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Iron-Promoted Domino Dehydrogenative Annulation of Deoxybenzoins and Alkynes Leading to β-Aryl-α-Naphthols

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Abstract: A strategy for synthesis of β-aryl-α-naphthols has been established through an iron-promoted domino C(sp^3)–H/C(sp)–H and C(sp^2)–H/C(sp)–H dehydrogenative coupling of deoxybenzoins and alkynes. The synthesis uses inexpensive materials with a broad substrate scope and features simple operations with excellent regioselectivity. This study provides an alternative access to various β-aryl-α-naphthols and the synthetic protocol should have potential applications in medicinal, materials science, and related areas.

Keywords: β-Aryl-α-naphthols; Iron-promoted; C-H functionalization; Deoxybenzoins; Radical reactions

Introduction

β-Aryl-α-naphthol structural motif is embedded in numerous natural and bioactive molecules (Figure1).[1] These molecules have shown a wide range of pharmacological activities including anti-HIV, anti-viral, antitumor, and anticancer properties.[2] In addition to their interesting pharmacological activities, these molecules also possess remarkable electrochemical and photochemical properties and can be used as valuable synthetic intermediates for functional materials.[3] Naphthol-derived axially chiral compounds are widely used as chiral ligands in metal complexes and catalysts.[4] Suzuki-type cross-coupling reaction between α-naphthols and aryl partners is the typical method for the preparation of β-aryl-α-naphthols (Scheme 1a).[5] However, this method requires use of a multistep process and/or starting materials which are difficult to access. Recently, several groups[6a–f] reported efficient syntheses of highly substituted

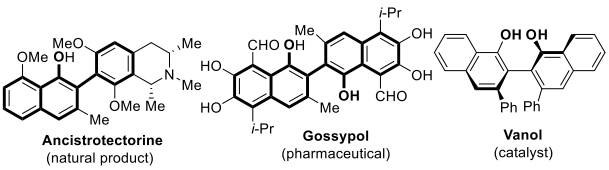
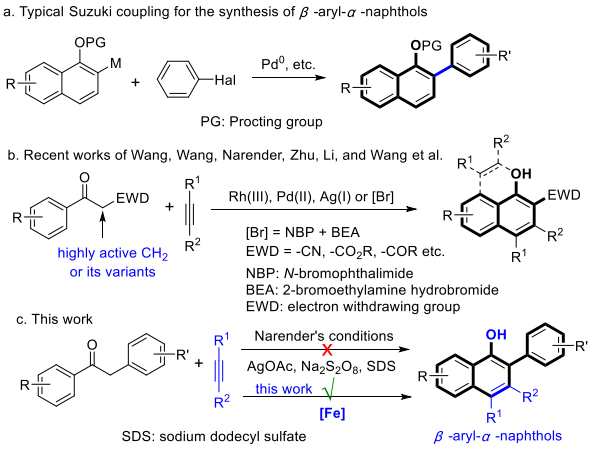


Figure 1. The compounds containing β-aryl-α-naphthol.



Scheme 1. The synthesis of β-aryl-α-naphthols.

α-naphthol via an elegant direct intermolecular C–H functionalization process (Scheme 1b). Although the method is concise and powerful, the protocol requires use of substrates possessing an active methylene group or its variant. Indeed, we could well repeat Narender's results[6c] with ethyl benzoylacetate and phenylacetylene (**2a**) as the substrates, but the reaction of deoxybenzoin (**1a**) with phenylacetylene under the same conditions did not give the desired β-phenyl-α-naphthol product, indicating that deoxybenzoins are the challenging substrates for the reaction (Scheme 1c). We were attracted by the

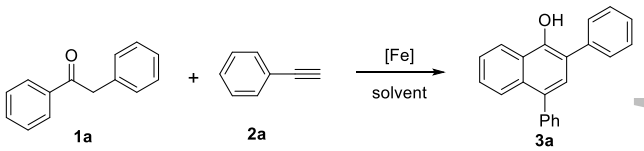
efficiency in transforming deoxybenzoins and arylacetylenes into β-aryl-α-naphthols in terms of atom- and step-economy, and environmentally benign profiles and were motivated to explore the essential reaction conditions.

At present, while the precious metal catalysts (especially platinum-group metals: Ru, Rh, Pd etc.) are ubiquitous in laboratory and industry applications, there is a growing impetus to replace them with much more sustainable and earth-abundant metals.[7] This is due to not only the scarce and expensive nature of the precious metals, but also their relatively high toxicity.[8] Among the earth-abundant metals, iron is particularly attractive because it is the second most abundant metal on earth and is one of the cheapest of all metals. Moreover, iron is closely related to the life and plays a very important role in the human body as a "king metal".[9] Recently, the iron-catalyzed organic transformations have received great attentions.[10] Despite considerable progresses have been made in the field, iron catalysis is still in its infancy. Herein, we report on an iron-promoted domino dehydrogenative annulation of deoxybenzoins with alkynes to form β-aryl-α-naphthols. To the best of our knowledge, this is the first report that allows the synthesis of various β-aryl-α-naphthols in an effective and concise manner by direct intermolecular dehydrogenation annulation of deoxybenzoins and alkynes.

Results and Discussion

Our investigation started with a reaction between deoxybenzoin (**1a**) and phenylacetylene (**2a**) in xylene with 15 mol % of iron species as the catalyst and potassium persulfate ($K_2S_2O_8$) as the oxidant at 135 ºC in air. To our delight, the desired product **3a** was obtained with the catalyst $FeSO_4$, $FeCl_3$ or Fe_2O_3 (Table 1, entries 1–3) with Fe_2O_3 affording the best result. Then, using Fe_2O_3 as the catalyst, other oxidants were examined. $Na_2S_2O_8$ provided a slightly low yield (51%, entry 4), while 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) gave a better yield (62%, entry 5). Other oxidants, such as *tert*-butyl hydroperoxide,[11] hydrogen peroxide (30 wt.% in water), dicumyl peroxide, di-*tert*-butyl peroxide,[12] 2-iodoxybenzoic acid, and $PhI(OAc)_2$, provided less than 50% yields (entry 6). Considering that Fe_2O_3 can also act as the oxidant and is much cheaper than DDQ, 1.00 equiv of Fe_2O_3 was used along without adding another oxidant. It is pleased to observe an improved yield of **3a** to 65% (entry 7). Next, the reaction was investigated under different atmospheres. It was demonstrated that oxygen was inferior to the reaction, whereas argon atmosphere provided the best yield (82%, entry 8 vs. entry 9). Use of other iron species including a variety of Fe^{2+} and Fe^{3+} salts instead of Fe_2O_3 led to decreased yields or no formation of the desired product **3a** (entry 10). Optimization on reaction temperatures and solvents indicated that 135 ºC and xylene remained the best combination (entries 11 and 12). A control experiment showed that, in the absence of Fe_2O_3, the product **3a** could not be detected under otherwise identical conditions (entry 13). Finally, in the absence of the iron catalyst, other oxidants failed to promote this transformation. $K_2S_2O_8$ (1.00 equiv) and DDQ (1.00 equiv) only provided 11% and 9% yields, respectively; and $PhI(OAc)_2$ (1.00 equiv) did not generate **3a** (entry 14).

Table 1. Optimization of conditions for the synthesis of β-aryl-α-naphthol **3a**.[a]



Entry	[Fe] (equiv)	Temp. (ºC)	Sol-vent	Atmo-sphere	Yield (%)[b]
1[c]	$FeSO_4$ (0.15)	135	xylene	air	15
2[c]	$FeCl_3$ (0.15)	135	xylene	air	5
3[c]	Fe_2O_3 (0.15)	135	xylene	air	53
4[d]	Fe_2O_3 (0.15)	135	xylene	air	51
5[e]	Fe_2O_3 (0.15)	135	xylene	air	62
6[f]	Fe_2O_3 (0.15)	135	xylene	air	<50
7	Fe_2O_3 (1.00)	135	xylene	air	65
8	Fe_2O_3 (1.00)	135	xylene	O_2	40
9	Fe_2O_3 (1.00)	135	xylene	Ar	82
10[g]	Other irons (1.00)	135	xylene	Ar	<55
11[g]	Fe_2O_3 (1.00)	others	xylene	Ar	<76
12[g]	Fe_2O_3 (1.00)	others	others	Ar	<47
13	–	135	xylene	Ar	0
14[h]	–	135	xylene	Ar	<12

[a] Reaction conditions: unless otherwise noted, the reaction was carried out with **1a** (0.5 mmol) and **2a** (1.0 mmol) in solvent (3 mL) under Ar (1 atm) atmosphere at 135 ºC for 20 h. [b] Isolated yields. [c] Using $K_2S_2O_8$ (1.00 equiv) as the oxidant. [d] Using $Na_2S_2O_8$ (1.00 equiv) as the oxidant. [e] Using DDQ (1.00 equiv) as the oxidant. [f] Using other oxidant: *tert*-butyl hydroperoxide (1.00 equiv, 21% yield), hydrogen peroxide (30 wt. % in water, 1.00 equiv, 16% yield), dicumyl peroxide (1.00 equiv, 41% yield), di-*tert*-butyl peroxide (1.00 equiv, 49% yield), 2-iodoxybenzoic acid (1.00 equiv, 17% yield), and $PhI(OAc)_2$ (1.00 equiv 37% yield) [g] See the Supporting Information. [h] In the absence of iron catalyst, $K_2S_2O_8$ (1.00 equiv) and DDQ (1.00 equiv) provided 11% and 9% yields, respectively, and $PhI(OAc)_2$ (1.00 equiv) did not provide **3a**.

Having established the optimal reaction conditions, we next examined the substrate scope and generality of the iron-promoted dehydrogenative annulation. Deoxybenzoins (**1**) bearing either an electron-donating or electron-withdrawing group on both aromatic rings all reacted smoothly with the alkyne

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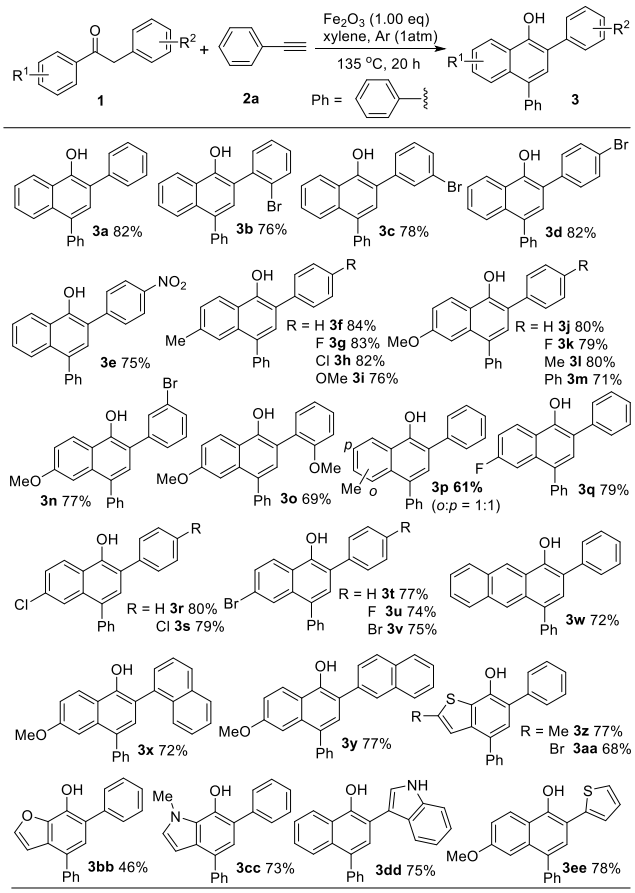
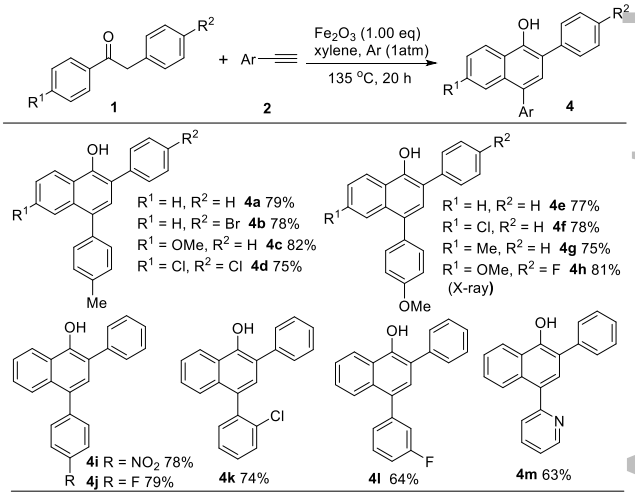


Scheme 2. Substrate scope of deoxybenzoins. The reaction was carried out with **1** (0.5 mmol), **2a** (1.0 mmol) and Fe_2O_3 (0.5 mmol) in xylene (3 mL) under Ar (1 atm) atmosphere at 135 ºC for 20 h. Isolated yields are given.

2a to afford the desired β-aryl-α-naphthols (**3**) in good yields (Scheme 2). Various functional groups, such as fluoro, chloro, bromo, methyl, methoxy, phenyl, and nitro groups were tolerated under the conditions, which provided great opportunities for further functionalization of the compounds **3b**–**3v**. Tolerance of the C–Br bond under the annulation conditions is remarkably valuable due to many opportunities for synthetic manipulation of the C–Br bond under mild conditions. It is found that the deoxybenzoin with *meta*-substitute on the left aromatic ring reacted with **2a** successfully to afford the annulated product **3p**, while the *ortho*-substituted analogue didn't react with **2a**, presumably caused by a steric effect. The anthracene and binaphthyl compounds **3w**–**3y** could be obtained in 72–77% yield, implying that the extended ring systems on both reaction partners did not exert visible influence on the annulation. The synthesized binaphthyls are found in many axial chiral catalysts (e.g. vanols),[13] and the current synthetic method should have broad applications in the catalysis area. Heteroarenes are prevalent in many biologically relevant molecules. Gratifyingly, the substrates with heteroaromatic rings on the left side of **1**, such as thiophene, furan, and pyrrole rings, were also suitable for the annulation reaction to afford the desired benzothiophene, benzofuran, and indole products **3z**–**3cc** in 46–77% yields, respectively. Similarly, the substrates **1** with a heteroaromatic ring on the other side, such as indole and thiophene rings, reacted smoothly with **2a**, to afford the corresponding products **3dd** and **3ee** in 75% and 78% yields, respectively. It should be mentioned that the phenyl group of phenylacetylene (**2a**) was only found at the C4 position of α-naphthols, and no 3-phenyl isomers could be detected in the reaction mixtures. The results indicated that the annulation reaction features excellent regioselectivity. β-Ketoester (e.g. ethyl benzoylacetate) is an enabling substrate in many organic reactions, but it could not react with **2a** to generate the corresponding α-hydroxy-β-naphthoate under the current reaction conditions. It suggests that our annulation protocol has remarkable selectivity for deoxybenzoin substrates.

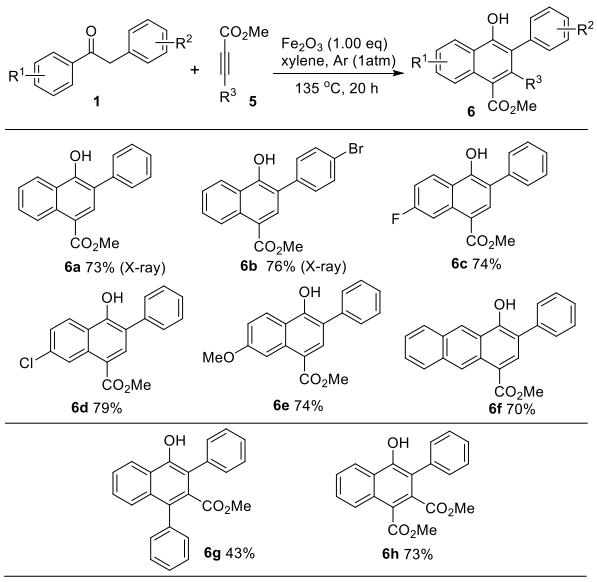
Then, we applied the iron-promoted annulation using a series of aryl-substituted alkynes. As illustrated in Scheme 3, both electron-donating (Me, OMe) and electron-withdrawing (NO_2, F and Cl) substituents were well tolerated on the phenyl ring of **2** to furnish the products **4a**–**4l**. 2-Ethynylpyridine, which contains a heterocycle moiety, was compatible with the reaction conditions to afford the product **4m** in 63% yield. Again the reaction showed excellent regioselectivity with the aryl group of arylacetylenes attached to the C4-position of α-naphthols. The structure of **4h** was confirmed by single crystal X-ray structural analysis (see the Supporting Information).



Scheme 3. Substrate scope of arylacetylenes. Reaction conditions: 1 (0.5 mmol), 2 (1.0 mmol) and Fe_2O_3 (0.5 mmol) in xylene (3 mL) under Ar (1 atm) atmosphere at 135 ºC for 20 h. Isolated yields are given.

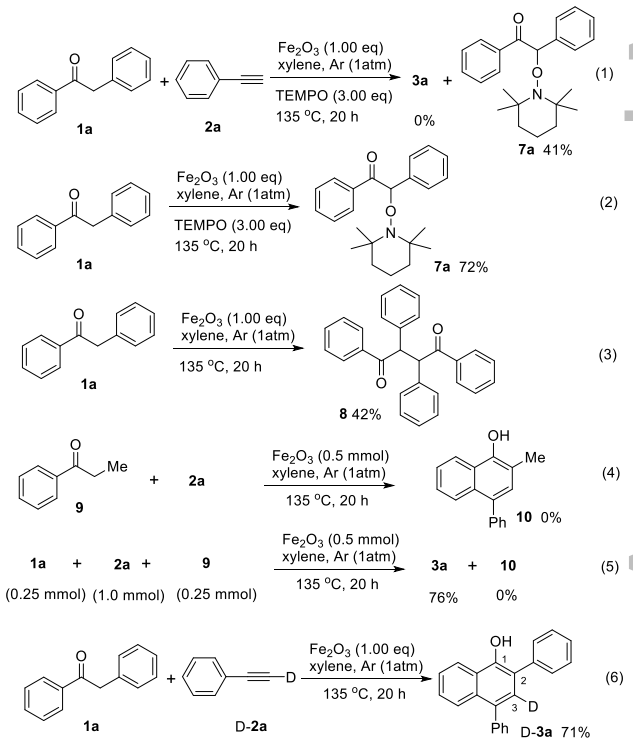
Next, methyl propiolate (**5, R^3 = H)**, a non-aryl-substituted alkyne, was examined for the annulation (Scheme 4). It was pleased to find that methyl propiolate was also suitable for the iron-promoted

annulation with various deoxybenzoins to provide the desired β-aryl-α-naphthols **6a**–**6f** in 70–79% yields. The excellent regioselectivity was observed, namely, the methoxycarbonyl group was found at the C4-position of the α-naphthols and the C3-substituted isomers were not detected. The structure of the products **6a** and **6b** were unambiguously confirmed by single crystal X-ray diffraction analysis (see the Supporting Information). Finally, two internal alkynes were investigated for the annulation. Methyl phenylpropiolate (**5g**, R^3 = Ph) and dimethyl acetylenedicarboxylate (**5h**, R^3 = CO_2Me) reacted with **1a** successfully to give the corresponding products **6g** and **6h** in 43% and 73% yields, respectively. Excellent regioselectivity was also observed for the formation of **6g** from the unsymmetrical alkyne. In the previous reports,[14] the reaction of 1-phenylpropan-2-one and **2a** could produce the naphthalene product. However, we did not detect any similar naphthalene derivative under our annulation conditions.



Scheme 4. Annulation of propiolates. The reaction was carried out with **1** (0.5 mmol), **5** (1.0 mmol) and Fe_2O_3 (0.5 mmol) in xylene (3 mL) under Ar (1 atm) atmosphere at 135 ºC for 20 h. Isolated yields are given.

To understand the mechanism of the reaction, we carried out a series of control experiments. First, under the standard reaction conditions, 2,2,6,6-tetramethylpiperidinooxy (TEMPO, 3.0 equiv) was introduced into the reaction system of **1a** and **2a**. After 20 hours at 135 ºC, instead of **3a**, the adduct **7a** formed from **1a** and TEMPO was isolated in 41% yield along with recovery of **1a** (48%) and **2a** (96%) (Eq. 1). The results indicated that the benzoyl-stabilized benzyl radical should be formed in the reaction. Then, additional control experiments were implemented under the above standard reaction conditions. Without the alkyne **2a**, **1a** reacted with TEMPO to afford **7a** in 72% yield (Eq. 2). In the absence of both the alkyne **2a** and TEMPO, the homocoupling dimer **8** of **1a** was obtained in 42% yield (Eq. 3). These results further demonstrated that the benzyl radical was very likely involved in the iron-promoted annulation reaction. Finally, the ketone **9** was used to react with **2a** under the standard reaction conditions, but the annulation product **10** was not generated at all (Eq. 4). A competitive reaction of **1a** and **9** with the alkyne **2a** was carried out (Eq. 5). Interestingly, it only afforded **3a** in 76% yield, but **10** was not detected. This finding indicated that the current annulation protocol has good preference for the reaction of deoxybenzoins. In order to identify the origin of the C3-hydrogen atom of β-aryl-α-naphthols, an experiment using the deuterium-labeled D-**2a** was carried out (Eq. 6). The reaction of **1a** with deuterated phenylacetylene D-**2a** proceeded smoothly under the standard reaction conditions to give the corresponding D-**3a** in 71% yield with the deuterium totally incorporated into the C3-position. The results implied that the C3-H of β-aryl-α-naphthols came from the terminal alkynes which should engage in an addition reaction in the annulation process.



On the basis of the above results and the related reports in the literature,[15] a tentative reaction mechanism for the iron-promoted dehydrogenative annulation of deoxybenzoins with alkynes to form β-

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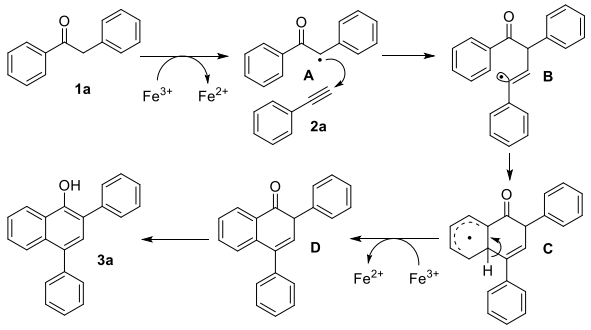
aryl-α-naphthols is proposed in Scheme 5. Initially, Fe^{3+} oxidizes the substrate **1a** to generate the stabilized radical **A**,[16] which subsequently undergoes a regioselective addition reaction to the alkyne **2a** to form the vinyl radical **B**. The observed regioselectivity of the addition might be attributed to the stabilization of the vinyl radical by the ajacent aryl group.[17] Intramolecular cyclization of **B** produces the cyclic radial intermediate **C**, which might be converted into **D** by Fe^{3+} oxidation and deprotonation. Finally, keto–enol tautomerism transforms **D** into the desired product **3a**. In the reaction, argon atmosphere was found superior than air and oxygen presumably due to the inhibition of the radical reaction by molecular oxygen.[18]



Scheme 5. Proposed annulation mechanism.

Conclusion

In summary, we have developed a novel approach for the synthesis of β-aryl-α-naphthols through an iron-promoted domino $C(sp^3)$−H/C(sp)−H and $C(sp^2)$−H/C(sp)−H dehydrogenative couplings of deoxybenzoins and alkynes. The new strategy features inexpensive materials and simple reaction conditions, excellent functional group tolerance, good substrate scope, and excellent regioselectivity. The described protocol should have general applications in the synthesis of various bioactive and functional β-aryl-α-naphthols. Preliminary mechanistic studies indicate that the annulation proceeds via a radical process. Further transformations of β-aryl-α-naphthols are currently underway and the results will be reported in due course.

Experimental Section

General information: All reactions were carried out under argon. Unless otherwise noted, all commercial reagents and solvents were used as received without further purification. Most of reagents bought from Adamas-beta. Analytical thin-layer chromatography was performed with 0.25 mm pre-coated commercial silica gel plates (TLC Silica Gel 60 F254), visualization of the developed chromatogram was performed by fluorescence. Flash column chromatography was performed over silica gel (200–300 mesh). Proton nuclear magnetic resonance (^{1}H NMR) spectra and carbon-13 nuclear magnetic resonance (^{13}C NMR) spectra were recorded on Bruker UltraShield□400 (400 MHz) spectrometer or Varian Unity Inova-400 (400 MHz) spectrometer (^{1}H and ^{13}C NMR at 400 and 100 MHz, respectively). ^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ (TMS, δ = 0.00 ppm for ^{1}H and δ = 77.10 ppm for ^{13}C) or DMSO-d_6 (δ = 2.50 ppm for 1H and δ = 39.52 ppm for ^{13}C) using the solvent residue peaks as the internal references. Multiplicities are reported as follows: s = singlet, d = doublet, t = triplet, m = multiplet, br. s = broad singlet. Infrared (IR) data were recorded using film on potassium bromide plate on a Bruker Tensor 27 FT-IR spectrometer. Absorbance frequencies are reported in reciprocal centimeters (cm^{-1}). High resolution mass spectra were acquired on a Bruker Daltonics MicroTof-QII mass spectrometer. X-ray single crystal structural analyses were performed on Bruker Smart APEXIICCD instrument using Mo-Kα radiation. The structures were solved and refined using the SHELXTL software package.

General procedure for β-Aryl-α-Naphthols: A 10 mL round-bottom flask was charged with 2-phenylacetophenone derivatives (0.5 mmol), Fe_2O_3 (0.5 mmol) and xylene (3 mL). Then, the flask was degassed for 50 seconds, and then was filled with argon gas. After alkyne derivative (1.0 mmol) was added, the resultant mixture was stirred at 135 ºC for 20 h under argon. The reaction mixture was cooled to room temperature and was filtered off through a small pad of silica gel with rinsing by EtOAc. The combined filtrate was concentrated under reduced pressure and the residue was then purified by flash column chromatography over silica gel to afford the desired product.

2,4-Diphenylnaphthalen-1-ol (3a):[19] 121.4 mg, 82% yield; White solid; mp = 103–104 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.44 (s, 1H), 8.42 (d, J = 8.3 Hz, 1H), 7.81 (d, J = 8.3 Hz, 1H), 7.68 (d, J = 7.5 Hz, 2H), 7.56–7.56 (m, 1H), 7.51–7.39 (m, 8H), 7.37–7.31 (m, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 148.6, 140.1, 138.7, 131.8, 131.3, 130.0 (× 2), 129.7 (× 2), 129.5, 128.5 (× 2), 128.3 (× 2), 127.1, 126.8, 126.5, 126.3, 125.3, 125.2, 123.0, 122.9; IR (film): 3502, 3051, 3024, 2922, 2852, 1630, 1572, 1496, 1412, 1367, 1049, 1022, 758, 702 cm^{-1}; HRMS (ESI) m/z calculated for $C_{22}H_{15}O^-$ [M–H]$^-$: 295.1128; found 295.1130.

2-(2-Bromophenyl)-4-phenylnaphthalen-1-ol (3b): 142.1 mg, 76% yield; White solid; mp = 67–68 ºC; Eluant EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.43 (s, 1H), 8.39 (d, J = 8.0 Hz, 1H), 7.84 (d, J = 8.0 Hz, 1H), 7.74 (d, J = 8.0 Hz, 1H), 7.61–7.38 (m, 9H), 7.36–7.29 (m, 1H), 7.11 (s, 1H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 148.9, 139.9, 139.4, 132.6, 132.6, 131.6, 130.6, 129.9 (× 2), 129.6, 129.3, 128.5 (× 2), 127.6, 127.0, 126.7, 125.7, 125.2, 125.2, 124.1, 123.1, 122.1; IR (film): 3523, 3055, 2922, 2852, 1572, 1448, 1371, 1209, 1024, 858, 756, 698 cm^{-1}; HRMS (ESI) m/z calculated for $C_{22}H_{14}BrO^-$ [M-H]$^-$: 373.0234; found 373.0237.

2-(3-Bromophenyl)-4-phenylnaphthalen-1-ol (3c): 145.8 mg, 78% yield; White solid; mp = 69–70 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.63 (s, 1H), 8.44 (d, J = 8.4 Hz, 1H), 7.90 (s, 1H), 7.81 (d, J = 8.3 Hz, 1H), 7.66 (d, J = 7.6 Hz, 1H), 7.59–7.44 (m, 7H), 7.39 (t, J = 7.6 Hz, 2H), 7.33 (s, 1H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 148.9, 141.1, 139.9, 132.3, 131. 9, 131.6, 130.4, 130.0 (× 2), 129.5, 128.9, 128.7, 128.4 (× 2), 127.1, 126.7, 126.2, 125.4, 125.3, 123.0, 121.6, 121.4; IR (film): 3545, 3060, 2925, 1718, 1660, 1577, 1450, 1373, 1211, 1049, 883, 768, 702 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{22}H_{14}BrO^-$ [M-H]$^-$: 373.0234; found 373.0235.

2-(4-Bromophenyl)-4-phenylnaphthalen-1-ol (3d): 153.3 mg, 82% yield; White solid; mp = 88–89 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.57 (s, 1H), 8.41 (d, J = 8.4 Hz, 1H), 7.80 (d, J = 8.3 Hz, 1H), 7.63 (s, 4H), 7.60–7.46 (m, 6H), 7.45–7.38 (m, 1H), 7.30 (s, 1H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 148.8, 140.0, 137.9, 131.8 (× 3), 131.5, 131.2 (2C), 130.0 (× 2), 128.9, 128.5 (× 2), 127.1, 126.7, 126.2, 125.4, 125.3, 123.0, 121.6, 120.1; IR (film): 3541, 3458, 3064, 3021, 2925, 2854, 1660, 1595, 1489, 1365, 1217, 829, 758, 702 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{22}H_{14}BrO^-$ [M-H]$^-$: 373.0234; found 373.0240.

2-(4-Nitrophenyl)-4-phenylnaphthalen-1-ol (3e): 127.9 mg, 75% yield; Yellow solid; mp = 172–173 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.88 (s, 1H), 8.44 (d, J = 8.3 Hz, 1H), 8.30 (d, J = 8.6 Hz, 2H), 7.98 (d, J = 8.6 Hz, 2H), 7.81 (d, J = 8.3 Hz, 1H), 7.65–7.48 (m, 6H), 7.44 (dd, J = 8.7, 4.4 Hz, 1H), 7.38 (s, 1H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 149.5, 145.9, 145.9, 139.8, 132.2, 132.0, 130.9 (× 2), 130.0 (× 2), 128.6, 128.5 (× 2), 127.2 (× 2), 126.2, 125.6, 125.4, 123.4 (× 2), 123.2, 120.8; IR (film): 3425, 2922, 2850, 1595, 1516, 1344, 1205, 1103, 1047, 849, 769, 694 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{22}H_{14}NO_3^-$ [M-H]$^-$: 340.0979; found 340.0984.

6-Methyl-2,4-diphenylnaphthalen-1-ol (3f): 130.2 mg, 84% yield; White solid; mp = 82–83 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.36 (s, 1H), 8.32 (d, J = 8.6 Hz, 1H), 7.67 (d, J = 7.2 Hz, 2H), 7.58 (s, 1H), 7.52–7.37 (m, 8H), 7.33 (t, J = 7.4 Hz, 1H), 7.28 (s, 1H), 2.39 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 148.7, 140.3, 138.8, 135.6, 131.6, 131.7, 129.9 (× 2), 129.7 (× 2), 129.6, 128.5 (× 2), 128.3 (× 2), 127.3, 126.9, 126.7, 124.5, 124.1, 123.0, 122.1, 21.5; IR (film): 3423, 3026, 2922, 1657, 1601, 1493, 1444, 1238, 1028, 758, 696 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{23}H_{17}O^-$ [M-H]$^-$: 309.1285; found 309.1292.

2-(4-Fuorophenyl)-6-methyl-4-phenylnaphthalen-1-ol (3g): 136.2 mg, 83% yield; White solid; mp = 80–81 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.41 (s, 1H), 8.32 (d, J = 8.6 Hz, 1H), 7.68 (dd, J = 9.1, 4.6 Hz, 2H), 7.58 (s, 1H), 7.47 (s, 4H), 7.39 (d, J = 8.3 Hz, 2H), 7.26 (t, J = 8.7 Hz, 3H), 2.38 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 161.2 (d, J_{CF} = 242.0 Hz), 148.7, 140.3, 135.7, 135.1 (d, J_{CF} = 3.0 Hz), 131.6, 131.6 (d, J_{CF} = 8.0 Hz, × 2), 131.2, 130.0 (× 2), 129.5, 128.5 (× 2), 127.4, 127.0, 124.5, 124.2, 123.0, 121.1, 115.1 (d, J_{CF} = 21.0 Hz, × 2), 21.6; IR (film): 3427, 2924, 2854, 1660, 1601, 1508, 1446, 1228, 1157, 833, 771, 700 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{23}H_{16}FO^-$ [M-H]$^-$: 327.1191; found 327.1190.

2-(4-Chlorophenyl)-6-methyl-4-phenylnaphthalen-1-ol (3h): 141.1 mg, 82% yield; White solid; mp = 125–126 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.49 (s, 1H), 8.32 (d, J = 8.6 Hz, 1H), 7.67 (d, J = 8.2 Hz, 2H), 7.57 (s, 1H), 7.47 (d, J = 5.3 Hz, 6H), 7.39 (d, J = 8.3 Hz, 2H), 7.26 (s, 1H), 2.38 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 148.8, 140.2, 137.6, 135.9, 131.8, 131.4 (× 2), 131.4, 131.3, 130.0 (× 2), 129.2, 128.5 (× 2), 128.2 (× 2), 127.5, 127.0, 124.5, 124.2, 123.1, 120.8, 21.6; IR (film): 3562, 3413, 2922, 2852, 1603, 1572, 1489, 1381, 1163, 1082, 891, 831, 767, 700 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{23}H_{16}ClO^-$ [M-H]$^-$: 343.0895; found 343.0903.

2-(4-Methoxyphenyl)-6-methyl-4-phenylnaphthalen-1-ol (3i): 129.2 mg, 76% yield; White solid; mp = 86–87 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.23 (s, 1H), 8.32 (d, J = 8.6 Hz, 1H), 7.67–7.53 (m, 3H), 7.48 (d, J = 4.3 Hz, 4H), 7.44–7.34 (m, 2H), 7.27 (s, 1H), 7.01 (d, J = 8.6 Hz, 2H), 3.79 (s, 3H), 2.38 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 158.2, 148.4, 140.4, 135.3, 131.3, 131.1, 130.9, 130.7 (× 2), 129.9 (× 2), 129.6, 128.4 (× 2), 127.2, 126.9, 124.5, 124.1, 122.9, 121.8, 113.8 (× 2), 55.1, 21.5; IR (film): 3442, 2924, 2848, 1662, 1603, 1508, 1444, 1243, 1107, 1022, 827, 762, 698 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{24}H_{19}O_2^-$ [M-H]$^-$: 339.1391; found 339.1399.

6-Methoxy-2,4-diphenylnaphthalen-1-ol (3j): 130.4 mg, 80% yield; White solid; mp = 79–80 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.36 (s, 1H), 8.35 (d, J = 9.2 Hz, 1H), 7.66 (d, J = 8.0 Hz, 2H), 7.57–7.37 (m, 7H), 7.36–7.28 (m, 2H), 7.26–7.17 (m, 2H), 3.72 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 157.7, 148.9, 140.4, 138.8, 132.7, 130.7, 130.3, 129.8 (× 2), 129.6 (× 2), 128.6 (× 2), 128.3 (× 2), 127.0, 126.6, 124.9, 121.5, 121.1, 116.9, 104.2, 54.9; IR (film): 3419, 2924, 2854, 1658, 1589, 1508, 1448, 1227, 1157, 1078, 835, 771, 700 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{23}H_{17}O_2^-$ [M-H]$^-$: 325.1234; found 325.1226.

2-(4-Fluorophenyl)-6-methoxy-4-phenylnaphthalen-1-ol (3k): 135.9 mg, 79% yield; White solid; mp = 82–83 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.38 (s, 1H), 8.33 (d, J = 9.2 Hz, 1H), 7.68 (dd, J = 8.3, 5.8 Hz, 2H), 7.58–7.44 (m, 4H), 7.40 (t, J = 6.9 Hz, 1H), 7.28–7.22 (m, 4H), 7.18 (d, J = 2.1 Hz, 1H), 3.72 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 161.1 (d, J_{CF} = 242.0 Hz), 157.7, 148.8, 140.3, 135.0 (d, J_{CF} = 3.0 Hz), 132.7, 131.5 (d, J_{CF} = 8.0 Hz, × 2), 130.6, 130.1, 129.8 (× 2), 128.5 (× 2), 127.0, 124.9, 121.4, 120.1, 116.9, 115.0 (d, J_{CF} = 20.0 Hz, × 2), 104.2, 54.9; IR (film): 3421, 2925, 2850, 1658, 1599, 1508, 1446, 1238, 1159,

1022, 835, 771, 700 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{23}H_{16}FO_2^-$ [M-H]$^-$: 343.1140; found 343.1148.

6-Methoxy-4-phenyl-2-(p-tolyl)naphthalen-1-ol (3l): 136.1 mg, 80% yield; White solid; mp = 83–84 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.26 (s, 1H), 8.33 (d, *J* = 9.2 Hz, 1H), 7.67–7.46 (m, 6H), 7.41 (d, *J* = 6.8 Hz, 1H), 7.30–7.20 (m, 4H), 7.18 (s, 1H), 3.72 (s, 3H), 2.34 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 157.6, 148.6, 140.4, 135.8, 135.6, 132.5, 130.5, 130.2, 129.8 (× 2), 129.4 (× 2), 128.9 (× 2), 128.5 (× 2), 126.9, 124.9, 121.5, 120.9, 116.8, 104.2, 54.9, 20.8; IR (film): 3423, 2924, 1657, 1597, 1442, 1242, 1184, 1107, 1024, 820, 768, 702 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{24}H_{19}O_2$ [M-H]$^-$: 339.1391; found 339.1394.

2-([1,1'-Biphenyl]-4-yl)-6-methoxy-4-phenylnaphthalen-1-ol (3m): 142.8 mg, 71% yield; White solid; mp = 167–168 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.43 (s, 1H), 8.34 (d, *J* = 9.2 Hz, 1H), 7.81–7.69 (m, 6H), 7.56–7.47 (m, 6H), 7.44–7.34 (m, 2H), 7.34 (s, 1H), 7.24 (dd, *J* = 9.2, 2.4 Hz, 1H), 7.19 (d, *J* = 2.4 Hz, 1H), 3.73 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 157.7, 149.1, 140.4, 140.0, 138.3, 137.9, 132. 8, 130.7, 130.2 (× 3), 129.9 (× 2), 129.1 (× 3), 128.6 (× 2), 127.4, 127.1, 126.6 (× 3), 125.0, 121.6, 120.6, 117.0, 104.2, 54.9; IR (film): 3454, 2922, 2852, 1618, 1483, 1425, 1163, 1020, 901, 839, 768, 698 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{29}H_{21}O_2^-$ [M-H]$^-$: 401.1547; found 401.1536.

2-(3-Bromophenyl)-6-methoxy-4-phenylnaphthalen-1-ol (3n): 155.6 mg, 77% yield; White solid; mp = 91–92 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.56 (s, 1H), 8.34 (d, *J* = 9.2 Hz, 1H), 7.88 (s, 1H), 7.65 (d, *J* = 7.8 Hz, 1H), 7.57–7.45 (m, 5H), 7.40 (dt, *J* = 12.6, 4.7 Hz, 2H), 7.29 (s, 1H), 7.24 (dd, *J* = 9.2, 2.4 Hz, 1H), 7.19 (d, *J* = 2.3 Hz, 1H), 3.72 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 157.9, 149.1, 141.2, 140.2, 133.0, 132.2, 130.8, 130.4, 129.8 (× 2), 129.8, 129.3, 128.6, 128.5 (× 2), 127.0, 124.9, 121.5, 121.4, 119.6, 117.1, 104.3, 54.9; IR (film): 3375, 2922, 2854, 1581, 1435, 1302, 1176, 1022, 827, 700 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{23}H_{16}BrO_2^-$ [M-H]$^-$: 403.0339; found 403.0348.

6-Methoxy-2-(2-methoxyphenyl)-4-phenylnaphthalen-1-ol (3o): 122.8 mg, 69% yield; White solid; mp = 87–88 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, *J* = 9.2 Hz, 1H), 7.54 (d, *J* = 7.1 Hz, 2H), 7.47 (t, *J* = 7.5 Hz, 3H), 7.42–7.35 (m, 2H), 7.33 (s, 1H), 7.23 (d, *J* = 3.5 Hz, 1H), 7.21–7.07 (m, 3H), 6.95 (s, 1H), 3.95 (s, 3H), 3.78 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.4, 155.5, 149.1, 141.1, 133.7, 132.9, 131.9, 130.9, 130.2 (× 2), 129.0, 128.4 (× 2), 127.5, 126.9, 125.2, 122.5, 121.2, 117.4, 117.1, 111.9, 104.5, 56.5, 55.3; IR (film): 3361, 2935, 1624, 1601, 1574, 1493, 1462, 1423, 1265, 1233, 1195, 1127, 1025, 907, 755 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{24}H_{19}O_3^-$ [M-H]$^-$: 355.1340; found 355.1325.

5-Methyl-2,4-diphenylnaphthalen-1-ol (**3p-*o*)** and **7-methyl-2,4-diphenylnaphthalen-1-ol** (**3p -*p***) (The two compounds are inseparable): 94.5 mg, 61% yield (*o*:*p*=1:1); Colorless gum; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, *J* = 8.3 Hz, 1H), 8.22 (s, 1H), 7.87 (d, *J* = 8.5 Hz, 1H), 7.70–7.23 (m, 25H), 5.94 (s, 1H), 5.90 (s, 1H), 2.62 (s, 3H), 2.11 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.7, 146.9, 144.9, 140.8, 137.4, 137.4, 135.3, 133.0, 131.5, 132.8, 130.8, 130.4, 130.3(× 2), 130.0 (× 3), 129.7 (× 2), 129.4, 129.4, 129.4, 128.9, 128.3 (× 2), 128.2, 128.0 (× 2), 127.6, 126.9, 126.6, 126.6, 125.8, 125.8, 125.6, 125.4, 125.3, 124.7, 124.7, 121.7 (× 2), 121.3, 120.9, 119.9, 25.2, 21.9; IR (film): 3531, 3452, 3055, 2923, 1652, 1592, 1497, 1434, 1365, 1302, 1206, 1163, 1049, 766, 702 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{23}H_{17}O^-$ [M-H]$^-$: 309.1285; found 309.1273.

6-Fluoro-2,4-diphenylnaphthalen-1-ol (3q): 124.1 mg, 79% yield; White solid; mp = 73–74 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.60 (s, 1H), 8.54–8.44 (m, 1H), 7.66 (d, *J* = 7.6 Hz, 2H), 7.56–7.31 (m, 11H).; ^{13}C NMR (100 MHz, DMSO-d_6) δ 160.6 (d, J_{CF} = 243.0 Hz), 148.9, 139.6, 138.4, 132.4 (d, J_{CF} = 4.0 Hz), 131.2 (d, J_{CF} = 5.0 Hz), 130.9, 129.8 (× 2), 129.6 (× 2), 128.6 (× 2), 128.4 (× 2), 127.3, 126.9, 126.4 (d, J_{CF} = 9.0 Hz), 123.6, 122.6, 115.1 (d, J_{CF} = 25.0 Hz), 108.4 (d, J_{CF} = 22.0 Hz); IR (film): 3545, 3057, 1693, 1628, 1572, 1493, 1302, 1174, 1045, 899, 816, 771, 702 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{22}H_{14}FO^-$ [M-H]$^-$: 313.1034; found 313.1032.

6-Chloro-2,4-diphenylnaphthalen-1-ol (3r): 132.0 mg, 80% yield; White solid; mp = 91–92 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.64 (s, 1H), 8.42 (d, *J* = 9.1 Hz, 1H), 7.71 (d, *J* = 1.9 Hz, 1H), 7.67 (d, *J* = 7.5 Hz, 2H), 7.57 (dd, *J* = 9.1, 2.0 Hz, 1H), 7.55–7.42 (m, 7H), 7.39–7.32 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.5, 139.9, 136.8, 133.0, 132.9, 132.2, 130.2 (× 2), 129.8, 129.8 (× 2), 129.3 (× 2), 128.6 (× 2), 128.3, 127.4, 126.4, 124.7, 124.7, 122.9, 121.2; IR (film): 3517, 2922, 2852, 1647, 1566, 1489, 1444, 1296, 1198, 1024, 874, 820, 702 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{22}H_{14}ClO^-$ [M-H]$^-$: 329.0739; found 329.0740.

6-Chloro-2-(4-chlorophenyl)-4-phenylnaphthalen-1-ol (3s): 143.4 mg, 79% yield; White solid; mp = 93–94 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.77 (s, 1H), 8.42 (d, *J* = 9.1 Hz, 1H), 7.72 (d, *J* = 1.9 Hz, 1H), 7.67 (d, *J* = 8.5 Hz, 2H), 7.56 (dd, *J* = 9.1, 2.0 Hz, 1H), 7.52–7.40 (m, 7H), 7.36 (s, 1H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 149.0, 139.3, 137.1, 132.3, 131.8, 131.6, 131.5 (× 2), 131.1, 130.5, 129.9 (× 2), 128.7 (× 2), 128.3 (× 2), 127.4, 125.8, 125.7, 124.7, 123.8, 122.3; IR (film): 3519, 2924, 2854, 1655, 1568, 1487, 1369, 1294, 1196, 1084, 876, 769, 700 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{22}H_{13}Cl_2O^-$ [M-H]$^-$: 363.0349; found 363.0353.

6-Bromo-2,4-diphenylnaphthalen-1-ol (3t): 144.0 mg, 77% yield; White solid; mp = 70–71 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.64 (s, 1H), 8.34 (d, *J* = 9.0 Hz, 1H), 7.88 (s,

1H), 7.73–7.64 (m, 3H), 7.54–7.44 (m, 7H), 7.40–7.32 (m, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 148.9, 139.4, 138.2, 132.5, 130.9, 130.8, 129.9 (× 2), 129.6 (× 2), 128.7 (2C), 128.4 (× 2), 128.2, 127.4, 127.0, 126.9, 125.7, 124.9, 123.7, 120.2; IR (film): 3514, 3448, 2922, 2852, 1658, 1581, 1442, 1298, 1203, 1074, 1024, 862, 702, 698 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{22}H_{14}BrO^-$ [M-H]$^-$: 373.0234; found 373.0229.

6-Bromo-2-(4-fluorophenyl)-4-phenylnaphthalen-1-ol (3u): 145.0 mg, 74% yield; White solid; mp = 76–77 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.69 (s, 1H), 8.33 (d, *J* = 9.0 Hz, 1H), 7.87 (d, *J* = 1.8 Hz, 1H), 7.76–7.65 (m, 3H), 7.54–7.44 (m, 5H), 7.36 (s, 1H), 7.28 (t, *J* = 8.8 Hz, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 161.4 (d, J_{CF} = 243.0 Hz), 148.9, 139.3, 134.5 (d, J_{CF} = 3.0 Hz), 132.6, 131.6 (d, J_{CF} = 8.0 Hz, × 2), 130.9, 130.7, 129.9 (× 2), 128.7 (× 2), 128.2, 127.4, 127.0, 125.7, 124.9, 122.7, 120.3, 115.2 (d, J_{CF} = 20.0 Hz, × 2); IR (film): 3419, 3067, 2922, 2858, 2351, 1660, 1590, 1506, 1227, 1156, 1086, 876, 831, 699 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{22}H_{13}BrFO^-$ [M-H]$^-$: 391.0139; found 391.0148.

6-Bromo-2-(4-bromophenyl)-4-phenylnaphthalen-1-ol (3v): 271.1 mg, 75% yield; White solid; mp = 83–84 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.73 (s, 1H), 8.34 (d, *J* = 9.0 Hz, 1H), 7.87 (d, *J* = 1.3 Hz, 1H), 7.73–7.58 (m, 5H), 7.56–7.40 (m, 5H), 7.35 (s, 1H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 148.9, 139.2, 137.4, 132.7, 131.7 (× 2), 131.2 (× 2), 130.9, 130.3, 129.9 (× 2), 128.6 (× 2), 128.2, 127.4, 126.9, 125.7, 124.9, 122.4, 120.4, 120.4; IR (film): 3425, 2925, 2854, 1655, 1597, 1493, 1446, 1242, 1101, 760, 700 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{22}H_{13}Br_2O^-$ [M-H]$^-$: 450.9339; found 450.9336.

2,4-Diphenylanthracen-1-ol (3w): 124.6 mg, 72% yield; White solid; mp = 177–178 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.44 (s, 1H), 8.35 (d, *J* = 9.1 Hz, 1H), 7.93 (d, *J* = 7.7 Hz, 1H), 7.87 (d, *J* = 9.2 Hz, 1H), 7.69 (d, *J* = 7.3 Hz, 2H), 7.63 (d, *J* = 8.6 Hz, 1H), 7.50–7.44 (m, 6H), 7.40–7.35 (m, 3H), 7.31 (s, 1H), 7.09 (t, *J* = 7.4 Hz, 1H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 149.1, 144.8, 138.2, 133.1, 132.5, 132.2, 129.6 (× 2), 129.5, 129.1 (× 2), 129.0 (× 2), 128.5 (× 2), 128.4, 128.1, 127.6, 127.1, 127.0, 126.6, 126.3, 125.1, 125.0, 124.8, 121.3; IR (film): 3539, 3442, 2924, 2852, 1647, 1595, 1421, 1309, 1220, 1144, 818, 746, 700 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{26}H_{17}O^-$ [M-H]$^-$: 345.1285; found 345.1289.

6'-Methoxy-4'-phenyl-[1,2'-binaphthalen]-1'-ol (3x): 135.0 mg, 72% yield; White solid; mp = 83–84 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.31 (d, *J* = 9.2 Hz, 1H), 7.94 (d, *J* = 6.4 Hz, 2H), 7.78 (d, *J* = 8.3 Hz, 1H), 7.62–7.50 (m, 5H), 7.47–7.44 (m, 3H), 7.40–7.30 (m, 3H), 7.27–7.19 (m, 1H), 5.37 (s, 1H), 3.81 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.5, 148.3, 140.8, 134.2, 134.1, 133.8, 132.1, 131.4, 130.4, 130.2 (× 2), 128.9, 128.7, 128.6, 128.4 (× 2), 126.9, 126.9, 126.4, 125.9, 125.9, 124.6, 119.6, 117.6, 117.3, 104.7, 55.3; IR (film): 3530, 3056, 2926, 2852, 1661, 1626, 1600, 1494, 1440, 1423, 1372, 1301, 1264, 1234,1034, 781 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{27}H_{19}O_2^-$ [M-H]$^-$: 375.1391; found 375.1382.

6-Methoxy-4-phenyl-[2,2'-binaphthalen]-1-ol (3y): 144.7 mg, 77% yield; White solid; mp = 75–76 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.46 (s, 1H), 8.38 (d, *J* = 9.2 Hz, 1H), 8.18 (s, 1H), 8.03–7.91 (m, 3H), 7.86 (dd, *J* = 8.5, 1.6 Hz, 1H), 7.59–7.55 (m, 2H), 7.54–7.49 (m, 4H), 7.45–7.39 (m, 2H), 7.26 (dd, *J* = 9.2, 2.5 Hz, 1H), 7.21 (d, *J* = 2.4 Hz, 1H), 3.74 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 158.2, 149.5, 140.8, 136.8, 133.7, 133.2, 132.3, 131.1, 130.8, 130.2 (× 2), 128.9 (× 2), 128.6, 128.4 (× 2), 127.8 (× 2), 127.4, 126.4, 126.2, 125.4, 121.9, 121.3, 117.4, 104.7, 55.3; IR (film): 3531, 2927, 2852, 1624, 1597, 1505, 1442, 1421, 1266, 1237, 1202, 1182, 1029, 823, 766, 751, 708 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{27}H_{19}O_2^-$ [M-H]$^-$: 375.1391; found 375.1377.

2-Methyl-4,6-diphenylbenzo[b]thiophen-7-ol (3z): 121.6 mg, 77% yield; Yellow solid; mp = 87–88 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.59–7.49 (m, 6H), 7.43 (dt, *J* = 6.8, 4.5 Hz, 3H), 7.36 (t, *J* = 7.4 Hz, 1H), 7.24 (d, *J* = 3.8 Hz, 1H), 7.13 (d, *J* = 0.9 Hz, 1H), 5.72 (s, 1H), 2.60 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.9, 142.2, 140.9, 140.1, 136.9, 129.9, 129.7 (× 2), 129.3 (× 2), 129.1 (× 2), 128.5 (× 2), 127.9, 127.6, 127.4, 126.9, 121.6, 121.5, 16.5; IR (film): 3399, 3057, 3025, 2920, 1732, 1665, 1598, 1466, 1437, 1386, 1220, 848, 767, 702 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{21}H_{15}OS$ [M-H]$^-$: 315.0849; found 315.0858.

2-Bromo-4,6-diphenylbenzo[b]thiophen-7-ol (3aa): 129.2 mg, 68% yield; Yellow solid; mp = 59–60 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.87 (s, 1H), 7.64 (d, *J* = 7.5 Hz, 2H), 7.57 (d, *J* = 7.4 Hz, 2H), 7.53–7.43 (m, 5H), 7.39 (dd, *J* = 14.6, 7.3 Hz, 2H), 7.27 (s, 1H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 146.6, 139.6, 137.7, 137.7, 131.8, 129.5 (× 2), 129.0, 128.8 (× 2), 128.7 (× 2), 128.7, 128.4 (× 2), 127.2, 127.1, 126.2, 124.9, 115.5; IR (film): 3435, 3055, 2921, 2853, 1650, 1604, 1492, 1452, 1211, 1034, 831, 767, 700 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{20}H_{12}BrOS^-$ [M-H]$^-$: 378.9798; found 378.9810.

4,6-Diphenylbenzofuran-7-ol (3bb): 65.8 mg, 46% yield; White solid; mp = 72–73 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.88 (s, 1H), 7.95 (d, *J* = 2.2 Hz, 1H), 7.88–7.81 (m, 2H), 7.69–7.59 (m, 2H), 7.49–7.41 (m, 4H), 7.39 (s, 1H), 7.36–7.31 (m, 2H), 7.29 (d, *J* = 2.2 Hz, 1H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 152.1, 147.1, 144.5, 138.6, 136.0, 129.6 (× 2), 128.6 (× 2), 127.9 (× 2), 127.8 (× 2), 126.9, 126.3, 126.2, 122.3, 117.9, 116.7, 105.0; IR (film): 3058, 2944, 2852, 1661, 1606, 1476, 1442, 1321, 1225, 1047, 760 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{20}H_{13}O_2^-$ [M-H]$^-$: 285.0921; found 285.0919.

1-Methyl-4,6-diphenyl-1H-indol-7-ol (3cc): 109.2 mg, 73% yield; Yellow solid; mp = 85–86 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.58–7.52 (m, 2H), 7.51–7.44 (m, 4H), 7.38 (tt, *J* = 14.7, 4.7 Hz, 4H), 6.99–6.89 (m, 2H), 6.68 (d, *J* = 3.1 Hz, 1H), 5.56 (s, 1H), 3.33 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 144.8, 140.1, 137.9, 135.2, 130.4 (× 2), 130.3, 129.6 (× 2), 129.3 (× 2), 127.7 (× 2), 127.2, 127.0, 126.5, 120.3, 119.1, 116.8, 98.5, 36.8; IR (film): 3415, 2923, 2855, 1718, 1477, 1352, 1257, 1208, 1072, 762, 702 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{21}H_{16}NO^-$ [M-H]$^-$: 298.1237; found 298.1236.

2-(1H-indol-3-yl)-4-phenylnaphthalen-1-ol (3dd): 125.2 mg, 75% yield; White solid; mp = 75–76 ºC; Eluant: EtOAc–petroleum ether (1:10, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.47 (d, *J* = 7.9 Hz, 1H), 8.39 (s, 1H), 8.00 (d, *J* = 7.8 Hz, 1H), 7.73 (d, *J* = 7.8 Hz, 1H), 7.66–7.41 (m, 10H), 7.36 (t, *J* = 7.6 Hz, 1H), 7.26 (t, *J* = 7.5 Hz, 1H), 6.06 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.3, 140.9, 136.6, 132.6, 131.9, 130.4 (× 2), 129.5, 128.3 (× 2), 126.9, 126.4, 126.3, 125.9, 125.4, 124.5, 123.4, 123.2, 122.7, 120.9, 119.9, 113.8, 112.3, 111.7; IR (film): 3416, 3056, 1723, 1674, 1599, 1572, 1505, 1456, 1414, 1245, 1218, 1095, 1031, 767, 743, 702 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{24}H_{16}NO^-$ [M-H]$^-$: 334.1237; found 334.1227.

6-Methoxy-4-phenyl-2-(thiophen-2-yl)naphthalen-1-ol (3ee): 129.1 mg, 78% yield; White solid; mp = 48–49 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.33–8.23 (m, 1H), 7.55–7.44 (m, 4H), 7.43–7.38 (m, 3H), 7.28 (d, *J* = 3.5 Hz, 1H), 7.22–7.15 (m, 3H), 6.17 (s, 1H), 3.77 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.7, 148.2, 140.6, 139.3, 133.9, 131.8, 130.1 (× 2), 129.2, 128.5 (× 2), 128.1, 127.1, 126.6, 126.0, 124.7, 119.8, 117.8, 112.1, 104.9, 55.3; IR (film): 3507, 2928, 1624, 1607, 1578, 1494, 1470, 1426, 1384, 1354, 1268, 1232, 1180, 1037, 1008, 896, 776 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{21}H_{15}O_2S^-$ [M-H]$^-$: 331.0798; found 331.0785.

2-Phenyl-4-(p-tolyl)naphthalen-1-ol (4a): 122.5 mg, 79% yield; White solid; mp = 83–84 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.38 (s, 1H), 8.40 (d, *J* = 8.4 Hz, 1H), 7.81 (d, *J* = 8.3 Hz, 1H), 7.67 (d, *J* = 7.1 Hz, 2H), 7.54 (d, *J* = 7.1 Hz, 1H), 7.50–7.43 (m, 3H), 7.36 (t, *J* = 8.4 Hz, 3H), 7.33–7.25 (m, 3H), 2.38 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 148.4, 138.8, 137.2, 136.2, 131.7, 131.4, 129.9 (× 2), 129.7 (× 2), 129.3, 129.1 (× 2), 128.3 (× 2), 126.8, 126.4, 126.3, 125.3, 125.2, 122.9, 122.9, 20.8; IR (film): 3442, 3028, 2924, 2854, 1657, 1599, 1508, 1450, 1209, 1047, 820, 764, 696 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{23}H_{17}O^-$ [M-H]$^-$: 309.1285; found 309.1279.

2-(4-Bromophenyl)-4-(p-tolyl)naphthalen-1-ol (4b): 151.3 mg, 78% yield; White solid; mp = 84–85 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.47 (s, 1H), 8.39 (d, *J* = 8.4 Hz, 1H), 7.80 (d, *J* = 8.3 Hz, 1H), 7.63 (s, 4H), 7.57–7.52 (m, 1H), 7.49 (d, *J* = 7.9 Hz, 1H), 7.37 (d, *J* = 7.9 Hz, 2H), 7.29 (d, *J* = 11.0 Hz, 3H), 2.38 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 148.5, 137.9, 137.0, 136.2, 131.8, 131.8 (× 2), 131.5, 131.1 (× 2), 129.8 (× 2), 129.0 (× 2), 128.7, 126.5, 126.2, 125.3, 125.3, 122.9, 121.6, 120.1, 20.8; IR (film): 3390, 2920, 2852, 1655, 1597, 1487, 1441, 1346, 1232, 1105, 820, 760 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{23}H_{16}BrO^-$ [M-H]$^-$: 387.0390; found 387.0384.

6-Methoxy-2-phenyl-4-(p-tolyl)naphthalen-1-ol (4c): 139.5 mg, 82% yield; White solid; mp = 62–63 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.35 (s, 1H), 8.38–8.34 (m, 1H), 7.66 (d, *J* = 8.0 Hz, 2H), 7.45–7.40 (m, 4H), 7.33–7.22 (m, 6H), 3.72 (s, 3H), 2.36 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 157.6, 148.7, 138.9, 137.5, 136.1, 132.8, 130.7, 130.2, 129.7 (× 2), 129.6 (× 2), 129.2 (× 2), 128.3 (× 2), 126.5, 124.9, 121.6, 121.1, 116.9, 104.2, 54.9, 20.8; IR (film): 3357, 2920, 2850, 1734, 1655, 1460, 1377, 1026, 771 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{24}H_{19}O_2^-$ [M-H]$^-$: 339.1391; found 339.1372.

6-Chloro-2-(4-chlorophenyl)-4-(p-tolyl)naphthalen-1-ol (4d): 141.8 mg, 75% yield; White solid; mp = 127–128 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.70 (s, 1H), 8.40 (d, *J* = 9.1 Hz, 1H), 7.72 (d, *J* = 1.9 Hz, 1H), 7.68 (d, *J* = 8.4 Hz, 2H), 7.57 (dd, *J* = 9.0, 1.7 Hz, 1H), 7.50 (d, *J* = 8.4 Hz, 2H), 7.42–7.28 (m, 5H), 2.38 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 148.8, 137.1, 136.6, 136.3, 132.4, 131.8, 131.5, 131.4 (× 2), 131.1, 130.3, 129.8 (× 2), 129.2 (× 2), 128.3 (× 2), 125.7, 125.6, 124.7, 123.9, 122.3, 20.8; IR (film): 3519, 2920, 2852, 1620, 1568, 1487, 1298, 1203, 1084, 1038, 876, 823, 727, 685 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{23}H_{15}Cl_2O^-$ [M-H]$^-$: 377.0505; found 377.0497.

4-(4-Methoxyphenyl)-2-phenylnaphthalen-1-ol (4e): 125.6 mg, 77% yield; White solid; mp = 117–118 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.33 (s, 1H), 8.38 (d, *J* = 8.2 Hz, 1H), 7.81 (d, *J* = 8.2 Hz, 1H), 7.67 (d, *J* = 7.2 Hz, 2H), 7.58–7.39 (m, 6H), 7.35 (t, *J* = 7.4 Hz, 1H), 7.28 (s, 1H), 7.06 (d, *J* = 8.6 Hz, 2H), 3.82 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 158.4, 148.3, 138.7, 132.3, 131.5, 131.5, 131.0 (× 2), 129.7 (× 2), 129.3, 128.3 (× 2), 126.7, 126.3, 126.3, 125.3, 125.2, 122.9, 122.9, 113.9 (× 2), 55.2; IR (film): 3386, 2924, 2846, 1572, 1508, 1441, 1302, 1236, 1176, 1020, 831, 764, 706 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{23}H_{17}O_2^-$ [M-H]$^-$: 325.1234; found 325.1231.

6-Chloro-4-(4-methoxyphenyl)-2-phenylnaphthalen-1-ol (4f): 140.4 mg, 78% yield; White solid; mp = 128–129 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.59 (s, 1H), 8.40 (d, *J* = 9.0 Hz, 1H), 7.72 (s, 1H), 7.66 (d, *J* = 7.4 Hz, 2H), 7.56 (d, *J* = 8.9 Hz, 1H), 7.51–7.39 (m, 4H), 7.36 (d, *J* = 12.0 Hz, 2H), 7.08 (d, *J* = 8.2 Hz, 2H), 3.82 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 158.6, 148.5, 138.3, 132.3, 131.5, 131.2, 131.0 (× 2), 130.7 (× 2), 129.6 (× 2), 128.4 (× 2), 126.9, 125.6, 125.6, 124.8, 123.9, 123.6, 114.1 (× 2), 55.2; IR (film): 3491, 2922, 2850, 1612, 1568, 1510, 1308, 1248,

1207, 1031, 768, 698 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{23}H_{16}ClO_2^-$ [M-H]$^-$: 359.0844; found 359.0836.

4-(4-Methoxyphenyl)-6-methyl-2-phenylnaphthalen-1-ol (4g): 127.5 mg, 75% yield; White solid; mp = 67–68 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.29 (s, 1H), 8.30 (d, *J* = 8.6 Hz, 1H), 7.66 (d, *J* = 7.4 Hz, 2H), 7.58 (s, 1H), 7.44 (t, *J* = 7.5 Hz, 2H), 7.39 (t, *J* = 6.8 Hz, 3H), 7.32 (t, *J* = 7.3 Hz, 1H), 7.24 (s, 1H), 7.05 (d, *J* = 8.4 Hz, 2H), 3.81 (s, 3H), 2.39 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 158.4, 148.3, 138.9, 135.5, 132.5, 131.8, 131.0 (× 2), 130.9, 129.7 (× 2), 129.5, 128.3 (× 2), 127.3, 126.6, 124.6, 124.3, 123.0, 122.1, 113.9 (× 2), 55.1, 21.6; IR (film): 3543, 3028, 2925, 2841, 1732, 1606, 1510, 1456, 1306, 1246, 1182, 1041, 831, 775, 704 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{24}H_{19}O_2$ [M-H]$^-$: 339.1391; found 339.1399.

2-(4-Fluorophenyl)-6-methoxy-4-(4-methoxyphenyl) naphthalen-1-ol (4h): 151.5 mg, 81% yield; White solid; mp = 135–136 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.32 (s, 1H), 8.31 (d, *J* = 9.2 Hz, 1H), 7.67 (dd, *J* = 8.7, 5.7 Hz, 2H), 7.44 (d, *J* = 8.6 Hz, 2H), 7.31–7.20 (m, 5H), 7.05 (d, *J* = 8.6 Hz, 2H), 3.82 (s, 3H), 3.73 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 161.1 (d, J_{CF} = 241.0 Hz), 158.3, 157.6, 148.5, 135.1 (d, J_{CF} = 3.0 Hz), 132.9, 132.5, 131.5 (d, J_{CF} = 8.0 Hz, × 2), 130.9 (× 2), 130.4, 129.9, 124.9, 121.5, 120.1, 116.9, 115.0 (d, J_{CF} = 21.0 Hz, × 2), 113.9 (× 2), 104.32, 55.1, 54.9; IR (film): 3398, 2954, 2835, 1514, 1508, 1431, 1309, 1238, 1101, 1022, 903, 827 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{24}H_{18}FO_3^-$ [M-H]$^-$: 373.1245; found 373.1240; CCDC 1940564 contains the crystallographic data for **4h** that can be obtained free of charge from the CCDC via www.ccdc.cam.ac.uk/data_request/cif.

4-(4-Nitrophenyl)-2-phenylnaphthalen-1-ol (4i): 133.0 mg, 78% yield; Yellow solid; mp = 64–65 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.41 (d, *J* = 8.2 Hz, 1H), 8.31 (d, *J* = 8.1 Hz, 2H), 7.80 (d, *J* = 8.2 Hz, 1H), 7.66 (d, *J* = 8.1 Hz, 2H), 7.60–7.43 (m, 7H), 7.33 (s, 1H), 6.02 (s, 1H); ^{13}C NMR (100 MHz, C DCl_3) δ 148.5, 147.6, 146.9, 136.7, 131.6, 131.1 (× 2), 130.3, 129.8 (× 2), 129.4 (× 2), 129.0, 128.4, 127.4, 125.9, 124.9, 124.7, 123.7 (× 2), 123.2, 121.0; IR (film): 3512, 3062, 2924, 2851, 1723, 1586, 1510, 1342, 1211, 1045, 852, 760, 698 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{22}H_{14}NO_3$ [M-H]$^-$: 340.0979; found 340.0982.

4-(4-Fluorophenyl)-2-phenylnaphthalen-1-ol (4j): 124.0 mg, 79% yield; White solid; mp = 59–60 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.38 (d, *J* = 8.3 Hz, 1H), 7.83 (d, *J* = 8.3 Hz, 1H), 7.60–7.39 (m, 9H), 7.29 (s, 1H), 7.15 (t, *J* = 8.6 Hz, 2H), 5.90 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.2 (d, J_{CF} = 244.0 Hz), 147.5, 137.2, 136.6 (d, J_{CF} = 3.0 Hz), 132.3, 131.9, 131.8 (d, J_{CF} = 8.0 Hz, × 2), 131.8, 129.7 (× 2), 129.4 (× 2), 128.7, 128.1, 126.8, 125.6, 124.6, 122.9, 120.9, 115.2 (d, J_{CF} = 21.0 Hz, × 2); IR (film): 3428, 3049, 2921, 2853, 2320, 1505, 1452, 1305, 1214, 1045, 837, 764 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{22}H_{14}FO$ [M-H]$^-$: 313.1034; found 313.1037.

4-(2-Chlorophenyl)-2-phenylnaphthalen-1-ol (4k): 121.7 mg, 74% yield; White solid; mp = 59–60 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.47 (d, *J* = 8.3 Hz, 1H), 7.66 (d, *J* = 7.6 Hz, 2H), 7.63–7.55 (m, 5H), 7.53 (d, *J* = 6.7 Hz, 1H), 7.48 (t, *J* = 6.2 Hz, 2H), 7.44–7.41 ((m, 2H), 7.39 (s, 1H), 6.03 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.8, 139.1, 137.1, 134.5, 132.6, 132.3, 129.9, 129.7 (× 2), 129.6, 129.4 (× 2), 128.9, 128.9, 128.0, 126.8, 126.6, 125.8, 125.6, 124.3, 122.8, 120.7; IR (film): 3529, 3058, 2923, 1622, 1576, 1499, 1437, 1374, 1308, 1209, 1048, 856, 759, 703 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{22}H_{14}ClO^-$ [M-H]$^-$: 329.0739; found 329.0743.

4-(3-Fluorophenyl)-2-phenylnaphthalen-1-ol (4l): 100.5 mg, 64% yield; White solid; mp = 81–82 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.43 (d, *J* = 8.2 Hz, 1H), 7.93 (d, *J* = 8.3 Hz, 1H), 7.67–7.43 (m, 8H), 7.37 (s, 1H), 7.33 (d, *J* = 7.6 Hz, 1H), 7.27 (d, *J* = 11.2 Hz, 1H), 7.14 (t, *J* = 8.3 Hz, 1H), 5.96 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.8 (d, J_{CF} = 245.0 Hz), 147.8, 142.9 (d, J_{CF} = 7.0 Hz), 137.1, 131.9, 131.6 (d, J_{CF} = 2.0 Hz), 129.8, 129.8, 129.4, 128.7, 128.2, 126.9, 126.1 (d, J_{CF} = 3.0 Hz), 125.7, 125.5, 124.6, 122.9, 120.9, 117.3 (d, J_{CF} = 21.0 Hz), 113.9 (d, J_{CF} = 21.0 Hz); IR (film): 3535, 3062, 2924, 2856, 1578, 1496, 1443, 1371, 1308, 1189, 1050, 869, 773, 704 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{22}H_{14}FO^-$ [M-H]$^-$: 313.1034; found 313.1030.

2-Phenyl-4-(pyridin-2-yl)naphthalen-1-ol (4m): 93.6 mg, 63% yield; White solid; mp = 190–191 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.55 (s, 1H), 8.73 (d, *J* = 4.4 Hz, 1H), 8.42 (d, *J* = 8.3 Hz, 1H), 8.16 (d, *J* = 8.3 Hz, 1H), 7.90 (t, *J* = 7.7 Hz, 1H), 7.70–7.67 (m, 3H), 7.59–7.45 (m, 5H), 7.41–7.34 (m, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 158.5, 149.5, 149.1, 138.6, 136.8, 131.1, 130.4, 129.6 (× 2), 128.3 (× 2), 126.8, 126.5, 126.2, 125.5, 125.2, 124.8, 122.8, 122.7, 121.9; IR (film): 2925, 1264, 733, 703 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{21}H_{14}NO^-$ [M-H]$^-$: 296.1081; found 296.1078.

Methyl 4-hydroxy-3-phenyl-1-naphthoate (6a): 101.5 mg, 73% yield; White solid; mp = 88–89 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.24 (s, 1H), 8.96 (d, *J* = 8.4 Hz, 1H), 8.43 (d, *J* = 8.0 Hz, 1H), 8.16 (s, 1H), 7.74–7.64 (m, 1H), 7.63–7.59 (m, 3H), 7.49 (t, *J* = 7.6 Hz, 2H), 7.39 (t, *J* = 7.4 Hz, 1H), 3.88 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 166.8, 153.9, 137.8, 134.2, 131.9, 129.6 (× 2), 128.5 (× 2), 128.1, 127.2, 125.9, 125.6, 125.3, 123.1, 121.9, 117.5, 51.9; IR (film): 3398, 2947, 1685, 1566, 1052, 1439, 1250, 1053, 922, 787, 692 cm^{-1}; HRMS (ESI) *m/z* calculated for $C_{18}H_{13}O_3^-$ [M-H]$^-$: 277.0870; found 277.0866. CCDC 1940565 contains the crystallographic data for **6a** that can be obtained free of charge from the CCDC via www.ccdc.cam.ac.uk/data_request/cif.

Methyl 3-(4-bromophenyl)-4-hydroxy-1-naphthoate (6b): 135.3 mg, 76% yield; White solid; mp = 153–154 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.04 (d, *J* = 8.7 Hz, 1H), 8.35 (d, *J* = 8.2 Hz, 1H), 8.16 (s, 1H), 7.68–7.65 (m, 3H), 7.57 (t, *J* = 7.2 Hz, 1H), 7.40 (d, *J* = 8.3 Hz, 2H), 6.23 (s, 1H), 3.95 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.6, 152.1, 135.1, 133.1, 132.9 (× 2), 132.7, 131.1 (× 2), 128.7, 126.1, 125.9, 124.5, 122.8, 122.7, 119.2, 119.2, 52.0; IR (film): 3369, 2924, 2852, 1684, 1566, 1498, 1433, 1375, 1219, 1126, 1049, 781, 735 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{18}H_{12}BrO_3^-$ [M-H]$^-$: 354.9975; found 354.9971. CCDC 1940559 contains the crystallographic data for **6b** that can be obtained free of charge from the CCDC via www.ccdc.cam.ac.uk/data_request/cif.

Methyl 7-fluoro-4-hydroxy-3-phenyl-1-naphthoate (6c): 109.6 mg, 74% yield; White solid; mp = 127–128 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.80 (dd, *J* = 12.3, 2.5 Hz, 1H), 8.36 (dd, *J* = 9.3, 6.1 Hz, 1H), 8.27 (s, 1H), 7.58–7.41 (m, 5H), 7.31 (ddd, *J* = 9.3, 7.8, 2.6 Hz, 1H), 6.34 (s, 1H), 3.94 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.3, 162.7 (d, J_{CF} = 245.0 Hz), 152.5, 135.8, 134.9, 134.2 (d, J_{CF} = 10.0 Hz), 129.9 (× 2), 129.4 (× 2), 128.6, 125.7 (d, J_{CF} = 9.0 Hz), 121.5, 119.9, 118.1 (d, J_{CF} = 6.0 Hz), 116.0 (d, J_{CF} = 25.0 Hz), 110.1 (d, J_{CF} = 24.0 Hz), 52.0; IR (film): 3398, 2922, 2850, 1697, 1630, 1570, 1500, 1223, 1115, 879, 771, 702 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{18}H_{12}FO_3^-$ [M-H]$^-$: 295.0776; found 295.0777.

Methyl 7-chloro-4-hydroxy-3-phenyl-1-naphthoate (6d): 123.2 mg, 79% yield; White solid; mp = 142–143 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.49 (s, 1H), 9.03 (s, 1H), 8.52–8.35 (m, 1H), 8.19 (s, 1H), 7.69–7.56 (m, 3H), 7.55–7.46 (m, 2H), 7.44–7.34 (m, 1H), 3.87 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 166.4, 154.2, 137.4, 135.7, 133.4, 132.6, 129.5 (× 2), 128.6 (× 2), 127.4, 126.0, 125.6, 124.4, 124.1, 122.6, 116.2, 51.9; IR (film): 3502, 2924, 1703, 1566, 1491, 1377, 1213, 1088, 1045, 877, 773, 704 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{18}H_{12}ClO_3^-$ [M-H]$^-$: 311.0480; found 311.0475.

Methyl 4-hydroxy-7-methoxy-3-phenyl-1-naphthoate (6e): 113.9 mg, 74% yield; White solid; mp = 133–134 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.21 (s, 1H), 8.50 (d, *J* = 2.5 Hz, 1H), 8.34 (d, *J* = 9.3 Hz, 1H), 8.17 (s, 1H), 7.58 (d, *J* = 7.2 Hz, 2H), 7.48 (t, *J* = 7.6 Hz, 2H), 7.37 (t, *J* = 7.3 Hz, 1H), 7.26 (dd, *J* = 9.3, 2.5 Hz, 1H), 3.91 (s, 3H), 3.87 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 166.9, 159.1, 154.4, 137.9, 135.1, 134.0, 129.5 (× 2), 128.5 (× 2), 127.0, 124.9, 120.9, 120.4, 117.4, 115.7, 104.4, 55.1, 51.7; IR (film): 3404, 2922, 2850, 1689, 1572, 1495, 1425, 1190, 1101, 1026, 860, 702, 594 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{19}H_{15}O_4^-$ [M-H]$^-$: 307.0976; found 307.0985.

Methyl 4-hydroxy-3-phenylanthracene-1-carboxylate (6f): 114.8 mg, 70% yield; White solid; mp = 79–80 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.27 (d, *J* = 9.1 Hz, 1H), 8.15 (d, *J* = 8.4 Hz, 1H), 7.93 (dd, *J* = 7.8, 1.3 Hz, 1H), 7.83 (d, *J* = 9.0 Hz, 1H), 7.74 (s, 1H), 7.65–7.54 (m, 6H), 7.48 (ddd, *J* = 5.5, 4.3, 2.6 Hz, 1H), 6.11 (s, 1H), 3.96 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.5, 150.5, 135.9, 133.4, 130.1, 129.9 (× 2), 129.3 (× 2), 129.0, 128.7, 128.6 (× 2), 127.7, 127.2, 126.7, 125.8, 122.9, 122.8, 122.4, 120.5, 52.7; IR (film): 2924, 2854, 1712, 1574, 1429, 1225, 1109, 1007, 825, 769, 702 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{22}H_{15}O_3$ [M-H]$^-$: 327.1027; found 327.1036.

Methyl 4-hydroxy-1,3-diphenyl-2-naphthoate (6g): [20] 76.7 mg, 43% yield; White solid; mp = 58–59 ºC; Eluant: EtOAc–petroleum ether (1:20, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.36 (d, *J* = 8.3 Hz, 1H), 7.68–7.37 (m, 13H), 5.70 (s, 1H), 3.21 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.1, 147.9, 137.9, 134.3, 132.7, 132.3, 130.7 (2C), 130.4 (× 2), 130.1, 129.5 (× 2), 128.8, 128.1 (× 2), 127.6, 127.2, 126.8, 126.4, 124.4, 122.6, 118.3, 51.6; IR (film): 3531, 2922, 1732, 1504, 1382, 1310, 1284, 1230, 1065, 896, 702 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{24}H_{17}O_3^-$ [M-H]$^-$: 353.1183; found 353.1190.

Dimethyl 4-hydroxy-3-phenylnaphthalene -1,2-dicarboxylate (6h): 122.7 mg, 73% yield; White solid; mp = 65–66 ºC; Eluant: EtOAc–petroleum ether (1:15, R_f = 0.30). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.38–8.28 (m, 2H), 7.70–7.56 (m, 2H), 7.56–7.43 (m, 3H), 7.43–7.34 (m, 2H), 5.93 (s, 1H), 3.95 (s, 3H), 3.53 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.4, 167.8, 151.2, 133.6, 133.5, 130.8, 130.3 (× 2), 129.5 (× 2), 129.0, 128.6, 127.1, 125.9, 124.3, 122.8, 120.9, 118.8, 52.6, 52.2; IR (film): 3514, 2950, 1723, 1567, 1498, 1376, 1294, 1226, 1071, 994, 743 cm^{-1}; HRMS (ESI) *m*/*z* calculated for $C_{20}H_{15}O_5^-$ [M-H]$^-$: 335.0925; found 335.0931.

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FULL PAPER

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