	2.620 mm ⁻¹	
F(000)	728	
Crystal size	.42 x .33 x .15 mm ³	
Theta range for data collection	2.20 to 28.28°	
Index ranges	-11<=h<=5, -14<=k<=14, -21<=l<=22	
Reflections collected	11674	
Independent reflections	3890 [R(int) = 0.0338]	
Completeness to theta = 28.28°	100.0 %	
Absorption correction	None	
Refinement method	Full-matrix least-squares on F ²	
Data / restraints / parameters	3890 / 0 / 199	
Goodness-of-fit on F ²	0.995	
Final R indices [I>2sigma(I)]	R1 = 0.0280, wR2 = 0.0667	
R indices (all data)	R1 = 0.0309, wR2 = 0.0673	
Absolute structure parameter	-0.017(7)	
Largest diff. peak and hole	0.620 and -0.215 e.Å ⁻³	

Table 2. Atomic coordinates (x 10⁴) and equivalent isotropic displacement parameters (Å² x 10³) for NSJt. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
Br(1)	6739(1)	1193(1)	2475(1)	41(1)
C(5)	6098(2)	-1315(2)	3753(1)	32(1)
C(13)	8650(2)	-178(2)	3560(1)	27(1)
O(1)	6337(2)	-3416(1)	3508(1)	45(1)
C(11)	6502(2)	1138(2)	5660(1)	31(1)
C(10)	6743(3)	2099(2)	6188(1)	40(1)
C(3)	7773(2)	-1700(2)	5150(1)	31(1)
C(1)	6686(2)	-2566(2)	3946(1)	32(1)
C(16)	11351(3)	46(2)	2593(1)	45(1)
C(8)	9493(3)	1613(2)	6276(1)	41(1)
C(14)	10073(2)	-710(2)	3775(1)	36(1)
C(2)	7502(2)	-2682(2)	4695(1)	34(1)
C(15)	11412(3)	-605(2)	3294(1)	44(1)
C(9)	8220(3)	2319(2)	6491(1)	43(1)
C(18)	8635(3)	465(2)	2842(1)	31(1)
C(7)	9272(3)	667(2)	5750(1)	33(1)
O(2)	5100(2)	818(1)	5340(1)	39(1)
C(4)	7170(2)	-319(2)	4066(1)	27(1)
C(12)	3752(3)	1506(2)	5560(2)	48(1)
C(6)	7792(2)	433(2)	5442(1)	27(1)
N(1)	7548(2)	-565(1)	4912(1)	27(1)
C(17)	9960(3)	594(2)	2369(1)	40(1)

Table 3.

Bond lengths [Å] and angles [°] for NSJt.

Br(1)-C(18)	1.903(2)
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C(5)-C(1)	1.514(3)
C(5)-C(4)	1.526(3)
C(13)-C(18)	1.392(3)
C(13)-C(14)	1.392(3)
C(13)-C(4)	1.520(3)
O(1)-C(1)	1.232(2)
C(11)-O(2)	1.351(2)
C(11)-C(6)	1.395(3)
C(11)-C(10)	1.399(3)
C(10)-C(9)	1.374(3)
C(3)-N(1)	1.338(2)
C(3)-C(2)	1.351(3)
C(1)-C(2)	1.431(3)
C(16)-C(15)	1.374(3)
C(16)-C(17)	1.381(3)
C(8)-C(7)	1.382(3)
C(8)-C(9)	1.382(3)
C(14)-C(15)	1.395(3)
C(18)-C(17)	1.380(3)
C(7)-C(6)	1.382(3)
O(2)-C(12)	1.425(2)
C(4)-N(1)	1.470(2)
C(6)-N(1)	1.434(2)

C(1)-C(5)-C(4)	113.61(15)
C(18)-C(13)-C(14)	116.59(18)
C(18)-C(13)-C(4)	121.35(17)
C(14)-C(13)-C(4)	122.03(17)
O(2)-C(11)-C(6)	116.09(17)
O(2)-C(11)-C(10)	125.29(19)
C(6)-C(11)-C(10)	118.62(19)
C(9)-C(10)-C(11)	120.0(2)
N(1)-C(3)-C(2)	125.03(18)
O(1)-C(1)-C(2)	124.23(19)
O(1)-C(1)-C(5)	120.17(18)
C(2)-C(1)-C(5)	115.29(16)
C(15)-C(16)-C(17)	119.6(2)
C(7)-C(8)-C(9)	119.4(2)
C(13)-C(14)-C(15)	121.6(2)
C(3)-C(2)-C(1)	119.86(18)
C(16)-C(15)-C(14)	120.0(2)
C(10)-C(9)-C(8)	121.15(18)
C(17)-C(18)-C(13)	122.3(2)
C(17)-C(18)-Br(1)	117.54(15)
C(13)-C(18)-Br(1)	120.13(15)
C(6)-C(7)-C(8)	120.1(2)
C(11)-O(2)-C(12)	117.63(17)
N(1)-C(4)-C(13)	111.65(15)
N(1)-C(4)-C(5)	108.68(15)
C(13)-C(4)-C(5)	112.27(15)
C(7)-C(6)-C(11)	120.73(17)
C(7)-C(6)-N(1)	120.36(17)
C(11)-C(6)-N(1)	118.88(18)
C(3)-N(1)-C(6)	121.94(16)
C(3)-N(1)-C(4)	119.45(15)
C(6)-N(1)-C(4)	118.40(14)

C(18)-C(17)-C(16) 119.8(2)

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($\text{\AA}^2 \times 10^3$) for NSJt. The anisotropic displacement factor exponent takes the form: $-2\pi^2 [h^2 a^{*2} U^{11} + \dots + 2hka^*b^*U^{12}]$

	U ¹¹	U ²²	U ³³	U ²³	U ¹³	U ¹²
Br(1)	58(1)	42(1)	25(1)	6(1)	-1(1)	13(1)
C(5)	26(1)	44(1)	26(1)	-2(1)	-2(1)	-4(1)
C(13)	31(1)	25(1)	25(1)	-3(1)	0(1)	-3(1)
O(1)	52(1)	42(1)	39(1)	-12(1)	3(1)	-16(1)
C(11)	37(1)	32(1)	23(1)	2(1)	2(1)	1(1)
C(10)	47(1)	37(1)	34(1)	-8(1)	7(1)	9(1)
C(3)	37(1)	33(1)	23(1)	3(1)	-2(1)	1(1)
C(1)	30(1)	36(1)	29(1)	-4(1)	7(1)	-10(1)
C(16)	43(1)	48(1)	44(1)	-10(1)	16(1)	-13(1)
C(8)	43(1)	40(1)	40(1)	-8(1)	-11(1)	1(1)
C(14)	33(1)	40(1)	35(1)	2(1)	-1(1)	1(1)
C(2)	40(1)	27(1)	34(1)	2(1)	2(1)	-1(1)
C(15)	34(1)	48(1)	50(1)	-3(1)	3(1)	-1(1)
C(9)	54(1)	37(1)	38(1)	-14(1)	-4(1)	3(1)
C(18)	44(1)	27(1)	23(1)	-3(1)	-1(1)	0(1)
C(7)	36(1)	34(1)	29(1)	0(1)	-4(1)	5(1)
O(2)	33(1)	43(1)	41(1)	-5(1)	2(1)	4(1)
C(4)	30(1)	29(1)	23(1)	1(1)	-2(1)	4(1)
C(12)	34(1)	58(1)	52(1)	10(1)	8(1)	11(1)
C(6)	36(1)	25(1)	21(1)	0(1)	1(1)	0(1)
N(1)	35(1)	26(1)	20(1)	-1(1)	-2(1)	0(1)
C(17)	55(1)	38(1)	26(1)	-2(1)	8(1)	-12(1)

Table 5. Hydrogen coordinates ($\times 10^4$) and isotropic displacement parameters ($\text{\AA}^2 \times 10^3$) for NSJt.

	x	y	z	U(eq)
H(5A)	5057	-1214	3985	38
H(5B)	5999	-1235	3175	38
H(10A)	5903	2590	6333	48
H(3A)	8145	-1821	5670	37
H(16A)	12242	116	2271	54
H(8A)	10488	1774	6484	49
H(14A)	10131	-1147	4250	43
H(2A)	7844	-3432	4867	40
H(15A)	12347	-976	3448	53
H(9A)	8367	2953	6847	52
H(7A)	10122	187	5603	40
H(4A)	6583	439	4042	33
H(12A)	2835	1182	5301	72
H(12B)	3898	2325	5395	72
H(12C)	3615	1476	6132	72
H(17A)	9916	1049	1901	47

Table 6. Torsion angles [$^\circ$] for NSJt.

O(2)-C(11)-C(10)-C(9)	178.3(2)
C(6)-C(11)-C(10)-C(9)	-1.2(3)
C(4)-C(5)-C(1)-O(1)	-152.52(18)
C(4)-C(5)-C(1)-C(2)	33.6(2)
C(18)-C(13)-C(14)-C(15)	-0.1(3)
C(4)-C(13)-C(14)-C(15)	178.09(18)
N(1)-C(3)-C(2)-C(1)	-10.5(3)
O(1)-C(1)-C(2)-C(3)	-177.2(2)
C(5)-C(1)-C(2)-C(3)	-3.6(3)
C(17)-C(16)-C(15)-C(14)	0.1(3)
C(13)-C(14)-C(15)-C(16)	0.6(3)
C(11)-C(10)-C(9)-C(8)	0.9(3)
C(7)-C(8)-C(9)-C(10)	-0.3(3)
C(14)-C(13)-C(18)-C(17)	-1.2(3)
C(4)-C(13)-C(18)-C(17)	-179.35(17)
C(14)-C(13)-C(18)-Br(1)	178.28(14)
C(4)-C(13)-C(18)-Br(1)	0.1(2)
C(9)-C(8)-C(7)-C(6)	0.1(3)
C(6)-C(11)-O(2)-C(12)	178.98(17)
C(10)-C(11)-O(2)-C(12)	-0.5(3)
C(18)-C(13)-C(4)-N(1)	-156.43(16)
C(14)-C(13)-C(4)-N(1)	25.5(2)
C(18)-C(13)-C(4)-C(5)	81.2(2)
C(14)-C(13)-C(4)-C(5)	-96.9(2)
C(1)-C(5)-C(4)-N(1)	-48.5(2)
C(1)-C(5)-C(4)-C(13)	75.5(2)
C(8)-C(7)-C(6)-C(11)	-0.5(3)
C(8)-C(7)-C(6)-N(1)	-178.43(19)
O(2)-C(11)-C(6)-C(7)	-178.54(17)
C(10)-C(11)-C(6)-C(7)	1.0(3)
O(2)-C(11)-C(6)-N(1)	-0.6(2)
C(10)-C(11)-C(6)-N(1)	178.99(17)
C(2)-C(3)-N(1)-C(6)	177.0(2)
C(2)-C(3)-N(1)-C(4)	-8.2(3)
C(7)-C(6)-N(1)-C(3)	63.3(3)
C(11)-C(6)-N(1)-C(3)	-114.7(2)
C(7)-C(6)-N(1)-C(4)	-111.5(2)
C(11)-C(6)-N(1)-C(4)	70.5(2)
C(13)-C(4)-N(1)-C(3)	-87.3(2)
C(5)-C(4)-N(1)-C(3)	37.1(2)
C(13)-C(4)-N(1)-C(6)	87.6(2)
C(5)-C(4)-N(1)-C(6)	-148.01(16)
C(13)-C(18)-C(17)-C(16)	1.9(3)
Br(1)-C(18)-C(17)-C(16)	-177.58(15)
C(15)-C(16)-C(17)-C(18)	-1.3(3)

Symmetry transformations used to generate equivalent atoms: