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Asymmetric Total Syntheses of (−)-Hedycoropyrans A and B

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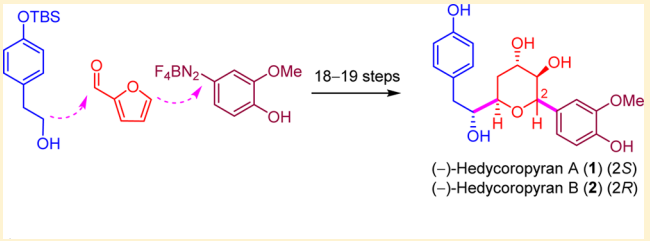
Supporting Information

ABSTRACT: The first and asymmetric total synthesis of (−)-hedycoropyrans A (**1**) was accomplished in 18 steps with 5.4% overall yield. The key features of our strategy include (1) construction of the unusual *trans*-2-aryl-6-alkyl tetrahydropyran core via Achmatowicz rearrangement, Zn-mediated reductive deoxygenation, and Heck−Matsuda coupling reaction, and (2) installation of 3,4-*anti*-dihydroxy from the corresponding 3,4-*syn*-dihydroxy THP through chemo- and regioselective IBX oxidation and Evans−Saksena reduction. In addition, C2 epimerization of (−)-hedycoropyan A (**1**) under the acidic condition furnished (−)-hedycoropyan B (**2**) with 71% yield. This finding might suggest the biogenetic origin of hedycoropyran B.



INTRODUCTION

Hedycoropyrans A (**1**) and B (**2**) (Figure 1) were isolated in 2015 by Lee and co-workers from the Asian herb *Hedychium*

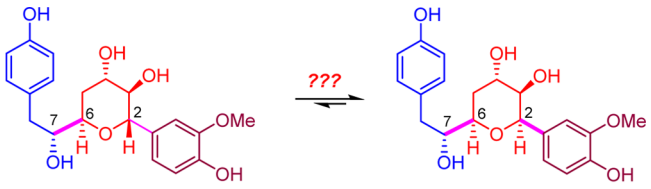


Figure 1. Selected diarylheptanoid natural products.

coronarium Koenig (Zingiberaceae).[1] Their biological activity has not been evaluated, partially due to the extremely low natural abundance (**1**, 1.0 mg and **2**, 0.2 mg from 14.5 kg of the powdered dried rhizomes, respectively). Structurally, hedycoropyran A (**1**) represents a rare diarylheptanoid with a *trans*-2-aryl-6-alkyl tetrahydropyran (THP) core, the stereochemistry of which at C2 consists of the only structural difference from hedycoropyran B (**2**). The co-occurrence of the THP epimers is very interesting but unusual in terms of their biogenesis.[2] It is usually suspected that epimerization might occur during the isolation process. However, no experimental evidence is available.

Prior synthetic efforts on THP-containing diarylheptanoids (THP-DAHs), mostly on the synthesis of centrolobine, have led to the development of various methods for the construction of 2,6-*cis*-configured THPs. For example, hetero-Diels−Alder reaction,[3] ring-closing olefin metathesis,[4] Prins cyclization,[5] intramolecular etherification,[6] intramolecular amide enolate alkylation,[7] oxa-Michael addition,[8] Maitland−Japp reaction,[9] and intramolecular Barbier-type[10] strategies were employed as the key steps for the synthesis of centrolobine. However, the synthetic methods for the corresponding 2,6-*trans*-configured THP-DAHs are rather underdeveloped, which is not surprising, given the fact that the 2,6-*cis*-disubstituted THP lacking 1,3-diaxial interactions is thermodynamically more stable. Recently, our group developed an efficient strategy featuring Achmatowicz rearrangement (AchR) and Heck−Matsuda coupling for the construction of the *trans*-2-aryl-6-alkyldihydropyrans and achieved the total syntheses of 2,6-*trans*-configured THP-DAHs including musellarins A−C,[11] diospongin B, and parvistones D and E.[12] To further expand the synthetic utility of this strategy, we undertook the synthetic studies of hedycoropyrans A and B, culminating in the first asymmetric total synthesis.

Our synthetic efforts were primarily focused on hedycoropyran A, and we envisioned that hedycoropyran A might be used as the synthetic precursor of hedycoropyran B via C2 epimerization at the late stage as hinted in Scheme 1. The most striking structural difference of hedycoropyrans A from other 2,6-*trans*-configured THP-DAHs lies in the presence of the chiral secondary alcohol at C7 and the 3,4-*anti*-dihydoxy on the THP ring. This structural difference significantly increases the synthetic challenge and casts uncertainty over our strategy as shown in Scheme 1 because (i) Achmatowicz rearrangement (AchR) of furfuryl diols (cf., **IV**) usually affords the 6,8-dioxabicyclo[3.2.1]octanes (6,8-DOBCOs), (ii) the C7 alcohol beta to both the carbonyl and the phenol of many advanced intermediates (cf., **I** and **II**) could readily undergo dehydration under either acidic or basic conditions, and (iii) 3,4-*anti*-dihydroxy could not be obtained directly by the well-established *syn*-dihydroxylation of reaction products derived from the sequential Achmatowicz/deoxygenation/Heck−Matsuda reactions (**IV** → **III** → **II** → **I**). Nevertheless, we believe that these challenges could be solved in the course of

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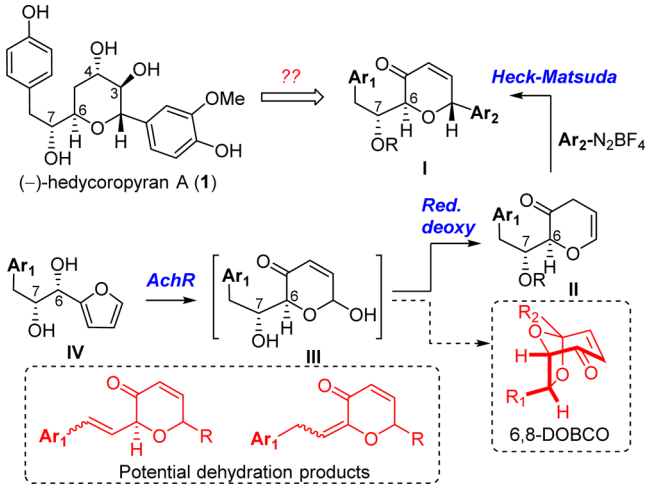
Scheme 1. Synthetic Analysis of (−)-Hedycoropyran A (1)

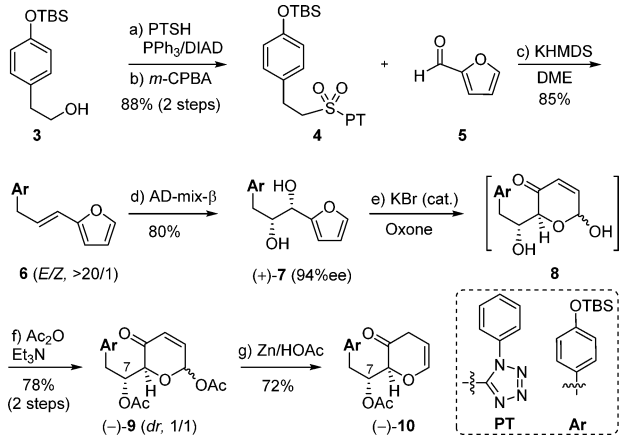


experiments. If successful, these synthetic studies would greatly expand the synthetic utility of our AchR strategy in the total synthesis of natural 2,6-*trans*-THP-DAHs.

RESULTS AND DISCUSSION

Our synthesis (Scheme 2) began with the preparation of sulfone **4** by Mitsunobu reaction[13] of TBS-protected tyrosol

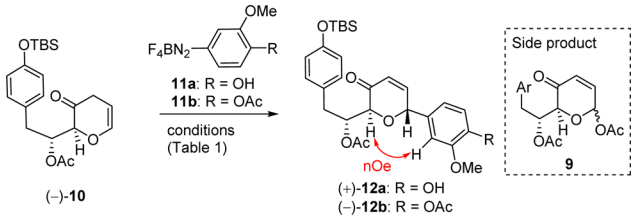
Scheme 2. Synthesis of the Enol Ether 10



(**3**)[14] with 1-phenyl-1*H*-tetrazol-5-yl thiol (PTSH) and *m*-CPBA oxidation. Julia−Kocienski[15] olefination of **4** and furfural (**5**) was effectively promoted by KHMDS at −78 °C in anhydrous DME (dimethoxyethane) to give the alkene **6** in 85% yield with excellent stereoselectivity (*E*/*Z*, >20/1). It was noted that the *E*/*Z* selectivity was significantly affected by the solvent (THF: *E*/*Z* = 5/1), instead of the counterion of the base. Sharpless asymmetric dihydroxylation[16] of **6** with AD mix-*β* provided the requisite vicinal diol **7** (94% ee by HPLC), which underwent smoothly Achmatowicz rearrangement under our catalytic condition[17] [KBr (cat.) and oxone] to provide **9** in 78% yield after immediate double acetylation. The subsequent reductive *γ*-deoxygenation proceeded under our previously described condition[12] to afford **10** in 72% yield. Notably, the C7 acetate *β* to both the carbonyl and the aryl groups survived during both the acetylation under the mild basic condition (Et_3N) and the deoxygenation under the acidic condition (HOAc).

Unexpectedly, we encountered a challenge in the stereoselective Heck−Matsuda reaction of enol ether **10** with aryl diazo compounds **11a** and **11b** under our previously reported condition[11,12] (Table 1). Reaction of **10** with either of the two

Table 1. Condition Optimization for Heck−Matsuda Arylation of Enol Ether 10



entry	ArN_2BF_4	Pd[a]	base[b]	solvent	time (h)	yield[c]
1	**11a**	$Pd(OAc)_2$	NaOAc	ACN	3	**12a** (21%), **9** (45%)
2	**11b**	$Pd(OAc)_2$	NaOAc	ACN	3	**12b** (12%), **9** (35%)
3	**11a**	$Pd_2(dba)_3$	NaOAc	ACN	3	**12a** (25%), **9** (40%)
4	**11a**	$Pd(OAc)_2$	DBMP	ACN	3	**12a** (56%)
5	**11a**	$Pd_2(dba)_3$	n.a.	ACN	24	**12a** (20%)[d]
6	**11a**	$\mathbf{Pd_2(dba)_3}$	**DBMP**	**ACN**	**3**	**12a** (**82%**)
7	**11b**	$Pd_2(dba)_3$	DBMP	ACN	24	**12b** (49%)

[a]10 mol % $Pd(OAc)_2$ or 5 mol % $Pd_2(dba)_3$ was used. [b]4 equiv of base was used in all entries. [c]Isolated yield. [d]S.M. cannot be completely consumed after 24 h. DBMP: 2,6-*tert*-butyl-4-methyl-pyridine. ACN: acetonitrile.

aryl diazonium salts (**11a** and **11b**) delivered the desired 2,6-*trans*-DHP products **12a** and **12b**, respectively, in only 12−25% yields (entries 1−3). The acetoxypyranone **9** was identified as the major side product (35−45%), which might be attributed to the presence of the excess base NaOAc (4 equiv).[18] This was consistent with the result that replacing the sodium acetate with 2,6-di-*tert*-butyl-4-methyl-pyridine significantly improved the yield (entry 4), and that $Pd_2(dba)_3$ (entry 6) was the better precatalyst than $Pd(OAc)_2$ (entry 4).[19] It was also noted that the base was essential to accelerate the reaction (entry 5) and that **12a** outperformed **12b** (entry 7) in the Heck−Matsuda coupling reaction. The relative configuration of the desired 2,6-*trans*-THP product **12a** was further confirmed by the NOE experiment (see the Supporting Information).

With the desired 2,6-*trans*-THP core **12a** in hand, we next pursued the stereoselective installation of the 3,4-*anti*-diol through direct epoxide opening (Scheme 3). TIPS protection of **12a** and subsequent diastereoselective epoxidation[20] with benzyltrimethylammonium hydroxide (also known as Triton B) and *tert*-butyl hydroperoxide (TBHP) provided the epoxy ketone **13** in 67% yield, along with significant but unavoidable HOAc elimination product **13′** (10−20%). The high diastereoselectivity of **13** (NOE experiment, see the Supporting Information) was attributed to the nucleophilic attack (oxa-Michael addition) from the opposite face of the C2 aryl group. Next, we attempted a variety of conditions for direct epoxide ring opening such as H_2O at reflux,[21] NaOAc/H_2O,[22] trifluoroacetic acid (TFA)/THF/H_2O,[23] $Sc(OTf)_3$/AcOH,[24] and $BF_3{\cdot}OEt_2$ in toluene.[20] Unfortunately, the desired *anti*-diol **14** was not observed. Analysis of the reaction mixture indicated that some side products were resulted from desilylation, deacetylation, HOAc elimination, and/or C2 epimerization.

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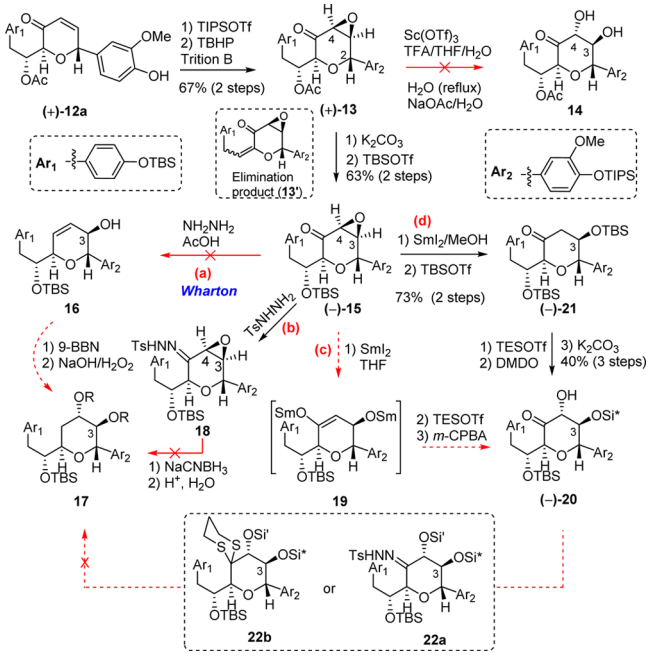
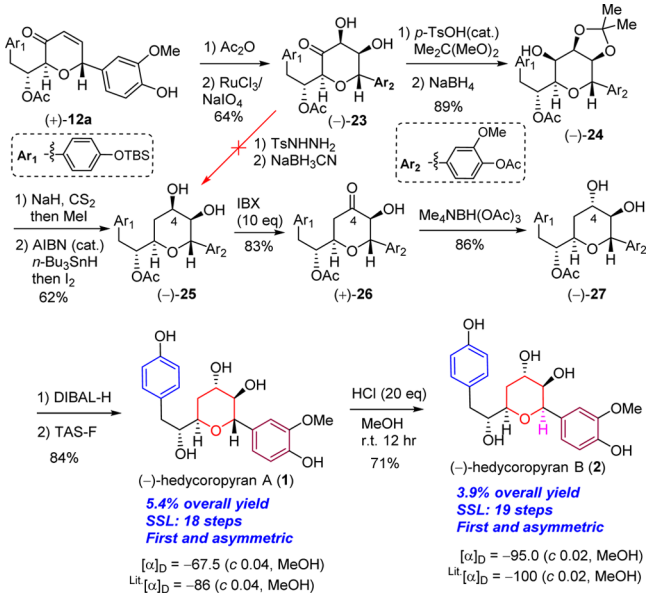
Scheme 3. Attempted Methods for Installation of the 3,4-*anti*-Diol from Epoxide Opening



To prevent the potential HOAc elimination, the C7 acetate was converted to the corresponding TBS ether **15** in 63% yield (the side product **13′** was also obtained in 17% yield), and then we attempted the epoxide opening under the above-mentioned conditions. Unfortunately, these attempts did not afford the desired *anti*-diol. Next, we envisioned that Wharton reaction[25] of the epoxy ketone **15** followed by regio- and stereoselective hydroboration/oxidation[26] might furnish hedycoropyran A (**1**) after global deprotection (method a, **15** → **16** → **17**). Surprisingly, various known conditions for Wharton reaction resulted in either decomposition or an unknown product (not fully characterized). On the other hand, we suspected that the keto carbonyl might be responsible for the unsuccessful attempts of epoxide openings and should be removed first by modified Wolf–Kishner[27] deoxygenation (method b). Condensation of **15** and $TsNHNH_2$ gave the tosylhydrazone **18** in 69% yield. Unfortunately, the reduction of **18** was problematic, and no deoxygenation product (epoxide or **17**) was observed. Next, we attempted an indirect epoxide opening strategy by exploiting the neighboring carbonyl group (method c): SmI_2-promoted reductive epoxide opening and subsequent Rubottom oxidation.[28] Our initial efforts focusing on trapping the reductive intermediate **19** with silylating reagents (TMSCl, TESCl, TESOTf, TBSOTf, etc.) proved fruitless due to significant decomposition after being treated with silylating agents.[29] After tremendous experimentation (particularly for oxidative α-hydroxylation of the ketone including L-proline/ONPh,[30] $PhI(OAc)_2$,[31] NaHMDS/Davis reagent,[32] etc.), a five-step sequence[33] was developed to provide the 3,4-*anti*-diol derivative **20** in 29% overall yield. Disappointingly, deoxygenation of the ketonic carbonyl group by the modified Wolf–Kishner reduction led to full decomposition, while 1,3-dithiane **22b** for Raney-Ni desulfurization was not successfully prepared from **20** under various known conditions (e.g., $BF_3{\cdot}Et_2O$). At this stage, we had to abandon the epoxide opening strategy for installation of the 3,4-*anti*-diol.

Next, we decided to prepare the 3,4-*anti*-diol from the corresponding 3,4-*syn*-diol (Scheme 4). To this end, acetylation

Scheme 4. Completion of the First Total Syntheses of Hedycoropyrans A (1) and B (2)



of the phenol **12a** and $RuCl_3$-catalyzed diastereoselective dihydroxylation[34] provided 3,4-*syn*-diol **23** in 64% yield as the single diastereomer. The relative stereochemistry was further verified by NOE experiments (see the Supporting Information). It was noted later that protection of the phenol **12a** as the acetate derivative was crucial to minimize the destructive interference in the Barton–McCombie deoxygenation.[35] It was to our surprise that modified Wolf–Kishner deoxygenation of the ketonic carbonyl of **23** with $TsNHNH_2/NaBH_3CN$ resulted in a complex mixture, while this deoxygenation protocol worked efficiently with the similar dihydroxy ketone in our previous studies.[12] Nevertheless, a four-step sequence involving acetonide protection, $NaBH_4$ reduction of the ketone, and two-step Barton–McCombie deoxygenation was developed to deoxygenate the ketonic carbonyl and afford **25** in 55% yield. Notably, the iodine workup of the reaction not only converted the excess $(n\text{-Bu})_3SnH$ and side product $(n\text{-Bu})_3SnSn(n\text{-Bu})_3$ to $(n\text{-Bu})_3SnI$ but also concomitantly unmasked the 3,4-*syn*-diol from its acetonide.[36] The stereochemical inversion of the C4 alcohol **25** was achieved by IBX oxidation[37] (83% yield) followed by Evans–Saksena reaction[38] (86% yield). Interestingly, the IBX oxidation yielded only the single diastereomer, which was in contrast to our previously reported result[12] that a diastereomeric mixture was obtained from the oxidation of the similar diol with $RuCl_3$/oxone.[39] A two-step global deprotection (deacetylation with DIBAL-H and desilylation with TAS-F) furnished (−)-hedycoropyran A (**1**) as the single isomer in 84% yield. To our delight, treatment of hedycoropyran A with HCl (20 equiv) in methanol promoted effectively the C2 epimerization, furnishing hedycoropyran B in 71% yield. All spectroscopic data of our synthetic samples were well consistent with those reported for the natural hedycoropyrans A and B.[40] The same sign of the specific optical rotation derived from our synthetic samples and the natural ones confirmed the absolute configuration assigned originally by calculated and experimental ECD data.

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CONCLUSION

We have achieved the first asymmetric total syntheses of (−)-hedycoropyan A (**1**) and (−)-hedycoropyan B (**2**) with a 5.4% overall yield in 18 steps and a 3.9% overall yield in 19 steps, respectively. The key synthetic stragety features (1) an efficient sequence of Achmatowicz rearrangement, reductive γ-deoxygenation, and Heck−Matsuda coupling to construct the main 2,6-*trans* dihydropyran skeleton, and (2) regioselective stereochemical inversion of the 3,4-*syn*-diol to the 3,4-*anti*-diol through IBX oxidition and Evans−Saksena reduction. Notably, C2 epimerization of (−)-hedycoropyan A (**1**) in acidic condition at rt gave (−)-hedycoropyan B (**2**) in 71% yield. This finding might suggest the biogenetic origin of hedycoropyan B. Our synthetic studies greatly expand the utility of our previously reported strategy for the synthesis of 2,6-*trans*-dihydropyrans and provide a viable way to supply these scarce natural products for biological activity evaluation.

EXPERIMENTAL SECTION

NMR spectra were recorded on a 400 MHz spectrometer (400 MHz for ^{1}H, 100 MHz for ^{13}C). Chemical shifts are reported in parts per million (ppm) as values relative to the internal chloroform (7.26 ppm for ^{1}H and 77.16 ppm for ^{13}C), benzene (7.16 ppm for ^{1}H and 128.06 ppm for ^{13}C), and methanol (3.31 ppm for ^{1}H and 49.00 ppm for ^{13}C). Infrared (IR) spectra were recorded as neat samples (liquid films on KBr plates). HRMS spectra were recorded with a TOF detector. Reactions were carried out in oven or flame-dried glassware under a nitrogen atmosphere, unless otherwise noted. Tetrahydrofuran (THF) was freshly distilled before use from sodium using benzophenone as indicator. Dichloromethane (CH_2Cl_2) and dimethoxyethane (DME) was freshly distilled before use from calcium hydride (CaH_2). All other anhydrous solvents were dried over 3 or 4 Å molecular sieves. Standard workup and purification were performed as follows: the reaction was quenched with aqueous satd $NaHCO_3$ or NH_4Cl, the organic layer was extracted with the organic solvent (CH_2Cl_2 or EtOAc) three times, the conbined organic fractions were washed with brine, dried over anhydrous Na_2SO_4 or $MgSO_4$, filtered, and concentrated in vacuo, and the resulting residue was purified by flash column chromatography (hexane and ethyl acetate as eluents) on silica gel.

5-((4-((*tert*-Butyldimethylsilyl)oxy)phenethyl)sulfonyl)-1-phenyl-1*H*-tetrazole (4). To a stirred solution of the TBS-protected tyrosol **3** (12.6 g, 50.1 mmol) in anhydrous THF (400 mL) at 0 °C were added PPh_3 (19.7 g, 75.0 mmol), 1-phenyl-1*H*-tetrazole-5-thiol (PTSH, 13.4 g, 75.0 mmol), and diisopropyl azodicarboxylate (DIAD, 5.17 g, 75.0 mmol). The reaction mixture was allowed to warm to rt and was stirred for an additional 6 h. The reaction then was quenched by addition of satd aq NH_4Cl (100 mL) and extracted with EtOAc (3 × 80 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 10:1) to afford the desired sulfide product as a colorless oil. To a stirred solution of the sulfide product obtained above in CH_2Cl_2 (400 mL) at 0 °C were added $NaHCO_3$ (20.2 g, 240 mmol) and 3-chloroperbenzoic acid (*m*-CPBA, 24.4 g, 120 mmol, ca. 85 wt %). The reaction mixture was stirred at rt overnight. The reaction was quenched by addition of satd aq Na_2SO_3 solution (100 mL), and the reaction mixture was extracted with CH_2Cl_2 (3 × 100 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 10:1) to afford the desired sulfone product **4** (19.6 g, 44.1 mmol, 88% yield over two steps) as a yellowish oil. IR (neat, cm^{-1}): 2956, 2887, 2858, 1720, 1511, 1347, 1155. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.69−7.68 (m, 2H), 7.64−7.60 (m, 3H), 7.11 (d, J = 8.4 Hz, 2H), 6.80 (d, J = 8.4 Hz, 2H), 3.98−3.94 (m, 2H), 3.21−3.17 (m, 2H), 0.99 (s, 9H), 0.20 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.1, 153.5, 133.1, 131.6, 129.8 (2 × C), 129.6 (2 × C), 129.0, 125.2 (2 × C), 120.7 (2 × C), 57.6, 27.8, 25.8, 18.3 (3 × C), −4.3 (2 × C). HRMS (TOF, CI$^+$) m/z calcd for $C_{21}H_{28}N_4O_3SSi$, $[M]^+$ 444.1651, found 444.1656.

(*E*)-*tert*-Butyl(4-(3-(furan-2-yl)allyl)phenoxy)dimethylsilane (6). To a stirred solution of sulfone **4** (13.3 g, 30.1 mmol) in anhydrous dimethoxyethane (DME, 100 mL) at −78 °C was added potassium bis(trimethylsilyl)amide (KHMDS, 1.0 M in THF, 45.2 mL, 45.2 mmol) slowly. After the mixture was stirred at −78 °C for 30 min, the furfural **5** (4.32 g, 45.2 mmol) was added very slowly. After completion of the addition, the reaction mixture was stirred at −78 °C for an additional 2 h. The reaction then was quenched by addition of satd aq NH_4Cl (50 mL). The organic phase was collected, and the aqueous phase was extracted with EtOAc (3 × 50 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 100:1) to afford the desired alkene product **6** (8.02 g, 25.5 mmol, 85% yield, ratio of E/Z isomers >20/1) as a colorless oil. IR (neat, cm^{-1}): 3025, 2957, 2932, 2896, 1608, 1509, 1262, 961. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 (s, 1H), 7.17 (d, J = 8.2 Hz, 2H), 6.89 (d, J = 8.2 Hz, 2H), 6.45−6.38 (m, 2H), 6.30 (d, J = 15.9 Hz, 1H), 6.23 (d, J = 3.3 Hz, 1H), 3.53 (d, J = 6.7 Hz, 2H), 1.11 (s, 9H), 0.30 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.1, 153.2, 141.5, 132.6, 129.7 (2 × C), 128.8, 120.1 (2 × C), 119.5, 111.2, 106.6, 38.4, 25.8, 18.3 (3 × C), −4.3 (2 × C). HRMS (TOF, CI$^+$) m/z calcd for $C_{19}H_{26}O_2Si$, $[M]^+$ 314.1702, found 314.1709.

(1*S*,2*R*)-3-(4-((*tert*-Butyldimethylsilyl)oxy)phenyl)-1-(furan-2-yl)propane-1,2-diol ((+)-7). To a stirred solution of alkene **6** (8.02 g, 25.5 mmol) in *t*-BuOH/H_2O (100 mL/100 mL) at 0 °C were added sequentially K_2CO_3 (10.6 g, 76.5 mmol), $K_3Fe(CN)_5$ (25.2 g, 76.5 mmol), $(DHQD)_2PHAL$ (397 mg, 0.51 mmol), $MeSO_2NH_2$ (2.43 g, 25.5 mmol), and $K_2OsO_4{\cdot}(H_2O)_2$ (188 mg, 0.51 mmol). The reaction mixture was stirred at 0 °C for 48 h. The reaction was quenched by addition of satd aq Na_2SO_3 (50 mL). The organic phase was collected, and the aqueous phase was extracted with EtOAc (3 × 50 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 2:1) to afford desired diol (+)-7 (7.11 g, 20.4 mmol, 80% yield, 94 ee %) as a yellowish oil. $[\alpha]_D^{20}$ = +3.8 (*c* 0.56, $CHCl_3$). IR (neat, cm^{-1}): 3435, 3024, 2953, 2853, 2365, 1450, 1182, 1091, 1013, 781. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 (dt, J = 1.7, 0.9 Hz, 1H), 7.06 (d, J = 8.2 Hz, 2H), 6.77 (dd, J = 7.9, 1.3 Hz, 2H), 6.35−6.32 (m, 2H), 4.50 (d, J = 5.8 Hz, 1H), 4.12−4.06 (m, 1H), 2.7−2.60 (m, 2H), 0.99 (s, 9H), 0.19 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.4, 154.2, 142.3, 130.5 (2 × C), 130.4, 120.2 (2 × C), 110.5, 107.9, 74.4, 70.1, 38.6, 25.8, 18.3 (3 × C), −4.3 (2 × C). HRMS (TOF, CI$^+$) m/z calcd for $C_{19}H_{32}NO_4Si$, $[M + NH_4]^+$ 366.2095, found 366.2091.

(6*S*)-6-((*R*)-1-Acetoxy-2-(4-((*tert*-butyldimethylsilyl)oxy)-phenyl)ethyl)-5-oxo-5,6-dihydro-2*H*-pyran-2-yl acetate ((−)-9). To a stirred solution of furfuryl diol (+)-7 (7.11 g, 20.4 mmol) in THF/H_2O (80 mL/20 mL) at 0 °C were added KBr (0.24 g, 2.04 mmol), $NaHCO_3$ (0.86 g, 10.2 mmol), and Oxone (15.1 g, 24.5 mmol). The reaction mixture was stirred at 0 °C for 1 h. The reaction was then quenched by addition of satd aq $NaHCO_3$ (80 mL) and extracted with EtOAc (3 × 50 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The crude product was used for the next step without further purification. To a stirred solution of the crude product obtained above in CH_2Cl_2 (60 mL) were added acetic anhydride (Ac_2O, 4.16 g, 40.8 mmol), Et_3N (4.33 g, 40.8 mmol), and 4-dimethylaminopyridine (DMAP, 1.01 g, 8.16 mmol) at 0 °C. The reaction mixture was allowed to warm to rt and stirred overnight. The reaction was quenched by addition of satd aq NH_4Cl (50 mL) and extracted with CH_2Cl_2 (3 × 50 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on

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silica gel (hexane/EtOAc = 4:1) to afford the desired reddish oil product (−)-**9** (7.14 g, 15.9 mmol, 78% yield over two steps) as a 1:1 diastereomeric mixture. $[\alpha]_D^{20}$ = −12.3 (*c* 0.88, $CHCl_3$). IR (neat, cm^{-1}): 3062, 3027, 2931, 2863, 1745, 1701, 1511, 1370, 1253, 1103, 915, 752. ^1H NMR for one isomer (400 MHz, $CDCl_3$) δ 7.08 (d, *J* = 8.4 Hz, 2H), 6.85 (ddd, *J* = 10.4, 3.8, 2.8 Hz, 1H), 6.73 (dd, *J* = 15.1, 8.5 Hz, 2H), 6.48 (q, *J* = 1.4 Hz, 1H), 6.22−6.13 (m, 1H), 5.56 (ddd, *J* = 10.7, 5.6, 2.1 Hz, 1H), 4.09−4.05 (m, 1H), 2.95 (dd, *J* = 12.9, 5.6 Hz, 1H), 2.91−2.81 (m, 1H), 2.05 (s, 3H), 1.96 (s, 3H), 0.93 (s, 9H), 0.14 (s, 6H). ^{13}C NMR for one isomer (100 MHz, $CDCl_3$) δ 192.8, 169.7, 169.1, 154.6, 144.5, 130.7 (2 × C), 130.0, 128.7, 120.2 (2 × C), 88.1, 77.4, 73.2, 34.8, 25.7 (3 × C), 21.0, 20.8, −4.4 (2 × C). ^1H NMR for the other isomer (400 MHz, $CDCl_3$) δ 7.15 (d, *J* = 8.4 Hz, 2H), 6.85 (ddd, *J* = 10.4, 3.8, 2.8 Hz, 1H), 6.73 (dd, *J* = 15.1, 8.5 Hz, 2H), 6.62 (d, *J* = 3.7 Hz, 1H), 6.22−6.13 (m, 1H), 5.44 (ddd, *J* = 8.5, 7.0, 2.9 Hz, 1H), 4.24 (d, *J* = 2.1 Hz, 1H), 2.91−2.81 (m, 2H), 2.18 (s, 3H), 1.96 (s, 3H), 0.93 (s, 9H), 0.14 (s, 6H). ^{13}C NMR for the other isomer (100 MHz, $CDCl_3$) δ 192.4, 169.7, 169.2, 154.6, 141.8, 130.5 (2 × C), 129.0, 128.6, 120.1 (2 × C), 86.6, 74.1, 72.7, 34.3, 25.6 (3 × C), 20.9, 18.2, − 4.5 (2 × C). HRMS (TOF, CI^-) *m*/*z* calcd for $C_{23}H_{31}O_7Si$, $[M - H]^-$ 447.1845, found 447.1853.

(*R*)-2-(4-((*tert*-Butyldimethylsilyl)oxy)phenyl)-1-((*S*)-3-oxo-3,4-dihydro-2*H*-pyran-2-yl)ethyl Acetate ((−)-10). To a stirred solution of (−)-**9** (2.68 g, 5.96 mmol) in acetic acid (6 mL) was added activated Zn powder (3.88 g, 59.6 mmol) at rt. The reaction mixture was stirred at rt for 5 h. The reaction was then quenched by addition of satd aq $NaHCO_3$ (50 mL) and extracted with CH_2Cl_2 (3 × 30 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 8:1) to afford the desired product (−)-**10** (1.68 g, 4.31 mmol, 72% yield) as a colorless oil. $[\alpha]_D^{20}$ = −22.7 (*c* 0.68, $CHCl_3$). IR (neat, cm^{-1}): 3038, 2947, 2860, 1739, 1508, 1457, 1339, 1236, 1137, 904. ^1H NMR (400 MHz, C_6D_6) δ 7.12 (d, *J* = 8.4 Hz, 2H), 6.77 (d, *J* = 8.4 Hz, 2H), 6.30 (dt, *J* = 5.9, 2.1 Hz, 1H), 5.77 (ddd, *J* = 9.0, 6.1, 2.7 Hz, 1H), 4.38 (dt, *J* = 5.9, 3.7 Hz, 1H), 3.97 (td, *J* = 2.5, 1.1 Hz, 1H), 3.10−2.97 (m, 2H), 2.46−2.29 (m, 2H), 1.63 (s, 3H), 0.97 (s, 9H), 0.09 (s, 6H). ^{13}C NMR (100 MHz, C_6D_6) δ 203.4, 169.4, 155.0, 143.5, 131.0 (2 × C), 129.6, 120.6 (2 × C), 98.3, 79.5, 73.9, 35.7, 34.8, 25.9 (3 × C), 20.5, 18.4, −4.3 (2 × C). HRMS (TOF, CI^-) *m*/*z* calcd for $C_{21}H_{29}O_5Si$, $[M - H]^-$ 389.1790, found 389.1780.

(*E*)-2-Methoxy-4-((tetrafluoro-λ^5-boranyl)diazenyl)phenol (11a). To a stirred solution of 4-nitroguaiacol (3.01 g, 17.7 mmol) in ethyl acetate (20 mL) and ethanol (60 mL) was added Pd/C (188 mg, 0.18 mmol, 10 wt % Pd on activated carbon) under N_2 atmosphere at rt. The reaction mixture was bubbled by H_2 (g) for 10 min, and then the gas outlet was closed and the reaction mixture was stirred at rt overnight before filtration through Celite. The solvent was removed under reduced pressure, and the crude product was used for the next step without further purification. To a stirred solution of the crude product in 2-propanol (2 mL) was added HBF_4 (3.6 M solution in water, 7.02 mL, 26.3 mmol) under N_2 atmosphere at 0 °C. After completion of the addition, the reaction mixture was allowed to stir at 0 °C for 30 min, and then $NaNO_2$ (1.52 g, 22.0 mmol) was added portionwise to the mixture and stirred at 0 °C for additional 30 min. The precipitates were collected by filtration, and the resulting solid was washed with MeOH twice and dried under reduced pressure to afford the green powder **11a** (2.44 g, 10.3 mmol, 58% yield over two steps). It was noted that **11a** was unstable, and consequently spectra of IR and HRMS could not be obtained. ^1H NMR (400 MHz, DMSO-d_6) δ 7.84 (dd, *J* = 9.4, 2.7 Hz, 1H), 7.28 (d, *J* = 2.6 Hz, 1H), 6.32 (d, *J* = 9.4 Hz, 1H), 3.70 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 172.5, 150.5, 130.9, 122.3, 106.2, 78.4, 55.5.

(*R*)-2-(4-((*tert*-Butyldimethylsilyl)oxy)phenyl)-1-((2*S*,6*R*)-6-(4-hydroxy-3-methoxyphenyl)-3-oxo-3,6-dihydro-2*H*-pyran-2-yl)-ethyl Acetate ((+)-12a). To a stirred solution of the enol ether (−)-**10** (1.05 g, 2.70 mmol) in CH_3CN (20 mL) were added $Pd_2(dba)_3$ (0.13 g, 0.14 mmol), 2,6-di-*tert*-butyl-4-methylpyridine (2.21 g, 10.8 mmol), and aryldiazonium salt **11a** (0.98 g, 4.05 mmol) at rt. The reaction mixture was stirred at rt for 4 h. The reaction was quenched by addition of satd aq NH_4Cl (30 mL) and extracted with EtOAc (3 × 20 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 3:1) to afford the desired product (+)-**12a** (1.14 g, 2.20 mmol, 82% yield) as a reddish oil. $[\alpha]_D^{20}$ = +70.4 (*c* 0.91, $CHCl_3$). IR (neat, cm^{-1}): 3363, 2948, 1755, 1701, 1511, 1472, 1372, 1253, 1100, 915, 840. ^1H NMR (400 MHz, $CDCl_3$) δ 7.12 (dd, *J* = 10.4, 3.4 Hz, 1H), 6.93 (d, *J* = 8.0 Hz, 1H), 6.86−6.85 (m, 2H), 6.75 (d, *J* = 8.5 Hz, 2H), 6.54 (d, *J* = 8.4 Hz, 2H), 6.28 (d, *J* = 1.9 Hz, 1H), 5.89 (s, 1H), 5.69 (dd, *J* = 3.5, 1.9 Hz, 1H), 5.49 (ddd, *J* = 8.6, 6.7, 2.8 Hz, 1H), 4.03 (d, *J* = 2.8 Hz, 1H), 3.87 (s, 3H), 2.85−2.82 (m, 2H), 2.01 (s, 3H), 0.95 (s, 9H), 0.14 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.9, 170.0, 154.4, 149.1, 147.1, 146.8, 130.4 (2 × C), 128.7, 127.2, 122.0, 119.9 (2 × C), 114.7, 111.2, 74.7, 74.6, 73.4, 60.5, 56.1, 35.0, 25.7 (3 × C), 21.1, 18.2, −4.4 (2 × C). HRMS (TOF, CI^-) *m*/*z* calcd for $C_{28}H_{36}O_7Si$, $[M]^-$ 512.2230, found 512.2220.

(*R*)-2-(4-((*tert*-Butyldimethylsilyl)oxy)phenyl)-1-((1*S*,2*S*,4*S*,6*S*)-2-(3-methoxy-4-((triisopropylsilyl)oxy)phenyl)-5-oxo-3,7-dioxabicyclo[4.1.0]heptan-4-yl)ethyl Acetate ((+)-13). To a stirred solution of (+)-**12a** (0.61 g, 1.18 mmol) in CH_2Cl_2 (10 mL) at 0 °C were added 2,6-lutidine (0.41 mL, 3.51 mmol) and triisopropylsilyl trifluoromethanesulfonate (TIPSOTf, 0.47 mL, 1.76 mmol) dropwise. After completion of the addition, the reaction mixture was allowed to warm to rt and stirred for additional 4 h. The reaction was quenched by addition of satd aq $CuSO_4$ solution (20 mL) and extracted with CH_2Cl_2 (3 × 20 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The crude product was used for the next step without further purification. To a stirred solution of the crude product in THF/H_2O (10 mL/10 mL) at 0 °C were added *tert*-butylhydroperoxide (70 wt % in H_2O, 2 mL) and Triton B (40 wt % in H_2O, 51 μL, 0.12 mmol). The reaction mixture was stirred at 0 °C for 2 h. The reaction was then quenched by addition of satd aq Na_2SO_3 (30 mL), and the resulting mixture was extracted with EtOAc (3 × 20 mL). The combined organic fractions were washed with brine, dried over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel using eluents (hexane/EtOAc = 10:1) to give the epoxyketone (+)-**13** (0.54 g, 0.79 mmol, 67% yield over two steps) as a yellowish oil. $[\alpha]_D^{20}$ = +56.3 (*c* 0.42, $CHCl_3$). IR (neat, cm^{-1}): 3034, 3014, 2920, 2856, 1767, 1736, 1460, 1271, 1115, 813. ^1H NMR (400 MHz, $CDCl_3$) δ 6.88−6.82 (m, 4H), 6.75 (dd, *J* = 8.1, 2.1 Hz, 1H), 6.57−6.54 (m, 2H), 5.47 (d, *J* = 1.5 Hz, 1H), 5.25 (ddd, *J* = 8.8, 6.2, 2.2 Hz, 1H), 3.89 (dd, *J* = 4.0, 1.6 Hz, 1H), 3.81 (s, 3H), 3.66 (d, *J* = 4.0 Hz, 1H), 3.58 (d, *J* = 2.1 Hz, 1H), 2.88−2.83 (m, 2H), 2.06 (s, 3H), 1.28−1.20 (m, 3H), 1.07 (dd, *J* = 7.4, 1.5 Hz, 18H), 0.93 (s, 9H), 0.12 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 202.4, 170.1, 154.5, 151.6, 147.1, 130.3 (2 × C), 128.7, 126.4, 120.6, 120.5 (2 × C), 120.0, 113.0, 75.3, 74.3, 71.3, 55.7, 55.1, 54.4, 34.9, 25.7 (3 × C), 21.1 (3 × C), 18.2, 18.0 (6 × C), 12.9, −4.39, −4.41. HRMS (TOF, LD^+) *m*/*z* calcd for $C_{37}H_{56}NaO_8Si_2$, $[M + Na]^+$ 707.3406, found 707.3402.

(1*S*,2*S*,4*S*,6*S*)-4-((*R*)-1-((*tert*-Butyldimethylsilyl)oxy)-2-(4-((*tert*-butyldimethylsilyl)oxy)phenyl)ethyl)-2-(3-methoxy-4-((triisopropylsilyl)oxy)phenyl)-3,7-dioxabicyclo[4.1.0]heptan-5-one ((−)-15). To a stirred solution of the epoxyketone (+)-**13** (0.54 g, 0.79 mmol) in methanol (5 mL) was added K_2CO_3 (0.13 g, 0.95 mmol) at 0 °C. The reaction mixture was stirred at 0 °C for 2 h, and then the solvent was removed under reduced pressure. The resulting residue was diluted with CH_2Cl_2 (10 mL) and quenched by addition of satd aq NH_4Cl (20 mL). The organic phase was collected, and the aqueous phase was extracted with CH_2Cl_2 (3 × 10 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The crude product was used for the next step without further purification. To a stirred solution of the crude product in CH_2Cl_2 (20 mL) at 0 °C were added 2,6-lutidine (0.28 mL, 2.37 mmol) and *tert*-butyldimethylsilyl trifluoromethanesulfonate (TBSOTf, 0.26 mL, 1.19

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mmol) dropwise. After completion of the addition, the reaction mixture was allowed to warm to rt and stirred for an additional 3 h. The reaction was quenched by addition of satd aq $CuSO_4$ solution (20 mL) and extracted with CH_2Cl_2 (3 × 10 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel using eluents (hexane/EtOAc = 10:1) to give the epoxyketone (−)-**15** (0.38 g, 0.50 mmol, 63% yield over two steps) as a yellowish oil. $[\alpha]_D^{20}$ = −62.7 (*c* 0.31, $CHCl_3$). IR (neat, cm^{-1}): 3058, 3020, 2923, 2850, 1741, 1606, 1467, 1256, 1115, 836. ^1H NMR (400 MHz, $CDCl_3$) δ 6.86−6.80 (m, 4H), 6.73 (dd, *J* = 8.1, 2.1 Hz, 1H), 6.54 (d, *J* = 8.4 Hz, 2H), 5.45 (d, *J* = 1.5 Hz, 1H), 4.25−4.18 (m, 1H), 3.86 (dd, *J* = 4.0, 1.6 Hz, 1H), 3.79 (s, 3H), 3.63 (d, *J* = 4.0 Hz, 1H), 3.40 (d, *J* = 2.1 Hz, 1H), 2.96 (dd, *J* = 13.3, 9.2 Hz, 1H), 2.63 (dd, *J* = 13.3, 5.7 Hz, 1H), 1.28−1.22 (m, 3H), 1.07 (dd, *J* = 7.4, 1.6 Hz, 18H), 0.94 (s, 9H), 0.88 (s, 9H), 0.11 (s, 6H), 0.01 (s, 3H), −0.04 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 205.1, 154.3, 151.5, 146.8, 130.34 (2 × C), 130.3, 127.1, 120.6, 120.4, 120.0 (2 × C), 113.1, 77.6, 74.9, 70.9, 55.7, 55.3, 54.8, 38.9, 26.0 (3 × C), 25.8 (3 × C), 18.27, 18.25, 18.0 (6 × C), 13.0 (3 × C), −4.35, −4.37, −5.0. HRMS (TOF, LD^+) *m*/*z* calcd for $C_{41}H_{68}NaO_7Si_3$, $[M + Na]^+$ 779.4165, found 779.4170.

(2*S*,5*R*,6*S*)-5-((*tert*-Butyldimethylsilyl)oxy)-2-((*R*)-1-((*tert*-butyldimethylsilyl)oxy)-2-(4-((*tert*-butyldimethylsilyl)oxy)-phenyl)ethyl)-6-(3-methoxy-4-((triisopropylsilyl)oxy)phenyl)-dihydro-2*H*-pyran-3(4*H*)-one ((−)-21). To a stirred solution of the epoxyketone (−)-**15** (0.27 g, 0.40 mmol) in THF/MeOH (3 mL/1 mL) degassed by nitrogen for 15 min was added SmI_2 (0.1 M in THF, 10.4 mL, 1.04 mmol) at −78 °C. The reaction mixture was stirred at −78 °C for 30 min. The reaction was quenched by addition of satd aq $NaHCO_3$ (10 mL) and extracted with EtOAc (3 × 10 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 5:1) to afford the desired β-hydroxyketone as colorless oil. To a stirred solution of the β-hydroxyketone in CH_2Cl_2 (20 mL) at 0 °C were added 2,6-lutidine (0.14 mL, 1.20 mmol) and *tert*-butyldimethylsilyl trifluoromethanesulfonate (TBSOTf, 0.13 mL, 0.60 mmol) dropwise. After completion of the addition, the reaction mixture was allowed to warm to rt and was stirred for an additional 3 h. The reaction was quenched by addition of satd aq $CuSO_4$ solution (20 mL) and extracted with CH_2Cl_2 (3 × 10 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel using eluents (hexane/EtOAc = 15:1) to give the desired product (−)-**21** (255 mg, 0.29 mmol, 73% yield over two steps) as a yellowish oil. $[\alpha]_D^{20}$ = −89.6 (*c* 0.22, $CHCl_3$). IR (neat, cm^{-1}): 3013, 2958, 2950, 2887, 2861, 1798, 1535, 1260. ^1H NMR (400 MHz, $CDCl_3$) δ 6.98−6.95 (m, 3H), 6.88 (d, *J* = 2.3 Hz, 2H), 6.73−6.65 (m, 2H), 5.21 (d, *J* = 9.1 Hz, 1H), 4.22 (ddd, *J* = 10.5, 4.8, 2.6 Hz, 1H), 3.93 (td, *J* = 9.4, 6.0 Hz, 1H), 3.84 (s, 3H), 3.79 (d, *J* = 2.5 Hz, 1H), 2.97 (ddd, *J* = 18.8, 15.0, 8.2 Hz, 2H), 2.74−2.58 (m, 2H), 1.30−1.25 (m, 3H), 1.12 (d, *J* = 7.3 Hz, 18H), 0.97 (d, *J* = 1.4 Hz, 18H), 0.74 (s, 9H), 0.16 (s, 6H), 0.10 (s, 3H), 0.03 (s, 3H), −0.15 (s, 3H), −0.47 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 210.9, 154.3, 150.7, 145.4, 133.2, 130.7 (2 × C), 130.1, 120.7, 120.1 (2 × C), 119.9, 111.6, 81.2, 79.6, 77.9, 71.3, 55.7, 50.0, 39.6, 26.1 (3 × C), 25.8 (3 × C), 25.7 (3 × C), 18.3, 18.1, 18.0 (6 × C), 17.8, 13.1 (3 × C), −4.28, −4.30, −4.6, −4.7, −4.9, −5.2. HRMS (TOF, LD^+) *m*/*z* calcd for $C_{47}H_{84}NaO_7Si_4$, $[M + Na]^+$ 895.5186, found 895.5189.

(2*S*,4*R*,5*R*,6*S*)-5-((*tert*-Butyldimethylsilyl)oxy)-2-((*R*)-1-((*tert*-butyldimethylsilyl)oxy)-2-(4-((*tert*-butyldimethylsilyl)oxy)-phenyl)ethyl)-4-hydroxy-6-(3-methoxy-4-((triisopropylsilyl)-oxy)phenyl)dihydro-2*H*-pyran-3(4*H*)-one ((−)-20). To a stirred solution of (−)-**21** (120 mg, 0.14 mmol) in CH_2Cl_2 (5 mL) at 0 °C were added triethylamine (0.19 mL, 1.40 mmol) and triethyl trifluoromethanesulfonate (TESOTf, 0.25 mL, 1.12 mmol) dropwise. After completion of the addition, the reaction mixture was allowed to warm to rt and stirred for additional 8 h. The reaction was quenched by addition of satd aq $NaHCO_3$ solution (10 mL) and extracted with CH_2Cl_2 (3 × 10 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The crude silyl enol ether was used for the next step without further purification. To a stirred solution of the crude silyl enol ether in CH_2Cl_2 (5 mL) at 0 °C was added dimethyldioxirane (2.8 mL of 0.1 M in acetone, 0.28 mmol). After completion of the addition, the reaction mixture was allowed to stir at 0 °C for 3 h, and then the solvent was removed under reduced pressure. The resulting residue was redissolved in methanol (4 mL), and K_2CO_3 (38.7 mg, 0.28 mmol) was added and stirred at rt for 30 min. The resulting residue was diluted with CH_2Cl_2 (10 mL) and quenched by addition of satd aq NH_4Cl (10 mL). The organic phase was collected, and the aqueous phase was extracted with CH_2Cl_2 (3 × 10 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel using eluents (hexane/EtOAc = 10:1) to give the desired product (−)-**20** (48.1 mg, 56.1 μmol, 40% yield over three steps) as a yellowish oil. $[\alpha]_D^{20}$ = −52.8 (*c* 0.41, $CHCl_3$). IR (neat, cm^{-1}): 3441, 3033, 3006, 2930, 2856, 1763, 1472, 1262, 1128, 819. ^1H NMR (400 MHz, $CDCl_3$) δ 6.90−6.83 (m, 5H), 6.65 (d, *J* = 8.4 Hz, 2H), 5.30 (d, *J* = 8.7 Hz, 1H), 4.66 (d, *J* = 8.7 Hz, 1H), 4.20 (dq, *J* = 7.8, 2.4 Hz, 1H), 4.09 (dd, *J* = 9.5, 7.9 Hz, 1H), 3.99 (d, *J* = 2.6 Hz, 1H), 3.84 (s, 3H), 2.95 (dd, *J* = 13.1, 10.4 Hz, 1H), 2.73 (dd, *J* = 13.1, 4.7 Hz, 1H), 1.26 (ddd, *J* = 10.0, 7.4, 2.7 Hz, 3H), 1.12 (d, *J* = 7.3 Hz, 18H), 0.97 (d, *J* = 5.3 Hz, 18H), 0.76 (s, 9H), 0.16 (s, 6H), 0.09 (d, *J* = 12.2 Hz, 6H), 0.03 (d, *J* = 8.2 Hz, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 202.5, 154.5, 151.1, 146.2, 131.7, 130.7 (2 × C), 129.5, 121.5, 120.23 (2 × C), 120.16, 112.1, 81.3, 80.8, 78.8, 69.2, 55.8, 39.4, 26.0 (3 × C), 25.9 (3 × C), 25.8 (3 × C), 18.3, 18.2, 18.1 (6 × C), 18.0, 13.1 (3 × C), −4.3 (2 × C), −4.7, −4.8, −4.9. HRMS (TOF, LD^+) *m*/*z* calcd for $C_{47}H_{84}NaO_8Si_4$, $[M + Na]^+$ 911.5135, found 911.5147.

4-((2*R*,6*S*)-6-((*R*)-1-Acetoxy-2-(4-((*tert*-butyldimethylsilyl)-oxy)phenyl)ethyl)-5-oxo-5,6-dihydro-2*H*-pyran-2-yl)-2-methoxyphenyl Acetate ((−)-12b). To a stirred solution of (+)-**12a** (0.80 g, 1.56 mmol) in CH_2Cl_2 (10 mL) were added acetic anhydride (0.16 g, 1.56 mmol), pyridine (0.13 g, 1.56 mmol), and 4-dimethylaminopyridine (DMAP, 38.1 mg, 31.2 μmol) at 0 °C. The reaction mixture was allowed to warm to rt and stirred for 3 h. The reaction then was quenched by addition of satd aq NH_4Cl (10 mL) and extracted with CH_2Cl_2 (3 × 10 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel using eluents (hexane/EtOAc = 4:1) to give the desired product (−)-**12b** (0.57 g, 1.42 mmol, 91% yield) as a reddish oil. $[\alpha]_D^{20}$ = −55.4 (*c* 0.72, $CHCl_3$). IR (neat, cm^{-1}): 3011, 2956, 2859, 1745, 1702, 1609, 1511, 1472, 1372, 1253, 1100, 915. ^1H NMR (400 MHz, $CDCl_3$) δ 7.10 (dd, *J* = 10.4, 3.3 Hz, 1H), 7.06 (d, *J* = 8.1 Hz, 1H), 7.00 (d, *J* = 1.9 Hz, 1H), 6.93 (dd, *J* = 8.1, 1.9 Hz, 1H), 6.79 (d, *J* = 8.4 Hz, 2H), 6.59 (d, *J* = 8.4 Hz, 2H), 6.25 (dd, *J* = 10.4, 2.0 Hz, 1H), 5.72 (dd, *J* = 3.3, 2.0 Hz, 1H), 5.46 (ddd, *J* = 8.2, 7.0, 2.9 Hz, 1H), 4.07 (d, *J* = 2.9 Hz, 1H), 3.81 (s, 3H), 2.86−2.84 (m, 2H), 2.31 (s, 3H), 2.00 (s, 3H), 0.95 (s, 9H), 0.14 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.4, 169.8, 168.6, 154.3, 151.6, 148.7, 140.4, 134.7, 130.3 (2 × C), 128.6, 127.1, 123.1, 120.6, 120.0 (2 × C), 112.5, 75.1, 74.1, 73.4, 56.0, 35.0, 25.6 (3 × C), 21.0, 20.6, 18.1, −4.6 (2 × C). HRMS (TOF, CI^-) *m*/*z* calcd for $C_{30}H_{38}O_8Si$, $[M]^-$ 554.2336, found 554.2331.

4-((2*S*,3*R*,4*S*,6*S*)-6-((*R*)-1-Acetoxy-2-(4-((*tert*-butyldimethyl-silyl)oxy)phenyl)ethyl)-3,4-dihydroxy-5-oxotetrahydro-2*H*-pyran-2-yl)-2-methoxyphenyl Acetate ((−)-23). To a stirred solution of $NaIO_4$ (0.37 g, 1.73 mmol) in H_2O (3 mL) was added $CeCl_3$ (18.0 mg, 0.15 mmol) at rt. After being stirred for 5 min, EtOAc (7.5 mL) and CH_3CN (9 mL) were added, and the mixture was cooled to 0 °C. After being stirred for 5 min, $RuCl_3$ (0.1 M in H_2O, 1.5 mL, 0.15 mmol) was added at 0 °C. After being stirred for an additional 5 min, starting material (−)-**12b** (0.57 g, 1.42 mmol) dissolved in EtOAc (1.5 mL) was added at 0 °C dropwise. The

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reaction mixture was stirred at 0 °C for 2 h. The reaction was quenched by addition of satd aq Na_2SO_3 (10 mL) and extracted with EtOAc (3 × 10 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 1:1) to afford the desired *syn*-diol (−)-**23** (0.59 g, 0.99 mmol, 70% yield) as a yellowish oil. $[\alpha]_D^{20}$ = −40.4 (*c* 0.73, $CHCl_3$). IR (neat, cm^{-1}): 3455, 3016, 2956, 2899, 1766, 1741, 1610, 1464, 1371, 1261, 1163, 1062, 972, 841. ^1H NMR (400 MHz, $CDCl_3$) δ 7.12−7.06 (m, 5H), 6.75 (d, *J* = 8.2 Hz, 2H), 5.70 (d, *J* = 4.5 Hz, 1H), 5.33 (d, *J* = 3.3 Hz, 1H), 4.60 (q, *J* = 4.3, 3.6 Hz, 2H), 4.32 (d, *J* = 4.4 Hz, 1H), 3.84 (d, *J* = 8.1 Hz, 3H), 3.08−2.89 (m, 2H), 2.32 (s, 3H), 1.97 (s, 3H), 0.97 (s, 9H), 0.17 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 207.8, 169.9, 169.2, 154.7, 151.5, 139.6, 138.2, 130.6 (2 × C), 128.9, 123.2, 120.3 (2 × C), 117.9, 110.0, 79.2, 79.0, 75.8, 74.2, 72.8, 56.1, 35.7, 25.8 (3 × C), 21.0, 20.8, 18.3, −4.3 (2 × C). HRMS (TOF, CI^+) *m*/*z* calcd for $C_{30}H_{44}NO_{10}Si$, $[M + NH_4]^+$ 606.2729, found 606.2755.

4-((3*aS*,4*S*,6*R*,7*R*,7*aR*)-6-((*R*)-1-Acetoxy-2-(4-((*tert*-butyldimethylsilyl)oxy)phenyl)ethyl)-7-hydroxy-2,2-dimethyltetrahydro-4*H*-[1,3]dioxolo[4,5-*c*]pyran-4-yl)-2-methoxyphenyl Acetate ((−)-24). To a stirred solution of (−)-**23** (0.32 g, 0.55 mmol) in CH_2Cl_2 (5 mL) were added *p*-toluenesulfonic acid monohydrate (10.4 mg, 0.06 mmol) and $Me_2C(OMe)_2$ (0.57 g, 5.48 mmol) at rt. The reaction mixture was stirred at rt for 3 h. The reaction was quenched by addition of satd aq $NaHCO_3$ (10 mL) and extracted with CH_2Cl_2 (3 × 10 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The crude product was used for the next step without further purification. To a stirred solution of the crude product above in MeOH/CH_2Cl_2 (2 mL/2 mL) was added $NaBH_4$ (25.2 mg, 0.66 mmol) at 0 °C. The reaction mixture was stirred at rt for 1 h. The reaction was quenched by addition of satd aq NH_4Cl (5 mL) and extracted with CH_2Cl_2 (3 × 10 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 4:1) to afford the desired product (−)-**24** (0.31 g, 0.49 mmol, 89% yield over two steps) as a yellowish oil. $[\alpha]_D^{20}$ = −19.8 (*c* 0.46, $CHCl_3$). IR (neat, cm^{-1}): 3449, 3024, 2991, 2930, 2867, 1758, 1450, 1369, 1259, 1160, 1050, 870. ^1H NMR (400 MHz, $CDCl_3$) δ 7.10 (d, *J* = 8.5 Hz, 2H), 7.06 (s, 1H), 6.99 (d, *J* = 2.2 Hz, 2H), 6.75 (d, *J* = 8.4 Hz, 2H), 5.69 (ddd, *J* = 8.8, 7.6, 4.1 Hz, 1H), 5.03 (d, *J* = 7.9 Hz, 1H), 4.34−4.21 (m, 3H), 3.83 (s, 3H), 3.78−3.71 (m, 1H), 3.11 (dd, *J* = 14.0, 4.1 Hz, 1H), 2.76 (dd, *J* = 14.1, 8.8 Hz, 1H), 2.70 (s, 1H), 2.30 (s, 3H), 1.88 (s, 3H), 1.57 (s, 3H), 1.39 (s, 3H), 0.97 (s, 9H), 0.18 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.3, 169.2, 154.4, 150.9, 139.4, 139.2, 130.5 (2 × C), 130.0, 122.4, 120.0 (2 × C), 118.4, 111.4, 109.9, 76.8, 74.4, 74.2, 73.7, 72.9, 66.0, 56.0, 36.2, 26.4, 25.8 (3 × C), 24.4, 21.1, 20.8, 18.3, −4.3 (2 × C). HRMS (TOF, CI^+) *m*/*z* calcd for $C_{33}H_{50}NO_{10}Si$, $[M + NH_4]^+$ 648.3204, found 648.3176.

4-((2*S*,3*R*,4*R*,6*R*)-6-((*R*)-1-Acetoxy-2-(4-((*tert*-butyldimethylsilyl)oxy)phenyl)ethyl)-3,4-dihydroxytetrahydro-2*H*-pyran-2-yl)-2-methoxyphenyl Acetate ((−)-25). To a stirred solution of (−)-**24** (50.0 mg, 79.1 μmol) in anhydrous THF (0.5 mL) was added sodium hydride (60% dispersion in mineral oil, 3.8 mg, 94.8 μmol) at 0 °C. The reaction mixture was stirred at 0 °C for 30 min, and then carbon disulfide (30.1 mg, 0.40 mmol) was added and stirred at 0 °C for an additional 30 min. Iodomethane (12.4 mg, 87.1 μmol) was added finally and stirred at 0 °C for additional 1 h. The reaction was quenched by addition of satd aq NH_4Cl (5 mL) and extracted with EtOAc (3 × 5 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 6:1) to afford the desired methyl xanthate as a yellowish oil. To a stirred solution of the methyl xanthate above in toluene (3 mL) was added azobis(isobutyronitrile) (AIBN, 1.3 mg, 7.9 μmol) at rt. After completion of the addition, the tube was evacuated and backfilled with nitrogen three times, and then $(n\text{-Bu})_3SnH$ (0.20 g, 0.69 mmol) was added and the sealed tube was heated to 110 °C for 1 h. The reaction mixture was cooled to rt and quenched by addition of excess iodine and stirred for 30 min at rt. The reaction was quenched by addition of satd aq Na_2SO_3 (10 mL) and extracted with EtOAc (3 × 10 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 1:3) to afford the desired THP-*syn*-diol (−)-**25** (28.2 mg, 49.1 μmol, 62% yield over two steps) as a yellowish oil. $[\alpha]_D^{20}$ = −28.0 (*c* 0.61, $CHCl_3$). IR (neat, cm^{-1}): 3445, 3049, 2943, 2889, 1760, 1442, 1353, 1220, 1169, 895, 747. ^1H NMR (400 MHz, $CDCl_3$) δ 7.06−6.99 (m, 4H), 6.93 (dd, *J* = 8.2, 1.8 Hz, 1H), 6.73 (d, *J* = 8.4 Hz, 2H), 5.64 (ddd, *J* = 10.0, 6.8, 3.4 Hz, 1H), 5.00 (d, *J* = 6.0 Hz, 1H), 4.08−4.03 (m, 1H), 4.01 (s, 1H), 3.81 (s, 3H), 3.78−3.71 (m, 1H), 3.60 (brs, 1H), 2.98 (dd, *J* = 14.0, 3.5 Hz, 1H), 2.71 (dd, *J* = 13.9, 9.8 Hz, 1H), 2.30 (d, *J* = 2.6 Hz, 3H), 1.86 (s, 3H), 0.96 (s, 9H), 0.16 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.5, 169.3, 154.4, 151.5, 139.6, 136.9, 130.4 (2 × C), 130.1, 123.0, 120.2 (2 × C), 119.4, 111.8, 75.1, 74.0, 72.6, 70.6, 66.5, 56.0, 36.6, 31.1, 25.8 (3 × C), 21.0, 20.8, 18.3, −4.3 (2 × C). HRMS (TOF, CI^+) *m*/*z* calcd for $C_{30}H_{46}NO_9Si$, $[M + NH_4]^+$ 592.2936, found 592.2952.

4-((2*S*,3*S*,6*R*)-6-((*R*)-1-Acetoxy-2-(4-((*tert*-butyldimethylsilyl)oxy)phenyl)ethyl)-3-hydroxy-4-oxotetrahydro-2*H*-pyran-2-yl)-2-methoxyphenyl Acetate ((+)-26). To a stirred solution of the THP-*syn*-diol (−)-**25** (20.0 mg, 35.1 μmol) in anhydrous DMSO (5 mL) was added IBX (97.4 mg, 0.35 mmol) at rt. The reaction was stirred at rt for 2 h. The reaction was quenched by addition of water (10 mL) and extracted with EtOAc (3 × 10 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 1:1) to afford the desired α-hydroxyketone (+)-**26** (16.6 mg, 29.1 μmol, 83% yield) as a colorless oil. $[\alpha]_D^{20}$ = +60.1 (*c* 0.39, $CHCl_3$). IR (neat, cm^{-1}): 3470, 2950, 2935, 1775, 1738, 1458, 1378, 1260, 1130. ^1H NMR (400 MHz, $CDCl_3$) δ 7.17−7.14 (m, 2H), 7.11−7.08 (m, 3H), 6.74 (d, *J* = 8.4 Hz, 2H), 5.18 (ddd, *J* = 8.5, 6.6, 3.3 Hz, 1H), 4.95 (d, *J* = 9.1 Hz, 1H), 4.44 (dd, *J* = 8.2, 3.3 Hz, 1H), 4.10 (d, *J* = 9.2 Hz, 1H), 3.90 (s, 3H), 2.98−2.89 (m, 2H), 2.84 (dd, *J* = 13.4, 6.6 Hz, 1H), 2.52 (d, *J* = 14.4 Hz, 1H), 2.33 (s, 3H), 1.96 (d, *J* = 2.5 Hz, 3H), 0.96 (s, 9H), 0.17 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 206.3, 169.9, 169.2, 154.7, 151.2, 140.0, 138.1, 130.6 (2 × C), 128.9, 122.8, 120.3 (2 × C), 119.4, 111.0, 80.2, 77.8, 77.4, 73.7, 56.1, 41.0, 36.1, 25.8 (3 × C), 21.0, 20.9, 18.3, 1.2, −4.3. HRMS (TOF, CI^-) *m*/*z* calcd for $C_{30}H_{39}O_9Si$, $[M - H]^-$ 571.2369, found 571.2356.

4-((2*S*,3*R*,4*S*,6*R*)-6-((*R*)-1-Acetoxy-2-(4-((*tert*-butyldimethylsilyl)oxy)phenyl)ethyl)-3,4-dihydroxytetrahydro-2*H*-pyran-2-yl)-2-methoxyphenyl Acetate ((−)-27). To a stirred solution of α-hydroxyketone (+)-**26** (16.6 mg, 29.1 μmol) in CH_3CN/AcOH (0.5 mL/0.5 mL) was added $Me_4NBH(OAc)_3$ (37.2 mg, 0.14 mmol) at −30 °C. The reaction was stirred at −30 °C for 3 h. The reaction then was quenched by addition of 0.5 N aqueous sodium potassium tartrate (0.5 mL) with vigorous stirring for 30 min at rt. The mixture then was diluted by addition of satd aq $NaHCO_3$ (10 mL) and extracted with EtOAc (3 × 10 mL). The combined organic fractions were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 1:3) to afford the desired THP-*anti*-diol (−)-**27** (14.3 mg, 24.9 μmol, 86% yield) as a colorless oil. $[\alpha]_D^{20}$ = −39.8 (*c* 0.52, $CHCl_3$). IR (neat, cm^{-1}): 3456, 3029, 2950, 2895, 1732, 1435, 1347, 1232, 1175, 889, 756. ^1H NMR (400 MHz, $CDCl_3$) δ 7.03 (d, *J* = 8.0 Hz, 2H), 7.02−6.95 (m, 3H), 6.80−6.69 (m, 2H), 5.49 (td, *J* = 8.1, 5.1 Hz, 1H), 4.51 (d, *J* = 9.5 Hz, 1H), 4.02 (t, *J* = 7.2 Hz, 1H), 3.98−3.88 (m, 1H), 3.84 (s, 3H), 3.38 (t, *J* = 9.1 Hz, 1H), 2.93 (dd, *J* = 14.0, 5.1 Hz, 1H), 2.70 (dd, *J* = 14.0, 8.2 Hz, 1H), 2.31 (s, 3H), 2.14 (d, *J* = 5.0 Hz, 1H), 2.00−1.95 (m, 1H), 1.91 (s, 3H), 0.96 (s, 9H), 0.17 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.4, 169.6, 154.5, 151.3, 139.7, 137.7, 130.5 (2 × C), 129.4, 122.8, 120.2 (3 × C), 111.8, 77.5, 76.9, 74.3, 73.3, 69.1, 56.0,

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37.0, 33.1, 25.8 (3 × C), 21.2, 20.8, 18.4, 1.2, −4.3. HRMS (TOF, CI$^+$) m/z calcd for $C_{30}H_{46}NO_9Si$, $[M + NH_4]^+$ 592.2936, found 592.2921.

(−)-Hedycoropyran A (1). To a stirred solution of the THP-*anti*-diol (−)-**27** (14.3 mg, 24.9 μmol) in CH_2Cl_2 (2 mL) at 0 °C was added diisobutylaluminum hydride solution (DIBAL-H, 1.0 M in hexane, 0.25 mL, 0.25 mmol) dropwise. The reaction mixture was allowed to warm to rt and stirred for additional 4 h. The reaction was then quenched by addition of $Na_2SO_4{\cdot}10H_2O$ (160 mg, 0.50 mmol) and stirred for 15 min before anhydrous $MgSO_4$ was added. After filtration through Celite, the filtrate was collected and concentrated under reduced pressure. The crude product was used for the next step without further purification. To a stirred solution of the crude product above in wet CH_3CN (1 mL) was added a solution of tris-(dimethylamino)sulfonium difluorotrimethylsilicate (TAS-F, 6.9 mg, 24.9 μmol) in CH_3CN (1 mL) at rt. After being stirred for 4 h, the mixture was filtered through a pad of silica gel, which was carefully rinsed with CH_2Cl_2/MeOH (10 mL/10 mL). The combined filtrates were concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (CH_2Cl_2/MeOH = 10:1) to afford the desired (−)-hedycoropyran A (**1**) (7.9 mg, 20.9 μmol, 84% yield) as a white solid. $[\alpha]_D^{20}$ = −67.5 (*c* 0.04, MeOH). {Lit.[1] $[\alpha]_D^{20}$ = −86 (*c* 0.04, MeOH).} IR (neat, cm^{-1}): 3451, 2960, 2855, 1608, 1513, 1463, 1259, 1034. ^{1}H NMR (400 MHz, CD_3OD) δ 7.14−6.99 (m, 3H), 6.90 (dd, *J* = 8.1, 2.0 Hz, 1H), 6.78 (d, *J* = 8.1 Hz, 1H), 6.77−6.62 (m, 2H), 4.50 (d, *J* = 9.1 Hz, 1H), 4.11−3.96 (m, 2H), 3.87 (s, 3H), 3.81−3.73 (m, 1H), 3.40 (t, *J* = 8.7 Hz, 1H), 2.94 (brs, 1H), 2.84 (dd, *J* = 13.9, 4.8 Hz, 1H), 2.61 (dd, *J* = 13.9, 7.7 Hz, 1H), 2.18 (ddd, *J* = 13.5, 5.3, 2.5 Hz, 1H), 1.86 (ddd, *J* = 13.6, 10.9, 6.4 Hz, 1H). ^{13}C NMR (100 MHz, CD_3OD) δ 156.8, 148.7, 147.2, 132.9, 131.5 (2 × C), 130.8, 122.0, 116.0 (2 × C), 115.7, 112.6, 78.6, 77.8, 76.4, 73.8, 70.7, 56.4, 40.6, 35.2. HRMS (TOF, ESI MS$^-$) m/z calcd for $C_{20}H_{23}O_7$, $[M - H]^-$ 375.1449, found 375.1459.

(−)-Hedycoropyran B (2). To a stirred solution of the (−)-hedycoropyran A (**1**) (5.0 mg, 13.3 μmol) in MeOH (0.5 mL) was added hydrochloric acid solution (HCl, 1.0 M in ether, 0.27 mL, 0.27 mmol) dropwise at rt. The reaction mixture was stirred at rt for 12 h. The solvent then was removed and concentrated under reduced pressure. The resulting residue was purified by flash column chromatography on silica gel (CH_2Cl_2/MeOH = 10:1) to afford the desired (−)-hedycoropyran B (**2**) (3.6 mg, 9.4 μmol, 71% yield) as a white solid. $[\alpha]_D^{20}$ = −95.0 (*c* 0.02, MeOH). {Lit.[1] $[\alpha]_D^{20}$ = −100 (*c* 0.04, MeOH).} IR (neat, cm^{-1}): 3489, 2955, 2852, 1596, 1509, 1455, 1262, 1038. ^{1}H NMR (400 MHz, CD_3OD) δ 7.13 (d, *J* = 1.9 Hz, 1H), 7.02 (d, *J* = 8.5 Hz, 2H), 6.88 (dd, *J* = 8.2, 1.9 Hz, 1H), 6.80 (d, *J* = 8.1 Hz, 1H), 6.67 (d, *J* = 8.5 Hz, 2H), 4.74 (s, 1H), 4.04 (q, *J* = 3.0 Hz, 1H), 3.89 (s, 3H), 3.76 (d, *J* = 12.5 Hz, 1H), 3.65−3.56 (m, 2H), 2.94 (dd, *J* = 13.3, 7.3 Hz, 1H), 2.77 (dd, *J* = 13.4, 7.1 Hz, 1H), 2.26−2.17 (m, 1H), 1.42 (d, *J* = 14.2 Hz, 1H). ^{13}C NMR (100 MHz, CD_3OD) δ 156.7, 148.7, 146.5, 133.0, 131.4 (2 × C), 131.0, 119.9, 116.1 (2 × C), 115.7, 111.6, 77.1, 76.3, 74.2, 72.2, 69.5, 56.5, 40.1, 30.2. HRMS (TOF, ESI MS$^+$) m/z calcd for $C_{20}H_{24}NaO_7$, $[M + Na]^+$ 399.1414, found 399.1419.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.6b02738.

Tables and figures for NMR spectral comparison of synthetic and natural products, copies of ^{1}H and ^{13}C NMR of new compounds, and HPLC chromatographs for compound **7** (PDF)

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Notes

The authors declare no competing financial interest.

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