Supporting Information

Visible-light-induced oxidative coupling of vinylarenes with diselenides leading to α-aryl and α-alkyl selenomethylketones

Gong-Qing Liu*, Wei Yi, Peng-Fei Wang, Ji Liu, Meng Ma, Da-Yun Hao, Liang Ming and Yong Ling*

School of Pharmacy, Nantong University, 19 Qixiu Road, Nantong 226001, People's Republic of China

E-mail: gqliu@ntu.edu.cn; Lyyy111@sina.com

Content

1. General information ........................................................................................................................................S1
2. Light sources, glassware and setup for irradiations .......................................................................................S1
3. Green chemistry metrics ...............................................................................................................................S2
4. Mechanistic studies ........................................................................................................................................S4
   1) Light-dark cycle experiments ........................................................................................................................S4
   2) 18O labeling experiments ...........................................................................................................................S5
   3) TEMPO trapping experiments ....................................................................................................................S6
   4) UV-Vis absorption and emission spectra ....................................................................................................S7
   5) Experiments for mechanistic studies ..........................................................................................................S9
   6) Tentative reaction pathway .........................................................................................................................S9
5. General procedure for the synthesis of α-selenomethyl ketones .................................................................S10
6. Characterization data .....................................................................................................................................S10
7. References .....................................................................................................................................................S26
8. Copies of NMR spectra .................................................................................................................................S27
1. General information

Solvents and reagents
Reagents were used as received without further purification unless otherwise indicated. Solvents were dried and distilled prior to use. Petroleum ether used had a boiling point range of 60–90°C. Diselenides were prepared from the corresponding iodides with elemental selenium according to Braga’s report.¹

Chromatography
Chromatographic purification of products was performed as flash column chromatography on silica gel (200–300 meshes). Thin-layer chromatography (TLC) was carried out on silica plates (TLC Silica GF254). Visualization of the compounds was accomplished by projecting UV-light onto the developed plates.

NMR spectra
NMR spectra were recorded on a Bruker Avance-III HD (¹H NMR: 400 MHz, ¹³C NMR: 100 MHz) spectrometer. Chemical shifts are referenced to residual solvent signals (CDCl₃: 7.26 ppm and 77.16 ppm for ¹H NMR and ¹³C NMR respectively) and reported in parts per million (ppm) relative to tetramethylsilane (TMS). Spin–spin coupling constants (J) were given in Hz. Multiplicities of NMR signals are abbreviated as follows: br = broad, s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet.

Mass spectra
High resolution mass spectrometry (HRMS) analyses were carried out on a Thermo Fisher Q Exactive Mass Spectrometer.

Melting points
Melting points were determined on glass slides using a WRX-4 digital display microscopic melting point apparatus and were presented uncorrected.

Optical rotations
Optical rotations were determined using a WZZ-2S polarimeter with a sodium lamp (D-line, λ = 589 nm). [α]_D_espValues are reported at a certain temperature (temp) and all concentrations are given in g/100 mL.

2. Light sources, glassware and setup for irradiations

Light sources
All photoreactions were performed using a 24 W energy-saving household CFL bulb (cool daylight, 6500 K) by Opple. Please refer to the website (https://detail.tmall.com/item.htm?id=36296589905&spm=a1z09.2.0.0.289f2e8dLvLPS&u=nkj7u3r52c7) for more detail. The emission spectrum of such a lamp was recorded and is presented in Figure S5a.
**Glassware**
All reactions were performed in 10 mL vials made of Synthware. For detailed technical information, the reader is directed to the homepage of Synthware: http://www.xinweier.com/.

**Setup for irradiations**
All photoreactions were performed with the 24W energy-saving CFL-bulb introduced above. The reaction vessel was placed approximately 1 cm from the light source. A typical reaction setup is shown in Figure S1. A fan placed next to the photoreactor was used to keep the temperature constant during the reaction time (about 24 °C).

![Figure S1: Setup for irradiations with a 24 W CFL](image)

**3. Green chemistry metrics**

(1) **E-Factor analysis**
According to its original definition (*Green Chem. 2007, 9, 1273*), the Sheldon E factor value (mass of waste/mass of product) takes into account only the mass of waste generated in a process, and its calculation is performed by simply dividing the sum of the molecular weight of all substances produced by molecular weight of the desired products, with reference to the stoichiometric equation. Thus, the amount of silica gel and the mass of solvent used for work-up and chromatography are usually not included in the calculation. We have followed this trend in our own calculation.

**This work:**

\[
\text{Total amount of reactants: } 20.8 + 31.2 + 3.2 = 55.2 \text{mg} \\
\text{Amount of final product: } 48.4 \text{ mg} \\
\text{Amount of waste: } 55.2 - 48.4 = 6.8 \text{mg} \\
\text{E-Factor = Amount of waste/Amount of product = } 6.8 / 48.4 = 0.14
\]

**Pace’s work (Org. Lett. 2018 2685-2688):**

\[
\text{Total amount of reactants: } 83 + 212 + 40 = 335 \text{mg} \\
\text{Amount of final product: } 121 \text{ mg} \\
\text{E-Factor = Amount of waste/Amount of product = } 335 / 121 = 2.77
\]
Total amount of reactants: 83+212+40 = 335 mg
Amount of final product: 121 mg
Amount of waste: 335 – 121 = 214 mg
E-Factor = Amount of waste/Amount of product = 214 / 121 = 1.77

(2) Atom economy (AE):

This work:

\[
\text{AE} = \frac{[\text{MW of product}]}{\sum (\text{MW of stoichiometric reactants})} \times 100% \\
= \frac{(275)}{(104+1/2\times312+1/2\times32)} \times 100% \\
= 100%
\]

Pace’s work (Org. Lett. 2018 2685-2688):

\[
\text{AE} = \frac{[\text{MW of product}]}{\sum (\text{MW of stoichiometric reactants})} \times 100% \\
= \frac{(275)}{(181+1.3\times326+1.25\times64)} \times 100% \\
= 40%
\]

(3) Process mass intensity (PMI):

This work:

\[
\text{PMI} = \frac{\sum \text{(mass of stoichiometric reactants)}}{\text{mass of product}} \\
= \frac{(20.8+31.2+3.2)}{48.4} \\
= 1.14
\]

Pace’s work (Org. Lett. 2018 2685-2688):

\[
\text{PMI} = \frac{\sum \text{(mass of stoichiometric reactants)}}{\text{mass of product}} \\
= \frac{(83+212+40)}{121} \\
= 2.77
\]

(4) Reaction mass efficiency (RME):

This work:
RME = \[\frac{\text{mass of product}}{\sum \text{mass of stoichiometric reactants}}\] × 100%
= \[\frac{48.4}{(20.8+31.2+3.2)}\] × 100%
= 88%

Pace’s work (*Org. Lett.* 2018 2685-2688):

RME = \[\frac{\text{mass of product}}{\sum \text{mass of stoichiometric reactants}}\] × 100%
= \[\frac{121}{(83+212+40)}\] × 100%
= 36%

### 4. Mechanistic studies

1) Light-dark cycle experiments.
The reaction was performed under air atmosphere using 0.2 mmol of styrene, 0.1 mmol Ph$_2$Se$_2$ and 2.0 mL ethyl acetate. The reaction was alternatingly irradiated with a 24 W fluorescent household bulb and kept in the dark for 2 hour intervals. Aliquots were taken at the start and after each interval, the solvent was removed with a rotary evaporator and diluted with CDCl$_3$ and subjected to $^1$H NMR measurements. The reaction yield was determined by $^1$H NMR spectroscopy using 1,3,5-trimethoxybenzene as internal standard. The changes in yield observed during the dark phases fall within the margin of error and are thus negligible (Scheme S1).

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Time (h)</th>
<th>NMR Yield of 3a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>5</td>
<td>37</td>
</tr>
<tr>
<td>Dark</td>
<td>7</td>
<td>35</td>
</tr>
<tr>
<td>Light</td>
<td>12</td>
<td>71</td>
</tr>
<tr>
<td>Dark</td>
<td>14</td>
<td>72</td>
</tr>
<tr>
<td>Light</td>
<td>19</td>
<td>84</td>
</tr>
<tr>
<td>Dark</td>
<td>21</td>
<td>85</td>
</tr>
<tr>
<td>Light</td>
<td>26</td>
<td>93</td>
</tr>
</tbody>
</table>
2) $^{18}$O labeling experiments

\[
\text{Ph} \quad + \quad \text{PhSe}_2 \quad \xrightarrow{\text{CFL, EA, r.t.}} \quad \text{Ph} - \text{SePh}^{18}\text{O}
\]

The styrene 1a (0.2 mmol) and diphenyl diselenide 2a (0.1 mmol) in ethyl acetate (2 mL) were added to a Schlenk tube equipped with a magnetic stir bar. A balloon filled with $^{18}$O$_2$/N$_2$ was connected to the Schlenk tube through the side arm and purged one time. The mixture was stirred for 20 h under visible-light irradiation. Then, the solvent of reaction mixture was evaporated under reduced pressure to an oily residue, which was separated on a silica gel column with petroleum ether and ethyl acetate as eluent to afford the desired products. Isolated yield: 78%.

The detection of HRMS for 3a': C$_{14}$H$_{12}^{18}$OSe (M+H)$^+$: calculated 279.01686, found 279.01608 suggests that the carbonyl oxygen atom of the α-selenoketone originates from dioxygen. The HRMS spectra of 3a' was pasted here for information (Figure S2).

Figure S2 HRMS spectra of 3a'
3) TEMPO trapping experiments

To a 10 mL vessel with magnetic stir bar were added 0.2 mmol of styrene, 0.1 mmol \( \text{Ph}_2\text{Se}_2 \), 0.3 mmol of TEMPO and 2 mL of EtOAc. The reaction mixture was stirred in air and irradiated with a 24W household compact fluorescent lamp from a distance of 1 cm. After 20 hours, the reaction mixture was diluted with dichloromethane and the crude material was examined by ESI-MS. A trace amount of TEMPO adducts \( 7' \) was detected on ESI-MS implying the generation of selenium radical \( \text{A} \) during the reaction (Figure S3). Additionally, 42% isolated yield of \( 7 \) was obtained, suggesting that the benzyl radical species \( \text{B} \) is the intermediate of this reaction. The NMR spectra of \( 7 \) was pasted here for information (Figure S4).

![Figure S3 HRMS spectra of 7']

**2,2,6,6-Tetramethyl-1-(1-phenyl-2-(phenylessalanyloxy)ethoxy)piperidine** (7). The crude product was purified by silica gel chromatography (petroleum ether/ethyl acetate = 90/1) to give compound \( 7 \) (35 mg, 42%) as an oil. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta/\text{ppm}=7.31 – 7.14 \) (m, 7H), 7.13 – 7.07 (m, 3H), 4.80 (dd, \( J = 9.8, 4.1 \) Hz, 1H), 3.57 (dd, \( J = 11.5, 4.1 \) Hz, 1H), 3.22 (dd, \( J = 11.5, 9.8 \) Hz, 1H), 1.62 – 1.03 (m, 9H), 1.1 (s, 3H), 0.93 (s, 3H), 0.57 (s, 3H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \( \delta/\text{ppm}= 140.8, 131.6, 129.7, 127.8, 126.9, 126.7, 126.6, 125.6, 84.8, 58.9, 39.3, 33.1, 19.3, 16.1. \) Spectral data are in good agreement with literature values.\(^2\)
Figure S4 NMR spectra of 7

4) UV-Vis absorption and emission spectra
UV-visible absorption spectra were collected on a UV1800PC (Jinghua, China). The samples were prepared 1.80×10⁻⁴ mol/L in EtOAc. The spectra obtained were listed as follow (Figure S5a). Figure S5a reveals that absorption maxima of diphenyl diselenide 2a are located around 330 nm, with corresponding absorption band
extending from visible light region, while styrene 1a has no absorb to UV-visible light. Additionally, UV-visible absorption spectra of 1:1 molar ratio double-component samples in EtOAc were also collected and no obvious changes absorption was observed. This UV-Vis indicates that the involvement of any photoactive intermediates (EDA complexes) seems very unlikely.

All reactions were performed using 24 W energy-saving household CFL bulb by Opple (see section II of this SI), the emission spectrum of which is shown in Figure S5b. The emission spectrum of blue and green lamp was also collected and is provided below (Figure S5c and S5d). These results corroborate the use of commercial white and blue lamp as suitable for the preparation of selenomethyl ketones, while the emission spectrum of green light source and the absorption spectrum of the substrate do not exactly match.

![Figure S5](image1.png)

Figure S5. a) UV-visible absorption spectra of samples; b) Emission spectra of CFL lamps used; c) Emission spectra of blue lamps used; d) Emission spectra of green lamps used.
5) Experiments for mechanistic studies

Experiment for mechanistic studies

Scheme S2. Control experiments

6) Tentative reaction pathway

The formation of ketones 3 is described in detail as above. Analogue of intermediates C, S1, D and E are involved as previously reported literatures (see ref. 36).
5. General procedure for the synthesis of α-selenomethyl ketones

The reaction was carried out in an open air system. To a 10 mL vessel with magnetic stir bar were added 0.2 mmol vinylarene, 0.1 mmol diselenide and 2 mL of EtOAc. The reaction mixture was stirred and irradiated with a 24W household compact fluorescent lamp from a distance of 1 cm. The reaction was monitored by TLC. After completion of reaction (ca. 20 h), the solvent was removed with a rotary evaporator. The pure product was obtained by flash chromatography on silica gel using petroleum ether and ethyl acetate as the eluent.

6. Characterization data

1-Phenyl-2-(phenylselenyl)ethan-1-one (3a). Compound 3a was prepared according to the general procedure and isolated as an oil (48 mg, 88% yield) after flash chromatography (petroleum ether/ethyl acetate = 30/1).

$^1$H NMR (400 MHz, CDCl$_3$) δ/ppm= 7.83 – 7.78 (m, 2H), 7.51 – 7.43 (m, 3H), 7.36 (t, $J = 7.7$ Hz, 2H), 7.23 – 7.16 (m, 3H), 4.10 (s, 2H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ/ppm= 193.9, 134.4, 133.0, 132.2, 128.2, 128.0, 127.7, 127.6, 127.1, 31.7.

Spectral data are in good agreement with literature values.$^3$

2-(Phenylselenyl)-1-(p-tolyl)ethan-1-one (3b). Compound 3b was prepared according to the general procedure and isolated as a yellow solid (52 mg, 90% yield) after flash chromatography (petroleum ether/ethyl acetate = 30/1).

mp = 34-35 °C.

$^1$H NMR (400 MHz, CDCl$_3$) δ/ppm= 7.71 (d, $J = 8.2$ Hz, 2H), 7.50 – 7.43 (m, 2H), 7.24 – 7.13 (m, 5H), 4.08 (s, 2H), 2.33 (s, 3H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ/ppm= 193.7, 143.2, 132.9, 131.9, 128.3, 128.2, 128.1, 127.8, 127.0, 31.7, 20.7.

Spectral data are in good agreement with literature values.$^3$

1-(4-Methoxyphenyl)-2-(phenylselenyl)ethan-1-one (3c). Compound 3c was prepared according to the general procedure and isolated as a white solid (53 mg, 86% yield) after flash chromatography (petroleum ether/ethyl acetate = 15/1).

mp = 63-65 °C.

$^1$H NMR (400 MHz, CDCl$_3$) δ/ppm= 7.79 (d, $J = 8.9$ Hz, 2H), 7.49 – 7.45 (m, 2H),
7.23 – 7.18 (m, 3H), 6.83 (d, J = 8.9 Hz, 2H), 4.07 (s, 2H), 3.79 (s, 3H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ/ppm= 192.7, 162.6, 132.8, 130.0, 128.2, 128.2, 127.4, 126.9, 112.7, 54.5, 31.6.

Spectral data are in good agreement with literature values.$^3$

1-(4-(tert-Butyl)phenyl)-2-(phenylselanyl)ethan-1-one (3d). Compound 3d was prepared according to the general procedure and isolated as an oil (61 mg, 92% yield) after flash chromatography (petroleum ether/ethyl acetate = 20/1).

$^1$H NMR (400 MHz, CDCl$_3$) δ/ppm= 7.75 (d, J = 8.5 Hz, 2H), 7.49 – 7.44 (m, 2H), 7.23 – 7.17 (m, 3H), 4.09 (s, 2H), 1.26 (s, 9H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ/ppm= 192.7, 162.6, 132.8, 130.0, 128.2, 128.2, 127.4, 126.9, 112.7, 54.5, 31.6.

HRMS (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{18}$H$_{21}$OSe 333.0752; Found 333.0758.

1-(4-Fluorophenyl)-2-(phenylselanyl)ethan-1-one (3e). Compound 3e was prepared according to the general procedure and isolated as an oil (49 mg, 83% yield) after flash chromatography (petroleum ether/ethyl acetate = 30/1).

$^1$H NMR (400 MHz, CDCl$_3$) δ/ppm= 7.84 – 7.77 (m, 2H), 7.47 – 7.42 (m, 2H), 7.24 – 7.16 (m, 3H), 7.04 – 6.97 (m, 2H), 4.06 (s, 2H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ/ppm= 192.4, 164.76 (d, J = 255.3 Hz), 133.1, 130.8 (d, J = 3.1 Hz), 130.4 (d, J = 9.4 Hz), 128.3, 127.8, 127.2, 114.7 (d, J = 21.9 Hz), 31.5.

$^{19}$F NMR (376 MHz, CDCl$_3$) δ/ppm= -104.7.

HRMS (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{14}$H$_{12}$FOSe 295.0032; Found 295.0032.

1-(4-Chlorophenyl)-2-(phenylselanyl)ethan-1-one (3f). Compound 3f was prepared according to the general procedure and isolated as an oil (49 mg, 79% yield) after flash chromatography (petroleum ether/ethyl acetate = 60/1).

$^1$H NMR (400 MHz, CDCl$_3$) δ/ppm= 7.72 (d, J = 8.6 Hz, 2H), 7.46 – 7.41 (m, 2H), 7.75 (d, J = 8.6 Hz, 2H), 7.24 – 7.17 (m, 3H), 4.05 (s, 2H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ/ppm=192.7, 138.7, 133.1, 132.7, 129.1, 128.3, 127.9, 127.7, 127.3, 31.4.

Spectral data are in good agreement with literature values.$^3$
1-(4-Bromophenyl)-2-(phenylselanyl)ethan-1-one (3g). Compound 3g was prepared according to the general procedure and isolated as yellow solid (57 mg, 80% yield) after flash chromatography (petroleum ether/ethyl acetate = 60/1).

mp = 41-42 °C.

$^1$H NMR (400 MHz, CDCl$_3$) δ/ppm= 7.72 (d, $J = 8.6$ Hz, 2H), 7.48 (d, $J = 8.6$ Hz, 2H), 7.46 – 7.41 (m, 2H), 7.24 – 7.17 (m, 3H), 4.04 (s, 2H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ/ppm= 192.9, 133.1, 133.1, 130.9, 129.2, 128.3, 127.6, 127.4, 127.3, 31.4.

Spectral data are in good agreement with literature values.$^4$

4-(2-(Phenylselanyl)acetyl)phenyl acetate (3h). Compound 3h was prepared according to the general procedure and isolated as a white solid (57 mg, 85% yield) after flash chromatography (petroleum ether/ethyl acetate = 10/1).

mp = 56-59 °C.

$^1$H NMR (400 MHz, CDCl$_3$) δ/ppm= 7.83 (d, $J = 8.8$ Hz, 2H), 7.48 – 7.41 (m, 2H), 7.23 – 7.16 (m, 3H), 7.08 (d, $J = 8.8$ Hz, 2H), 4.07 (s, 2H), 2.24 (s, 3H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ/ppm= 192.7, 167.8, 153.4, 133.0, 131.9, 129.3, 128.3, 127.8, 127.2, 120.8, 31.5, 20.1.

HRMS (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{16}$H$_{15}$O$_3$Se 335.0181; Found 335.0180.

4-(2-(Phenylselanyl)acetyl)phenyl benzoate (3i). Compound 3i was prepared according to the general procedure and isolated as a yellow solid (60 mg, 76% yield) after flash chromatography (petroleum ether/ethyl acetate = 10/1).

mp = 86-88 °C.

$^1$H NMR (400 MHz, CDCl$_3$) δ/ppm= 8.13 (d, $J = 7.8$ Hz, 2H), 7.88 (d, $J = 8.6$ Hz, 2H), 7.58 (dd, $J = 10.6$, 4.3 Hz, 1H), 7.50 – 7.42 (m, 4H), 7.24 – 7.18 (m, 5H), 4.10 (s, 2H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ/ppm= 192.7, 163.5, 153.7, 133.1, 132.9, 132.0, 129.4, 129.2, 128.3, 128.0, 127.9, 127.7, 127.2, 120.9, 31.6.

HRMS (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{21}$H$_{17}$O$_3$Se 397.0337; Found 397.0345.
1-[[1,1'-Biphenyl]-4-yl]-2-(phenylselanyl)ethan-1-one (3j). Compound 3j was prepared according to the general procedure and isolated as a white solid (64 mg, 91% yield) after flash chromatography (petroleum ether/ethyl acetate = 30/1).

**mp** = 105-107 °C.

**^1H NMR** (400 MHz, CDCl₃) δ/ppm= 7.88 – 7.83 (m, 2H), 7.58 – 7.51 (m, 4H), 7.49 – 7.44 (m, 2H), 7.42 – 7.35 (m, 2H), 7.34 – 7.29 (m, 1H), 7.22 – 7.15 (m, 3H), 4.11 (s, 2H).

**^13C NMR** (100 MHz, CDCl₃) δ/ppm= 193.5, 144.9, 138.7, 133.1, 133.0, 132.9, 128.3, 128.2, 127.9, 127.3, 127.1, 126.23, 126.20, 31.7.

Spectral data are in good agreement with literature values.⁵

1-(4-(Chloromethyl)phenyl)-2-(phenylselanyl)ethan-1-one (3k). Compound 3k was prepared according to the general procedure and isolated as an oil (54 mg, 83% yield) after flash chromatography (petroleum ether/ethyl acetate = 20/1).

**^1H NMR** (400 MHz, CDCl₃) δ/ppm= 7.79 (d, J = 8.4 Hz, 2H), 7.45 (dd, J = 7.7, 1.8 Hz, 2H), 7.37 (d, J = 8.4 Hz, 2H), 7.27 – 7.13 (m, 3H), 4.53 (s, 2H), 4.08 (s, 2H).

**^13C NMR** (100 MHz, CDCl₃) δ/ppm= 193.5, 144.9, 138.7, 133.1, 133.0, 128.3, 128.2, 127.9, 127.3, 127.1, 126.23, 126.20, 31.7.

**HRMS** (ESI/Q-TOF) m/z: [M+H]^+ Calcd for C₁₅H₁₄ClOSe 324.9893; Found 324.9891.

4-(2-(Phenylselanyl)acetyl)benzoic acid (3l). Compound 3l was prepared according to the general procedure and isolated as a yellow solid (52 mg, 81% yield) after flash chromatography (petroleum ether/ethyl acetate = 1/1).

**mp** = 126-128 °C.

**^1H NMR** (400 MHz, CDCl₃) δ/ppm= 8.09 (d, J = 8.5 Hz, 2H), 7.87 (d, J = 8.5 Hz, 2H), 7.44 (dd, J = 8.0, 1.6 Hz, 2H), 7.30 – 7.09 (m, 3H), 4.11(s, 2H).

**^13C NMR** (100 MHz, CDCl₃) δ/ppm= 193.1, 141.5, 134.2, 133.1, 128.3, 128.1, 127.8, 127.7, 127.2, 44.2, 31.6.

**HRMS** (ESI/Q-TOF) m/z: [M+H]^+ Calcd for C₁₅H₁₂O₃Se 321.00244; Found 321.00192

4-(2-(Phenylselanyl)acetyl)benzaldehyde (3m). Compound 3m was prepared according to the general procedure and isolated as a yellow solid (45 mg, 74% yield) after flash chromatography (petroleum ether/ethyl acetate = 10/1).

**mp** = 47-49 °C.
**1H NMR** (400 MHz, CDCl$_3$) δ/ppm = 10.01 (s, 1H), 7.91 (d, $J = 8.5$ Hz, 2H), 7.85 (d, $J = 8.6$ Hz, 2H), 7.43 (dd, $J = 8.0$, 1.6 Hz, 2H), 7.27 – 7.13 (m, 3H), 4.09 (s, 2H).

**13C NMR** (100 MHz, CDCl$_3$) δ/ppm = 193.0, 190.5, 138.8, 137.9, 133.2, 128.7, 128.3, 128.2, 127.4, 127.3, 31.6.

**HRMS** (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{15}$H$_{12}$O$_2$Se 305.00753; Found 306.00696.

---

2-(Phenylselanyl)-1-(4-(trifluoromethyl)phenyl)ethan-1-one (3n). Compound 3n was prepared according to the general procedure and isolated as a yellow solid (59 mg, 86% yield) after flash chromatography (petroleum ether/ethyl acetate = 30/1).

mp = 44-46° C.

**1H NMR** (400 MHz, CDCl$_3$) δ/ppm = 7.86 (d, $J = 8.2$ Hz, 2H), 7.58 (d, $J = 8.2$ Hz, 2H), 7.46 – 7.33 (m, 2H), 7.27 – 7.10 (m, 3H), 4.06 (s, 2H).

**13C NMR** (100 MHz, CDCl$_3$) δ/ppm = 192.7, 137.1, 133.3, 128.3, 128.0, 127.4, 127.3, 124.6 (q, $J_{C-F} = 3.7$ Hz), 123.8, 121.1, 31.4.

**19F NMR** (376 MHz, CDCl$_3$) δ/ppm = -63.1.

**HRMS** (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{15}$H$_{11}$F$_3$OSe 345.00000; Found 344.99936.

---

1-(4-Nitrophenyl)-2-(phenylselanyl)ethan-1-one (3o). Compound 3o was prepared according to the general procedure and isolated as a red solid (53 mg, 83% yield) after flash chromatography (petroleum ether/ethyl acetate = 10/1).

mp = 72-74 °C.

**1H NMR** (400 MHz, CDCl$_3$) δ/ppm = 8.16 (d, $J = 8.7$ Hz, 2H), 7.90 (d, $J = 8.7$ Hz, 2H), 7.45 – 7.35 (m, 2H), 7.34 – 7.14 (m, 3H), 4.07 (s, 3H).

**13C NMR** (100 MHz, CDCl$_3$) δ/ppm = 191.9, 149.2, 139.0, 133.4, 128.6, 128.4, 127.6, 127.0, 122.7, 31.4.

Spectral data are in good agreement with literature values.$^3$

---

1-(2-Chlorophenyl)-2-(phenylselanyl)ethan-1-one (3p). Compound 3p was prepared according to the general procedure and isolated as an oil (43 mg, 70% yield) after flash chromatography (petroleum ether/ethyl acetate = 100/1).

**1H NMR** (400 MHz, CDCl$_3$) δ/ppm = 7.41 – 7.32 (m, 3H), 7.30 – 7.24 (m, 2H), 7.21 – 7.14 (m, 4H), 4.14 (s, 2H).

**13C NMR** (100 MHz, CDCl$_3$) δ/ppm = 197.3, 137.7, 133.7, 132.0, 131.1, 130.4, 130.3,
129.2, 128.6, 128.0, 126.8, 36.4. Spectral data are in good agreement with literature values.\(^5\)

1-(3-Bromophenyl)-2-(phenylselanyl)ethan-1-one (3q). Compound 3q was prepared according to the general procedure and isolated as a yellow solid (55 mg, 77% yield) after flash chromatography (petroleum ether/ethyl acetate = 50/1). mp = 36-37 °C.

\(^1\)H NMR (400 MHz, CDCl\(_3\)) δ/ppm= 7.88 (t, J = 1.8 Hz, 1H), 7.71 – 7.67 (m, 1H), 7.61 – 7.56 (m, 1H), 7.47 – 7.42 (m, 2H), 7.25 – 7.17 (m, 4H), 4.03 (s, 2H).

\(^13\)C NMR (100 MHz, CDCl\(_3\)) δ/ppm=192.4, 136.1, 135.0, 133.3, 130.7, 129.1, 128.3, 127.5, 127.4, 126.2, 121.9, 31.4.

HRMS (ESI/Q-TOF) m/z: [M+H]^+ Calcd for C\(_{14}\)H\(_{12}\)BrOSe 354.9231; Found 354.9234.

1-(2,4-Dimethylphenyl)-2-(phenylselanyl)ethan-1-one (3r). Compound 3r was prepared according to the general procedure and isolated as an oil (51 mg, 84% yield) after flash chromatography (petroleum ether/ethyl acetate = 90/1).

\(^1\)H NMR (400 MHz, CDCl\(_3\)) δ/ppm= 7.45 – 7.39 (m, 2H), 7.36 (d, J = 7.9 Hz, 1H), 7.23 – 7.09 (m, 3H), 6.96 (d, J = 1.7 Hz, 1H), 6.90 (dd, J = 7.9, 1.7 Hz, 1H), 4.05 (s, 2H), 2.34 (s, 3H), 2.25 (s, 3H).

\(^13\)C NMR (100 MHz, CDCl\(_3\)) δ/ppm=196.7, 141.2, 138.6, 132.5, 132.2, 131.9, 128.19, 128.12, 128.08, 126.7, 125.1, 34.5, 20.42, 20.36.

HRMS (ESI/Q-TOF) m/z: [M+H]^+ Calcd for C\(_{16}\)H\(_{16}\)OSe 305.04391; Found 305.04330.

1-(Perfluorophenyl)-2-(phenylselanyl)ethan-1-one (3s). Compound 3s was prepared according to the general procedure and isolated as an oil (46 mg, 63% yield) after flash chromatography (petroleum ether/ethyl acetate = 20/1).

\(^1\)H NMR (400 MHz, CDCl\(_3\)) δ/ppm= 7.52 – 7.47 (m, 2H), 7.41 – 7.23 (m, 3H), 3.99 (s, 2H).

\(^13\)C NMR (100 MHz, CDCl\(_3\)) δ/ppm= 144.7 (m), 143.0 (m), 142. (m), 140.5 (m), 137.7 (m), 135.1 (m), 133.2, 128.3, 127.7, 126.3, 36.8.

\(^{19}\)F NMR (376 MHz, CDCl\(_3\)) δ/ppm= -139.7, -149.2, -160.2.

HRMS (ESI/Q-TOF) m/z: [M+H]^+ Calcd for C\(_{14}\)H\(_{8}\)F\(_{5}\)OSe 366.9655; Found 366.9667.
2-(Phenylselanyl)-2,3-dihydro-1H-inden-1-one (3t). Compound 3t was prepared according to the general procedure and isolated as an oil (38 mg, 66% yield) after flash chromatography (petroleum ether/ethyl acetate = 50/1).

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$/ppm = 7.70 (d, $J = 7.7$ Hz, 1H), 7.54 – 7.48 (m, 3H), 7.31 – 7.24 (m, 2H), 7.20 – 7.15 (m, 3H), 4.14 (dd, $J = 7.6$, 2.7 Hz, 1H), 3.56 (dd, $J = 18.0$, 7.6 Hz, 1H), 3.09 (dd, $J = 18.0$, 2.6 Hz, 1H).

$^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$/ppm = 202.2, 151.2, 134.5, 134.3, 134.0, 128.0, 127.4, 126.7, 126.5, 125.2, 123.4, 42.3, 34.1.

Spectral data are in good agreement with literature values.$^6$

2-(Phenylselanyl)-3,4-dihydronaphthalen-1(2H)-one (3u). Compound 3u was prepared according to the general procedure and isolated as a yellow solid (42 mg, 70% yield) after flash chromatography (petroleum ether/ethyl acetate = 50/1).

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$/ppm = 7.99 (dd, $J = 7.8$, 1.1 Hz, 1H), 7.57 – 7.51 (m, 2H), 7.44 – 7.37 (m, 1H), 7.28 – 7.21 (m, 4H), 7.16 (d, $J = 7.7$ Hz, 1H), 4.19 (t, $J = 4.5$ Hz, 1H), 3.22 – 3.10 (m, 1H), 2.81 (dt, $J = 17.1$, 4.5 Hz, 1H), 2.50 – 2.39 (m, 1H), 2.34 – 2.24 (m, 1H).

$^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$/ppm = 192.7, 141.8, 134.4, 132.5, 130.5, 130.2, 128.1, 127.6, 127.3, 127.1, 126.7, 126.6, 125.9, 47.6, 28.3, 26.0.

Spectral data are in good agreement with literature values.$^7$

1-(Naphthalen-2-yl)-2-(phenylselanyl)ethan-1-one (3v). Compound 3v was prepared according to the general procedure and isolated as a yellow solid (54 mg, 83% yield) after flash chromatography (petroleum ether/ethyl acetate = 30/1).

mp = 66-68 °C.

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$/ppm = 8.20 (s, 1H), 7.89 (dd, $J = 8.6$, 1.8 Hz, 1H), 7.82 – 7.72 (m, 3H), 7.55 – 7.42 (m, 4H), 7.24 – 7.15 (m, 3H), 4.21 (s, 2H).

$^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$/ppm = 194.0, 134.6, 133.2, 131.7, 131.3, 129.5, 128.6, 128.2, 128.1, 127.6, 127.5, 127.2, 126.7, 125.7, 123.3, 31.8.

Spectral data are in good agreement with literature values.$^3$

2-(Phenylselanyl)-1-(pyridin-4-yl)ethan-1-one (3w). Compound 3w was prepared according to the general procedure and isolated as an oil (31 mg, 56% yield) after flash chromatography (petroleum ether/ethyl acetate = 3/1).
$^1$H NMR (400 MHz, CDCl$_3$) δ/ppm= 8.67 (d, $J = 6.2$ Hz, 2H), 7.53 (d, $J = 6.2$ Hz, 2H), 7.46 – 7.34 (m, 2H), 7.31 – 7.13 (m, 3H), 4.02 (s, 2H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ/ppm= 193.8, 150.8, 141.5, 134.4, 129.4, 128.6, 128.1, 121.6, 32.2.

HRMS (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for $C_{13}H_{12}NOSe$ 278.0079; Found 278.0081.

1-(4-Methylthiazol-5-yl)-2-(phenylselanyl)ethan-1-one (3x). Compound 3x was prepared according to the general procedure and isolated as a yellow solid (51 mg, 86% yield) after flash chromatography (petroleum ether/ethyl acetate = 5/1).

mp = 78-80 °C.

$^1$H NMR (400 MHz, CDCl$_3$) δ/ppm= 8.76 (s, 1H), 7.50 – 7.41 (m, 2H), 7.25 – 7.17 (m, 3H), 3.92 (s, 2H), 2.66 (s, 3H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ/ppm= 133.2, 130.5, 128.3, 128.2, 127.4, 127.2, 126.7, 35.7, 17.2.

HRMS (ESI /Q-TOF) m/z: [M+H]$^+$ Calcd for $C_{12}H_{12}NOSSe$ 297.9799; Found 297.9800.

2-(Phenylselanyl)-1-(thiophen-2-yl)ethan-1-one (3y). Compound 3y was prepared according to the general procedure and isolated as an oil (47 mg, 83% yield) after flash chromatography (petroleum ether/ethyl acetate = 15/1).

$^1$H NMR (400 MHz, CDCl$_3$) δ/ppm= 7.56 (dd, $J = 4.9$, 0.9 Hz, 1H), 7.51 – 7.47 (m, 2H), 7.47 – 7.44 (m, 1H), 7.23 – 7.18 (m, 3H), 7.01 – 6.97 (m, 1H), 3.99 (s, 2H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ/ppm= 187.3, 141.7, 133.2, 131.7, 131.1, 131.7, 128.2, 128.1, 127.2, 127.1, 32.1.

Spectral data are in good agreement with literature values.$^5$

1-Phenyl-2-(phenylselanyl)propan-1-one (3z). Compound 3z was prepared according to the general procedure and isolated as an oil (35 mg, 61% yield) after flash chromatography (petroleum ether/ethyl acetate = 30/1).

$^1$H NMR (400 MHz, CDCl$_3$) δ/ppm= 7.88 – 7.77 (m, 2H), 7.54 – 7.43 (m, 1H), 7.42 – 7.31 (m, 4H), 7.30 – 7.25 (m, 1H), 7.23 – 7.15 (m, 2H), 4.62 (q, $J = 6.8$ Hz, 1H), 1.57 (d, $J = 6.8$ Hz, 3H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ/ppm= 195.3, 135.6, 134.8, 131.8, 128.0, 127.9, 127.5, 127.4, 125.8, 38.7, 16.2.

Spectral data are in good agreement with literature values.$^8$
(8R,9S,13S,14S)-13-Methyl-3-(2-(phenylselanyl)acetyl)-6,7,8,9,11,12,13,14,15,16-decahydro-17H-cyclopenta[a]phenanthren-17-one (3aa). Compound 3aa was prepared according to the general procedure and isolated as an oil (69 mg, 77% yield) after flash chromatography (petroleum ether/ethyl acetate = 6/1).

$\left[\alpha\right]_{D}^{15} = +167.1$, $c=0.023$ g/100 mL, CHCl$_3$.

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$/ppm= 7.58 (d, $J = 8.2$ Hz, 1H), 7.52 (s, 1H), 7.49 – 7.45 (m, 2H), 7.28 (d, $J = 8.2$ Hz, 1H), 7.24 – 7.17 (m, 3H), 4.07 (s, 2H), 2.89 – 2.81 (m, 2H), 2.50 – 2.33 (m, 2H), 2.32 – 2.21 (m, 1H), 2.02 – 1.88 (m, 3H), 1.63 – 1.34 (m, 7H), 0.85 (s, 3H).

$^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$/ppm= 220.1, 193.9, 144.7, 136.0, 132.9, 132.0, 128.4, 128.3, 128.2, 127.0, 125.1, 124.6, 49.5, 46.9, 43.7, 36.8, 34.8, 31.7, 30.5, 28.3, 25.2, 24.5, 20.6, 12.8.

HRMS (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{26}$H$_{29}$O$_2$Se 453.1327; Found 453.1326.

7-(2-(Phenylselanyl)acetyl)-2H-chromen-2-one (3ab). Compound 3ab was prepared according to the general procedure and isolated as a yellow solid (59 mg, 86% yield) after flash chromatography (petroleum ether/ethyl acetate =4/1).

mp = 90-92 °C.

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$/ppm= 7.71 – 7.63 (m, 3H), 7.50 – 7.40 (m, 3H), 7.24 – 7.16 (m, 3H), 6.45 (d, $J = 9.6$ Hz, 1H), 4.08 (s, 2H).

$^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$/ppm= 220.2, 192.2, 159.0, 152.7, 141.4, 136.9, 133.2, 128.4, 127.5, 127.3, 127.1, 123.2, 121.2, 117.9, 116.1, 31.5.

HRMS (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{17}$H$_{13}$O$_3$Se 345.0024; Found 345.0026.

(1R,2S,5R)-2-isopropyl-5-methylcyclohexyl 4-(2-(phenylselanyl)acetyl)benzoate (3ac). Compound 3ac was prepared according to the general procedure and isolated as an oil (82 mg, 90% yield) after flash chromatography (petroleum ether/ethyl acetate = 45/1).

$\left[\alpha\right]_{D}^{15} = -30.2$, $c=0.046$ g/100 mL, CHCl$_3$.

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$/ppm= 8.00 (d, $J = 8.6$ Hz, 1H), 7.83 (d, $J = 8.6$ Hz, 1H), 7.47 – 7.39 (m, 2H), 7.24 – 7.16 (m, 3H), 4.88 (td, $J = 10.9, 4.4$ Hz, 1H), 4.08 (s, 2H), 2.09 – 2.01 (m, 1H), 1.91 – 1.81 (m, 1H), 1.70 – 1.62 (m, 2H), 1.54 – 1.43 (m, 2H), 1.19 (d, $J = 11.9$ Hz, 1H), 1.10 – 1.00 (m, 2H), 0.86 (d, $J = 3.7$ Hz, 3H), 0.85 (d, $J = 4.2$ Hz, 3H), 0.72 (d, $J = 7.0$ Hz, 3H).
**$^{13}$C NMR** (100 MHz, CDCl$_3$) $\delta$/ppm=193.2, 164.1, 137.5, 133.6, 133.1, 128.7, 128.3, 127.6, 127.5, 127.3, 74.5, 46.2, 39.9, 33.2, 31.7, 30.4, 25.5, 22.6, 21.0, 19.7, 15.5.

**HRMS** (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{25}$H$_{31}$O$_3$Se 459.1433; Found 459.1428.

4-(2-(Phenylselanyl)acetyl)phenyl

5-(2,5-dimethylphenoxy)-2,2-dimethylpentanoate (3ad). Compound 3ad was prepared according to the general procedure and isolated as an oil (89 mg, 85% yield) after flash chromatography (petroleum ether/ethyl acetate = 20/1).

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$/ppm= 7.84 – 7.76 (m, 2H), 7.48 – 7.40 (m, 2H), 7.22 – 7.15 (m, 3H), 7.04 – 6.98 (m, 2H), 6.92 (d, $J$ = 7.4 Hz, 2H), 6.59 (d, $J$ = 7.4 Hz, 1H), 6.54 (s, 1H), 4.06 (s, 2H), 3.90 (t, $J$ = 5.2 Hz, 2H), 2.22 (s, 3H), 2.09 (s, 3H), 1.80 (s, 4H), 1.30 (s, 6H).

$^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$/ppm=192.7, 174.7, 155.8, 153.9, 135.8, 135.5, 133.0, 131.8, 129.3, 129.3, 128.3, 127.9, 127.1, 122.5, 120.7, 119.8, 110.9, 66.6, 41.6, 36.1, 31.6, 24.2, 24.1, 20.4, 14.8.

**HRMS** (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{29}$H$_{33}$O$_3$Se 525.1539; Found 525.1542.

4-(2-(Phenylselanyl)acetyl)phenyl (S)-2-(6-methoxynaphthalen-2-yl)propanoate (3ae). Compound 3ae was prepared according to the general procedure and isolated as an oil (83 mg, 83% yield) after flash chromatography (petroleum ether/ethyl acetate = 10/1).

$[\alpha]_{D}^25$ = + 91.5, c=0.033 g/100 mL, CHCl$_3$.

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$/ppm= 7.76 (d, $J$ = 8.7 Hz, 2H), 7.71 – 7.64 (m, 3H), 7.45 – 7.38 (m, 3H), 7.21 – 7.15 (m, 3H), 7.11 – 7.04 (m, 2H), 7.00 – 6.94 (m, 2H), 4.07 – 4.00 (m, 3H), 3.84 (s, 3H), 1.62 (d, $J$ = 7.1 Hz, 3H).

$^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$/ppm=192.7, 171.5, 156.8, 153.6, 133.7, 133.0, 132.9, 131.9, 129.2, 128.3, 128.2, 127.9, 127.8, 127.1, 126.5, 125.2, 124.9, 120.6, 118.2, 104.6, 54.3, 44.6, 31.5, 17.4.

**HRMS** (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{29}$H$_{25}$O$_4$Se 505.0913; Found 505.0921.

((3aR,5R,5aS,8aS,8bR)-2,2,7,7-Tetramethyltetrahydro-5H-bis([1,3]dioxolo)[4,5-b:4',5'-d]pyran-5-yl)methyl 4-(2-(phenylselanyl)acetyl)benzoate (3af). Compound
Compound 3af was prepared according to the general procedure and isolated as an oil (86 mg, 77% yield) after flash chromatography (petroleum ether/ethyl acetate = 10/1).

\[ \alpha \] \[^{19}D \] = -41.0, c=0.13 g/100 mL, CHCl3.

\[^1^H\] NMR (400 MHz, CDCl3) \( \delta /ppm = 8.01 \) (d, \( J = 8.5 \) Hz, 2H), 7.82 (d, \( J = 8.5 \) Hz, 2H), 7.46 – 7.40 (m, 2H), 7.25 – 7.16 (m, 3H), 5.50 (d, \( J = 5.0 \) Hz, 1H), 4.59 (dd, \( J = 7.9, 2.5 \) Hz, 1H), 4.48 (dd, \( J = 11.6, 4.7 \) Hz, 1H), 4.39 (dd, \( J = 11.6, 7.7 \) Hz, 1H), 4.29 (dd, \( J = 5.0, 2.5 \) Hz, 1H), 4.26 (dd, \( J = 7.9, 1.8 \) Hz, 1H), 4.14 – 4.10 (m, 1H), 4.09 (s, 3H), 1.45 (s, 3H), 1.41 (s, 3H), 1.29 (s, 3H), 1.27 (s, 3H).

\[^{13}C\] NMR (100 MHz, CDCl3) \( \delta /ppm = 193.2, 164.5, 137.8, 133.2, 132.8, 128.9, 127.6, 127.5, 127.3, 108.8, 107.8, 95.3, 70.1, 69.7, 69.5, 65.1, 63.4, 31.6, 25.0, 25.0, 23.9, 23.5.

HRMS (ESI/Q-TOF) m/z: [M+H]^+ Calcd for \( C_{20}H_{31}O_8Se \) 563.1179; Found 563.1182.

(5R,5aR,8aR,9R)-8-Oxo-9-(3,4,5-trimethoxyphenyl)-5,5a,6,8,8a,9-hexahydrofuro[3′,4′:6,7]naphtho[2,3-d][1,3]dioxol-5-yl 4-(2-phenylselanyl)acetylebenzoate (3ag). Compound 3ag was prepared according to the general procedure and isolated as a white solid (91 mg, 64% yield) after flash chromatography (petroleum ether/ethyl acetate = 4/1).

\[ \alpha \] \[^{19}D \] = -38.1, c=0.10 g/100 mL, CHCl3.

mp = 84-86 °C.

\[^1^H\] NMR (400 MHz, CDCl3) \( \delta /ppm = 8.02 \) (d, \( J = 8.4 \) Hz, 2H), 7.87 (d, \( J = 8.4 \) Hz, 2H), 7.47 – 7.41 (m, 2H), 7.27 – 7.17 (m, 3H), 6.78 (s, 1H), 6.53 (s, 1H), 5.93 (d, \( J = 8.3 \) Hz, 2H), 4.59 (d, \( J = 3.4 \) Hz, 1H), 4.38 (dd, \( J = 9.1, 6.2 \) Hz, 1H), 4.26 (t, \( J = 9.7 \) Hz, 1H), 4.12 – 4.05 (m, 2H), 3.72 (d, \( J = 11.0 \) Hz, 9H), 1.97 (s, 1H), 1.22 – 1.16 (m, 4H).

\[^{13}C\] NMR (100 MHz, CDCl3) \( \delta /ppm = 192.9, 172.6, 164.9, 151.7, 147.3, 146.8, 138.4, 136.2, 133.7, 133.2, 131.9, 131.6, 128.9, 128.4, 127.8, 127.4, 127.0, 108.9, 107.1, 106.0, 100.7, 73.8, 70.4, 59.7, 55.1, 44.6, 42.7, 37.8, 31.6, 28.7.

HRMS (ESI/Q-TOF) m/z: [M+H]^+ Calcd for \( C_{37}H_{33}O_8Se \) 717.1233; Found 717.1237.

2-(Methylselanyl)-1-phenylethano-1-one (4a). Compound 4a was prepared according to the general procedure and isolated as an oil (30 mg, 70% yield) after flash chromatography (petroleum ether/ethyl acetate = 50/1).

\[^1^H\] NMR (400 MHz, CDCl3) \( \delta /ppm = 7.93 – 7.87 \) (m, 2H), 7.50 (t, \( J = 7.4 \) Hz, 1H), 7.40 (t, \( J = 7.6 \) Hz, 2H), 3.69 (s, 2H), 2.02 (s, 3H).

\[^{13}C\] NMR (100 MHz, CDCl3) \( \delta /ppm = 194.5, 135.1, 133.2, 128.7, 128.7, 27.9, 5.9.

S20
Spectral data are in good agreement with literature values.²

2-(Ethylselanyl)-1-phenylethanol-1-one (4b). Compound 4b was prepared according to the general procedure and isolated as an oil (30 mg, 66% yield) after flash chromatography (petroleum ether/ethyl acetate = 70/1).

¹H NMR (400 MHz, CDCl₃) δ/ppm=8.03 – 7.69 (m, 2H), 7.55 – 7.44 (m, 1H), 7.39 (dd, J = 8.3, 7.0 Hz, 2H), 3.72 (s, 2H), 2.60 (q, J = 7.5 Hz, 2H), 1.34 (t, J = 7.4 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ/ppm=194.0, 134.2, 132.1, 127.7, 127.6, 25.2, 18.2, 14.1.

Spectral data are in good agreement with literature values.⁴

2-(Benzylselanyl)-1-phenylethanol-1-one (4c). Compound 4c was prepared according to the general procedure and isolated as a yellow solid (36 mg, 63% yield) after flash chromatography (petroleum ether/ethyl acetate = 40/1).

mp = 82-84 °C.

¹H NMR (400 MHz, CDCl₃) δ/ppm= 7.89 – 7.82 (m, 2H), 7.53 – 7.47 (m, 1H), 7.42 – 7.36 (m, 2H), 7.31 – 7.27 (m, 2H), 7.26 – 7.21 (m, 2H), 7.18 – 7.15 (m, 1H), 3.80 (s, 2H), 3.64 (s, 2H).

¹³C NMR (100 MHz, CDCl₃) δ/ppm= 194.0, 137.2, 134.3, 132.2, 128.2, 127.7, 127.6, 127.5, 126.0, 27.6, 25.5.

Spectral data are in good agreement with literature values.⁹

2-(Cyclohexylselanyl)-1-phenylethanol-1-one (4d). Compound 4d was prepared according to the general procedure and isolated as an oil (32 mg, 57% yield) after flash chromatography (petroleum ether/ethyl acetate = 120/1).

¹H NMR (400 MHz, CDCl₃) δ/ppm=7.94 – 7.80 (m, 2H), 7.57 – 7.45 (m, 1H), 7.41 – 7.37 (m, 2H), 3.74 (s, 2H), 3.00 (tt, J = 10.6, 3.7 Hz, 1H), 2.06 – 1.88 (m, 2H), 1.68 – 1.63 (m, 2H), 1.48 – 1.37 (m, 2H), 1.36 – 1.21 (m, 4H).

¹³C NMR (100 MHz, CDCl₃) δ/ppm= 194.6, 134.3, 132.1, 127.7, 127.6, 39.8, 32.9, 28.7, 28.6, 25.7, 24.8, 24.7.

HRMS (ESI/Q-TOF) m/z: [M+H]⁺ Calcd for C₁₄H₁₈OSe 283.05956; Found 283.05908.

2-(Heptylselanyl)-1-phenylethanol-1-one (4e). Compound 4e was prepared according to the general procedure and isolated as an oil (36 mg, 60% yield) after flash chromatography (petroleum ether/ethyl acetate = 100/1).
H NMR (400 MHz, CDCl$_3$) δ/ppm=7.96 – 7.82 (m, 2H), 7.56 – 7.44 (m, 1H), 7.41 – 7.37 (m, 2H), 3.70 (s, 2H), 2.60 (t, $J = 7.5$ Hz, 2H), 1.71 – 1.48 (m, 3H), 1.33 – 1.13 (m, 7H), 0.80 (t, $J = 7.1$ Hz, 3H).

C NMR (100 MHz, CDCl$_3$) δ/ppm=194.0, 134.2, 132.1, 127.7, 127.6, 30.7, 28.8, 28.7, 27.7, 25.5, 24.8, 21.6, 13.1.

HRMS (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{15}$H$_{22}$OSe : 299.09086; Found : 299.09042.

2-((4-Methoxyphenyl)selanyl)-1-phenylethan-1-one (4f). Compound 4f was prepared according to the general procedure and isolated as an oil (40 mg, 65% yield) after flash chromatography (petroleum ether/ethyl acetate = 25/1).

H NMR (400 MHz, CDCl$_3$) δ/ppm=7.79 (d, $J = 8.7$ Hz, 2H), 7.56 – 7.41 (m, 1H), 7.38 – 7.28 (m, 4H), 6.73 (d, $J = 8.7$ Hz, 2H), 3.99 (s, 2H), 3.72 (s, 3H).

C NMR (100 MHz, CDCl$_3$) δ/ppm=194.0, 159.1, 135.9, 134.5, 132.1, 127.7, 127.5, 117.8, 113.9, 54.6, 32.3.

HRMS (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{15}$H$_{15}$O$_2$Se : 307.0232; Found : 307.0242.

2-((4-(tert-Butyl)phenyl)selanyl)-1-phenylethan-1-one (4g). Compound 4g was prepared according to the general procedure and isolated as an oil (48 mg, 72% yield) after flash chromatography (petroleum ether/ethyl acetate = 50/1).

H NMR (400 MHz, CDCl$_3$) δ/ppm=7.78 (d, $J = 8.0$ Hz, 2H), 7.47 (t, $J = 7.4$ Hz, 1H), 7.41 – 7.31 (m, 4H), 7.21 (d, $J = 8.0$ Hz, 2H), 4.07 (s, 2H), 1.23 (s, 9H).

C NMR (100 MHz, CDCl$_3$) δ/ppm=194.2, 150.4, 134.5, 133.1, 132.2, 127.7, 127.5, 125.3, 124.4, 33.6, 31.8, 30.2.

HRMS (ESI/Q-TOF) m/z: [M+H]$^+$ Calcd for C$_{18}$H$_{21}$O$_2$Se : 333.0752; Found : 333.0761.

2-((4-Chlorophenyl)selanyl)-1-phenylethan-1-one (4h). Compound 4h was prepared according to the general procedure and isolated as a white solid (51 mg, 83% yield) after flash chromatography (petroleum ether/ethyl acetate = 65/1).

mp = 52-54 °C.

H NMR (400 MHz, CDCl$_3$) δ/ppm=7.80 (d, $J = 8.0$ Hz, 2H), 7.53 – 7.47 (m, 1H), 7.40 – 7.33 (m, 4H), 7.16 (d, $J = 8.0$ Hz, 2H), 4.08 (s, 2H).

C NMR (100 MHz, CDCl$_3$) δ/ppm=193.6, 134.4, 134.3, 133.5, 132.4, 128.4, 127.6, 125.9, 31.8.

Spectral data are in good agreement with literature values.$^{10}$
1-Phenyl-2-((4-(trifluoromethoxy)phenyl)selanyl)ethan-1-one (4i). Compound 4i was prepared according to the general procedure and isolated as an oil (50 mg, 69% yield) after flash chromatography (petroleum ether/ethyl acetate = 15/1).

1H NMR (400 MHz, CDCl3) δ/ppm= 7.79 (d, J = 8.3 Hz, 2H), 7.51 – 7.44 (m, 3H), 7.37 (t, J = 7.7 Hz, 2H), 7.04 (d, J = 8.3 Hz, 2H), 4.10 (s, 2H).

13C NMR (100 MHz, CDCl3) δ/ppm= 193.7, 134.7, 134.3, 132.4, 127.7, 127.6, 126.0, 120.6, 120.4 (q, J = 249.8 Hz), 31.8.

19F NMR (376 MHz, CDCl3) δ/ppm= -57.84.

HRMS (ESI/Q-TOF) m/z: [M+H]+ Calcd for C15H12F3O2Se 360.9949; Found 360.9954.

2-((4-Fluorophenyl)selanyl)-1-phenylethan-1-one (4j). Compound 4j was prepared according to the general procedure and isolated as an oil (37 mg, 63% yield) after flash chromatography (petroleum ether/ethyl acetate = 40/1).

1H NMR (400 MHz, CDCl3) δ/ppm= 7.90 – 7.66 (m, 2H), 7.52 – 7.46 (m, 1H), 7.45 – 7.40 (m, 2H), 7.36 (dd, J = 8.4, 7.1 Hz, 2H), 6.89 (t, J = 8.7 Hz, 2H), 4.04 (s, 1H).

13C NMR (100 MHz, CDCl3) δ/ppm= 193.8, 161.97 (d, J = 248.6 Hz), 135.8 (d, J = 8.1 Hz), 134.3, 132.3, 127.6 (d, J = 3.1 Hz), 122.2, 121.1, 115.4 (d, J = 21.6 Hz), 32.0.

19F NMR (376 MHz, CDCl3) δ/ppm= -112.7.

Spectral data are in good agreement with literature values.11

2-(Benzod[1,3]dioxol-5-ylselanyl)-1-phenylethan-1-one (4k). Compound 4k was prepared according to the general procedure and isolated as an oil (40 mg, 63% yield) after flash chromatography (petroleum ether/ethyl acetate = 30/1).

1H NMR (400 MHz, CDCl3) δ/ppm= 7.80 (d, J = 7.1 Hz, 2H), 7.55 – 7.44 (m, 1H), 7.37 (dd, J = 8.4, 7.1 Hz, 2H), 7.07 – 6.73 (m, 2H), 6.64 (d, J = 8.5 Hz, 1H), 5.90 (s, 2H), 4.01 (s, 2H).

13C NMR (100 MHz, CDCl3) δ/ppm= 193.9, 147.3, 147.0, 134.4, 132.2, 128.4, 127.7, 127.6, 118.7, 114.4, 108.1, 100.3, 32.5.

HRMS (ESI/Q-TOF) m/z: [M+H]+ Calcd for C15H13O3Se 321.0024; Found 321.0032.

2-(Naphthalen-2-ylselanyl)-1-phenylethan-1-one (4l). Compound 4l was prepared according to the general procedure and isolated as an oil (49 mg, 75% yield) after flash chromatography (petroleum ether/ethyl acetate = 50/1).

1H NMR (400 MHz, CDCl3) δ/ppm= 8.29 (dt, J = 7.6, 1.0 Hz, 1H), 7.83 – 7.66 (m, 5H), 7.52 – 7.38 (m, 3H), 7.33 – 7.23 (m, 3H), 4.10 (s, 2H).
13C NMR (100 MHz, CDCl3) δ/ppm = 195.2, 135.5, 134.9, 134.4, 134.1, 133.2, 129.8, 128.8, 128.7, 128.5, 128.2, 127.7, 127.1, 126.4, 125.8, 32.7.
Spectral data are in good agreement with literature values.12

1-Phenyl-2-(thiophen-2-y selanyl)ethan-1-one (4m). Compound 4m was prepared according to the general procedure and isolated as an oil (45 mg, 80% yield) after flash chromatography (petroleum ether/ethyl acetate = 20/1).

1H NMR (400 MHz, CDCl3) δ/ppm = 7.78 (dd, J = 8.3, 1.1 Hz, 2H), 7.52 – 7.46 (m, 1H), 7.40 – 7.31 (m, 3H), 7.08 (dd, J = 3.5, 1.1 Hz, 1H), 6.88 (dd, J = 5.3, 3.5 Hz, 1H), 4.05 (s, 2H).

13C NMR (100 MHz, CDCl3) δ/ppm = 193.7, 136.2, 134.4, 132.3, 131.1, 127.7, 127.6, 127.2, 121.2, 34.8.

HRMS (ESI/Q-TOF) m/z: [M+H]+ Calcd for C12H11OSSe 282.9690; Found 282.9688.

(R)-4-((2-Oxo-2-phenylethyl)selanyl)-N-(1-phenylethyl)butanamide (4n). Compound 4n was prepared according to the general procedure and isolated as an oil (40 mg, 52% yield) after flash chromatography (petroleum ether/ethyl acetate = 2/1).

[α]D25 = + 31.6, c=0.038 g/100 mL, CHCl3.

1H NMR (400 MHz, CDCl3) δ/ppm = 7.88 – 7.82 (m, 2H), 7.54 – 7.45 (m, 1H), 7.39 (dd, J = 8.4, 7.0 Hz, 2H), 7.30 – 7.16 (m, 5H), 5.88 (d, J = 8.0 Hz, 1H), 5.10 – 5.02 (m, 1H), 3.69 (s, 2H), 2.62 (td, J = 7.2, 1.5 Hz, 2H), 2.20 (t, J = 7.3 Hz, 2H), 2.04 – 1.90 (m, 2H), 1.42 (d, J = 7.0 Hz, 3H).

13C NMR (100 MHz, CDCl3) δ/ppm = 194.2, 170.0, 142.2, 134.1, 132.3, 127.6, 127.64, 126.3, 125.2, 47.7, 35.1, 25.6, 24.6, 24.2, 20.8.

HRMS (ESI/Q-TOF) m/z: [M+H]+ Calcd for : C20H23NO2Se 390.09668; Found 390.09631.

(R)-1-Phenylethyl 4-((2-oxo-2-phenylethyl)selanyl)butanoate (4o). Compound 4o was prepared according to the general procedure and isolated as an oil (44 mg, 57% yield) after flash chromatography (petroleum ether/ethyl acetate = 20/1).

[α]D25 = + 34.0, c=0.11 g/100 mL, CHCl3.

1H NMR (400 MHz, CDCl3) δ/ppm = 7.90 – 7.83 (m, 2H), 7.57 – 7.42 (m, 1H), 7.38 (dd, J = 8.4, 7.0 Hz, 2H), 7.30 – 7.17 (m, 5H), 5.81 (q, J = 6.6 Hz, 1H), 3.68 (s, 2H), 2.60 (t, J = 7.3 Hz, 2H), 2.36 (td, J = 7.3, 1.9 Hz, 2H), 2.06 – 1.82 (m, 2H), 1.45 (d, J
1-Phenyl-2-(phenylselanyl)ethan-1-ol (5). To ketone 3a (55 mg, 0.2 mmol) in MeOH (10 mL) at room temperature was added NaBH₄ (15 mg, 0.4 mmol), and the mixture was stirred overnight. The resulting mixture was treated with water (10 mL), 1 M NaOH (10 mL) and then was extracted with EtOAc (3 × 20 mL). The combined organic layer was dried over Na₂SO₄ and concentrated. The resulting residue was chromatographed (petroleum ether/ethyl acetate = 5/1) to give alcohol 5 (51 mg, 93%) as an oil.

**N-Benzyl-1-phenyl-2-(phenylselanyl)ethan-1-amine (6).** Benzylation (86 mg, 0.8 mmol) was added to ketone 3a (55 mg, 0.2 mmol) in ether (10 ml) at 0 °C under argon. A solution of titanium tetrachloride (28 mg, 0.15 mmol) in heptane (2 ml) was then slowly introduced. The mixture was stirred for 30 min at 0 °C and then for 3 h at room temperature. The titanium salts were filtered and rinsed with ether. The resulting mixture was concentrated under reduced pressure with a rotary evaporator to give imine, which was used in the subsequent step without further purification.

To the resulting imine in ethanol (10 ml) at -78 °C under argon, were added successively sodium cyanoborohydride (12 mg, 0.2 mmol) and acetic acid (12 mg, 0.2 mmol). The reaction mixture was stirred for 1 h at -78 °C and quenched with water (10 ml). The resulting mixture was extracted with EtOAc (3×20 mL), and the combined extracts were dried over Na₂SO₄ and concentrated. The crude product was purified by silica gel chromatography (petroleum ether/ethyl acetate = 30/1) to give compound 6 (53 mg, 73%) as an oil.
Spectral data are in good agreement with literature values.14

**(E)-1,2-Diphenylethene (8).**

\[ \text{H NMR (400 MHz, CDCl}_3\text{) } \delta/\text{ppm}= 7.55 - 7.40 \text{ (m, 4H), 7.28 (t, } J = 7.7 \text{ Hz, 4H), 7.23 - 7.10 \text{ (m, 2H), 7.04 (s, 2H).} \]

\[ \text{C NMR (100 MHz, CDCl}_3\text{) } \delta/\text{ppm}= 136.3, 127.6, 126.6, 125.5. \]

Spectral data are in good agreement with literature values.15

**(Z)-1,2-Diphenylethene (9).**

\[ \text{H NMR (400 MHz, CDCl}_3\text{) } \delta/\text{ppm}= 7.35 - 6.88 \text{ (m, 10H), 6.52 (s, 2H).} \]

\[ \text{C NMR (100 MHz, CDCl}_3\text{) } \delta/\text{ppm}= 136.2, 129.2, 127.8, 127.2, 126.0. \]

Spectral data are in good agreement with literature values.16

**Benzophenone (11).** To a 10 mL vessel with magnetic stir bar were added 0.2 mmol 1,1-diphenylethylene, 0.1 mmol Ph₂Se₂ and 2 mL of EtOAc. The reaction mixture was stirred and irradiated with a 24W household compact fluorescent lamp from a distance of 1 cm. After 20 h, the solvent was removed with a rotary evaporator. The crude product was purified by silica gel chromatography (petroleum ether/ethyl acetate = 10/1) to give compound 11 (16 mg, 43%) as an oil.

\[ \text{H NMR (400 MHz, CDCl}_3\text{) } \delta/\text{ppm}= 7.85 - 7.77 \text{ (m, 4H), 7.63 - 7.54 \text{ (m, 2H), 7.52 - 7.41 \text{ (m, 4H).} \]

\[ \text{C NMR (100 MHz, CDCl}_3\text{) } \delta/\text{ppm}= 196.6, 196.7, 137.6, 132.5, 130.1, 128.3. \]

Spectral data are in good agreement with literature values.17

7. References


8. Copies of NMR spectra
\[ \text{O} \text{Ph} \]

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3a

\[ \text{Me} \text{O} \text{Ph} \]

$^1$H NMR (400 MHz, CDCl$_3$) of 3b
$^1$H NMR (400 MHz, CDCl$_3$) of 3c

$^1$C NMR (100 MHz, CDCl$_3$) of 3b
$^{13}$C NMR (100 MHz, CDCl$_3$) of 3c

$^1$H NMR (400 MHz, CDCl$_3$) of 3d
$^1$H NMR (400 MHz, CDCl$_3$) of 3e

$^13$C NMR (100 MHz, CDCl$_3$) of 3d
$^{13}$C NMR (100 MHz, CDCl$_3$) of 3e

$^{19}$F NMR (376 MHz, CDCl$_3$) of 3e
$^1$H NMR (400 MHz, CDCl₃) of 3f

$^1$H NMR (400 MHz, CDCl₃) of 3f
$^1$H NMR (400 MHz, CDCl$_3$) of 3g

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3g
$^1$H NMR (400 MHz, CDCl$_3$) of 3h

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3h
$^1$H NMR (400 MHz, CDCl₃) of 3l

$^{13}C$ NMR (100 MHz, CDCl₃) of 3l
$^1$H NMR (400 MHz, CDCl$_3$) of 3j

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3j
$^1$H NMR (400 MHz, CDCl$_3$) of 3k

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3k
$^1$H NMR (400 MHz, CDCl$_3$) of 3I

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3I
$^1$H NMR (400 MHz, CDCl₃) of 3m

$^{13}$C NMR (100 MHz, CDCl₃) of 3m
$^1$H NMR (400 MHz, CDCl$_3$) of 3n

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3n
$^{13}$C NMR (100 MHz, CDCl$_3$) of 3e

$^1$H NMR (400 MHz, CDCl$_3$) of 3p
$^{13}$C NMR (100 MHz, CDCl$_3$) of 3p

$^1$H NMR (400 MHz, CDCl$_3$) of 3q
$^{13}\text{C NMR (100 MHz, CDCl}_3\text{)}$ of 3q

$^1\text{H NMR (400 MHz, CDCl}_3\text{)}$ of 3r
$^{13}$C NMR (100 MHz, CDCl$_3$) of 3r

$^1$H NMR (400 MHz, CDCl$_3$) of 3s
$^{13}$C NMR (100 MHz, CDCl$_3$) of 3a

$^{19}$F NMR (375 MHz, CDCl$_3$) of 3a
$^1$H NMR (400 MHz, CDCl$_3$) of 3t

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3t
$^1$H NMR (400 MHz, CDCl$_3$) of 3u

$^{13}$H NMR (100 MHz, CDCl$_3$) of 3u
$^1$H NMR (400 MHz, CDCl$_3$) of 3ν

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3ν
$^1$H NMR (400 MHz, CDCl$_3$) of $3w$

$^{13}$C NMR (100 MHz, CDCl$_3$) of $3w$
$^1$H NMR (400 MHz, CDCl$_3$) of 3x

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3x
$^1$H NMR (400 MHz, CDCl$_3$) of 3y

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3y
$^1$H NMR (400 MHz, CDCl$_3$) of 3x

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3x
$^1$H NMR (400 MHz, CDCl$_3$) of 3aa

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3aa
$^1$H NMR (400 MHz, CDCl$_3$) of 3ab

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3ab
$^1$H NMR (400 MHz, CDCl$_3$) of 3ac

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3ac
$^1$H NMR (400 MHz, CDCl$_3$) of 3ad

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3ad

S58
$^1$H NMR (400 MHz, CDCl$_3$) of 3ae

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3ae
$^1$H NMR (400 MHz, CDCl$_3$) of 3af

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3af
$^1$H NMR (400 MHz, CDCl$_3$) of 3ag

$^{13}$C NMR (100 MHz, CDCl$_3$) of 3ag
$^{1}$H NMR (400 MHz, CDCl$_3$) of 4a

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4a
$^1$H NMR (400 MHz, CDCl$_3$) of 4b

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4b
$^1$H NMR (400 MHz, CDCl$_3$) of 4c

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4c
$^1$H NMR (400 MHz, CDCl$_3$) of 4d

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4d
$^1$H NMR (400 MHz, CDCl$_3$) of 4e

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4e
$^1$H NMR (400 MHz, CDCl$_3$) of 4f

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4f
$^1$H NMR (400 MHz, CDCl$_3$) of 4g

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4g
$^1$H NMR (400 MHz, CDCl$_3$) of 4h

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4h
$^1$H NMR (400 MHz, CDCl$_3$) of 4i

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4i
$^1$H NMR (400 MHz, CDCl$_3$) of 4j

$^1$F NMR (376 MHz, CDCl$_3$) of 4l
$^{13}$C NMR (100 MHz, CDCl$_3$) of 4

$^{19}$F NMR (376 MHz, CDCl$_3$) of 4
$^1$H NMR (400 MHz, CDCl$_3$) of 4k

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4k
$^1$H NMR (400 MHz, CDCl$_3$) of 4l

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4l
$^1$H NMR (400 MHz, CDCl$_3$) of 4m

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4m
$^1$H NMR (400 MHz, CDCl$_3$) of 4n

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4n
$^1$H NMR (400 MHz, CDCl$_3$) of 4o

$^{13}$C NMR (100 MHz, CDCl$_3$) of 4o
\[ \text{H NMR (400 MHz, CDCl}_3\text{) of 5} \]

\[ \text{C NMR (100 MHz, CDCl}_3\text{) of 5} \]
$^1$H NMR (400 MHz, CDCl$_3$) of 8

$^{13}$C NMR (100 MHz, CDCl$_3$) of 8
$^1$H NMR (100 MHz, CDCl$_3$) of 9

$^{13}$C NMR (100 MHz, CDCl$_3$) of 9
$^1$H NMR (400 MHz, CDCl$_3$) of 11

$^{13}$C NMR (400 MHz, CDCl$_3$) of 11