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Note

Synthesis of a potential tetrasaccharide ligand for E-selectin

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Abstract

A potential tetrasaccharide ligand for E-selectin, ($Na^+{}^-O_3SO$-3)Galβ-(1→4)[Fucα-(1→3)]Glcβ-(1→6)Gal, an analogue of the ovarian cystadenoma glycoprotein tetrasaccharide fragment, was synthesized in a highly practical way.

Keywords: Potential selectin ligand; Tumor-related oligosaccharides; Oligosaccharide; Synthesis

1. Introduction

The role of carbohydrates in cell-adhesion processes, specifically, the interaction between the selectins and the Lewis sugars or their derivatives, has led to extensive studies in both biology and chemistry.[1,2] Following their reports that disclosed the isolation of a mixture of two sulfated tetrasaccharides from an ovarian cystadenoma glycoprotein which exhibited E-selectin-binding properties comparable to those of sialylated compounds,[3] Chai et al.[4] reported another group of strong E-selectin-binding oligosaccharide components released from the same source (Fig. 1). In structure **b**, biantennary sulfated Lewis$^{a/x}$ components were attached to galactose via β-(1→3) or β-(1→6) glycosidic bonds, and Nicolaou et al.[5] have reported the synthesis of the tetrasaccharide with β-(1→3)-linked galactose at the reducing terminal of sulfated Le$^{a/x}$.

In our studies on tumor-related oligosaccharides, we focused our attention on another tetrasaccharide fragment of the foregoing structure in which β-(1→6)-linked galactose was attached to the reducing end of sulfated Le^x, e.g., ($Na^+{}^-O_3SO$-3) Galβ-(1→4)[Fucα→(1→3)]GlcNAcβ-(1→6)Gal. Meanwhile, simplification of sLe$^{x/a}$ sugars to analogues that are inexpensive, easy to prepare, and preserve the binding affinities and specificities of the original structure is very important for the development of sLe$^{x/a}$ based selectin antagonists. Previous structure–activity relationship (SAR) studies showed that the acetylated amino group of the GlcNAc residue was not essential for the interaction with selectins, and replacement of the core glucosamine residue of sLe^x and sLe^a with glucose was found to have little or no effect on selectin recognition.[6a,b] From this point of view, we replaced GlcNAc by glucose, since the substitution greatly facilitates the synthesis by eliminating the need for troublesome nitrogen protection/deprotection and without sacrifice of the expected biological activity. We report here a highly practical synthesis of the tetrasaccharide ($Na^+{}^-O_3SO$-3)Galβ-(1→4)[Fucα-(1→3)]Glcβ-(1→6)Gal, an analogue of the ovarian cystadenoma glycoprotein tetrasaccharide fragment having E-selectin-binding activity.

Fig. 1. Oligosaccharide components released from ovarian cystadenoma glycoprotein.

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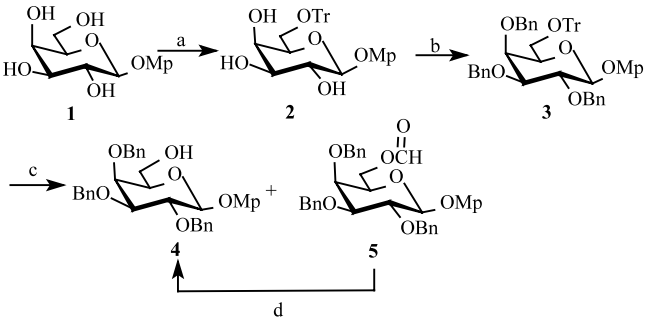


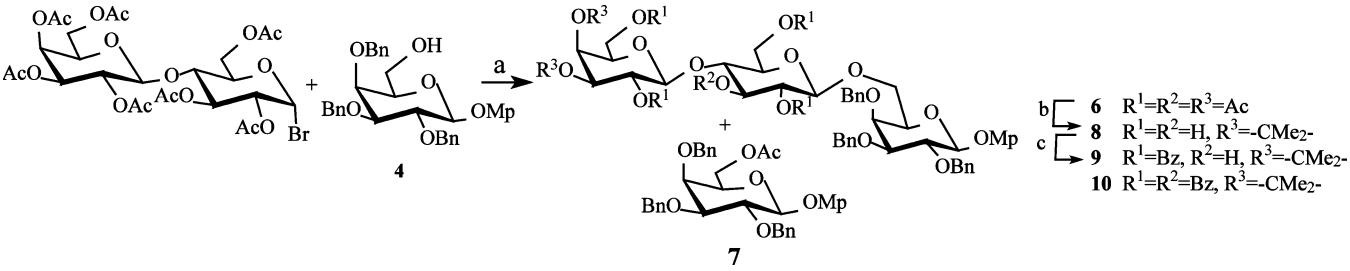
Scheme 1. Synthesis of glycosyl acceptor **4**. (a) TrCl, DMAP; (b) NaH, BnBr; (c) formic acid–ether; (d) NaOMe 80% (three steps).

2. Results and discussion

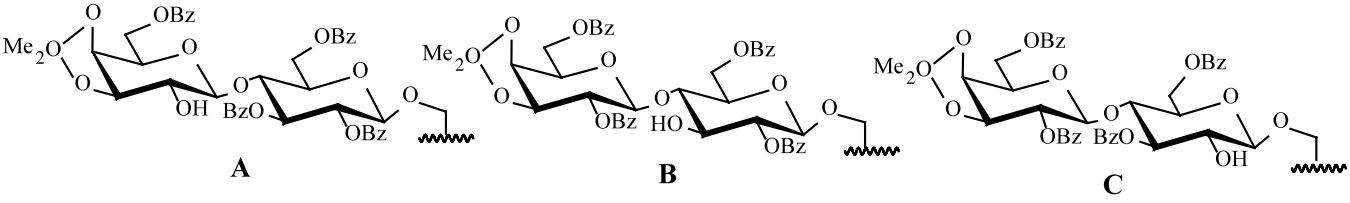
For the galactose at the reducing end, the anomeric center was masked by a 4-methoxyphenyl (Mp) group,[7] which can either be maintained in the final deprotective product or be removed selectively under mild conditions. The galactose derivatives **1**[7] was treated with chlorotriphenylmethane in pyridine–dichloromethane in the presence of DMAP[8] to afford the 6-trityl derivative **2**, which was peralkylated with benzyl bromide to generate **3**. Removing the trityl group with formic acid in ether[9] led to the formation of **4** and a significant amount of formylated byproduct **5** (about 20% of the product was formylated, as judged by column chromatography) which could be converted back into the desired glycosyl acceptor **4** by treating the crude product with sodium methoxide (Scheme 1).

The linear trisaccharide skeleton **6** was constructed with the glycosyl acceptor **4** and acetylated lactosyl bromide under activation by 1:1 Ag_2CO_3–AgOTf in high yield (Scheme 2). A small amount of trans-acetylation product **7** was also isolated as byproduct. In the following steps, the selective protection of the lactose portion to allow the 3-OH of glucose to remain free is the key step in our work. Hasegawa et al.[10] have developed an effective and interesting selective benzoylation method to achieve this goal in which 3′,4′-*O*-isopropylidenelactose was used as starting material, and these reaction conditions were later optimized by Kondo et al.[11]. However, whether this reaction can still work well with the more complicated lactose-containing oligosaccharide substrate remains unknown.

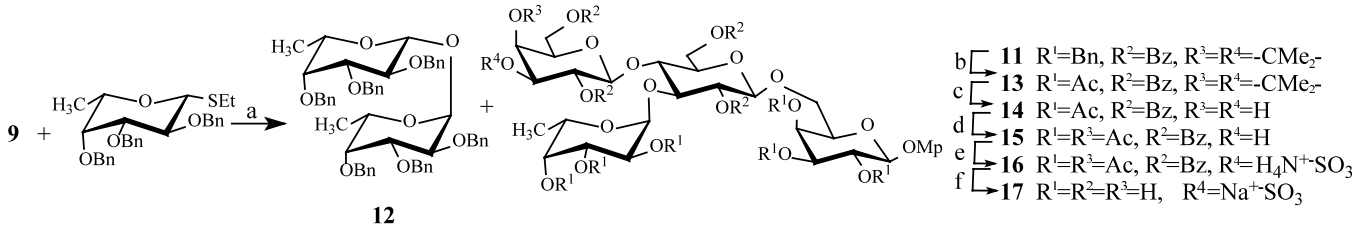
In our work, trisaccharide **6** was first deacetylated and then isopropylidenated at the 3,4-OH of the lactose portion according to Catelani's method[12] to obtain the benzoylation substrate. Selective benzoylation was performed following Kondo's procedure and one main product, together with a minor one, were isolated from the crude product. From their mass spectra, it was easy to deduce that the minor one was the perbenzoylation product, while the main one had the correct molecular weight, namely leaving one hydroxy group free, as expected. However the position of benzoylation had to be confirmed since the substrate we used was a trisaccharide. Owing to the higher reactivity of 6-OH compared with that of 2-OH or 3-OH, there are in theory three possible selective benzoylation patterns for the trisaccharide **8** (Scheme 3).



Scheme 2. Synthesis of the trisaccharide skeleton and its selective benzyolation. (a) 1:1 Ag_2CO_3–AgOTf, CH_2Cl_2, 0 °C, 83%; (b) (i) NaOMe–MeOH; (ii) camphorsulfonic acid, 4 Å molecular sieves, 2,2-dimethoxypropane, rt, 24 h.; (iii) NEt_3; 10:1 MeOH–H_2O, 100 °C, 5 h, 71% (three steps); (c) BzCl, toluene–pyridine, 0 °C 65.4%.



Scheme 3. Three possible selective benzoylation patterns.



Scheme 4. Synthesis of the target tetrasaccharide. (a) $CuBr_2$–$Bu_4N^+Br^-$, $ClCH_2CH_2Cl$–DMF, rt, 48 h. 70.8%; (b) (i) 20% Pd–C, H_2, MeOH–dioxane, rt, 20 h; (ii) Ac_2O–Py, DMAP 71.8%; (c) $TsOH{\cdot}H_2O$, EtOAc, rt, 69.2%; (d) (i) $CH_3C(OMe)_3$, $TsOH{\cdot}H_2O$; (ii) 80% HOAc, rt 90% (two steps); (e) $SO_3{\cdot}$Py complex, DMF, rt quantitative yield; (f) NaOMe–MeOH, 64.5%

In the ^{1}H NMR spectrum of the main product, two hexose hydrogen atoms underwent significant downfield shifts, to 5.35 and 5.18 ppm, respectively, due to their acylation. In the ^{1}H,^{1}H-COSY NMR spectrum, these two hydrogen atoms correlate with an anomeric proton, indicating that they are 2′-H and 2″-H of the lactose portion. Thus, **B** represents the structure of the main product, which is also the structure we desired.

In the next step, the perbenzylated L-fucose ethyl thioglycoside[13] was employed as the glycosyl donor to couple with the selective benzoylation product **9** under activation by $CuBr_2$–NBu_4Br,[14] affording compound **11**. About 10% of the glycosyl donor self-coupled to afford difucose **12** as a byproduct. Based on the different chemical shifts (5.20 and 4.50 ppm) and coupling constants (3.3 and 7.8 Hz) of the two anomeric hydrogen atoms, it is interesting that the two fucose residues has different configurations at their anomeric centers (Scheme 4).

It has been reported that the glycosidic bond of fucose is very sensitive under acidic conditions.[15] To enhance its tolerance to acidic treatment and simplify the final deprotection steps, the electron-donating benzyl groups were replaced by electron-withdrawing acetyl groups in the following steps (Scheme 4). The first attempt to hydrogenate **11** by using 20% $Pd(OH)_2$–C as a catalyst failed since a considerable amount of deisopropylidenation product was formed, along with the desired compound. However, 20% Pd–C was a suitable alternative which effectively suppressed this side reaction. After acetylation and deisopropylidenation with $TsOH{\cdot}H_2O$, the 4″-OH of the non-reducing terminal galactose was selectively protected with an acetyl group by using the trimethyl orthoacetate method.[16] Sulfation of **15** with the $SO_3{\cdot}$Py complex in DMF followed by deacetylation with methanolic sodium methoxide and then passing through Sephadex G-10 resin gave the target compound **17** as an amorphous sodium salt.

In conclusion, we have synthesized a sulfated tetrasaccharide having potential E-selectin-binding activities in a highly practical way. The biological investigations of the target compound may expand the library of biological tools and provide useful information for SAR research of Lewis sugar-based selectin antagonists.

3. Experimental

General methods.—All reactions were monitored by TLC on Silica Gel GF_{254}. Column chromatography was performed using Silica Gel H_{60}. All solvents were dried and/or distilled before use. Melting points were determined with a X_4 apparatus and are uncorrected. Optical rotations were measured at rt with an AA-10R (Optical Activity Co., Ltd) polarimeter. NMR spectra were recorded (internal standard tetramethylsilane) with a Bruker ARX-400 or Jeol-300 type spectrometer using $CDCl_3$ as the solvent. Elemental analyses were performed on a Perkin–Elmer 240C instrument. MALDI-TOF were recorded on a LDI-1700 instrument.

*4-Methoxyphenyl 2,3,4-tri-*O*-benzyl-β-*D*-galactopyranoside* (**4**) *and 4-methoxyphenyl 2,3,4-tri-*O*-benzyl-6-*O*-formyl-β-*D*-galactopyranoside* (**5**).—4-Methoxyphenyl 2,3,4-tri-*O*-benzyl-6-*O*-trityl-β-D-galactopyranoside (**3**, 8.5 g, 10.6 mmol) was dissolved in 1:1 Et_2O–formic acid (80 mL) and stirred at rt for 8 h. After dilution with Et_2O (200 mL), the mixture was washed with water (5 × 30 mL) and the aqueous phase back-extracted with Et_2O. The organic phase was combined and washed with satd $NaHCO_3$, and dried with $MgSO_4$. After concentration, the residue was dissolved in 1:1 $CHCl_3$–MeOH (70 mL) and NaOMe (300 mg) was added. The mixture was stirred at rt for 1 h, and then neutralized with cationic resin (H^+). The solution was concentrated and the residue purified with silica-gel chromatography (4:1 acetone–light petroleum) to give compound **4** as white needles (4.5 g, 80%), mp 123–125 °C, $[\alpha]_D$ −20.5° (*c* 0.39, CH_2Cl_2); R_f 0.35 (1:3 acetone–light petroleum); ^{1}H NMR (400 MHz, $CDCl_3$): 7.26–7.35 (m, 15 H, ArH), 6.76–6.97 (4 H, AA′BB′, Mp), 4.64–5.00 (m, 7 H, 3 × PhC*H*$_2$ and H-1), 4.07 (dd, 1 H, *J* 9.70, 7.70 Hz, H-2), 3.74–3.79 (m, 2 H), 3.73 (s, 3 H, OC*H*$_3$), 3.57 (m, 1 H, H-6b), 3.42–3.49 (m, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): 151.2, 151.4 (C-1 and C-4, Mp), 138.5, 138.3, 138.2, 128.6, 128.5, 128.3, 128.2, 128.0, 127.8, 127.6 (Ar-C), 118.3 (2 C, Mp), 114.5 (2 C, Mp), 102.9 (C-1), 82.2, 79.3, 75.4, 74.9, 74.2, 73.4, 72.7 (C-2,3,4,5 and O*C*H$_2$Ph), 61.9 (C-6), 55.7 (OCH$_3$). Anal. Calcd for $C_{34}H_{36}O_7$: C, 73.40; H, 6.47. Found: C, 73.15; H, 6.49.

If the crude product was not treated with NaOMe, a noticeable amount of formylated product **5** could be separated by column chromatography as white needles, mp 113–114 °C, $[\alpha]_D$ −10.1° (*c* 1.19, CH_2Cl_2); R_f 0.48 (1:3 acetone–light petroleum); ^{1}H NMR (300 MHz, $CDCl_3$): 7.91 (s, 1 H, *H*COO), 7.28–7.36 (m, 15 H, Ar-H), 6.78–7.01 (AA′BB′, 4 H, Mp), 4.65–5.04 (m, 7 H, 3 × PhC*H*$_2$ and H-1), 4.30–4.36 (m, 1 H, H-6a), 4.07–4.1 (m, 2 H), 3.81–3.85 (m, 1 H), 3.76 (s, 3 H, OC*H*$_3$), 3.58–3.66 (m, 2 H); ^{13}C NMR (75 MHz, $CDCl_3$) 160.4 (H*C*OO), 155.3, 151.5 (C-1 and C-4, Mp), 138.4, 138.2, 138.0, 128.5, 128.4, 128.2, 127.8, 127.7, 127.6 (Ar-C), 118.6 (2 C, Mp), 114.5 (2 C, Mp), 103.2 (C-1), 82.0, 79.1, 75.4, 74.4, 73.5, 72.8, 72.2 (C-2,3,4,5 and Ph*C*H$_2$), 62.7 (C-6), 55.6 (O*C*H$_3$). Anal. Calcd for $C_{35}H_{36}O_8$: C, 71.93; H, 6.16. Found: C, 71.79; H, 6.25.

4-Methoxyphenyl (2,3,4,6-tetra-O-*acetyl-β*-D-*galactopyranosyl)-(1→4)-(2,3,6-tri*-O-*acetyl-β*-D-*glucopyranosyl)-(1→6)-2,3,4-tri*-O-*benzyl-β*-D-*galactopyranoside* (**6**) *and 4-methoxyphenyl 6*-O-*acetyl-2,3,4-tri*-O-*benzyl-β*-D-*galactopyranoside* (**7**).—Compound **5** (3.0 g, 5.42 mmol) was dissolved in CH_2Cl_2 (50 mL), and powdered molecular sieve (3.5 g) was added. After being stirred at rt for 3 h, the mixture was cooled to 0 °C and Ag_2CO_3 (6.0 g), and AgOTf (3.5 g) were added successively. The peracetylated lactosyl bromide (10.0 g) dissolved in CH_2Cl_2 (25mL) was then added dropwise. the mixture was kept at 0 °C for 2 h and stirred overnight at rt. After dilution with CH_2Cl_2 and filtration through Celite, the filtrate was washed successively with satd $NaHCO_3$, 10% $Na_2S_2O_3$, water, and satd NaCl. The solution was dried, concentrated, and the residue purified with column chromatography (1:1 light petroleum–EtOAc) to afford the title compound **6** as a white foam (5.3 g, 83%), mp 88–90 °C, $[\alpha]_D$ −9.64° (*c* 0.83, CH_2Cl_2); R_f 0.26 (1:1 light petroleum–EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): 7.26–7.37 (m, 15 H, ArH), 6.95 (AA′BB′, 4 H, OMp), 3.58–5.34 (30 H, m, sugar H, 3 × PhCH$_2$, OCH$_3$), 2.14 (s, 3 H, OAc), 2.05 (s, 6 H, 2 × OAc), 2.04 (s, 6 H, 2 × OAc), 1.96 (s, 3 H, OAc), 1.89 (s, 3 H, OAc); ^{13}C NMR (75 MHz, $CDCl_3$): 170.2, 170.0, 169.5, 169.0 (C=O), 155.2, 151.5 (C-1 and C-4, Mp), 138.4, 138.2, 138.2, 128.4, 128.3, 128.3, 128.2, 128.2, 127.7, 127.7, 127.6, 127.5 (Ar-C), 117.9, 114.6 (2 C each, Mp), 102.8 (C-1), 100.9, 100.1 (C-1′, C-1″), 81.7, 79.1, 76.1, 75.3, 74.9, 74.3, 73.4, 73.2, 72.7, 72.4, 71.8, 70.9, 70.6, 69.0, 68.7, 66.5, 61.9, 60.7 (sugar C and PhCH$_2$), 55.6 (OCH$_3$), 20.7, 20.6, 20.5, 20.5, 20.4, 20.4 (*C*H$_3$CO); MALDI-TOF: 1197.4 [M + Na]$^+$, 1213.4 [M + K]$^+$. Anal. Calcd for $C_{60}H_{70}O_{24}$: C, 61.30; H, 6.01. Found: C, 60.95; H, 5.88.

The acetylated glycosyl acceptor **7** was also separated as byproduct, R_f 0.62 (1:1 light petroleum–EtOAc), $[\alpha]_D$ −8.51° (*c* 0.94, CH_2Cl_2); ^{1}H NMR (300 MHz, $CDCl_3$): 7.24–7.39 (m, 15 H, ArH), 6.92 (AA′BB′, 4 H, OMp), 3.60–5.06 (m, 13 H), 3.77 (s, 3 H, OCH$_3$), 1.98 (s, 3 H, CH$_3$CO).

4-Methoxyphenyl (3,4-O-*isopropylidene-β*-D-*galactopyranosyl)-(1→4)-(β*-D-*glucopyranosyl)-(1→6)-2,3,4-tri*-O-*benzyl-β*-D-*galactopyranoside* (**8**).—Compound **6** (4.0 g, 3.4 mmol) was dissolved in MeOH (30 mL), and 1 M NaOMe–MeOH (3 mL) was added dropwise. The mixture was stirred overnight at rt. After neutralization with cationic resin (H^+), the solution was concentrated and toluene evaporated from the residue. 2,2-Dimethoxypropane (40 mL) and CSA (30 mg) were added to the residue and the mixture was stirred for 24 h at rt. The clear solution so obtained was neutralized with a few drops of Et_3N and concentrated. Methanol (40 mL) and water (4 mL) were added to the residue and the mixture was refluxed for 6 h. The solution was concentrated, toluene evaporated from it, and the residue was purified by column chromatography to afford the title compound as white foam (2.2 g, 71%), mp 102–104 °C, $[\alpha]_D$ −40.91° (*c* 0.88, CH_2Cl_2); R_f 0.21 (1:1 $CHCl_3$–MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): 7.20–7.28 (m, 15 H, ArH), 6.82 (AA′BB′, 4 H, Mp), 3.15–4.88 (m, 30 H), 1.38 (s, 3 H, C*Me*$_2$),1.20 (s, 3 H, C*Me*$_2$); ^{13}C NMR (75 MHz, $CDCl_3$): 154.8, 151.3 (C-1 and C-4, Mp), 138.3, 138.3, 128.3, 128.2, 128.1, 127.5, 127.3 (Ar-C), 118.1, 114.5 (2 C each, OMp), 110.2 [(CH$_3$)$_2$*C*], 102.7, 102.3, 102.2 (C-1, C-1′, C-1″), 81.8, 80.3, 79.2, 79.0, 76.6, 75.2, 74.9, 74.3, 74.0, 73.7, 73.2, 73.0, 68.5, 61.8, 61.4 (sugar C and Ph*C*H$_2$), 55.5 (OCH$_3$), 26.9, 26.1 [(*C*H$_3$)$_2$C]; MALDI-TOF: 943.6 [M + Na]$^+$, 960.1 [M + K]$^+$. Anal. Calcd for $C_{49}H_{60}O_{17}$: C, 63.93; H, 6.51. Found: C, 63.68; H, 6.48.

4-Methoxyphenyl (2,6-di-O-*benzoyl-3,4*-O-*isopropylidene-β*-D-*galactopyranosyl)-(1→4)-(2,6-di*-O-*benzoyl-β*-D-*glucopyranosyl)-(1→6)-2,3,4-tri*-O-*benzyl-β*-D-*galactopyranoside* (**9**) *and 4-methoxyphenyl (2,6-di*-O-*benzoyl-3,4*-O-*isopropylidene-β*-D-*galactopyranosyl)-(1→4)-(2,3,6-tri*-O-*benzoyl-β*-D-*glucopyranosyl)-(1→6)-2,3,4-tri*-O-*benzyl-β*-D-*galactopyranoside* (**10**).—Compound **8** (600 mg, 0.65 mmol) was dissolved in toluene (6 mL) and pyridine (4.5 mL), and then cooled to 0 °C, and benzoyl chloride (600 μL) was added dropwise. The mixture was stirred at 0 °C for 3 h, and MeOH (1 mL) was added to quench the reaction. After dilution with EtOAc (50 mL), the solution was successively washed with cold 1 M H_2SO_4, satd $NaHCO_3$, and water, dried with $MgsO_4$ and then concentrated. The residue was purified by column chromatography to afford compound **9** as white foam (570 mg, 65.4%), mp 96–98 °C, $[\alpha]_D$ +15.69° (*c* 0.51, CH_2Cl_2); R_f 0.40 (2.5:1 cyclohexane–EtOAc); IR: 3460 cm^{-1} (–OH); ^{1}H NMR (400 MHz, $CDCl_3$): 7.15–8.04 (m, 35 H, ArH), 6.86 (AA′BB′, 4 H, OMp), 5.35 (t, 1 H, *J* 7.80 Hz, H-2′), 5.18 (dd, 1 H, H-2″), 4.93, 4.91, 4.75, 4.70 (ABq, 2 H, PhC*H*$_2$), 4.79 (dd, 1 H, H-5′), 4.80, 4.75, 4.58, 4.56 (ABq, 2 H, PhC*H*$_2$), 4.60–4.68 (m, 3 H, H-1, H-1′,

H-1″), 4.42–4.49 (ABq, 2 H, PhCH_2), 4.37–4.40 (m, 2 H, H-6′), 4.26–4.27 (m, 3 H, H-3, H-4, H-6a″), 4.00–4.25 (m, 1 H, H-6b″), 3.89–3.94 (m, 2 H, H-2, H-3″), 3.76 (s, 3 H, OCH_3), 3.71–3.75 (m, 4 H, H-4, H-4″, H-6), 3.57–3.58 (m, 1 H, H-5″), 3.41–3.43 (m, 1 H, H-5′), 3.35 (dd, 1 H, $J_{3,4}$ 2.89, $J_{2,3}$ 9.78 Hz, H-3), 1.63, 1.35 [2 s, 6 H, C(CH_3)$_2$]; ^{13}C NMR (100 MHz, $CDCl_3$): 166.5, 165.5, 165.3, 165.2 (Ph*C*O), 155.3, 151.5 (C-1 and C-4, Mp), 138.3, 133.1, 129.9, 129.8, 129.8, 129.7, 129.6, 129.6, 129.1, 128.8, 128.4, 128.4, 128.4, 128.3, 128.3, 128.2, 128.2, 128.1, 127.6, 127.5, 127.5, 127.4 (Ar-C), 118.9, 114.5 (2 C each, Mp), 111.2 [(CH$_3$)$_2$*C*], 103.3 (C-1), 101.5 (C-1′), 100.5 (C-1″), 82.2 (C-4″), 81.9 (C-3), 78.9 (C-2), 75.3 (Ph*C*H$_2$), 74.5 (Ph*C*H$_2$), 74.1(C-5), 73.4 (C-3″), 73.4 (C-4), 73.2 (C-3′), 73.0 (C-2′), 73.0 (C-2″), 72.8 (Ph*C*H$_2$), 72.1 (C-4′, C-5″), 67.8 (C-6), 63.7 (C-6′, C-5′), 62.4 (C-6″), 55.6 (OCH_3), 27.6, 26.3 [(*C*H$_3$)$_2$C]; MALDI-TOF: 1358.9 $[M+Na]^+$, 1375.4 $[M+K]^+$. Anal. Calcd for $C_{77}H_{76}O_{21}$: C, 69.15; H, 5.73. Found: C, 68.89; H, 5.91.

The perbenzoylated product (**10**, 110 mg) was also obtained as a colorless syrup, $[\alpha]_D$ +25.23° (*c* 1.11, CH_2Cl_2); R_f 0.48 (2.5:1 cyclohexane–EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): 7.17–8.08 (m, 40 H, ArH), 6.96 (AA′BB′, 4 H, Mp), 5.65 (t, 1 H, *J* 9.48 Hz, H-3′), 5.38 (dd, 1 H, *J* 7.99, 9.58 Hz, H-2′), 5.12 (t, 1 H, *J* 7.19 Hz, H-2″), 4.53–4.96 (m, 10 H, 3 × PhCH_2, H-1, H-1′, H-1″, H-6a′), 4.44–4.50 (m, 1 H, H-6b′), 4.18–4.23 (m, 3 H, H-3″, H-4′, H-6a), 4.04–4.06 (m, 1 H, H-6b), 3.94–3.96 (m, 1 H, H-2), 3.80 (s, 3 H, OCH_3), 3.64–3.79 (m, 6 H, H-4, H-5, H-4″, H-5″, H-6a″, H-5′), 3.390–3.393 (m, 1 H, H-6b″), 3.38–3.39 (dd, 1 H, H-3), 1.51, 1.24 (2s, 6 H, C*Me*$_2$); ^{13}C NMR (100 MHz, $CDCl_3$): 165.9, 165.8, 165.4, 165.2, 164.9 (Ph*C*O), 155.5, 151.3 (Mp), 138.4, 138.3, 138.2, 133.4, 133.2, 132.9, 129.9, 129.8, 129.8, 129.7, 129.6, 129.5, 129.5, 129.3, 129.2, 128.7, 128.5, 128.4, 128.3, 128.3, 128.2, 128.1, 128.1, 127.6, 127.5, 127.4 (Ar-C), 118.7, 114.6 (2 C each, Mp), 110.8 [(CH$_3$)$_2$*C*], 103.0 (C-1), 100.5, 100.1 (C-1′, C-1″), 81.8, 78.9, 75.3, 75.2, 74.4, 74.4, 73.5, 73.3, 73.1, 72.9, 72.9, 72.6, 72.0, 71.3, 67.9, 62.8, 62.4 (sugar C and Ph*C*H$_2$), 55.7 (OCH_3), 27.4, 26.9 [(*C*H$_3$)$_2$C]. Anal. Calcd for $C_{84}H_{80}O_{22}$: C, 69.99; H, 5.59. Found: C, 69.64; H, 5.45.

4-Methoxyphenyl (2,6-di-O-*benzoyl-3,4*-O-*isopropylidene*-*β*-D-*galactopyranosyl)*-*(1→4)*-O-*[(2,3,4-tri*-O-*benzyl*-*α*-L-*fucopyranosyl)*-*(1→3)*-*2,6-di*-O-*benzoyl*-*β*-D-*glucopyranosyl)*-*(1→6)*-*2,3,4-tri*-O-*benzyl*-*β*-D-*galactopyranoside* (**11**).—Compound **9** (1.3 g, 1 mmol), ethyl 2,3,4-tri-*O*-benzyl-1-thio-β-L-fucopyranoside (1.8 g, 3.8 mmol), and 2,6-di-*t*-butyl-4-methylpyridine (205 mg) were dissolved in 1,2-dichloroethane (20 mL) and DMF (4 mL), powdered 4 Å molecular sieves (2.5 g) were added, and the mixture was stirred at rt for 5 h. Tetrabutylammonia bromide (1.9 g, 6 mmol), and $CuBr_2$ (1.3 g, 6 mmol) were added, and the mixture was stirred continuously for 30 h, and then diluted with CH_2Cl_2.The precipitate was filtered off and the filtrate was successively washed with satd $NaHCO_3$, water, and satd NaCl solution, dried with $MgSO_4$ and then concentrated. The crude product was purified by column chromatography (2:3:1.5 cyclohexane–toluene–EtOAc) to afford **11** as a white foam (1.3 g, 70.8%), mp 94–96 °C, $[\alpha]_D$ +25.6° (*c* 1.25, CH_2Cl_2); R_f 0.60 (2:3:1.5 cyclohexane–toluene–EtOAc), ^{1}H NMR (400 MHz, $CDCl_3$): 6.79–8.13 (m, 54 H, Ar-H), 5.38–5.41 (m, 2 H, H-2′, Fuc H-1), 5.23 (t, 1 H, H-2″), 4.88–4.94 (m, 3 H, PhCH_2, Fuc H-5), 4.73–4.79 (m, 5 H, 2 × PhCH_2, H-6a″), 4.55–4.64 (m, 3 H, H-1 and PhCH_2), 4.43–4.49 (m, 6 H, H-1′, H-1″, H-6′and PhCH_2), 4.24–4.32 (m, 2 H, H-4 and H-6b″), 4.12–4.22 (m, 5 H, H-3, H-3′, H-3″, PhCH_2), 4.08 (t, 1 H, H-4′), 3.88–3.91 (m, 2 H, H-2, Fuc H-2), 3.73–3.79 (m, 4 H, H-4, H-5″, H-6b, Fuc H-4), 3.72 (s, 3 H, OCH_3), 3.60–3.64 (m, 1 H, H-6a), 3.30–3.32 (m, 1 H, H-5′), 3.27–3.30 (m, 2 H, H-5, Fuc H-3), 1.50, 1.30 [2 s, 6 H, C(CH_3)$_2$], 1.32 (d, 3 H, Fuc H-6); ^{13}C NMR (100M Hz, $CDCl_3$): 166.1, 165.9, 164.7 (Ph*C*O), 155.4, 151.4 (C-1 and C-4, Mp), 139.1, 138.7, 138.4, 138.3, 138.3, 138.1, 137.8, 133.5, 133.4, 133.4, 129.8, 129.7, 129.6, 129.5, 129.4, 129.3, 129.2, 129.1, 128.9, 128.7, 128.6, 128.6, 128.5, 128.2, 128.2, 128.2, 128.1, 128.1, 128.0, 128.0, 127.7, 127.5, 127.4, 127.4, 127.4, 127.3, 126.9, 126.7, 125.2 (Ar-C), 118.9, 114.4 (2 C each, Mp), 110.8 [(CH$_3$)$_2$*C*], 103.2 (C-1), 101.0, 100.1 (C-1′, C-1″), 97.4 (Fuc C-1), 81.7 (Fuc C-3), 79.1 (C-3″), 78.8 (C-2), 78.2 (C-4), 77.2 (C-3′), 75.5 (Fuc C-2), 75.2 (Ph*C*H$_2$), 74.9 (Ph*C*H$_2$), 74.8 (C-2′), 74.7 (C-4′), 74.4 (Ph*C*H$_2$), 73.9 (C-3), 73.6 (C-5), 73.3 (Ph*C*H$_2$), 73.2 (C-5′), 73.1 (C-2″), 73.0 (Fuc C-4), 72.6 (Ph*C*H$_2$), 72.5 (C-4″and Ph*C*H$_2$), 71.4 (C-5″), 67.4 (C-6), 66.4 (Fuc C-5), 62.6 (C-6″), 62.2 (C-6′), 55.7 (OCH_3), 27.7, 26.2 [(*C*H$_3$)$_2$C], 16.8 (Fuc C-6); MALDI-TOF: 1775.2 $[M+Na]^+$, 1790.9 $[M+K]^+$. Anal. Calcd for $C_{104}H_{104}O_{25}$: C, 71.22; H, 5.98. Found: C, 71.20; H, 5.94.

(2,3,4-Tri-*O*-benzyl-α-L-fucopyranosyl) 2,3,4-tri-*O*-benzyl-β-L-fucopyranoside (**12**, 190 mg) was also separated as a colorless syrup, $[\alpha]_D$ −24.78° (*c* 1.36, CH_2Cl_2); R_f 0.75 (2:3:1.5 toluene–cyclohexane–EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): 7.16–7.31 (m, 30 H, ArH), 5.20 (d, 1 H, $J_{1,2}$ 3.31 Hz, Fuc α H-1), 4.60–5.08 (m, 12 H, 6 × PhCH_2), 4.50 (d, 1 H, $J_{1,2}$ 7.83 Hz, Fuc β H-1), 4.30 (m, 1 H, Fuc α H-5), 4.02–4.11 (m, 2 H, Fuc α H-2, Fuc α H-4), 3.82–3.86 (m, 1 H, Fuc β H-2), 3.65 (br, 1 H, Fuc α H-3), 3.44–3.51 (m, 3 H, Fuc β H-3, β H-4, β H-5), 1.05–1.10 (m, 6 H, Fuc α H-6, Fuc β H-6); ^{13}C NMR (100 MHz, $CDCl_3$): 139.0, 138.8, 138.7, 138.5, 138.5, 138.4, 128.5, 128.2, 128.1, 128.1, 128.0, 127.9, 127.6, 127.5, 127.5, 127.4, 127.4, 127.3, 127.3, 127.2, 127.0 (Ar-C), 103.6 (Fuc β C-1), 99.8 (Fuc α C-1), 82.6, 78.6, 77.9, 76.0, 75.9, 74.7, 74.4, 73.2, 73.0, 72.6, 70.5, 67.1 (sugar C and Ph*C*H$_2$), 16.8 (Fuc C-6), 16.2 (Fuc C-6).

4-Methoxyphenyl (2,6-di-O-benzoyl-3,4-O-isopropylidene-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-O-acetyl-L-fucopyranosyl)-(1→3)-2,6-di-O-benzoyl-β-D-glucopyranosyl]-(1→6)-2,3,4-tri-O-acetyl-β-D-galactopyranoside (**13**).—A solution of **11** (600 mg, 0.34 mmol) in MeOH (40 mL) and 1,4-dioxane (40 mL) was stirred for 12 h at rt in the presence of a catalytic amount of 20% Pd–C under hydrogen, then filtered, and concentrated. A solution of the residue in pyridine (15 mL) and Ac_2O (10 mL) was stirred for 24 h at rt, and then cooled in an ice bath. Methanol (10 mL) was added and after stirring for 0.5 h, the mixture was concentrated and coevaporated with benzene twice to afford the title compound. The crude product (360 mg, 71.8%) was used in the next step without further purification. Preparative TLC was performed to obtain a sample for NMR analysis. $[\alpha]_D$ −45.3° (*c* 0.5, CH_2Cl_2); R_f 0.31 (2:1 cyclohexane–acetone); ^{1}H NMR (400 MHz, $CDCl_3$): 7.27–8.11 (m, 20 H, ArH), 6.78–6.83 (AA′BB′, 4 H, Mp), 5.25–5.40 (m, 7 H, H-2, H-4, H-2′, H-2″, Fuc H-1, Fuc H-3, Fuc H-4), 5.14–5.16 (m, 1 H, Fuc H-5), 5.02–5.10 (m, 1 H, Fuc H-2), 4.90–4.94 (m, 2 H, H-3, H-6a″), 4.81 (m, 1 H, H-6b″), 4.69 (d, 1 H, $J_{1,2}$ 7.97 Hz, H-1), 4.63–4.66 (m, 1 H, H-6a′), 4.53–4.55 (m, 2 H, H-1′, H-1″), 4.42 (m, 1 H, H-6b′), 4.25–4.28 (m, 1 H, H-3″), 4.17–4.19 (m, 1 H, H-4″), 4.07–4.12 (m, 2 H, H-3′, H-4′), 3.80–4.02 (m, 1 H, H-5″), 4.77 (s, 3 H, OCH_3), 3.64–3.73 (m, 3 H, H-5, H-6), 3.45 (m, 1 H, H-5′), 2.11, 2.04, 1.96, 1.92, 1.86. 1.85 (6 s, 6 × OAc), 1.60, 1.33 [2 s, 6 H, $C(CH_3)_2$], 1.34 (d, 3 H, *J* 4.94 Hz, Fuc H-6); ^{13}C NMR (100 MHz, $CDCl_3$): 170.5, 170.0, 169.8, 169.5, 169.3, 166.2, 165.8, 164.8, 164.7 (Ph*C*O, CH_3*C*O), 155.8, 151.0 (Mp), 133.5, 133.4, 133.3, 130.3, 129.7, 129.6, 129.3, 129.2, 129.1, 129.0, 128.7, 128.6, 128.6, 128.5 (Ar-C), 118.8, 114.6 (2 C each, Mp), 111.0 [$(CH_3)_2$*C*], 100.9, 100.4, 100.3 (C-1, C-1′, C-1″), 96.3 (Fuc C-1), 77.4 (C-3′), 74.9, 74.2 (C-3), 74.2, 73.4 (C-4), 73.2 (C-4′, C-5″), 72.1 (C-5), 71.6 (C-5′), 70.6 (C-2), 68.8 (C-3″), 68.2 (Fuc C-3), 67.6, 67.0 (Fuc C-2), 66.7 (C-6″), 64.6 (Fuc C-5), 62.7 (C-6′), 61.9 (C-6), 55.7 (OCH_3), 27.7, 26.0 [(CH_3)$_2$C], 20.7, 20.6, 20.5, 20.5, 20.5, 20.4 (6 × *C*H_3CO), 16.0 (Fuc C-6).

4-Methoxyphenyl (2,6-di-O-benzoyl-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-O-acetyl-α-L-fucopyranosyl)-(1→3)-2,6-di-O-benzoyl-β-D-glucopyranosyl]-(1→6)-2,3,4-tri-O-acetyl-β-D-galactopyranoside (**14**).—Compound **13** (650 mg) was dissolved in MeOH (3 mL) and EtOAc (3 mL), and $TsOH\cdot H_2O$ (90 mg) was added. The mixture was stirred at rt for 2.5 h. After neutralization with a few drops of Et_3N, the solution was concentrated and the crude product purified by preparative TLC (2:1 cyclohexane–acetone) to afford the title compound as a white foam (450 mg, 69.2%), mp 152–154 °C, $[\alpha]_D$ −40.91° (*c* 0.88, CH_2Cl_2); R_f 0.21 (1:2 acetone–cyclohexane); ^{1}H NMR (400 MHz, $CDCl_3$): 7.26–8.14 (m, 20 H, ArH), 6.77–6.86 (AA′BB′, 4 H, OMp), 5.37–5.38 (m, 1 H, Fuc H-4), 5.25–5.33 (m, 5 H, Fuc H-3, H-2, H-4, H-2′, H-2″), 5.24 (d, 1 H, $J_{1,2}$ 4.04 Hz, Fuc H-1), 5.10–5.22 (m, 1 H, Fuc H-5), 5.03 (dd, 1 H, $J_{1,2}$ 3.97, $J_{2,3}$ 10.80 Hz, Fuc H-2), 4.94 (dd, 1 H, $J_{3,4}$ 3.47, $J_{2,3}$ 10.45 Hz, H-3), 4.86 (m, 1 H, H-6a″), 4.64–4.73 (m, 4 H, H-1, H-1″, H-6a′, H-6b″), 4.55 (d, 1 H, $J_{1,2}$ 8.01 Hz, H-1′), 4.43 (m, 1 H, H-6b′), 4.07–4.14 (m, 2 H, H-3′, H-4′), 3.97–3.98 (m, 1 H, H-4″), 3.76 (s, 3 H, OCH_3), 3.65–3.74 (s, 5 H, H-5, H-6, H-3″, H-5″), 3.59–3.61 (m, 1 H, H-5′), 2.04, 2.03, 1.97, 1.92, 1.89, 1.88 (6 s, 18 H, 6 × CH_3CO), 1.28 (d, 3 H, $J_{5,6}$ 6.54 Hz, Fuc H-6); ^{13}C NMR (100 MHz, $CDCl_3$): 170.7, 170.4, 170.0, 169.8, 169.3, 166.4, 165.9, 165.8, 164.7 (Ph*C*O and CH_3*C*O), 155.8, 151.0 (C-1 and C-4, Mp), 133.4, 133.4, 129.9, 129.8, 129.8, 129.6, 129.4, 129.3, 129.3, 129.0, 128.7, 128.6, 128.6, 128.5 (Ar-C), 118.8, 114.6 (2 C each, Mp), 100.9 (C-1″), 100.6 (C-1), 100.1 (C-1′), 96.2 (Fuc C-1), 74.8 (C-3′), 74.1, 73.4, 73.3 (C-5′), 73.3 (C-4′), 73.2 (C-5″), 72.6, 72.5, 71.5 (Fuc C-4), 70.6 (C-3), 68.8, 68.7, 68.1 (C-4″), 67.6, 67.0 (Fuc C-2), 66.6 (C-6), 64.7 (Fuc C-5), 62.1 (C-6′), 62.0 (C-6″), 55.6 (OCH_3), 20.68, 20.65, 20.54, 20.47, 20.45, 20.37 (6 × *C*H_3CO), 15.7 (Fuc C-6); MALDI-TOF: 1448.2 $[M + Na]^+$, 1464.1 $[M + K]^+$; Anal. Calcd for $C_{71}H_{76}O_{31}$: C, 59.83; H, 5.37. Found: C, 59.95; H, 5.10.

4-Methoxyphenyl (4-O-acetyl-2,6-di-O-benzoyl-β-D-galactopyranosyl)-(1→4)-O-[(2,3,4-tri-O-acety-α-L-fucopyranosyl)-(1→3)-2,6-di-O-benzoyl-β-D-glucopyranosyl]-(1→6)-2,3,4-tri-O-acetyl-β-D-galactopyranoside (**15**).—Compound **14** (400 mg) was dissolved in benzene (3 mL), and trimethyl orthoacetate (750 μL) and CSA (10 mg) were added to the solution. The mixture was stirred at rt for 0.5 h and then two drops of Et_3N added. After concentration, 80% HOAc (2.5 mL) was added to the residue and the solution was stirred at rt for 20 min. The mixture was diluted with CH_2Cl_2 (50 mL) and washed with satd $NaHCO_3$. The aqueous phase was back extracted with CH_2Cl_2 and the combined organic layer was dried with $MgSO_4$ and then concentrated. Preparative TLC (1:2 acetone–cyclohexane) of the residue gave the title compound as a white foam (370 mg, 90%), mp 156–158 °C. $[\alpha]_D$ −49.23° (*c* 0.65, CH_2Cl_2); R_f 0.35 (2:1 cyclohexane–acetone); ^{1}H NMR (400 MHz, $CDCl_3$): 7.27–8.12 (m, 20 H, ArH), 6.78–6.86 (AA′BB′, 4 H, Mp), 5.46–5.47 (m, 1 H, Fuc H-4), 5.39–5.40 (m, 1 H, H-4″), 5.24–5.33 (m, 6 H, H-2, H-4, Fuc H-1, Fuc H-3, H-2′, H-2″), 5.18 (m, 1 H, Fuc H-5), 5.05 (dd, 1 H, $J_{1,2}$ 3.94, $J_{2,3}$ 10.90 Hz, Fuc H-2), 4.94 (dd, 1 H, $J_{3,4}$ 3.38, $J_{2,3}$ 10.48 Hz, H-3), 4.68–4.75 (m, 5 H, H-1, H-1″, H-6″, H-6a′), 4.57 (d, 1 H, $J_{1,2}$ 9.81 Hz, H-1′), 4.42–4.46 (m, 1 H, H-6b′), 4.09–4.12 (m, 2 H, H-3′, H-4′), 3.93 (dd, 1 H, $J_{3,4}$ 3.58, $J_{2,3}$ 9.81 Hz, H-3″), 3.76 (s, 3 H, OCH_3), 3.65–3.75 (m, 4 H, H-5, H-6, H-5″), 3.48 (br, 1 H, H-5′), 2.22, 2.11, 2.10, 2.04, 1.96, 1.91, 1.87 (7 s, 21 H, 7 × CH_3CO), 1.36 (d, 3 H, $J_{5,6}$ 6.51 Hz, Fuc H-6); ^{13}C NMR (100 MHz,

$CDCl_3$): 171.1, 170.6, 169.9, 169.8, 169.3, 165.9, 165.8, 165.3, 164.6 (Ph*C*O and CH_3*C*O), 155.7, 150.9 (C-1 and C-4, Mp), 133.5, 133.4, 133.3, 129.8, 129.7, 129.5, 129.2, 129.0, 128.9, 128.9, 128.7, 128.6, 128.5, 128.4 (Ar-C), 118.7, 114.5 (2 C each, Mp), 100.8 (C-1″), 100.5 (C-1), 100.4 (C-1′), 96.2 (Fuc C-1), 74.6 (C-3′), 74.0, 73.8 (C-4′),73.2 (C-5′), 73.1, 72.5, 71.7, 71.3 (Fuc C-4), 71.1 (C-3″), 70.5 (C-3), 69.3 (C-4″), 68.7, 68.4 (C-2″), 67.5, 66.7 (Fuc C-2), 66.6 (C-6), 64.3 (Fuc C-5), 61.9 (C-6′), 61.3 (C-6″), 55.6 (OCH_3), 20.6, 20.6, 20.5, 20.4, 20.4, 20.4, 20.3 (7 × *C*H_3CO), 15.8 (Fuc C-6). MALDI-TOF: 1489.2 $[M + Na]^+$, 1505.3 $[M + K]^+$. Anal. Calcd for $C_{73}H_{78}O_{32}$: C, 59.75; H, 5.36. Found: C, 59.47; H, 5.19.

*4-Methoxyphenyl (4-*O*-acetyl-2,6-di-*O*-benzoyl-3-*O*-sulfo-β-*D*-galactopyranosyl)-(1→4)-[(2,3,4-tri-*O*-acetyl-α-*L*-fucopyranosyl)-(1→3)-2,6-di-*O*-benzoyl-β-*D*-glucopyranosyl]-(1→6)-2,3,4-tri-*O*-acetyl-β-*D*-galactopyranoside triethylammonium salt* (**16**).—A mixture of (60 mg, 0.041 mmol) and pyridine–sulfur trioxide complex (40 mg) in DMF (0.5 mL) was stirred at rt for 3 h. A few drops of Et_3N were added and the solvent was removed below 40 °C in a vacuum. The residue was purified by preparative TLC to afford the title compound as an amorphous solid mass (70 mg, quantitative yield), $[\alpha]_D$ −43.2° (*c* 0.37, CH_2Cl_2); ^{1}H NMR (400 MHz, $CDCl_3$): 5.81 (br, 1 H, H-3″), 5.44 (br, 1 H, Fuc H-4), 5.25–5.33 (m, 6 H, Fuc H-1, H-3, H-2, H-4, H-2″, H-4″), 5.20–5.21 (m, 1 H, Fuc H-5), 5.04 (dd, 1 H, $J_{1,2}$ 3.76, $J_{2,3}$ 10.86 Hz, Fuc H-2), 4.96 (dd, 1 H, $J_{3,4}$ 3.26, $J_{2,3}$ 10.22 Hz, H-3), 4.69–4.85 (m, 6 H, H-1, H-1″, H- 2″, H-6″, H-6a′), 4.53 (d, 1 H, *J* 7.95 Hz, H-1′), 4.21–4.24 (m, 1 H, H-6b′), 4.00–4.14 (m, 3 H, H-3, H-4′, H-5″), 3.76 (s, 3 H, OCH_3), 3.57–3.69 (m, 3 H, H-5, H-6), 3.41–3.43 (br, 1 H, H-5′), 2.83–2.94 [q, *J* 7.43 Hz, $(CH_3CH_2)_3N$], 2.11 (s, 6 H, 2 × CH_3CO), 2.05 (s, 3 H, C*H*$_3$CO), 1.92 (s, 6 H, 2 × C*H*$_3$CO), 1.86 (s, 3 H, C*H*$_3$CO), 1.82 (s, 3 H, C*H*$_3$CO), 1.35 (d, 3 H, $J_{5,6}$ 6.25 Hz, Fuc H-6), 1.11 [t, *J* 7.29 Hz, $(CH_3CH_2)_3N$]; ^{13}C NMR (100 MHz, $CDCl_3$): 170.6, 169.9, 169.8, 169.78, 169.73, 169.32, 166.0, 165.5, 164.7 (Ph*C*O, CH_3*C*O), 155.8, 151.0 (C-1 and C-4, Mp), 114.6 (2 C, Mp), 100.83 (C-1″), 100.8 (C-1), 100.39 (C-1′), 96.2 (Fuc C-1), 75.1, 74.6, 74.0, 73.5, 73.2, 71.8, 71.4, 70.6, 70.1, 68.9, 68.6, 67.6, 66.8, 66.6, 64.4, 61.6, 60.3 (sugar C), 55.6 (OCH_3), 46.3 $[CH_3CH_2]_3N$], 20.8, 20.7, 20.6, 20.5, 20.5, 20.4, 20.3 (7 × *C*H_3CO), 15.8 (Fuc C-6), 8.4 [(*C*$H_3CH_2)_3N$]; MALDI-TOF: 1544.0 $[M - NH(C_2H_5)_3]^+$.

*4-Methoxyphenyl (3-*O*-sulfo-β-*D*-galactopyranosyl)-(1→4)-*O*-[(α-*L*-fucopyranosyl)-(1→3)-β-*D*-glucopyranosyl]-(1→6)-β-*D*-galactopyranoside sodium salt* (**17**).—Compound **16** (60 mg, 0.08 mmol) was dissolved in abs MeOH (1 mL) and then 0.5 M NaOMe solution (0.45 mL) was added. The mixture was stirred at rt for 20 h. A few drops of water was added and the solvent was removed below 40 °C in a vacuum. The residue was dissolved in water (2 mL) and then purified by column chromatography on Sephadex G-10. After lyophilization, the title compound was obtained as a white amorphous solid mass (20 mg, 64.5%), $[\alpha]_D$ −72.7° (*c* 0.11, water); ^{1}H NMR (400 MHz, D_2O): 5.45 (d, 1 H, $J_{1,2}$ 4.00 Hz, Fuc H-1), 5.00 (d, 1 H, $J_{1,2}$ 7.20 Hz, H-1), 4.49–4.54 (m, 2 H, H-1′, H-1″), 4.32 (dd, 1 H, $J_{3,4}$ 3.20, $J_{2,3}$ 10.00 Hz, H-3″), 4.07–4.27 (m, 1 H, Fuc H-3), 4.02–4.07 (m, 3 H, H-4, H-6a, H-6a″), 3.95–3.99 (m, 3 H, Fuc H-3, H-5, H-6b″), 3.88 (t, 1 H, *J* 9.20 Hz, H-4′), 3.83 (s, 3 H, OCH_3), 3.71–3.81 (m, 8 H, Fuc H-2, H-2′, H-3′, H-6′, H-5″, H-2, H-6b, H-4), 3.62–3.65 (m, 2 H, H-2″, H-4″), 3.54 (t, 3 H, *J* 8.00 Hz, H-2′), 3.42–3.46 (m, 1 H, H-5′), 1.19 (d, 3 H, $J_{5,6}$ 6.80 Hz, Fuc H-6); ^{13}C NMR (100 MHz, D_2O): 155.5, 151.7 (C-1 and C-4, Mp), 119.0 (2 C, Mp), 115.9 (2 C, Mp), 103.1 (C-1′), 102.3 (C-1″), 102.2 (C-1), 99.2 (Fuc C-1), 81.0 (C-3″), 77.7, 76.0 (C-5″), 75.5 (2 C, C-2, C-4″), 75.0 (C-4), 73.7, 73.3, 72.8, 71.4, 70.1 (C-2″), 69.7 (C-6″), 69.6, 68.9 (C-4′), 67.5 (Fuc C-3), 67.3 (Fuc C-5), 62.2 (C-6′), 60.5 (C-6), 56.8 (OCH_3), 16.1 (Fuc C-6); MALDI-TOF: 834.2 $[M - Na]^+$.

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