Highly Enantioselective Azadiene Diels-Alder Reactions Catalyzed by Chiral *N*-Heterocyclic Carbenes

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Supporting Information

General Methods. All reactions utilizing air- or moisture-sensitive reagents were performed in dried glassware under an atmosphere of dry argon. Chlorobenzene and CH₂Cl₂ were distilled over CaH₂. Toluene and THF were dried by passage over activated alumina under Ar atmosphere. All aldehydes were purified by distillation prior to use. Diisopropylethylamine (DIPEA) was distilled from KOH. Other reagents were used without further purification. Thin layer chromatography (TLC) was performed on Merck precoated plates (silica gel 60 F₂₅₄, Art 5715, 0.25 mm) and were visualized by fluorescence quenching under UV light or by staining with phosphomolybdic acid. Silica-gel preparative thin-layer chromatography (PTLC) was performed using plates prepared from Merck Kieselgel 60 PF₂₅₄ (Art 7747). Column chromatography was performed on E. Merck Silica Gel 60 (230–400 Mesh) using a forced flow of 0.5–1.0 bar. ¹H NMR (400 MHz) and ¹³C NMR (100 MHz) were measured on a Varian Unity 400 spectrometer. Chemical shifts are expressed in parts per million (PPM) downfield from residual solvent peaks and coupling constants are reported as Hertz (Hz). Splitting patterns are indicated as follows: br, broad; s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet. Infrared (IR) spectra were recorded on a JASCO FT/IR-430 spectrophotometer and are reported as wavenumber (cm⁻¹). Optical rotations were measured on a Jasco DIP-1000 polarimeter operating at the sodium D line with a 100 mm path length cell, and are reported as follows: [α]^T (concentration (g/100 ml), solvent).

HPLC Conditions. Column, Diacel Chiralpak AS-H, (4.6 x 250mm) Eluent: hexanes/*i*-PrOH. Flow Rate 1.0 mL/min. Detection: 254 nm. Column, Diacel Chiralpak AD-H, (4.6 x250mm) Eluent: hexanes/*i*PrOH. Flow Rate 1.0 mL/min. Detection: 254 nm. Column, Diacel Chiralpak OD-H, (4.6 x250mm) Eluent: hexanes/*i*PrOH. Flow Rate 1.0 mL/min. Detection: 254 nm.

General procedure for NHC-catalyzed, enantioselective azadiene Diels-Alder reactions.

The reaction of ethyl *trans*-4-oxo-2-butenate¹ and *trans*-*N*-(4-methoxybenzenesulfonyl)-3-phenylprop-2-ene-1-imine is representative: Into an oven dried 2.0 mL vial was added the enal (6.5 mL, 0.054 mmol, 1.1 equiv), imine (14.7 mg, 0.049 mmol, 1.0 equiv) and triazolium salt **9** (1.8 mg, 0.005 mmol, 0.10 equiv). The vial was crimped with a Teflon-lined crimp seal. To this mixture was added 1.0 mL 10:1 toluene/THF (0.05 M), followed by diisopropylethylamine (0.8 μ L, 0.005 mmol, 0.10 equiv). The resulting solution was stirred at room temperature for 23 h. The reaction mixture was concentrated under reduced pressure, and the residue was purified by PTLC (2:1 hexane/EtOAc) to afford the dihydropyridinone product as a white solid (19.8 mg, 90% yield).

Ethyl 2-((3*S*,4*S*)-1-(4-methoxyphenylsulfonyl)-2-oxo-4-phenyl-1,2,3,4-tetrahydropyridin-3-yl)acetate (Table 2, entry 1). Prepared according to the general procedure from ethyl *trans*-4-oxo-2-butenate and *trans*-*N*-(4-methoxybenzenesulfonyl)-3-phenylprop-2-ene-1-imine using 10 mol % **9** as the catalyst in 90% yield as a white solid. $[\alpha]_D^{20}$ (c 1.19, CHCl₃) = +105.2 ; mp = 111–113 °C; ¹H NMR (400 MHz, CDCl₃) δ 8.04 (dd, 2H, *J* = 7.0, 2.1 Hz), 7.16–7.12 (m, 2H), 7.06–6.99 (m, 4H), 6.58 (dd, 2H, *J* = 8.0, 1.1 Hz), 5.60 (dd, 1H, *J* = 8.0, 6.5 Hz), 4.18–4.08 (m, 2H), 3.92 (s, 3H), 3.65 (t, 1H, *J* = 6.9 Hz), 3.55–3.53 (m, 1H), 2.57 (dd, 1H, *J* = 17.3, 6.1 Hz), 1.94 (dd, 1H, *J* = 17.3, 7.5 Hz), 1.21 (t, 3H, *J* = 7.0 Hz); ¹³C NMR (100 MHz, CDCl₃) δ 171.7, 169.0, 164.3, 136.8, 131.4, 129.2, 128.9, 127.9, 127.9, 124.6, 114.3, 113.6, 61.0, 56.0, 44.1, 42.0, 31.6, 14.3; IR (thin film) ν 3086, 2982, 1720, 1594, 1496, 1454, 1406, 1367, 1264, 1132, 1091,

(1) Lancaster Synthesis (Alfa Aesar) Cat. No. 18481 (25 g/\$50.97).

1026 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{22}\text{H}_{23}\text{NO}_6\text{S}$ $[\text{M}+\text{Na}]^+$ 452.1138, found 452.1160; >99% ee (3*R*, 4*R*)-isomer as determined by HPLC (AS-H, 9:1 hexanes/*i*-PrOH), $t_{\text{r}}(3\text{S}, 4\text{S}) = 53.9$ min, $t_{\text{r}}(3\text{R}, 4\text{R}) = 39.2$ min. For the (3*R*, 4*R*) enantiomer (Table 2, entry 2), $[\alpha]_{\text{D}}^{20}$ (c 0.98, CHCl_3) = –112.7.

Ethyl 2-((3*S*,4*S*)-4-(4-methoxyphenyl)-1-(4-methoxyphenylsulfonyl)-2-oxo-1,2,3,4-tetrahydropyridin-3-yl)acetate (Table 2, entry 3). Prepared according to the general procedure from ethyl *trans*-4-oxo-2-butenate and *trans*-*N*-(4-methoxybenzenesulfonyl)-3-(4-methoxyphenyl)prop-2-en-1-imine using 10 mol % **9** as the catalyst in 81% yield as a yellow solid. $[\alpha]_{\text{D}}^{20}$ (c 1.04, CHCl_3) = +143.6; mp = 107–110 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.03 (dd, 2H, $J = 7.1, 1.8$ Hz), 7.13 (d, 1H, $J = 8.1$ Hz), 7.05 (dd, 2H, $J = 7.1, 1.8$ Hz), 6.55–6.48 (m, 4H), 5.59 (dd, 1H, $J = 8.0, 6.6$ Hz), 4.16–4.09 (m, 2H), 3.92 (s, 3H), 3.71 (s, 3H), 3.60 (t, 1H, J

= 6.9 Hz), 3.52–3.47 (m, 1H), 2.58 (dd, 1H, J = 17.2, 6.0 Hz), 1.95 (dd, 1H, J = 17.2, 7.7 Hz), 1.22 (t, 3H, J = 7.0 Hz); ^{13}C NMR (100 MHz, CDCl_3) δ 171.8, 169.1, 164.3, 159.2, 131.4, 129.2, 128.5, 124.3, 114.3, 114.3, 113.9, 113.6, 61.0, 56.0, 55.3, 44.3, 41.2, 31.5, 14.4; IR (thin film) ν 3055, 2840, 1720, 1647, 1511, 1498, 1463, 1442, 1366, 1263, 1167, 1090, 1028 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{23}\text{H}_{25}\text{NO}_7\text{S}$ $[\text{M}+\text{Na}]^+$ 482.1243, found 482.1253; >99% ee (3*S*, 4*S*)-isomer as determined by HPLC (AS-H, 4:1 hexanes/*i*-PrOH), t_{r} (3*S*, 4*S*) = 49.3 min, t_{r} (3*R*, 4*R*) = 29.6 min.

Ethyl 2-((3*S*,4*S*)-4-(4-acetylphenyl)-1-(4-methoxyphenylsulfonyl)-2-oxo-1,2,3,4-tetrahydropyridin-3-yl)acetate (Table 2, entry 4). Prepared according to the general procedure from ethyl *trans*-4-oxo-2-butenate and *trans*-*N*-(4-methoxybenzenesulfonyl)-1-(4-(3-iminoprop-1-enyl)phenyl)ethanone using 10 mol % **9** as the catalyst in 55% yield as a yellow oil. $[\alpha]_{\text{D}}^{20}$ (c 1.22, CHCl_3) = +168.2; ^1H NMR (400 MHz, CDCl_3) δ 8.04 (dd, 2H, J = 6.9, 2.1 Hz), 7.59 (dd, 2H, J = 6.5, 1.9 Hz), 7.19 (d, 1H, J = 8.0 Hz), 7.07 (dd, 2H, J = 6.9, 2.1 Hz), 6.69 (dd, 2H, J =

6.6, 1.7 Hz), 5.59 (dd, 1H, $J = 8.0, 6.6$ Hz), 4.14–4.11 (m, 2H), 3.95 (s, 3H), 3.74 (t, 1H, $J = 6.9$ Hz), 3.58–3.53 (m, 1H), 2.58 (dd, 1H, $J = 17.4, 6.0$ Hz), 2.52 (s, 3H), 1.90 (dd, 1H, $J = 17.4, 7.8$ Hz), 1.22 (t, 3H, $J = 7.2$ Hz); ^{13}C NMR (100 MHz, CDCl_3) δ 197.5, 171.5, 168.6, 164.5, 142.3, 136.6, 131.4, 128.9, 128.2, 125.3, 114.3, 112.7, 94.6, 61.1, 56.1, 43.9, 41.7, 31.4, 26.7, 14.3; IR (thin film) ν 3020, 2983, 2842, 1723, 1682, 1594, 1497, 1363, 1267, 1167, 1091, 1024 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{24}\text{H}_{25}\text{NO}_7\text{S}$ $[\text{M}+\text{Na}]^+$ 494.1243, found 494.1265; >99% ee (3*S*, 4*S*)-isomer as determined by HPLC (OD-H, 4:1 hexanes/*i*-PrOH), $t_r(3S, 4S) = 28.6$ min, $t_r(3R, 4R) = 35.1$ min.

Ethyl 2-((3*S*,4*S*)-4-(furan-2-yl)-1-(4-methoxyphenylsulfonyl)-2-oxo-1,2,3,4-tetrahydropyridin-3-yl)acetate (Table 2, entry 5). Prepared according to the general procedure from ethyl *trans*-4-oxo-2-butenate and *trans*-*N*-(4-methoxybenzenesulfonyl)-3-(furan-2-yl)prop-2-en-1-imine using 10 mol % **9** as the catalyst in 71% yield as a yellow solid. $[\alpha]_{\text{D}}^{20}$ (c 1.58, CHCl_3) = +125.7; mp = 98–100 °C; ^1H NMR (400 MHz, CDCl_3) δ 7.98 (dd, 2H, $J = 7.0, 1.9$ Hz), 7.12 (d,

2H, $J = 8.0$ Hz), 7.00 (dd, 2H, $J = 7.0, 1.9$ Hz), 6.87 (d, 1H, $J = 1.8$ Hz), 6.11 (dd, 1H, $J = 3.2, 1.8$ Hz), 5.82 (d, 1H, $J = 3.2$ Hz), 5.51 (dd, 1H, $J = 8.0, 6.8$ Hz), 4.15–4.10 (m, 2H), 3.90 (s, 3H), 3.75 (t, 1H, $J = 6.7$ Hz), 3.45–3.40 (m, 1H), 2.72 (dd, 1H, $J = 17.3, 6.0$ Hz), 2.52 (s, 3H), 2.04 (dd, 1H, $J = 17.3, 7.7$ Hz), 1.22 (t, 3H, $J = 7.0$ Hz); ^{13}C NMR (100 MHz, CDCl_3) δ 171.7, 168.7, 164.2, 142.6, 131.4, 129.6, 125.7, 114.1, 110.4, 108.0, 61.0, 56.0, 43.2, 35.1, 31.5, 14.3; IR (thin film) ν 3114, 2982, 2843, 1724, 1595, 1498, 1363, 1263, 1167, 1133, 1092, 1025 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{20}\text{H}_{21}\text{NO}_7$ S $[\text{M}+\text{Na}]^+$ 494.1243, found 494.1265; >99% ee (3*S*, 4*S*)-isomer as determined by HPLC (AD-H, 9:1 hexanes/*i*-PrOH), $t_r(3S, 4S) = 43.7$ min, $t_r(3R, 4R) = 27.4$ min.

Ethyl 2-((3*S*,4*S*)-1-(4-methoxyphenylsulfonyl)-2-oxo-4-propyl-1,2,3,4-tetrahydropyridin-3-yl)acetate (Table 1, entry 6). Prepared according to the general procedure from ethyl *trans*-4-oxo-2-butenate and *trans*-*N*-(4-methoxybenzenesulfonyl)-hex-2-en-1-imine using 10 mol % **9** as the catalyst in 58% yield as a colorless oil. $[\alpha]_{\text{D}}^{20}$ (c 0.64, CHCl_3) = -17.3 ; ^1H NMR (400

MHz, CDCl₃) δ 7.92 (dd, 2H, J = 6.9, 2.0 Hz), 6.97 (dd, 2H, J = 6.9, 2.0 Hz), 5.53 (dd, 1H, J = 8.0, 6.6 Hz), 4.13–4.11 (m, 2H), 3.87 (s, 3H), 3.24 (q, 1H, J = 6.3 Hz), 2.82 (dd, 1H, J = 16.6, 7.2 Hz), 2.41–2.38 (m, 1H), 2.24 (dd, 1H, J = 16.6, 7.0 Hz), 1.22 (t, 3H, J = 7.2 Hz), 1.25–1.02 (m, 4H), 0.73 (t, 3H, J = 7.2 Hz); ¹³C NMR (100 MHz, CDCl₃) δ 171.7, 170.2, 164.2, 131.1, 129.5, 124.2, 114.9, 114.1, 61.0, 55.9, 43.4, 34.5, 31.6, 31.4, 19.3, 14.3, 14.2; IR (thin film) ν 3046, 1723, 1595, 1506, 1418, 1358, 1271, 1133 cm⁻¹; HRMS (ESI) calcd for C₁₉H₂₅NO₆ S [M+Na]⁺ 418.1294, found 418.1287; >99% ee (3*S*, 4*S*)-isomer as determined by HPLC (AS-H, 9:1 hexanes/*i*-PrOH), t_r (3*S*, 4*S*) = 55.0 min, t_r (3*R*, 4*R*) = 28.2 min.

tert-Butyl 2-((3*S*,4*S*)-1-(4-methoxyphenylsulfonyl)-2-oxo-4-phenyl-1,2,3,4-tetrahydropyridin-3-yl)acetate (Table 3, entry 1). Prepared according to the general procedure from *tert*-butyl *trans*-4-oxo-2-butenate and *trans*-*N*-(4-methoxybenzenesulfonyl)-3-phenylprop-2-en-1-imine using 10 mol % **9** as the catalyst in 70% yield white solid. $[\alpha]_D^{20}$ (c 1.07, CHCl₃) = +90.4; mp = 139–142 °C; ¹H NMR (400 MHz, CDCl₃) δ 8.03 (dd, 2H, J = 6.9, 2.1 Hz), 7.16–7.13 (m,

2H), 7.05– 7.00 (m, 4H), 6.60 (dd, 2H, $J = 8.2, 1.0$ Hz), 5.59 (dd, 1H, $J = 8.1, 6.6$ Hz), 3.92 (s, 3H), 3.66 (t, 1H, $J = 6.9$ Hz), 3.49–3.43 (m, 1H), 2.57 (dd, 1H, $J = 17.3, 6.1$ Hz), 1.94 (dd, 1H, $J = 17.3, 7.5$ Hz), 1.41 (s, 9H); ^{13}C NMR (100 MHz, CDCl_3) δ 171.0, 169.0, 164.3, 136.9, 131.4, 129.2, 128.9, 128.0, 127.8, 124.5, 114.2, 113.6, 81.1, 56.0, 44.2, 41.9, 32.5, 28.2; IR (thin film) ν 3086, 2976, 1715, 1594, 1496, 1364, 1264, 1167, 1080 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{24}\text{H}_{27}\text{NO}_6\text{S}$ $[\text{M}+\text{Na}]^+$ 480.1451, found 480.1456; 97% ee (3*S*, 4*S*)-isomer as determined by HPLC (AS-H, 9:1 hexanes/*i*-PrOH), $t_r(3S, 4S) = 19.4$ min, $t_r(3R, 4R) = 14.1$ min.

From (R,S) Catalyst:

(3*S*,4*S*)-1-(4-Methoxyphenylsulfonyl)-3-(2-oxopropyl)-4-phenyl-3,4-dihydropyridin-2(1*H*)-one (Table 3, entry 2). Into an oven dried 2.0 mL vial was added (*E*)-4-oxopent-2-enal (10.0 mg 0.10 mmol, 1.0 equiv), *trans*-*N*-(4-methoxybenzenesulfonyl)-3-phenylprop-2-en-1-imine (30.1 mg, 0.10 mmol, 1.0 equiv) and chiral catalyst **9** (5.5 mg, 0.01 mmol, 0.10 equiv). The vial was

crimped with a Teflon-lined crimp seal. To this mixture was added 2.0 mL 10:1 toluene/THF (0.05 M), followed by diisopropylethylamine (1.7 μ L, 0.01 mmol, 0.10 equiv). The resulting solution was stirred at room temperature for 15 h before an additional 1.0 equiv of enal was added and the resulting solution was stirred for an additional 23h. The reaction mixture was concentrated under reduced pressure, and the residue was purified by PTLC (2:1 hexane/EtOAc) to afford the lactam product as a white solid (20.4 mg, 51% yield). $[\alpha]_D^{20}$ (c 1.10, CHCl_3) = +186.4; mp = 150–152 $^\circ\text{C}$; ^1H NMR (400 MHz, CDCl_3) δ 7.97 (dd, 2H, J = 6.9, 2.0 Hz), 7.14 (d, 2H, J = 8.2 Hz), 7.06–6.98 (m, 5H), 6.56 (dd, 2H, J = 7.2, 1.1 Hz), 5.60 (dd, 1H, J = 8.0, 6.2 Hz), 3.93 (s, 3H), 3.62–3.60 (m, 2H), 2.75 (dd, 1H, J = 18.6, 5.2 Hz), 2.05 (s, 3H), 2.04 (dd, 1H, J = 18.6, 6.9 Hz); ^{13}C NMR (100 MHz, CDCl_3) δ 206.3, 169.5, 164.3, 137.4, 131.4, 129.0, 127.8, 124.4, 114.3, 113.7, 56.0, 43.0, 41.8, 40.1, 30.5; IR (thin film) ν 3111, 3028, 2842, 1713, 1594, 1496, 1362, 1264, 1167, 1091, 1024 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{21}\text{H}_{21}\text{NO}_5$ S $[\text{M}+\text{Na}]^+$ 422.1032, found 422.1034; >99% ee (3*S*, 4*S*)-isomer as determined by HPLC (AD-H, 9:1 hexanes/*i*-PrOH), $t_r(3S, 4S)$ = 44.3 min, $t_r(3R, 4R)$ = 36.2 min.

(3*S*,4*S*)-1-(4-Methoxyphenylsulfonyl)-3-(2-oxopropyl)-4-propyl-3,4-dihydropyridin-2(1*H*)-one (Table 3, entry 3). Prepared according to the general procedure from (*E*)-4-oxopent-2-enal and *trans*-*N*-(4-methoxybenzenesulfonyl)-hex-2-en-1-imine using 10 mol % **9** as the catalyst in 70% yield as a yellow oil. $[\alpha]_D^{20}$ (c 0.91, CHCl₃) = −5.7; ¹H NMR (400 MHz, CDCl₃) δ 7.91 (dd, 2H, *J* = 6.9, 2.0 Hz), 6.97 (dd, 2H, *J* = 6.9, 2.0 Hz), 5.54 (dd, 1H, *J* = 8.0, 6.6 Hz), 3.87 (s, 3H), 3.24 (q, 1H, *J* = 6.3 Hz), 2.82 (dd, 1H, *J* = 16.6, 7.2 Hz), 2.41–2.38 (m, 1H), 2.24 (dd, 1H, *J* = 16.6, 7.0 Hz), 1.22 (t, 3H, *J* = 7.2 Hz), 1.25–1.02 (m, 4H), 0.73 (t, 3H, *J* = 7.2 Hz); ¹³C NMR (100 MHz, CDCl₃) δ 206.0, 170.7, 164.1, 131.0, 129.6, 128.8, 124.1, 115.1, 114.4, 114.1, 55.9, 42.4, 39.8, 34.7, 32.1, 30.6, 19.5, 14.3; IR (thin film) ν 3010, 2957, 1713, 1595, 1497, 1362, 1262, 1092, 1023 cm^{−1}; HRMS (ESI) calcd for C₁₈H₂₃NO₅S [M+Na]⁺ 388.1189, found 388.1175; 98% ee (3*S*, 4*S*)-isomer as determined by HPLC (AS-H, 9:1 hexanes/*i*-PrOH), *t*_r(3*S*, 4*S*) = 68.1 min, *t*_r(3*R*, 4*R*) = 55.1 min.

(3*S*,4*S*)-4-(4-Methoxyphenyl)-1-(4-methoxyphenylsulfonyl)-3-(2-oxophenethyl)-3,4-dihydropyridin-2(1*H*)-one (Table 3, entry 4). Prepared according to the general procedure from (*E*)-4-oxo-4-phenylbut-2-enal and *trans*-*N*-(4-methoxybenzenesulfonyl)-3-(4-methoxyphenyl)prop-2-en-1-imine using 10 mol % **9** as the catalyst in 52% yield as a yellow solid. $[\alpha]_D^{20}$ (c 0.87, CHCl₃) = +232.3; mp = 159–161 °C; ¹H NMR (400 MHz, CDCl₃) δ 8.06 (dd, 2H, *J* = 7.0, 2.0 Hz), 7.81 (dd, 1H, *J* = 7.2, 1.4 Hz), 7.55–7.51 (m, 1H), 7.41–7.38 (m, 1H), 7.17 (d, 1H, *J* = 8.1 Hz), 7.06 (dd, 2H, *J* = 7.0, 2.0 Hz), 6.51–6.45 (m, 4H), 5.64 (dd, 1H, *J* = 8.1, 6.3 Hz), 3.92 (s, 3H), 3.90–3.74 (m, 2H), 3.70 (s, 3H), 3.37 (dd, 1H, *J* = 18.4, 3.5 Hz), 2.61 (dd, 1H, *J* = 18.4, 8.0 Hz); ¹³C NMR (100 MHz, CDCl₃) δ 197.8, 169.8, 164.3, 159.1, 136.7, 133.5, 131.4, 129.3, 129.1, 128.9, 128.8, 128.2, 124.2, 114.3, 114.3, 114.2, 56.0, 55.3, 43.5, 40.7, 35.1; IR (thin film) ν 3025, 2987, 1716, 1684, 1495, 1510, 1361, 1264, 1166, 1091, 1028 cm⁻¹; HRMS (ESI) calcd for C₂₇H₂₅NO₆ S [M+Na]⁺ 514.1294, found 514.1307; >99% ee (3*S*, 4*S*)-isomer as determined by HPLC (AS-H, 4:1 hexanes/*i*-PrOH), *t*_r(3*S*, 4*S*) = 64.7 min, *t*_r(3*R*, 4*R*) = 52.2 min.

Ethyl 2-((3*S*,4*S*)-4-(4-bromophenyl)-1-(4-methoxyphenylsulfonyl)-2-oxo-1,2,3,4-tetrahydropyridin-3-yl)acetate. Prepared according to the general procedure from ethyl *trans*-4-oxo-2-butenate and *trans*-*N*-(4-methoxybenzenesulfonyl)-3-(4-bromophenyl)prop-2-en-1-imine in 35% yield as a yellow solid. $[\alpha]_D^{20}$ (c 1.42, CHCl₃) = +151.4; mp = 109–111 °C; ¹H NMR (400 MHz, CDCl₃) δ 8.02 (dd, 2H, *J* = 7.1, 2.1 Hz), 7.17–7.12 (m, 2H), 7.05 (dd, 2H, *J* = 7.1, 2.2 Hz), 6.46 (dd, 2H, *J* = 6.5, 2.1 Hz), 5.57 (dd, 1H, *J* = 8.0, 6.6 Hz), 4.14–4.10 (m, 2H), 3.94 (s, 3H), 3.66–3.60 (m, 1H), 3.53–3.51 (m, 1H), 2.59 (dd, 1H, *J* = 17.4, 6.0 Hz), 1.91 (dd, 1H, *J* = 17.4, 7.9 Hz), 1.22 (t, 3H, *J* = 7.4 Hz); ¹³C NMR (100 MHz, CDCl₃) δ 171.6, 168.7, 164.4, 135.8, 132.1, 131.4, 129.6, 128.8, 125.0, 121.8, 114.4, 114.4, 113.0, 61.1, 56.1, 43.9, 41.3, 31.4, 14.3; IR (thin film) ν 3087, 2978, 1719, 1594, 1496, 1365, 1263, 1190, 1166, 1091, 1025 cm⁻¹; HRMS (ESI) calcd for C₂₂H₂₂BrNO₆ S [M+Na]⁺ 530.0248, found 530.0254; >99% ee (3*S*,4*S*)-isomer as determined by HPLC (AS-H, 9:1 hexanes/*i*-PrOH), *t*_r(3*S*, 4*S*) = 65.6 min, *t*_r(3*R*, 4*R*) = 44.6 min.

***cis*-3-Benzyl-1-(4-methoxyphenylsulfonyl)-4-phenyl-3,4-dihydropyridin-2(1H)-one (14).**

Prepared according to the general procedure from 2-chloro-3-phenylpropanal and *trans*-*N*-(4-methoxybenzenesulfonyl)-3-phenylprop-2-ene-1-imine using 10 mol % **7** and 1.5 equiv DIPEA in 40% yield. ¹H NMR (400 MHz, CDCl₃) δ 8.02 (dd, 2H, *J* = 7.0, 2.1 Hz), 7.24-7.10 (m, 4H), 7.09- 6.94 (m, 7H), 6.47 (dd, 2H, *J* = 8.0, 1.0Hz), 5.48 (dd, 1H, *J* = 8.0, 6.3 Hz), 3.90 (s, 3H), 3.33- 3.30 (m, 1H), 3.27- 3.21 (m, 1H), 3.15 (dd, 1H, *J* = 14.6, 4.3 Hz), 2.10 (dd, 1H, *J* = 14.6, 9.0 Hz); ¹³C NMR (100 MHz, CDCl₃) δ 170.2, 164.3, 138.8, 137.4, 131.5, 129.2, 129.1, 128.8, 128.7, 128.2, 127.7, 126.6, 124.1, 114.4, 114.3, 56.0, 48.9, 41.1, 31.5; IR (thin film) ν 3062, 3029, 2926, 1721, 1594, 1496, 1362, 1263, 1167, 1091, 1027 cm⁻¹; HRMS(ESI) calcd for C₂₅H₂₃NO₄ S [M+Na]⁺ 456.1240, found 456.1247.

Preparation of Enals.

All enals were prepared according to the literature procedures and have been previously reported^{2,3}.

(*E*)-tert-Butyl 4-oxobut-2-enoate. ¹H NMR (400 MHz, CDCl₃) δ 9.58 (d, 1H, *J* = 7.4 Hz), 6.71 (dd, 1H, *J* = 15.9, 7.4Hz), 6.51 (d, 1H, *J* = 15.9 Hz), 1.36 (s, 12H); ¹³C NMR (100 MHz, CDCl₃) δ 192.8, 141.7, 139.6, 82.4, 27.9.

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- (2) Klei, A.; Jong, R. L. P.; Lugtenburg, J.; Tielens, A. G. M. *Eur. J. Org. Chem.* **2002**, 3015–3023.
- (3) Satoh, T.; Hanaki, N.; Kuramochi, Y.; Inoue, Y.; Hosoya, K.; Sakai, K. *Tetrahedron*, **2002**, 58, 2533–2549.

(E)-4-Oxopent-2-enal. ^1H NMR (400 MHz, CDCl_3) δ 9.77 (d, 1H, $J = 7.1$ Hz), 6.83 (d, 1H, $J = 16.3$ Hz), 6.72 (dd, 1H, $J = 16.3, 7.0$ Hz), 2.40 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 198.1, 193.7, 145.5, 138.3, 28.1.

(E)-4-Oxo-4-phenylbut-2-enal. ^1H NMR (400 MHz, CDCl_3) δ 9.89 (d, 1H, $J = 7.5$ Hz), 8.00–7.99 (m, 2H), 7.74–7.64 (m, 2H), 7.56–7.52 (m, 2H), 6.99 (dd, 1H, $J = 15.8, 7.5$ Hz); ^{13}C NMR (100 MHz, CDCl_3) δ 193.0, 190.0, 142.3, 139.4, 136.4, 134.4, 129.2, 129.2.

General procedure for the preparation of imines. All imines were prepared according to literature protocols.⁴ The corresponding aldehyde dimethyl acetal (1.0 equiv) and the arylsulfonamide (1.0 equiv) were mixed in a flask equipped with a Dean-Stark condenser. The neat mixture was heated to 180 °C for 30 min. The resulting melt was cooled to room temperature and the solid was crystallized from toluene to yield the product.

***trans*-N-(4-Methoxybenzenesulfonyl)-3-phenylprop-2-en-1-imine.**⁴ ^1H NMR (400 MHz, CDCl_3) δ 8.74 (d, 1H, $J = 9.5$ Hz), 7.89 (d, 2H, $J = 8.9$ Hz), 7.54–7.40 (m, 6H), 7.00–6.93 (m, 3H), 3.85 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 170.5, 163.7, 153.8, 134.2, 131.7, 130.2, 129.7, 129.3, 128.7, 124.7, 114.5, 55.8.

***trans*-N-(4-Methoxybenzenesulfonyl)-3-(4-methoxyphenyl)prop-2-en-1-imine.** Yellow solid; mp = 116–118 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.67 (d, 1H, $J = 9.5$ Hz), 7.84 (dd, 2H, $J = 6.9$,

(4) He, M; Bode, J. W. *Org. Lett.* **2005**, 7, 3131–3134

1.8 Hz), 7.46 (d, 2H, $J = 8.8$ Hz), 7.37 (d, 1H, $J = 15.6$ Hz), 6.95 (dd, 2H, $J = 6.9, 1.8$ Hz), 6.88 (d, 2H, $J = 8.8$ Hz), 6.81 (dd, 1H, $J = 15.6, 9.5$ Hz), 3.82 (s, 3H), 3.81 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 170.9, 163.7, 162.7, 153.9, 130.8, 130.2, 127.2, 122.5, 114.9, 114.6, 55.9, 55.7; IR (thin film) ν 3007, 2938, 2840, 1596, 1573, 1319, 1259, 1166, 1151, 1090, 1025 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{17}\text{H}_{17}\text{NO}_4\text{S}$ $[\text{M}+\text{Na}]^+$ 354.0770, found 354.0766.

trans-N-(4-Methoxybenzenesulfonyl)-1-(4-(3-iminoprop-1-enyl)phenyl)ethanone. Yellow solid; mp = 173–176 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.72 (d, 1H, $J = 9.3$ Hz), 7.94 (d, 2H, $J = 8.3$ Hz), 7.85 (dd, 2H, $J = 7.0, 2.0$ Hz), 7.58 (d, 2H, $J = 8.3$ Hz), 7.45 (d, 1H, $J = 15.8$ Hz), 7.00 (dd, 1H, $J = 15.8, 9.3$ Hz), 6.96 (dd, 2H, $J = 7.0, 2.0$ Hz), 3.83 (s, 3H), 2.57 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 197.4, 170.0, 164.0, 151.5, 138.9, 138.4, 130.5, 129.5, 129.2, 128.8, 127.2, 114.7, 114.4, 55.9, 27.0; IR (thin film) ν 3009, 2840, 1682, 1623, 1579, 1498, 1266, 1151, 1091, 1023 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{18}\text{H}_{17}\text{NO}_4\text{S}$ $[\text{M}+\text{Na}]^+$ 366.0770, found 366.0780.

trans-N-(4-Methoxybenzenesulfonyl)-3-(furan-2-yl)prop-2-en-1-imine. Brown solid; mp = 100–103 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.67 (d, 1H, $J = 9.7$ Hz), 7.89 (dd, 2H, $J = 6.9, 2.0$ Hz), 7.57 (d, 1H, $J = 1.9$ Hz), 7.21 (d, 1H, $J = 15.5$ Hz), 7.00 (dd, 2H, $J = 6.9, 2.0$ Hz), 6.83 (dd, 1H, $J = 15.5, 9.7$ Hz), 6.77 (d, 1H, $J = 3.5$ Hz), 6.54 (dd, 1H, $J = 3.5, 1.9$ Hz), 3.87 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 170.0, 163.7, 151.1, 146.7, 138.6, 130.3, 128.8, 122.5, 117.7, 114.6, 114.4, 113.3, 55.9, 55.8; IR (thin film) ν 3127, 2842, 1623, 1581, 1463, 1261, 1150, 1090, 1020 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{14}\text{H}_{13}\text{NO}_4\text{S}$ $[\text{M}+\text{Na}]^+$ 314.0457, found 314.0463.

***trans*-N-(4-Methoxybenzenesulfonyl)-hex-2-en-1-imine.** Yellow solid; mp = 45–48 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.57 (d, 1H, J = 9.4 Hz), 7.05 (dd, 2H, J = 6.7, 2.0 Hz), 7.00 (dd, 2H, J = 6.7, 2.0 Hz), 6.87 (dt, 1H, J = 15.4, 7.0 Hz), 6.35 (dd, 1H, J = 15.4, 9.4 Hz), 3.87 (s, 3H), 2.35–2.29 (m, 2H), 1.53 (q, 2H, J = 7.3 Hz), 0.94 (t, 3H, J = 7.4 Hz); ^{13}C NMR (100 MHz, CDCl_3) δ 171.0, 163.7, 160.6, 130.2, 129.6, 128.5, 114.5, 114.5, 55.8, 35.6, 21.2, 13.7; IR (thin film) ν 3087, 2963, 2934, 2874, 1636, 1595, 1498, 1323, 1262, 1154, 1092, 1023 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{13}\text{H}_{17}\text{NO}_3\text{S}$ $[\text{M}+\text{Na}]^+$ 290.0821, found 290.0815.

***trans*-N-(4-Methoxybenzenesulfonyl)-3-(4-bromophenyl)prop-2-en-1-imine.** Yellow solid; mp = 170–173 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.74 (d, 1H, J = 9.4 Hz), 7.90 (d, 2H, J = 8.9 Hz), 7.56 (d, 2H, J = 8.9 Hz), 7.43–7.39 (m, 3H), 7.02–6.99 (m, 3H), 3.88 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 170.2, 164.0, 152.0, 133.3, 132.7, 130.4, 130.0, 129.7, 126.3, 125.5, 114.7, 55.9; IR (thin film) ν 3028, 2840, 1620, 1594, 1575, 1320, 1261, 1152, 1091, 1024 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{16}\text{H}_{14}\text{BrNO}_3\text{S}$ $[\text{M}+\text{Na}]^+$ 401.9769, found 401.9786.

2-Mesityl-6,10b-dihydro-4H,5aH-(5R)-oxa-3,10c-diaza-(2S)-azoniacyclopenta[c]fluorene.

Prepared in analogy to the method of Rovis⁵ using mesitylhydrazine. White solid; $[\alpha]_{\text{D}}^{20}$ (c 1.00, EtOH) = +129.3; ^1H NMR (400 MHz, DMSO) δ 11.46 (s, 1H), 7.67 (d, 1H, J = 7.3 Hz), 7.45–7.33 (m, 3H), 7.21 (s, 2H), 6.14 (d, 1H, J = 3.8 Hz), 5.26 (d, 1H, J = 16.0 Hz), 5.08 (d, 1H, J = 16.0 Hz), 4.99 (t, 1H, J = 4.3 Hz), 3.49 (dd, 1H, J = 4.9 Hz, 17.1 Hz), 3.16 (d, 1H, J = 17.1 Hz), 2.37 (s, 3H), 2.12 (s, 6H); ^{13}C NMR (100 MHz, DMSO) δ 150.2, 144.7, 141.5, 140.7, 136.1,

(5) Kerr, M. S.; Read de Alaniz, J.; Rovis, T. *J. Org. Chem.* **2005**, 70, 5725–5728.

134.9, 131.3, 129.4, 129.3, 127.3, 125.5, 124.0, 76.9, 61.2, 59.8, 37.1, 20.7, 17.0; IR (thin film) ν 2923, 2853, 1580, 1460, 1222, 1099 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{21}\text{H}_{22}\text{N}_3\text{O}^+$ $[\text{M}]^+$ 332.1757, found 332.1754. For the (*S*, *R*)-enantiomer: $[\alpha]_{\text{D}}^{20}$ (c 1.00, EtOH) = -129.4 .

Determination of the relative and absolute stereochemistry of the dihydropyridinone products. The stereochemistry was determined by single crystal x-ray analysis of the product derived from 4-bromo-cinnamaldehyde imine (see above for characterization details.): A colorless crystal of approximate dimensions 0.3*0.2*0.09 mm was mounted on a glass fiber and transferred to a Bruker CCD platform diffractometer. The SMART⁶ program was used to determine the unit cell parameters and data collection (20 sec / frame, 0.3 deg. /frame for a sphere of diffraction data). The data were collected at room temperature. The raw frame data were processed using SAINT⁷ program. The absorption correction was applied using program SADABS.⁸ The structure was solved by direct methods and refined on F² by full-matrix least-squares techniques. Hydrogen atoms were theoretically added. At convergence, GOF = 1.099 for 288 variables refined to R₁ = 0.0822 for 1517 reflections with $I > 2\sigma(I)$. The absolute structure was determined from the Flack parameters,⁹ the two enantiomers gave the Flack parameters - 0.03(2) and 1.04(0.03), respectively. See the corresponding CIF file for further information.

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- (6) SMART Software Users Guide, Version 5.1, Bruker Analytical X-ray Systems, Inc., Madison, WI 1999.
- (7) SAINT Software Users Guide, Version 5.1, Bruker Analytical X-ray Systems, Inc., Madison, WI 1999.
- (8) Sheldrick, G. M. SADABS, Version 2.05, Bruker Analytical X-ray Systems, Inc.; Madison, WI 2001.
- (9) Flack, H. D., *Acta Cryst.* A39(1983) 876-881.

Figure 1. ORTEP representation (50% probability level) of ethyl 2-((3*S*,4*S*)-4-(4-bromophenyl)-1-(4-methoxyphenylsulfonyl)-2-oxo-1,2,3,4-tetrahydro-pyridin-3-yl)acetate. For clarity only the H atoms at the stereogenic centers are shown.