Supporting Information

Enantioselective gold-catalyzed intermolecular [2+2]-cycloadditions of 3-styrylindoles with N-allenyl oxazolidinone

Haoxiang Hu, Yidong Wang, Deyun Qian, Zhan-Ming Zhang, Lu Liu* and Junliang Zhang*

Shanghai Key Laboratory of Green Chemistry and Chemical Processes, School of Chemistry and Molecular Engineering, East China Normal University, 3663 North Zhongshan Road, Shanghai 200062, P. R. China.

Fax: (+86)-021-6223-3213; E-mail: lliu@chem.ecnu.edu.cn, jlzhang@chem.ecnu.edu.cn

Table Contents

1. General information.................................................................................. S2
2. Optimization of conditions....................................................................... S3
3. Synthesis of Ligands (S, R,)-X1-X8....................................................... S4
4. Synthesis of substrates 1a-1t and 2....................................................... S10
5. General procedure for the [2+2] cycloaddition and copies of HPLC data ........................................................................................................ S16
6. References................................................................................................ S46
7. X-ray crystal data..................................................................................... S46
8. Copies of NMR spectra for Ligands, substrates and [2+2] adducts.. S47
1. General Information

$^1$H NMR spectra, $^{13}$C NMR spectra were recorded on a Bruker 400 MHz spectrometer in CDCl$_3$. All signals are reported in ppm with the internal TMS signal at 0 ppm as a standard. Data for $^1$H NMR spectra are reported as follows: chemical shift (ppm, referenced to TMS; s = singlet, d = doublet, t = triplet, dd = doublet of doublets, m = multiplet), coupling constant (Hz), and intergration. Data for $^{13}$C NMR are reported in terms of chemical shift (ppm) relative to residual solvent peak (CDCl$_3$ : 77.00 ppm).

Reactions were monitored by thin layer chromatography (TLC) using silica gel plates. Flash column chromatography was performed over silica gel (300-400 mesh). Dichloromethane were freshly distilled from CaH$_2$; THF was freshly distilled from sodium metal prior to use; AgOTf, AgNTf$_2$, AgBF$_4$, and AgCH$_3$O$_3$S were purchased from Alfa-Aesar Company and used directly. The $[\alpha]_D$ was recorded using PolAAr 3005 High Accuracy Polarimeter. Infrared (IR) spectra were obtained using a Bruker tensor 27 infrared spectrometer. The ee was recorded using UltiMate 3000 HPLC from Dionex Company.
2. Optimization of conditions

a. Screening of ligands.

\[
\begin{align*}
\text{Ph}_3 \text{C} & \quad + \quad \text{Ph}_3 \text{C} \\
1a & \quad 0.11 \text{ mmol} & 2 & \quad 0.1 \text{ mmol} \\
\text{Au(SMe}_2\text{)Cl (5.5 mol\%)} & \quad L (5.5 \text{ mol\%)} & \quad \text{AgNTf}_2 (5 \text{ mol\%)} & \quad \text{CH}_2\text{Cl}_2 \\
& \quad 50 \degree \text{C, 0.5 h, 1 h,} \\
\end{align*}
\]

\[R = \text{Ph, (S, R)_X-M1, -12\% ee, 77\% yield}\]
\[R = 3,5-\text{-diert-butyl-4-methoxyl, (S, R)_2-M2, -11\% ee, 76\% yield}\]
\[R = 1-\text{nap, (S, R)_3-M3, -32\% ee, 79\% yield}\]
\[R = \text{Me, (S, R)_3-M4, 9\% ee, 73\% yield}\]

\[\begin{array}{c|c|c}
\text{Entry} & \text{Silver salt} & \text{Ee (\%)}^b & \text{Yield (\%)}^c \\
\hline
1 & \text{AgNTf}_2 & 88 & 92 \\
2 & \text{AgC}_4\text{F}_7\text{O}_2 & 76 & 88 \\
3 & \text{AgBF}_4 & 90 & 90 \\
4 & \text{AgCH}_3\text{OS} & 78 & 84 \\
5 & \text{AgOTf} & 91 & 91 \\
6 & \text{AgSbF}_6 & 86 & 89 \\
\end{array}
\]

*The reactions were carried out in 1.5 mL CH\(_2\)Cl\(_2\). Yields of (-)-3a were NMR yields, and ee values were determined by chiral HPLC.

b. Screening of silver salt\(^a\).

\[
\begin{align*}
\text{Ph}_3 \text{C} & \quad + \quad \text{Ph}_3 \text{C} \\
1a & \quad 0.11 \text{ mmol} & 2 & \quad 0.1 \text{ mmol} \\
\text{Au(SMe}_2\text{)Cl (5.5 mol\%)} & \quad (S, R)_3-X (5.5 \text{ mol\%)} & \quad [\text{Ag}] (5 \text{ mol\%)} & \quad \text{CH}_2\text{Cl}_2, 50 \degree \text{C, 0.5 h,} \\
& \quad \text{(-)-3a} \\
\end{align*}
\]

The reactions were carried out in 1.5 mL CH\(_2\)Cl\(_2\). Yields of (-)-3a were NMR yields, and ee values were determined by chiral HPLC.
c. Further Optimization.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Entry</th>
<th>solvent</th>
<th>T. (°C)</th>
<th>Ee (%)\textsuperscript{b}</th>
<th>Yield (%)\textsuperscript{c}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CH\textsubscript{2}Cl\textsubscript{2}</td>
<td>-50</td>
<td>91</td>
<td>91</td>
</tr>
<tr>
<td>2</td>
<td>DCE</td>
<td>-40</td>
<td>78</td>
<td>91</td>
</tr>
<tr>
<td>3</td>
<td>CHCl\textsubscript{3}</td>
<td>-50</td>
<td>87</td>
<td>91</td>
</tr>
<tr>
<td>4</td>
<td>CH\textsubscript{2}Cl\textsubscript{2}</td>
<td>-60</td>
<td>92</td>
<td>90</td>
</tr>
<tr>
<td>5</td>
<td>CH\textsubscript{2}Cl\textsubscript{2}</td>
<td>-70</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>6</td>
<td>CH\textsubscript{2}Cl\textsubscript{2}</td>
<td>-78</td>
<td>94</td>
<td>92</td>
</tr>
</tbody>
</table>

\textsuperscript{a}The reactions were carried out in 1.5 mL solvent. \textsuperscript{b}Determined by chiral HPLC. \textsuperscript{c}NMR yield.

3. Synthesis of Ligands (S, R\textsubscript{s})-X1-X8

(1) Synthesis of 6.

To a solution of 15.1 g HP(1-Ad\textsubscript{2}) (50 mmol) in toluene (150 mL), 9 mL 2-(2-Brdmophenyl)-1,3-dioxolane (60 mmol, 1.2 equiv), 600 mg Pd(OAc)\textsubscript{2} (2.5 mmol, 5 mol%), 1.65 g dppf (3.0 mmol, 6 mol%) and 5.75 g NaOtBu (60 mmol, 1.0 equiv) was added. The reaction was stirred at 110 °C for 8 h, and then was cooled to ambient temperature. The solid was filtered off by celite and washed with CH\textsubscript{2}Cl\textsubscript{2}. The filtrate was concentrated in vacuo. The residue was purified by recrystallization and m1 was obtained in 80% yield: yellow solid. \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) δ 7.78 (d, J = 7.6 Hz, 1H), 7.70-7.68 (m, 1H), 7.44-7.40 (m, 1H), 7.35-7.31 (m, 1H), 6.87 (d, J = 8.0 Hz, 1H), 4.18-4.03 (m, 4H), 2.01-1.98 (m, 6H), 1.89-1.86 (m, 12H), 1.66 (s, 12H). \textsuperscript{31}P NMR (162 MHz, CDCl\textsubscript{3}) δ 14.50. \textsuperscript{13}C NMR (100 MHz, CDCl\textsubscript{3}) δ 145.1 (d, J\textsubscript{CP} = 22.0 Hz), 135.9 (d, J\textsubscript{CP} = 3.0 Hz), 133.8 (d, J\textsubscript{CP} = 28.0 Hz), 129.2, 127.1, 126.6 (d, J\textsubscript{CP} = 7.0 Hz),
101.3 (d, $J_{CP} = 38.0$ Hz), 65.5, 41.8 (d, $J_{CP} = 13.0$ Hz), 36.84 (d, $J_{CP} = 22.0$ Hz), 36.82, 28.7 (d, $J_{CP} = 7.0$ Hz). MS (70 eV): m/z (%): 376 (M$^+$, 2.07), 105 (100). HRMS calcd for C$_{25}$H$_{39}$N$_2$O$_2$P: 376.1587, found: 376.1585.

To a solution of 4.5 g m1 (10 mmol) in 90 mL THF, 20 mL H$_2$O and 3 mL H$_2$SO$_4$ was added. The reaction mixture was heated at 60 °C for 3 h, and then was cooled to room temperature. The reaction was quenched by saturated NaHCO$_3$ solution and extracted with EtOAc for 2 times. The combined organic layer was dried over Na$_2$SO$_4$ and concentrated in vacuo. The residue was purified by flash chromatography (hexane : EtOAc = 20:1) to get 6 as yellow solid (89% yield). $^1$H NMR (400 MHz, CDCl$_3$) δ 11.24 (d, $J = 8.8$ Hz, 1H), 7.98-7.95 (m, 1H), 7.90-7.88 (m, 1H), 7.57-7.52 (m, 1H), 7.51-7.47 (m, 1H), 1.98-1.87 (m, 18H), 1.67 (s, 12H). $^{31}$P NMR (162 MHz, CDCl$_3$) δ 8.92. $^{13}$C NMR (100 MHz, CDCl$_3$) δ 194.6 (d, $J_{CP} = 41.0$ Hz), 143.6 (d, $J_{CP} = 17.0$ Hz), 138.4 (d, $J_{CP} = 35.0$ Hz), 136.8 (d, $J_{CP} = 2.0$ Hz), 131.4, 129.1-129.0 (m), 127.5 (d, $J_{CP} = 6.0$ Hz), 41.9 (d, $J_{CP} = 12.0$ Hz), 37.0 (d, $J_{CP} = 22.0$ Hz), 36.8, 28.7 (d, $J_{CP} = 8.0$ Hz). MS (70 eV): m/z (%): 406 (M$^+$, 40.68), 135 (100). HRMS calcd for C$_{27}$H$_{35}$OP: 406.2426, found: 406.2423.

(2) Synthesis of ($R_s$)-8.

The sulfinyl imine ($R_s$)-8 was prepared according to the modified procedure of literature.[1] To a solution of 2.03 g o-phosphino aldehyde 6 (5 mmol) in 20 mL THF was added 909 mg ($R$)-(+-)-2-methyl-2-propanesulfinamide 7 (7.5 mmol, 1.5 equiv) and 3.1 mL Ti(OEt)$_4$ (15 mmol, 3.0 equiv). The reaction was heated at 50 °C for 10 h. When completed, the reaction mixture was quenched by saturated NaHCO$_3$ solution, filtered by celite, and washed with ethyl acetate for twice. The filtrate was extracted with EtOAc, dried over Na$_2$SO$_4$, and concentrated in vacuo. Further purification was
accomplished by flash chromatography (hexane : EtOAc = 10:1) to isolate \((R)_S-8\) as yellow solid (85% yield). \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 9.87 (d, \(J = 7.6\) Hz, 1H), 8.09-8.06 (m, 1H), 7.87-7.85 (m, 1H), 7.46-7.44 (m, 2H), 1.93-1.87 (m, 18H), 1.70-1.60 (m, 12H), 1.27 (s, 9H). \(^{31}\)P NMR (162 MHz, CDCl\(_3\)) \(\delta\) 12.56. \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 164.5 (d, \(J_{CP} = 38.0\) Hz), 142.1 (d, \(J_{CP} = 22.0\) Hz), 137.7 (d, \(J_{CP} = 33.0\) Hz), 136.7 (d, \(J_{CP} = 2.0\) Hz), 129.6, 128.9, 128.0 (d, \(J_{CP} = 6.0\) Hz), 57.8, 41.8 (d, \(J_{CP} = 4.0\) Hz), 41.6 (d, \(J_{CP} = 4.0\) Hz), 37.2-37.1 (m), 36.9 (d, \(J_{CP} = 2.0\) Hz), 36.8, 28.7 (d, \(J_{CP} = 9.0\) Hz), 22.7. HRMS(ESI) calcd for C\(_{31}\)H\(_{45}\)NOPS [M+H\(^+\)]: 510.2954, found: 510.3013. \([\alpha]_D^{20} = -155.1\ (c = 0.3, \text{CHCl}_3)\).

**3) Synthesis of \((S, R)_S-X1-X8\).**

**General procedure:** To a solution of 510 mg \((R)_S-8\) (1.0 mmol) in 10 mL CH\(_2\)Cl\(_2\) at -55 °C was added Grignard reagent (15 mmol, 3.0 equiv) in THF. The mixture was stirred at -55 °C for 4-6 h and then was warmed to room temperature with stirring overnight. When completed, the reaction mixture was quenched by the addition of saturated NH\(_4\)Cl solution and diluted with ethyl acetate. The organic layer was separated, and the aqueous layer was extracted twice with EtOAc. The combined organic layers were dried over Na\(_2\)SO\(_4\), filtered, concentrated, and purified by flash chromatography (hexane : CH\(_2\)Cl\(_2\) : EtOAc = 6:2:1) to isolated \((S, R)_S-X1-X8\) as yellow solid.

**1) Synthesis of \((S,R)_S-X1**

\[
\text{Ph} \quad \begin{array}{c}
\text{N} \\
\text{O} \\
\text{S} \\
\text{PAd}_2 \\
(S,R)_S-X1
\end{array}
\]
Yellow solid. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.76-7.73 (m, 2H), 7.46-7.40 (m, 3H), 7.38-7.23 (m, 3H), 7.17 (t, \(J = 7.2\) Hz, 1H), 7.07-7.03 (m, 1H), 3.65 (d, \(J = 3.2\) Hz, 1H), 2.06-2.00 (m, 3H), 1.95-1.83 (m, 6H), 1.70-1.48 (m, 21H), 1.22 (s, 9H). \(^{31}\)P NMR (162 MHz, CDCl\(_3\)) \(\delta\) 14.47. \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 149.5 (d, \(J_{CP} = 24.0\) Hz), 142.8, 136.7 (d, \(J_{CP} = 2.0\) Hz), 133.6 (d, \(J_{CP} = 29.0\) Hz), 129.3 (d, \(J_{CP} = 2.0\) Hz), 128.7, 128.2, 127.9 (d, \(J_{CP} = 6.0\) Hz), 127.2, 125.4, 59.6 (d, \(J_{CP} = 34.0\) Hz), 55.8, 41.8 (d, \(J_{CP} = 13.0\) Hz), 41.4 (d, \(J_{CP} = 13.0\) Hz), 37.4 (d, \(J_{CP} = 23.0\) Hz), 36.8 (d, \(J_{CP} = 15.0\) Hz), 36.5, 28.7 (d, \(J_{CP} = 9.0\) Hz), 22.7. HRMS(ESI) calcd for C\(_{37}\)H\(_{50}\)NOPS [M+H\(^+\)]: 588.3423, found: 588.3497. 

\([\alpha]_D^{20} = -34.2\) (c = 0.3, CHCl\(_3\)).

(2) Synthesis of (S,R\(_3\))-X2

\[
\begin{align*}
\text{Me} & \quad \text{O} \\
\text{N} & \quad \text{S} \quad \text{PAd}_2 \\
\text{(S,R\(_3\))-X2} & \\
\item Yellow solid. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.73 (d, \(J = 7.8\) Hz, 1H), 7.47-7.43 (m, 1H), 7.37 (t, \(J = 7.8\) Hz, 1H), 7.23-7.20 (m, 1H), 6.00-5.91 (m, 1H), 3.36 (d, \(J = 5.2\) Hz, 1H), 2.04-1.84 (m, 18H), 1.68-1.66 (m, 12H), 1.51 (d, \(J = 6.8\) Hz, 3H), 1.16 (s, 9H). \(^{31}\)P NMR (162 MHz, CDCl\(_3\)) \(\delta\) 14.87. \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 152.4 (d, \(J = 25.0\) Hz), 136.2, 132.1 (d, \(J = 26.0\) Hz), 129.2, 126.4 (d, \(J = 5.0\) Hz), 125.1, 55.5, 52.5 (d, \(J = 35.0\) Hz), 42.0 (d, \(J = 13.0\) Hz), 41.7 (d, \(J = 12.0\) Hz), 37.2 (d, \(J = 22.4\) Hz), 36.9 (d, \(J = 4.0\) Hz), 36.6, 28.8 (d, \(J = 4.0\) Hz), 28.7 (d, \(J = 4.0\) Hz), 25.7, 22.6. HRMS(ESI) calcd for C\(_{32}\)H\(_{48}\)NOPS [M+H\(^+\)]: 526.3267, found: 526.3272. 
\([\alpha]_D^{20} = -80.3\) (c = 0.3, CHCl\(_3\)).

(3) Synthesis of (S,R\(_3\))-X3

\[
\begin{align*}
\text{Et} & \quad \text{O} \\
\text{N} & \quad \text{S} \quad \text{PAd}_2 \\
\text{(S,R\(_3\))-X3} & \\
\item Yellow solid. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.73 (d, \(J = 8.0\) Hz, 1H), 7.40-7.33 (m, 2H), 7.22-7.18 (m, 1H), 5.76 (s, 1H), 3.45 (s, 1H), 2.00-1.80 (m, 20H), 1.67 (d, \(J = 13.2\) Hz, 12H), 1.14 (s, 9H), 0.93 (t, \(J = 7.2\) Hz, 3H). \(^{31}\)P NMR (162 MHz, CDCl\(_3\)) \(\delta\) 15.13. \(^{13}\)C
NMR (100 MHz, CDCl₃) δ 151.7 (d, Jₘᵣₖ = 25.0 Hz), 136.4 (m), 132.4 (d, Jₘᵣₖ = 27.0 Hz), 128.9, 126.8 (m), 124.9, 55.6, 42.2 (d, Jₘᵣₖ = 13.0 Hz), 41.6 (d, Jₘᵣₖ = 12.0 Hz), 41.2, 37.3 (d, Jₘᵣₖ = 23.0 Hz), 36.9, 36.9 (d, Jₘᵣ₆ = 24.0 Hz), 28.8, (d, Jₘᵣ₆ = 9.0 Hz), 28.7 (d, Jₘᵣ₆ = 9.0 Hz), 22.6, 19.5, 14.2. HRMS(ESI) calcd for C₃₄H₅₀NOPS [M+H⁺]: 540.3423, found: 540.3439. [α]₀²⁰ = -79.2 (c = 0.3, CHCl₃).

(4) Synthesis of (S,R₃)-X⁴

Yellow solid. \(^1^H\) NMR (400 MHz, CDCl₃) δ 7.73 (d, J = 7.6 Hz, 1H), 7.39-7.33 (m, 2H), 7.23-7.18 (m, 1H), 5.74-5.67 (m, 1H), 3.3 (d, J = 5.2 Hz, 1H), 2.01-1.82 (m, 22H), 1.61 (d, J = 12.4 Hz, 12H), 1.14 (s, 9H), 0.96-0.93 (t, J = 7.6 Hz, 3H). \(^{31}\)P NMR (162 MHz, CDCl₃) δ 15.27. \(^{13}\)C NMR (100 MHz, CDCl₃) δ 151.2 (d, Jₘᵣ₆ = 25.0 Hz), 136.3 (d, Jₘᵣ₆ = 2.0 Hz), 132.6 (d, Jₘᵣ₆ = 26.0 Hz), 128.9, 126.8 (d, Jₘᵣ₆ = 6.0 Hz), 124.9, 58.1 (d, Jₘᵣ₆ = 32.0 Hz), 55.6, 42.2 (d, Jₘᵣ₆ = 13.0 Hz), 41.7 (d, Jₘᵣ₆ = 12.0 Hz), 37.3 (d, Jₘᵣ₆ = 13.0 Hz), 36.93 (d, Jₘᵣ₆ = 24.0 Hz), 36.90, 31.8, 28.84 (d, Jₘᵣ₆ = 8.0 Hz), 28.76 (d, Jₘᵣ₆ = 9.0 Hz), 22.6, 10.8. HRMS(ESI) calcd for C₃₄H₅₂NOPS [M+H⁺]: 554.3589, found: 554.3580. [α]₀²⁰ = -41.4 (c = 0.3, CHCl₃).

(5) Synthesis of (S,R₃)-X⁵

Yellow solid. \(^1^H\) NMR (400 MHz, CDCl₃) δ 7.73 (d, J = 7.6 Hz, 1H), 7.40-7.33 (m, 2H), 7.23-7.18 (m, 1H), 5.75 (s, 1H), 3.43 (s, 1H), 2.02-1.82 (m, 22H), 1.77 (s, 1H), 1.69-1.64 (m, 12H), 1.44-1.40 (m, 1H), 1.14 (s, 9H), 0.87 (t, J = 6.8 Hz, 3H). \(^{31}\)P NMR (162 MHz, CDCl₃) δ 15.19. \(^{13}\)C NMR (100 MHz, CDCl₃) δ 151.7 (d, J = 25.0 Hz), 136.4, 132.4 (d, J = 26.0 Hz), 128.9, 126.7, 124.9, 55.6, 42.2 (d, J = 13.0 Hz), 41.6 (d, J = 12.0 Hz), 38.8, 37.3 (d, J = 23.0 Hz), 36.90, 36.87 (d, J = 24.0 Hz), 28.8 (d, J = 9.0 Hz), 28.7
(d, J = 9.0 Hz), 28.5, 22.6, 13.9. HRMS(ESI) calcd for C_{35}H_{54}NOPs [M+H^+]: 568.3736, found: 568.3738. \([\alpha]_D^{20} = -67.5 \ (c = 0.3, \text{CHCl}_3)\).

(6) Synthesis of (S,R,S)-X6

Yellow solid. \(^1H\) NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.73 (d, \(J = 8.0\) Hz, 1H), 7.40-7.33 (m, 2H), 7.23-7.18 (m, 1H), 5.75 (s, 1H), 3.43 (s, 1H), 2.04-1.82 (m, 22H), 1.70-1.65 (m, 12H), 1.26-1.22 (m, 9H), 1.14 (s, 9H), 0.84 (t, \(J = 1.6\) Hz, 3H). \(^{31}P\) NMR (162 MHz, CDCl\(_3\)) \(\delta\) 15.19. \(^{13}C\) NMR (100 MHz, CDCl\(_3\)) \(\delta\) 151.6 (d, \(J_{CP} = 25.0\) Hz), 136.3, 132.4 (d, \(J_{CP} = 27.0\) Hz), 128.9, 126.7, 124.9, 55.6, 42.2 (d, \(J_{CP} = 13.0\) Hz), 41.6 (d, \(J_{CP} = 12.0\) Hz), 39.1, 37.2 (d, \(J_{CP} = 23.0\) Hz), 36.9, 36.8 (d, \(J_{CP} = 24.0\) Hz), 31.6, 29.2, 28.8 (d, \(J_{CP} = 9.0\) Hz), 28.7 (d, \(J_{CP} = 9.0\) Hz), 26.2, 22.5 (d, \(J_{CP} = 5.0\) Hz), 14.0. HRMS(ESI) calcd for C_{37}H_{58}NOPs [M+H^+]: 596.4056, found: 596.4049. \([\alpha]_D^{20} = -76.6 \ (c = 0.3, \text{CHCl}_3)\).

(7) Synthesis of (S,R,R)-X7

Yellow solid. \(^1H\) NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.72 (d, \(J = 7.8\) Hz, 1H), 7.40-7.32 (m, 2H), 7.22-7.17 (m, 1H), 5.72 (s, 1H), 3.41 (s, 1H), 2.01-1.79 (m, 22H), 1.65 (d, \(J = 10.8\) Hz, 12H), 1.58-1.49 (m, 1H), 1.13 (s, 9H), 0.84 (t, \(J = 6.4\) Hz, 6H). \(^{31}P\) NMR (162 MHz, CDCl\(_3\)) \(\delta\) 15.18. \(^{13}C\) NMR (100 MHz, CDCl\(_3\)) \(\delta\) 151.7 (d, \(J_{CP} = 25.0\) Hz), 136.3, 132.4 (d, \(J_{CP} = 27.0\) Hz), 128.9, 126.7 (d, \(J_{CP} = 6.0\) Hz), 124.8, 55.5, 42.2 (d, \(J_{CP} = 13.0\) Hz), 41.6 (d, \(J_{CP} = 12.0\) Hz), 37.2 (d, \(J_{CP} = 23.0\) Hz), 36.87, 36.85 (d, \(J_{CP} = 24.0\) Hz), 35.4, 28.81 (d, \(J_{CP} = 9.0\) Hz), 28.7 (d, \(J_{CP} = 9.0\) Hz), 27.9, 22.6, 22.5, 22.4. HRMS(ESI) calcd for C_{37}H_{56}NOPs [M+H^+]: 582.3893, found: 582.3902. \([\alpha]_D^{20} = -87.1 \ (c = 0.3, \text{CHCl}_3)\).

s 9
(8) Synthesis of (S,R<sub>S</sub>)-X8

Yellow solid. ¹H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.72 (d, J = 7.6 Hz, 1H), 7.41-7.33 (m, 2H), 7.23-7.18 (m, 1H), 5.73 (s, 1H), 3.38 (s, 1H), 2.01-1.81 (m, 20H), 1.65 (d, J = 7.8 Hz, 12H), 1.14 (s, 9H), 0.92 (s, 2H), 0.83 (s, 9H). ³¹P NMR (162 MHz, CDCl<sub>3</sub>) δ 15.27. ¹³C NMR (100 MHz, CDCl<sub>3</sub>) δ 151.8 (d, J<sub>CP</sub> = 24.7 Hz), 136.3, 132.5 (d, J<sub>CP</sub> = 26.5 Hz), 128.9, 126.6 (d, J<sub>CP</sub> = 5.8 Hz), 124.9, 60.0, 55.5, 46.5, 42.3 (d, J<sub>CP</sub> = 12.7 Hz), 41.6 (d, J<sub>CP</sub> = 12.0 Hz), 40.6, 37.3 (d, J<sub>CP</sub> = 22.7 Hz), 36.89, 36.88 (d, J<sub>CP</sub> = 24.1 Hz), 34.4, 30.2, 29.7, 29.2, 28.8 (d, J<sub>CP</sub> = 9.0 Hz), 28.7 (d, J<sub>CP</sub> = 9.0 Hz), 22.6. HRMS(ESI) calcd for C<sub>37</sub>H<sub>58</sub>NOPS [M+H<sup>+</sup>]: 596.4049, found: 596.4066. [α]<sub>D</sub> = -84.0 (c = 0.3, CHCl<sub>3</sub>).

4. Synthesis of substrates 1a-1t and 2.

All 3-vinylindole substrates were synthesized according to our previous procedure.<sup>2</sup> The spectra of known compounds such as 1a, 1b and 2 are consistent with the literature, which are not included here except 1a as a typical procedure.

Typical Procedure for synthesis of 3-styrylindoles.

n-BuLi (2.5 M in hexane solution) (9.6 mL, 24 mmol) was slowly added to the suspension of RCH<sub>2</sub>PPh<sub>3</sub>Br (10.39 g, 24 mmol) in dry THF (130 mL) at -20 °C. The mixture was stirred at room temperature for 2 hours followed by the addition of S1 (3.18 g, 20 mmol) in THF (20 mL) at -20 °C. Then the mixture was stirred at room
temperature for 2 hours, monitored by TLC and quenched by saturated solution of NH₄Cl at room temperature. The extracts with ethyl acetate were washed by Saturated salt water and dried over anhydrous Na₂SO₄, then the solvent was removed under reduced pressure. The crude product was purified by column chromatography to give (E)-Product (2.70 g, 58%) as a white solid and (Z)-product (1.86 g, 40%) as a colorless liquid.

(1) Synthesis of 1d

White solid. ¹H NMR (400 MHz, CDCl₃) δ 7.97 (d, J = 7.6Hz, 1H), 7.46-7.43 (m, 2H), 7.38-7.36 (m, 2H), 7.32-7.16 (m, 5H), 7.09-7.05 (m, 1H), 3.73 (s, 3H), 1.35-1.31 (m, 9H). ¹³C NMR (100 MHz, CDCl₃) δ 149.5, 137.6, 135.9, 128.2, 125.5, 125.4, 124.6, 122.1, 120.8, 120.2, 120.0, 114.1, 109.5, 34.5, 32.8, 31.3. MS (70 eV): m/z (%): 289 (M⁺, 100). HRMS calcd for C₂₁H₂₃N: 289.1830, found: 289.1833.

(2) Synthesis of 1e

Yellow solid. ¹H NMR (400 MHz, CDCl₃) δ 7.97 (d, J = 8.0 Hz, 1H), 7.31-7.19 (m, 5H), 7.16 (s, 1H), 7.12-7.02 (m, 3H), 3.82 (s, 3H), 6.78-6.73 (m, 1H), 3.72 (s, 3H). ¹³C NMR (100 MHz, CDCl₃) δ 159.9, 140.2, 137.7, 129.5, 128.6, 126.1, 124.5, 122.2, 121.9, 120.2, 120.0, 118.4, 113.8, 112.1, 110.9, 109.5, 55.2, 32.8. MS (70 eV): m/z (%): 263
(M⁺, 100). HRMS calcd for C₁₉H₁₇NO: 263.1312, found: 263.1312.

(3) Synthesis of 1f

![Chemical structure of 1f]

Yellow solid. ¹H NMR (400 MHz, CDCl₃) δ 7.98 (d, J = 7.6 Hz, 1H), 7.33-7.17 (m, 5H), 7.14 (s, 2H), 7.03 (d, J = 16.4 Hz, 1H), 6.85 (s, 1H), 3.75 (s, 3H), 2.34 (s, 6H). ¹³C NMR (100 MHz, CDCl₃) δ 138.6, 138.0, 137.7, 128.3, 128.2, 126.2, 125.0, 123.6, 122.2, 121.2, 120.3, 119.9, 114.1, 109.5, 32.8, 21.3. MS (70 eV): m/z (%): 261 (M⁺, 100). HRMS calcd for C₁₉H₁₉N: 261.1517, found: 261.1518.

(4) Synthesis of 1i

![Chemical structure of 1i]

Yellow solid. ¹H NMR (400 MHz, CDCl₃) δ 7.95 (d, J = 8.0 Hz, 1H), 7.47-7.40 (m, 2H), 7.34-7.24 (m, 2H), 7.23-7.15 (m, 3H), 7.06-6.98 (m, 3H), 3.75 (s, 3H). ¹⁹F NMR (376 MHz, CDCl₃) δ -116.10. ¹³C NMR (100 MHz, CDCl₃) δ 162.9, 160.5, 137.7, 134.8 (d, J = 3.0 Hz), 128.4, 127.0 (d, J = 7.7 Hz), 126.1, 123.6, 122.3, 121.4 (d, J = 2.0 Hz), 120.1 (d, J = 9.3 Hz), 115.4 (d, J = 21.0 Hz), 113.8, 109.6, 32.8. MS (70 eV): m/z (%): 251 (M⁺, 100). HRMS calcd for C₁₇H₁₄NF: 251.1110, found: 251.1112.

(5) Synthesis of 1k
White solid. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.28 (d, $J = 8.4$ Hz, 1H), 8.08-8.04 (m, 1H), 7.88-7.81 (m, 2H), 7.77-7.71 (m, 2H), 7.56-7.44 (m, 3H), 7.34-7.23 (m, 4H), 7.19 (s, 1H), 3.71 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 137.7, 136.2, 133.8, 131.2, 128.8, 128.5, 126.9, 125.8, 125.6, 124.5, 123.9, 122.6, 121.6, 120.3, 120.2, 114.4, 109.6, 32.8. MS (70 eV): m/z (%): 283 (M$^+$, 100). HRMS calcd for C$_{21}$H$_{17}$N: 283.1361, found: 283.1364.

(6) Synthesis of 1m

Yellow solid. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.08 (d, $J = 16.4$ Hz, 1H), 7.41 (d, $J = 8.4$ Hz, 2H), 7.33-7.28 (m, 4H), 7.18 (d, $J = 8.0$ Hz, 1H), 7.04-6.97 (m, 1H), 6.65 (d, $J = 16.4$ Hz, 1H), 3.69 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 138.1, 137.2, 131.5, 127.3, 126.8, 124.8, 124.4, 123.6, 122.5, 122.0, 120.0, 114.8, 114.3, 108.9, 33.1.

(7) Synthesis of 1o

White solid. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.84 (d, $J = 8.0$ Hz, 1H), 7.47 (d, $J = 7.6$ Hz, 2H), 7.34-7.28 (m, 2H), 7.24-7.13 (m, 2H), 7.08-7.01 (m, 4H), 3.65 (s, 3H), 2.48 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 138.7, 138.1, 132.0, 128.5, 128.1, 126.3, 125.6, 124.4,
123.9, 121.8, 121.7, 119.9, 113.8, 109.5, 32.7, 21.8. MS (70 eV): m/z (%): 247(M⁺, 100). HRMS calcd for C_{18}H_{17}N: 247.1361, found: 247.1362.

(8) Synthesis of 1p

Yellow solid. ¹H NMR (400 MHz, CDCl₃) δ 7.75 (d, J = 8.0 Hz, 1H), 7.46 (d, J = 7.6 Hz, 2H), 7.33-7.27 (m, 2H), 7.23-7.14 (m, 2H), 7.08 (s, 1H), 7.06-6.94 (m, 2H), 6.92 (d, J = 7.2 Hz, 1H), 4.00 (s, 3H), 2.72 (s, 3H). ¹³C NMR (100 MHz, CDCl₃) δ 138.7, 136.3, 129.7, 128.6, 127.4, 126.4, 125.7, 124.9, 121.5, 121.3, 120.2, 118.1, 113.6, 37.0, 19.7. MS (70 eV): m/z (%): 247 (M⁺, 100). HRMS calcd for C_{18}H_{17}N: 247.1361, found: 247.1363.

(9) Synthesis of 1r

White solid. ¹H NMR (400 MHz, CDCl₃) δ 8.01-7.96 (m, 1H), 7.43 (d, J = 8.4 Hz, 2H), 7.34-7.18 (m, 10H), 7.06 (d, J = 16.4 Hz, 1H), 6.89 (d, J = 8.4 Hz, 2H), 5.30 (s, 2H), 3.82 (s, 3H). ¹³C NMR (100 MHz, CDCl₃) δ 158.5, 137.2, 137.1, 131.4, 128.8, 127.7, 127.2, 126.84, 126.81, 126.4, 124.9, 122.3, 120.3, 120.1, 119.4, 114.8, 114.1, 110.0, 55.3, 50.1. MS (70 eV): m/z (%): 339 (M⁺, 100). HRMS calcd for C_{24}H_{21}NO: 339.1623, found: 339.1621.

(10) Synthesis of 1s
Yellow solid. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.02-7.98 (m, 1H), 7.43 (d, $J$ = 8.4 Hz, 2H), 7.35 (d, $J$ = 8.4 Hz, 2H), 7.28-7.17 (m, 8H), 7.13-7.05 (m, 3H), 5.20 (s, 2H), 1.33 (s, 9H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ 149.5, 137.2, 137.0, 135.8, 128.8, 127.7, 127.5, 126.8, 126.4, 125.5, 125.4, 125.0, 122.3, 120.7, 120.3, 120.2, 114.7, 110.0, 50.0, 34.5, 31.3. MS (70 eV): m/z (%): 365 (M$^+$, 100). HRMS calcd for C$_{27}$H$_{27}$N: 365.2144, found: 365.2146.

(11) Synthesis of 1t

White solid. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.02-7.94 (m, 1H), 7.40 (d, $J$ = 8.4 Hz, 2H), 7.34-7.20 (m, 10H), 7.16-7.10 (m, 2H), 7.03 (d, $J$ = 16.8 Hz, 1H), 5.29 (s, 2H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 137.3, 137.1, 136.9, 131.9, 128.8, 128.7, 128.0, 127.8, 126.9, 126.8, 126.3, 123.8, 122.5, 122.1, 120.4, 120.3, 114.3, 110.1, 50.1. MS (70 eV): m/z (%): 343 (M$^+$, 100). HRMS calcd for C$_{23}$H$_{18}$NCl: 343.1128, found: 343.1125.

(12) Synthesis of 1w

Yellow liquid. (mixture, E: Z = 1.56: 1) $^1$H NMR (400 MHz, CDCl$_3$) δ [7.82 (d, $J$ = 8.2 Hz, 0.3H), 7.62-7.56 (m, 2H), 7.50-7.44 (m, 2H), 7.28-7.23 (m, 4H), 7.14-7.05 (m, 2H), 5.29 (s, 2H), 1.33 (s, 9H). MS (70 eV): m/z (%): 343 (M$^+$, 100). HRMS calcd for C$_{23}$H$_{18}$NCl: 343.1128, found: 343.1125.
0.39H), 7.66 (d, J = 8.2 Hz, 0.61H)], [7.34-7.11 (m, 3H)], [7.12 (s, 0.61H),7.00 (s, 0.39H)], [6.66-6.61 (m, 0.61H), 6.57-6.53 (m, 0.39H)], [6.24-6.10 (m, 0.39H), 5.77-5.66 (m, 0.61H)], [3.78 (s, 1.83H), 3.72 (s, 1.17H)], [1.96-1.87 (m, 3H)]. $^{13}$C NMR (100 MHz, CDCl$_3$) δ [137.4, 136.2], [127.9, 127.4], [126.6, 126.2], [123.2, 122.6], [122.0, 121.9], [121.8, 120.5], [120.0, 119.3], [119.5, 119.1], [114.1, 112.4], [109.3, 109.1], [32.8, 32.6], [18.9, 15.6]. MS (70 eV): m/z (%): 171 (M$^+$, 100). HRMS calcd for C$_{12}$H$_{13}$N: 171.1048, found: 171.1045.

5. General procedure for the [2+2] cycloaddition and copies of HPLC data

![Chemical Reaction](image)

The solution of (S,R)-X$^8$ (0.012 mmol, 6 mol %) and Au(SMe$_2$)Cl (0.01 mmol, 5 mol%) in 1 mL CH$_2$Cl$_2$ was stirred at rt for 2 hours, and then remove the solvent. After completion, the gold complex and AgOTf (0.01 mmole, 5 mol %) in CH$_2$Cl$_2$ (1 mL) was stirred at rt for 15 min. Then the above catalyst solution then was added to the solution of 1a (0.22 mmol, 1.1 equiv) and 2 (0.2 mmol) in DCM (3 mL) at -78°C. The reaction was determined by TLC, after the less component was consumed, the solution was removed under reduced pressure. The diastereomeric ratio was determined by crude $^1$H NMR, the resulting crude mixture was purified by flash column chromatography on silica gel with petroleum ether/ethyl acetate (3:1) as the solvent to afford product. The enantiomeric excesses of the products were determined by chiral stationary phase HPLC using a Chiralpak such as AD-H, AS-H, OD-H, etc.

(1) Synthesis of 3a
White solid. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.49 (d, $J = 8.0$ Hz, 1H), 7.39-7.29 (m, 5H), 7.28-7.21 (m, 2H), 7.10-7.03 (m, 1H), 6.98 (s, 1H), 6.54 (d, $J = 2.0$ Hz, 1H). 4.48-4.43 (m, 1H), 4.07-4.00 (m, 1H), 3.88 (dd, $J = 16.8$, 8.8 Hz 1H), 3.78 (s, 3H), 3.55-3.30 (m, 4H), 3.00-2.94 (m, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 156.3, 144.8, 137.5, 128.5, 126.5, 126.4, 126.0, 123.2, 121.9, 119.5, 119.1, 117.6, 117.0, 109.4, 62.1, 47.6, 46.4, 44.2, 33.6, 32.8. MS (70 eV): m/z (%): 358 (M$^+$, 72.16), 271 (100). HRMS calcd for C$_{23}$H$_{22}$N$_2$O$_2$: 356.1681, found: 358.1685. $[\alpha]_D^{20} = -11.1$ (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 95: 5, 0.8 mL/min, 233 nm; $t_r$ (minor) = 29.37 min, $t_r$ (major) = 33.50 min, 95% ee.

<table>
<thead>
<tr>
<th>Chromatogram</th>
<th>U-VP 21 N/2/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20.007</td>
<td>-32.089</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Integration Results</th>
<th>Retention Time</th>
<th>Area mAU/min</th>
<th>Height mAU</th>
<th>Relative Area %</th>
<th>Relative Height %</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>1</td>
<td>20.067</td>
<td>200.277</td>
<td>245.192</td>
<td>5944</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>32.983</td>
<td>201.699</td>
<td>222.457</td>
<td>49.56</td>
</tr>
<tr>
<td>Total</td>
<td>405.959</td>
<td>468.059</td>
<td>100.00</td>
<td>160.69</td>
<td></td>
</tr>
</tbody>
</table>

S 17
(2) Synthesis of 3b

White solid. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.49 (d, $J = 7.6$ Hz, 1H), 7.31 (d, $J = 8.4$ Hz, 1H), 7.28-7.20 (m, 3H), 7.14 (d, $J = 8.0$ Hz, 2H), 7.09-7.04 (m, 1H), 6.96 (s, 1H), 6.54-6.52 (d, $J = 2.4$ Hz, 1H), 4.42-4.38 (m, 1H), 4.06-3.98 (m, 1H), 3.91-3.86 (m, 1H), 3.76 (s, 3H), 3.54-3.26 (m, 4H), 2.96-2.90 (m, 1H), 2.35 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 156.3, 141.8, 137.5, 135.9, 129.2, 126.4, 126.3, 126.0, 123.3, 121.9, 119.5, 119.1, 117.5, 117.1, 109.3, 62.1, 47.7, 46.0, 44.2, 33.7, 32.7, 21.0. MS (70 eV): m/z (%): 372 (M$^+$, 100). HRMS calcd for C$_{24}$H$_{24}$N$_2$O$_2$: 372.1838, found: 372.1837. [$\alpha$]$_D^{20}$ = 26.9 (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 95: 5, 1.0 mL/min, 233 nm; tr (minor) = 24.47 min, tr (major) = 26.97 min, 92% ee.
(3) Synthesis of 3c

White solid. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.47 (d, $J = 8.0$ Hz, 1H), 7.32 (d, $J = 8.4$ Hz,
1H), 7.27-7.23 (m, 3H), 7.07 (t, J = 7.6 Hz, 1H), 6.96 (s, 1H), 6.88 (d, J = 8.4 Hz, 2H), 6.53 (s, 1H), 4.40-4.37 (m, 1H), 4.04 (dd, J = 14.8, 8.8 Hz, 1H), 3.90 (dd, J = 16.8, 8.4 Hz, 1H), 3.81 (s, 3H), 3.77 (s, 3H), 3.54-3.26 (m, 4H), 2.95-2.87 (m, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 158.3, 156.3, 137.4, 137.0, 127.5, 126.3, 125.9, 123.2, 121.9, 119.5, 119.1, 117.5, 117.1, 113.9, 109.3, 62.1, 55.3, 47.9, 45.8, 44.2, 33.8, 32.8. MS (70 eV): m/z (%): 388 (M$^+$, 26.8), 263 (100). [α]$_D^{20}$ = 7.9 (c = 0.3, CHCl$_3$). HRMS calcld for C$_{24}$H$_{24}$N$_2$O$_3$: 388.1787, found: 388.1789. HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 95: 5, 0.5 mL/min, 233 nm; tr (minor) = 85.30 min, tr (major) = 91.95 min, 93% ee.
(4) Synthesis of 3d

White solid. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\): 7.53 (d, \(J = 8.0\) Hz, 1H), 7.41-7.22 (m, 6H), 7.11-7.06 (m, 1H), 6.97 (s, 1H), 6.52 (d, \(J = 2.4\) Hz, 1H), 4.45-4.41 (m, 1H), 4.07-4.00 (m, 1H), 3.89 (dd, \(J = 16.8, 8.8\) Hz 1H), 3.77 (s, 3H), 3.56-3.30 (m, 4H), 2.98-2.93 (m, 1H), 1.33 (s, 9H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\): 156.3, 149.2, 141.8, 137.5, 126.3, 126.1, 126.0, 125.4, 123.4, 121.9, 119.5, 119.1, 117.5, 117.2, 109.3, 62.1, 47.5, 45.8, 44.2, 34.4, 33.6, 32.8, 31.4. MS (70 eV): m/z (%): 414 (M+, 35.0), 44 (100). HRMS calcd for C\(_{27}\)H\(_{30}\)N\(_2\)O\(_2\): 414.2307, found: 414.2309. \([\alpha]_D^{20}\) = 32.9 (c = 0.3, CHCl\(_3\)). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 90: 10, 0.8 mL/min, 210 nm; tr (minor) = 14.67 min, tr (major) = 17.9 min, 92% ee.
(5) Synthesis of 3e

White solid. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.49 (d, $J = 8.0$ Hz, 1H), 7.31-7.29 (m, 1H), 7.27-7.18 (m, 2H), 7.10-7.04 (m, 1H), 6.96 (s, 1H), 6.91 (d, $J = 7.6$ Hz, 1H), 6.87 (s, 1H), 6.80-6.76 (m, 1H), 6.52 (d, $J = 2.0$ Hz, 1H), 4.46-4.42 (m, 1H), 4.05-3.98 (m, 1H), 3.86 (dd, $J = 16.8$, 8.8 Hz, 1H), 3.78 (s, 3H), 3.76 (s, 3H), 3.54-3.27 (m, 4H), 3.02-2.91 (m, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 159.8, 156.3, 146.5, 137.5, 129.5, 126.3, 126.0, 123.0, 122.0, 119.5, 119.1, 118.9, 117.6, 117.0, 112.4, 111.6, 109.4, 62.1, 55.2, 47.5, 46.4, 44.2, 33.5, 32.8. MS (70 eV): m/z (%): 388 (M$^+$, 44.58), 301 (100). HRMS calcd for C$_{24}$H$_{24}$N$_2$O$_3$: 388.1787, found: 388.1784. $[\alpha]_D^{20} = 6.9$ (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 95: 5, 0.8 mL/min, 233 nm; tr (minor) = 43.56 min, tr (major) = 52.79 min, 91% ee.
(6) Synthesis of 3f
White solid. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.52 (d, $J = 8.0$ Hz, 1H), 7.32 (d, $J = 8.0$ Hz, 1H), 7.28-7.22 (m, 1H), 7.11-7.03 (m, 1H), 6.99-6.93 (m, 3H), 6.88 (s, 1H), 6.52 (d, $J = 2.0$, 1H), 4.45-4.42 (m, 1H), 4.05-3.99 (m, 1H), 3.87 (dd, $J = 16.4$, 8.8 Hz, 1H), 3.77 (s, 3H), 3.53-3.26 (m, 4H), 3.01-2.92 (m, 1H), 2.32 (s, 6H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 156.3, 144.7, 137.9, 137.5, 128.0, 126.3, 126.0, 124.3, 123.5, 121.9, 119.6, 119.0, 117.5, 117.1, 109.3, 62.0, 47.5, 46.3, 44.2, 33.6, 32.7, 21.3. MS (70 eV): m/z (%): 386 (M$^+$, 99.68), 44 (100). HRMS calcd for C$_{25}$H$_{26}$N$_2$O$_2$: 386.1994, found: 386.1996. [α]$^2_{D}$ = 8.1 (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 70: 30, 0.8 mL/min, 210 nm); tr (major) = 8.83 min, tr (minor) = 9.83 min, 95% ee.
(7) Synthesis of 3g

Yellow solid. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.47-7.43 (m, 3H), 7.32 (d, $J = 8.4$ Hz, 1H), 7.28-7.23 (m, 2H), 7.19 (d, $J = 8.4$ Hz, 2H), 7.11-7.04 (m, 1H), 6.96 (s, 1H), 6.53 (dd, $J = 4.4$, 2.4 Hz, 1H), 4.40-4.36 (m, 1H), 4.06-3.99 (m, 1H), 3.89 (dd, $J = 16.8$, 9.2 Hz, 1H), 3.78 (s, 3H), 3.53-3.30 (m, 4H), 2.96-2.88 (m, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 156.3, 143.8, 137.4, 131.6, 128.3, 126.2, 126.0, 122.4, 122.0, 119.3, 119.2, 117.8, 116.7, 109.4, 62.1, 47.7, 45.9, 44.2, 33.5, 32.8. MS (70 eV): m/z (%): 436 (M$^+$, 100), 438 ([M+2]$^+$, 99.16). HRMS calcd for C$_{23}$H$_{21}$N$_2$O$_2$Br: 436.0786, found: 436.0787. [α]$_D^{20} = 57.9$ (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 95: 5, 0.4 mL/min, 233 nm; tr (major) = 93.10 min, tr (minor) = 97.37 min, 89% ee.
(8) Synthesis of 3h

Yellow solid. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.49-7.41 (m, 3H), 7.32 (d, \(J = 8.4\) Hz, 1H), 7.28-7.15 (m, 3H), 7.11-7.05 (m, 1H), 6.96 (s, 1H), 6.53 (d, \(J = 2.0\) Hz, 1H), 4.42-4.37 (m, 1H), 4.06-3.99 (m, 1H), 3.86 (dd, \(J = 16.4, 8.4\) Hz, 1H), 3.77 (s, 3H), 3.53-3.27 (m, 4H), 2.96-2.88 (m, 1H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 156.2, 143.8, 137.5, 131.6, 128.2, 126.2, 126.0, 122.5, 122.0, 120.0, 119.3, 119.2, 117.8, 116.7, 109.4, 62.1, 47.7, 45.9, 44.2, 33.5, 32.8. MS (70 eV): m/z (%): 392 (M\(^+\), 99.52), 394 ([M+2]\(^+\), 35.32), 305 (100).

HRMS calcd for C\(_{23}\)H\(_{21}\)N\(_2\)O\(_2\)Cl: 392.1295, found: 392.1292. \([\alpha]_{D}^{20} = 21.9\) (c = 0.3, CHCl\(_3\)). HPLC conditions: Chiralpak OD-H, hexane/2-propanol = 95: 5, 0.8 mL/min, 210 nm; tr (major) = 10.96 min, tr (minor) = 13.74 min, 91% ee.
(9) Synthesis of 3i

Yellow solid. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.45 (d, $J = 8.0$ Hz, 1H), 7.35-7.22 (m, 4H), 7.11-6.95 (m, 4H), 6.53 (dd, $J = 4.4$, 2.4 Hz, 1H), 4.40-4.36 (m, 1H), 4.06-3.98 (m, 1H),
3.94-3.85 (m, 1H), 3.78 (s, 3H), 3.55-3.31 (m, 4H), 2.95-2.87 (m, 1H). $^{19}$F NMR (377 MHz, CDCl$_3$) $\delta$ -116.71. $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 162.7, 160.3, 156.3, 140.5 (d, $J = 3.0$ Hz), 137.5, 127.9 (d, $J = 8$ Hz), 126.3, 126.0, 122.9, 122.0, 119.3 (d, $J = 15.0$ Hz), 117.7, 116.8, 115.3 (d, $J = 21.0$ Hz), 109.4, 62.1, 47.9, 45.8, 44.2, 33.8, 32.8. MS (70 eV): m/z (%): 376 (M$^+$, 2.07), 105 (100). HRMS calcd for C$_{23}$H$_{21}$N$_2$O$_2$F: 376.1587, found: 376.1585. [$\alpha$]$_D^{20}$ = -10.3 (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 70: 30, 0.8 mL/min, 233 nm); tr (major) = 9.76 min, tr (minor) = 13.49 min, 94% ee.

**Integration Results**

<table>
<thead>
<tr>
<th>No.</th>
<th>Peak Name</th>
<th>Retention Time (min)</th>
<th>Area (nl*µL/µg)</th>
<th>Height (µAU)</th>
<th>Relative Area</th>
<th>Relative Height (%)</th>
<th>Amount (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>560.490</td>
<td>770.639</td>
<td>100.00</td>
<td>100.00</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

**Integration Results**

<table>
<thead>
<tr>
<th>No.</th>
<th>Peak Name</th>
<th>Retention Time (min)</th>
<th>Area (µL*µg)</th>
<th>Height (µAU)</th>
<th>Relative Area</th>
<th>Relative Height (%)</th>
<th>Amount (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>9.770</td>
<td>408.870</td>
<td>947.347</td>
<td>90.92</td>
<td>90.17</td>
<td>n.a.</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>13.487</td>
<td>18.897</td>
<td>7.955</td>
<td>3.08</td>
<td>0.03</td>
<td>n.a.</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>483.952</td>
<td>1065.552</td>
<td>100.00</td>
<td>100.00</td>
<td>n.a.</td>
</tr>
</tbody>
</table>
(10) Synthesis of 3j

White solid. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.62 (d, $J = 8.0$ Hz, 1H), 7.35 (d, $J = 8.4$ Hz, 1H), 7.32-7.25 (m, 1H), 7.23-7.20 (m, 1H), 7.13 (t, $J = 7.2$ Hz, 1H), 7.01-6.97 (m, 2H), 6.93 (d, $J = 4.2$ Hz, 1H), 6.68 (d, $J = 2.4$ Hz, 1H), 4.56-4.50 (m, 1H), 4.13-4.04 (m, 1H), 3.93 (dd, $J = 16.8$, 8.8 Hz, 1H), 3.81 (s, 3H), 3.77-3.71 (m, 1H), 3.57-3.41 (m, 3H), 3.06-2.99 (m, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 156.2, 148.7, 137.5, 126.9, 126.2, 126.1, 123.2, 123.1 122.0, 121.8, 119.5, 119.2, 118.0, 116.4, 109.4, 62.1, 49.1, 44.1, 42.1, 35.3, 32.8. MS (70 eV): m/z (%): 364 (M$^+$, 6.37), 119 (100). HRMS calcd for C$_{21}$H$_{20}$N$_2$O$_2$S: 364.1245, found: 364.1248. $[\alpha]_D^{20} = 3.2$ (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 90: 10, 0.8 mL/min, 210 nm); tr (minor) = 18.44 min, tr (major) = 20.89 min, 85% ee.
(11) Synthesis of 3k

Yellow solid. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.84 (d, $J = 8.0$ Hz, 1H), 7.79-7.70 (m, 3H), 7.58-7.49 (m, 2H), 7.46-7.40 (m, 1H), 7.37-7.22 (m, 3H), 7.08-7.00 (m, 2H), 6.54 (dd, $J = 4.4$, 2.0 Hz, 1H), 4.76-4.71 (m, 1H), 4.35-4.26 (m, 1H), 4.04-3.96 (m, 1H), 3.93-3.85 (m, 1H), 3.78 (s, 3H), 3.65-3.36 (m, 3H), 3.09-3.01 (m, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 156.2, 139.9, 137.4, 133.9, 131.5, 128.6, 126.9, 126.6, 126.4, 125.64, 125.59, 125.5, 124.2, 123.5, 122.1, 121.9, 119.6, 119.2, 117.6, 116.9, 109.4, 62.1, 45.1, 44.3, 43.0, 34.0, 32.8. MS (70 eV): m/z (%): 408 (M$^+$, 41.13), 44 (100). HRMS calcld for C$_{27}$H$_{24}$N$_2$O$_2$: 408.1838, found: 408.1833. $[\alpha]_D^{20} = -62.0$ (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 90: 10, 0.8 mL/min, 210 nm); tr (minor) = 20.69 min, tr
(major) = 23.59 min, 89% ee.

(12) Synthesis of 31

White solid. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.36 (d, $J$ = 7.2 Hz, 2H), 7.33-7.20 (m, 3H),
7.24-7.14 (m, 3H), 7.06-7.01 (m, 1H), 6.55 (s, 1H), 5.24-5.16 (m, 1H), 4.15 (dd, J = 14.8, 8.8 Hz, 1H), 3.93 (dd, J = 16.8, 8.8 Hz, 1H), 3.78 (s, 3H), 3.72 (dd, J = 17.2, 8.8 Hz, 1H), 3.59-3.49 (m, 1H), 3.42-3.33 (m, 2H), 2.85-2.76 (m, 1H). $^1$H NMR (100 MHz, CDCl$_3$) δ 156.3, 144.7, 138.4, 128.5, 128.2, 126.9, 126.2, 124.2, 123.7, 122.5, 117.9, 117.1, 118.0, 113.9, 108.7, 62.2, 48.3, 46.0, 44.1, 34.4, 33.1. MS (70 eV): m/z (%): 436 (M$^+$, 70.75), 438 (M$^+$+2, 70.09), 349 (100). HRMS calcd for C$_{23}$H$_{21}$N$_2$O$_2$Br: 346.0786, found: 346.0783. [α]$_D^{20}$ = -41.9 (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 95: 5, 1.0 mL/min, 233 nm; tr (minor) = 19.64 min, tr (major) = 21.26 min, 84% ee.
(13) Synthesis of 3m

White solid. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.42 (d, $J$ = 8.4 Hz, 2H), 7.30-7.16 (m, 5H), 7.06 (t, $J$ = 8.0 Hz, 1H), 6.58 (s, 1H), 5.16-5.10 (m, 1H), 4.21 (dd, $J$ = 15.2, 8.8 Hz, 1H), 3.99 (dd, $J$ = 16.4, 8.8 Hz, 1H), 3.80 (s, 3H), 3.76-3.70 (m, 1H), 3.58-3.49 (m, 1H), 3.41-3.26 (m, 2H), 2.78-2.70 (m, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 156.3, 143.8, 138.4, 131.3, 128.7, 128.4, 123.7, 122.7, 119.8, 117.5, 113.8, 108.7, 62.2, 47.6, 46.0, 43.9, 34.4, 33.2. HRMS (ESI) calcld for C$_{23}$H$_{20}$N$_2$O$_2$Br$_2$ [M+Na$^+$]: 536.9784, found: 536.9778. $[\alpha]_D^{20} = 1.7$ (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 70: 30, 0.8 mL/min, 233 nm; tr (major) = 8.97 min, tr (minor) = 17.75 min, 84% ee.
(14) Synthesis of 3n

![Chemical structure of 3n]

White solid. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.45-7.33 (m, 4H), 7.32-7.22 (m, 3H), 7.10 (d, $J = 8.0$ Hz, 1H), 6.96 (s, 1H), 6.57 (d, $J = 2.0$ Hz, 1H), 4.46-4.44 (m, 1H), 4.11-4.02 (m, 1H), 3.93 (dd, $J = 16.8$, 8.8 Hz, 1H), 3.78 (s, 3H), 3.61-3.33 (m, 4H), 3.03-2.96 (m, 1H), 2.45 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 156.3, 144.9, 135.9, 128.5, 128.4, 126.5, 126.3, 126.1, 123.6, 123.2, 119.1, 117.5, 116.5, 109.0, 62.1, 47.7, 46.3, 44.2, 33.5, 32.8, 21.4. MS (70 eV): m/z (%): 372 (M$^+$, 100). HRMS calcld for C$_{24}$H$_{24}$N$_2$O$_2$: 372.1838, found: 372.1835. $[\alpha]_D^{20} = -5.1$ (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak OD-H, hexane/2-propanol = 80: 20, 0.6 mL/min, 210 nm; tr (major) = 16.92 min, tr (minor) = 19.70 min, 85% ee.
(15) Synthesis of 3o

![Chemical Structure of 3o](image)
White solid. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.48-7.31 (m, 5H), 7.29-7.21 (m, 1H), 7.12 (s, 1H), 7.04 -6.87 (m, 2H), 6.55 (s, 1H), 4.51-4.40 (m, 1H), 4.10-4.02 (m, 1H), 3.90 (dd, $J$ = 16.8, 8.4 Hz, 1H), 3.74 (s, 3H), 3.59-3.28 (m, 4H), 3.07-2.93 (m, 1H), 2.50 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 156.3, 144.9, 137.9, 131.9, 128.5, 126.5, 126.3, 125.4, 124.17, 123.0, 120.9, 119.2, 117.6, 117.0, 109.4, 62.1, 47.7, 46.4, 44.2, 33.5, 32.7, 21.8. MS (70 eV): m/z (%): 372 (M$^+$, 100). HRMS calcd for C$_{24}$H$_{24}$N$_2$O$_2$: 372.1838, found: 372.1844. [α]$^{	ext{D}}$_20 = 0.9 (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 95: 5, 0.8 mL/min, 233 nm; tr (minor) = 27.49 min, tr (major) = 30.11 min, 91% ee.
(16) Synthesis of 3p

White solid. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.28-7.21 (m, 4H), 7.22-7.12 (m, 2H), 6.85-6.82 (m, 2H), 6.78 (s, 1H), 6.46 (d, $J = 2.4$ Hz, 1H), 4.37-4.31 (m, 1H), 4.02-3.93 (m, 1H), 3.96 (s, 3H), 3.85 (dd, $J = 16.8$, 8.8 Hz, 1H), 3.49-3.33 (m, 3H), 3.30-3.21 (m, 1H), 2.91-2.82 (m, 1H), 2.69 (s, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 156.3, 145.0, 136.2, 128.5, 127.6, 127.3, 126.5, 126.3, 124.6, 122.9, 121.4, 119.4, 117.6, 117.5, 116.8, 62.1, 47.4, 46.4, 44.1, 36.7, 33.6, 19.7. MS (70 eV): m/z (%): 372 (M$^+$, 81.09), 285 (100). HRMS calcd for C$_{24}$H$_{24}$N$_2$O$_2$: 372.1838, found: 372.1835. $[\alpha]_D^{20} = -23.5 \ (c = 0.3, \ CHCl_3)$. HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 90: 10, 0.8 mL/min, 254 nm; tr (minor) = 14.12 min, tr (major) = 17.00 min, 81% ee.

<table>
<thead>
<tr>
<th>Integration Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>Total:</td>
</tr>
</tbody>
</table>
(17) Synthesis of 3q

White solid. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.47 (d, $J = 8.0$ Hz, 1H), 7.37-7.14 (m, 10H), 7.12-7.09 (m, 2H), 7.08-7.04 (m, 2H), 6.49 (dd, $J = 4.4$, 2.4 Hz, 1H), 5.28 (dd, $J = 22.4$, 16 Hz, 2H), 4.47-4.42 (m, 1H), 3.96-3.90 (m, 1H), 3.67 (dd, $J = 16.8$, 8.8 Hz, 1H), 3.62-3.53 (m, 1H), 3.43-3.25 (m, 3H), 3.03-2.95 (m, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 156.2, 144.7, 137.6, 137.0, 128.8, 128.5, 127.8, 126.8, 126.52, 126.48, 126.4, 125.3, 123.3, 122.2, 119.6, 119.4, 117.6, 109.9, 61.9, 50.0, 47.7, 46.3, 44.3, 33.5. MS (70 eV): m/z (%): 434 (M$^+$, 59.67), 91 (100). HRMS calcld for C$_{29}$H$_{26}$N$_2$O$_2$: 434.1994, found: 434.1999. $[\alpha]_{D}^{20} = -7.7$ (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 95: 5, 1.0 mL/min, 233 nm; tr (minor) = 27.68 min, tr (major) = 36.82 min, 92% ee.
(18) Synthesis of 3r

White solid. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.46 (d, $J = 8.0$ Hz, 1H), 7.34-7.18 (m, 7H),
7.14-7.03 (m, 4H), 6.87 (d, J = 8.8 Hz, 2H), 6.49 (d, J = 2.0 Hz, 1H), 5.28 (dd, J = 20.4, 16.0 Hz, 2H), 4.42-4.37 (m, 1H), 3.99-3.89 (m, 1H), 3.81 (s, 3H), 3.67 (dd, J = 17.2, 8.4 Hz, 1H), 3.51 (dd, J = 16.0, 7.2 Hz, 1H), 3.45-3.22 (m, 3H), 2.99-2.91 (m, 1H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 158.2, 156.3, 137.6, 137.0, 136.9, 128.8, 127.8, 127.5, 126.8, 126.6, 125.3, 123.5, 122.2, 119.6, 119.4, 117.7, 117.6, 113.9, 109.9, 61.9, 55.3, 50.0, 47.9, 45.8, 44.4, 33.8. MS (70 eV): m/z (%): 464 (M\(^+\), 55.59), 91 (100). HRMS calcd for C\(_{30}\)H\(_{28}\)N\(_2\)O\(_3\): 464.2100, found: 464.2096. \([\alpha]\)\(_D\)\(^{20}\) = 20.7 (c = 0.3, CHCl\(_3\)). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 90: 10, 0.8 mL/min, 254 nm); tr (minor) = 36.88 min, tr (major) = 40.79 min, 95% ee.
(19) Synthesis of 3s

White solid. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.53 (d, \(J = 8.0\) Hz, 1H), 7.38-7.32 (m, 2H), 7.31-7.22 (m, 6H), 7.21-7.18 (m, 1H), 7.12-7.03 (m, 4H), 6.49 (d, \(J = 2.0\) Hz, 1H), 5.28 (dd, \(J = 20.4, 16.0\) Hz, 2H), 4.47-4.42 (m, 1H), 3.97-3.92 (m, 1H), 3.69 (dd, \(J = 17.2, 8.8\) Hz, 1H), 3.59-3.53 (m, 1H), 3.44-3.37 (dd, \(J = 15.2, 8.8\) Hz, 1H), 3.37-3.25 (m, 2H), 3.00-2.94 (m, 1H), 1.33 (s, 9H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 156.2, 149.2, 141.7, 137.6, 137.0, 128.8, 127.8, 126.8, 126.6, 126.2, 125.3, 123.5, 122.2, 119.6, 119.4, 117.7, 117.5, 109.8, 61.9, 55.3, 50.0, 47.9, 45.8, 44.4, 33.8. MS (70 eV): m/z (%): 490 (M\(^+\), 55.59), 91 (100). HRMS calcd for C\(_{33}\)H\(_{34}\)N\(_2\)O\(_2\): 490.2620, found: 490.2617. \([\alpha]_D^{20}\) = 37.5 (c = 0.3, CHCl\(_3\)). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 90: 10, 0.8 mL/min, 254 nm; tr (minor) = 16.33 min, tr (major) = 23.47 min, 93% ee.
(20) Synthesis of 3t

White solid. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.45 (d, \(J = 8.0\) Hz, 1H), 7.39-7.14 (m, 9H), 7.13-7.04 (m, 4H), 6.51 (d, \(J = 2.4\) Hz, 1H), 5.32 (dd, \(J = 23.6, 16.0\) Hz, 2H), 4.42-4.37 (m, 1H), 3.98-3.91 (m, 1H), 3.72-3.64 (m, 1H), 3.58-3.52 (m, 1H), 3.47-3.28 (m, 3H), 2.98-2.91 (m, 1H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 156.2, 143.1, 137.5, 137.0, 132.0, 128.8, 128.6, 127.9, 127.8, 126.7, 126.4, 125.3, 122.7, 122.3, 119.5, 119.4, 117.8, 117.3, 109.9, 61.9, 50.0, 47.8, 45.8, 44.3, 33.5. MS (70 eV): m/z (%): 468 (M\(^+\), 27.43), 91 (100). HRMS calcld for C\(_{29}\)H\(_{33}\)N\(_2\)O\(_2\)Cl: 468.1605, found: 468.1602. \([\alpha]_D^{20} = 36.9\) (c = 0.3, CHCl\(_3\)). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 90: 10, 0.8 mL/min, 210 nm); tr (minor) = 23.63 min, tr (major) = 28.74 min, 85% ee.
(21) Synthesis of 3u

White solid. $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.47 (d, $J = 8.0$ Hz, 1H), 7.37-7.27 (m, 5H), 7.26-7.16 (m, 2H), 7.09-7.01 (m, 2H), 6.52 (dd, $J = 4.4$, 2.0 Hz, 1H), 6.04-5.92 (m, 1H), 5.19 (dd, $J = 10.4$, 1.2 Hz, 1H), 5.04 (dd, $J = 16.8$, 1.2 Hz, 1H), 4.74-4.69 (m, 2H),
4.46-4.42 (m, 1H), 4.03-3.97 (m, 1H), 3.87-3.80 (m, 1H), 3.61-3.28 (m, 4H), 3.03-2.94 (m, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 156.2, 144.7, 136.8, 133.4, 128.5, 126.4, 126.3, 125.0, 123.4, 122.0, 119.5, 119.4, 117.5, 117.3, 117.1, 109.7, 62.0, 48.7, 47.6, 46.3, 44.2, 33.6. MS (70 eV): m/z (%): 384 (M$^+$, 100). HRMS calcd for C$_{25}$H$_{24}$N$_2$O$_2$: 384.1838, found: 384.1840. [α]$^D_{20} = -18.5$ (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak AD-H, hexane/2-propanol = 90:10, 0.8 mL/min, 210 nm; tr (minor) = 14.41 min, tr (major) = 17.18 min, 93% ee.

(22) Synthesis of 3w
White solid. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.62 (d, J = 7.6 Hz, 1H), 7.38-7.22 (m, 2H), 7.19-7.13 (m, 1H), 6.94 (s, 1H), 6.46 (s, 1H), 4.21-4.06 (m, 1H), 4.01-3.91 (m, 2H), 3.79 (s, 3H), 3.62-3.49 (m, 2H), 3.11-3.05 (m, 1H), 2.43-2.32 (m, 2H), 1.36 (d, J = 6.4 Hz, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$) δ 156.3, 137.4, 126.4, 125.7, 123.7, 121.8, 119.1, 118.9, 117.5, 117.4, 109.3, 62.1, 45.9, 44.1, 36.8, 33.8, 32.7, 21.4. MS (70 eV): m/z (%): 296 (M+, 24.35), 57 (100). HRMS calcd for C$_{18}$H$_{20}$N$_2$O$_2$: 296.1525, found: 196.1528. [α]$_D^{20}$ = -30.5 (c = 0.3, CHCl$_3$). HPLC conditions: Chiralpak OD-H, hexane/2-propanol = 70: 30, 0.8 mL/min, 233 nm); tr (minor) = 8.10 min, tr (major) = 10.24 min, 69% ee.
6. References


7. X-ray crystal data
(S, R)-X8

(S, R)-X8
$1w \text{ (E:Z = 1.56:1)}$