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## A general copper-catalysed enantioconvergent radical Michaelis– Becker-type C(*sp*<sup>3</sup>)–P cross-coupling

In the format provided by the authors and unedited

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#### Supplementary tables for experiments

Supplementary Table 1. Reaction condition optimization: solvent effect for  $S_N2$  reaction

Br S Ph	+ $H \sim \frac{O}{OEt}$ Cs <sub>2</sub> CO <sub>3</sub> (2.0 equiv solvent, r.t., 5 d	d Ph
(±)-E1	P1	1
Entry	Solvent	Yield of 1 (%) <sup>b</sup>
1	EtOH	0
2	NMP	27
3	DMF	18
4	DMSO	25
5	MeCN	10
6	EtOAc	0
7	<sup><i>i</i></sup> Pr <sub>2</sub> O	0
8	$CCl_4$	0
9	THF	Trace
10	DME	Trace

<sup>a</sup>Reaction conditions: **E1** (0.15 mmol), **P1** (0.1 mmol) and  $Cs_2CO_3$  (2.0 equiv.) in solvent (1.0 mL) at room temperature for 5 days under argon. <sup>b</sup>Yields were based on <sup>1</sup>H NMR analysis of the crude product using  $CH_2Br_2$  as an internal standard. NMP, *N*-methyl-2-pyrrolidone; DMF, *N*,*N*-dimethylformamide; DMSO, dimethyl sulfoxide; THF, tetrahydrofuran; DME, dimethoxyethane.

Br	+ H-DEt	Cul (15 mol%), <b>L*14</b> (18 mol%) <sup>a</sup>	<sup>0</sup> ≈P<	OEt O OEt OEt + Eto OEt
Plir	<sup>11</sup> OEt	Base (2.0 equiv.), THF, r.t., 5 d	Ph	EtO <sup>P</sup> O
(±)-E1	P1		1	1'
Entry	Base	Yield (%)	) <sup>b</sup>	e.e. of 1 (%) <sup>c</sup>
		1	1′	
1	$Cs_2CO_3$	54	5	82
2	LiOt-Bu	0	0	ND
3	KOt-Bu	6	0	ND
4	CsOH	0	0	ND
5	KOH	5	0	ND
6	DBU	8	0	ND
7	Et <sub>3</sub> N	0	0	ND
8	DIPEA	0	0	ND

Supplementary Table 2. Reaction condition optimization: screening of bases

<sup>a</sup>Reaction conditions: **E1** (0.15 mmol), **P1** (0.1 mmol), CuI (15 mol%), L\*14 (18 mol%), and base (2.0 equiv.) in THF (1.0 mL) at room temperature for 5 days under argon. <sup>b</sup>Yields were based on <sup>1</sup>H NMR analysis of the crude product using CH<sub>2</sub>Br<sub>2</sub> as an internal standard. <sup>c</sup>e.e. values were based on HPLC analysis. ND, not determined. DBU, 1,8-diazabicyclo[5.4.0]undec-7-ene; DIPEA, diisopropylethylamine.

Ph	+ H-JOEt OEt	Cul (15 mol%), L*14 (2.0 equiv.), T Cs <sub>2</sub> CO <sub>3</sub>	<sup>l</sup> (18 mol%) <sup>a</sup> HF, T, 5 d ►	O DEt = OEt Ph	+ EtO POEt EtO POEt
Entry	P1 T (°C)	Vield (%) <sup>b</sup>		1	<sup>1'</sup> e.e. of 1 (%) <sup>c</sup>
	- ( - )	1	1'		
1	25	54	5		82
2	20	60	6		81
3	0	60	3		88
4	-15	67	4		91
5	-30	0	0		

Supplementary Table 3. Reaction condition optimization: screening of temperature

<sup>a</sup>Reaction conditions: **E1** (0.15 mmol), **P1** (0.1 mmol), CuI (15 mol%), **L\*14** (18 mol%), and  $Cs_2CO_3$  (2.0 equiv.) in THF (1.0 mL) for 5 days under argon. <sup>b</sup>Yields were based on <sup>1</sup>H NMR analysis of the crude product using CH<sub>2</sub>Br<sub>2</sub> as an internal standard. <sup>c</sup>e.e. values were based on HPLC analysis.

Ph	+ H [Cu] (15 n	[Cu] (15 mol%), <b>L*14</b> <sup>(18 mol%)</sup> <sub>a</sub> (2 0 equiv.) THE -15 °C 5 d		+ EtO CEt
<sub>(±)-</sub> E1	OEt Cs <sub>2</sub> CO <sub>3</sub> (2:0 P1	, equiv. <sub>/</sub> , mir, =15, 0, 5 u	Ph 1	EtO <sup>-/ ©</sup> O 1'
Entry	[Cu]	Yield (%) <sup>b</sup>		e.e. of 1 (%) <sup>c</sup>
		1	1′	
1	Cu <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>	0	0	-
2	CuCO <sub>3</sub>	0	0	_
3	CuBr <sub>2</sub>	0	0	-
4	Cu <sub>2</sub> O	0	0	_
5	CuBr	71	19	90
6	CuSCN	62	23	90
7	Cu(PPh <sub>3</sub> ) <sub>3</sub> Br	45	46	91
8	CuBr•Me <sub>2</sub> S	12	4	90
9	CuI	67	4	91

#### Supplementary Table 4. Reaction condition optimization: screening of copper salts

<sup>a</sup>Reaction conditions: **E1** (0.15 mmol), **P1** (0.1 mmol), [Cu] (15 mol%), **L** (18 mol%), and Cs<sub>2</sub>CO<sub>3</sub> (2.0 equiv.) in THF (1.0 mL) at -15 °C for 5 days under argon. <sup>b</sup>Yields were based on <sup>1</sup>H NMR analysis of the crude product using CH<sub>2</sub>Br<sub>2</sub> as an internal standard. <sup>c</sup>e.e. values were based on HPLC analysis.

Ph +	$H = \frac{O}{OEt} = \frac{Cul (15)}{Cs_2CO_3}$	5 mol%), <b>L*14</b> (18 mol%) <sup>)</sup> ::0 equiv.), THF, –15 *C,	a 5 d → Ph	OEt 0 0€t OEt + Et0 0€t Et0 00€t
Entry	E1/P1	<b>P1</b> Yield (%) <sup>b</sup>		e.e. of 1(%) <sup>c</sup>
		1	1′	
1	1.5:1	67	4	91
2	1:1	60	11	90
3	0.8:1	54	14	91
4	0.6:1	48	5	91

Supplementary Table 5. Reaction condition optimization: screening of substrate ratio

<sup>a</sup>Reaction conditions: **E1** (X mmol), **P1** (0.1 mmol), CuI (15 mol%), L\*14 (18 mol%), and Cs<sub>2</sub>CO<sub>3</sub> (2.0 equiv.) in THF (1.0 mL) at -15 °C for 5 days under argon. <sup>b</sup>Yields were based on <sup>1</sup>H NMR analysis of the crude product using CH<sub>2</sub>Br<sub>2</sub> as an internal standard. <sup>c</sup>e.e. values were based on HPLC analysis.

Ph Ph	+ H <sup>-</sup> I-OEt _	Cul (x mol%), L*14 <sup>(y mol%)</sup> a Cs <sub>2</sub> CO <sub>3</sub> <sup>(2.0</sup> equiv.), THF, -15 ° C, 5 d		OEt OEt +	O OEt EtO OEt EtO OEt
(±)-E1	P1	_ 0	1		1'
Entry	CuI (x mol%)	L*14	Yield	d (%) <sup>b</sup>	e.e. of 1
		(y mol%)	1	1′	(%)°
1	15	21	70	5	90
2	15	18	80	3	90
3	15	15	73	4	90
4	15	12	77	5	88
5	15	9	72	4	88
6	21	18	75	2	91
7	18	18	83	2	91
8	10	12	73	2	91
9	5	6	50	10	90

Supplementary Table 6. Reaction condition optimization: screening of catalyst ratio

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<sup>a</sup>Reaction conditions: **E1** (0.15 mmol), **P1** (0.1 mmol), CuI (x mol%), L\*14 (y mol%), and Cs<sub>2</sub>CO<sub>3</sub> (2.0 equiv.) in THF (1.0 mL) at -15 °C for 5 days under argon. <sup>b</sup>Yields were based on <sup>1</sup>H NMR analysis of the crude product using CH<sub>2</sub>Br<sub>2</sub> as an internal standard. <sup>c</sup>e.e. values were based on HPLC analysis.

TIPS (±)-I	Bn + H = OEt OEt $Bn + H = OEt OEt$ $Bn + H = OEt$	Cul (10 mol%), L*14 (12 mol%) <sub>a</sub> Cs <sub>2</sub> CO <sub>3</sub> (2.0 equiv.), solvent, r.t., 5 d	TIPS 33
Entry	Solvent	Yield (%)	e.e. of 33 (%)
1	THF	68	53
2	DCM	70	72
3	CH <sub>3</sub> CN	82	3
4	DMSO	64	2
5	PhF	80	85
6	PhCF <sub>3</sub>	70	76
7	PhCl	72	94
8 <sup>b</sup>	PhCl	84 (76)	97

#### Supplementary Table 7. Reaction condition optimization for propargyl bromide

<sup>a</sup>Reaction conditions: racemic **E30** (0.075 mmol), **P1** (0.05 mmol), CuI (10 mol%), L\*14 (12 mol%) and  $Cs_2CO_3$  (2.0 equiv.) in solvent (0.5 mL) at room temperature (r.t.) for 5 days under argon. Yields were based on <sup>1</sup>H NMR analysis of the crude product using CH<sub>2</sub>Br<sub>2</sub> as an internal standard. e.e. values were based on HPLC analysis. <sup>b</sup>Conducted at 0 °C. Isolated yield in parenthesis.

	0 H H (±). <b>E44</b>	O ↓ OEt P1	(10 mol%), <sup>L*</sup> (12 mol%), Cs <sub>2</sub> CO <sub>3</sub> <sup>a</sup> solvent, r.t., 2 d		0
	OMe N N N N N N N N N N N N N N N N N N N	=			H N Start
<b>F</b> (					
Ent	ry Solvent	L*	Cs <sub>2</sub> CO <sub>3</sub> (x equiv.)	Yield (%)	e.e. (%)
<b>Ent</b>	ry Solvent	L*	Cs <sub>2</sub> CO <sub>3</sub> (x equiv.)	<b>Yield (%)</b>	<b>e.e. (%)</b>
1	THF	L*14	2.0	11	-18
Ent	ry Solvent	L*	Cs <sub>2</sub> CO <sub>3</sub> (x equiv.)	<b>Yield (%)</b> 11 12	<b>e.e. (%)</b>
1	THF	L*14	2.0		-18
2	1,4-dioxane	L*14	2.0		-12
Ent	ry Solvent	L*	Cs <sub>2</sub> CO <sub>3</sub> (x equiv.)	<b>Yield (%)</b>	<b>e.e. (%)</b>
1	THF	L*14	2.0	11	-18
2	1,4-dioxane	L*14	2.0	12	-12
3	1,4-dioxane	L*15	2.0	9	20
Ent	ry Solvent	L*	Cs <sub>2</sub> CO <sub>3</sub> (x equiv.)	<b>Yield (%)</b> 11 12 9 30	e.e. (%)
1	THF	L*14	2.0		-18
2	1,4-dioxane	L*14	2.0		-12
3	1,4-dioxane	L*15	2.0		20
4	1,4-dioxane	L*16	2.0		4
Ent	ry Solvent	L*	Cs <sub>2</sub> CO <sub>3</sub> (x equiv.)	<b>Yield (%)</b> 11 12 9 30 76	e.e. (%)
1	THF	L*14	2.0		-18
2	1,4-dioxane	L*14	2.0		-12
3	1,4-dioxane	L*15	2.0		20
4	1,4-dioxane	L*16	2.0		4
5	1,4-dioxane	L*16	0.5		62
Entr	ry Solvent	L*	Cs <sub>2</sub> CO <sub>3</sub> (x equiv.)	<b>Yield (%)</b> 11 12 9 30 76 99	e.e. (%)
1	THF	L*14	2.0		-18
2	1,4-dioxane	L*14	2.0		-12
3	1,4-dioxane	L*15	2.0		20
4	1,4-dioxane	L*16	2.0		4
5	1,4-dioxane	L*16	0.5		62
6 <sup>b</sup>	1,4-dioxane	L*16	0.5		60
Entr	ry Solvent	L*	Cs <sub>2</sub> CO <sub>3</sub> (x equiv.)	Yield (%) 11 12 9 30 76 99 54	e.e. (%)
1	THF	L*14	2.0		-18
2	1,4-dioxane	L*14	2.0		-12
3	1,4-dioxane	L*15	2.0		20
4	1,4-dioxane	L*16	2.0		4
5	1,4-dioxane	L*16	0.5		62
6 <sup>b</sup>	1,4-dioxane	L*16	0.5		60
7 <sup>b</sup> ,	1,4-dioxane	L*16	0.5		67

**Supplementary Table 8.** Reaction condition optimization for  $\alpha$ -aminocarbonyl alkyl bromide

<sup>a</sup>Reaction conditions: racemic **E44** (0.075 mmol), **P1** (0.05 mmol), CuI (10 mol%), L\* (12 mol%) and Cs<sub>2</sub>CO<sub>3</sub> in solvent (0.5 mL) at room temperature (r.t.) for 2 days under argon. Yields were based on <sup>1</sup>H NMR analysis of the crude product using 1,3,5-trimethoxybenzene as an internal standard. e.e. value was based on HPLC analysis. <sup>b</sup>Racemic **E44** (0.05 mmol), **P1** (0.05 mmol) was used. 1,4-dioxane/THF = 1/1.<sup>c</sup>Conducted at 10 °C for 16 h. <sup>d</sup>Conducted at 0 °C for 2 days.

**Supplementary Table 9.** Reaction condition optimization for  $\alpha$ -aminocarbonyl- $\alpha$ -phenyl alkyl chloride



1	IHF	L*14	$Cs_2CO_3(2.0)$	<5	12	
2	THF	L*16	$Cs_2CO_3$ (2.0)	24	0	
3	THF	L*17	$Cs_2CO_3$ (2.0)	38	0	
4	THF	L*18	$Cs_2CO_3$ (2.0)	14	0	
5	THF	L*19	$Cs_2CO_3$ (2.0)	12	0	
6	THF	L*17	K <sub>3</sub> PO <sub>4</sub> (2.0)	6	13	
7	Toluene	L*17	K <sub>3</sub> PO <sub>4</sub> (2.0)	16	42	
8	Toluene	L*17	K <sub>3</sub> PO <sub>4</sub> (6.0)	39(39)	40	

<sup>a</sup>Reaction conditions: racemic **E46** (0.05 mmol), **P1** (0.075 mmol), CuI (10 mol%), L\* (15 mol%) and base in solvent (1.0 mL) at room temperature (r.t.) for 40 h under argon. Yields were based on <sup>1</sup>H NMR analysis of the crude product using PPh<sub>3</sub> as an internal standard. Isolated yield in parenthesis. e.e. value was based on HPLC analysis.

Supplementary Fig. 1. The reaction of benzyl bromide  $(\pm)$ -E2 with diphenylphosphine oxide.



<sup>a</sup>The reaction of  $(\pm)$ -E2 with diphenylphosphine (HPPh<sub>2</sub>) gave similar results with that of diphenylphosphine oxide.

Supplementary Fig. 2. Failed alkyl halide substrates. No conversion of the following alkyl bromide or iodide was observed in the reaction with **P1** under the standard reaction conditions.



#### **General information**

Reactions were carried out under argon atmosphere using Schlenk techniques. Reagents were purchased at the highest commercial quality and used without further purification, unless otherwise stated. Cuprous iodide (99.999%) was purchased from Sigma-Aldrich. Cesium carbonate (Cs<sub>2</sub>CO<sub>3</sub>) was purchased from Bide Pharmatech Ltd., which was directly used without further treatment. Anhydrous THF were purchased from Titan, which was distilled after refluxing with sodium and benzophenone. Analytical thin layer chromatography (TLC) was performed on precoated silica gel 60 GF254 plates. Flash column chromatography was performed using Tsingdao silica gel (60, particle size 0.040–0.063 mm). As the eluent, the petroleum ether (PE), hexane, ethyl acetate (EtOAc), dichloromethane (CH<sub>2</sub>Cl<sub>2</sub>) and methanol were purchased from Shanghai Titan Scientific Co. Ltd without further purification. Visualization on TLC was achieved by use of UV light (254 nm), iodine or basic KMnO4 indicator. NMR spectra were recorded on Bruker DRX-400 spectrometers at 400 MHz for <sup>1</sup>H NMR, 100 MHz for <sup>13</sup>C NMR, 376 MHz for <sup>19</sup>F NMR, 162 MHz for <sup>31</sup>P NMR and 128 MHz for <sup>11</sup>B NMR respectively, in CDCl<sub>3</sub> with tetramethylsilane (TMS) as an internal standard. The chemical shifts were expressed in ppm and coupling constants were given in Hz. Data for <sup>1</sup>H NMR are recorded as follows: chemical shift (ppm), multiplicity (s, singlet; d, doublet; t, triplet; q, quartet; p, pentet, m, multiplet; br, broad), coupling constant (Hz), integration. Data for <sup>13</sup>C NMR were reported in terms of chemical shift ( $\delta$ , ppm), multiplicity (d, doublet), coupling constant (Hz), integration. Mass spectrometric data were obtained using Bruker Apex IV RTMS. Enantiomeric excess (e.e.) was determined using SHIMADZU LC-20AD with SPD-20AV detector or Agilent high-performance liquid chromatography (HPLC) with Hatachi detector (at appropriate wavelength). Column conditions were reported in the experimental section below. Specific optical rotation was measured on a Rudolph-Autopol I.

#### General procedure for synthesis of substrates

#### The structures of electrophiles



#### The synthesis of benzyl bromide

Benzyl bromide E1 was purchased form Bide Pharmatech.

Benzyl bromide E12, E47 was prepared according to the procedure below. Other benzyl bromides were prepared according to previously reported procedure<sup>1-3</sup>. The synthesis of E12

To a solution of 4-(thiophen-2-yl)benzaldehyde (721 mg, 3.83 mmol) in anhydrous THF (10 mL) was slowly added ethylmagnesium bromide (1.0 M in THF, 1.2 equiv.) at 0 °C under an argon atmosphere. The reaction mixture was then warmed up to room temperature and stirred until the aldehyde was completely consumed (monitored by TLC). The reaction was quenched by 3.0 M HCl (10 mL) and extracted with CH<sub>2</sub>Cl<sub>2</sub> (10 mL  $\times$  3). The combined organic phase was dried over Na<sub>2</sub>SO<sub>4</sub>, filtered, and concentrated under reduced pressure. The residue was quickly filtered through a short pad of silica gel to afford the desired alcohol (680 mg, 81% yield), which was directly used in the next step without further purification.

To a solution of the crude alcohol (680 mg, 3.1 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (5 mL) was added PBr<sub>3</sub> (2.2 mmol) with vigorous stirring at 0 °C and the resulting reaction mixture was stirred at room temperature. After completion of the reaction (monitored by TLC), the mixture was quenched with water at 0 °C and extracted with CH<sub>2</sub>Cl<sub>2</sub> (5 mL × 3). The combined organic phase was washed by brine, dried over Na<sub>2</sub>SO<sub>4</sub>, filtered through a silica gel pad, and concentrated under reduced pressure to afford the corresponding alkyl bromide (871 mg, 99%), which was directly used without further purification or stored in a refrigerator unless otherwise noted. (The product readily decomposed in air and on silica gel.)

#### 2-(4-(1-Bromopropyl)phenyl)thiophene (E12)



<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.63 – 7.58 (m, 2H), 7.45 – 7.39 (m, 2H), 7.34 (dd, J = 3.6, 1.2 Hz, 1H), 7.30 (dd, J = 5.1, 1.1 Hz, 1H), 7.10 (dd, J = 5.1, 3.6 Hz, 1H), 4.92 (dd, J = 8.1, 6.8 Hz, 1H), 2.40 – 2.13 (m, 2H), 1.04 (t, J = 7.3 Hz, 3H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 143.8, 141.3, 134.5, 128.2, 128.0, 126.2, 125.2, 123.5, 57.3, 33.2, 13.1.

**HRMS** (ESI) m/z calcd. For  $C_{13}H_{13}S [M - Br]^+ 201.0732$ , found 201.0731.

The synthesis of E47



To a suspension of LiAlH<sub>4</sub> (3 g, 80 mmol) in anhydrous Et<sub>2</sub>O (30 mL) was added the solution of (*E*)-3-(3,4-dichlorophenyl)acrylic acid (4.34 g, 20 mmol) in 20 mL Et<sub>2</sub>O at 0 °C under argon atmosphere. The resulting mixture was stirred at room temperature over night. Upon completion (monitored by TLC), the reaction mixture was quenched by 2N HCl (30 mL). The organic layer was separated and the remaining aqueous phase was extract with EtOAc (30 mL  $\times$  5). The combined organic layers were dried over anhydrous Na<sub>2</sub>SO<sub>4</sub>, filtered and concentrated under reduced pressure. The residue was directly used in the next step without further purification.

To a mixture of the crude alcohol obtained above and triphenylphosphine (1.2 equiv.) in DCM (30 mL) was added *N*-bromosuccinimide (1.2 equiv.) in one portion at 0 °C under an argon atmosphere. After stirred at 0 °C for 10 min, the reaction mixture was allowed to warm to room temperature and stirred for another 1 hour. The mixture was filtered and washed with DCM. The combined filtrate was concentrated under reduced pressure to afford the residue, which was purified by column chromatography on silica gel to provide the corresponding alkyl bromide (3.45 g, 64% in two steps).

To a solution of alkyl bromide (15 mmol, 1.0 equiv.) in CCl<sub>4</sub> (30 mL) were added *N*bromosuccinimide (2.67 g, 15 mmol, 1.0 equiv.) and benzoyl peroxide (1.09 g, 4.5 mmol, 30 mol%). The resulting mixture was then refluxed overnight. After completion of reaction (monitored by TLC), the reaction mixture was cooled to room temperature. The precipitate was filtered off through a pad of celite and washed with CCl<sub>4</sub> (10.0 mL). The filtrate was concentrated under reduced pressure to afford the residue, which was purified by column chromatography on silica gel (petroleum ether) to afford the corresponding alkyl bromide product as a white solid (3.68 g, 71% yield).

#### 1,2-Dichloro-4-(1,3-dibromopropyl)benzene (E47)



**m.p.** 45–48 °C

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.51 (s, 1H), 7.43 (d, *J* = 8.3 Hz, 1H), 7.25 (d, *J* = 8.2 Hz, 1H), 5.11 (dd, *J* = 9.0, 5.6 Hz, 1H), 3.60 – 3.49 (m, 1H), 3.46 – 3.36 (m, 1H), 2.78 – 2.64 (m, 1H), 2.55 – 2.42 (m, 1H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 141.0, 133.0, 132.8, 131.0, 129.5, 126.9, 50.3, 41.9, 30.7.

#### The synthesis of propargyl bromides

The propargyl bromides were prepared according to previously reported procedure<sup>4</sup>. **E37**, **E38** was prepared according to the procedure below.



#### **General procedure 1:**

<sup>n</sup>BuLi (2.4 M in hexane, 1.3 equiv) was added dropwise into a solution of alkynes (1.3 equiv.) in anhydrous THF (1 M) at -78 °C. The mixture was then stirred at room temperature for 30 min and cooled to -78 °C again. Aldehyde (1.0 equiv.) was added dropwise at that temperature. Then the mixture was warmed up to room temperature and stirred for overnight. The mixture was quenched by saturated aq. NH<sub>4</sub>Cl, extracted with EtOAc, dried over Na<sub>2</sub>SO<sub>4</sub>, and filtered. The organic phase was concentrated under reduced pressure and the residue was purified by column chromatography to afford the desired propargyl alcohol.

To a solution of imidazole (1.2 equiv.) in dry CH<sub>2</sub>Cl<sub>2</sub> (1 M) was added propargyl alcohol (1.0 equiv.) at room temperature under an argon atmosphere. The solution was stirred for 15 min, followed by the addition of dibromotriphenylphosphorane (1.2 equiv.). The reaction mixture was stirred at room temperature overnight. After completion of reaction (monitored by TLC), the reaction was quenched by the addition of silica gel. The solvent was removed under reduced pressure to afford the residue, which was purified by column chromatography to afford the desired propargyl bromide.

Propargyl chloride was prepared according to the previously reported procedure<sup>4</sup>.

#### 2-(3-Bromo-5-(triisopropylsilyl)pent-4-yn-1-yl)isoindoline-1,3-dione (E37)



According to general procedure 1 with 2-(3-hydroxy-5-(triisopropylsilyl)pent-4-yn-1-yl)isoindoline-1,3-dione (467.2 mg, 1.2 mmol, 1.0 equiv.), E37 was obtained as a white foam (338.0 mg, 63% yield).

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>) δ 7.88 – 7.80 (m, 2H), 7.75 – 7.68 (m, 2H), 4.59 (t, J = 6.6 Hz, 1H), 3.96 – 3.89 (m, 2H), 2.40 (q, J = 7.0 Hz, 2H), 1.09 – 1.01 (m, 21H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 168.0, 134.0, 132.0, 123.3, 104.6, 89.8, 38.1, 35.9, 33.7, 18.5, 11.1.

**HRMS** (ESI) m/z calcd. For  $C_{22}H_{31}BrNO_2Si [M + H]^+ 448.1302$ , found 448.1306.

#### (3-Bromo-8-chlorooct-1-yn-1-yl)triisopropylsilane (E38)



According to general procedure 1 with 2-(3-hydroxy-5-(triisopropylsilyl)pent-4-yn-1-yl)isoindoline-1,3-dione (1.6 g, 5.1 mmol, 1.0 equiv.), E38 was obtained as a white foam (208.3 mg, 11% yield).

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>)  $\delta$  4.55 (t, J = 6.6 Hz, 1H), 3.54 (t, 2H), 2.07 – 1.98 (m, 2H), 1.85 – 1.75 (m, 2H), 1.64 – 1.45 (m, 4H), 1.07 (s, 21H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 105.6, 88.9, 44.8, 39.5, 37.2, 32.3, 26.5, 25.9, 18.5, 11.1.

HRMS (ESI) m/z calcd. For C<sub>17</sub>H<sub>32</sub>BrClSi [M + H]<sup>+</sup> 379.1218, found 379.1206

#### The synthesis of α-carbonyl alkyl bromide

The  $\alpha$ -carbonyl alkyl bromide E44 was prepared according to previously reported procedure<sup>5</sup>.

The synthesis of E45



To a solution of 2-bromohexanoic acid (0.97 g, 5 mmol, 1.0 equiv.), aniline (1.86 g, 20 mmol, 4.0 equiv.), and DMAP (61 mg, 0.5 mmol, 0.1 equiv.) in DCM (10 mL) was added EDCI (1.5 g, 8 mmol, 1.6 equiv.) at 0 °C. The reaction mixture was then warmed up to room temperature and stirred overnight. After completion (monitored by TLC), the reaction was quenched with 1.0 M HCl (25 mL) and extracted with DCM (20 mL  $\times$  3). The combined organic phase was washed with brine, dried over Na<sub>2</sub>SO<sub>4</sub> and filtrated. The filtrate was evaporated and the residue was purified by column chromatography on silica gel (petroleum ether/EtOAc = 10/1) to yield the product **E45** as a white solid (1.05 g, 78% yield).

#### 2-Bromo-N-phenylhexanamide (E45)



**m.p.** 47–50 °C

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  8.17 (s, 1H), 7.54 (d, *J* = 7.9 Hz, 2H), 7.34 (t, *J* = 7.8 Hz, 2H), 7.15 (t, *J* = 7.4 Hz, 1H), 4.44 (dd, *J* = 8.1, 5.5 Hz, 1H), 2.28 – 2.15 (m, 1H), 2.15 – 2.01 (m, 1H), 1.58 – 1.30 (m, 4H), 0.92 (t, *J* = 7.2 Hz, 3H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 167.1, 137.3, 129.2, 125.2, 120.2, 52.2, 35.8, 29.5, 22.1, 14.0.
HRMS (ESI) m/z calcd. for C<sub>12</sub>H<sub>17</sub>BrNO [M + H]+ 270.0488, found 270.0484.

#### The synthesis of α-aminocarbonyl-α-aryl alkyl chloride

#### The synthesis of E46



According to the literature reported procedure with slightly modification<sup>6</sup>: 2phenylbutanoic acid (1.64 g, 10 mmol) was dissolved in SOCl<sub>2</sub> (5.0 mL), and the resulting solution was heated at 80 °C for 30 min with vigorous stirring. The mixture was allowed to cool to room temperature, and then N-chlorosuccinimide (3.34 g, 25 mmol), SOCl<sub>2</sub> (3.0 mL), and HCl (concentrated; 3 drops) were added. The resulting mixture was heated at 90 °C for 2.5 h and then allowed to cool to room temperature. The precipitate was removed by filtration, washed by CCl<sub>4</sub> (5.0 mL) and the filtrate was concentrated by evaporation. The resulting liquid residue was used directly in the next step.

The Solution fo  $\alpha$ -chloro acid chloride in anhydrous CH<sub>2</sub>Cl<sub>2</sub> (5.0 mL) was added dropwise to a solution of 3-(methylsulfonyl)aniline (10 mmol) and triethylamine (4.2 mL, 30 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (30 mL) at 0 °C. The reaction was stirred at 0 °C for 15 min and then warmed up to room temperature. After completion (monitored by TLC), the reaction was quenched by the addition of 1.0 M HCl, the organic layer was washed by brine, dried over Na<sub>2</sub>SO<sub>4</sub>, filtered and concentrated under reduced pressure to afford the crude material, which was purified by flash chromatography to yield the product **E46** as a pale yellow solid (1.48 g, 42%).

2-Chloro-*N*-(3-(methylsulfonyl)phenyl)-2-phenylbutanamide (E46)

**m.p.** 91–93 °C

<sup>1</sup>**H NMR** (400 MHz, CHCl<sub>3</sub>)  $\delta$  8.56 (s, 1H), 8.10 – 8.05 (m, 1H), 7.93 – 7.86 (m, 1H), 7.72 – 7.67 (m, 1H), 7.63 – 7.57 (m, 2H), 7.53 (t, *J* = 8.0 Hz, 1H), 7.43 – 7.30 (m, 3H), 3.05 (s, 3H), 2.64 (dq, *J* = 14.3, 7.1 Hz, 1H), 2.43 (dq, *J* = 14.4, 7.2 Hz, 1H), 1.05 (t, *J* = 7.2 Hz, 3H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 168.7, 141.4, 139.7, 138.4, 130.3, 128.84, 128.8, 126.4, 125.0, 123.4, 118.7, 79.2, 44.4, 35.0, 9.5.

**HRMS** (ESI) m/z calcd. for  $C_{17}H_{19}CINO_3S [M + H]^+ 352.0769$ , found 352.0765.

#### Enantioconvergent Radical Michaelis-Becker-Type C(sp<sup>3</sup>)-P Cross-Coupling

General procedure A for asymmetric C(sp<sup>3</sup>)–P cross-coupling: scope of (hetero)benzyl bromides



An oven-dried resealable Schlenk tube equipped with a magnetic stir bar was charged with CuI (5.7 mg, 0.03 mmol, 15 mol%), L\*14 (30 mg, 0.036 mmol, 18 mol%), and Cs<sub>2</sub>CO<sub>3</sub> (130.3 mg, 0.4 mmol, 2.0 equiv.). The tube was evacuated and backfilled with argon three times. Then THF (2.0 mL) was added by syringe under argon. Finally, (hetero)benzyl bromides (0.30 mmol, 1.5 equiv.) and H-phosphonates (0.2 mmol, 1.0 equiv.) were sequentially added into the mixture and the reaction mixture was stirred at -15 °C for 5 days. Upon completion, the precipitate was filtered off and washed with EtOAc. The filtrate was evaporated and the residue was purified by column chromatography on silica gel to afford the desired products.

#### General procedure B for asymmetric C(sp<sup>3</sup>)–P cross-coupling: scope of propargyl

halides



An oven-dried resealable Schlenk tube equipped with a magnetic stir bar was charged with CuI (3.8 mg, 0.020 mmol, 10 mol%), L\*14 (20 mg, 0.024 mmol, 12 mol%), and Cs<sub>2</sub>CO<sub>3</sub> (130.3 mg, 0.40 mmol, 2.0 equiv.). The tube was evacuated and backfilled with argon three times. Then PhCl (2.0 mL) was added by syringe under argon. Finally, propargyl halides (0.30 mmol, 1.5 equiv.) and H-phosphonates (0.20 mmol, 1.0 equiv.) were sequentially added into the mixture and the reaction mixture was stirred at 0 °C

for 5 days. Upon completion, the precipitate was filtered off and washed by EtOAc. The filtrate was evaporated and the residue was purified by column chromatography on silica gel to afford the desired products.

# General procedure C for asymmetric C(sp<sup>3</sup>)–P cross-coupling: α-aminocarbonyl alkyl bromides



An oven-dried resealable Schlenk tube equipped with a magnetic stir bar was charged with CuI (3.8 mg, 0.020 mmol, 10 mol%), L\*16 (20 mg, 0.024 mmol, 12 mol%), Cs<sub>2</sub>CO<sub>3</sub> (32.6 mg, 0.10 mmol, 0.5 equiv.) and  $\alpha$ -aminocarbonyl alkyl bromides (0.20 mmol, 1 equiv.). The tube was evacuated and backfilled with argon three times. Then mixed solvent of 1,4-dioxane and THF (vol/ vol = 1/1, 2.0 mL) and H-phosphonate (0.20 mmol, 1.0 equiv.) were sequentially added into the mixture and the reaction mixture was stirred at 10 °C for 16 h. Upon completion, the precipitate was filtered off and washed by EtOAc. The filtrate was evaporated and the residue was purified by column chromatography on silica gel to afford the desired products.

#### General procedure D for asymmetric C(sp<sup>3</sup>)–P cross-coupling: α-aminocarbonyl-

#### a-aryl alkyl chloride



An oven-dried resealable Schlenk tube equipped with a magnetic stir bar was charged with CuI (3.8 mg, 0.020 mmol, 10 mol%), L\*17 (12.7 mg, 0.03 mmol, 15 mol%), K<sub>3</sub>PO<sub>4</sub> (255 mg, 1.2 mmol, 6 equiv.) and  $\alpha$ -aminocarbonyl- $\alpha$ -aryl alkyl chloride (0.20 mmol, 1 equiv.). The tube was evacuated and backfilled with argon three times. Then toluene and H-phosphonate (0.30 mmol, 1.5 equiv.) were sequentially added into the mixture and the reaction mixture was stirred at room temperature for 40 h. Upon completion, the precipitate was filtered off and washed by EtOAc. The filtrate was evaporated and the residue was purified by column chromatography on silica gel to afford the desired products.

#### General procedure for the synthesis of racemates

#### General procedure E for the synthesis of racemates 1-32



An oven-dried resealable Schlenk tube equipped with a magnetic stir bar was charged with CuI (1.9 mg, 0.01 mmol, 10 mol%), Lrac (3.2 mg, 0.012 mmol, 12 mol%), and Cs<sub>2</sub>CO<sub>3</sub> (65.2 mg, 0.20 mmol, 2.0 equiv.). The tube was evacuated and backfilled with argon three times. Then THF (1.0 mL) was added by syringe under argon. Finally, (hetero)benzyl bromides (0.15 mmol, 1.5 equiv.) and H-phosphonates (0.10 mmol, 1.0 equiv.) were sequentially added into the mixture and the reaction mixture was stirred at room temperature for 1 day. Upon completion, the precipitate was filtered off and washed with EtOAc. The filtrate was evaporated and the residue was purified by column chromatography on silica gel to afford the desired products.

#### General procedure F for the synthesis of racemates 33-49



An oven-dried resealable Schlenk tube equipped with a magnetic stir bar was charged with CuI (1.9 mg, 0.01 mmol, 10 mol%), Lrac (3.2 mg, 0.012 mmol, 12 mol%), and Cs<sub>2</sub>CO<sub>3</sub> (65.2 mg, 0.20 mmol, 2.0 equiv.). The tube was evacuated and backfilled with argon three times. Then PhCl (1.0 mL) was added by syringe under argon. Finally, propargyl halides (0.15 mmol, 1.5 equiv.) and H-phosphonates (0.10 mmol, 1.0 equiv.) were sequentially added into the mixture and the reaction mixture was stirred at 0 °C for 5 days. Upon completion, the precipitate was filtered off and washed by EtOAc. The filtrate was evaporated and the residue was purified by column chromatography on silica gel to afford the desired products.

#### General procedure G for the synthesis of racemates 50-51



An oven-dried resealable Schlenk tube equipped with a magnetic stir bar was charged with CuI (1.9 mg, 0.01 mmol, 10 mol%), Lrac (3.2 mg, 0.012 mmol, 12 mol%), Cs<sub>2</sub>CO<sub>3</sub> (16.3 mg, 0.05 mmol, 0.5 equiv.) and  $\alpha$ -aminocarbonyl alkyl bromides (0.10 mmol, 1

equiv.). The tube was evacuated and backfilled with argon three times. Then 1,4dioxane (1.0 ml) and H-phosphonates (0.10 mmol, 1.0 equiv.) were sequentially added into the mixture and the reaction mixture was stirred at room temperature for 1 day. Upon completion, the precipitate was filtered off and washed by EtOAc. The filtrate was evaporated and the residue was purified by column chromatography on silica gel to afford the desired products.

#### General procedure H for the synthesis of racemates 52



An oven-dried resealable Schlenk tube equipped with a magnetic stir bar was charged with CuI (1.9 mg, 0.01 mmol, 10 mol%), **Lrac** (1.5 mg, 0.015 mmol, 15 mol%), K<sub>3</sub>PO<sub>4</sub> (127.5 mg, 0.6 mmol, 6 equiv.) and  $\alpha$ -aminocarbonyl- $\alpha$ -aryl alkyl chloride (0.10 mmol, 1 equiv.). The tube was evacuated and backfilled with argon three times. Then toluene (1.0 ml) and H-phosphonates (0.15 mmol, 1.5 equiv.) were sequentially added into the mixture and the reaction mixture was stirred at room temperature for 40 h. Upon completion, the precipitate was filtered off and washed by EtOAc. The filtrate was evaporated and the residue was purified by column chromatography on silica gel to afford the desired product.

#### Analytical data for products (1-52)

#### Diethyl (*R*)-(1-phenylethyl)phosphonate (1)



According to the **general procedure A**, substrate **E1** (55.5 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **4** as a colorless oil (33.9 mg, 70% yield, 90% e.e.). The absolute configuration of **1** was determined to be *R* by comparing its HPLC spectrum and optical rotation with those reported in the literature<sup>7</sup>.

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 95/5, flow rate 0.5 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 16.10 min,  $t_R$  (major) = 18.79 min.

**HPLC** analysis: Chiralpak AD-H (hexane/ *i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda = 215$  nm),  $t_R$  (minor) = 7.95 min,  $t_R$  (major) = 9.48 min. [ $\alpha$ ]<sub>D</sub><sup>27</sup>= +4.85 (*c* 0.275, CHCl<sub>3</sub>). <sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>) δ 7.42 – 7.17 (m, 5H), 4.13 – 3.71 (m, 4H), 3.17 (dq, J = 22.4, 7.4 Hz, 1H), 1.58 (dd, J = 18.5, 7.4 Hz, 3H), 1.27 (t, J = 7.1 Hz, 3H), 1.13 (t, J = 7.8, 6.4 Hz, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 137.9 (d, J = 6.8 Hz), 128.6 (d, J = 6.4 Hz), 128.3 (d, J = 2.7 Hz), 127.0 (d, J = 3.3 Hz), 62.3 (d, J = 7.1 Hz), 61.8 (d, J = 7.2 Hz), 38.4 (d, J = 137.8 Hz), 16.3 (d, J = 5.9 Hz), 16.2 (d, J = 5.8 Hz), 15.5 (d, J = 5.1 Hz). <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>) δ 29.73.

**HRMS** (ESI) m/z calcd. for C<sub>12</sub>H<sub>20</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 243.1145, found 243.1140.

#### Diethyl (R)-(1-phenylpropyl)phosphonate (2)



According to the **general procedure A**, substrate **E2** (59.7 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **2** as a colorless oil (36.0 mg, 70% yield, 93% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 95/5, flow rate 0.5 mL/min,  $\lambda$  = 210 nm),  $t_R$  (minor) = 15.20 min,  $t_R$  (major) = 17.60 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.41 – 7.19 (m, 5H), 4.18 – 3.62 (m, 4H), 2.89 (ddd, *J* = 22.3, 11.2, 4.1 Hz, 1H), 2.25 – 2.07 (m, 1H), 2.05 – 1.88 (m, 1H), 1.28 (t, *J* = 7.1 Hz, 3H), 1.09 (t, *J* = 7.1 Hz, 3H), 0.85 (t, *J* = 7.4, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.2 (d, J = 6.6 Hz), 129.5 (d, J = 6.8 Hz), 128.5 (d, J = 2.3 Hz), 127.2 (d, J = 3.0 Hz), 62.6 (d, J = 7.0 Hz), 61.8 (d, J = 7.1 Hz), 46.7 (d, J = 136.6 Hz), 23.2 (d, J = 3.2 Hz), 16.5 (d, J = 5.9 Hz), 16.4 (d, J = 5.7 Hz), 12.6 (d, J = 16.1 Hz).

<sup>31</sup>**P** NMR (162 MHz, CDCl<sub>3</sub>) δ 29.02.

**HRMS** (ESI) m/z calcd. for C<sub>13</sub>H<sub>22</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 257.1301, found 257.1294.

#### Dibutyl (R)-(1-phenylpropyl)phosphonate (3)



According to the **general procedure A**, substrate **E2** (59.7 mg, 0.30 mmol) and dibutyl phosphonate **P2**(38.8 mg, 0.20 mmol) were employed to yield the product **3** as a colorless oil (51.3 mg, 82% yield, 90% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 95/5, flow rate 0.5 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 13.71 min,  $t_R$  (major) = 17.98 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$ 7.31 – 7.16 (m, 5H), 4.03 – 3.86 (m, 2H), 3.86 – 3.74 (m, 1H), 3.68 – 3.56 (m, 1H), 2.87 (ddd, J = 22.2, 11.2, 4.1 Hz, 1H), 2.21 – 2.05 (m, 1H), 2.04 – 1.84 (m, 1H), 1.71 – 1.45 (m, 2H), 1.45 – 1.27 (m, 4H), 1.27 – 1.14 (m, 2H), 0.88 (t, J = 7.4 Hz, 3H), 0.84 – 0.76 (m, 6H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.3 (d, J = 6.7 Hz), 129.4 (d, J = 6.8 Hz), 128.5 (d, J = 2.6 Hz), 127.1 (d, J = 3.2 Hz), 66.2 (d, J = 7.3 Hz), 65.4 (d, J = 7.4 Hz), 46.6 (d, J = 137.0 Hz), 32.6 (d, J = 6.0 Hz), 32.5 (d, J = 5.9 Hz), 23.3 (d, J = 3.4 Hz), 18.7 (d, J = 12.9 Hz), 13.7 (d, J = 5.9 Hz), 12.6 (d, J = 16.1 Hz).

<sup>31</sup>**P** NMR (162 MHz, CDCl<sub>3</sub>) δ 28.82.

**HRMS** (ESI) m/z calcd. for C<sub>17</sub>H<sub>30</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 313.1927, found 313.1921.

#### Diisopropyl (R)-(1-phenylpropyl)phosphonate (4)



According to the **general procedure A**, substrate **E2** (59.7 mg, 0.30 mmol) and diethyl phosphonate **P3**(33.2 mg, 0.20 mmol) were employed to yield the product **4** as a colorless oil (33.8 mg, 68% yield, 94% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 95/5, flow rate 0.5 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 12.75 min,  $t_R$  (major) = 15.90 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.33 – 7.14 (m, 5H), 4.62 (m, 1H), 4.35 (m, 1H), 2.77 (ddd, J = 22.4, 11.4, 3.9 Hz, 1H), 2.19 – 2.02 (m, 1H), 1.99 – 1.80 (m, 1H), 1.24 (dd, J = 6.2, 2.5 Hz, 6H), 1.17 (d, J = 6.2 Hz, 3H), 0.83 (d, J = 6.2 Hz, 3H), 0.79 (td, J = 7.4, 1.0 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.6 (d, J = 6.4 Hz), 129.6 (d, J = 7.0 Hz), 128.4 (d, J = 2.6 Hz), 127.0 (d, J = 3.1 Hz), 71.0 (d, J = 7.2 Hz), 70.0 (d, J = 7.5 Hz), 47.2 (d, J = 138.8 Hz), 24.4 (d, J = 2.9 Hz), 24.1 (d, J = 4.4 Hz), 23.5 (d, J = 3.3 Hz), 23.3 (d, J = 5.7 Hz), 12.7 (d, J = 16.5 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 27.38.

**HRMS** (ESI) m/z calcd. for C<sub>15</sub>H<sub>26</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 285.1614, found 285.1608.

Diisobutyl (R)-(1-phenylpropyl)phosphonate (5)



According to the **general procedure A**, substrate **E2** (59.7 mg, 0.30 mmol) and diisobutyl phosphonate **P4**(38.8 mg, 0.20 mmol) were employed to yield the product **5** as a colorless oil (56.4 mg, 90% yield, 89% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 95/5, flow rate 0.5 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 10.83 min,  $t_R$  (major) = 15.12 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 7.33 – 7.16 (m, 5H), 3.80 – 3.64 (m, 2H), 3.59 (dt, J = 9.7, 6.3 Hz, 1H), 3.41 (dt, J = 9.7, 6.4 Hz, 1H), 2.90 (ddd, J = 22.3, 11.2, 4.1 Hz, 1H), 2.24 – 2.07 (m, 1H), 2.02 – 1.89 (m, 1H), 1.89 – 1.79 (m, 1H), 1.75 – 1.64 (m, 1H), 0.87 (d, J = 6.7 Hz, 6H), 0.83 (td, J = 7.3, 1.0 Hz, 3H), 0.77 (dd, J = 6.8, 5.2 Hz, 6H). <sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>) δ 136.3 (d, J = 6.7 Hz), 129.4 (d, J = 6.9 Hz), 128.5 (d, J = 2.5 Hz), 127.1 (d, J = 3.2 Hz), 72.3 (d, J = 7.5 Hz), 71.7 (d, J = 7.6 Hz), 46.5 (d, J = 137.3 Hz), 29.3 (d, J = 6.4 Hz), 29.2 (d, J = 6.3 Hz), 23.3 (d, J = 3.4 Hz), 18.8 (d, J = 2.1 Hz), 18.7 (d, J = 5.9 Hz), 12.6 (d, J = 16.1 Hz). <sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 28.44.

**HRMS** (ESI) m/z calcd. for C<sub>17</sub>H<sub>30</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 313.1927, found 313.1920.

#### Diethyl (R)-(1-(p-tolyl)propyl)phosphonate (6)



According to the **general procedure A**, substrate **E3** (63.9 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **6** as a colorless oil (36.7 mg, 68% yield, 92% e.e.).

**HPLC** analysis: Chiralpak IG (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 19.69 min,  $t_R$  (major) = 22.08 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.17 (dd, J = 8.2, 2.3 Hz, 2H), 7.10 (d, J = 7.9 Hz, 2H), 4.11 – 3.94 (m, 2H), 3.93 – 3.81 (m, 1H), 3.78 – 3.64 (m, 1H), 2.83 (ddd, J = 22.2, 11.2,4.0 Hz, 1H), 2.30 (d, J = 2.1 Hz, 3H), 2.18 – 2.03 (m, 1H), 1.92 (dddt, J = 13.8, 11.2,9.6, 7.2 Hz, 1H), 1.26 (t, J = 7.1 Hz, 3H), 1.09 (t, J = 7.1 Hz, 3H), 0.82 (td, J = 7.4, 1.0 Hz, 3H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.7 (d, J = 3.4 Hz), 132.9 (d, J = 6.8 Hz), 129.24 (d,

J = 2.5 Hz), 129.19 (d, J = 1.8 Hz), 62.4 (d, J = 7.0 Hz), 61.7 (d, J = 7.2 Hz), 46.1 (d, J = 136.9 Hz), 23.2 (d, J = 3.2 Hz), 21.2, 16.5 (d, J = 6.0 Hz), 16.4 (d, J = 5.8 Hz), 12.6 (d, J = 16.1 Hz). <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>)  $\delta$  29.24. HRMS (ESI) *m/z* calcd. for C<sub>14</sub>H<sub>24</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 271.1458, found 271.1451.

#### Diethyl (R)-(1-(m-tolyl)propyl)phosphonate (7)



According to the **general procedure A**, the reaction was conducted at -15 °C for 4 days and then at -5 °C for 1 day. Substrate E4 (63.9 mg, 0.30 mmol) and diethyl phosphonate P1(27.6 mg, 0.20 mmol) were employed to yield the product 7 as a colorless oil (27.1 mg, 50% yield, 90% e.e.).

**HPLC** analysis: Chiralpak IF (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (major) = 10.30 min,  $t_R$  (minor) = 11.33 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.19 (t, J = 7.5 Hz, 1H), 7.13 – 7.06 (m, 2H), 7.08 – 7.01 (m, 1H), 4.04 (m, 2H), 3.95 – 3.79 (m, 1H), 3.78 – 3.63 (m, 1H), 2.83 (ddd, J = 22.3, 11.2, 4.1 Hz, 1H), 2.33 (s, 3H), 2.22 – 2.05 (m, 1H), 2.03 – 1.84 (m, 1H), 1.27 (t, J = 7.1 Hz, 3H), 1.09 (t, J = 7.1 Hz, 3H), 0.89 – 0.79 (m, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  138.0 (d, J = 2.5 Hz), 136.0 (d, J = 6.6 Hz), 130.2 (d, J = 6.9 Hz), 128.4 (d, J = 2.5 Hz), 127.9 (d, J = 3.2 Hz), 126.4 (d, J = 6.8 Hz), 62.5 (d, J = 7.0 Hz), 61.8 (d, J = 7.1 Hz), 46.5 (d, J = 136.5 Hz), 23.2 (d, J = 3.5 Hz), 21.6, 16.5 (d, J = 6.1 Hz), 16.4 (d, J = 5.9 Hz), 12.7 (d, J = 16.1 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ.29.17

**HRMS** (ESI) m/z calcd. for C<sub>14</sub>H<sub>24</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 271.1458, found 271.1452.

#### Diethyl (*R*)-(1-([1,1'-biphenyl]-4-yl)propyl)phosphonate (8)



According to the **general procedure A**, substrate **E5** (82.6 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **8** as a colorless oil (39.7 mg, 60% yield, 91% e.e.).

**HPLC** analysis: Chiralpak IF (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda = 254$  nm),  $t_R$  (major) = 19.64 min,  $t_R$  (minor) = 21.47 min.

**1H NMR** (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.65 – 7.52 (m, 4H), 7.47 – 7.28 (m, 5H), 4.16 – 3.97 (m, 2H), 4.00 – 3.86 (m, 1H), 3.85 – 3.71 (m, 1H), 2.94 (ddd, *J* = 22.3, 11.2, 4.1 Hz, 1H), 2.27 – 2.11 (m, 1H), 2.09 – 1.90 (m, 1H), 1.29 (t, *J* = 7.1 Hz, 3H), 1.12 (t, *J* = 7.1 Hz, 3H), 0.88 (td, *J* = 7.3, 1.0 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  140.8 (d, J = 1.4 Hz), 139.9 (d, J = 3.5 Hz), 135.2 (d, J = 6.9 Hz), 129.8 (d, J = 6.9 Hz), 128.8, 127.3, 127.2 (d, J = 2.7 Hz), 127.1, 62.6 (d, J = 6.9 Hz), 61.9 (d, J = 7.2 Hz), 46.3 (d, J = 136.9 Hz), 23.2 (d, J = 3.5 Hz), 16.5 (d, J = 6.0 Hz), 16.4 (d, J = 5.8 Hz), 12.7 (d, J = 16.1 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 28.90.

**HRMS** (ESI) m/z calcd. for C<sub>19</sub>H<sub>26</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 333.1614, found 333.1608.

#### Diethyl (R)-(1-(3-fluorophenyl)propyl)phosphonate (9)



According to the **general procedure A**, substrate **E6** (65.1 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **9** as a colorless oil (33 mg, 60% yield, 94% e.e.).

**HPLC** analysis: Chiralpak IH (hexane/*i*-PrOH = 95/5, flow rate 0.5 mL/min,  $\lambda$  = 254 nm),  $t_R$  (major) = 11.27 min,  $t_R$  (minor) = 13.06 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.32 – 7.23 (m, 1H), 7.12 – 7.06 (m, 1H), 7.06 – 7.00 (m, 1H), 6.98 – 6.90 (m, 1H), 4.16 – 3.71 (m, 4H), 2.88 (ddd, *J* = 22.3, 11.3, 4.0 Hz, 1H), 2.25 – 2.07 (m, 1H), 2.00 – 1.84 (m, 1H), 1.28 (t, *J* = 7.1 Hz, 3H), 1.13 (t, *J* = 7.1 Hz, 3H), 0.84 (td, *J* = 7.4, 1.0 Hz, 3H).

<sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>)  $\delta$  162.9 (d, J = 243.0 Hz), 140.1 – 137.1 (m), 129.9 (dd, J = 8.3, 2.6 Hz), 125.3 (dd, J = 7.1, 2.9 Hz), 116.2 (dd, J = 21.8, 6.8 Hz), 114.1 (dd, J = 21.0, 3.3 Hz), 62.6 (d, J = 7.0 Hz), 62.0 (d, J = 7.1 Hz), 46.5 (dd, J = 137.4, 1.8 Hz), 23.2 (d, J = 3.6 Hz), 16.5 (d, J = 6.0 Hz), 16.4 (d, J = 5.8 Hz), 12.6 (d, J = 16.1 Hz). <sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>)  $\delta$  28.10 (d, J = 1.62 Hz, 1P).

<sup>19</sup>**F NMR** (376 MHz, CDCl<sub>3</sub>)  $\delta$  –113.21 (d, J = 2.0 Hz, 1F).

**HRMS** (ESI) m/z calcd. for C<sub>13</sub>H<sub>21</sub>FO<sub>3</sub>P [M + H]<sup>+</sup> 275.1207, found 275.1200.

Diethyl (R)-(1-(3-chlorophenyl)propyl)phosphonate (10)



According to the **general procedure A**, substrate **E7** (70.0 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **10** as a pale yellow oil (34.4 mg, 59% yield, 92% e.e.).

**HPLC** analysis: Chiralpak ID (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (major) = 10.51 min,  $t_R$  (minor) = 11.54 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.34 – 7.17 (m, 4H), 4.15 – 4.00 (m, 2H), 3.94 (m, 1H), 3.81 (m, 1H), 2.86 (ddd, J = 22.3, 11.2, 4.0 Hz, 1H), 2.16 (m, 1H), 2.01 – 1.83 (m, 1H), 1.29 (t, J = 7.1 Hz, 3H), 1.14 (t, J = 7.1 Hz, 3H), 0.85 (td, J = 7.3, 1.0 Hz, 3H).

<sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>)  $\delta$  138.5 (d, J = 6.7 Hz), 134.3 (d, J = 2.9 Hz), 129.8 (d, J = 2.6 Hz), 129.5 (d, J = 7.0 Hz), 127.6 (d, J = 6.6 Hz), 127.4 (d, J = 3.2 Hz), 62.6 (d, J = 7.1 Hz), 62.0 (d, J = 7.2 Hz), 46.4 (d, J = 137.4 Hz), 23.1 (d, J = 3.6 Hz), 16.5 (d, J = 5.9 Hz), 16.4 (d, J = 5.9 Hz), 12.6 (d, J = 16.0 Hz). <sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>)  $\delta$  28.00.

1 With (102 With 2, CDC13) 0 28.00.

**HRMS** (ESI) m/z calcd. for C<sub>13</sub>H<sub>21</sub>ClO<sub>3</sub>P [M + H]<sup>+</sup> 291.0911, found 291.0906.

#### Diethyl (R)-(1-(3-bromophenyl)propyl)phosphonate (11)



According to the **general procedure A**, substrate **E8** (83.4 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **11** as a colorless oil (36.7 mg, 55% yield, 91% e.e.).

**HPLC** analysis: Chiralpak IH (hexane/*i*-PrOH = 95/5, flow rate 0.5 mL/min,  $\lambda$  = 214 nm),  $t_R$  (major) = 12.35 min,  $t_R$  (minor) = 15.43 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.45 – 7.40 (m, 1H), 7.40 – 7.33 (m, 1H), 7.28 – 7.22 (m, 1H), 7.17 (t, J = 7.8 Hz, 1H), 4.13 – 3.98 (m, 2H), 3.97 – 3.86 (m, 1H), 3.84 – 3.73 (m, 1H), 2.83 (ddd, J = 22.4, 11.2, 4.1 Hz, 1H), 2.23 – 2.05 (m, 1H), 1.99 – 1.81 (m, 1H), 1.27 (t, J = 7.0 Hz, 3H), 1.12 (t, J = 7.1 Hz, 3H), 0.83 (td, J = 7.4, 1.0 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  138.7 (d, J = 6.6 Hz), 132.4 (d, J = 7.0 Hz), 130.3 (d, J = 3.2 Hz), 130.0 (d, J = 2.6 Hz), 128.0 (d, J = 6.7 Hz), 122.5 (d, J = 2.9 Hz), 62.6 (d, J = 7.0 Hz), 62.0 (d, J = 7.2 Hz), 46.3 (d, J = 137.4 Hz), 23.1 (d, J = 3.6 Hz), 16.5 (d, J

= 5.9 Hz), 16.3 (d, J = 5.8 Hz), 12.6 (d, J = 15.9 Hz). <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>)  $\delta$  27.97. HRMS (ESI) m/z calcd. for C<sub>13</sub>H<sub>21</sub>BrO<sub>3</sub>P [M + H]<sup>+</sup> 335.0406, found 335.0398.

Diethyl (R)-(1-(4-(trifluoromethyl)phenyl)propyl)phosphonate (12)



According to the **general procedure A**, substrate **E9** (80.1 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **12** as a colorless oil (39.4 mg, 61% yield, 93% e.e.).

**HPLC** analysis: Chiralpak AD (hexane/*i*-PrOH = 95/5, flow rate 0.5 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 17.51 min,  $t_R$  (major) = 19.95 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$ 7.56 (d, J = 8.0 Hz, 2H), 7.42 (dd, J = 8.3, 2.4 Hz, 2H), 4.13 – 3.98 (m, 2H), 3.97 – 3.86 (m, 1H), 3.85 – 3.73 (m, 1H), 2.95 (ddd, J = 22.5, 11.2, 4.0 Hz, 1H), 2.26 – 2.06 (m, 1H), 2.04 – 1.87 (m, 1H), 1.27 (t, J = 7.1 Hz, 3H), 1.11 (t, J = 7.1 Hz, 3H), 0.82 (t, J = 7.4 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  140.7 (d, J = 6.5 Hz), 129.7 (d, J = 6.7 Hz), 129.6 (dq, J = 3.3Hz, 129.5 Hz), 125.6 – 125.3 (m), 124.3 (q, J = 272.0 Hz), 62.6 (d, J = 7.1 Hz), 62.1 (d, J = 7.2 Hz), 46.6 (d, J = 137.3 Hz), 23.1 (d, J = 3.7 Hz), 16.5 (d, J = 6.0 Hz), 16.4 (d, J = 5.7 Hz), 12.6 (d, J = 16.0 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 27.74.

<sup>19</sup>F NMR (376 MHz, CDCl<sub>3</sub>)  $\delta$  –62.51 (d, J = 2.6 Hz). HRMS (ESI) *m*/*z* calcd. for C<sub>14</sub>H<sub>21</sub>F<sub>3</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 325.1175, found 325.1168.

Diethyl (R)-(1-(3-cyanophenyl)ethyl)phosphonate (13)



According to the **general procedure A**, substrate **E10** (63.0 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **13** as a colorless oil (34.8 mg, 65% yield, 87% e.e.).

**HPLC** analysis: Chiralpak AD (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 16.18 min,  $t_R$  (major) = 17.74 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.65 – 7.57 (m, 2H), 7.56 – 7.51 (m, 1H), 7.42 (t, J =

7.7 Hz, 1H), 4.15 – 3.78 (m, 4H), 3.19 (dq, J = 22.6, 7.4 Hz, 1H), 1.56 (dd, J = 18.2, 7.4 Hz, 3H), 1.27 (t, J = 7.1 Hz, 3H), 1.17 (t, J = 7.1 Hz, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  140.0 (d, J = 6.8 Hz), 133.4 (d, J = 6.2 Hz), 132.3 (d, J = 6.7 Hz), 130.9 (d, J = 3.2 Hz), 129.3 (d, J = 2.6 Hz), 118.8, 112.6 (d, J = 2.6 Hz), 62.7 (d, J = 7.1 Hz), 62.4 (d, J = 7.1 Hz), 38.3 (d, J = 138.8 Hz), 16.5 (d, J = 5.8 Hz), 16.4

(d, J = 5.6 Hz), 15.3 (d, J = 5.3 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 27.93.

**HRMS** (ESI) m/z calcd. for C<sub>13</sub>H<sub>19</sub>NO<sub>3</sub>P [M + H]<sup>+</sup> 268.1097, found 268.1091.

Diethyl (R)-(1-(3-acetylphenyl)ethyl)phosphonate (14)



According to the **general procedure A**, substrate **E11** (68.1 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **14** as a colorless oil (36.0 mg, 63% yield, 88% e.e.).

**HPLC** analysis: Chiralcel OJ-H (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 14.78 min,  $t_R$  (major) = 20.86 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.90 (d, J = 2.6 Hz, 1H), 7.86 – 7.78 (m, 1H), 7.56 (d, J = 7.7 Hz, 1H), 7.40 (t, J = 7.7 Hz, 1H), 4.10 – 3.77 (m, 4H), 3.23 (dq, J = 22.5, 7.4 Hz, 1H), 2.58 (s, 3H), 1.58 (dd, J = 18.3, 7.4 Hz, 3H), 1.25 (t, J = 7.1 Hz, 3H), 1.14 (t, J = 7.0 Hz, 3H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  198.1, 138.9 (d, J = 6.8 Hz), 137.3 (d, J = 3.0 Hz), 133.4 (d, J = 6.2 Hz), 128.8 (d, J = 2.6 Hz), 128.6 (d, J = 6.9 Hz), 127.2 (d, J = 3.0 Hz), 62.5 (d, J = 7.1 Hz), 62.2 (d, J = 7.2 Hz), 38.4 (d, J = 138.1 Hz), 26.8, 16.5 (d, J = 5.9 Hz), 16.4 (d, J = 5.8 Hz), 15.5 (d, J = 5.2 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 28.91.

**HRMS** (ESI) m/z calcd. for C<sub>14</sub>H<sub>22</sub>O<sub>4</sub>P [M + H]<sup>+</sup> 285.1250, found 285.1245.

Diethyl (R)-(1-(4-(thiophen-2-yl)phenyl)propyl)phosphonate (15)



According to the general procedure A, substrate E12 (84.4 mg, 0.30 mmol) and diethyl

phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **15** as a colorless oil (24.4 mg, 36% yield, 91% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 11.88 min,  $t_R$  (major) = 13.49 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.60 – 7.54 (m, 2H), 7.39 – 7.22 (m, 4H), 7.12 – 7.01 (m, 1H), 4.18 – 3.99 (m, 2H), 3.98 – 3.87 (m, 1H), 3.83 – 3.73 (m, 1H), 2.97 – 2.84 (m, 1H), 2.28 – 2.08 (m, 1H), 2.08 – 1.91 (m, 1H), 1.29 (td, *J* = 7.2, 2.7 Hz, 3H), 1.13 (td, *J* = 7.0, 2.6 Hz, 3H), 0.87 (td, *J* = 7.5, 2.7 Hz, 3H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  144.2, 135.5 (d, J = 7.1 Hz), 133.3 (d, J = 3.6 Hz), 129.9 (d, J = 7.0 Hz), 128.1, 126.0 (d, J = 2.9 Hz), 124.8, 123.1, 62.6 (d, J = 7.2 Hz), 61.9 (d, J = 7.2 Hz), 46.3 (d, J = 137.0 Hz), 23.1 (d, J = 3.6 Hz), 16.6 (d, J = 6.1 Hz), 16.4 (d, J = 5.7 Hz), 12.6 (d, J = 16.3 Hz). <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>)  $\delta$  28.83.

**1** 1000 (102 10112, CDC13) 0 20:05:

#### Diethyl (R)-(1-(naphthalen-2-yl)propyl)phosphonate (16)



According to the **general procedure A**, the reaction was conducted at -15 °C for 4 days and then at -5 °C for 1 day. Substrate **E13** (74.7 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **16** as a colorless oil (32.1 mg, 52% yield, 91% e.e.).

**HPLC** analysis: Chiralpak IF (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 17.65 min,  $t_R$  (major) = 20.66 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.86 – 7.73 (m, 4H), 7.52 – 7.39 (m, 3H), 4.06 (m, 2H), 3.89 (m, 1H), 3.71 (m, 1H), 3.07 (ddd, J = 22.3, 11.2, 4.1 Hz, 1H), 2.32 – 2.17 (m, 1H), 2.12 – 1.98 (m, 1H). 1.28 (t, J = 7.1 Hz, 3H), 1.07 (t, J = 7.1 Hz, 3H), 0.86 (t, J = 7.3 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  133.7 (d, J = 7.0 Hz), 133.5 (d, J = 2.6 Hz), 132.7 (d, J = 2.3 Hz), 128.4 (d, J = 8.8 Hz), 128.2 (d, J = 2.1 Hz), 127.8 (d, J = 1.3 Hz), 127.7 (d, J = 1.5 Hz), 127.3 (d, J = 5.3 Hz), 126.1, 125.8 (d, J = 1.5 Hz), 62.6 (d, J = 7.0 Hz), 61.9 (d, J = 7.3 Hz), 46.7 (d, J = 136.8 Hz), 23.2 (d, J = 3.4 Hz), 16.5 (d, J = 5.9 Hz), 16.4 (d, J = 5.8 Hz), 12.7 (d, J = 16.2 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 28.82.

**HRMS** (ESI) m/z calcd. for C<sub>17</sub>H<sub>24</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 307.1458, found 307.1452.

Diethyl (R)-(1-(5-bromopyridin-3-yl)ethyl)phosphonate (17)



According to the **general procedure A**, substrate **E14** (79.5 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **17** as a pale yellow oil (54.0 mg, 84% yield, 91% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 14.96 min,  $t_R$  (major) = 15.99 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  8.56 (s, 1H), 8.44 (s, 1H), 7.88 – 7.79 (m, 1H), 4.16 – 3.83 (m, 4H), 3.16 (dq, J = 22.6, 7.4 Hz, 1H), 1.57 (dd, J = 18.0, 7.4 Hz, 3H), 1.29 (t, J = 7.1 Hz, 3H), 1.20 (t, J = 7.0 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$ 149.6 (d, J = 3.3 Hz), 148.2 (d, J = 7.4 Hz), 138.6 (d, J = 5.6 Hz), 136.0 (d, J = 6.8 Hz), 120.8 (d, J = 3.0 Hz), 62.8 (d, J = 7.1 Hz), 62.6 (d, J = 7.2 Hz), 35.8 (d, J = 140.0 Hz), 16.6 (d, J = 5.8 Hz), 16.5 (d, J = 5.8 Hz), 15.2 (d, J = 5.2 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 27.47.

**HRMS** (ESI) m/z calcd. for C<sub>11</sub>H<sub>18</sub>BrNO<sub>3</sub>P [M + H]<sup>+</sup> 322.0202, found 322.0196.

#### Diethyl (R)-(1-(6-bromopyridin-3-yl)ethyl)phosphonate (18)



According to the **general procedure A**, substrate **E15** (79.5 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **18** as a pale yellow oil (44.5 mg, 69% yield, 90% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 90/10, flow rate 1.0 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 11.79 min,  $t_R$  (major) = 13.71 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  8.25 (t, J = 2.6 Hz, 1H), 7.57 (dt, J = 8.3, 2.5 Hz, 1H), 7.42 (d, J = 8.3 Hz, 1H), 4.15 – 3.80 (m, 4H), 3.12 (dq, J = 22.5, 7.4 Hz, 1H), 1.53 (dd, J = 18.0, 7.4 Hz, 3H), 1.26 (t, J = 7.1 Hz, 3H), 1.17 (t, J = 7.1 Hz, 3H).

<sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>)  $\delta$  150.3 (d, J = 7.9 Hz), 140.7 (d, J = 3.8 Hz), 138.6 (d, J = 5.2 Hz), 133.6 (d, J = 6.8 Hz), 127.9 (d, J = 2.6 Hz), 62.7 (d, J = 7.1 Hz), 62.4 (d, J = 7.2 Hz), 35.4 (d, J = 140.0 Hz), 16.5 (d, J = 5.8 Hz), 16.4 (d, J = 5.7 Hz), 15.1 (d, J

= 5.2 Hz). <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>)  $\delta$  27.54. HRMS (ESI) *m/z* calcd. for C<sub>11</sub>H<sub>18</sub>BrNO<sub>3</sub>P [M + H]<sup>+</sup> 322.0202, found 322.0196.

#### Diethyl (R)-(1-(quinolin-3-yl)ethyl)phosphonate (19)



According to the **general procedure A**, the reaction was conducted at -15 °C for 4 days and then at -5 °C for 1 day. Substrate **E16** (70.8 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **19** as a pale yellow oil (23.0 mg, 39% yield, 82% e.e.).

**HPLC** analysis: Chiralpak IC (hexane/*i*-PrOH = 60/40, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 15.37 min,  $t_R$  (major) = 20.93 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>)  $\delta$  8.85 (t, J = 1.9 Hz, 1H), 8.15 (t, J = 2.9 Hz, 1H), 8.11 – 8.05 (m, 1H), 7.84 – 7.78 (m, 1H), 7.69 (ddt, J = 8.3, 7.0, 1.2 Hz, 1H), 7.54 (ddd, J = 8.1, 6.9, 1.2 Hz, 1H), 4.16 – 4.01 (m, 2H), 4.01 – 3.93 (m, 1H), 3.93 – 3.83 (m, 1H), 3.39 (dq, J = 22.5, 7.4 Hz, 1H), 1.69 (dd, J = 18.1, 7.4 Hz, 3H), 1.29 (t, J = 7.1 Hz, 3H), 1.16 (t, J = 7.1 Hz, 3H).

<sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>)  $\delta$  151.6 (d, J = 6.0 Hz), 147.4 (d, J = 2.3 Hz), 135.1 (d, J = 7.1 Hz), 131.4 (d, J = 7.1 Hz), 129.4 (d, J = 1.5 Hz), 129.3 (d, J = 1.5 Hz), 128.0 (d, J = 2.8 Hz), 127.9 (d, J = 1.4 Hz), 127.0, 62.7 (d, J = 7.1 Hz), 62.4 (d, J = 7.2 Hz), 36.2 (d, J = 139.5 Hz), 16.6 (d, J = 5.8 Hz), 16.5 (d, J = 5.7 Hz), 15.4 (d, J = 5.1 Hz). <sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>)  $\delta$  28.40.

**HRMS** (ESI) m/z calcd. for C<sub>15</sub>H<sub>21</sub>NO<sub>3</sub>P [M + H]<sup>+</sup> 294.1254, found 294.1247.

#### Diethyl (1-(thiazol-4-yl)ethyl)phosphonate (20)



According to the **general procedure A**, the reaction was conducted at -15 °C for 4 days and then at 0 °C for 1 day. Substrate E17 (57.6 mg, 0.30 mmol) and diethyl phosphonate P1(27.6 mg, 0.20 mmol) were employed to yield the product 20 as a pale yellow oil (36.2 mg, 73% yield, 88% e.e.).

**HPLC** analysis: Chiralpak ID (hexane/*i*-PrOH = 90/10, flow rate 1.0 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 17.04 min,  $t_R$  (major) = 20.58 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  8.76 (d, J = 2.0 Hz, 1H), 7.31 – 7.26 (m, 1H), 4.21 – 3.86 (m, 4H), 3.62 (dq, J = 22.3, 7.4 Hz, 1H), 1.62 (dd, J = 18.0, 7.4 Hz, 3H), 1.28 (t, J = 7.1 Hz, 3H), 1.21 (t, J = 7.1 Hz, 3H). <sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  154.2 (d, J = 6.5 Hz), 152.3, 115.4 (d, J = 7.1 Hz), 62.5

(d, J = 6.9 Hz), 62.3 (d, J = 6.8 Hz), 35.0 (d, J = 140.8 Hz), 16.6 (d, J = 5.9 Hz), 16.5 (d, J = 5.8 Hz), 15.3 (d, J = 5.2 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 28.17.

**HRMS** (ESI) m/z calcd. for C<sub>9</sub>H<sub>17</sub>NO<sub>3</sub>PS [M + H]<sup>+</sup> 250.0661, found 250.0656.

#### Diethyl (*R*)-(1-(thiophen-3-yl)propyl)phosphonate (21)



According to the **general procedure A**, the reaction was conducted at -15 °C for 4 days and then at -5 °C for 1 day. Substrate **E18** (61.5 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **21** as a colorless oil (43.4 mg, 83% yield, 87% e.e.).

**HPLC** analysis: Chiralpak IG (hexane/*i*-PrOH = 97/3, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 26.76 min,  $t_R$  (major) = 28.20 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.26 (t, J = 4.0 Hz, 1H), 7.12 (td, J = 3.3, 1.3 Hz, 1H), 7.06 (dt, J = 4.9, 1.4 Hz, 1H), 4.10 – 3.96 (m, 2H), 3.95 – 3.85 (m, 1H), 3.82 – 3.70 (m, 1H), 3.04 (ddd, J = 21.9, 11.1, 4.0 Hz, 1H), 2.23 – 2.00 (m, 1H), 1.96 – 1.77 (m, 1H), 1.26 (t, J = 7.1 Hz, 3H), 1.12 (t, J = 7.1 Hz, 3H), 0.85 (td, J = 7.4, 1.0 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.3 (d, J = 7.1 Hz), 128.3 (d, J = 4.6 Hz), 125.5 (d, J = 1.8 Hz), 123.0 (d, J = 10.0 Hz), 62.5 (d, J = 7.0 Hz), 61.8 (d, J = 7.2 Hz), 41.9 (d, J = 139.6 Hz), 23.5 (d, J = 3.3 Hz), 16.5 (d, J = 5.9 Hz), 16.4 (d, J = 5.8 Hz), 12.6 (d, J = 15.7 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 28.30.

**HRMS** (ESI) m/z calcd. for C<sub>15</sub>H<sub>21</sub>NO<sub>3</sub>P [M + H]<sup>+</sup> 294.1254, found 294.1247.

#### Diethyl (R)-(1-phenylbutyl)phosphonate (22)



According to the general procedure A, substrate E19 (63.9 mg, 0.30 mmol) and diethyl

phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **22** as a pale yellow oil (34.1 mg, 63% yield, 91% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 95/5, flow rate 0.5 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 15.94 min,  $t_R$  (major) = 17.57 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.36 – 7.19 (m, 5H), 4.14 – 3.96 (m, 2H), 3.95 – 3.83 (m, 1H), 3.78 – 3.65 (m, 1H), 3.01 (ddd, J = 22.6, 11.1, 4.2 Hz, 1H), 2.10 – 1.88 (m, 2H), 1.33 – 1.13 (m, 5H), 1.09 (t, J = 7.1 Hz, 3H), 0.86 (t, J = 7.3 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.4 (d, J = 6.9 Hz), 129.4 (d, J = 6.9 Hz), 128.5 (d, J = 2.6 Hz), 127.1 (d, J = 3.3 Hz), 62.6 (d, J = 7.0 Hz), 61.8 (d, J = 7.2 Hz), 44.5 (d, J = 137.0 Hz), 31.8 (d, J = 3.6 Hz), 20.9 (d, J = 15.6 Hz), 16.5 (d, J = 5.9 Hz), 16.3 (d, J = 5.8 Hz), 13.7.

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 29.22.

**HRMS** (ESI) m/z calcd. for C<sub>14</sub>H<sub>24</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 271.1458, found 271.1451.

#### Diethyl (R)-(1-phenylpentyl)phosphonate (23)



According to the **general procedure A**, substrate **E20** (68.1 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **23** as a colorless oil (31.0 mg, 55% yield, 89% e.e.).

**HPLC** analysis: Chiralpak IH (hexane/*i*-PrOH = 95/5, flow rate 0.8 mL/min,  $\lambda = 254$  nm),  $t_R$  (major) = 6.24 min,  $t_R$  (minor) = 7.44 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.35 – 7.16 (m, 5H), 4.13 – 3.94 (m, 2H), 3.94 – 3.80 (m, 1H), 3.77 – 3.62 (m, 1H), 2.97 (ddd, *J* = 22.6, 11.3, 4.0 Hz, 1H), 2.14 – 1.84 (m, 2H), 1.37 – 1.11 (m, 7H), 1.08 (t, *J* = 7.0 Hz, 3H), 0.82 (t, *J* = 7.1 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.5 (d, J = 6.9 Hz), 129.4 (d, J = 6.8 Hz), 128.5 (d, J = 2.6 Hz), 127.1 (d, J = 3.2 Hz), 62.6 (d, J = 7.0 Hz), 61.8 (d, J = 7.2 Hz), 44.8 (d, J = 136.8 Hz), 29.9 (d, J = 15.2 Hz), 29.5 (d, J = 3.5 Hz), 22.4, 16.5 (d, J = 6.0 Hz), 16.4 (d, J = 5.8 Hz), 13.9.

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 29.18.

**HRMS** (ESI) m/z calcd. for C<sub>14</sub>H<sub>24</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 285.1614, found 285.1609.
Diethyl (R)-(1-phenylheptyl)phosphonate (24)



According to the **general procedure A**, substrate **E21** (76.6 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **24** as a pale yellow oil (43.7 mg, 70% yield, 86% e.e.).

**HPLC** analysis: Chiralpak IG (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (major) = 12.30 min,  $t_R$  (minor) = 13.69 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 7.36 – 7.14 (m, 5H), 4.14 – 3.94 (m, 2H), 3.94 – 3.80 (m, 1H), 3.76 – 3.62 (m, 1H), 2.96 (ddd, *J* = 22.5, 11.3, 4.0 Hz, 1H), 2.13 – 1.85 (m, 2H), 1.34 – 1.15 (m, 11H), 1.07 (t, *J* = 7.1 Hz, 3H), 0.82 (t, *J* = 6.8 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.4 (d, J = 6.8 Hz), 129.4 (d, J = 6.9 Hz), 128.5 (d, J = 2.6 Hz), 127.1 (d, J = 3.3 Hz), 62.6 (d, J = 7.0 Hz), 61.8 (d, J = 7.2 Hz), 44.8 (d, J = 136.7 Hz), 31.6, 29.7 (d, J = 3.5 Hz), 29.0, 27.7 (d, J = 15.1 Hz), 22.7, 16.5 (d, J = 6.1 Hz), 16.3 (d, J = 5.8 Hz), 14.1.

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 29.21.

**HRMS** (ESI) m/z calcd. for C<sub>17</sub>H<sub>30</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 313.1927, found 313.1921.

#### Diethyl (R)-(1,4-diphenylbutyl)phosphonate (25)



According to the **general procedure A**, substrate **E22** (86.8 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **25** as a colorless oil (35.7 mg, 52% yield, 88% e.e.).

**HPLC** analysis: Chiralcel OJ-H (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 11.44 min,  $t_R$  (major) = 22.62 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.34 – 7.19 (m, 7H), 7.17 – 7.11 (m, 1H), 7.11 – 7.05 (m, 2H), 4.13 – 3.95 (m, 2H), 3.92 – 3.82 (m, 1H), 3.74 – 3.62 (m, 1H), 3.01 (ddd, J = 22.6, 11.3, 4.1 Hz, 1H), 2.67 – 2.48 (m, 2H), 2.23 – 1.91 (m, 2H), 1.63 – 1.45 (m, 2H), 1.26 (t, J = 7.1 Hz, 3H), 1.07 (t, J = 7.1 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  142.0, 136.1 (d, J = 6.9 Hz), 129.3 (d, J = 6.9 Hz), 128.6 (d, J = 2.8 Hz), 128.4, 128.3, 127.2 (d, J = 3.3 Hz), 125.8, 62.6 (d, J = 7.0 Hz), 61.8 (d, J = 7.2 Hz), 44.6 (d, J = 137.1 Hz), 35.5, 29.5 (d, J = 15.3 Hz), 29.3 (d, J = 3.3

Hz), 16.5 (d, J = 6.0 Hz), 16.3 (d, J = 5.8 Hz). <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>)  $\delta$  28.90. HRMS (ESI) *m/z* calcd. for C<sub>20</sub>H<sub>28</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 347.1771, found 347.1763.

### Diethyl (R)-(3-(5-methylfuran-2-yl)-1-phenylpropyl)phosphonate (26)



According to the **general procedure A**, substrate **E23** (83.8 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **26** as a colorless oil (22.2 mg, 33% yield, 87% e.e.).

**HPLC** analysis: Chiralcel OJ-H (hexane/*i*-PrOH = 95/5, flow rate 0.8 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 8.13 min,  $t_R$  (major) = 10.41 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 7.38 – 7.21 (m, 5H), 5.85 – 5.78 (m, 2H), 4.14 – 3.94 (m, 2H), 3.96 - 3.82 (m, 1H), 3.78 - 3.64 (m, 1H), 3.03 (ddd, J = 22.6, 11.4, 3.5 Hz, 1H), 2.61 - 2.23 (m, 4H), 2.23 (s, 3H), 1.28 (t, J = 7.1 Hz, 3H), 1.08 (t, J = 7.1 Hz, 3H). <sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>) δ 153.0, 150.6, 135.8 (d, J = 6.9 Hz), 129.5 (d, J = 6.8 Hz), 128.6 (d, J = 2.6 Hz), 127.3 (d, J = 3.2 Hz), 106.3, 105.9, 62.6 (d, J = 7.0 Hz), 61.9 (d, J = 7.3 Hz), 43.8 (d, J = 137.9 Hz), 28.3 (d, J = 2.6 Hz), 26.0 (d, J = 16.4 Hz), 16.5 (d, J = 6.1 Hz), 16.3 (d, J = 5.9 Hz), 13.6.

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 28.65.

**HRMS** (ESI) m/z calcd. for C<sub>18</sub>H<sub>26</sub>O<sub>4</sub>P [M + H]<sup>+</sup> 337.1563, found 337.1555.

#### Diethyl (R)-(4-chloro-1-phenylbutyl)phosphonate (27)



According to the **general procedure A**, substrate **E24** (74.3 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **27** as a pale yellow oil (39.7 mg, 65% yield, 93% e.e.).

**HPLC** analysis: Chiralpak IH (hexane/*i*-PrOH = 95/5, flow rate 0.5 mL/min,  $\lambda$  = 254 nm),  $t_R$  (major) = 14.51 min,  $t_R$  (minor) = 18.14 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 7.36 – 7.22 (m, 5H), 4.16 – 3.97 (m, 2H), 3.97 – 3.83 (m, 1H), 3.79 – 3.64 (m, 1H), 3.47 (t, *J* = 6.5 Hz, 2H), 3.00 (ddd, *J* = 22.7, 11.3, 4.3 Hz,

1H), 2.34 - 2.19 (m, 1H), 2.17 - 2.03 (m, 1H), 1.76 - 1.60 (m, 2H), 1.29 (t, J = 7.1 Hz, 3H), 1.10 (t, J = 7.1 Hz, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  135.6 (d, J = 6.9 Hz), 129.2 (d, J = 6.8 Hz), 128.6 (d, J = 2.5 Hz), 127.3 (d, J = 3.1 Hz), 62.7 (d, J = 7.0 Hz), 61.9 (d, J = 7.3 Hz), 44.4, 44.0 (d, J = 138.0 Hz), 30.6 (d, J = 15.5 Hz), 27.1 (d, J = 3.0 Hz), 16.4 (d, J = 6.0 Hz), 16.2 (d, J = 5.8 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 28.22.

**HRMS** (ESI) m/z calcd. for C<sub>14</sub>H<sub>23</sub>ClO<sub>3</sub>P [M + H]<sup>+</sup> 305.1068, found 305.1063.

Diethyl (R)-(4-bromo-1-phenylbutyl)phosphonate (28)



According to the **general procedure A**, substrate **E25** (87.6 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **28** as a colorless oil (52.0 mg, 74% yield, 94% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 95/5, flow rate 0.5 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 25.93 min,  $t_R$  (major) = 27.43 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.38 – 7.16 (m, 5H), 4.13 – 3.94 (m, 2H), 3.94 – 3.80 (m, 1H), 3.76 – 3.62 (m, 1H), 3.38 – 3.25 (m, 2H), 2.98 (ddd, *J* = 22.8, 11.2, 4.3 Hz, 1H), 2.31 – 2.17 (m, 1H), 2.15 – 2.00 (m, 1H), 1.83 – 1.67 (m, 2H), 1.27 (t, *J* = 7.1 Hz, 3H), 1.07 (t, *J* = 7.0 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  135.7 (d, J = 6.9 Hz), 129.3 (d, J = 6.7 Hz), 128.7 (d, J = 2.6 Hz), 127.4 (d, J = 3.2 Hz), 62.7 (d, J = 7.0 Hz), 62.0 (d, J = 7.2 Hz), 44.0 (d, J = 138.0 Hz), 33.0 (d, J = 1.4 Hz), 30.8 (d, J = 15.7 Hz), 28.4 (d, J = 3.0 Hz), 16.5 (d, J = 6.0 Hz), 16.3 (d, J = 5.9 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 28.11.

**HRMS** (ESI) m/z calcd. for C<sub>14</sub>H<sub>23</sub>BrO<sub>3</sub>P [M + H]<sup>+</sup> 349.0563, found 349.0556.

#### Ethyl (R)-4-(diethoxyphosphoryl)-4-phenylbutanoate (29)



According to the **general procedure A**, substrate **E26** (81.3 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **29** as a

colorless oil (34.0 mg, 52% yield, 89% e.e.).

**HPLC** analysis: Chiralpak IF (hexane/*i*-PrOH = 90/10, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (major) = 15.84 min,  $t_R$  (minor) = 18.81 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 7.35 – 7.19 (m, 5H), 4.15 – 3.95 (m, 4H), 3.95 – 3.80 (m, 1H), 3.77 – 3.63 (m, 1H), 3.07 (ddd, *J* = 22.8, 10.6, 4.4 Hz, 1H), 2.48 – 2.12 (m, 4H), 1.27 (t, *J* = 7.0 Hz, 3H), 1.19 (t, *J* = 7.1 Hz, 3H), 1.07 (t, *J* = 7.0 Hz, 3H).

<sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>)  $\delta$  172.9, 135.4 (d, J = 6.6 Hz), 129.4 (d, J = 6.7 Hz), 128.7 (d, J = 2.4 Hz), 127.5 (d, J = 3.1 Hz), 62.7 (d, J = 6.9 Hz), 62.0 (d, J = 7.0 Hz), 60.5, 43.8 (d, J = 138.2 Hz), 32.2 (d, J = 15.7 Hz), 25.3 (d, J = 2.2 Hz), 16.5 (d, J = 6.1 Hz), 16.3 (d, J = 5.8 Hz), 14.3.

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 28.28.

**HRMS** (ESI) m/z calcd. for C<sub>16</sub>H<sub>26</sub>O<sub>5</sub>P [M + H]<sup>+</sup> 329.1512, found 329.1506.

#### Diethyl (R)-(4-cyano-1-phenylbutyl)phosphonate (30)



According to the **general procedure A**, substrate **E27** (81.3 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **30** as a pale yellow oil (45.4 mg, 77% yield, 92% e.e.).

**HPLC** analysis: Chiralpak IF (hexane/*i*-PrOH = 90/10, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (major) = 22.56 min,  $t_R$  (minor) = 26.75 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.37 – 7.20 (m, 5H), 4.16 – 3.96 (m, 2H), 3.94 – 3.81 (m, 1H), 3.77 – 3.63 (m, 1H), 2.98 (ddd, *J* = 22.8, 11.0, 4.5 Hz, 1H), 2.28 (t, *J* = 7.2 Hz, 2H), 2.26 – 2.02 (m, 2H), 1.58 (m, 2H), 1.28 (t, *J* = 7.1 Hz, 3H), 1.08 (t, *J* = 7.1 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  135.3 (d, J = 6.9 Hz), 129.1 (d, J = 6.7 Hz), 128.8 (d, J = 2.5 Hz), 127.5 (d, J = 3.1 Hz), 119.2, 62.8 (d, J = 7.1 Hz), 62.0 (d, J = 7.3 Hz), 44.1 (d, J = 138.6 Hz), 29.0 (d, J = 3.1 Hz), 23.7 (d, J = 15.9 Hz), 16.9 (d, J = 6.1 Hz), 16.4 (d, J = 6.0 Hz), 16.2 (d, J = 5.8 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 27.64.

**HRMS** (ESI) m/z calcd. for C<sub>15</sub>H<sub>23</sub>NO<sub>3</sub>P [M + H]<sup>+</sup> 296.1410, found 296.1406.

Diethyl (*R*)-(3-(5,5-dimethyl-1,3-dioxan-2-yl)-1-phenylpropyl)phosphonate (31)



According to the **general procedure A**, the reaction was conducted at -15 °C for 4 days and then at 0 °C for 1 day. Substrate **E28** (94.0 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **31** as a colorless oil (38.4 mg, 52% yield, 85% e.e.).

**HPLC** analysis: Chiralpak IG (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 36.88 min,  $t_R$  (major) = 39.73 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.38 – 7.16 (m, 5H), 4.32 (t, *J* = 4.9 Hz, 1H), 4.15 – 3.95 (m, 2H), 3.93 – 3.79 (m, 1H), 3.74 – 3.60 (m, 1H), 3.53 (ddd, *J* = 11.3, 5.2, 2.7 Hz, 2H), 3.39 – 3.27 (m, 2H), 2.99 (ddd, *J* = 22.4, 11.5, 4.2 Hz, 1H), 2.31 – 2.14 (m, 1H), 2.10 – 1.95 (m, 1H), 1.50 (td, *J* = 8.0, 4.9 Hz, 2H), 1.26 (t, *J* = 7.1 Hz, 3H), 1.12 (s, 3H), 1.05 (t, *J* = 7.1 Hz, 3H), 0.67 (s, 3H).

<sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.0 (d, J = 6.8 Hz), 129.4 (d, J = 6.9 Hz), 128.6 (d, J = 2.6 Hz), 127.2 (d, J = 3.1 Hz), 101.8 (d, J = 1.7 Hz), 77.3 (d, J = 1.8 Hz), 62.6 (d, J = 7.0 Hz), 61.9 (d, J = 7.3 Hz), 44.6 (d, J = 137.6 Hz), 32.9 (d, J = 15.5 Hz), 30.2, 24.4 (d, J = 2.9 Hz), 23.1, 21.9, 16.5 (d, J = 6.0 Hz), 16.3 (d, J = 5.8 Hz). <sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>)  $\delta$  28.85.

**HRMS** (ESI) m/z calcd. for C<sub>19</sub>H<sub>32</sub>O<sub>5</sub>P [M + H]<sup>+</sup> 371.1982, found 371.1973.

## Diethyl (R)-(1-phenylpent-4-en-1-yl)phosphonate (32)



According to the **general procedure A**, substrate **E29** (67.5 mg, 0.30 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20 mmol) were employed to yield the product **32** as a colorless oil (29.1 mg, 52% yield, 89% e.e.).

**HPLC** analysis: Chiralpak IE (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (major) = 24.09 min,  $t_R$  (minor) = 26.26 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.36 – 7.20 (m, 5H), 5.80 – 5.65 (m, 1H), 5.01 – 4.87 (m, 2H), 4.13 – 3.98 (m, 2H), 3.94 – 3.82 (m, 1H), 3.77 – 3.63 (m, 1H), 3.04 (ddd, J = 22.7, 11.0, 3.9 Hz, 1H), 2.26 – 1.81 (m, 4H), 1.28 (t, J = 7.1 Hz, 3H), 1.09 (t, J = 7.0 Hz, 3H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  137.5, 136.0 (d, *J* = 6.8 Hz), 129.5 (d, *J* = 6.8 Hz), 128.6 (d, *J* = 2.6 Hz), 127.2 (d, *J* = 3.2 Hz), 115.7, 62.6 (d, *J* = 7.0 Hz), 61.8 (d, *J* = 7.2 Hz), 43.8 (d, *J* = 137.6 Hz), 31.4 (d, *J* = 15.7 Hz), 28.8 (d, *J* = 3.0 Hz), 16.5 (d, *J* = 6.1 Hz), 16.3 (d, *J* = 5.8 Hz). <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>)  $\delta$  29.01. HRMS (ESI) *m/z* calcd. for C<sub>15</sub>H<sub>24</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 283.1458, found 283.1452.

Diethyl (R)-(5-phenyl-1-(triisopropylsilyl)pent-1-yn-3-yl)phosphonate (33)



According to the **general procedure B**, substrate **E30** (113.9 mg, 0.30 mmol) and diethyl phosphonate **P1** (27.6 mg, 0.20 mmol) were employed to yield the product **33** as a colorless oil (66.4 mg, 76% yield, 97% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 98/2, flow rate 1.0 mL/min,  $\lambda$  = 220 nm),  $t_R$  (minor) = 8.49 min,  $t_R$  (major) = 8.99 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 7.31 – 7.26 (m, 2H), 7.24 – 7.15 (m, 3H), 4.22 – 4.09 (m, 4H), 3.06 – 2.96 (m, 1H), 2.89 – 2.73 (m, 2H), 2.19 – 2.09 (m, 1H), 2.07 – 1.97 (m, 1H), 1.31 (td, *J* = 7.1, 2.5 Hz, 6H), 1.15 – 1.05 (m, 21H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  140.8, 128.6, 128.4, 126.1, 102.2 (d, J = 12.1 Hz), 85.4 (d, J = 8.4 Hz), 63.0 (d, J = 7.2 Hz), 62.7 (d, J = 6.9 Hz), 33.5 (d, J = 14.3 Hz), 31.1 (d, J = 4.0 Hz), 31.0 (d, J = 144.4 Hz), 18.6, 16.4 (d, J = 2.7 Hz), 16.3 (d, J = 2.7 Hz), 11.3. <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>)  $\delta$  23.75.

**HRMS** (ESI) m/z calcd. for  $C_{24}H_{42}O_3PSi [M + H]^+ 437.2635$ , found 437.2634.



According to the **general procedure B** at room temperature, substrate **E43** (100.5 mg, 0.30 mmol) and diethyl phosphonate **P1** (27.6 mg, 0.20 mmol) were employed to yield the product **33** as a colorless oil (48.0 mg, 55% yield, 94% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 98/2, flow rate 1.0 mL/min,  $\lambda$  = 220 nm), t<sub>R</sub> (minor) = 8.64 min, t<sub>R</sub> (major) = 9.17 min.

Dimethyl (R)-(5-phenyl-1-(triisopropylsilyl)pent-1-yn-3-yl)phosphonate (34)



According to the **general procedure B**, substrate **E30** (113.9 mg, 0.30 mmol) and dimethyl phosphonate **P5** (22.1 mg, 0.20 mmol) were employed to yield the product **34** as a colorless oil (63.7 mg, 78% yield, 97% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 98/2, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 12.12 min,  $t_R$  (major) = 12.97 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.31 – 7.26 (m, 2H), 7.23 – 7.17 (m, 3H), 3.81 (d, J = 10.6 Hz, 3H), 3.78 (d, J = 10.7 Hz, 3H), 3.05 – 2.97 (m, 1H), 2.93 – 2.72 (m, 2H), 2.17 – 1.99 (m, 2H), 1.15 – 1.07 (m, 21H).

<sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>)  $\delta$  140.6, 128.6, 128.4, 126.1, 101.7 (d, *J* = 12.2 Hz), 85.8 (d, *J* = 8.6 Hz), 53.8 (d, *J* = 7.1 Hz), 53.3 (d, *J* = 6.9 Hz), 33.4 (d, *J* = 14.4 Hz), 31.0 (d, *J* = 4.0 Hz), 30.4 (d, *J* = 144.6 Hz), 18.5, 11.2.

<sup>31</sup>**P** NMR (162 MHz, CDCl<sub>3</sub>) δ 26.21.

HRMS (ESI) m/z calcd. for  $C_{22}H_{38}O_3PSi [M + H]^+ 409.2322$ , found 409.2323.

#### Dibutyl (R)-(5-phenyl-1-(triisopropylsilyl)pent-1-yn-3-yl)phosphonate (35)



According to the **general procedure B**, substrate **E30** (113.9 mg, 0.30 mmol) and dibutyl phosphonate **P2** (38.8 mg, 0.20 mmol) were employed to yield the product **35** as a colorless oil (53.7 mg, 54% yield, 97% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 98/2, flow rate 0.8 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 10.77 min,  $t_R$  (major) = 12.98 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.33 – 7.26 (m, 2H), 7.24 – 7.15 (m, 3H), 4.15 – 4.04 (m, 4H), 3.07 – 2.96 (m, 1H), 2.90 – 2.71 (m, 2H), 2.22 – 2.09 (m, 1H), 2.07 – 1.96 (m, 1H), 1.68 – 1.59 (m, 4H), 1.45 – 1.34 (m, 4H), 1.16 – 1.06 (m, 21H), 0.92 (t, *J* = 7.4 Hz, 6H).

<sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>) δ 140.7, 128.6, 128.4, 126.1, 102.3 (d, *J* = 12.2 Hz), 85.3 (d, *J* = 8.6 Hz), 66.7 (d, *J* = 7.3 Hz), 66.4 (d, *J* = 7.1 Hz), 32.6 (d, *J* = 3.4 Hz), 32.5 (d,

J = 3.3 Hz), 31.1 (d, J = 4.0 Hz), 30.9 (d, J = 144.4 Hz), 18.7 (d, J = 1.3 Hz), 18.6, 13.5, 11.2. <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>)  $\delta$  23.73. HRMS (ESI) m/z calcd. for C<sub>28</sub>H<sub>50</sub>O<sub>3</sub>PSi [M + H]<sup>+</sup> 493.3261, found 493.3261.

Diisobutyl (R)-(5-phenyl-1-(triisopropylsilyl)pent-1-yn-3-yl)phosphonate (36)



According to the general procedure B, substrate E30 (113.9 mg, 0.30 mmol) and diisobutyl phosphonate P4 (38.8 mg, 0.20 mmol) were employed to yield the product 36 as a colorless oil (70.1 mg, 71% yield, 95% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 99/1, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 7.20 min,  $t_R$  (major) = 8.06 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.31 – 7.26 (m, 2H), 7.23 – 7.16 (m, 3H), 3.92 – 3.80 (m, 4H), 3.06 – 2.98 (m, 1H), 2.91 – 2.74 (m, 2H), 2.25 – 2.11 (m, 1H), 2.09 – 1.98 (m, 1H), 1.98 – 1.86 (m, 2H), 1.11 (d, *J* = 3.6 Hz, 21H), 0.94 (d, *J* = 2.2 Hz, 6H), 0.92 (d, *J* = 2.1 Hz, 6H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  140.8, 128.6, 128.4, 126.1, 102.4 (d, *J* = 12.1 Hz), 85.3 (d, *J* = 8.4 Hz), 72.8 (d, *J* = 7.6 Hz), 72.6 (d, *J* = 7.4 Hz), 33.5 (d, *J* = 14.3 Hz), 31.2 (d, *J* = 4.0 Hz), 30.9 (d, *J* = 144.8 Hz), 29.3 (d, *J* = 2.7 Hz), 29.2 (d, *J* = 2.8 Hz), 18.7 (d, *J* = 2.2 Hz), 18.6, 11.2.

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 23.38.

**HRMS** (ESI) m/z calcd. for  $C_{28}H_{50}O_3PSi [M + H]^+ 493.3261$ , found 493.3261.

## Dibenzyl (R)-(5-phenyl-1-(triisopropylsilyl)pent-1-yn-3-yl)phosphonate (37)



According to the **general procedure B**, substrate **E30** (113.9 mg, 0.30 mmol) and dibenzyl phosphonate **P6** (52.4 mg, 0.20 mmol) were employed to yield the product **37** as a colorless oil (73.9 mg, 66% yield, 95% e.e.).

**HPLC** analysis: Chiralpak IH (hexane/*i*-PrOH = 94/6, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 12.88 min,  $t_R$  (major) = 14.41 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 7.39 – 7.22 (m, 12H), 7.21 – 7.12 (m, 3H), 5.11 – 4.99 (m, 4H), 3.03 – 2.93 (m, 1H), 2.92 – 2.81 (m, 1H), 2.79 – 2.69 (m, 1H), 2.17 – 1.96 (m, 2H), 1.15 – 1.01 (m, 21H).

<sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>)  $\delta$  140.6, 136.2 (d, J = 6.1 Hz), 136.2 (d, J = 6.0 Hz), 128.6, 128.5, 128.4, 128.3 (d, J = 2.7 Hz), 127.7 (d, J = 4.0 Hz), 126.1, 101.9 (d, J = 12.6 Hz), 85.8 (d, J = 8.6 Hz), 68.3 (d, J = 6.9 Hz), 68.1 (d, J = 6.8 Hz), 33.4 (d, J = 14.5 Hz), 31.3 (d, J = 144.6 Hz), 31.0 (d, J = 3.9 Hz), 18.6, 11.2.

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 24.85.

**HRMS** (ESI) m/z calcd. for  $C_{34}H_{46}O_3PSi [M + H]^+ 561.2948$ , found 561.2950.

Dibenzyl (*R*)-(4-(triisopropylsilyl)but-3-yn-2-yl)phosphonate (38)

According to the **general procedure B**, substrate **E31** (113.9 mg, 0.30 mmol) and dibenzyl phosphonate **P6** (52.4 mg, 0.20 mmol) were employed to yield the product **38** as a colorless oil (74.4 mg, 79% yield, 96% e.e.).

**HPLC** analysis: Chiralpak IH (hexane/*i*-PrOH = 98.5/1.5, flow rate 1.0 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 15.75 min,  $t_R$  (major) = 16.72 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.39 – 7.28 (m, 10H), 5.16 – 5.03 (m, 4H), 2.99 (dq, *J* = 24.3, 7.2 Hz, 1H), 1.46 (dd, *J* = 17.9, 7.2 Hz, 3H), 1.10 – 0.99 (m, 21H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.3 (d, J = 6.2 Hz), 136.2 (d, J = 5.9 Hz), 128.5 (d, J = 1.4 Hz), 128.3 (d, J = 3.8 Hz), 127.7 (d, J = 6.6 Hz), 103.6 (d, J = 12.4 Hz), 84.0 (d, J = 8.6 Hz), 68.3 (d, J = 7.0 Hz), 68.1 (d, J = 6.7 Hz), 26.1 (d, J = 145.5 Hz), 18.5, 15.6 (d, J = 6.0 Hz), 11.2.

<sup>31</sup>**P** NMR (162 MHz, CDCl<sub>3</sub>) δ 25.88.

HRMS (ESI) m/z calcd. for  $C_{27}H_{40}O_3PSi [M + H]^+ 471.2479$ , found 471.2481.

## Dibenzyl (R)-(1-(triisopropylsilyl)pent-1-yn-3-yl)phosphonate (39)



According to the **general procedure B**, substrate **E32** (91.0 mg, 0.30 mmol) and dibenzyl phosphonate **P6** (52.4 mg, 0.20 mmol) were employed to yield the product **39** as a colorless oil (88.1 mg, 91% yield, 95% e.e.).

**HPLC** analysis: Chiralpak IH (hexane/*i*-PrOH = 98/2, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 9.87 min,  $t_R$  (major) = 11.21 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 7.38 – 7.27 (m, 10H), 5.15 – 5.02 (m, 4H), 2.84 (ddd, *J* = 24.6, 10.3, 4.1 Hz, 1H), 1.99 – 1.86 (m, 1H), 1.81 – 1.67 (m, 1H), 1.11 (t, *J* = 6.9 Hz, 3H), 1.08 – 1.01 (m, 21H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.4 (d, J = 6.2 Hz), 136.3 (d, J = 6.2 Hz), 128.5 (d, J = 1.8 Hz), 128.3 (d, J = 4.0 Hz), 127.8 (d, J = 5.9 Hz), 102.1 (d, J = 12.4 Hz), 85.3 (d, J = 8.8 Hz), 68.3 (d, J = 7.0 Hz), 68.1 (d, J = 6.7 Hz), 33.7 (d, J = 143.8 Hz), 23.0 (d, J = 4.5 Hz), 18.6, 12.4 (d, J = 14.3 Hz), 11.3.

<sup>31</sup>**P** NMR (162 MHz, CDCl<sub>3</sub>) δ 24.95.

HRMS (ESI) m/z calcd. for  $C_{28}H_{42}O_3PSi [M + H]^+ 485.2635$ , found 485.2637.

#### Diethyl (R)-(1-phenyl-4-(triisopropylsilyl)but-3-yn-2-yl)phosphonate (40)



According to the **general procedure B**, substrate **E33** (109.6 mg, 0.30 mmol) and diethyl phosphonate **P1** (27.6 mg, 0.20 mmol) were employed to yield the product **40** as a colorless oil (66.7 mg, 79% yield, 92% e.e.).

**HPLC** analysis: Chiralpak IH (hexane/*i*-PrOH = 99/1, flow rate 1.0 mL/min,  $\lambda$  = 220 nm),  $t_R$  (minor) = 10.19 min,  $t_R$  (major) = 12.03 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 7.32 – 7.24 (m, 4H), 7.23 – 7.18 (m, 1H), 4.28 – 4.14 (m, 4H), 3.24 (ddd, J = 13.0, 9.2, 3.7 Hz, 1H), 3.13 (ddd, J = 24.0, 11.0, 3.7 Hz, 1H), 2.90 (ddd, J = 13.1, 11.0, 7.0 Hz, 1H), 1.34 (t, J = 7.1 Hz, 6H), 1.06 – 0.94 (m, 21H). <sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>) δ 138.4 (d, J = 15.4 Hz), 129.1, 128.2, 126.6, 101.8 (d, J = 12.1 Hz), 85.9 (d, J = 8.4 Hz), 63.2 (d, J = 7.2 Hz), 62.8 (d, J = 6.8 Hz), 35.5 (d, J = 3.7 Hz), 34.0 (d, J = 142.0 Hz), 18.4, 16.4 (d, J = 3.4 Hz), 16.3 (d, J = 3.4 Hz), 11.1. <sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 22.94.

HRMS (ESI) m/z calcd. for  $C_{23}H_{40}O_3PSi [M + H]^+ 423.2479$ , found 423.2478.

Diethyl

yl)phosphonate (41)

According to the **general procedure B**, substrate **E34** (113.9 mg, 0.30 mmol) and diethyl phosphonate **P1** (27.6 mg, 0.20 mmol) were employed to yield the product **41** as a colorless oil (62.6 mg, 71% yield, 97% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 99.2/0.8, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 18.75 min,  $t_R$  (major) = 20.30 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 5.92 – 5.89 (m, 1H), 5.86 – 5.82 (m, 1H), 4.26 – 4.11 (m, 4H), 2.99 – 2.72 (m, 3H), 2.24 (s, 3H), 2.22 – 2.12 (m, 1H), 2.03 – 1.91 (m, 1H), 1.36 – 1.30 (m, 6H), 1.13 – 1.04 (m, 21H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  152.5, 150.7, 106.3, 105.8, 101.9 (d, *J* = 12.1 Hz), 85.3 (d, *J* = 8.6 Hz), 63.0 (d, *J* = 7.1 Hz), 62.7 (d, *J* = 6.9 Hz), 30.9 (d, *J* = 144.6 Hz), 28.0 (d, *J* = 3.7 Hz), 25.9 (d, *J* = 14.9 Hz), 18.6, 16.4 (d, *J* = 2.1 Hz), 16.3 (d, *J* = 2.1 Hz), 13.5, 11.2.

<sup>31</sup>**P** NMR (162 MHz, CDCl<sub>3</sub>) δ 23.68.

**HRMS** (ESI) m/z calcd. for  $C_{23}H_{42}O_4PSi [M + H]^+ 441.2584$ , found 441.2585.

## Dibenzyl (R)-(6-(5,5-dimethyl-1,3-dioxan-2-yl)-1-(triisopropylsilyl)hex-1-yn-3-

## yl)phosphonate (42)



According to the **general procedure B**, substrate **E35** (129.5 mg, 0.30 mmol) and dibenzyl phosphonate **P6** (52.4 mg, 0.20 mmol) were employed to yield the product **42** as a colorless oil (95.5 mg, 78% yield, 94% e.e.).

**HPLC** analysis: Chiralpak IH (hexane/*i*-PrOH = 98/2, flow rate 1.0 mL/min,  $\lambda$  = 220 nm),  $t_R$  (minor) = 10.48 min,  $t_R$  (major) = 14.51 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.37 – 7.27 (m, 10H), 5.15 – 5.01 (m, 4H), 4.37 (t, J = 4.7 Hz, 1H), 3.56 (d, J = 11.0 Hz, 2H), 3.37 (d, J = 10.9 Hz, 2H), 2.98 – 2.84 (m, 1H), 1.90 – 1.50 (m, 6H), 1.16 (s, 3H), 1.08 – 1.00 (m, 21H), 0.70 (s, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.3 (d, J = 6.2 Hz), 136.2 (d, J = 6.1 Hz), 128.4 (d, J = 1.6 Hz), 128.2 (d, J = 4.0 Hz), 127.7 (d, J = 5.4 Hz), 101.9 (d, J = 12.6 Hz), 101.6, 85.3 (d, J = 8.8 Hz), 77.1, 77.0, 68.3 (d, J = 7.0 Hz), 68.0 (d, J = 6.8 Hz), 33.8, 31.9 (d, J = 144.1 Hz), 30.0, 28.8 (d, J = 4.3 Hz), 22.9, 22.0 (d, J = 14.4 Hz), 21.8, 18.5, 11.2. <sup>31</sup>**P** NMR (162 MHz, CDCl<sub>3</sub>)  $\delta$  24.93.

**HRMS** (ESI) m/z calcd. for  $C_{35}H_{54}O_5PSi [M + H]^+ 613.3473$ , found 613.3473.

(R)-4-(diethoxyphosphoryl)-6-(triisopropylsilyl)hex-5-yn-1-yl benzoate (43)

According to the **general procedure B**, substrate **E36** (131.0 mg, 0.30 mmol) and diethyl phosphonate **P1** (27.6 mg, 0.20 mmol) were employed to yield the product **43** as a colorless oil (46.5 mg, 47% yield, 97% e.e.).

**HPLC** analysis: Chiralcel OD-3 (hexane/*i*-PrOH = 98/2, flow rate 0.5 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 29.81 min,  $t_R$  (major) = 35.00 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  8.06 – 7.99 (m, 2H), 7.57 – 7.50 (m, 1H), 7.41 (t, *J* = 7.7 Hz, 2H), 4.41 – 4.31 (m, 2H), 4.24 – 4.11 (m, 4H), 2.94 (ddd, *J* = 24.7, 10.2, 3.9 Hz, 1H), 2.21 – 2.12 (m, 1H), 2.09 – 1.81 (m, 3H), 1.31 (t, *J* = 7.0 Hz, 6H), 1.09 – 1.00 (m, 21H).

<sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>)  $\delta$  166.5, 132.9, 130.3, 129.6, 128.3, 102.0 (d, *J* = 12.1 Hz), 85.4 (d, *J* = 8.5 Hz), 64.2, 63.1 (d, *J* = 7.2 Hz), 62.7 (d, *J* = 6.9 Hz), 31.4 (d, *J* = 144.5 Hz), 26.9 (d, *J* = 13.4 Hz), 26.3 (d, *J* = 4.2 Hz), 18.5, 16.4 (d, *J* = 2.9 Hz), 16.3 (d, *J* = 2.8 Hz), 11.2.

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 23.36.

HRMS (ESI) m/z calcd. for  $C_{26}H_{44}O_5PSi [M + H]^+ 495.2690$ , found 495.2691.

Diethyl (R)-(5-(1,3-dioxoisoindolin-2-yl)-1-(triisopropylsilyl)pent-1-yn-3-

yl)phosphonate (44)



According to the **general procedure B**, substrate **E37** (134.1 mg, 0.30 mmol) and diethyl phosphonate **P1** (27.6 mg, 0.20 mmol) were employed to yield the product **44** as a colorless oil (86.0 mg, 85% yield, 92% e.e.).

**HPLC** analysis: Chiralcel OD-3 (hexane/*i*-PrOH = 97/3, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 19.81 min,  $t_R$  (major) = 21.82 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.87 – 7.78 (m, 2H), 7.73 – 7.66 (m, 2H), 4.23 – 4.10 (m, 4H), 4.06 – 3.95 (m, 1H), 3.90 – 3.78 (m, 1H), 2.96 (ddd, *J* = 24.9, 10.7, 3.8 Hz, 1H), 2.29 – 2.15 (m, 1H), 2.13 – 1.99 (m, 1H), 1.34 – 1.28 (m, 6H), 1.11 – 0.95 (m, 21H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 168.1, 133.9, 132.1, 123.2, 101.1 (d, J = 12.6 Hz), 85.8 (d, J = 8.6 Hz), 63.1 (d, J = 7.2 Hz), 63.0 (d, J = 6.9 Hz), 36.5 (d, J = 16.5 Hz), 29.9 (d, J = 145.2 Hz), 28.4 (d, J = 3.8 Hz), 18.5, 16.4 (d, J = 1.7 Hz), 16.3 (d, J = 1.7 Hz), 11.2. <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>) δ 22.68.

**HRMS** (ESI) m/z calcd. for  $C_{26}H_{41}NO_5PSi [M + H]^+ 506.2486$ , found 506.2488.

## Dibenzyl (R)-(8-chloro-1-(triisopropylsilyl)oct-1-yn-3-yl)phosphonate (45)



According to the **general procedure B**, substrate **E38** (114.0 mg, 0.30 mmol) and dibenzyl phosphonate **P6** (52.4 mg, 0.20 mmol) were employed to yield the product **45** as a colorless oil (97.5 mg, 87% yield, 95% e.e.).

**HPLC** analysis: Chiral INA (hexane/*i*-PrOH = 98.5/1.5, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 22.99 min,  $t_R$  (major) = 24.55 min.

<sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.38 – 7.28 (m, 10H), 5.16 – 5.01 (m, 4H), 3.49 (t, J = 6.7 Hz, 2H), 2.89 (ddd, J = 24.9, 10.4, 4.1 Hz, 1H), 1.88 – 1.63 (m, 5H), 1.53 – 1.34 (m, 3H), 1.10 – 1.00 (m, 21H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.3 (d, J = 6.1 Hz), 136.2 (d, J = 6.1 Hz), 128.5 (d, J = 1.4 Hz), 128.3 (d, J = 3.6 Hz), 127.8 (d, J = 5.1 Hz), 102.0 (d, J = 12.7 Hz), 85.4 (d, J = 8.7 Hz), 68.4 (d, J = 7.0 Hz), 68.1 (d, J = 6.9 Hz), 44.8, 32.3, 31.9 (d, J = 144.2 Hz), 28.9 (d, J = 4.3 Hz), 26.7 (d, J = 13.8 Hz), 26.1, 18.6, 11.2.

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 24.89.

HRMS (ESI) m/z calcd. for C<sub>31</sub>H<sub>47</sub>ClO<sub>3</sub>PSi [M + H]<sup>+</sup> 561.2715, found 561.2717.

#### Dibenzyl (R, Z)-(1-(triisopropylsilyl)undec-8-en-1-yn-3-yl)phosphonate (46)



According to the **general procedure B**, substrate **E39** (115.7 mg, 0.30 mmol) and dibenzyl phosphonate **P6** (52.4 mg, 0.20 mmol) were employed to yield the product **46** as a colorless oil (83.9 mg, 74% yield, 95% e.e.).

**HPLC** analysis: Chiralpak IH (hexane/*i*-PrOH = 97/3, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 6.58 min,  $t_R$  (major) = 9.02 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>) δ 7.38 – 7.27 (m, 10H), 5.43 – 5.24 (m, 2H), 5.18 – 5.01 (m, 4H), 2.91 (ddd, J = 24.8, 10.6, 4.1 Hz, 1H), 2.09 – 1.94 (m, 4H), 1.90 – 1.62 (m, 3H), 1.49 – 1.25 (m, 3H), 1.16 – 0.99 (m, 21H), 0.94 (t, J = 7.5 Hz, 3H). <sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>) δ 136.3 (d, J = 6.1 Hz), 136.2 (d, J = 6.1 Hz), 131.8, 128.7, 128.4 (d, J = 1.5 Hz), 128.2 (d, J = 4.0 Hz), 127.7 (d, J = 5.5 Hz), 102.1 (d, J = 12.5 Hz), 85.1 (d, J = 8.7 Hz), 68.3 (d, J = 7.0 Hz), 68.0 (d, J = 6.8 Hz), 31.9 (d, J = 143.9 Hz), 29.0 (d, J = 4.3 Hz), 28.9, 27.1 (d, J = 13.8 Hz), 26.8, 20.4, 18.5, 14.3, 11.2. <sup>31</sup>**P** NMR (162 MHz, CDCl<sub>3</sub>) δ 25.12.

**HRMS** (ESI) m/z calcd. for  $C_{34}H_{52}O_3PSi [M + H]^+ 567.3418$ , found 567.3418.

Diethyl (R)-(5-phenyl-1-(triethylsilyl)pent-1-yn-3-yl)phosphonate (47)



According to the **general procedure B**, substrate **E40** (101.2 mg, 0.30 mmol) and diethyl phosphonate **P1** (27.6 mg, 0.20 mmol) were employed to yield the product **47** as a colorless oil (51.3 mg, 65% yield, 90% e.e.).

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 99/1, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 12.18 min,  $t_R$  (major) = 14.48 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.31 – 7.26 (m, 2H), 7.24 – 7.17 (m, 3H), 4.25 – 4.09 (m, 4H), 3.06 – 2.94 (m, 1H), 2.89 – 2.72 (m, 2H), 2.18 – 1.98 (m, 2H), 1.32 (t, *J* = 7.1 Hz, 6H), 1.03 (t, *J* = 7.9 Hz, 9H), 0.70 – 0.57 (m, 6H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 140.8, 128.6, 128.4, 126.1, 101.5 (d, J = 12.0 Hz), 86.7 (d, J = 8.5 Hz), 63.2 (d, J = 7.1 Hz), 62.8 (d, J = 6.9 Hz), 33.4 (d, J = 14.1 Hz), 31.0 (d, J = 144.2 Hz), 30.9 (d, J = 4.1 Hz), 16.4 (d, J = 2.2 Hz), 16.3 (d, J = 2.2 Hz), 7.4, 4.4. <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>) δ 23.56.

HRMS (ESI) m/z calcd. for  $C_{21}H_{36}O_3PSi [M + H]^+ 395.2166$ , found 395.2167.

## Diethyl (R)-(6,6-dimethyl-1-phenylhept-4-yn-3-yl)phosphonate (48)



48

According to the general procedure B, substrate E41 (83.8 mg, 0.30 mmol) and diethyl

phosphonate **P1** (27.6 mg, 0.20 mmol) were employed to yield the product **48** as a colorless oil (41.1 mg, 61% yield, 75% e.e.).

**HPLC** analysis: Chiral INA (hexane/*i*-PrOH = 98/2, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 8.98 min,  $t_R$  (major) = 12.27 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 7.32 – 7.25 (m, 2H), 7.25 – 7.15 (m, 3H), 4.23 – 4.08 (m, 4H), 3.01 – 2.91 (m, 1H), 2.81 – 2.65 (m, 2H), 2.10 – 1.93 (m, 2H), 1.36 – 1.29 (m, 6H), 1.26 (s, 9H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  141.0, 128.6, 128.3, 126.0, 93.1 (d, J = 9.8 Hz), 72.5 (d, J = 12.5 Hz), 63.1 (d, J = 7.0 Hz), 62.6 (d, J = 7.0 Hz), 33.3 (d, J = 14.2 Hz), 31.04, 31.00 (d, J = 2.6 Hz), 29.7 (d, J = 145.5 Hz), 27.5 (d, J = 2.6 Hz), 16.4 (d, J = 2.9 Hz), 16.3 (d, J = 3.0 Hz).

<sup>31</sup>**P** NMR (162 MHz, CDCl<sub>3</sub>) δ 24.84.

**HRMS** (ESI) m/z calcd. for  $C_{19}H_{30}O_{3}P [M + H]^+ 337.1927$ , found 337.1927.

## Diethyl (R)-(5-phenyl-1-(trimethylsilyl)pent-1-yn-3-yl)phosphonate (49)



#### 49

According to the **general procedure B**, substrate **E42** (88.6 mg, 0.30 mmol) and diethyl phosphonate **P1** (27.6 mg, 0.20 mmol) were employed to yield the product **49** as a colorless oil (47.2 mg, 67% yield, 84% e.e.).

**HPLC** analysis: Chiralpak IH (hexane/*i*-PrOH = 98/2, flow rate 1.0 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 8.99 min,  $t_R$  (major) = 10.22 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 7.33 – 7.26 (m, 2H), 7.24 – 7.16 (m, 3H), 4.25 – 4.06 (m, 4H), 3.03 – 2.92 (m, 1H), 2.87 – 2.69 (m, 2H), 2.15 – 1.98 (m, 2H), 1.32 (t, *J* = 7.1 Hz, 6H), 0.19 (s, 9H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  140.9, 128.7, 128.6, 126.2, 100.5 (d, *J* = 12.0 Hz), 89.5 (d, *J* = 8.6 Hz), 63.5 (d, *J* = 7.2 Hz), 63.0 (d, *J* = 7.0 Hz), 33.5 (d, *J* = 13.8 Hz), 31.1 (d, *J* = 144.3 Hz), 30.9 (d, *J* = 4.1 Hz), 16.6 (d, *J* = 2.2 Hz), 16.5 (d, *J* = 2.2 Hz), 0.1 (d, *J* = 1.1 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 23.54.

**HRMS** (ESI) m/z calcd. for  $C_{18}H_{30}O_3PSi [M + H]^+ 353.1696$ , found 353.1695.

Diethyl (S)-(1-oxo-1-(phenylamino)propan-2-yl)phosphonate (50)

According to the **general procedure C**, substrate **E44** (48.4 mg, 0.20 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20mmol) were employed to yield the product **50** as a white solid (25.3 mg, 42% yield, 67% e.e.).

**m.p.** 73–76 °C

**HPLC** analysis: Chiralpak IE (hexane/*i*-PrOH = 90/10, flow rate 1.0 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 12.34 min,  $t_R$  (major) = 13.26 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  8.53 (s, 1H), 7.53 (d, *J* = 8.1 Hz, 2H), 7.30 (t, *J* = 7.7 Hz, 2H), 7.09 (t, *J* = 7.2 Hz, 1H), 4.22 – 4.10 (m, 4H), 2.80 (ddd, *J* = 21.9, 10.2, 4.4 Hz, 1H), 2.12 – 1.87 (m, 2H), 1.33 (td, *J* = 7.1, 3.2 Hz, 6H), 1.09 (t, *J* = 7.4 Hz, 3H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  165.7, 138.0, 128.9 (d, *J* = 7.2 Hz), 124.2, 119.9 (d, *J* = 4.9 Hz), 63.2 (d, *J* = 6.9 Hz), 62.8 (d, *J* = 6.8 Hz), 48.8 (d, *J* = 128.8 Hz), 20.9 (d, *J* = 4.8 Hz), 16.5 (d, *J* = 2.5 Hz), 16.4 (d, *J* = 2.5 Hz), 13.0 (d, *J* = 14.9 Hz). <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>)  $\delta$  25.86.

**HRMS** (ESI) m/z calcd. for C<sub>14</sub>H<sub>23</sub>NO<sub>4</sub>P [M + H]<sup>+</sup> 300.1359, found 300.1361.

# Diethyl (S)-(1-oxo-1-(phenylamino)hexan-2-yl)phosphonate (51)



According to the **general procedure C**, substrate **E45** (54.0 mg, 0.20 mmol) and diethyl phosphonate **P1**(27.6 mg, 0.20mmol) were employed to yield the product **51** as a pale yellow oil (27.2 mg, 42% yield, 71% e.e.).

**HPLC** analysis: Chiralpak IE (hexane/*i*-PrOH = 90/10, flow rate 1.0 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 10.64 min,  $t_R$  (major) = 11.43 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  8.52 (s, 1H), 7.57 – 7.47 (m, 2H), 7.34 – 7.25 (m, 2H), 7.14 – 7.04 (m, 1H), 4.26 – 4.07 (m, 4H), 2.88 (ddd, *J* = 22.0, 10.6, 3.9 Hz, 1H), 2.12 – 1.78 (m, 2H), 1.55 – 1.28 (m, 10H), 0.90 (t, *J* = 7.1 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  165.9, 138.0, 129.1, 124.4, 119.9, 63.2 (d, *J* = 6.8 Hz), 63.0 (d, *J* = 6.7 Hz), 47.4 (d, *J* = 128.4 Hz), 30.6 (d, *J* = 14.0 Hz), 27.1 (d, *J* = 4.8 Hz), 22.5, 16.6 (d, *J* = 2.4 Hz), 16.5 (d, *J* = 2.6 Hz), 13.9.

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 25.98.

**HRMS** (ESI) m/z calcd. for C<sub>16</sub>H<sub>27</sub>NO<sub>4</sub>P [M + H]<sup>+</sup> 328.1672, found 328.1673.

(1-((3-(methylsulfonyl)phenyl)amino)-1-oxo-2-phenylbutan-2-

## Diethyl

yl)phosphonate (52)

According to the **general procedure D**, substrate **E46** (70.37 mg, 0.20 mmol) and diethyl phosphonate **P1** (27.6 mg, 0.20 mmol) were employed to yield the product **52** as a white solid (35.4 mg, 39% yield, 40% e.e.).

**m.p.** 145–148 °C

**HPLC** analysis: Chiralpak IG (hexane/*i*-PrOH = 70/30, flow rate 1.0 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 16.80 min,  $t_R$  (major) = 23.37 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  9.37 (s, 1H), 8.16 (t, J = 2.0 Hz, 1H), 7.87 – 7.80 (m, 1H), 7.71 – 7.64 (m, 1H), 7.52 (t, J = 8.0 Hz, 1H), 7.49 – 7.43 (m, 2H), 7.37 (t, J = 7.6 Hz, 2H), 7.34 – 7.28 (m, 1H), 4.16 – 3.95 (m, 4H), 3.06 (s, 3H), 2.59 – 2.33 (m, 2H), 1.26 (dt, J = 8.4, 7.1 Hz, 6H), 0.98 (t, J = 7.4 Hz, 3H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  168.2, 141.5, 139.1, 134.9 (d, *J* = 5.8 Hz), 130.2, 129.5 (d, *J* = 6.6 Hz), 128.4 (d, *J* = 1.7 Hz), 127.8 (d, *J* = 2.3 Hz), 124.8, 122.9, 118.6, 64.1 (d, *J* = 7.6 Hz), 63.8 (d, *J* = 7.5 Hz), 59.3 (d, *J* = 130.1 Hz), 44.4, 27.0 (d, *J* = 4.0 Hz), 16.5 (d, *J* = 2.7 Hz), 16.4 (d, *J* = 2.9 Hz), 9.7 (d, *J* = 8.8 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 26.00.

**HRMS** (ESI) m/z calcd. for C<sub>21</sub>H<sub>29</sub>NO<sub>6</sub>PS [M + H]<sup>+</sup> 454.1448, found 454.1437.

Procedure for synthetic applications (53–58)

The synthesis of 53, 54



Diethyl (*R*)-(5-phenylpent-1-yn-3-yl)phosphonate (53)



To a solution of **33** (43.7 mg, 0.10 mmol, 1.0 equiv., 97% e.e.) in THF (1.0 mL) was added acetic acid (0.24 mmol, 1.2 equiv.) under an argon atmosphere. Then TBAF (0.22 mL, 0.22 mmol, 1.1 equiv, 1 M in THF) were added into the solution dropwise at 0 °C, and the mixture was stirred at room temperature. After completion of the reaction (monitored by TLC), the reaction mixture was poured into water (10 mL) and extracted with  $CH_2Cl_2$  (3 × 10 mL). The combined organic layer was dried over MgSO<sub>4</sub>, filtered, and concentrated under reduced pressure to give the residue, which was purified by column chromatography on silica gel to afford the product **53** as a colorless oil (19.6 mg, 70% yield, 95% e.e.).

**HPLC** analysis: Chiralpak AS (hexane/*i*-PrOH = 95/5, flow rate 1.0 mL/min,  $\lambda$  = 214 nm), t<sub>R</sub> (minor) = 9.16 min, t<sub>R</sub> (major) = 11.16 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.32 – 7.26 (m, 2H), 7.25 – 7.17 (m, 3H), 4.26 – 4.10 (m, 4H), 3.07 – 2.94 (m, 1H), 2.84 – 2.69 (m, 2H), 2.29 (dd, *J* = 6.5, 2.7 Hz, 1H), 2.17 – 1.97 (m, 2H), 1.36 – 1.30 (m, 6H).

<sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>)  $\delta$  140.6, 128.6, 128.5, 126.2, 78.7 (d, *J* = 12.4 Hz), 72.6 (d, *J* = 10.0 Hz), 63.3 (d, *J* = 7.0 Hz), 62.9 (d, *J* = 6.9 Hz), 33.4 (d, *J* = 14.0 Hz), 30.7 (d, *J* = 4.1 Hz), 29.7 (d, *J* = 145.4 Hz), 16.4 (d, *J* = 5.8 Hz).

<sup>31</sup>**P** NMR (162 MHz, CDCl<sub>3</sub>) δ 23.99.

**HRMS** (ESI) m/z calcd. for  $C_{15}H_{21}NaO_3P [M + Na]^+ 303.1121$ , found 303.1113.

#### Diethyl (S)-(1-phenylpentan-3-yl)phosphonate (54)



To a mixture of Pd/C (12.0 mg, 10% w/w Pd on carbon) in THF (1.0 mL) was added **53** (28.0 mg, 0.10 mmol, 1.0 equiv., 95% e.e.) under an argon atmosphere. Then the reaction flask was evacuated and refilled with hydrogen through a balloon. The resulting reaction mixture was stirred under the hydrogen atmosphere at room temperature for 10 min. After completion, the reaction mixture was filtered with EtOAc. The filtrate was concentrated under reduced pressure and the residue was purified by column chromatography on silica gel to yield **54** as a colorless oil (26.9 mg, 95% yield, 95% e.e.).

**HPLC** analysis: Chiral INA (hexane/*i*-PrOH = 99.5/0.5, flow rate 1.0 mL/min,  $\lambda$  = 214 nm), t<sub>R</sub> (minor) = 46.19 min, t<sub>R</sub> (major) = 49.00 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 7.32 – 7.25 (m, 2H), 7.24 – 7.14 (m, 3H), 4.21 – 4.01 (m, 4H), 2.83 – 2.64 (m, 2H), 2.08 – 1.96 (m, 1H), 1.85 – 1.74 (m, 2H), 1.72 – 1.63 (m, 2H), 1.35 – 1.27 (m, 6H), 1.02 (t, *J* = 7.3 Hz, 3H).

<sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>)  $\delta$  141.8, 128.42, 128.37, 125.9, 61.4 (d, *J* = 7.2 Hz), 61.3 (d, *J* = 7.1 Hz), 36.7 (d, *J* = 138.0 Hz), 33.6 (d, *J* = 9.3 Hz), 29.5 (d, *J* = 3.4 Hz), 21.1 (d, *J* = 3.7 Hz), 16.5 (d, *J* = 5.9 Hz), 11.9 (d, *J* = 9.2 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 34.38.

**HRMS** (ESI) m/z calcd. for  $C_{15}H_{26}O_{3}P [M + H]^+ 285.1614$ , found 285.1613.

#### The synthesis of 55



According to the literature reported procedure<sup>8-9</sup> with slightly modification. AlCl<sub>3</sub> (160 mg, 1.20 mmol, 12.0 equiv.) was added to a suspension of LiAlH<sub>4</sub> (15.2 mg, 0.40 mmol, 4 equiv.) in THF (1 mL) in four portions at -78 °C. The mixture was 0.5 h at 0 °C. Then a solution of BH<sub>3</sub>•THF (0.20 mmol, equiv.) in THF was added. The mixture was slowly added to a solution of diethyl (*R*)-(1-phenylpropyl)phosphonate **2** (25.6 mg, 0.10 mmol, 1.0 equiv.) in THF (1 mL) dropwise by syringe under an argon atmosphere. The mixture was stirred at 0 °C for an additional 15 min. Upon completion (monitored by TLC), another batch of BH<sub>3</sub>•THF solution (0.20 mmol, 2 equiv.) was added and the mixture was stirred at 0 °C for an additional 15 min.

The mixture obtained above was quenched slowly with aqueous solution of KOH (30%, 1 mL) under an argon atmosphere. Then tetrabutylammonium iodide (TBAI, 7.39 mg, 20 mmol%) and 1,4-diiodobutane (62.0 mg, 0.20 mmol, 2.0 equiv.) were sequentially added into the mixture and the reaction mixture was stirred at room temperature for 6 hours. Upon completion, the solution was diluted with EtOAc, washed with water, brine, dried over Na<sub>2</sub>SO<sub>4</sub> and filtered. The filtrate was concentrated under reduced pressure to give the residue, which was purified by column chromatography on silica gel (petroleum ether/EtOAc = 10/1) to afford the desired phosphine borane **55** as a colorless oil (9.7 mg, 44% in two steps, 92% e.e.).

**HPLC** analysis: Chiralpak IE (hexane/*i*-PrOH = 98/2, flow rate 0.5 mL/min,  $\lambda$  = 214 nm),  $t_R$  (minor) = 20.31 min,  $t_R$  (major) = 21.42 min.

<sup>1</sup>**H** NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.39 – 7.16 (m, 5H), 2.74 (td, *J* = 12.2, 4.1 Hz, 1H), 2.16 – 1.90 (m, 2H), 1.87 – 1.69 (m, 4H), 1.68 – 1.44 (m, 4H), 0.87 (t, *J* = 7.3 Hz, 3H), 1.06 – 0.18 (m, 3H).

<sup>13</sup>**C NMR** (100 MHz, CDCl<sub>3</sub>)  $\delta$  137.2 (d, J = 4.5 Hz), 129.0 (d, J = 4.4 Hz), 128.8 (d, J = 1.9 Hz), 127.4 (d, J = 2.4 Hz), 45.0 (d, J = 24.8 Hz), 26.9 (d, J = 18.0 Hz), 25.0 (d, J = 34.5 Hz), 23.8 (d, J = 3.9 Hz), 22.5 (d, J = 34.6 Hz), 13.2 (d, J = 12.1 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 40.54 – 38.71 (m).

<sup>11</sup>**B** NMR (128 MHz, CDCl<sub>3</sub>)  $\delta$  -39.13 (d, J = 55.3 Hz).

**HRMS** (ESI) m/z calcd. for C<sub>13</sub>H<sub>20</sub>P [M – BH<sub>3</sub>+H]<sup>+</sup> 207.1297, found 207.1296.

#### The synthesis of α-aryl-substituted fosmidomycin 58



Dibenzyl (R)-(3-bromo-1-(3,4-dichlorophenyl)propyl)phosphonate (56)



An oven-dried resealable Schlenk tube equipped with a magnetic stir bar was charged with CuI (28.6 mg, 0.15 mmol, 15 mol%), L\*14 (150 mg, 0.18 mmol, 18 mol%), and Cs<sub>2</sub>CO<sub>3</sub> (651.6 mg, 2.00 mmol, 2.0 equiv.). The tube was evacuated and backfilled with argon three times. Then THF (10 mL) was added by syringe under an argon atmosphere. Finally, 1,2-dichloro-4-(1,3-dibromopropyl)benzene E47 (520.3 mg, 1.50 mmol, 1.5 equiv.) and H-phosphonate P6 (262.2 mg, 1.00 mmol, 1.0 equiv.) were sequentially added into the mixture and the reaction mixture was stirred at -15 °C for 5 d. Upon completion, the precipitate was filtered off and washed with EtOAc. The filtrate was evaporated and the residue was purified by column chromatography on silica gel (petroleum ether/EtOAc = 4/1) to afford the desired product 56 as a white solid (346 mg, 66%, 93% e.e.).

**m.p.** 41–45 °C

**HPLC** analysis: Chiralpak IA (hexane/*i*-PrOH = 90/10, flow rate 1.0 mL/min,  $\lambda$  = 230 nm),  $t_R$  (minor) = 20.92 min,  $t_R$  (major) = 22.92 min.

<sup>1</sup>**H NMR** (400 MHz, CDCl<sub>3</sub>) δ 7.40 – 7.27 (m, 10H), 7.18 – 7.12 (m, 2H), 7.11 – 7.05 (m, 1H), 5.11 – 4.90 (m, 2H), 4.82 (d, *J* = 8.6 Hz, 2H), 3.44 – 3.25 (m, 2H), 3.04 – 2.94 (m, 1H), 2.57 – 2.29 (m, 2H).

<sup>13</sup>**C** NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  136.0 (d, J = 5.5 Hz), 135.9 (d, J = 5.7 Hz), 134.7 (d, J = 6.9 Hz), 132.9 (d, J = 2.7 Hz), 132.0 (d, J = 3.7 Hz), 131.3 (d, J = 7.1 Hz), 130.7 (d, J = 2.6 Hz), 128.9 – 128.6 (m), 128.3, 128.1, 68.4 (d, J = 7.1 Hz), 68.0 (d, J = 7.1 Hz), 42.2 (d, J = 140.2 Hz), 32.4 (d, J = 1.9 Hz), 31.0 (d, J = 17.8 Hz).

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 27.49.

**HRMS** (ESI) m/z calcd. for C<sub>23</sub>H<sub>23</sub>BrCl<sub>2</sub>O<sub>3</sub>P [M + H]<sup>+</sup> 526.9940, found 526.9932.

Dibenzyl (R)-(3-(N-(benzyloxy)formamido)-1-(3,4-dichlorophenyl)propyl)phosp honate (57)



An oven-dried resealable Schlenk tube equipped with a magnetic stir bar was charged with Na<sub>2</sub>CO<sub>3</sub> (21.2 mg, 0.20 mmol, 1.0 equiv.). The tube was evacuated and backfilled with argon three times. Then anhydrous DMF (1 mL) and *O*-benzylhydroxylamine (49.4 mg, 0.40 mmol, 2.0 equiv.) were sequentially added under argon. The mixture was stirred at room temperature for 5 min. Finally, **56** (105.6 mg, 0.20 mmol, 1.0 equiv.) was added into the mixture and the mixture was stirred at 50 °C for 30 h. Upon completion (monitored by TLC), the mixture was allowed to cool down to room temperature and then diluted with 10 mL water. EtOAc was added to extract the product from the aqueous layer (3 mL ×3). The combined organic layer was washed by brine, dried over Na<sub>2</sub>SO<sub>4</sub>, and filtered. The filtrate was evaporated under reduced pressure to give the residue, which was purified by column chromatography on silica gel (petroleum ether/EtOAc = 2/1) to afford the desired product as a white solid (48.7 mg, 43%, **m.p.** 52–56 °C).

According to the literature reported procedure<sup>10</sup> with slightly modification. To a solution of carbonyl diimidazole (64.8 mg, 0.40 mmol) in THF (1.5 mL) was added formic acid (18.4 mg, 0.40 mmol) at 0 °C and the reaction mixture was stirred at that temperature for 30 min. Then, a solution of the product obtained above (42 mg, 0.074 mmol) in THF (1.5 mL) was added and the reaction was stirred at 10 °C overnight. The solvent was removed under reduced pressure, and the residue was purified by column chromatography on silica gel (petroleum ether/EtOAc = 1/2) to afford the desired product **57** as a sticky solid (38.5 mg, 87%, 92% e.e.).

**HPLC** analysis: Chiralpak IB (hexane/*i*-PrOH = 70/30, flow rate 1.0 mL/min,  $\lambda$  = 254 nm),  $t_R$  (minor) = 9.50 min,  $t_R$  (major) = 10.62 min.

<sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) 8.12 (s, 1H), 7.47 – 6.91 (m, 18H), 5.14 – 4.57 (m, 6H), 3.57 – 3.07 (m, 2H), 3.07 – 2.90 (m, 1H), 2.53 – 2.31 (m, 1H), 2.18 – 2.02 (m, 1H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 163.1, 135.9, 135.2, 134.1, 132.7, 131.8, 131.2, 130.6,

129.5, 129.3, 128.8, 128.73, 128.65, 128.6, 128.3, 128.1, 78.1, 68.4 (d, *J* = 7.0 Hz), 68.0 (d, *J* = 7.3 Hz), 42.2, 40.9, 27.1.

<sup>31</sup>**P NMR** (162 MHz, CDCl<sub>3</sub>) δ 27.43.

## (R)-(1-(3,4-Dichlorophenyl)-3-(N-hydroxyformamido)propyl)phosphonic acid (58)



To mixture of Pd/C (10.0 mg, 10% w/t Pd on carbon) in acetic acid (5.0 mL) was added 57 (59.8 mg, 0.10 mmol, 1.0 equiv.). Then, the reaction flask was evacuated and refilled with hydrogen through a balloon. The resulting reaction mixture was stirred under the hydrogen atmosphere at room temperature for 10 h. After completion, the reaction mixture was filtered and rinsed with water. The filtrate was concentrated under reduced pressure and the residue was redissolved in 10 mL water. The solution was filtered and washed with water (10 mL  $\times$  2), the filtrate was concentrated under reduced pressure to afford the desired product **58** (30.8 mg, 94% yield).

<sup>1</sup>**H NMR** (400 MHz, D<sub>2</sub>O)  $\delta$  8.17 and 7.50 (s ×2, 1H), 7.65 – 7.42 (m, 2H), 7.20 (d, *J* = 8.4 Hz, 1H), 3.57 – 3.34 (m, 2H), 2.93 (ddd, *J* = 22.4, 12.3, 3.4 Hz, 1H), 2.50 – 2.32 (m, 1H), 2.27 – 2.09 (m, 1H).

<sup>13</sup>C NMR (100 MHz, D<sub>2</sub>O) δ 163.8, 138.6 (d, *J* = 7.1 Hz), 132.0 (d, *J* = 2.8 Hz), 130.8 (d, *J* = 5.8 Hz), 130.7 (d, *J* = 2.3 Hz), 130.2 (d, *J* = 3.6 Hz), 129.0 (d, *J* = 5.9 Hz), 49.1, 42.8 (d, *J* = 129.6 Hz), 26.5.

<sup>31</sup>**P NMR** (162 MHz, D<sub>2</sub>O) δ 21.40, 21.03.

**HRMS** (ESI) m/z calcd. for C<sub>10</sub>H<sub>13</sub>Cl<sub>2</sub>NO<sub>5</sub>P [M + H]<sup>+</sup> 327.9903, found 327.9905.

## Mechanistic studies

# 1. Radical trap experiment with TEMPO



An oven-dried resealable Schlenk tube equipped with a magnetic stir bar was charged with CuI (5.7 mg, 0.03 mmol, 15 mol%), L\*14 (30 mg, 0.036 mmol, 18 mol%), Cs<sub>2</sub>CO<sub>3</sub> (130.3 mg, 0.40 mmol, 2.0 equiv.), and TEMPO (62.5 mg, 0.40 mmol, 2.0 equiv.). The tube was evacuated and backfilled with argon three times. Then THF (2.0 mL) was added by syringe under an argon atmosphere. Finally, E5 (0.30 mmol, 1.5 equiv.) and H-phosphonate P1 (0.20 mmol, 1.0 equiv.) were sequentially added into the mixture and the reaction mixture was stirred at -15 °C for 5 d. Upon completion, the precipitate was filtered off and washed with EtOAc. The filtrate was evaporated to afford the residue, which was purified by column chromatography on silica gel(petroleum ether/ethyl acetate = 20/1) to afford product 59<sup>4</sup>.

#### 2. The stereochemistry of alkyl halide and product during the reaction.

$$\begin{array}{c|c} & Br & & O \\ & & & \\ Ph & & \\ & & \\ (^{\pm})\_E5 & P1 \end{array} \xrightarrow{\begin{subarray}{c} & O \\ & & \\$$

An oven-dried resealable Schlenk tube equipped with a magnetic stir bar was charged with CuI (1.4 mg, 0.0075 mmol, 15 mol%), L\*14 (7.5 mg, 0.09 mmol, 18 mol%), and Cs<sub>2</sub>CO<sub>3</sub> (32.6 mg, 0.10 mmol, 2.0 equiv.). The tube was evacuated and backfilled with argon three times. Then THF (0.5 mL) was added by syringe under argon. Finally, E5 (20.6 mg, 0.075 mmol, 1.5 equiv.) and H-phosphonate P1 (6.9 mg, 0.05 mmol, 1.0 equiv.) were sequentially added into the mixture and the reaction mixture was stirred at -15 °C for appropriate time. Upon completion, the precipitate was filtered off and washed with EtOAc. The filtrate was evaporated and the residue was analyzed by <sup>1</sup>H NMR spectroscopy using CH<sub>2</sub>Br<sub>2</sub> as an internal standard. The product was then separated by preparative TLC. The e.e. values of 8 and recovered E5 were determined by HPLC analysis.



## NMR spectra























\_\_\_28.441

65



150 130 110 90 70 50 30 10 -10 -30 -50 -70 -90 -110 -130 -150 -170 -190 -210 -230 -25t f1 (ppm)









f1 (ppm)


28.102 <28.092





10 0 -10 -20 -30 -40 -50 -50 -50 -50 -50 -50 -50 -50 -50 -10 -120 -120 -130 -140 -150 -150 -150 -150 -150 -200 -210 f1 (ppm)







-140 120 100 80 60 40 20 6 -20 -40 -20 -40 -10 -10 -120 -120 -140 -160 -180 -220 -240 fi (ppm)





20 10 6 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210 -22 f1 (ppm)







- 140 ' 120 ' 160 ' 80 ' 60 ' 40 ' 20 ' 6 ' -20 ' -40 ' -80 ' -100 ' -120 ' -140 ' -150 ' -150 ' -200 ' -220 ' -240 f1 (ppm)







-140 120 100 80 60 40 20 6 -20 -20 -20 -40 -100 -120 -140 -150 -180 -20 -20 -220 -240 fl (ppm)







0.5

0.0 -0



140 140 110 90 70 50 30 10 10 -10 -30 -50 -90 -110 -130 -150 -170 -190 -210 -230 -25t





28.398













150 150 110 90 70 50 30 10 -10 -30 -50 -70 -90 -110 -130 -150 -170 -190 -210 -220 -225( f1 (ppm)







- 140 ' 120 ' 160 ' 80 ' 60 ' 40 ' 20 ' 6 ' -20 ' -40 ' -80 ' -100 ' -120 ' -140 ' -150 ' -150 ' -200 ' -220 ' -240 f1 (ppm)











150 150 110 90 70 50 30 10 -10 -30 -50 -70 -90 -110 -130 -150 -170 -190 -210 -220 -225( f1 (ppm)







-140 120 100 80 60 40 20 0 -20 -20 -20 -40 -120 -120 -120 -140 -160 -180 -200 -220 -240 fl (ppm)







150 ' 150 ' 110 ' 90 ' 70 ' 50 ' 30 ' 10 ' -10 ' -30 ' -50 ' -50 ' -10 ' -10 ' -150 ' -150 ' -150 ' -150 ' -150 ' -210 ' -230 ' -25( f1 (ppm)









150 1 150 1 110 1 90 1 70 1 50 1 30 1 10 1 -10 1 -30 1 -50 1 -70 1 -90 1 -110 1 -130 1 -150 1 -170 1 -190 1 -210 1 -230 1 -250 1 10 (ppm)




140 120 100 80 60 40 20 0 -20 -40 -60 -100 -120 -140 -160 -180 -200 -220 -240 f1 (ppm)





- 140 - 120 - 100 - 80 - 60 - 40 - 20 - 0 - -20 - -40 - -60 - -80 - -100 - -120 - -140 - -160 - -180 - -200 - -220 - -240 - f1 (ppm)





150 130 110 90 70 50 30 10 -10 -50 -50 -70 -90 -110 -130 -150 -170 -190 -210 -230 -25( f1 (ppm)





140 140 - 140 - 250 - 30 - 10 - 10 - 30 - 30 - 250 - 10 - 230 - 250 - 250 - 10 - 150 - 150 - 150 - 150 - 210 - 230 - 250











- 140 - 120 - 160 - 80 - 60 - 40 - 20 - 6 - 20 - 40 - 60 - -80 - -100 - -120 - -140 - 160 - -180 - -200 - -220 - -240 - f1 (ppm)





140 120 100 80 60 40 20 0 -20 -40 -60 -100 -120 -140 -160 -180 -200 -220 -240 f1 (ppm)





150 130 110 90 70 50 30 10 -10 -30 -50 -70 -90 -110 -130 -150 -170 -90 -210 -230 -25i f1 (ppm)





100 90 f1 (ppm)

80 70

50

190 180 170

160 150

140 130

120

110

30 20

50

40

60

\_

10 0







- 140 - 120 - 100 - 50 - 60 - 40 - 20 - 0 - -20 - -40 - -50 - -100 - -120 - -140 - -160 - -180 - -200 - -220 - -240 - f1 (ppm)













- 140 - 120 - 100 - 80 - 60 - 40 - 20 - 0 - -20 - -40 - -60 - -80 - -100 - -120 - -140 - -160 - -180 - -200 - -220 - -240 - f1 (ppm)









150 150 16 10 90 70 50 30 10 -10 -30 -50 -90 -110 -130 -150 -170 -190 -210 -230 -25( f1 (ppm)











- 140 - 120 - 100 - 80 - 60 - 40 - 20 - 0 - -20 - -40 - -60 - -80 - -100 - -120 - -140 - -160 - -180 - -200 - -220 - -240 - f1 (ppm)





140 120 100 - 80 60 40 20 6 - 20 - 40 - 20 - 10 - 120 - 140 - 180 - 180 - 20 - 220 - 240 f1 (ppa)





140'''120'''140''''80''''60''''40''''20''''6''''-20'''-40'''-60'''-60'''-120'''-120'''-140'''-160'''-180''-200''-220'''-240' f1 (ppm)





f1 (ppm)









\_\_\_23.989









150 150 110 90 70 50 30 10 -10 -30 -60 -70 -90 -110 -130 -150 -170 -190 -210 -230 -25( f1 (ppm)
















ومتعارضه فبالنباد فيترف أوفأ وأربان التناقية والمتعاولة والمتعارفة والمتعارفة

-140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -120 -140 -160 -180 -200 -220 -240 f1 (ppm)

# **HPLC** spectra



The HPLC spectra of 1 using Chiralcel AD-H  $_{mV}$ 



	<b>UL 11</b>		roum	
Peak#	Ret.	Time	Area	Area%
1	8.1	63	2540426	41.673
2	9.5	39	3555674	58.327



Peak Table

Detector A Ch1 215nm				
Peak#	Ret. Time	Area	Area%	
1	7.950	348761	3.938	
2	9.475	8508196	96.062	



PDA Ch1 210nm					
Peak#	Ret. Time	Area	Area%		
1	15.212	1795992	50.035		
2	17.641	1793463	49.965		



PDA Ch1 210nm					
Peak#	Ret. Time	Area	Area%		
1	15.202	550886	3. 593		
2	17.595	14779174	96.407		



PDA Ch2 214nm					
Peak#	Ret. Time	Area	Area%		
1	13.628	36798632	49.402		
2	18.003	37690200	50. 598		



PDA Ch2 214nm				
Peak#	Ret. T	ime	Area	Area%
1	13.70	90	4892145	4.871
2	17.9	76	95545397	95.129

mAU



PDA Ch	1 254nm		
Peak#	Ret. Time	Area	Area%
1	12.713	1414330	50.454
2	15, 890	1388871	49, 546



PDA Ch1 254nm						
Peak#	Ret. 1	Time	Area	Area%		
1	12.7	45	78972	3.187		
2	15.9	01	2399130	96.813		



Р	eaĸ	Tabi	e

]	PDA Ch1 254nm					
[	Peak#	Ret.	Time	Area	Area%	
	1	10.	791	650523	50.179	
ĺ	2	15.	256	645890	49.821	





Detector A Ch1 214nm					
Peak#	Ret. Time	Area	Area%		
1	10.590	1332510	49.892		
2	11.506	1338271	50.108		

mV



Peak Table

Detector A Ch1 214nm					
Peak#	Ret.	Time	Area	Area%	
1	10.	299	55232621	95.017	
2	11.	327	2896804	4.983	



Detector A Ch2 254nm					
Peak#	Ret.	Time	Area	Area%	
1	19.	755	16058402	49.958	
2	21.	457	16085273	50.042	





Detector A Ch2 254nm					
Peak#	Ret.	Time	Area	Area%	
1	19.	639	55463846	95.267	
2	21.	471	2755641	4.733	







mV



#### Peak Table

Detector A Ch1 214nm					
Peak#	Ret. Time	Area	Area%		
1	10.510	25049716	49.743		
2	11.435	25308948	50.257		



Detect	or A Chl 2	214nm	
Peak#	Ret. Time	Area	Area%
1	10. 505	41738364	96.019
2	11.539	1730670	3.981







Detector A Ch2 254nm					
Peak#	Ret. Time	Area	Area%		
1	12.036	23263424	50.078		
2	13.859	23190751	49.922		



Detector A Ch2 254nm					
Peak#	Ret. Time	Area	Area%		
1	11.884	1747706	4.395		
2	13.487	38020478	95.605		





Detector A Ch2 254nm					
Peak#	Ret. Time	Area	Area%		
1	17.631	2240972	50.058		
2	21.158	2235781	49.942		



Peak Table

Detector A Ch2 254nm				
Peak#	Ret.	Time	Area	Area%
1	17.	654	1555925	4.282
2	20.	660	34782066	95.718



Detector A Ch2 254nm					
Peak#	Ret.	Time	Area	Area%	
1	13.	999	3443564	49.524	
2	15.	319	3509691	50.476	

mV 500-Detector A Ch2 254nm 400-EtO\_OEt P=0 300-Br. 200-17 100-14.959 0-15. 0 2.5 7.5 17.5 5.0 10.0 12.5 20.0 min 0.0

Detect	or A Ch2	254nm	
Peak#	Ret. Tim	e Area	Area%
1	14.959	525111	4. 420
2	15.991	1135636	6 95.580







PDA Ch2 214nm					
Peak#	Ret. Time	Area	Area%		
1	26.819	5650889	49.922		
2	28.568	5668561	50.078		





F	DA Ch	2 21	4nm		
[]	Peak#	Ret.	Time	Area	Area%
	1	26.	763	5823759	6.442
	2	28.	199	84577582	93. 558





Detect	or A Ch1 2	214nm	
Peak#	Ret. Time	Area	Area%
1	12.687	13941251	49.921
2	13.690	13985172	50.079



Detector A Ch1 214nm					
Peak#	Ret. Time	Area	Area%		
1	12.300	64831779	93.199		
2	13.689	4730755	6.801		











mV



Detector A Ch1 214nm						
Peak#	Ret.	Time	Area	Area%		
1	36.	367	40693125	49.527		
2	39.	715	41471200	50.473		



Detector A Ch1 214nm						
Peak#	Ret. Tir	ne Area	Area%			
1	36.878	3372374	7.489			
2	39.731	41657574	92.511			

mAU







Peak Table

PDA Ch2 220nm						
Peak#	Ret. Time	Area	Area%			
1	8.512	1406529	49.670			
2	9.021	1425204	50.330			



Peak Table

PDA Ch2 220nm						
Peak#	Ret. Time	Area	Area%			
1	8.489	68664	1.287			
2	8.990	5266018	98.713			



PDA Ch2 220nm					
Peak#	Ret. Time	Area	Area%		
1	8.643	82323	2.883		
2	9.167	2772670	97.117		

mAU





PDA Ch2 214nm						
Peak#	Ret. Time	Area	Area%			
1	11.885	5303182	49.487			
2	12.790	5413185	50.513			





PDA Ch2 214nm						
Peak#	Ret. Time	Area	Area%			
1	12.119	214434	1.575			
2	12.967	13401744	98. 425			

mAU



PDA Ch2 214nm					
Peak#	Ret.	Time	Area	Area%	
1	10. 9	962	16200405	49.578	
2	12.2	273	16476303	50. 422	



PDA Ch2 214nm					
Peak#	Ret. Time	Area	Area%		
1	10.772	199329	1.581		
2	12.984	12411268	98.419		



PDA Ch2 214nm						
Peak#	Ret. Time	Area	Area%			
1	7.227	4967372	49.815			
2	8.089	5004338	50.185			



Peak Table

PDA Ch2 214nm						
Peak#	Ret. Time	Area	Area%			
1	7.197	194982	2.588			
2	8.062	7338653	97.412			

mAU



PDA Ch2 214nm						
Peak#	Ret. Time	Area	Area%			
1	12.793	9067507	49.373			
2	14.450	9297659	50.627			



Peak Table

PDA Ch2 214nm						
Peak#	Ret. Time	Area	Area%			
1	12.882	716462	2.573			
2	14.413	27132229	97.427			

mAU



PDA Ch1 254nm						
	Peak#	Ret. I	ìme	Area	Area%	
	1	15. 5	47	483934	49.304	
	2	16.8	18	497603	50.696	



Peak Table

PDA Ch1 254nm						
Peak#	Ret. Time	Area	Area%			
1	15.745	42980	2.144			
2	16.716	1961640	97.856			





PDA Ch2 214nm						
Peak#	Ret. Time	Area	Area%			
1	10.163	13985291	49.634			
2	11.732	14191570	50.366			





P	PDA Ch2 214nm						
]	Peak#	Ret.	Time	Area	Area%		
Γ	1	9.867		460376	2.640		
	2	11.	209	16981100	97.360		



PDA Ch2 214nm						
Peak#	Ret. Time	Area	Area%			
1	9.991	3217479	50.604			
2	11.950	3140710	49.396			


Peak Table

PDA Ch2 214nm						
Peak#	Ret. Time	Area	Area%			
1	10.192	215657	3.870			
2	12.033	5356429	96.130			

mAU



PDA Ch3 214nm						
Peak#	Ret. Time	Area	Area%			
1	18.880	3490160	49.681			
2	20, 396	3534924	50.319			





PDA Ch2 214nm						
Peak#	Ret. Time	Area	Area%			
1	18.745	33780	1.423			
2	20.295	2339471	98.577			





PDA Ch	2 220nm		
Peak#	Ret. Time	Area	Area%
1	10.249	14545543	49.719
2	14.359	14709791	50.281



PDA Ch2 220nm						
Peak#	Ret. Time	Area	Area%			
1	10.480	346328	3.207			
2	14.507	10452080	96.793			



PDA Ch1 254nm							
Peak#	Ret. Time	Area	Area%				
1	28.437	8961197	49.748				
2	34.597	9051859	50.252				



PDA Ch1 254nm						
Peak#	Ret. Time	Area	Area%			
1	29.809	137111	1.745			
2	34.997	7720396	98.255			

mAU



PDA Ch2 214nm					
	Peak#	Ret.	Time	Area	Area%
	1	19.	027	42464173	49.656
	2	21.	121	43053294	50.344



PDA Ch2 214nm					
Peak#	Ret. Time	Area	Area%		
1	19.809	901991	4.042		
2	21.817	21414015	95.958		





PDA Ch	2 214nm		
Peak#	Ret. Time	Area	Area%
1	22.607	13470320	50.201
2	24.802	13362661	49.799



Peak Table

PDA Ch2 214nm						
Peak#	Ret. 1	Time	Area	Area%		
1	22.9	85	1068759	2.581		
2	24.5	54	40341325	97.419		

mAU



Peak Table

PDA Ch2 214nm						
Peak#	Ret. Time	Area	Area%			
1	6.434	4004864	50.711			
2	8.844	3892621	49.289			



Peak Table

PDA Ch2 214nm					
Peak#	Ret. Time	Area	Area%		
1	6.581	349090	2.299		
2	9.016	14835502	97.701		



PDA Ch2 214nm					
Peak#	Ret. Time	Area	Area%		
1	12.063	17710441	49.977		
2	14.294	17727005	50.023		



Peak Table

PDA Ch2 214nm						
Peak#	Ret. Time	Area	Area%			
1	12.182	1947327	5.118			
2	14.480	36100439	94.882			

mAU



<u>PDA</u> Ch	2 214nm		
Peak#	Ret. Time	Area	Area%
1	9.006	7972470	49.246
2	12.042	8216602	50.754



PDA Ch2 214nm					
Peak#	Ret. Time	Area	Area%		
1	8.981	2001011	12.736		
2	12.268	13710741	87.264		





PDA Ch2 220nm				
Peak#	Ret. Time	Area	Area%	
1	8.871	1472318	49.097	
2	9,920	1526505	50, 903	



Peak Table

PDA Ch2 220nm					
Peak#	Ret. Time	Area	Area%		
1	8.988	546111	7.849		
2	10.221	6411833	92.151		



Peak Table

Detector A Ch2 254nm					
	Peak#	Ret.	Time	Area	Area%
	1	12.	377	9289378	49.740
	2	13.	456	9386356	50.260



Peak Table

Detector A Ch2 254nm					
Peak#	Ret.	Time	Area	Area%	
1	12.	344	8982532	16.633	
2	13.	260	45021018	83.367	



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Detector A Ch2 254nm					
Peak#	Ret. Time	Area	Area%		
1	10.686	3560894	50.412		
2	11.604	3502679	49.588		



Detector A Ch2 254nm					
Peak#	Ret. Time	Area	Area%		
1	10.636	7315976	14.288		
2	11.425	43889078	85.712		







Peak Table

PDA Ch2 214nm					
Peak#	Ret. Time	Area	Area%		
1	9.067	4566974	49.843		
2	11.184	4595734	50.157		



PDA Ch2 214nm

Peak#	Ret. Time	Area	Area%
1	9.158	339188	2.724
2	11.160	12110554	97.276





PDA Ch2 214nm				
Peak#	Ret. '	Time	Area	Area%
1	45.3	69	14736990	49.556
2	49.5	526	15001067	50.444





PDA Ch2 214nm						
Peak#	Ret. Time	Area	Area%			
1	46.194	434193	2.515			
2	49.003	16828343	97.485			



Detector A Ch1 214nm						
Peak#	Ret.	Time	Area	Area%		
1	19.	716	23434998	49.939		
2	21.	033	23491908	50.061		



Detector A Ch1 214nm					
Peak#	Ret. Time	Area	Area%		
1	20.311	2713853	4.094		
2	21.418	63579101	95.906		





PDA Ch1 254nm					
Peak#	Ret. Time	Area	Area%		
1	9.471	1384237	50.823		
2	10.803	1339391	49.177		



PDA Chi Z54nm					
Peak#	Ret. Time	Area	Area%		
1	9.495	138152	3.851		
2	10.616	3449619	96.149		

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