Electrophilic heterocycles: functionalization with enol silyl ethers.

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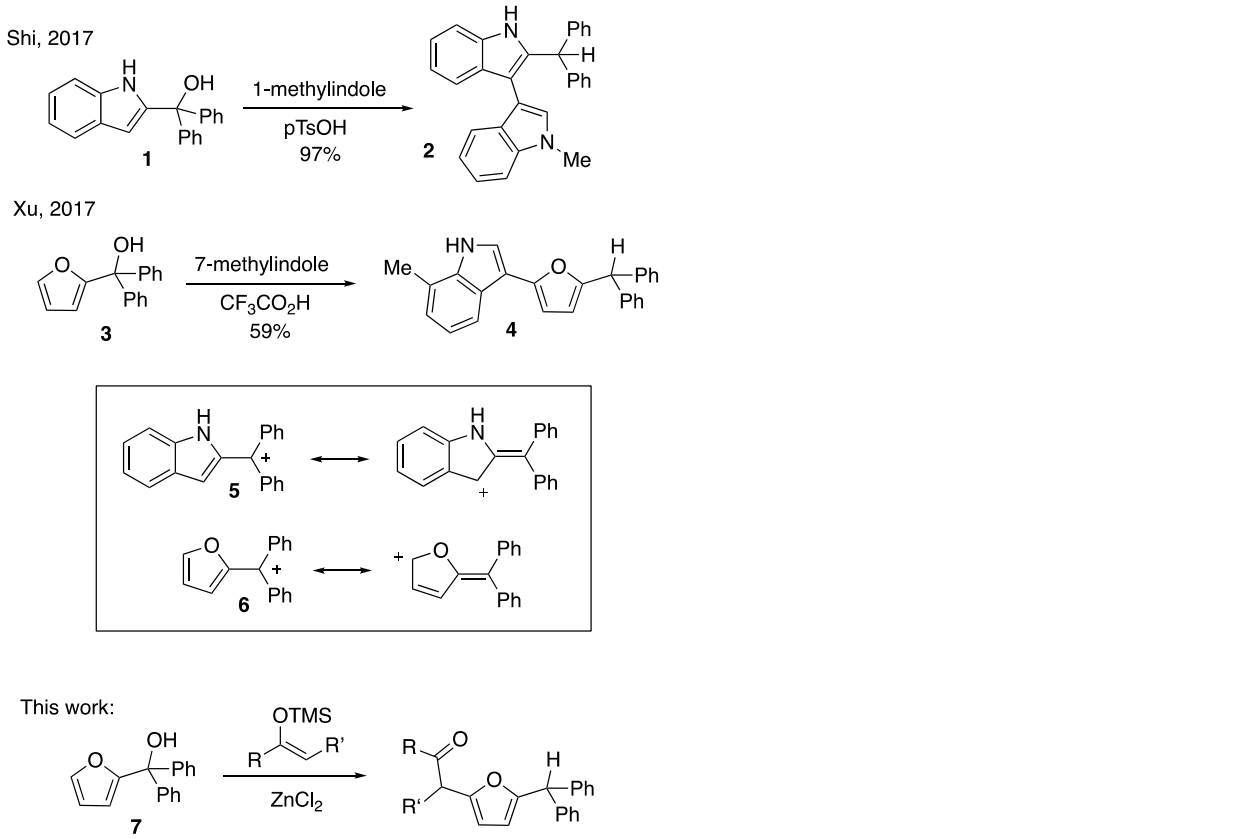
Abstract. A series of heterocyclic triaryl methanols were prepared and reacted with enol silyl ethers in the presence of $ZnCl_2$. This reaction gave a variety of functionalized heterocyclic products. A mechanism is proposed involving formation triaryl carbocation electrophiles with delocalization of positive charge to positions in the heterocyclic rings. Nucleophilic attack then occurs at a ring position of the heterocycle.

1. Introduction

Functionalized heterocyclic compounds are important synthetic targets. Roughly 70% of clinically useful pharmaceutical compounds contain one or more heterocyclic rings.[1] Improved access to heterocyclic scaffolds can lower the costs of pharmaceutical intermediates and provide routes to new chemical space for drug development. Heterocyclic compounds are also useful in numerous other applications, such as material science,[2] agrochemicals,[3] and dyes/pigments.[4] With the utility and value of this class of compounds, there continues to be great efforts to develop new synthetic methods in this area.

Several reports have described the ionization of heterocyclic substrates to provide triaryl carbocations.[5] Through the delocalization of the cationic charge, nucleophilic attack then occurs at a ring position rather than at the carbocation center. These transformations have included reactions with both π- and n-donor nucleophiles (Scheme 1). Shi and coworkers described the acid-catalyzed reaction of the indole alcohol **1** to produce the bisindole **2** from 1-methylindole.[5a] The indole-based triaryl alcohols have also been shown to couple with enaminones, thiophenols, azlactones, naphthols, phopshine oxides, and other nucleophiles.[5b-h] Likewise, the furan-based alcohol (**3**) was shown to couple with 7-methylindole with an acid promoter.[5i] Both the indole and furan-based systems exhibit delocalization of charge (**5**-**6**)

Scheme 1.

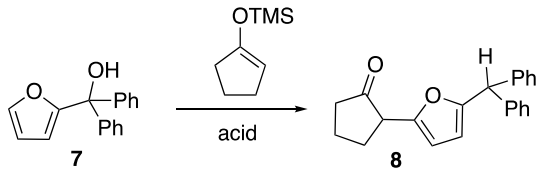


which enables nucleophilic attack at the ring positions. This regiochemistry may also be affected by the steric demands of nucleophilic attack at the triarylmethyl carbocation center, where C-C bond formation would produce a tetraaryl methane. Similar reactions have been reported with benzofuran and benzothiophene-based triaryl methanol compounds.[6,7] According to Mayr's scale of nucleophile strength,[8] indoles and enol silyl ethers have similar nucleophile strengths (indole: nucleophilicity, *N* 5.55 (s_N 1.09); 1-(trimethylsiloxy)cyclohexene, nucleophilicity, *N* 5.22 (s_N 1.00)). Based on this similarity, we reasoned that enol silyl ethers should be good reaction partners with these heterocyclic cations. In this paper, we describe a series of coupling reactions between triaryl alcohols and enol silyl ethers.

2. Results and Discussion

Our initial studies involved examining the chemistry of the 2-furyl alcohol (**7**) in a coupling reaction with 1-(trimethylsiloxy)cyclopentene. A series of Brønsted and Lewis acids were used to promote the coupling reaction (Table 1). However, no coupling product was obtained from any of the Brønsted acids. This may be due to the Brønsted acids reacting with the enol silyl ether before ionization of the alcohol can occur. With the use of Lewis acids, the coupling product **8** was obtained. The highest yield was obtained with $ZnCl_2$ (0.2 equiv) at 80°C, where compound **8** was isolated in 81% yield (entry 12). A reasonable yield (66%) was also obtained with $TiCl_4$ (0.2 equiv) at 25°C (entry 8), but elevated temperatures reduced the yield from this catalyst (entry 15). Aluminum chloride provided only low yields of the desired product, while boron trifluoride etherate gave just trace amounts of product. The desired coupling product **8** was isolated in 81% yield (entry 12), but a minor biproduct (**9**) of the reaction was

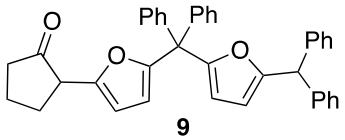
Table 1. Yields and conditions for the reaction of alcohol **7** and 1-(trimethylsiloxy)cyclopentene.[a,b]



7 8

Entry	Acid	Temp	Yield
1	H_2SO_4 (0.2 eq)	25°C	0%
2	CF_3CO_2H (0.2 eq)	25°C	0%
3	CF_3SO_3H (0.2 eq)	25°C	0%
4	H_2SO_4 (0.2 eq)	25°C	0%
5	CF_3CO_2H (0.2 eq)	25°C	0%
6	CF_3SO_3H (0.2 eq)	25°C	0%
7	$AlCl_3$ (0.2 eq)	25°C	33%
8	$TiCl_4$ (0.2 eq)	25°C	66%
9	$ZnCl_2$ (0.2 eq)	25°C	10%
10	$BF_3 \bullet Et_2O$ (0.2 eq)	25°C	trace
11	$ZnCl_2$ (0.1 eq)	80°C	60%
12	$ZnCl_2$ (0.2 eq)	80°C	81%
13	$ZnCl_2$ (0.5 eq)	80°C	80%
14	$AlCl_3$ (0.2 eq)	80°C	40%
15	$TiCl_4$ (0.2 eq)	80°C	20%
16	$BF_3 \bullet Et_2O$ (0.2 eq)	80°C	6%

[a]%Yield determined by NMR (entry 12, isolated yield). [b]Reaction conditions: 0.1 mmol **7**, 1 mL 1,2-dichloroethane, acid catalyst, 3 hr reaction.

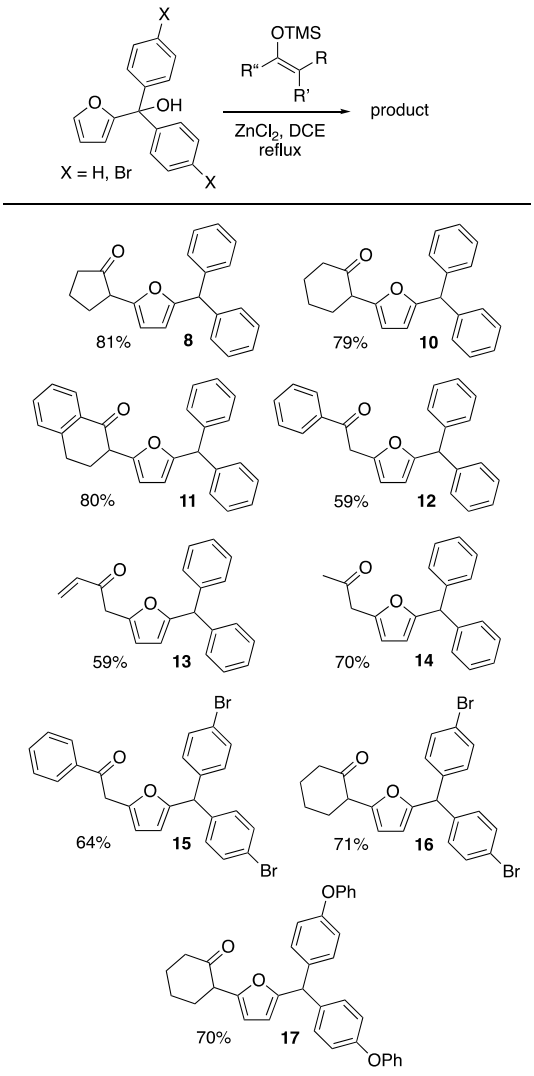


9

also isolated in 18% yield. Similar by-products were observed in coupling reactions with other systems (described below), but these by-products were typically formed in less than 10% yield

based on NMR analysis of crude product mixtures. Mass spectral analysis of the crude product mixture suggested trace amounts of higher oligomers. We attempted to carry out an oligomerization in the absence of an enol silyl ether, however there was not a clean conversion to macromolecules or higher oligomers.

Table 2. Products and isolated yields from the reaction of the triaryl alcohols with enol silyl ethers.

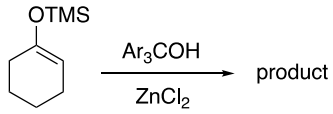


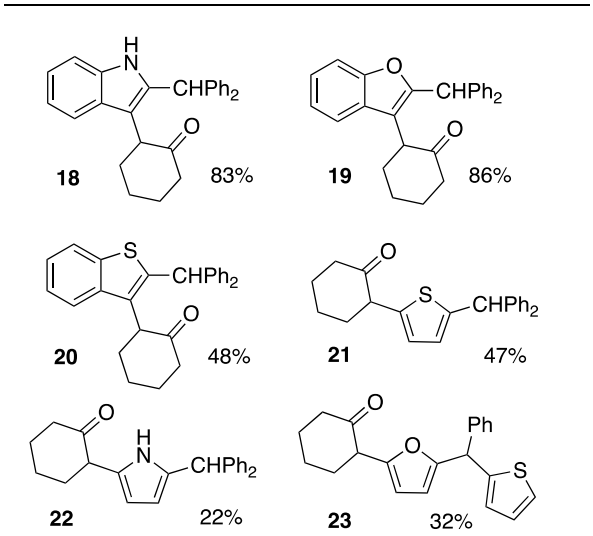
Reaction conditions: 0.1 mmol triaryl alcohol, 3 mL DCE, 20 mol% $ZnCl_2$ (as a 1.0 M solution in ether), with 0.1 mmol enol silyl ether at 85°C for 3 hrs.

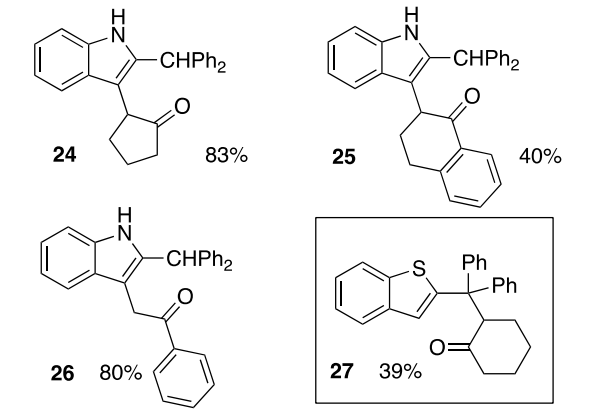
Using the optimized conditions, several types of enol silyl ethers were coupled with the the 2-furyl alcohol (**7**) and related bromophenyl and 4-phenoxyphenyl derivatives (Table 2). The starting triaryl alcohols are easily prepared from the benzophenone and 2-furyllithium. The cyclic enol silyl ethers give products (**8**, **10-11**, **16-17**) in good yields, as well as the acyclic coupling partner, (α-trimethylsiloxy)styrene, giving products **12-15**.

Prompted by the success with furan-based triaryl methanols, other heterocyclic systems were examined (Table 3). With the indole system, the reaction with 1-(trimethylsiloxy) cyclohexene and $ZnCl_2$ provides the cyclohexanone product **20** in good yield. The same triaryl methanol gives products **24-26** from the respective enol silyl ethers. Likewise, the benzofuran-based triarylmethanol gives product **19** in 86% yield. The benzothiophene system provides the cyclohexanone **20**, although it was isolated in just 48% yield (accompanied by product **27**, *vide infra*). A similar product yield was obtained from the diphenyl-2-(thienyl)methanol, as cyclohexanone **21** is isolated in 47% yield. These conversions were characterized by somewhat messy product mixtures, with TLC analysis indicating the presence of 6 or 7 minor products. In the case of the benzothiophene, the regioisomeric substitution product **27** was isolated in 39% yield. This type of substitution product could not be isolated from any of the other heterocyclic triarylmethanol product mixtures and it is unclear why the benzothiophene system would give product **27** in a relatively high yield. Although the pyrrole gives the expected cyclohexanone product (**22**), it was isolated in just 22% yield. Again, this conversion is characterized by the formation of numerous minor products (TLC showed at least 8 spots). The 2-(furyl)-phenyl-2-(thienyl)methanol was prepared from the reaction of 2-benzoylthiophene and 2-lithiofuran. This substrate provided compound **23** as the major product – from reaction at the furan ring

Table 3. Products and yields from the reactions of 1-(trimethylsiloxy)cyclohexene with triarylmethanols/$ZnCl_2$ and other products.





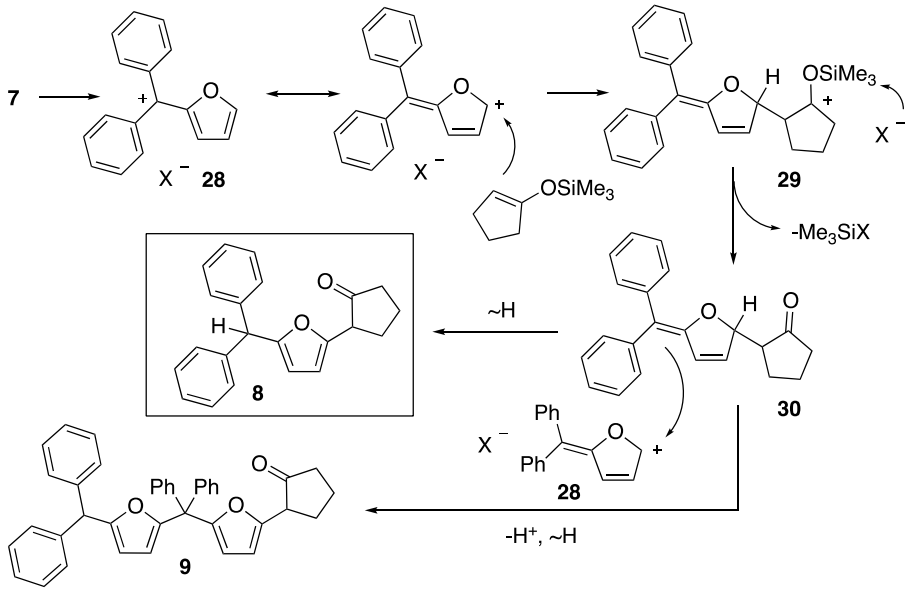


Reaction conditions: 0.1 mmol triaryl alcohol, 3 mL DCE, 20 mol% $ZnCl_2$ (as a 1.0 M solution in ether), with 0.1 mmol enol silyl ether at 85°C for 3 hrs.

instead of the thiophene ring. The regioselectivity was established by reducing the thienyl ring with Raney nickel to the butyl chain.

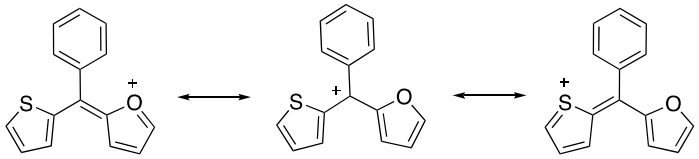
As has been suggested in previous reports,[5] this chemistry involves the ionization of the triarylmethanol to the corresponding carbocation (Scheme 1). For the heterocycles in this study, the carbocation center is delocalized into the ring positions and nucleophilic attack allows for functionalization of the heterocycle. Thus, compound **7** ionizes to the triarylcarbocation **28**. Charge delocalization leads to positive charge in the 5-position and reaction with the enol silyl ether gives **29** from C-C bond formation. Loss of $(CH_3)_3SiCl$ or $(CH_3)_3SiOH$ provides **30** and a hydrogen shift gives the major product **8**. This mechanism may also explain the formation of product **9**. If intermediate **30** is a persistent species, then a

Scheme 2. Proposed mechanism for the conversion of **7** to the major and minor products (**8** and **9**).



reaction with another triarylcarbocation (**28**) can provide compound **9**. Another mechanistic question involves the formation of product **23**, that is why would nucleophilic attack occur at

the furyl group rather than the thienyl group? It is suggested that the cationic charge is better stabilized by interaction with the ring oxygen atom than the same interaction with the ring sulfur atom. This effectively means that resonance form **31a** contributes more than structure **31b**, and consequently nucleophilic attack occurs at the furyl ring.



31a **31b**

3. Conclusion

In summary, we have found that heterocyclic triaryl methanols undergo a Lewis acid promoted ionization and the resulting carbocations may be functionalized at the heterocyclic rings with enol silyl ethers. A mechanism is proposed involving cationic charge delocalization into the heterocyclic ring and nucleophilic attach by the enol silyl ether.

4. Experimental Section

4.1 General experimental

Condensation reactions were performed in an inert atmosphere using thoroughly dried glassware. Products were isolated by flash chromatography using 60 Å silica gel. ^{1}H and ^{13}C NMR were carried out using a 300 or 500 MHz spectrometer. Chemical shifts were referenced to NMR solvent signals. High-resolution mass spectra were obtained from a commercial analytical laboratory with a time-of-flight (TOF) mass analyzer for data collection. Reagents and solvents were purchased from commercial suppliers and used as received. The enol silyl ethers

were purchased from a commercial supplier. Triflic acid was distilled before use and stored under a dry inert atmosphere.

4.2 General procedure A: synthesis of triaryl alcohols

The heterocycle (1 mmol) was dissolved in tetrahydrofuran (15 mL) and cooled to -78 ^{o}C. *N*-Butyllithium (1.1 mmol, 2.5 M in hexanes) was added slowly and the cold solution was stirred for 1 hr. The ketone (1.2 mmol) dissolved in tetrahydrofuran (10 mL) was added slowly over 30 min, the resulting mixture was stirred for 1 hour at -78^{o}C and gradually warmed to room temperature overnight. The reaction mixture was quenched with aqueous ammonium chloride and extracted with diether ether (3 x 20 mL). The combined organic extracts were washed with brine (2x), and dried over anhydrous sodium sulfate (Na_2SO_4). The resulting crude triaryl alcohol was then refined using column chromatography.

4.2.1 **Furan-2-yldiphenylmethanol (7).** Following general procedure A, furan (1.09 mL, 15 mmol), *n*-butyllithium (1.1 eq, 16.5 mmol, 6.6 mL), and benzophenone (1.2 eq, 16.5 mmol, 3.28 g) produced furan-2-yldiphenylmethanol (3.15 g, 12.6 mmol, 84%) as a white solid. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f 0.40 (10% ethyl acetate in hexanes). NMR spectral data matched previously reported data.[9] ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.49 (dd, J= 3.2, 1.0 Hz, 1H), 7.36-7.28 (m, 10H), 6.36 (dd, J=3.7, 0.5 Hz,1H), 5.95 (dd, J=3.6, 0.6 Hz, 1H), 3.13 (s, 1H). ^{13}C {^{1}H} NMR (125 MHz, $CDCl_3$): δ 157.9, 144.7, 142.7, 128.0, 127.7, 127.2, 110.1, 109.7, 78.0

4.3 General procedure B: synthesis of triaryl alcohols

The heterocyclic ester (1 mmol) was dissolved in tetrahydrofuran (15 mL) at -78 ^{o}C and phenyllithium (1.3 mL, 2.5 mmol, from 1.9 M solution in dibutyl ether) was added slowly. The

mixture was stirred for 1 hr at -78 ^{o}C, gradually warmed to room temperature, and allowed to stir for 8 hrs.. The reaction mixture was quenched with aqueous ammonium chloride and extracted with diether ether (3 x 20 mL). The combined organic extracts were washed with brine (2x), and dried over anhydrous sodium sulfate (Na_2SO_4). The resulting crude triaryl alcohol was then refined using column chromatography.

4.4 General procedure B: synthesis of functionalized heterocycle

In a 15 mL thick-walled pressure tube, the triaryl alcohol (1 mmol) was dissolved in 1,2-dichloroethane (3 mL) and $ZnCl_2$ (0.2 mL, 0.2 mmol, 1 M in diethyl ether) was slowly added to the mixture with stirring. After five minutes, the nucleophile (1 equivalent) was added and heated (oil bath) at 85°C for 3 hours. The reaction mixture was then quenched with deionized water and the product was extracted with chloroform (3 x 20 mL). The combined organic extracts were washed with brine (2x) and dried over sodium sulfate (Na_2SO_4). The resulting crude triaryl alcohol was then refined using column chromatography.

4.4.1 **2-(5-Benzhydrylfuran-2-yl)cyclopentanone (8).** Following general procedure C, furan-2-yldiphenylmethanol (250 mg, 1 mmol) and 1-(trimethylsiloxy)cyclopentene (0.18 mL, 1 mmol) produced 2-(5-benzhydrylfuran-2-yl)cyclopentanone (256 mg, 0.81 mmol, 81%) as a colorless oil. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.51 (10% ethyl acetate in hexanes). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.33-7.15 (m, 10H), 6.10 (d, J=3.1 Hz, 1H), 5.82-5.81 (m, 1H)m 5.42 (s, 1H), 3.39 (t, J= 9.1 Hz, 1H), 2.42-2.07 (m, 5H), 1.97-1.83 (m, 1H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 215.4, 155.9, 150.9, 141.9, 128.8, 128.3,

126.6, 109.2, 107.2, 50.9, 48.6, 37.8, 29.6, 20.8. HRMS (ESI-TOF): m/z $[M+H]^+$ calcd for $C_{22}H_{21}O_2$ 317.1536, found 317.1538.

4.4.2 **2-(5-((5-Benzhydrylfuran-2-yl)diphenylmethyl)furan-2-yl)cyclopentanone (9).** Following general procedure C, furan-2-yldiphenylmethanol (250 mg, 1 mmol) and 1-(trimethylsiloxy)cyclopentene (0.18 mL, 1 mmol) produced 2-(5-((5-benzhydrylfuran-2-yl)diphenylmethyl)furan-2-yl)cyclopentanone (57 mg, 0.18 mmol, 18%) as a colorless oil. The product was purified using column chromatography (Biotage SNAP Ultra 25 g, 7-10% ethyl acetate in hexanes). TLC: 10% ethyl acetate in hexanes (Rf: 0.47). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.33-7.24 (m, 14 H), 7.22-7.19 (m, 2H), 7.08-7.05 (m, 4H), 6.11 (d, J=3.2 Hz, 1H), 5.98-5.94 (m, 2H), 5.76 (d, J=3.2 Hz, 1H), 5.45 (bs, 1H), 3.42 (t, J=9.1 Hz, 1H), 2.42-2.34 (m, 2H), 2.30-2.18 (m, 1H), 2.12-1.99 (m, 2H), 1.93-1.84 (m, 1H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$): δ 215.6, 156.2, 156.0, 151.2, 143.9, 141.9, 129.3, 128.9, 128.3, 127.7 126.8, 126.6, 111.3, 110.8, 108.6, 107.2, 56.8, 50.8, 48.7, 37.7, 29.5, 20.8. HRMS (ESI-TOF): m/z $[M+Na]^+$ calcd $C_{39}H_{32}O_3Na$ 571.2244, found 571.2242.

4.4.3 **2-(5-Benzhydrylfuran-2-yl)cyclohexanone (10).** Following general procedure C, furan-2-yldiphenylmethanol (250 mg, 1 mmol) and 1-(trimethylsiloxy)cyclohexene (0.19 mL, 1 mmol) produced 2-(5-benzhydrylfuran-2-yl)cyclohexanone (261 mg, 0.79 mmol, 79%) as a yellow solid. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.51 (10% ethyl acetate in hexanes). MP 102-104 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.33-7.30 (m, 4H), 7.26-7.23 (m, 2H), 7.19 (d, J=7.4 Hz, 4H), 6.11 (d, J=2.9 Hz, 1H), 5.84 (d, J=1.6 Hz, 1H), 5.44 (s,

1H), 3.69 (dd, J=10.6 Hz, 5.4, 1H), 2.53-2.48 (m, 1H), 2.41-2.35 (m, 1H), 2.31-2.27 (m, 1H), 2.06-1.93 (m, 3H), 1.84-1.72 (m, 2H). ^{13}C {^{1}H} NMR (125 MHz, $CDCl_3$) δ 208.4, 155.6, 151.9, 142.04, 142.02, 128.8, 128.37, 128.35, 126.6, 109.2, 107.1, 50.8, 50.7, 41.5, 32.3, 27.6, 24.3 HRMS (ESI-TOF): m/z $[M+H]^+$ calcd for $C_{23}H_{23}O_2$ 331.1693, found 331.1695.

4.4.4 **2-(5-Benzhydrylfuran-2-yl)-3,4-dihydronaphthalen-1(2H)-one (11).** Following general procedure C, furan-2-yldiphenylmethanol (250 mg, 1 mmol) and (3,4-Dihydro-1-napthyloxy)trimethylsilane (0.22 mL, 1 mmol) produced 2-(5-benzhydrylfuran-2-yl)-3,4-dihydronaphthalen-1(2H)-one (302 mg, 0.80 mmol, 80%) as a colorless oil. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.47 (10% ethyl acetate in hexanes).^{1}H NMR (300 MHz, $CDCl_3$): δ 8.10 (dd, J= 3.9 Hz, 1.1, 1H), 7.50 (td, J= 6.1 Hz, 1.4, 1H), 7.36-7.17 (m, 14H), 6.10 (d, J-3.1, 1H), 5.84 (d, J=3.1 Hz, 1H), 5.45 (s, 1H), 3.92 (t, J=7.0, 1H), 3.01 (t, J= 6.1 Hz (2H), 2.44 (q, J=6.9 Hz, 2H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 195.4, 155.8, 151.5, 143.9, 142.00, 141.97, 133.5, 132.2, 128.8, 128.7, 128.4, 127.9, 126.7, 126.6, 109.2, 107.6, 50.9, 47.7, 28.4, 27.9. HRMS (ESI-TOF): m/z $[M+H]^+$ calcd for $C_{27}H_{22}O_2$ 379.1693, found 379.1690.

4.4.5 **2-(5-Benzhydrylfuran-2-yl)-1-phenylethanone (12).** Following general procedure C, furan-2-yldiphenylmethanol (250 mg, 1 mmol) and 1-phenyl-1-trimethylsiloxyethylene (0.20 mL, 1 mmol) produced 2-(5-benzhydrylfuran-2-yl)-1-phenylethanone (208 mg, 0.59 mmol, 59%) as a colorless oil. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.48

(10% ethyl acetate in hexanes).^{1}H NMR (300 MHz, $CDCl_3$): δ 8.02-7.99 (m, 2H), 7.61-7.56 (m, 1H), 7.49-7.43 (m, 2H), 7.34-7.26 (m, 6H), 7.21-7.18 (m, 4H), 6.21 (d, J=3.1 Hz, 1H), 5.88 (d, J= 1.5 Hz, 1H), 5.46 (s 1H), 4.30 (s, 2H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 195.1, 156.1, 147.7, 141.9, 136.2, 133.3, 128.8, 128.7, 128.6, 128.4, 126.7, 109.7, 108.9, 50.9, 38.8. HRMS (ESI-TOF): m/z $[M+Na]^+$ calcd for $C_{25}H_{20}O_2Na$ 375.1356, found 375.1366.

4.4.6 **1-(5-Benzhydrylfuran-2-yl)but-3-en-2-one (13).** Following general procedure C, furan-2-yldiphenylmethanol (125 mg, 0.5 mmol) and 2-trimethylsiloxy-1,3-butadiene (0.09 mL, 0.5 mmol) produced 1-(5-benzhydrylfuran-2-yl)but-3-en-2-one (89 mg, 0.29 mmol, 59%) as a yellow oil. The product was purified using column chromatography (Biotage SNAP Ultra 25 g, 8-10% ethyl acetate in hexanes). TLC: 10% ethyl acetate in hexanes (Rf: 0.49). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.37-7.34 (m, 4H), 7.30-7.27 (m, 2H), 7.23 (d, J= 7.3 Hz, 2H), 6.47-6.41 (m, 1H), 6.34-6.30 (m, 1H), 6.19 (d, J=3.0 Hz, 1H), 5.91 (d, J=3.0 Hz, 1H), 5.84 (d, J=10.5 Hz, 1H), 5.48 (s, 1H), 3.89 (s, 1H). ^{13}C {^{1}H} NMR (125 MHz, $CDCl_3$) δ 195.3, 156.4, 147.4, 141.8, 135.1, 129.4, 128.8, 128.4, 126.8, 109.6, 108.9, 50.9, 40.2. HRMS (ESI-TOF): m/z $[M+H]^+$ calcd for $C_{21}H_{19}O_2$ 303.1380, found 303.1385.

4.4.7 **1-(5-Benzhydrylfuran-2-yl)propan-2-one (14).** Following general procedure C, furan-2-yldiphenylmethanol (125 mg, 0.5 mmol) and isopropenyloxytrimethylsilane (0.09 mL, 0.5 mmol) produced 1-(5-benzhydrylfuran-2-yl)propan-2-one (102 mg, 0.35 mmol, 70%) as a yellow oil. The product was purified using column chromatography (Biotage SNAP Ultra 25 g, 10-12% ethyl acetate in hexanes). TLC: 20% ethyl acetate

in hexanes (Rf: 0.45). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.34 (t, J=7.6 Hz, 4H), 7.30-7.26 (m, 2H), 7.23 (d, J=7.2 Hz, 4H), 6.16 (d, J=3.1 Hz, 1H), 5.90 (d, J=3.0 Hz, 1H), 5.47 (s, 1H), 3.69 (s, 2H), 2.15 (s, 3H). ^{13}C {^{1}H} NMR (125 MHz, $CDCl_3$) δ 204.4, 156.4, 147.8, 141.8, 128.8, 128.5, 126.8, 109.6, 108.9, 50.9, 43.4, 29.1. HRMS (ESI-TOF): m/z $[M+H]^+$ calcd for $C_{20}H_{19}O_2$ 291.1380, found 291.1386.

4.4.8 **2-(5-(Bis(4-bromophenyl)methyl)furan-2-yl)-1-phenylethanone (15).** Following general procedure A, furan (0.363 mL, 5 mmol), *n*-butyllithium (5.5 mmol, 2.2 mL) and 4-4'-dibromobenzophenone (6.0 mmol, 2.04 g) produced bis(4-bromophenyl)(furan-2-yl)methanol (1.248 g, 3.05 mmol, 61%) as a white solid. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.36, (10% ethyl acetate in hexanes). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.48 (d, J=8.7 Hz, 5H), 7.20 (d, J= 8.6 Hz, 4H), 6.38-6.36 (dd, J= 3.3 Hz, 1.8 1H), 5.97 (d, J= 3.3 Hz, 1H), 3.33 (s, 1H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$): δ 156.7, 143.2, 143.0, 131.3, 129.0, 122.1, 110.3, 110.0, 77.4. HRMS (ESI-TOF): m/z $[M+Na]^+$ calcd for $C_{17}H_{12}Br_2O_2Na$ 430.9077, found 430.9091. Following general procedure C, bis(4-bromophenyl)(furan-2-yl)methanol (408 mg, 1 mmol) and 1-phenyl-1-trimethylsiloxyethylene (0.20 mL, 1 mmol) produced 2-(5-(bis(4-bromophenyl)methyl)furan-2-yl)-1-phenylethanone (326 mg, 0.64 mmol, 64%) as a colorless oil. The product was purified using column chromatography (10% ethyl acetate in hexanes.) TLC, Rf: 0.25 (10% ethyl acetate in hexanes). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.97 (d, J=8.3 Hz, 2H), 7.59-7.56 (m, 1H) 7.48-7.40 (m, 6H), 7.00 (d, J=8.3 Hz, 4H), 6.19 (s, 1H), 5.86 (s, 1H), 5.33 (s, 1H), 4.27 (s, 2H). ^{13}C {^{1}H} NMR (75 MHz,

$CDCl_3$) δ 194.9, 154.7 148.2, 140.3, 136.1, 133.4, 131.6, 130.4, 128.7, 128.6, 120.9, 109.9, 109.0, 49.7, 38.6. HRMS (ESI-TOF): m/z $[M+H]^+$ calcd for $C_{25}H_{18}Br_2O_2$ 508.9746 found 508.9726.

4.4.9 **2-(5-(Bis(4-bromophenyl)methyl)furan-2-yl)cyclohexanone (16).** Following general procedure C, bis(4-bromophenyl)(furan-2-yl)methanol (408 mg, 1 mmol) and 1-(trimethylsiloxy)cyclohexene (0.19 mL, 1 mmol) produced 2-(5-(bis(4-bromophenyl)methyl)furan-2-yl)cyclohexanone (346.5 mg, 0.71 mmol, 71%) as a colorless oil. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.25 (10% ethyl acetate in hexanes). ^1H NMR (500 MHz, $CDCl_3$): δ 7.46-7.44 (m, 4H), 7.04 (d, J=8.4 Hz, 4H), 6.11 (d, J=2.9 Hz, 1H), 5.84 (d, J=2.55 Hz, 1H), 5.34 (s, 1H), 3.67 (dd, J=10.4 Hz, 5.2, 1H), 2.51-2.48 (m, 1H), 2.42-2.35 (m, 1H), 2.31-2.29 (m, 1H), 2.09-2.07 (m, 1H), 2.01-1.96 (m, 2H), 1.82-1.85 (m, 2H). ^{13}C $\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 208.2, 154.3, 152.4, 140.5, 131.6, 130.5, 120.9, 109.5, 107.2, 50.6, 49.7, 41.7, 32.3, 27.6, 24.5. HRMS (ESI-TOF): m/z $[M+Na]^+$ calcd for $C_{23}H_{20}Br_2O_2Na$ 508.9722, found 508.9729.

4.4.10 **2-(5-(Bis(4-phenoxyphenyl)methyl)furan-2-yl)cyclohexanone (17).** Following general procedure A, furan (0.2 mL, 3 mmol), *n*-butyllithium (1.1 eq, 3.3 mmol, 1.3 mL), and bis(4-phenoxyphenyl)methanone (1.1 eq, 3.3 mmol, 1.1 g) produced furan-2-ylbis(4-phenoxyphenyl)methanol (639 mg, 1.47 mmol, 49%) as a yellow oil. The product was purified using column chromatography (Biotage SNAP Ultra 50 g, 4-6% ethyl acetate in hexanes). TLC: 10% ethyl acetate in hexanes (Rf: 0.35). ^1H NMR (500 MHz, $CDCl_3$): δ 7.50-7.49 (m, 1H), 7.41-7.37 (m, 4H), 7.35-7.33 (m, 4H), 7.18-7.15 (m,

2H), 7.10-7.08 (m, 4H), 7.02 (d, J=8.8 Hz, 4H), 6.39-6.38 (m, 1H), 6.03-6.02 (m, 1H), 3.21 (s, 1H). ^{13}C {^{1}H} NMR (125 MHz, $CDCl_3$): δ 157.9, 156.96, 156.91, 142.7, 139.4, 129.8, 128.8, 123.6, 119.2, 118.0, 110.2, 109.6, 77.5. HRMS (ESI-TOF): m/z $[M+Na]^+$ calcd for $C_{29}H_{22}O_4Na$ 457.1410, found 457.1419. Following general procedure C, furan-2-yl bis(4-phenoxyphenyl)methanol (78 mg, 0.18 mmol) and 1-(trimethylsiloxy)cyclohexene (0.035 mL, 0.18 mmol) produced 2-(5-(bis(4-phenoxyphenyl)methyl)furan-2-yl)cyclohexanone (61 mg, 0.12 mmol, 66%) as a yellow oil. The product was purified using column chromatography (Biotage SNAP Ultra 25 g, 9-11% ethyl acetate in hexanes). TLC: 20% ethyl acetate in hexanes (Rf: 0.55). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.35 (t, J=8.1 Hz, 4H), 7.17 (d, J=8.5 Hz, 4H), 7.11 (t, J=7.3 Hz, 2H), 7.04 (d, J=8.4 Hz, 4H), 6.98 (d, J=8.6 Hz, 4H), 6.13 (d, J=3.1 Hz, 1H), 5.89 (d, J=3.1 Hz, 1H), 5.42 (s, 1H), 3.72 (dd, J= 10.6 , 5.3 Hz, 1H), 2.54-2.49 (m, 1H), 2.43-2.37 (m, 1H), 2.33-2.29 (m, 1H), 2.08-1.95 (m, 3H), 1.87-1.73 (m, 2H). ^{13}C {^{1}H} NMR (125 MHz, $CDCl_3$) δ 208.4, 157.2, 155.9, 155.6, 152.1, 136.94, 136.91, 130.0, 129.7, 123.2, 118.9, 118.68, 188.67, 109.0, 107.1, 50.7, 49.5, 41.6, 32.2, 27.6, 24.4. HRMS (ESI-TOF): m/z $[M+Na]^+$ calcd for $C_{35}H_{30}O_4Na$ 537.2036, found 537.2039.

4.4.11 **2-(2-Benzhydryl-1H-indol-3-yl)cyclohexanone (18).** Following general procedure B, ethyl indole-2-carboxylate (125 mg, 1.0 mmol) and phenyllithium (1.9 M in diethyl ether) (2.5 mmol, 1.3 mL) produced (1H-indol-2-yl)diphenylmethanol (284 mg, 0.95 mmol, 95%) as a white solid. Subsequent trial produced similar yields. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.35 (10% ethyl acetate in hexanes). NMR spectrum matched previously reported

data.[10] ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.39 (bs, 1H), 7.61 (d, J=7.8 Hz, 1H), 7.42-7.37 M, 10H), 7.30-7.24 (m, 2H), 7.20-7.17 (m, 1H), 3.23 (s, 1H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 145.3, 142.8, 136.2, 128.2, 127.9, 127.3, 122.4, 120, 9, 120.0, 111.2, 103.5, 79.1. Following general procedure C, (1H-indol-2-yl)diphenylmethanol (299 mg, 1 mmol) and 1-(trimethylsiloxy)cyclohexene (0.19 mL, 1 mmol) produced 2-(2-benzhydryl-1H-indol-3-yl)cyclohexanone (315 mg, 0.83 mmol, 83%) as a colorless oil. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.43 (10% ethyl acetate in hexanes). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.66 (s, 1H), 7.43-7.30 (m, 7H), 7.26-7.24 (m, 3H), 7.20 (d, J=7.2, 2H), 7.16-7.10 (m, 2H), 5.77 (s, 1H), 3.72-3.68 (m, 1H), 2.61 (d, J=14.4, 1H), 2.42-2.38 (m, 1H), 2.19-2.10 (m, 2H), 1.96-1.83 (m, 3H), 1.65-1.60 (m, 1H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 209.4, 142.2, 141.8, 135.9, 135.5, 129.1, 128.8, 128.7, 127.7, 127.03, 127.00, 121.4, 120.0, 119.4, 111.0, 110.8, 48.9, 48.8, 42.4, 34.4, 27.5, 25.9. HRMS (ESI-TOF): m/z $[M+H]^+$ calcd for $C_{27}H_{26}NO$ 380.2009, found 380.2015.

4.4.12 **2-(2-Benzhydrylbenzofuran-3-yl)cyclohexanone (19).** Following general procedure B, ethyl benzofuran-2-carboxylate (190 mg, 1 mmol) and phenyllithium (1.9 M in diethyl ether) (2.5 mmol, 1.3 mL) produced benzofuran-2-yldiphenylmethanol (87 mg, 0.29 mmol, 29%). Subsequent trial produced similar yields. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.45, (10% ethyl acetate in hexanes). NMR spectrum matched previously reported data.[11] ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.56 (d, J=7.7 Hz, 1H), 7.50 (d, J=8.2 Hz, 1H), 7.46 (d, J=7.4, 4H), 7.42-7.39 (m, 6H), 7.34 (t, J= 15.0 Hz, 1H), 7.29 (t, J= 8.0 Hz, 2H), 6.39 (s,

1H), 3.35 (s, 1H). ^{13}C {^{1}H} NMR (125 MHz, $CDCl_3$): δ 160.4, 155.2, 144.1, 128.2, 127.9, 127.4, 124.6, 123.0, 121.4, 111.5, 106.6, 78.5. Following general procedure C, benzofuran-2-yldiphenylmethanol (300 mg, 1 mmol) and 1-(trimethylsiloxy)cyclohexene (0.19 mL, 1 mmol) produced 2-(5-benzhydrylfuran-2-yl)cyclohexanone (346 mg, 0.86 mmol, 86%) as a white solid. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.72 (10% ethyl acetate in hexanes). MP 192-194 °C. ^{1}H NMR (300 MHz, $CDCl_3$ w/ TMS): δ 7.49-7.46 (m, 2H), 7.39-7.33 (m, 7H), 7.24-7.17 (m, 3H), 6.97-6.93 (m, 2H), 5.24 (d, J= 2.2 Hz, 1H), 2.39-2.29 (m, 2H), 2.02-1.92 (m, 3H), 1.78-1.77 (m, 1H), 1.48-1.40 (m, 2H) 1.05-0.99 (m, 1H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 210.4, 158.1, 155.5, 139.7, 139.2, 130.0, 129.5, 129.0, 128.3, 127.9, 127.3, 126.8, 126.6, 126.4, 122.2, 115.9, 108.4, 52.4, 43.3, 4.6, 27.1, 26.5, 24.8. HRMS (ESI-TOF): m/z $[M+Na]^+$ calcd for $C_{27}H_{24}O_2Na$ 403.1669, found 403.1672.

4.4.13 **2-(2-Benzhydrylbenzo[b]thiophen-3-yl)cyclohexanone (20).** Following general procedure B, methyl benzothiophene-2-carboxylate (192 mg, 1 mmol) and phenyllithium (1.9 M in diethyl ether) (2.5 mmol, 1.3 mL) produced benzo[b]thiophen-2-yldiphenylmethanol (141 mg, 0.45 mmol, 45%) as a white solid. Subsequent trial produced similar yields. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.35 (10% ethyl acetate in hexanes). NMR spectrum matched previously reported data.[11] ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.85-7.82 (m, 1H), 7.73-7.70 (m, 1H), 7.52-7.49 (m, 4H), 7.43-7.36 (m, 8H), 7.01 (s, 1H), 3.20 (s, 1H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$): δ 152.8, 145.9, 140.3, 139.3,

128.2, 127.9, 127.6, 124.5, 124.4, 123.8, 123.7, 122.4, 80.6. Following general procedure C, benzo[b]thiophen-2-yldiphenylmethanol (316 mg, 1 mmol) and 1-(trimethylsiloxy)cyclohexene (0.19 mL, 1 mmol) produced 2-(2-benzhydrylbenzo[b]thiophen-3-yl)cyclohexanone **20** (190 mg, 0.48 mmol, 48%) as a white solid. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.52 (10% ethyl acetate in hexanes). MP 154-156 ^oC. ^1H NMR (300 MHz, $CDCl_3$): δ 7.38-7.22 (m, 11H), 7.15-7.12 (m, 2H), 7.05-7.02 (m, 1H), 5.61 (d, J=1.6, 1H), 2.65-2.59 (m, 1H), 2.28-2.20 (m, 2H), 2.02-1.87 (m, 2H), 1.81-1.77 (m, 1H), 1.57-1.29 (m, 2H), 1.20-1.05 (m, 1H). ^{13}C {^1H} NMR (75 MHz, $CDCl_3$): δ 210.1, 142.9, 142.4, 140.9, 140.4, 139.1, 133.3, 129.1, 128.9, 128.8, 128.3, 127.7, 127.4, 127.2, 126.6, 124.7, 120.8, 56.6, 48.6, 41.4, 26.6, 26.4, 24.9. HRMS (ESI-TOF): m/z $[M+Na]^+$ calcd for $C_{27}H_{24}OSNa$ 419.1440, found 419.1440.

4.4.14 **2-(5-Benzhydrylthiophen-2-yl)cyclohexanone (21).** Following general procedure B, benzophenone (729 mg, 4 mmol), 2-thienyllithium (1M in hexane) (4.4 mmol, 4.4 mL) produced diphenyl(thiophen-2-yl)methanol (0.453 g, 1.70 mmol, 42%) as a white solid. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.40 (10% ethyl acetate in hexanes). NMR spectrum matched previously reported data.[12] ^1H NMR (300 MHz, $CDCl_3$): δ 7.42-7.33 (m, 10H), 7.31 (d, J=1.0 Hz, 1H), 6.99-6.96 (dd, J=5.1 Hz, 3.6, 1H), 6.75 (dd, J=3.6 Hz, 1.2, 1H), 2.96 (s, 1H). ^{13}C {^1H} NMR (75 MHz, $CDCl_3$): δ 152.3, 146.6, 128.0, 127.6, 127.3, 126.9, 126.5, 125.7, 80.1. Following general procedure C, diphenyl(thiophen-2-yl)methanol (266 mg, 1 mmol) and 1-(trimethylsiloxy)cyclohexene (0.19 mL, 1 mmol)

produced 2-(5-benzhydrylthiophen-2-yl)cyclohexanone **21** (163 mg, 0.46 mmol, 46%) as a yellow solid. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f:0.54 (10% ethyl acetate in hexanes). MP 151-152 ^oC. ^1H NMR (300 MHz, $CDCl_3$): δ 7.41-7.18 (m, 11H), 6.50 (dd, J=6.3, 1.7 Hz, 1H), 6.15 (dd, J=6.3, 3.0 Hz, 1H), 4.80-4.77 (m, 1H), 2.68 (quintet, J=6.2 Hz, 1H), 2.47-2.34 (m, 3H), 2.15-2.13 (m, 1H), 1.97-1.87 (m, 1H), 1,76-1.68 (m, 2H), 1.50-1.37 (m, 1H). ^{13}C {^1H} NMR (75 MHz, $CDCl_3$): δ 211.4, 143.3, 142.5, 142.2, 134.8, 132.8, 130.2, 129.5, 129.1, 128.14, 128.09 126.9, 126.7, 57.1, 54.5, 42.2, 30.6, 28.8, 25.2. HRMS (ESI-TOF): m/z $[M+H]^+$ calcd for $C_{23}H_{23}OS$ 347.1464, found 347.1461.

4.4.15 **2-(5-Benzhydryl-1H-pyrrol-2-yl)cyclohexanone (22).** Following general procedure B, methyl-2-pyrrolecarboxylate (125 mg, 1 mmol) and phenyllithium (1.9 M in diethyl ether) (2.5 mmol, 1.3 mL) produced diphenyl(1H-pyrrol-2-yl)methanol (104 mg, 0.42 mmol, 42%). Subsequent trial produced similar yields. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.40 (10% ethyl acetate in hexanes). NMR spectrum matched previously reported data.[13] ^1H NMR (300 MHz, $CDCl_3$): δ 8.33 (bs, 1H), 7.35 (s, 10H), 6.73 (d, J=1.0 Hz, 1H), 6.18 (d, J=2.8 Hz, 1H), 5.87 (s, 1H), 3.03 (s, 1H). ^{13}C {^1H} NMR (75 MHz, $CDCl_3$): δ 145.9, 136.3, 128.1, 127.5, 127.1, 118.2, 109.1, 108.0, 78.5. Following general procedure C, diphenyl(1H-pyrrol-2-yl)methanol (249 mg, 1 mmol) and 1-(trimethylsiloxy)cyclohexene (0.19 mL, 1 mmol) produced 2-(5-benzhydryl-1H-pyrrol-2-yl)cyclohexanone (72 mg, 0.22 mmol, 22%) as a yellow solid. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f:

0.50 (10% ethyl acetate in hexanes). ^{1}H NMR (300 MHz, $CDCl_3$): δ) 8.48 (bs, 1H), 7.35-7.21(m, 11H), 5,91 (t, J= 3.3 Hz, 1H), 5.69 (t, J=5.7, 1H), 5.46 (s, 1H), 3.66-3.56 (m, 1H), 2.51-2.37 (m, 3H), 2.07-1.95 (m, 3H), 1.82-1.75 (m, 2H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 211.2, 143.22, 143.17, 133.3, 128.9, 128.4,126.6, 107.6, 105.3, 50.7,49.0, 41.6, 33.6, 27.3, 24.5. HRMS (ESI-TOF): m/z $[M+Na]^+$ calcd for $C_{23}H_{23}NONa$ 352.1672, found 352.1671.

4.4.16 **2-(5-(Phenyl(thiophen-2-yl)methyl)furan-2-yl)cyclohexanone (23).** Following general procedure A, furan (0.168 mL, 2.5 mmol), *n*-butyllithium (2.75 mmol, 1.1 mL) and 2-benzoylthiphene (3.0 mmol, 0.564 g) produced furan-2-yl(phenyl)(thiophen-2-yl)methanol (454 mg, 1.77 mmol, 71%) as a white solid. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 0.48 (10% ethyl acetate in hexanes). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.55-7.49 (m, 3H), 7.44-7.40 (m, 3H), 7.36-7.35 (m, 1H), 7.03-7.01 (m, 1H), 6.90-6.89 (m, 1H), 6.42-6.41 (m, 1H), 6.18-6.17 (m, 1H), 3.50 (d, J=0.7 Hz, 1H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 157.3, 149.4, 144.0, 142.7, 128.1, 128.0, 126.7, 126.4, 125.8, 110.2, 109.2, 76.1. HRMS (ESI-TOF): m/z $[M-H_2O]^+$ calcd for $C_{15}H_{11}OS$ 239.0525, found 235.0529. Following general procedure C, furan-2-yl(phenyl)(thiophen-2-yl)methanol (256 mg, 1 mmol) and 1-(trimethylsiloxy)cyclohexene (0.19 mL, 1 mmol) produced 2-(5-(phenyl(thiophen-2-yl)methyl)furan-2-yl)cyclohexanone (108 mg, 0.32 mmol, 32%) as an oil. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f: 43 (10% ethyl acetate in hexanes). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.33- 7.26 (m, 5H), 7.21-7.19 (m, 1H), 6.94-6.93 (m, 1H), 6.83-6.82 (m, 1H), 6.12 (d, J= 3.1 Hz, 1H), 6.00-

5.99 (m, 1H), 5.63 (s, 1H), 3.68 (dd, J= 10.7 Hz, 5.4, 1H), 2.50-2.25 (m, 4H), 2.08-1.89 (m, 3H), 1.88-1.70 (m, 2H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 208.3, 154.9, 152.0, 145.5, 141.7, 128.5, 128.4, 127.0, 126.5, 125.9, 124.5, 108.6, 107.2, 50.6, 46.1, 41.5, 32.4, 27.6, 24.3. HRMS (ESI-TOF): m/z $[M+H]^+$ calcd for $C_{21}H_{20}O_2S$ 337.1257, found 337.1261.

4.4.17 **2-(2-benzhydryl-1H-indol-3-yl)cyclopentanone (24).** Following general procedure C, (1H-indol-2-yl)diphenylmethanol (299 mg, 1 mmol) and 1-(trimethylsiloxy)cyclopentene (0.18 mL, 1 mmol) produced 2-(2-benzhydryl-1H-indol-3-yl)cyclopentanone (223 mg, 0.61 mmol, 61%) as a colorless oil. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, (Rf: 0.41 (10% ethyl acetate in hexanes). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.68 (bs, 1H), 7.39-7.37 (m, 4H), 7.36-7.28 (m, 3H), 7.25-7.21 (m, 5H), 7.16-7.13 (m, 1H), 7.11-7.08 (m, 1H), 5.79 (s, 1H), 3.49-3.45 (m, 1H), 2.56-2.50 (m, 1H), 2.45-2.37 (m, 1H), 2.14-2.04 (m, 3H), 1.84-1.80 (m, 1H). ^{13}C {^{1}H} NMR (125 MHz, $CDCl_3$) δ 219.0, 142.0, 141.6, 137.1, 135.5, 129.2, 129.0, 128.8, 128.9, 128.8, 127.11, 127.10, 127.0, 121.6, 119.6, 118.9, 111.2, 109.8, 48.7, 47.6, 38.6, 30.8, 21.3. HRMS (ESI-TOF): m/z $[M+H]^+$ calcd for $C_{26}H_{24}NO$ 366.1852, found 366.1840.

4.4.18 **2-(2-Benzhydryl-1H-indol-3-yl)-3,4-dihydronaphthalen-1(2H)-one (25).** Following general procedure C, (1H-indol-2-yl)diphenylmethanol (299 mg, 1 mmol) and (3,4-Dihydro-1-napthyloxy)trimethylsilane (0.22 mL, 1 mmol) produced 2-(2-benzhydryl-1H-indol-3-yl)-3,4-dihydronaphthalen-1(2H)-one (180 mg, 0.40 mmol, 40%) as a colorless oil. The product was purified using column chromatography (10% ethyl

acetate in hexanes). TLC, R_f 0.40 (10% ethyl acetate in hexanes). ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.21 (dd, J=8.0, 1.5, 1H), 7.69 (bs, 1H), 7.54 (td, J= 6.0 Hz, 1.4, 1H), 7.55-7.23 (m, 14H), 7.15-7.12 (m, 1H), 7.05-7.02 (m, 1H), 5.82 (s, 1H), 2.93-2.91 (m, 2H), 2.55-2.48 (m, 1H), 2.00-1.96 (m, 1H). ^{13}C {^{1}H} NMR (125 MHz, $CDCl_3$) δ 197.8, 144.3, 142.2, 141.6, 136.5, 135.6, 133.3, 133.1, 129.2, 129.1, 128.8, 128.7, 127.9, 127.4, 127.04, 127.01, 126.7, 121.5, 119.6, 119.5, 111.9, 111.1, 48.9, 46.6, 30.6, 30.1. HRMS (ESI-TOF): m/z $[M+Na]^+$ calcd for $C_{31}H_{24}NONa$ 450.1828, found 450.1836.

4.4.19 **2-(2-Benzhydryl-1H-indol-3-yl)-1-phenylethanone (26).** Following general procedure C, (1H-indol-2-yl)diphenylmethanol (299 mg, 1 mmol) and 1-phenyl-1-trimethylsiloxyethylene (0.21 mL, 1 mmol) produced 2-(2-benzhydryl-1H-indol-3-yl)-1-phenylethanone (339 mg, 0.80 mmol, 80%) as a colorless oil. The product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f, 0.40 (10% ethyl acetate in hexanes). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.97 (dd, J= 8.1 Hz, 0.9, 2H), 7.79 (bs, 1H), 7.62-7.59 (m, 2H), 7.44-7.27 (m, 7H), 7.26-7.16 (m, 7H), 5.93 (s, 1H), 4.31 (2,2H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 197.9, 141.7, 137.2, 137.0, 135.4, 132.9, 129.1, 128.9, 128.8, 128.5, 128.4, 127.0, 121.7, 119.9, 118.6, 111.0, 105.8, 48.7, 35.9. HRMS (ESI-TOF): m/z $[M+Na]^+$ calcd for $C_{29}H_{22}NONa$ 424.1672, found 424.1681.

4.4.20 **2-(Benzo[b]thiophen-2-yldiphenylmethyl)cyclohexanone (27).**Following general procedure C, benzo[b]thiophen-2-yldiphenylmethanol (316 mg, 1 mmol) and 1-(trimethylsiloxy)cyclohexene (0.19 mL, 1 mmol) produced 2-(benzo[b]thiophen-2-yldiphenylmethyl)cyclohexanone (154 mg, 0.39 mmol, 39%) as a colorless oil. The

product was purified using column chromatography (10% ethyl acetate in hexanes). TLC, R_f 0.51 (10% ethyl acetate in hexanes). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.40-7.36 (m, 5H), 7.34-7.30 (m, 2H), 7.27-7.24 (m, 4H), 7.17-7.12 (m, 2H), 7.05-7.02 (m, 1H), 5.14 (d, J= 8.5 Hz, 1H), 2.67-2.61 (m, 1H), 2.39-2.33 (m, 1H), 2.31-2.27 (m, 1H), 2.20-2.14 (m, 1H), 1.97-1.88 (m, 1H), 1.78-1.72 (m, 1H), 1.59-1.47 (m, 2H), 1.40-1.31 (m,1H). ^{13}C {^{1}H} NMR (125 MHz, $CDCl_3$): δ 210.4, 142.5, 141.7, 141.2, 140.4, 140.2, 138.1, 130.1, 129.1, 128.7, 128.1, 127.8, 127.5, 127.3, 125.8, 124.5, 121.4, 57.9, 49.4, 42.8, 33.1, 28.3, 25.4. HRMS (ESI-TOF): m/z $[M+Na]^+$ calcd for $C_{27}H_{24}SONa$ 419.1440, found 419.1440.

Declaration of competing interest. The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at

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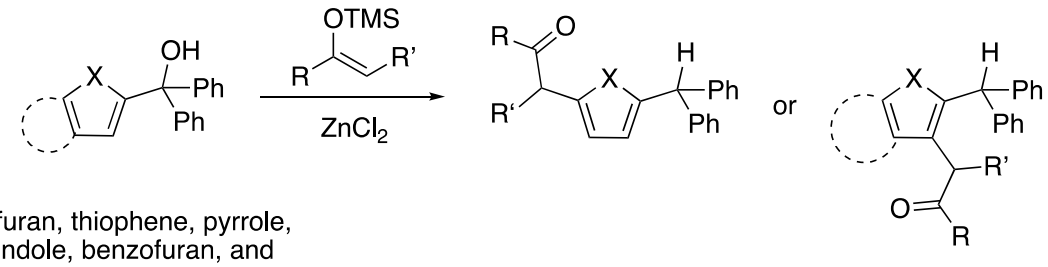
Graphical Abstract:



furan, thiophene, pyrrole, indole, benzofuran, and benzothiophene