Synthesis of 1-Substituted and 1,4-Disubstituted 2,3-Di-*O*-benzyl-1,6-anhydrogalactofuranoses

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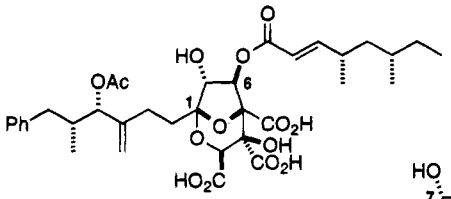
A method has been developed for synthesizing 1-substituted and 1,4-disubstituted 2,3-di-*O*-benzyl-1,6-anhydrogalactofuranoses **16** starting from **8**, a known 1,6-anhydropyranose prepared from D-galactose. Compounds such as **16** have potential utility for synthesis of the squalestatins and zaragozic acids.

The squalestatins and zaragozic acids are a family of naturally occurring fungal metabolites recently isolated by independent groups.[1,2] These natural products are potent inhibitors of squalene synthase and have potential as therapeutic agents for the treatment of hypercholesterolemia. All the squalestatins and zaragozic acids show a common bicyclic core and are different only at the C-1 alkyl and C-6 acyl side chains. Zaragozic acid A (squalestatin S_1) (**1**) is a representative example of this novel class of compounds.



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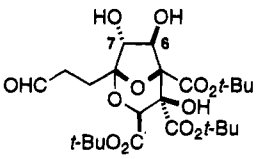

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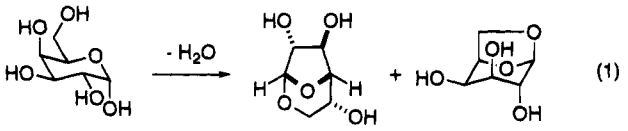
We have recently embarked on a program of synthesis of the squalestatins and zaragozic acids, our initial target being aldehyde **2**, which has been prepared in our laboratories[3] and by others[4] by degradation of **1**. This compound presents the advantage of being a potential precursor for the synthesis of all squalestatins and zaragozic acids reported so far.

The novel 4,6,7-trihydroxy-2,8-dioxabicyclo[3.2.1]octane-3,4,5-tricarboxylic acid core of these compounds was seen as a functionalized 1,6-anhydrofuranose. Because the stereochemistry at C-2 and C-3 of these carbohydrates correlates with the stereochemistry observed at C-6 and C-7 for the natural products, we sought a method for its preparation from either D-glucose or D-galactose. Although it is precedented that the dehydration of D-galactose (**3**) provides a 9:1 ratio of the corresponding 1,6-anhydrofuranose (**4**) over the 1,6-anhydropyranose (**5**) (eq 1),[5] this reaction has not been used with more elaborate



3 **4** **5** (1)

substrates. We report herein the results of our study directed toward the selective formation of C-4- and C-1,4-substituted 1,6-anhydrogalactofuranoses starting from a known 1,6-anhydro-D-galactopyranose derivative.

Our synthesis begins from the known alcohol **6**, which can be prepared in seven steps from β-D-galactose pentaacetate.[6] We chose this 1,6-anhydropyranose derivative as our starting material because its structure allows the selective protection of the C-2 and C-3 hydroxyl groups as benzyl ethers while leaving the C-4 hydroxyl group unprotected. We found that the best results for the oxidation of the C-4 hydroxyl group were obtained by using the trifluoroacetic anhydride/DMSO procedure.[7] Although the stereoselective addition of methylmagnesium bromide was precedented for a D-mannose derivative,[8] this reaction had not been studied in either the glucose or galactose series. We were pleased to find that the reaction of several nucleophiles with ketone **7** proceeded in high yields with exclusive α-face selectivity. In the case of the TBDPS-protected alcohol **8e**, the hydroxymethyl anion equivalent was added as the (isopropoxydimethylsilyl)methyl Grignard reagent followed by

[⊗] Abstract published in *Advance ACS Abstracts,* April 1, 1995.

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Scheme 1

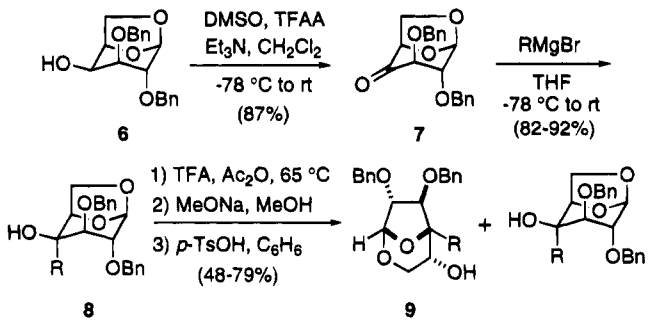


Table 1. Formation of 4-Substituted 1,6-Anhydrogalactofuranoses (Scheme 1)

R	substrate	% yield	product	ratio 9:8[a]	% yield[b]
Me	**8a**	92	**9a**	>95:5	79
Et	**8b**	82	**9b**	8:1	73
$CH_2CH{=}CH_2$	**8c**	86	**9c**	4:1	66
Ph	**8d**	92	**9d**	1:1	48
$CH_2OTBDPS$	**8e**	90[c]	**9e**	1:2	73
CO_2Et	**8g**	80[c]	**9f**	<5:95	11

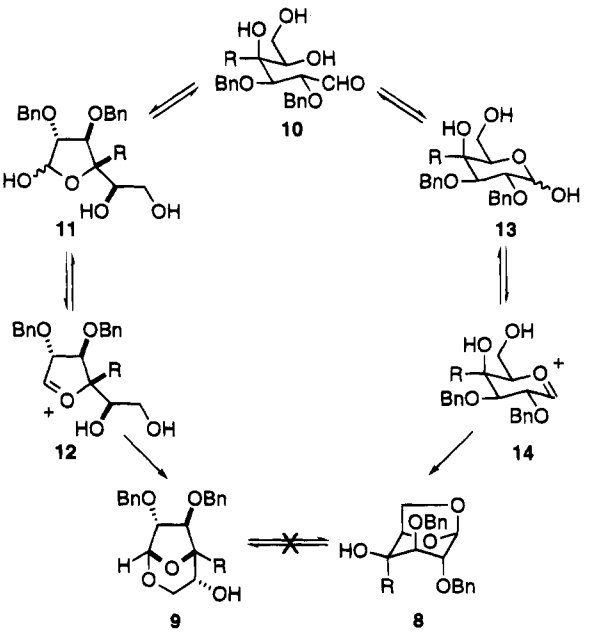
[a] Ratio determined by analysis of the crude ^1H NMR spectrum. [b] Combined overall yield of **8** and **9** from **8**. [c] Overall yield from **7**.

oxidation with hydrogen peroxide[9] to yield a primary alcohol **8f** which was selectively protected as the *tert*-butyldiphenylsilyl ether.[10] The α-hydroxy ester **8g** was also prepared in two steps by addition of (1-ethoxyvinyl)-lithium,[11] followed by ozonolysis of the resulting vinyl ether. The tertiary alcohols **8a-e,g** were then submitted to a three-step sequence without purification of any of the intermediates. Acetolysis of the anhydrosugar (Ac_2O, TFA) proceeded with concomitant acetylation of the C-4 hydroxyl group to give a triacetate which was a mixture at the anomeric position. The crude product was saponified (MeONa/MeOH) and the mixture of triols dehydrated to generate the 1,6-anhydrosugars **8** and **9** (Scheme 1).

The results are summarized in Table 1. Appropriate control experiments showed that the product ratios given are kinetic, not thermodynamic. The data in Table 1 show that with the methyl and ethyl derivatives **8a** and **8b** the desired 1,6-anhydrofuranose **9** is the predominant product. However, as the electronegativity of the C-4 substituent increases, the ratio of 1,6-anhydrofuranose **9** to 1,6-anhydropyranose **8** decreases. This phenomenon can be rationalized in the following manner (Scheme 2). Under acidic conditions, triols **11** and **13** should be under equilibrium through aldehyde **10**. Furanose **11** gives rise to 1,6-anhydrofuranose **9** by way of oxonium ion **12** and pyranose **13** provides 1,6-anhydropyranose **8** by way of oxonium ion **14**. Electronegative substituents at C-4 disfavor oxonium ion **12** more than oxonium ion **14**.

We then turned our attention to the preparation of 1,4-disubstituted 1,6-anhydrofuranoses. In order to introduce a substituent at C-1, selective oxidation of the anomeric position was necessary. As shown in Scheme 3, the anhydrosugar **8** was once again acetolyzed and the triacetate saponified to a mixture of triols. As expected, the C-5 and C-6 hydroxyl groups could be selectively ketalized (acetone, *p*-TsOH), and the resulting five-membered-ring hemiacetal was oxidized (PDC)[12] to the

Scheme 2



Scheme 3

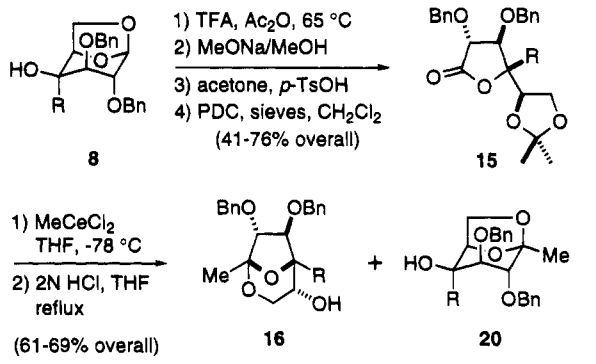


Table 2. Formation of 1,4-Disubstituted 1,6-Anhydrogalactofuranoses (Scheme 3)

R	lactone	% yield[a]	ratio **16**:**20**[b]	% yield[c]
$CH_2CH{=}CH_2$	**15a**	76	>10:1	69
Ph	**15b**	41	9:1	68
$CH_2OTBDPS$	**15c**	76	>10:1	61

[a] Overall yield from **8c-e**. [b] Ratio determined by analysis of the crude ^1H NMR spectrum. [c] Overall yield from **15a-c**.

corresponding γ-lactone **15**. Surprisingly, addition of methylmagnesium bromide or methyllithium to lactone **15** led to elimination of the benzyloxy group at C-3. This problem was solved by use of the less basic cerium reagent, generated by transmetalation of MeLi with $CeCl_3$.[13] The isopropylidene acetal of the crude addition product was hydrolyzed to provide preferentially the 1,4-dialkyl-1,6-anhydrofuranose **16** (Table 2).

The preferential formation of the 1,6-anhydrofuranose derivative is rationalized by the generation of a highly substituted oxonium ion **17** from hemiacetal **18** prior to its opening to ketone **19**. The oxonium ion **17** is then trapped by the C-6 hydroxyl group to provide the desired 1,6-anhydrofuranose derivative **16** as the major product while the 1,6-anhydropyranose derivative **20** is observed in a smaller amount (Scheme 4). We prepared the 5,6-

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Scheme 4

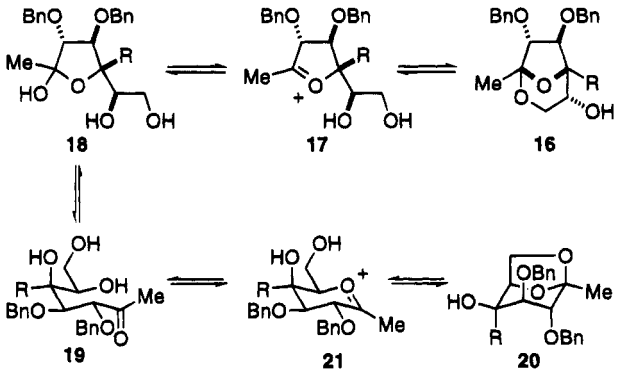

Table 3. Equilibration of 1,4-Disubstituted 1,6-Anhydrogalactofuranoses and -pyranoses

R	substrate	time	ratio 16:20[a]
$CH_2CH{=}CH_2$	**16a**	3 h	2:1
$CH_2CH{=}CH_2$	**20a**	3.5 h	2:1
Ph	**16b**	30 min	1:2
Ph	**20b**	90 min	1:2
$CH_2OTBDPS$	**16c**	75 min	1:1
$CH_2OTBDPS$	**20c**	1 h	1:1

[a] Ratio determined by analysis of the crude ^1H spectrum.

O-isopropylidene of compound **11c** and submitted it to the hydrolysis/dehydration sequence. The same ratio of **9c**:**8c** was observed (4:1), therefore proving that the equilibration through aldehyde **10c** must proceed when the starting material is an aldose.

When the reaction time of the dehydration step was prolonged, we noticed a substantial increase in the amount of the 1,6-anhydropyranose derivative **20**. We therefore separately resubmitted both **16** and **20** to our original dehydration conditions and found both compounds to provide identical ratios of **16** and **20** which appears to be the result of a thermodynamic equilibration through ketone **19**. This time, however, the observed ratios seem to be the result of a steric effect since the ratio of the 1,6-anhydropyranose **20** increases as the size of the C-4 substituent becomes larger (Table 3). We believe that the 1,4-disubstituted 1,6-anhydrofuranose **16** is selectively generated kinetically and slowly equilibrates to the 1,4-dialkyl-1,6-anhydrofuranose **20** under the reaction conditions.

Since the methodology described proved to be selective for the formation of 1,4-disubstituted 1,6-anhydrofuranoses, it is currently being applied for the preparation of relay compound **2**.

Experimental Section

General. Unless otherwise noted, starting materials were obtained from commercial suppliers and used without further purification. Diethyl ether and THF were distilled from Na/benzophenone ketyl, and benzene, CH_2Cl_2, and Et_3N were distilled from CaH_2, and ethyl vinyl ether was distilled from Na immediately prior to use. All reactions involving oxygen- or moisture-sensitive compounds were performed under a dry N_2 atmosphere. Organic extracts were dried with $MgSO_4$ and concentrated with a rotary evaporator under reduced pressure (aspirator). Silica gel chromatography was carried out with ICI SiliTech 32-63 D A silica gel according to Still's procedure.[14] Thin layer chromatography (TLC) was performed with Merck F-254 TLC plates. Melting points were measured in capillary tubes. ^1H and ^{13}C NMR spectra were measured in $CDCl_3$. Chemical shifts are expressed in ppm of the δ scale relative to internal $CDCl_3$. *J* values are in hertz. IR spectra were measured as thin films on NaCl plates unless otherwise indicated.

1,6-Anhydro-2,3-di-*O*-benzyl-β-D-gluco-hexopyrano-4-ulose (7). To a solution of DMSO (6.40 mL, 90.2 mmol) in 100 mL of CH_2Cl_2 at −78 °C was slowly added freshly-distilled trifluoroacetic anhydride (10.0 mL, 70.8 mmol). The solution was stirred for 10 min, and alcohol **6** in CH_2Cl_2 (20 mL, 2 × 5 mL rinse) was added. After 30 min, Et_3N (15.0 mL, 108 mmol) was added, and the mixture was allowed to warm to 0 °C over 50 min. The mixture was poured into H_2O (400 mL), extracted with CH_2Cl_2 (500 mL), and washed with H_2O (2 × 300 mL) and brine (200 mL). The organic extracts were dried, filtered, and concentrated to give a crude solid which was recrystallized from EtOAc/hexane to give ketone **7** (10.60 g, 87%). Mp: 69−70 °C. TLC: R_f 0.42 (EtOAc/hexane: 30/70). $[\alpha]_D$: +9.5 (*c* 0.19, $CHCl_3$). IR: 2895, 1745, 1495, 1455, 1095, 890, 730, 695 cm^{-1}. ^1H NMR (500 MHz): δ 3.55 (d, 1, *J* = 5.8), 3.72 (dd, 1, *J* = 7.4, 5.1), 3.99 (d, 1, 7.5), 4.43 (d, 1, *J* = 5.9), 4.59 (d, 1, *J* = 11.4), 4.67−4.68 (m, 3), 4.90 (d, 1, *J* = 11.3), 5.60 (s, 1), 7.28−7.40 (m, 10). ^{13}C NMR (100 MHz): δ 68.51, 72.75, 73.92, 78.84, 82.07, 82.81, 103.71, 127.82, 127.95, 127.97, 128.13, 128.41, 128.47, 137.23, 137.35, 208.13. Anal. Calcd for $C_{20}H_{20}O_5$: C, 70.58; H, 5.92. Found: C, 70.31; H, 6.00.

General Procedure for the Addition of Nucleophiles to Ketone 7. To ketone **7** in THF (0.25 M) at −78 °C was slowly added 2.0 equiv of the nucleophile. The solution was stirred at −78 °C for 30 min and allowed to warm to 0 °C over 2 h. The reaction mixture was poured into a saturated solution of NH_4Cl and extracted twice with ether. The organic extracts were washed with water and brine, dried, filtered, and concentrated. In all cases, the crude ^1H NMR showed only one diastereoisomer. The product (**8a-d**) was purified by flash chromatography on SiO_2 using EtOAc/hexane as the eluent.

1,6-Anhydro-2,3-di-*O*-benzyl-4-methyl-β-D-galactopyranose (8a). Colorless oil (92%). TLC: R_f 0.23 (EtOAc/hexane: 30/70). $[\alpha]_D$: −62.1 (*c* 0.24, $CHCl_3$). IR: 3500, 2960, 2890, 1500, 1455, 1370, 1170, 1145, 1075, 990, 925, 740, 700 cm^{-1}. ^1H NMR (400 MHz): δ 1.49 (s, 3), 3.34 (d, 1, *J* = 1.3), 3.52 (s, 1), 3.54 (s, 1), 3.60 (dd, 1, *J* = 7.5, 5.4), 4.06 (d, 1, 5.4), 4.17 (d, 1, *J* = 7.6), 4.33 (d, 1, *J* = 11.5), 4.53 (d, 1, *J* = 11.5), 4.54 (s, 2), 5.40 (s, 1), 7.26−7.37 (m , 10). ^{13}C NMR (100 MHz): δ 25.36, 63.62, 67.50, 72.09, 72.78, 74.90, 78.88, 80.51, 100.03, 127.68, 127.75, 127.99, 128.09, 128.50, 128.56, 137.02, 137.53. Anal. Calcd for $C_{21}H_{24}O_5$: C, 70.77; H, 6.79. Found: C, 70.48; H, 6.95.

1,6-Anhydro-2,3-di-*O*-benzyl-4-ethyl-β-D-galactopyranose (8b). Colorless oil (82%). TLC: R_f 0.34 (EtOAc/hexane: 25/75). $[\alpha]_D$: −56.5 (*c* 1.05 $CHCl_3$). IR: 3521, 2962, 2892, 1497, 1455, 1095, 739, 699 cm^{-1}. ^1H NMR (400 MHz): δ 0.96 (t, 3, *J* = 7.4), 1.75 (dq, 1, *J* = 14.3, 7.4), 1.99 (dq, 1, *J* = 14.3, 7.5), 3.39 (d, 1, *J* = 1.3), 3.52 (s, 1), 3.64 (dd, 1, *J* = 7.5, 5.6), 4.18−4.20 (m, 2), 4.33 (d, 1, *J* = 11.6), 4.53 (s, 2), 4.55 (d, 1, *J* = 11.4), 5.41 (s, 1), 7.27−7.38 (m, 10). ^{13}C NMR (100 MHz): δ 7.13, 29.61, 63.71, 68.97, 72.10, 72.72, 75.15, 76.59, 78.50, 100.18, 127.79, 128.01, 128.52, 128.59, 137.00, 137.54. Anal. Calcd for $C_{22}H_{26}O_5$: C, 71.33; H, 7.07. Found: C, 71.25; H, 7.04.

1,6-Anhydro-2,3-di-*O*-benzyl-4-allyl-β-D-galactopyranose (8c). Colorless oil (86%). TLC: R_f 0.30 (EtOAc/hexane: 25/75). $[\alpha]_D$: −58.1 (*c* 0.80 $CHCl_3$). IR: 3507, 2955, 2896, 1496, 1449, 1143, 1091, 926, 740, 700 cm^{-1}. ^1H NMR (500 MHz): δ 2.59 (dd, 1, *J* = 14.2, 8.0), 2.69 (dd, 1, *J* = 14.2, 6.5), 3.49 (d, 1, *J* = 5.4), 3.51 (d, 1, *J* = 13.8), 3.63 (dd, 1, *J* = 7.5, 5.6), 4.17−4.21 (m, 2), 4.35 (d, 1, *J* = 11.6), 4.47−4.55 (m, 3), 5.15−5.19 (m, 2), 5.43 (s, 1), 5.93 (dddd, 1, *J* = 14.6, 10.4, 7.9, 6.7), 7.28−7.39 (m, 10). ^{13}C NMR (125 MHz): δ 41.20. 63.55, 68.78, 71.95, 72.73, 74.93, 77.29, 77.63, 100.12, 119.01, 127.73, 127.82, 127.98, 128.13, 128.49, 128.55, 133.31, 136.92, 137.45. Anal. Calcd for $C_{23}H_{26}O_5$: C, 72.23; H, 6.85. Found: C, 72.05; H, 6.88.

1,6-Anhydro-2,3-di-*O*-benzyl-4-phenyl-β-D-galactopyranose (8d). White solid (92%). TLC: R_f 0.39 (EtOAc/hexane: 25/75). $[\alpha]_D$: −22.7 (*c* 0.51, $CHCl_3$). IR: 3495, 3060, 2895, 1601, 1495, 1420, 1325, 1090, 749, 697 cm^{-1}. ^1H NMR (400

(14) Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.

MHz): δ 3.66 (d, 1, *J* = 3.6), 3.70 (dd, 1H, *J* = 7.6, 5.4), 3.92 (d, 1, *J* = 3.6), 4.16 (s, 1), 4.34 (d, 1, *J* = 11.3), 4.50 (d, 1, *J* = 7.7), 4.53 (d, 1, *J* = 11.9), 4.59 (d, 1, *J* = 11.3), 4.61 (d, 1, *J* = 11.8), 4.65 (d, 1, *J* = 5.3), 5.61 (s, 1), 7.22–7.26 (m, 3), 7.31–7.46 (m, 10), 7.81–7.83 (m, 2). ^{13}C NMR (125 MHz): δ 63.89, 70.63, 72.07, 73.98, 79.30, 79.72, 81.31, 101.58, 125.85, 127.26, 127.71, 127.87, 127.95, 128.08, 128.14, 128.38, 128.45, 136.96, 137.48, 146.14. Anal. Calcd for $C_{26}H_{26}O_5$: C, 74.62; H, 6.26. Found: C, 74.36; H, 6.16.

1,6-Anhydro-2,3-di-*O*-benzyl-4-(hydroxymethyl)-β-D-galactopyranose (8f). To a solution of ketone **7** (9.63 g, 28.3 mmol) in THF (50 mL) at −78 °C was added [(dimethylisopropoxysilyl)methyl]magnesium chloride (45.0 mL of a 0.95 M solution in THF, 42.8 mmol). The solution was stirred at −78 °C for 1 h and at 0 °C for 1 h, poured into a cold saturated solution of NH_4Cl (200 mL), and extracted with ether (2 × 350 mL). The organic extracts were washed with cold H_2O (300 mL) and cold brine (250 mL), dried, filtered, and concentrated at 0 °C. The crude oil was dissolved in THF (75 mL) and MeOH (75 mL) to which was added $NaHCO_3$ (2.57 g, 30.6 mmol) and H_2O_2 (30% in H_2O, 25 mL). The suspension was heated to reflux for 12 h and cooled to 0 °C, and $Na_2S_2O_3$ (16 g) was very slowly added. The reaction mixture was filtered through a plug of Celite and washed thoroughly with ether (500 mL). The filtrate was washed with H_2O (200 mL) and brine (150 mL), dried, filtered, and concentrated. The crude oil was purified by flash chromatography on SiO_2 (EtOAc/hexane 60/40) to give **8f** as a colorless oil (9.44 g, 90%). TLC: R_f 0.24 (EtOAc/hexane: 50/50). $[\alpha]_D$: −69.4 (*c* 0.48 $CHCl_3$). IR: 3473, 2898, 1496, 1450, 1146, 1086, 914, 741, 698 cm^{-1}. ^{1}H NMR (500 MHz): δ 2.04 (brs, 1), 3.55 (s, 1), 3.57 (brs, 1), 3.66 (dd, 1, *J* = 7.4, 5.3), 3.68 (d, 1, *J* = 1.3), 3.80 (d, 1, *J* = 11.5), 3.84 (d, 1, *J* = 11.5), 4.19 (d, 1, *J* = 7.8), 4.20 (d, 1, *J* = 6.3), 4.35 (d, 1, *J* = 11.5), 4.51 (d, 1, *J* = 12.1), 4.56 (d, 1, *J* = 11.5), 4.57 (d, 1, *J* = 12.1), 5.41 (s, 1), 7.26–7.38 (m, 10). ^{13}C NMR (100 MHz): δ 63.82, 65.59, 69.66, 72.07, 74.66, 75.33, 75.52, 100.22, 127.84, 127.93, 128.11, 128.28, 128.58, 128.67, 136.86, 137.34. Anal. Calcd for $C_{21}H_{24}O_6$: C, 67.73; H, 6.50. Found: C, 67.66; H, 6.56,

1,6-Anhydro-2,3-di-*O*-benzyl-4-[[(*tert*-butyldiphenylsilyl)oxy]methyl]-β-D-galactopyranose (8e). To a solution of alcohol **8f** (0.682 g, 1.66 mmol) in DMF was added imidazole (0.310 g, 4.55 mmol) and *tert*-butyldiphenylsilyl chloride (0.550 mL, 2.12 mmol). The reaction mixture was stirred at rt overnight, poured into H_2O (15 mL), and extracted with ether (2 × 40 mL). The organic extracts were washed with H_2O (40 mL) and brine (25 mL), dried, filtered, and concentrated. The crude product was purified by flash chromatography on SiO_2 (EtOAc/hexane 25/75) to give **8e** as a colorless oil (1.118 g, 100%). TLC: R_f 0.44 (EtOAc/hexane 30/70). $[\alpha]_D$: −24.4 (*c* 0.34 $CHCl_3$). IR: 3525, 2950, 2859, 1455, 1428, 1145, 1113, 1029, 739, 700 cm^{-1}. ^{1}H NMR NMR (400 MHz): δ 1.07 (s, 9), 3.45 (s, 1), 3.52 (s, 1), 3.67 (dd, 1, *J* = 7.3, 5.5), 3.72 (d, 1 *J* = 1.1), 3.88 (d,1, *J* = 10.4), 3.99 (d,1, *J* = 10.4), 4.30 (m, 2), 4.41 (d, 1, *J* = 12.1), 4.47 (d, 1, *J* = 12.1), 4.48 (d, 1, *J* = 11.8), 4.58 (d, 1, *J* = 11.8), 5.42 (s, 1), 7.19–7.42 (m, 16), 7.69–7.76 (m, 4). ^{13}C NMR (100 MHz): δ 19.42, 26.82, 63.85, 66.78, 70.36, 71.89, 73.29, 74.89, 75.75, 100.24, 127.64, 127.81, 127.85, 128.06, 128.45, 128.58, 128.58, 129.57, 129.61, 133.24, 133.49, 135.62, 135.74, 137.30, 137.53. Anal. Calcd for $C_{37}H_{42}O_6Si$: C, 72.76; H, 6.93. Found: C, 72.98; H, 6.77.

1,6-Anhydro-2,3-di-*O*-benzyl-4-(1-ethoxyvinyl)-β-D-galactopyranose (8h). To a slurry of anhydrous $CeCl_3$ (19.56 g, 79.34 mmol) in THF (150 mL) at −78 °C was added (1-ethoxyvinyl)lithium in THF (0.51 mmol). The slurry was stirred for 25 min, and ketone **7** in THF (10.0 mL, 1 mL rinse) was added. After 2 h at −78 °C, the reaction mixture was poured into 200 mL of saturated NH_4Cl, extracted with ether (2 × 200 mL), and washed with brine. The organic layer was dried, filtered, and concentrated and the crude oil was purified by flash chromatography on SiO_2 (EtOAc/hexane 30/70) to give **8h** as an oil that crystallized upon standing to give a white solid. Mp: 95–96 °C (90% yield). TLC: R_f 0.42 (EtOAc/hexane: 30/70). $[\alpha]_D$: −23.2 (*c* 0.51 $CHCl_3$). IR: 3500, 2980, 2880, 1620, 1450, 1260, 1090, 730, 690 cm 1. ^{1}H NMR (400 MHz): δ 1.32 (t, 3, *J* = 7.0), 3.41 (s, 1), 3.46 (d, 1, *J* = 5.4), 3.50 (dd, 1, *J* = 7.3, 5.2), 3.80 (q, 2, *J* = 7.0), 4.02 (d, 1, *J* = 5.3), 4.16 (d, 1, *J* = 2.7), 4.38 (d, 1, *J* = 7.3), 4.52–4.64 (m, 6), 5.42 (s, 1), 7.25–7.35 (m, 10). ^{13}C NMR (100 MHz): δ 14.39, 63.47, 71.10, 72.26, 74.32, 77.74, 80.76, 82.27, 102.38, 127.85, 127.94, 128.09, 128.38, 128.44, 137.66, 137.80, 163.75. Anal. Calcd for $C_{24}H_{28}O_6$: C, 69.89; H, 6.84. Found: C, 69.77; H, 6.85.

1,6-Anhydro-2,3-di-*O*-benzyl-4-(ethoxycarbonyl)-β-D-galactopyranose (8g). To a solution of **8h** (1.85 g, 4.48 mmol) in 175 mL of CH_2Cl_2 at −78 °C was bubbled ozone until a blue color persisted. Dimethyl sulfide was added (6.0 mL), and the solution was warmed to rt and concentrated. The product was purified by flash chromatography on SiO_2 (EtOAc/hexane 30/70) to give **8g** as a colorless oil (1.65 g, 89%). TLC: R_f 0.21 (EtOAc/hexane: 30/70). $[\alpha]_D$: −67.3 (*c* 0.33 $CHCl_3$). IR: 3472, 2966, 2908, 1736, 1496, 1455, 1249, 1096, 743, 697 cm^{-1}. ^{1}H NMR (400 MHz): δ 1.27 (t, 3, *J* = 7.1), 3.55 (dd, 1, *J* = 3.7, 0.9), 3.60 (dd, 1, *J* = 7.7, 5.4), 3.75 (s, 1), 4.17–4.29 (m, 4), 4.49 (d, 1, *J* = 11.4), 4.56 (d, 1, *J* = 12.0), 4.62 (d, 1, *J* = 11.9), 4.64 (d, 1, *J* = 11.4), 4.78 (d, 1, *J* = 12.0), 5.43 (s, 1), 7.26–7.36 (m, 10). ^{13}C NMR (100 MHz): δ 13.94, 62.14, 63.31, 71.82, 73.71, 75.32, 76.15, 77.72, 101.60, 127.86, 127.90, 127.95, 128.12, 128.43, 128.50, 137.00, 137.42, 171.15. Anal. Calcd for $C_{23}H_{26}O_7$: C, 66.65; H, 6.32. Found: C, 66.44; H, 6.27.

General Procedure for the Formation of 4-Alkyl-1,6-anhydrofuranoses. To a solution of the alcohol **8a-e,h** in distilled acetic anhydride (0.10–0.05 M) was added distilled trifluoroacetic acid (TFA) (ratio Ac_2O/TFA = 10/1), and the solution was stirred at 65 °C for 2 h. The solution was concentrated, and analysis of the crude ^{1}H NMR showed a triacetate that was a mixture at the anomeric position. The crude product was dissolved in MeOH (0.10 M), and a catalytic amount of a 25 wt % solution of MeONa in MeOH was added (EtOH/NaOH for **8h**). The solution was stirred at rt until TLC analysis showed no high R_f spots (EtOAc/hexane:30/70). The crude mixture was filtered through a plug of SiO_2 and washed thoroughly with 50/50 EtOAc/hexane. The filtrate was concentrated, and ^{1}H NMR analysis of the crude product showed no acetate. The crude triol was dissolved in benzene (0.05 M) containing a catalytic amount of *p*-TsOH and was heated to reflux in a Dean-Stark apparatus until TLC analysis showed disappearance of the starting material. The mixture was cooled, poured into a saturated solution of $NaHCO_3$, and extracted twice with ether. The organic extracts were washed with H_2O and brine, dried, filtered, and concentrated. The ratio of products was determined by analysis of the ^{1}H NMR of the crude mixture. The product **9a-e** was purified by flash chromatography on SiO_2 using EtOAc/hexane as the eluent.

1,6-Anhydro-2,3-di-*O*-benzyl-4-methyl-β-D-galactofuranose (9a). White solid (77%). Mp: 94–95 °C. TLC: R_f 0.59 (EtOAc/hexane: 50/50). $[\alpha]_D$: +28.3 (*c* 0.21 $CHCl_3$). IR: 3600, 3040, 2980, 2895, 1500, 1460, 1170, 1110, 1070, 1030, 800, 680 cm^{-1}. ^{1}H NMR (400 MHz): δ 1.40 (s, 3), 1.97 (brd, 1, *J* = 3.9), 3.72–3.82 (m, 2), 3.94 (dd, 1, *J* = 8.5, 4.0), 4.00 (d, 1, *J* = 2.8), 4.12 (dd, 1, *J* = 4.4, 2.8), 4.48 (d, 1, *J* = 11.5), 4.56 (s, 2), 4.67 (d, 1, *J* = 11.5), 5.27 (d, 1, *J* = 4.5), 7.26–7.36 (m, 10). ^{13}C NMR (100 MHz): δ 17.01, 64.62, 68.61, 71.62, 72.28, 81.61, 84.73, 86.73, 95.92, 127.46, 127.59, 127.95, 128.31, 128.43, 137.47, 138.01. Anal. Calcd for $C_{21}H_{24}O_5$: C, 70.77; H, 6.79. Found: C, 70.86; H, 6.76.

1,6-Anhydro-2,3-di-*O*-benzyl-4-ethyl-β-D-galactofuranose (9b). White solid (65%). Mp: 111–112 °C. TLC: R_f 0.21 (EtOAc/hexane: 25/75). $[\alpha]_D$: +32.6 (*c* 0.65 $CHCl_3$). IR: 3507, 2966, 2896, 1455, 1102, 1020, 985, 744, 697 cm^{-1}. ^{1}H NMR (400 MHz): δ 1.03 (t, 3, *J* = 7.5), 1.75–1.86 (m, 1), 1.94–2.04 (m, 1), 3.79 (t, 1, *J* = 10.7), 3.98 (dd, 1, *J* = 11.0, 6.6), 4.03–4.07 (m, 3), 4.12 (dd, 1, *J* = 4.3, 3.0), 4.51 (d, 1, *J* = 11.4), 4.56 (d, 1, *J* = 11.9), 4.61 (d, 1, *J* = 11.9), 4.70 (d, 1, *J* = 11.4), 5.31 (d, 1, *J* = 4.4), 7.27–7.44 (m, 10). ^{13}C NMR (100 MHz): δ 7.43, 22.02, 64.15, 64.49, 71.67, 72.28, 82.12, 86.01, 86.85, 95.80, 127.44, 127.56, 127.94, 128.31, 128.44, 137.53, 138.09. Anal. Calcd for $C_{22}H_{26}O_5$: C, 71.33; H, 7.07. Found: C, 71.31; H, 7.12.

1,6-Anhydro-2,3-di-*O*-benzyl-4-allyl-β-D-galactofuranose (9c). White solid (53%). Mp: 109–110 °C. TLC: R_f

0.26 (EtOAc/hexane: 25/75). $[\alpha]_D$: +28.4 (*c* 0.82 $CHCl_3$). IR: 3455, 2901, 1496, 1454, 1108, 1027, 738, 697 cm^{-1}. ^1H NMR (400 MHz): δ 2.62 (d, 2, J = 7.3), 3.77 (t, 1, J = 10.8), 3.92–4.03 (m, 2), 4.11–4.13 (m, 2), 4.48 (d, 1, J = 11.4), 4.56 (d, 1, J = 11.8), 4.61 (d, 1, J = 11.8), 4.70 (d, 1, J = 11.4), 5.15 (dt, 1, J = 10.1, 1.0), 5.21 (ddd, 1, J = 17.2, 3.5, 1.5), 5.31 (d, 1, J = 4.0), 5.94–6.05 (m, 1), 7.29–7.39 (m, 10). ^{13}C NMR (100 MHz): δ 35.55, 64.22, 65.71, 71.57, 72.31, 81.67, 85.40, 86.61, 96.05, 118.29, 127.51, 127.64, 127.99, 128.35, 128.47, 134.24, 137.49, 137.94. Anal. Calcd for $C_{23}H_{26}O_5$: C, 72.23; H, 6.85. Found: C, 71.99; H, 7.21.

1,6-Anhydro-2,3-di-*O*-benzyl-4-phenyl-β-D-galactofuranose (9d). Colorless oil (24%). TLC: R_f 0.34 (EtOAc/hexane: 30/70). $[\alpha]_D$: +40.0 (*c* 0.90 $CHCl_3$). IR: 3450, 2918, 1496, 1454, 1216, 1078, 1021, 755, 700 cm^{-1}. ^1H NMR (400 MHz): δ 2.00 (bs, 1), 3.64 (dd, 1, J = 11.6, 7,7), 3.95–4.03 (m, 2), 4.27 (dd, 1, J = 4.5, 2.4), 4.47 (d, 1, J = 2.5), 4.48 (d, 1, J = 11.9), 4.52 (d, 1, J = 12.0), 4.56 (d, 1, J = 11.4), 4.78 (d, 1, J = 11.4), 5.54 (d, 1, J = 4.5), 7.09–7.12 (m, 2), 7.24–7.93 (m, 13H). ^{13}C NMR (100 MHz): δ 29.67, 64.34, 69.18, 71.00, 72.36, 80.91, 86.26, 87.62, 96.12, 126.66, 127.41, 127.51, 127.74, 128.04, 128.12, 128.47, 137.31, 137.39, 137.45. Anal. Calcd for $C_{26}H_{26}O_5$: C, 74.62; H, 6.26. Found: C, 74.43; H, 6.40.

1,6-Anhydro-2,3-di-*O*-benzyl-4-[[(*tert*-butyldiphenylsilyl)oxy]methyl]-β-D-galacto-pyranose (9e). Characterized as a 2:1 mixture of **9e:8e**. Colorless oil (73%). TLC: R_f 0.42 (EtOAc/hexane: 25/75). ^1H NMR (500 MHz): δ 1.12 (s, 9), 3.20 (bs, 1), 3.89 (d, 1, J = 10.9), 4.08 (dd, 1, J = 11.4, 6.8), 4.12 (dd, 1, J = 4.4, 2.7), 4.20 (d, 1, J = 10.9), 4.33 (d, 1, J = 2.6), 4.34–4.56 (m, 5), 4.72 (d, 1, J = 11.5), 5.35 (d, 1, J = 4.4), 7.19–7.53 (m, 16), 7.70–7.74 (m, 4). ^{13}C NMR (100 MHz): δ 19.12, 26.79, 64.01, 64.43, 65.79, 71.60, 72.22, 81.11, 84.19, 86.58, 96.07, 127.85, 127.88, 128.24, 128.39, 128.54, 129.94, 132.19, 135.55, 137.40, 137.71.

General Procedure for the Formation of γ-lactones. To a solution of the alcohol **8c-e** in distilled Ac_2O (0.10–0.05 M) was added distilled TFA (ratio Ac_2O/TFA = 10/1), and the solution was stirred at 65 °C for 2 h. The solution was concentrated, and analysis of the crude ^1H NMR spectrum showed a triacetate that was a mixture at the anomeric position. The crude product was dissolved in MeOH (0.10 M), and a catalytic amount of a 25 wt % solution of MeONa in MeOH was added. The solution was stirred at rt until TLC analysis showed no high R_f spots (EtOAc/hexane: 30/70). The crude mixture was filtered through a plug of SiO_2 and washed thoroughly with EtOAc/hexane 50/50. The filtrate was concentrated, and ^1H NMR analysis of the crude product showed no acetate. The crude triol was dissolved in acetone (0.05 M), and a catalytic amount of *p*-TsOH was added. The solution was stirred at rt until disappearance of the starting material. $NaHCO_3$ was added, and the reaction mixture was filtered and concentrated. The crude product was dissolved in CH_2Cl_2 (0.05 M), and PDC (3 equiv) was added with Celite and pulverized 4 Å MS (same amount as PDC). The suspension was stirred at rt until disappearance of the starting material, filtered through a plug of SiO_2, and washed thoroughly with EtOAc/hexane 25/75. The filtrate was concentrated, and the product (**15a-c**) was purified by chromatography on SiO_2 using EtOAc/hexane as the eluent.

2,3-Di-*O*-benzyl-4-allyl-5,6-*O*-isopropylidene-D-gluco-1,4-lactone (15a). Colorless oil (76%). TLC: R_f 0.47 (EtOAc/hexane: 30/70). $[\alpha]_D$: +32.9 (*c* 0.90 $CHCl_3$). IR: 2982, 2886, 1799, 1640, 1455, 1372, 1209, 1105, 1073, 1004, 851, 738, 699 cm^{-1}. ^1H NMR (400 MHz): δ 1.35 (s, 3), 1.41 (s, 3), 2.34 (dd, 1, J = 14.2, 8.0), 2.56 (dd, 1, J = 14.2, 6.2), 3.95 (dd, 1, J = 8.4, 7.5), 4.02 (dd, 1, J = 8.4, 6.6), 4.05–4.09 (m, 1,), 4.42 (d, 1, J = 8.1), 4.58 (d, 1, J = 8.1), 4.64 (d, 1, J = 11.7), 4.71 (d, 1, J = 11.7), 4.76 (d, 1, J = 11.4), 5.12 (d, 1, J = 11.4), 5.18–5.24 (m, 2), 5.81–5.92 (m, 1), 7.17–7.43 (m, 10). ^{13}C NMR (100 MHz): δ 25.48, 25.85, 36.29, 64.37, 72.50, 73.05, 77.67, 78.88, 80.80, 84.28, 109.72, 121.17, 127.58, 127.80, 127.88, 128.00, 128.07, 128.19, 128.32, 128.37, 128.42, 131.23, 136.90, 137.90, 171.91. Anal. Calcd for $C_{26}H_{30}O_6$: C, 71.21; H, 6.90. Found: C, 71.27; H, 6.90.

2,3-Di-*O*-benzyl-4-phenyl-5,6-*O*-isopropylidene-D-gluco-1,4-lactone (15b). Colorless oil (41%). TLC: R_f 0.55 (EtOAc/hexane: 25/75). $[\alpha]_D$: +28.8 (*c* 1.8 $CHCl_3$). IR: 2932, 1790, 1455, 1372, 1215, 1148, 737, 697 cm^{-1}. ^1H NMR (500 MHz): δ 1.39 (s, 3), 1.48 (s, 3), 3.66 (dd, 1, J = 8.5, 7.1), 3.74 (dd, 1, J = 8.6, 7.1), 4.19 (d, 1, J = 9.2), 4.58 (t, 1, J = 7.0), 4.66 (d, 1, J = 11.2), 4.80 (d, 1, J = 12.0), 4.85 (d, 1, J = 12.0), 4.89 (d, 1, J = 11.3), 7.18–7.41 (m, 15). ^{13}C NMR (100 MHz): δ 25.86, 64.41, 72.85, 73.44, 77.32, 83.85, 110.66, 126.13, 127.59, 127.65, 127.84, 127.95, 127.99, 128.22, 128.29, 128.35, 128.56, 134.86, 136.99, 137.36, 171.90. Anal. Calcd for $C_{29}H_{30}O_6$: C, 73.40; H, 6.37. Found: C, 73.08; H, 6.50.

2,3-Di-*O*-benzyl-4-[[(*tert*-butyldiphenylsilyl)oxy]methyl]-5,6-*O*-isopropylidene-D-gluco-1,4-lactone (15c). Colorless oil (76%). TLC: R_f 0.54 (EtOAc/hexane 30/70). $[\alpha]_D$: +34.5 (*c* 0.31 $CHCl_3$). IR: 2930, 1790, 1455, 1428, 1372, 1205, 1116, 741, 697 cm^{-1}. ^1H NMR (400 MHz): δ 0.93 (s, 9), 1.28 (s, 3), 1.33 (s, 3), 3.41 (d, 1, J = 10.9), 3.78–3.96 (m, 4), 4.56 (d, 1, J = 7.9), 4.63 (d, 1, J = 11.3), 4.72 (d, 1, J = 11.3), 4.84 (d, 1, J = 11.7), 4.87 (d, 1, J = 7.9), 5.13 (d, 1, J = 11.7), 7.15 (t, 2, J = 7.6), 7.25–7.42 (m, 14), 7.57–7.65 (m, 4). ^{13}C NMR (100 MHz): δ 18.90, 25.32, 25.88, 26.51, 62.48, 64.45, 72.51, 73.37, 75.06, 78.93, 81.05, 84.62, 109.78, 127.07, 127.92, 127.96, 128.12, 128.43, 128.55, 129.74, 129.95, 131.78, 132.23, 135.53, 135.60, 137.08, 137.53, 172.69. Anal. Calcd for $C_{40}H_{46}O_7Si$: C, 72.04; H, 6.95. Found: C, 72.34; H, 6.96.

General Procedure for the Formation of 1,4-Disubstituted 1,6-Anhydrofuranoses. To a suspension of anhydrous $CeCl_3$ (3.7 equiv) in THF (stirred overnight at rt, 0.2 M) at −78 °C was added methyllithium (1.4 M in ether, 3.4 equiv). The mixture was stirred for 0.5 h prior to addition to a solution of the lactone **15a-c** in THF (0.5 M), and the resulting mixture was stirred until disappearance of the starting material. The reaction mixture was poured into saturated NH_4Cl and extracted with ether, and the organic extracts were washed with water and brine, dried, filtered, and concentrated. The crude product was dissolved in THF (0.01 M), and 2 N HCl was added (ratio THF/2 N HCl 50/1). The solution was heated to reflux until complete disappearance of the starting material, cooled, poured into saturated $NaHCO_3$, and extracted with ether. The organic extracts were washed with water and brine, dried, filtered, and concentrated. The product **16a-c** and **20b** was purified by chromatography on SiO_2 using EtOAc/hexane as the eluent.

1,6-Anhydro-1-methyl-2,3-di-*O*-benzyl-4-allyl-β-D-galactofuranose (16a). Colorless oil (69%). TLC: R_f 0.28 (EtOAc/hexane 30/70). $[\alpha]_D$: +12.9 (*c* 0.70 $CHCl_3$). IR: 3453, 2898, 1640, 1497, 1455, 1388, 1185, 1104, 915, 739, 698 cm^{-1}. ^1H NMR (500 MHz): δ 1.50 (s, 3), 2.53–2.88 (m, 2), 3.83 (t, 1, J = 10.7), 3.93 (dd, 1, J = 11.0.6.6), 3.95 (d, 1, J = 2.8), 3.98 (dd, 1, J = 10.5, 6.6), 4.17 (d, 1, J = 2.8), 4.54 (d, 1, J = 11.6), 4.58 (d, 1, J = 11.6), 4.59 (d, 1, J = 11.7), 4.69 (d, 1, J = 11.7), 5.16 (ddd, 1, J = 11.1, 2.0, 1.0), 5.19 (ddd, 1, J = 17.2, 3.3, 1.5), 5.96–6.04 (m, 1), 7.24 (m, 10). ^{13}C NMR (125 MHz): δ 23.25, 35.31, 64.23, 64.77, 72.22, 72.56, 83.68, 84.74, 90.17, 102.42, 118.11, 126.95, 127.63, 127.73, 127.75, 127.83, 128.39, 128.53, 134.26, 137.67, 137.84. Anal. Calcd for $C_{24}H_{28}O_5$: C, 72.71; H, 7.12. Found: C, 72.34; H, 7.12.

1,6-Anhydro-1-methyl-2,3-di-*O*-benzyl-4-phenyl-β-D-galactofuranose (16b). Colorless oil (61%). TLC: R_f 0.48 (EtOAc/hexane 50/50). $[\alpha]_D$: +14.9 (*c* 0.90 $CHCl_3$). IR: 3495, 3031, 2929, 2880, 1497, 1454, 1398, 1115, 1029, 698 cm^{-1}. ^1H NMR (400 MHz): δ 1.68 (s, 3), 3.27 (dd, 1, J = 11.8, 6.9), 3.35 (dd, 1, J = 4.3, 11.8), 3.82 (d, 1, J = 1.3), 3.88 (d, 1, J = 1.3), 4.03 (d, 1, J = 11.5), 4.11 (d, 1, J = 11.3), 4.17 (dd, 1, J = 6.8, 4.2), 4.62 (d, 1, J = 12.1), 4.66 (d, 1, J = 12.1), 6.89–6.91 (m, 2), 7.16–7.18 (m, 4), 7.22–7.44 (m, 9H). ^{13}C NMR (100 MHz): δ 16.97, 62.62, 71.88, 72.82, 79.68, 86.05, 90.38, 91.81, 106.51, 127.73, 127.88, 127.97, 128.03, 128.17, 128.49, 133.02, 137.18, 137.45. Anal. Calcd for $C_{27}H_{28}O_5$: C, 74.98; H, 6.53. Found: C, 74.78; H, 6.55.

1,6-Anhydro-1-methyl-2,3-di-*O*-benzyl-4-[[(*tert*-butyldiphenylsilyl)oxy]methyl]-β-D-galactofuranose (16c). Colorless oil (61%). TLC: R_f 0.47 (EtOAc/hexane 30/70). $[\alpha]_D$: +17.3 (*c* 0.70 $CHCl_3$). IR: 3488, 2931, 2858, 1428, 1390, 1113, 741, 700 cm^{-1}. ^1H NMR (400 MHz): δ 1.08 (s, 9), 1.43 (s, 3), 3.47–3.50 (bs, 1), 3.79 (d, 1, J = 10.6), 3.88 (d, 1, J = 10.7), 3.88 (d, 1, J = 2.5), 4.02 (dd, 1, J = 11.4, 6.7), 4.16 (d, 1, J =

10.6), 4.25 (dd, 1, J = 10.6, 6.8), 4.37 (d, 1, J = 2.5), 4.55 (d, 1, J = 11.6), 4.56 (s, 2), 4.64 (d, 1, J = 11.7), 7.17–7.19 (m, 2), 7.22–7.46 (m, 14), 7.60–7.71 (m, 4). ^{13}C NMR (100 MHz): δ 19.10, 23.13, 26.87, 64.03, 65.00, 65.82, 82.83, 83.29, 90.24, 102.34, 127.63, 127.66, 127.73, 127.82, 127.85, 127.89, 128.34, 128.37, 128.44, 128.57, 130.01, 130.03, 132.01, 134.77, 135.62, 135.65, 135.73, 137.58, 137.70. Anal. Calcd for $C_{38}H_{44}O_6Si$: C, 73.04; H, 7.10. Found: C, 72.86; H, 7.27.

General Procedure for the Equilibration of 1,4-Disubstituted 1,6-Anhydrofuranoses. The anhydrosugar **16a-c** or **20a-c** (15 mg) and *p*-TsOH (100 mg) were dissolved in benzene (13 mL) containing H_2O (0.2 mL). The solution was heated to reflux until no change was observed by TLC analysis. The mixture was cooled to rt, poured into saturated $NaHCO_3$ (10 mL), and extracted with ether (2 × 15 mL). The organic extracts were combined, washed with H_2O (10 mL) and brine (10 mL) dried, filtered, and concentrated. The two anhydrosugars were separated by chromatography on SiO_2 using EtOAc/hexane as the eluent providing the 1,6-anhydrofuranose **16a-c** (described previously) and the 1,6-anhydropyranose **20a-c**.

1,6-Anhydro-1-methyl-2,3-di-*O*-benzyl-4-allyl-β-D-galactopyranose (20a). Colorless oil. TLC: R_f 0.39 (EtOAc/hexane: 30/70). $[\alpha]_D$: +12.7 (c 1.4 $CHCl_3$). IR: 3428, 2919, 1497, 1454, 1116, 915, 795, 751, 699 cm^{-1}. ^{1}H NMR (400 MHz): δ 1.48 (s, 3), 2.57 (dd, 1, J = 14.2, 8.2), 2.64 (ddt, 1, J = 14.2, 6.3, 1.3), 3.38 (d, 1, J = 1.0), 3.39–3.44 (bs, 1), 3.50 (d, 1, J = 1.2), 3.70 (dd, 1, J = 7.5, 5.4), 4.12 (d, 1, J = 5.6), 4.18 (d, 1, J = 7.7), 4.35 (d, 1, J = 11.6), 4.41 (d, 1, J = 11.8), 4.52 (d, 1, J = 11.8), 4.56 (d, 1, J = 11.6), 5.08–5.12 (m, 2), 5.87–5.95 (m, 1), 7.26–7.38 (m, 10). ^{13}C NMR (100 MHz): δ 20.74, 41.03, 64.38, 68.53, 72.74, 72.81, 77.20, 77.70, 79.05, 106.52, 118.90, 127.86, 128.07, 128.15, 128.22, 128.47, 128.61, 133.50, 137.15, 137.55. Anal. Calcd for $C_{24}H_{28}O_5$: C, 72.71; H, 7.12. Found: C, 72.71; H, 7.31.

1,6-Anhydro-1-methyl-2,3-di-*O*-benzyl-4-phenyl-β-D-galactopyranose (20b). Colorless oil. TLC: R_f 0.74 (EtOAc/hexane: 50/50). $[\alpha]_D$: +3.64 (c 1.4 $CHCl_3$). IR: 3442, 2900, 1496, 1454, 1388, 1177, 1099, 755, 699 cm^{-1}. ^{1}H NMR (500 MHz): δ 1.64 (s, 3), 3.78 (dd, 1, J = 10.6, 6.7), 4.00 (dd, 1, J = 11.4, 6.7), 4.02 (d, 1, J = 10.7), 4.06 (d, 1, J = 11.3), 4.12 (d, 1, J = 2.5), 4.40 (s, 2), 4.52 (d, 1, J = 2.4), 4.67 (d, 1, J = 11.6), 4.79 (d, 1, J = 11.8), 7.02–7.51 (m, 15). ^{13}C NMR (125 MHz): δ 23.69, 64.40, 68.51, 71.32, 72.65, 83.22, 86.85, 89.85, 102.62, 126.69, 127.35, 127.75, 127.78, 127.84, 127.93, 127.95, 128.05, 128.09, 128.13, 128.21, 128.45, 137.44, 137.66, 137.82. Anal. Calcd for $C_{27}H_{28}O_5$: C, 74.98; H, 6.53. Found: C, 75.18; H, 6.74.

1,6-Anhydro-1-methyl-2,3-di-*O*-benzyl-4-[[(*tert*-butyldiphenylsilyl)oxy]methyl]-β-D-galactopyranose (20c). Colorless oil. TLC: R_f 0.48 (EtOAc/hexane: 30/70). $[\alpha]_D$: −51.4 (c 1.0 $CHCl_3$). IR: 3526, 2930, 2856, 1455, 1384, 1112, 1047, 740, 700 cm^{-1}. ^{1}H NMR (500 MHz): δ 1.06 (s, 9), 1.47 (s, 3), 3.39 (d, 1, J = 1.0), 3.74 (dd, 1, J = 7.3, 5.4), 3.76–3.77 (m, 1), 3.89 (d, 1, J = 10.5), 3.96 (d, 1, J = 10.5), 4.24 (d, 1, J = 5.9), 4.29 (d, 1, J = 7.5), 4.32 (d, 1, J = 11.8), 4.45 (d, 1, J = 11.8), 4.52 (d, 1, J = 11.8), 4.60 (d, 1, J = 11.8), 7.17–7.64 (m, 16), 7.67 (dd, 2, J = 8.1, 1.3), 7.75 (dd, 2, J = 8.1, 1.4). ^{13}C NMR (125 MHz): δ 19.42, 20.74, 26.86, 64.62, 66.70, 70.70, 72.50, 73.30, 75.59, 76.60, 78.52, 106.69, 127.59, 127.62, 127.77, 127.81, 127.84, 128.03, 128.35, 128.58, 129.53, 129.58, 133.25, 133.59, 135.62, 135.81, 137.47, 137.49. Anal. Calcd for $C_{38}H_{44}O_6Si$: C, 73.04; H, 7.38. Found: C, 73.28; H, 7.10.

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