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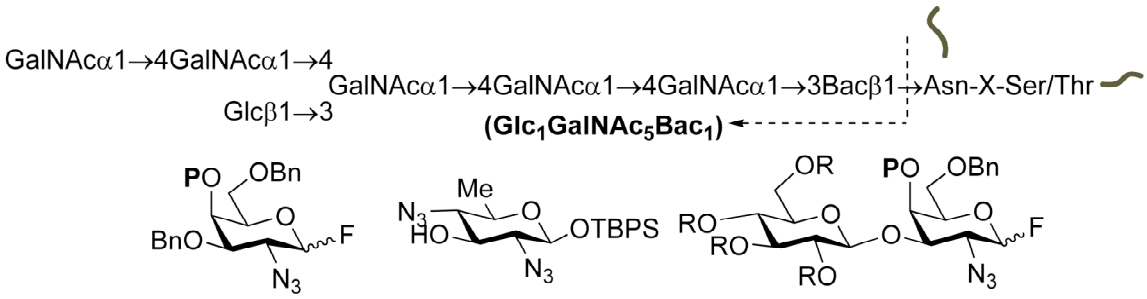

Synthesis of *N*-linked glycan derived from Gram-negative bacterium, *Campylobacter jejuni*

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Abstract—Recent research has revealed the presence of asparagine (Asn)-linked (*N*-linked) glycoproteins in certain prokaryotes. In this paper, we describe the chemical synthesis of a novel *N*-glycan derived from *C. jejuni*, a heptasaccharide composed of Asn-linked bacillosamine (Bac), repeating GalNAc and branching Glc, namely GalNAc-α(1,4)-GalNAc-α(1,4)-[Glc-β(1,3)-]GalNAc-α(1,4)-GalNAc-α(1,4)-GalNAc-α(1,3)-Bac. The synthesis started from a Bac acceptor, which was consecutively glycosylated with 4-*O*-pentafluoropropionyl (PFP) protected donors to give heptasaccharide. Reduction of azide groups was followed by debenzylation to complete the synthesis of the target oligosaccharide.

Keywords: bacterial *N*-glycan; *Campylobacter jejuni*; stereoselective 1,2-cis glycosylation; heptasaccharide.

1. Introduction

N-Glycans found in eukaryotic glycoproteins share a well-conserved core structure $Man_3GlcNAc_2$.[1] They are first introduced in the endoplasmic reticulum (ER) to an asparagines (Asn) residue as a tetradecasaccharide $Glc_3Man_9GlcNAc_2$ of the Asn-Xaa-Thr/Ser motif by oligosaccharyltransferase (OST).[2] Contrary to previous belief, recent research has revealed that certain prokaryotes produce *N*-glycosylated proteins.[3]

A major non-flagellin antigenic glycoprotein designated PEB3 or Cj0289c has been identified in the pathogenic Gram-negative bacterium *Campylobacter jejuni*.[4] This glycoprotein has multiple glycosylation sites, which carry *N*-linked glycans.[5] Recent research has revealed that the presence of an acidic amino acid at –2 position of Asn is required for the *N*-glycosylation in this microbe.[6] Their glycan chain is composed of an Asn-linked rare sugar bacillosamine (2,4-diacetamido-2,4,6-trideoxyglucose; Bac), pentameric α1→4 linked *N*-acetylgalactosamine (GalNAc) and a β-linked glucose (Glc) (**Fig. 1**).

In spite of its distinct structure, the manner *C. jejuni N*-glycan is incorporated to nascent polypeptide is strikingly similar to that of eukaryotes. In both cases, lipid-linked oligosaccharides are used as donors. Namely, preassembled Und-P-P-CHO (Und: undecaprenyl, CHO: $GalNAc_5GlcBac$, *C. jejuni*) or Dol-P-P-CHO (Dol: dolichyl, CHO: $Glc_3Man_9GlcNAc_2$,

eukaryotes), conveys CHO to nascent polypeptides, under the control of oligosaccharyl transferase (OST).[7] Recent research by Aebi et al. revealed that *C. jejuni* OST (PglB) glycosylation machinery has a relaxed specificity, which would allow researchers to produce *N*-linked glycoproteins with various glycans.[8] For instance, in vitro assembly of Und-P-P-linked glycoconjugate[9] and chemoenzymatic synthesis of glycopeptide by PglB[10] has been reported by Imperiali et al.

The presence of the *N*-linked glycan on the surface of *C. jejuni* was shown to play a key role in enteric adhesion to host cells,[11] and this adhesion constitutes the first step of virulence.[12] Besides causing gastroenteric disorder, *Campylobacter jejuni* infection is suggested to be involved in neuromuscular paralysis, Guillian Barré syndrome (GBS).[13]

In our earlier reports, we described the syntheses of key components of the *C. jejuni N*-glycan; hexasaccharide $Glc_1GalNAc_5$[14] and Asn-linked Bac.[15] Now, we report herein the synthesis of the full glycan structure $Glc_1GalNAc_5Bac_1$. It features the use of di-azido-trideoxyglucose derivative **2** as a masked Bac, and stereoselective α-glycosylation by 4-*O*-PFP protected GalN donors **3** (GalN) and **4** (Glc-GalN) (**Fig. 1**). All of the key components **2**, **3** and **4** are obtainable from 2-azido-galactose **1**[16] as a common precursor, which in turn can be prepared from galactose in large quantity.

[Fig. 1]

2. Results and Discussion

2-1. Synthetic design

Various approaches have been explored to facilitate the formation of α-glycosidic linkages of 2-amino hexopyranoses, such as GalNAc or *N*-acetylglucosamine (GlcNAc).[17-21] Among them, the use of 2-azido-2-deoxy-Gal/Glc derivatives[17] has been employed most extensively. The target heptasaccharide consists of five α-1,4-linked GlaNAc repeats, thus requiring glycosyl donor specifically protected at 4-*O*-position. Our previous work revealed that the pentafluoropropionyl (PFP) group[22] was suitable as a temporary protective group for this purpose. Namely, glycosylation with 4-*O*-PFP protected donors proceeded in a highly α-selective manner. In addition, deprotection of PFP proceeded under extremely mild conditions, with complete preservation of *O*-Ac groups.

With complete hexasaccharide fragment **7a** in place,[14] our initial attempt was directed to its coupling with Bac component. To that end, compound **7a** was converted to the corresponding fluoride **7c** through desilylation and fluorination. However, its coupling with **2** turned out to be

inefficient, giving **8** in modest yield (39%) and low stereoselectivety (α:β = 3.5:1) (**Scheme 1**). This result prompted us to redesign the synthetic route as depicted in **Fig. 1**. Thus, starting with the Bac component **2**, chain elongation with GalN (**3**, x2) and Glc-GalN (**4**) donors was expected to give the pentasaccharide **5**. Further coupling with **3** (x2) should complete the assembly of the heptasaccharide **6**.

[Scheme 1]

2-2. Glycosylation of the GalNAc donor with Bac component

Our previous work[14] revealed that the use of $AgClO_4$–Cp_2HfCl_2[23] in $CHCl_3$ was suitable for the α-selective glycosylation with 4-*O*-PFP protected donor **3a**. For instance, coupling with **10** proceeded in high yield (92%) and selectivity (α:β = 15.7:1) under these conditions.[14] Unexpectedly, however, coupling of the same donor with the diazide **2** proceeded only in modest yield and low selectivity (**Table 1**, entry 1). A substantial improvement (63%, α:β = 8.1:1) was observed, when the solvent was switched to benzene (entry 5). The yield was further increased (83%) by changing the proportion of $AgClO_4$:Cp_2HfCl_2 to 4:1 (entry 6). A similar result was obtained with an anomeric mixture of **3a** (entry 7).

[Table 1]

The effect of the nature of 4-*O* protective group was examined as summarized in **Table 1**. Preparation of Ac (**3b**), 2-naphthylmethyl (NAP, **3c**), 4-methoxybenzoyl (MBz, **3e**), 3,5-dimethoxybenzoyl (DMBz, **3f**), and 3,4,5-trimethoxybenzoyl (TMBz, **3g**) protected donors were prepared (**Scheme 2**). Interestingly, TMBz group (**3g**) gave the product with highest α-selectivity (entry 13). This result may be rationalized by remote participation from 4-position.[24] However, in this case, the separation of stereoisomers was difficult [$R_f(\alpha)$–$R_f(\beta) = 0.01$]. In addition, the deprotection of TMBz group required forcing conditions (NaOMe, MeOH, 50 °C), reflecting the steric hindrance of 4-position of GalN. It was accompanied by partial removal of the TBDPS group, and resulted in the unsatisfactory yield (43%) of 4-*O*-deprotectd product **14**. By contrast, a large difference of R_f values was observed for **13a** [$R_f(\alpha)$–$R_f(\beta) = 0.30$], making its chromatographic separation straightforward. Deprotection of PFP was extremely facile (3~5 mol% NaOMe, MeOH, r.t, <30 min) and provided **14** in quantitative yield. Considering these together, the use of **3a** was concluded to be the most practical.

Subsequent glycosylation of **14** with **3a** was performed under the conditions optimized for the coupling with **2** ($AgClO_4$-Cp_2HfCl_2, benzene), giving trisaccharide **15a** in excellent yield (98%) and selectivity (95:5). The latter was converted to **15b**, which was used for the coupling with

disaccharide donor **4** (**Scheme 3**).

[**Scheme 2**]

[**Scheme 3**]

2-4 Preparation of disaccharide donor and coupling with $(GalN)_2$Bac component .

In our previous work, we noted that glycosylation of the GlaN donor **3a** with disaccharide **16** proceeded with high selectivity (**Table 2**, entry 1), while the same reaction with disaccharide donor **4b** was sluggish and far less selective (entry 2, 3). Therefore, it was not surprising that attempted coupling between **4b** and **15b** was not efficient (entry 4).

With the hope that changing the protection of the Glc moiety might enhance the selectivity, *O*-benzylated donor **4a** and its 4^{GalN}-*O*-Ac counterpart **4c** were prepared (**Scheme 4**). To our delight, a sizable improvement was observed with **4a**, especially when the reaction was conducted in benzene (entry 6), giving **17** in reasonable yield (67%) and high selectivity (α:β = 14:1). By contrast, the selectivity was largely attenuated, when 4-*O*-acetylated donor **4c** was utilized (entry 7).

[Scheme 4]

[**Table 2**]

2-5. Completion of the synthesis

With pentasaccharide **17** in hand, further elongation of the GalN repeat was conducted, in a manner as described for **2** → **14** → **15** (**Scheme 3**). To begin with, removal of the PFP group from **17** gave **5**, which was glycosylated with **3a** to give **18** (89%). An additional round of PFP deprotection (to give **19**) and glycosylation provided the full-length heptasaccharide **21**, again in high yield (82%), which was converted to **6**. Although structural complexity precluded the rigorous estimation of the selectivity of these glycosylation steps, stereochemical homogeneity of chromatographically isolated **18** and **20** was evident from NMR analysis.

Simultaneous reduction of multiple azide groups turned out to be less straightforward than expected. Under controlled hydrogenation conditions with $Pd(OH)_2$-(*i*-Pr)$_2$NEt[25] or Lindlar catalyst[26] in MeOH, complete azide reduction required long reaction time and a large amount of a catalyst, resulting in a complex mixture. Attempted reduction with Me_3P-NaOH[27] or $LiAlH_4$ was also sluggish. Finally, we found that the smooth reduction took place by using $CoCl_2 \cdot (H_2O)_6$ and $NaBH_4$[28] in THF–H_2O (3:1), which possibly lead to the formation of active species Co_2B.[28,29]

After observing the complete formation of heptaamine **21**, immediate treatment of the reaction mixture with Ac_2O afforded the desired heptaamide **22**, which was isolated in satisfactory yield. The latter was then subjected to hydrogenolysis [H_2, $Pd(OH)_2$/C, MeOH-H_2O, 50 °C], giving completely debenzylated product as a *t*-butyldicyclohexyl glycoside **23**. Since a contamination of a small amount of cyclohexylmethyl ether caused by aromatic saturation was observed, purification was carefully conducted by reverse silica gel column (C-18) with water-methanol as an eluent, giving **23** in 42% yield.

^{1}H NMR spectrum of **23** (0.4%, w/v) was obtained in D_2O-CD_3OD (1:1) at 50 °C,[15] which clarified all anomeric signals derived from α-linked GalNAc residues ($J_{H1,2}$ = 2.8~3.6 Hz) and C1-Hs of β-linked Glc ($J_{H1,2}$ = 8.0 Hz) and Bac ($J_{H1,2}$ = 7.6 Hz) were assigned. Interestingly, higher concentration (1%, w/v) of **24** did not give assignable spectrum, due to extensive peak broadening.

3. Conclusion

We accomplished the first chemical synthesis of bacterial *N*-glycan found in pathogenic bacteria *Campylobacter jejuni*. Our synthetic routes utilized 2-azido-galactose derivative **1** as a common precursor of Bac (**2**) and GalN (**3**) components. After optimization, conditions for α-selective

glycosylation were identified for each elongation step.

4. Experimental

4.1. General procedures

All reactions sensitive to air and/or moisture were carried out under nitrogen or argon atmosphere with anhydrous solvents. Column chromatography was performed on silica gel 60N, 100-210 mesh (Kanto Kagaku Co., Ltd.). Preparative t.l.c. was performed on silica gel 60 F_{254}, 0.5 mm (E. Merck). Gel filtration was performed on Sephadex LH-20 (Pharmacia) or Bio-Beads SX-3 (Bio-Rad). All other reagents were purchased from the Wako Pure Chemical Industries Ltd., Kanto Chemicals Co. Ink., Tokyo Kasei Kogyo Co. and Aldrich Chemical Company. Melting points were determined with Büchi 510 melting point apparatus. Optical rotations were measured with a JASCO DIP 370 polarimeter. ^{1}H NMR spectra were recorded at 400 MHz on a JEOL JNM-AL 400 spectrometer and chemical shifts are referred to internal tetramethylsilane (0 ppm), $CDCl_3$ (7.24 ppm), D_2O (4.65 ppm) or CD_3OD (3.30 ppm). ^{13}C NMR spectra were recorded at 100 MHz on the same instrument and chemical shifts are referred to internal $CDCl_3$ (77.00 ppm) or CD_3OD (49.00 ppm). MALDI-TOF mass spectra were recorded on a SHIMADZU Kompact MALDI AXIMA-CFR spectrometer with 2,5-dihydroxybenzoic acid as the matrix. ESI-TOF

mass spectra were recorded on a JEOL AccuTOF JMS-T700LCK with CF_3CO_2Na as the internal standard. Elemental analyses were performed with a Fisons EA1108 instrument.

4.2. *tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-pentafluoropropionyl-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-[2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyl-(1→3)]-2-azido-6-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (8).

To a solution of **7a**[14] (20.1 mg, 8.07 μmol) in THF (1 mL) was added HF–pyridine (70%) (15.7 μL, 0.549 mmol) at room temperature. After stirring for 24 h, the reaction was quenched with powdered $NaHCO_3$. After dilution with EtOAc, the reaction mixture was washed with water and brine, dried over Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by silica gel column chromatography using gradient solvent system (hexane/EtOAc = 25/1 to 10/1 to 2/1 to 1/1 to 1/2) to give the title compound **7b** as an α,β-mixture (17.5 mg, 97%). **7b**: MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{110}H_{118}F_5N_{15}O_{31}Na$, 2262.8, found 2262.9; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{110}H_{118}F_5N_{15}O_{31}Na$, 2262.7936, found 2262.8014.

To a solution of **7b** (16.5 mg, 7.36 μmol) in dry CH_2Cl_2 (2 mL) was added diethylaminosulfur

trifluoride (DAST) (1.50 μL, 15.4 μmol) at –40 °C. After the reaction mixture was stirred for 4 h at the same temperature, the reaction was quenched with MeOH. After dilution with EtOAc at room temperature, the reaction mixture was washed with sat. $NaHCO_3$ aq. and brine, dried over Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by silica gel flash column chromatography using gradient solvent system (hexane/EtOAc = 50/1 to 25/1 to 10/1 to 5/1 to 3/1 to 1/1) to give **7c** as an α,β-mixture (15.0 mg, 91%, α:β = 4.0:1). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 5.53 (dd, *J* = 2.8, 52.8 Hz, FCH-1$^{\mathbf{7c\text{-}\alpha}}$, 1H); δ 4.82 (dd, *J* = 6.4, 52.8 Hz, FCH-1$^{\mathbf{7c\text{-}\beta}}$, 1H); MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{110}H_{117}F_6N_{15}O_{30}Na$, 2264.8, found 2264.8; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{110}H_{117}F_6N_{15}O_{30}Na$, 2264.7893, found 2264.7909.

A mixture of $AgClO_4$ (9.6 mg, 46.3 μmol), Cp_2HfCl_2 (8.7 mg, 22.9 μmol) and dried powdered MS (4Å) (250 mg) in dry benzene (1.0 mL) was stirred for 30 min at room temperature. To the mixture was added a solution of **7c** (α,β-mixture, 18.2 mg, 8.11 μmol) and Bac-acceptor **2**[15] (7.4 mg, 16 μmol) in dry benzene (2.0 mL) and the mixture was stirred for 4 h. The reaction mixture was diluted with EtOAc (10 mL), quenched with sat. $NaHCO_3$ aq. (10 mL) and filtered through Celite. The filtrate was extracted with EtOAc and combined organic layers were washed with brine. The washed organic layer was dried over Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by gel filtration chromatography (EtOAc–toluene, 1:1) to give the title compound **8** as an amorphous (8.6 mg, 39%, α:β = 3.5:1).

Major isomer (α): ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.00 (d, *J* = 5.6 Hz, H-6^{Bac}, 3H), 1.10 (s, TBPS, 9H), 1.77 (s, Ac, 3H), 2.02 (s, Ac, 3H), 2.03 (s, Ac, 3H), 2.07 (s, Ac, 3H), 2.77 (dq, *J* = 5.6, 9.6 Hz, H-5^{Bac}, 1H), 2.77 (dd, *J* = 5.2, 8.4 Hz, H-5^{GalN}, 1H), 3.03–3.17 (m, H-2^{GalNV}, H-3^{Bac}, H-4^{Bac}, H-5^{GalN} x 3, 6H), 3.26–3.33 (m, H-2^{GalNI}, H-2^{GalNII}, H-2^{Bac}, 3H), 3.46 (t, *J* = 9.6 Hz, H-6^{GalN}, 1H), 3.54 (dd, *J* = 6.0, 9.2 Hz, H-6^{GalN}, 1H), 3.58–3.65 (m, H-2^{GalNIII}, H-2^{GalNIV}, H-6^{GalN} x 2, 4H), 3.73 (dd, *J* = 4.8, 8.2 Hz, H-6^{GalN}, 1H), 3.79–4.03 (m, H-3^{GalNI}, H-3^{GalNII}, H-3^{GalNIII}, H-3^{GalNIV}, H-3^{GalNV}, H-6^{GalN} x 2, H-5^{Glc}, PhCH_2 x 6, 14H), 4.19 (dd, *J* = 6.0, 9.6 Hz, H-5^{GalN}, 1H), 4.23–4.29 (m, H-5^{GalN} x 2, H-6^{Glc}, 12H), 4.30 (d, *J* = 7.6 Hz, H-1^{Bac}, 1H), 4.31 (brs, H-4^{GalNIII}, 1H), 4.35 (d, *J* = 2.8 Hz, H-4^{GalNII}, 1H), 4.38 (d, *J* = 1.6 Hz, H-4^{GalNIV}, 1H), 4.40-4.44 (m, PhCH_2 x 2, 2H), 4.43 (d, *J* = 3.6 Hz, H-4^{GalNI}, 1H), 4.48–4.62 (m, H-5^{GalN} x 2, PhCH_2 x 5, 7H), 4.66 (d, *J* = 3.6 Hz, H-1^{GalNV}, 1H), 4.70 (d, *J* = 10.6 Hz, PhCH_2, 1H), 4.76 (d, *J* = 7.2 Hz, H-1^{Glc}, 1H), 4.82 (d, *J* = 12.0 Hz, PhCH_2, 1H), 4.85–4.91 (m, PhCH_2 x 2, 2H), 4.98 (d, *J* = 12.0 Hz, PhCH_2, 1H), 5.02 (d, *J* = 3.6 Hz, H-1^{GalNII}, 1H), 5.11 (d, *J* = 4.0 Hz, H-1^{GalNIII}, 1H), 5.23 (d, *J* = 4.0 Hz, H-1^{GalNIV}, 1H), 5.23–5.28 (m, H-2^{Glc}, H-3^{Glc}, H-4^{Glc}, 3H), 5.75 (d, *J* = 1.6 Hz, H-1^{GalNV}, 1H), 7.04–7.69 (m, Ar, 55H); MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{132}H_{144}F_5N_{21}O_{33}SiNa$, 2697.0, found 2696.5; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{132}H_{144}F_5N_{21}O_{33}SiNa$, 2696.9823, found 2696.9774.

4.3. Typical procedure for glycosylation:

***tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-pentafluoropropionyl-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (13a).**

A mixture of compound **2** (0.550 g, 1.217 mmol) and **3a** (0.928 g, 1.741 mmol) was co-evaporated with toluene twice and the residue was dissolved in benzene (10.0 mL). The solution was transferred by cannula to a stirred mixture of Cp_2HfCl_2 (0.923 g, 2.43 mmol), $AgClO_4$ (1.009 g, 4.87 mmol) and dried MS (4 g, 4Å) in benzene over 20 min. The mixture was stirred at room temperature for 6 h. The mixture was filtrated through Celite pad and the filter cake was washed with ethyl acetate. The filtrate was washed with saturated $NaHCO_3$ (aq.), water and brine, successively and dried over Na_2SO_4. The crude solution was concentrated and seperated by gel filtration with Bio-Beads SX-3 (toluene:ethyl acetate, 2:1) to provide the title compound as an α/β-mixtures (1.042 g, 89%, 86:14). Anomers were separated by flash silica gel chromatography (toluene:ethyl acetate, 100:1).

α-anomer: $[\alpha]^{25}_{D}$ +32.6° (*c* 1.34, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.00 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.03 (s, *t*-Bu, 9H), 2.71 (qd, *J* = 6.0, 9.2 Hz, H-5^{Bac}, 1H), 2.97–3.05 (m, H-4^{Bac}, H-3^{Bac}, 2H), 3.26 (dd, *J* = 7.6, 9.6 Hz, H-2^{Bac}, 1H), 3.31 (dd, *J* = 8.8, 17.6 Hz, H-6a^{GalN}, 1H), 3.47 (dd, *J* = 5.6, 9.2 Hz, H-6b^{GalN}, 1H), 3.53 (dd, *J* = 3.6, 10.8 Hz, H-2^{GalN}, 1H), 3.92 (dd, *J* = 2.4, 10.4 Hz,

H-3^{GalN}, 1H), 4.25 (d, *J* = 8.0 Hz, H-1^{Bac}, 1H), 4.38–4.49 (m, H-5^{GalN} , PhCH_2, 3H), 4.69 (d, *J* = 10.8 Hz, H-1, PhCH_2, 1H), 5.20 (d, *J* = 3.6 Hz, H-1^{GalN}, 1H), 5.79 (d, *J* = 2.0 Hz, H-4^{GalN}, 1H), 7.15–7.28 (m, Ar, 14H), 7.32–7.34 (m, Ar, 2H), 7.56–7.59 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.40, 19.25, 26.92, 59.39, 66.79, 67.35, 67.44, 68.90, 70.92, 70.10, 72.18, 73.75, 73.95, 96.74, 98.55, 127.21, 127.46, 127.75, 127.85, 127.90, 128.15, 128.27, 128.37, 129.67, 129.87, 132.25, 132.84, 135.63, 135.68, 136.36, 137.05; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{45}H_{48}F_5N_9O_8SiNa$, 988.32, found 988.26; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{45}H_{48}F_5N_9O_8SiNa$, 988.3213, found 988.3226.

β-anomer: $[\alpha]^{24}_D$ +43.63° (*c* 0.98, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.01 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.05 (s, *t*-Bu, 9H), 2.63 (qd, *J* = 6.0, 10.0 Hz, H-5^{Bac}, 1H), 2.99 (br t, *J* = 9.6 Hz, H-4^{Bac}, 1H), 3.33 (br t, *J* = 9.6 Hz, H-3^{Bac}, 1H), 3.36-3.49 (m, H-2^{Bac}, H-6a^{GalN}, H-3^{GalN}, H-5^{GalN}, 4H), 3.53 (dd, *J* = 5.6, 9.8 Hz, H-2^{GalN}, 1H), 3.68 (dd, *J* = 4.4, 9.2 Hz, H-6b^{GalN}, 1H), 4.23 (d, *J* = 7.6 Hz, H-1^{Bac}, 1H), 4.38-4.51 (m, PhCH_2, 3H), 4.61 (d, *J* = 8.0 Hz, H-1^{GalN}, 1H), 4.67 (d, *J* = 11.2 Hz, H-1, PhCH_2, 1H), 5.61 (d, *J* = 2.8 Hz, H-4^{GalN}, 1H), 7.22–7.42 (m, Ar, 16H), 7.64–7.68 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 18.25, 19.22, 26.90, 62.58, 65.94, 66.85, 68.85, 69.99, 70.28, 71.06, 72.47, 73.79, 74.61, 76.67, 79.75, 96.50, 101.64, 127.20, 127.43, 127.69, 127.89, 128.02, 128.29, 128.38, 129.66, 129.81, 132.35, 132.79, 133.27, 135.64, 135.74, 136.35, 136.99;

MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{45}H_{48}F_5N_9O_8SiNa$, 988.32, found 988.71; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{45}H_{48}F_5N_9O_8SiNa$, 988.3213, found 988.3207.

4.4. *tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-naphthylmethyl-β-D-galactopyranoside (11).

To a solution of compound **10**[14] (0.101 g, 0.162 mmol) in anhydrous THF was added 2-(bromomethyl)naphthalene (0.068 g, 0.31 mmol), NaH (8.0 mg, 0.32 mmol) and tetrabutylammonium iodide (24 mg, 0.065 mmol) at room temperature. Reaction mixture was stirred for 9 h. Triethylamine (1.0 mL) was added to the reaction mixture and diluted with CH_2Cl_2 followed by addition of ice chips. The reaction mixture was washed with water and brine and dried over Na_2SO_4. Concentrated crude product was purified on silica gel (hexane:ethyl acetate, 6:1) to afford the title compound as a colorless semi-solid (0.113 g, 91%).

^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.01 (s, *t*-Bu, 9H), 3.08–3.12 (m, H-3, H-5, 2H), 3.22 (dd, *J* = 5.6, 9.2 Hz, H-6a, 1H), 3.42 (dd, *J* = 7.6, 9.2 Hz, H-6b, 1H), 3.73 (d, *J* = 2.4, H-4, 1H), 3.83 (dd, *J* = 7.6, 10.4 Hz, H-2, 1H), 4.12 (d, *J* = 11.6 Hz, ArCH_2, 1H), 4.16 (d, *J* = 12.0 Hz, ArCH_2, 1H), 4.25 (d, *J* = 7.6 Hz, H-1, 1H), 4.52 (br s, ArCH_2, 2H), 4.62 (d, *J* = 12.0 Hz, ArCH_2, 1H), 4.92 (d, *J* = 11.6 Hz, ArCH_2, 1H), 6.99–7.01 (m, Ar, 2H), 7.14–7.35 (m, Ar, 18H), 7.58–7.70 (m, Ar, 7H); ^{13}C

NMR ($CDCl_3$, 100 MHz): δ 19.24, 26.85, 65.90, 68.32, 72.18, 72.49, 73.31, 74.52, 80.78, 96.95, 125.73, 125.90, 126.20, 126.67, 127.11, 127.38, 127.55, 127.61,127.70, 127.77, 127.89, 128.21, 128.34, 129.43, 129.63, 132.73, 132.85, 133.03, 133.26, 135.81, 135.91, 137.60, 137.68; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{47}H_{49}N_3O_5SiNa$, 786.34, found 786.58; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{47}H_{49}N_3O_5SiNa$, 786.3392, found 786.3341.

4.5. 2-Azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-naphthylmethyl-D-galactopyranose (12).

A solution of compound **11** (0.111g, 0.145 mmol) in dry THF was treated with HF–pyridine (70%) (0.1 mL, 3.498 mmol) for 13 h at room temperature. The reaction was quenched by addition of solid $NaHCO_3$ followed by dilution with CH_2Cl_2. The crude mixture was washed with water, brine and dried over Na_2SO_4. After concentration crude product was subjected to chromatographic purification on silica gel. Elution of column with hexane:ethyl acetate (4:1) provided the title compound (0.073 g, 96%) as highly viscous syrup.

^{1}H NMR ($CDCl_3$, 400 MHz): δ 3.30 (dd, H-3, *J* = 2.8, 10.4 Hz, 1H), 3.36–3.56 (m, H-5, H-6a, H-6b, 3H), 3.81 (dd, *J* = 8.0, 10.4 Hz, H-2, 1H), 3.84 (d, *J* = 2.8 Hz, H-4, 1H), 3.73 (d, *J* = 2.4, H-4, 1H), 3.93 (br s, ArCH_2, 2H), 4.32 (d, *J* = 12.0 Hz, ArCH_2, 1H), 4.40 (d, *J* = 12.0 Hz, ArCH_2, 1H), 4.43 (d, *J* = 8.0 Hz, 1H), 4.47 (d, *J* = 12.0 Hz, ArCH_2, 1H), 4.65 (d, *J* = 11.6 Hz, ArCH_2,

1H), 7.16–7.72 (m, Ar, 14H), 7.72–7.78 (m, Ar, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): (α, β) δ 60.32, 64.52, 68.62, 69.20, 69.57, 71.87, 72.60, 73.24, 73.40, 73.45, 73.66, 74.54, 74.59, 76.68, 80.85, 92.27, 96.37, 125.86, 125.98, 126.23, 126.29, 126.95, 127.57, 127.69, 127.74, 127.76, 127.89, 127.93, 127.99, 128.01, 128.29, 128.43, 128.46, 132.88, 132.98, 135.30, 135.37, 137.32, 137.35, 137.44; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{31}H_{31}N_3O_5Na$, 548.21, found 548.25; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{31}H_{31}N_3O_5Na$, 548.2161, found 548.2144.

4.6. 2-Azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-naphthylmethyl-D-galactopyranosyl fluoride (3c).

A solution of hemiacetal **12** (0.073 g, 0.14 mmol) in CH_2Cl_2 (12 mL) was cooled in ice-methanol bath. To the solution was added DAST (37 μL, 0.28 mmol) and reaction mixture was stirred for 3 h at ice-methanol bath to room temperature. The reaction was quenched by addition of MeOH and ice-chips. The mixture was extracted with CH_2Cl_2 and organic layer was washed with $NaHCO_3$, water and brine successively followed by drying with $MgSO_4$ and evaporation under reduced pressure. The crude products were purified on silica gel (hexane:ethyl acetate, 3:1) to furnish the title fluorides (α: 18.2 mg, β: 49.3 mg, 91%).

β-anomer: $[\alpha]^{24}_D$ –12.32° (*c* 2.34, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 3.35 (dd, *J* = 2.4, 10.0 Hz, H-3, 1H), 3.54–3.61 (m, H-5, H-6a, H-6b, 3H), 3.91 (br s, H-4, 1H), 3.93–3.99 (m, H-2,

1H), 4.31 (d, *J* = 11.6 Hz, ArCH_2, 1H), 4.40 (d, *J* = 11.6 Hz, ArCH_2, 1H), 4.64 (br s, ArCH_2, 2H) 4.70 (d, *J* = 11.6 Hz, ArCH_2, 1H), 4.92 (dd, *J* = 7.6, 52.8 Hz, H-1, 1H), 4.99 (d, *J* = 12.0 Hz, ArCH_2, 1H), 7.14–7.45 (m, Ar, 14H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 62.93, 63.13, 67.93, 71.32, 72.63, 73.56, 73.66, 73.72, 74.69, 79.98, 80.07, 107.10, 109.23, 125.89, 126.02, 126.78, 127.58, 127.70, 127.79, 127.83, 127.85, 127.99, 128.03, 128.35, 128.47, 132.90, 133.01, 135.23, 137.06, 137.28; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{31}H_{30}N_3O_4FNa$, 550.21, found 550.38.

α-anomer: $[\alpha]^{25}_D$ +60.77° (*c* 0.78, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 3.53–3.56 (m, H-3, H-5, 2H), 3.87–4.06 (m, H-6a, H-6b, H-2, 3H), 4.08 (br s, H-4, 1H), 4.33 (d, *J* = 11.6 Hz, ArCH_2, 1H), 4.42 (d, *J* = 12.0 Hz, ArCH_2, 1H), 4.66 (d, *J* = 11.6 Hz, ArCH_2, 1H), 4.69 (d, *J* = 15.6 Hz, ArCH_2, 1H), 4.70 (d, *J* = 11.6 Hz, ArCH_2, 1H), 4.97 (d, *J* = 16.0 Hz, ArCH_2, 1H), 5.61 (dd, *J* = 2.4, 53.2 Hz, H-1, 1H), 7.16–7.43 (m, Ar, 14H), 7.59–7.76 (m, Ar, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 59.60, 59.84, 67.93, 72.01, 72.32, 72.43, 73.52, 74.90, 105.29, 107.54, 125.94, 126.06, 126.10, 126.86, 127.60, 127.80, 127.82, 128.03, 128.09, 128.37, 128.53, 132.94, 133.04, 135.23, 137.08, 137.40; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{31}H_{30}N_3O_4FNa$, 550.21, found 550.43; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{31}H_{30}N_3O_4FNa$, 550.2118, found 550.20763.

4.7. 2-Azido-3,6-di-*O*-benzyl-2-deoxy-β-D-galactopyranosyl fluoride (3d).

Compound **3a** (0.152 g, 0.285 mmol) was dissolved in pyridine–EtOH (1:1, 6 mL) and solution was stirred for 55.5 h at room temperature. The solution was evaporated and the crude product was flash chromatographed (hexane–ethyl acetate, 5:1) to afford the compound **3d** as white solid (0.102 g, 92%).

$[\alpha]^{21}_{D}$ –31.88° (*c* 1.41, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 3.30 (dd, *J* = 2.8, 10.0 Hz, H-3, 1H), 3.54 (t, *J* = 6.0 Hz, H-5, 1H), 3.67–3.78 (m, H-2, H-6a, H-6b, 3H), 3.94 (br s, H-4, 1H), 4.49 (d, *J* = 12.0, PhCH_2, 1H), 4.53 (d, *J* = 12.0, PhCH_2, 1H), 4.62 (d, *J* = 12.0, PhCH_2, 1H), 4.64 (d, *J* = 12.0, PhCH_2, 1H), 4.89 (dd, *J* = 7.6, 52.4 Hz, H-1, 1H), 7.18–7.29 (m, Ar, 5H), 7.31–7.33 (m, Ar, 5H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 62.28, 62.50, 65.12, 68.59, 72.16, 73.34, 73.38, 73.72, 78.69, 78.80, 106.91, 109.05, 127.75, 127.81, 127.90, 128.25,128.37, 128.56, 136.65, 137.37; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{20}H_{22}N_3O_4FNa$, 410.14, found 410.17; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{20}H_{22}N_3O_4FNa$, 410.1492, found 410.1477.

4.8. 2-Azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-(4-methoxybenzoyl)-β-D-galactopyranosyl fluoride (3e).

4-Methoxybenzoyl chloride (54.0 mg, 0.316 mmol) was added to a solution of compound **3d** (95.0 mg, 0.245 mmol) in pyridine (13 mL) and the solution was stirred for 6.5 h at ambient

temperature under argon atmosphere. Ice chips were added to the reaction mixture followed by extraction in $CHCl_3$ and organic layer was successively washed with water and brine and dried over Na_2SO_4. The solvent was evaporated to dryness and crude product was purified to furnish the title compound as a semi-solid (0.108 g, 84%).

$[\alpha]^{25}_D$ +39.82° (*c* 1.12, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 3.56 (dd, *J* = 2.4, 10.0 Hz, H-3, 1H), 3.63 (t, *J* = 7.2 Hz, H-5, 1H), 3.68 (dd, *J* = 6.0, 15.6 Hz, H-6a, 1H), 3.78–3.84 (m, H-6b, H-2, 2H), 3.89 (s, C*H*$_3$OAr, 3H), 4.44 (d, *J* = 11.6 Hz, PhC*H*$_2$, 1H), 4.53 (d, *J* = 10.8 Hz, PhC*H*$_2$, 1H), 4.56 (d, *J* = 10.8 Hz, PhC*H*$_2$, 1H), 4.88 (d, *J* = 11.2 Hz, PhC*H*$_2$, 1H), 5.06 (dd, *J* = 8.0, 52.4 Hz, H-1, 1H), 5.81 (br s, H-4, 1H), 6.96 (d, *J* = 8.8 Hz, Ar, 2H), 7.28–7.36 (m, Ar, 10H), 8.05 (d, *J* = 8.8 Hz, Ar, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 55.51, 62.67, 62.87, 64.92, 67.74, 71.76, 72.96, 76.67, 77.20, 106.90, 109.04, 113.73, 121.50, 127.81, 127.86, 127.97, 128.26, 128.34, 131.96; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{28}H_{28}N_3O_6FNa$, 544.18, found 544.43; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{28}H_{28}N_3O_6FNa$, 544.1860, found 544.1888.

4.9. 2-Azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-(3,5-dimethoxybenzoyl)-β-D-galactopyranosyl fluoride (3f).

A solution of compound **3d** (85.0 mg, 0.219 mmol) in pyridine (12.0 mL) was added 3,5-

dimethoxybenzoyl chloride (56.0 mg, 0.279 mmol) and the mixture was stirred at ambient temperature for 8 h. Subsequent work-up as described for compound **3e** followed by flash chromatography on silica gel (toluene:ethyl acetate, 20:1) provided the title compound **3f** (89 mg, 74%) as white solid.

$[\alpha]^{25}_{D}$ +15.10° (*c* 1.87, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 3.51 (dd, *J* = 2.8, 10.4 Hz, H-3, 1H), 3.57 (dd, *J* = 7.2, 9.6 Hz, H-5, 1H), 3.65 (dd, *J* = 5.6, 9.2 Hz, H-6a, 1H), 3.71–3.81 (m, H-6b, H-2, 2H), 3.82 (s, C*H*$_3$OAr, 6H), 4.40 (d, *J* = 11.6 Hz, PhC*H*$_2$, 1H), 4.49 (d, *J* = 12.0 Hz, PhC*H*$_2$, 1H), 4.52 (d, *J* = 11.2 Hz, PhC*H*$_2$, 1H), 4.83 (d, *J* = 11.2 Hz, PhC*H*$_2$, 1H), 5.00 (dd, *J* = 7.2, 52.0 Hz, H-1, 1H), 5.78 (br s, H-4, 1H), 6.65 (t, *J* = 2.0 Hz, Ar, 1H), 7.17–7.34 (m, Ar, 12H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 55.65, 62.65, 62.86, 65.49, 67.59, 71.82, 72.71, 72.76, 73.79, 76.68, 105.62, 106.78, 107.54, 108.92, 127.76, 127.82, 127.92, 128.17, 128.27, 130.95, 136.49, 136.98, 164.97; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{29}H_{30}N_3O_7FNa$, 574.19, found 574.45; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{29}H_{30}N_3O_7FNa$, 574.1966, found 574.2010.

4.10. 2-Azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-(3,4,5-tri-methoxybenzoyl)-β-D-galactopyranosyl fluoride (3g).

To a solution of compound **3d** (56 mg, 0.15 mmol) in pyridine (10.0 mL) was added 3,4,5-

trimethoxybenzoyl chloride (40 mg, 0.173 mmol) followed by addition of DMAP (5 mg, 0.04 mmol) and the solution was stirred for 4 h at ambient temperature and then heated at 50°C for 1 h. Then the mixture was worked-up as mentioned for compound **3e** followed by purification by silica gel flash chromatography (toluene:ethyl acetate, 10:1), thus furnished the compound **3g** as light yellowish solid (58.0 mg, 69%).

$[\alpha]^{24}_{D}$ +21.76° (*c* 1.77, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 3.50 (dd, *J* = 3.2, 10.8 Hz, H-3, 1H), 3.57 (dd, *J* = 9.6, 10.8 Hz, H-6a, 1H), 3.62–3.66 (m, H-5, H-6b, H-2, 3H), 3.85 (s, C*H*$_3$OAr, 6H), 3.87 (s, C*H*$_3$OAr, 3H), 4.38 (d, *J* = 11.6 Hz, PhC*H*$_2$, 1H), 4.48 (d, *J* = 12.0 Hz, PhC*H*$_2$, 1H), 4.51 (d, *J* = 11.2 Hz, PhC*H*$_2$, 1H), 4.81 (d, *J* = 11.6 Hz, PhC*H*$_2$, 1H), 4.99 (dd, *J* = 7.6, 52.0 Hz, H-1, 1H), 5.75 (br s, H-4, 1H), 7.18–7.32 (m, Ar, 12H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 56.34, 60.93, 62.78, 62.99, 65.45, 67.58, 71.82, 72.76, 72.82, 73.76, 77.26, 106.83, 107.19, 108.97, 124.19, 127.83, 128.01, 128.24, 128.33, 136.57, 137.05, 142.77, 152.94, 164.95; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{30}H_{32}N_3O_8FNa$, 604.20, found 604.35; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{30}H_{32}N_3O_8FNa$, 604.2071, found 604.2121.

4.11. *tert*-Butyldiphenylsilyl 4-*O*-acetyl-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (13b).

Compound **13b** was synthesized from **3b** and acceptor **2** according to the procedure described for the preparation of compound **13a** except that $CHCl_3$ was used as a solvent, (58%, α:β = 3.0:1).

$[\alpha]^{25}_{D}$ +40.16° (*c* 0.76, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.08 (d, *J* = 6.4 Hz, H-6^{Bac}, 3H), 1.10 (s, *t*-Bu, 9H), 2.03 (s, C*H*$_3$CO, 3H), 2.79 (qd, *J* = 6.4, 9.2 Hz, H-5^{Bac}, 1H), 3.08 (br t, *J* = 9.2 Hz, H-4^{Bac}, 1H), 3.15 (br t, *J* = 9.2 Hz, H-3^{Bac}, 1H), 3.36 (dd, *J* = 7.6, 9.2 Hz, H-2^{Bac}, 1H), 3.45 (dd, *J* = 6.4, 9.6 Hz, H-6a^{GalN}, 1H), 3.51 (dd, *J* = 5.6, 9.2 Hz, H-6b^{GalN}, 1H), 3.68 (dd, *J* = 4.0, 10.8 Hz, H-2^{GalN}, 1H), 3.95 (dd, *J* = 3.2, 10.8 Hz, H-3^{GalN}, 1H), 4.33 (d, *J* = 7.6 Hz, H-1^{Bac}, 1H), 4.39 (br t, *J* = 9.2 Hz, H-5^{GalN}, 1H), 4.43 (d, *J* = 12.0 Hz, PhC*H*$_2$, 1H), 4.48 (d, *J* = 10.8 Hz, PhC*H*$_2$, 1H), 4.56 (d, *J* = 11.6 Hz, PhC*H*$_2$, 1H), 4.79 (d, *J* = 10.4 Hz, PhC*H*$_2$, 1H), 5.27 (d, *J* = 3.6 Hz, H-1^{GalN}, 1H), 5.72 (d, *J* = 2.0 Hz, H-4^{GalN}, 1H), 7.27–7.43 (m, Ar, 15H), 7.64–7.67 (m, Ar, 5H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.88, 19.17, 20.89, 59.37, 66.51, 67.54, 67.80, 68.50, 68.87, 70.86, 71.73, 73.62, 74.40, 78.51, 96.75, 98.78, 127.25, 127.51, 127.70, 127.88, 128.34, 128.36, 128.42, 129.70, 129.90, 132.36, 132.96, 135.72, 135.77, 137.00, 137.56, 169.96; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{44}H_{51}N_9O_8Si$ Na, 884.35, found 884.62; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{44}H_{51}N_9O_8Si$ Na, 884.3528, found 884.3549.

4.12. *tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-(2-naphthylmethyl)-α-D-

galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (13c).

The title compound was synthesized from **3c** and **2** in $CHCl_3$ by following the procedure for described for compound **13a**, (66%, α:β = 3.5:1).

^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.08 (d, *J* = 6.4 Hz, H-6^{Bac}, 3H), 1.11 (s, *t*-Bu, 9H), 2.80 (qd, *J* = 6.4, 9.6 Hz, H-5^{Bac}, 1H), 3.09 (br t, *J* = 9.6 Hz, H-4^{Bac}, 1H), 3.16 (br t, *J* = 9.6 Hz, H-3^{Bac}, 1H), 3.37 (dd, *J* = 8.0, 9.6 Hz, H-2^{Bac}, 1H), 3.54 (dd, *J* = 5.6, 8.8 Hz, H-6a^{GalN}, 1H), 3.62 (dd, *J* = 5.2, 8.8 Hz, H-6b^{GalN}, 1H), 3.98 (d, *J* = 13.6 Hz, ArCH_2, 1H), 3.99 (d, *J* = 13.6 Hz, ArCH_2, 1H), 4.16 (s, H-4^{GalN}, 1H), 4.24 (dd, *J* = 5.6, 7.6 Hz, H-5^{GalN}, 1H), 4.28–4.32 (m, H-2^{GalN}, H-3^{GalN}, 2H), 4.33 (d, *J* = 8.0 Hz, H-1^{Bac}, 1H), 4.34 (d, *J* = 11.6 Hz, ArCH_2, 1H), 4.45 (d, *J* = 11.6 Hz, ArCH_2, 1H), 4.72 (d, *J* = 11.6 Hz, ArCH_2, 1H), 5.02 (d, *J* = 11.6 Hz, ArCH_2, 1H), 5.27 (d, *J* = 2.8 Hz, H-1^{GalN}, 1H), 717–7.65 (m, Ar, 19H), 7.66–7.77 (m, Ar, 8H); MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{53}H_{57}N_9O_7SiNa$, 982.40, found 982.56; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{53}H_{57}N_9O_7SiNa$, 982.4048, found 982.4004.

4.13. *tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-(4-methoxybenzoyl)-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (13e).

Compound **13e** was obtained by coupling of **3e** and **2** according to the procedure described for

the preparation of **13a** except that $CHCl_3$ was used as a solvent, (40%, α:β = 3.8:1).

^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.11 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.13 (s, *t*-Bu, 9H), 2.82 (qd, *J* = 6.0, 9.2 Hz, H-5^{Bac}, 1H), 3.12 (br t, *J* = 9.2 Hz, H-4^{Bac}, 1H), 3.20 (br t, *J* = 9.6 Hz, H-3^{Bac}, 1H), 3.40 (dd, *J* = 7.6, 9.6 Hz, H-2^{Bac}, 1H), 3.45–3.60 (m, H-6a^{GalN}, H-6b^{GalN}, H-5^{GalN}, 3H), 3.79 (dd, *J* = 4.0, 10.0 Hz, H-2^{GalN}, 1H), 3.85 (s, C*H*$_3$OAr, 3H), 4.04 (dd, *J* = 2.8, 10.0 Hz, H-3^{GalN}, 1H), 4.38 (d, *J* = 7.6 Hz, H-1^{Bac}, 1H), 4.43–4.52 (m, PhC*H*$_2$, 3H), 4.92 (d, *J* = 10.8 Hz, PhC*H*$_2$, 1H), 5.39 (d, *J* = 4.0 Hz, H-1^{GalN}, 1H), 5.96 (d, *J* = 2.8 Hz, H-4^{GalN}, 1H), 6.90 (d, *J* = 8.8 Hz, Ar, 2H), 7.16–7.43 (m, Ar, 15H), 7.69–7.70 (m, Ar, 5H), 8.00 (d, *J* = 8.8 Hz, Ar, 2H); MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{50}H_{55}N_9O_9SiNa$, 976.37, found 976.41; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{50}H_{55}N_9O_9SiNa$, 976.3790, found 976.3798.

4.14. *tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-(3,5-dimethoxybenzoyl)-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (13f).

Donor **3f** was glycosylated with acceptor **2** in $CHCl_3$ according to the procedure described for the preparation of compound **13a** to furnish the title compound (15%, α:β = 8.1:1).

^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.07 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.09 (s, *t*-Bu, 9H), 2.81 (qd, *J* = 6.0, 9.2 Hz, H-5^{Bac}, 1H), 3.10 (br t, *J* = 9.2 Hz, H-4^{Bac}, 1H), 3.17 (br t, *J* = 9.2 Hz, H-3^{Bac}, 1H),

3.38 (dd, *J* = 7.6, 9.6 Hz, H-2^{Bac}, 1H), 3.46–3.55 (m, H-6a^{GalN}, H-6b^{GalN}, H-5^{GalN}, 3H), 3.70 (dd, *J* = 3.6, 10.4 Hz, H-2^{GalN}, 1H), 3.78 (s, CH_3OAr, 3H), 3.79 (s, CH_3OAr, 3H), 4.05 (dd, *J* = 3.2, 10.4 Hz, H-3^{GalN}, 1H), 4.35 (d, *J* = 8.0 Hz, H-1^{Bac}, 1H), 4.39–4.54 (m, PhCH_2, 3H), 4.89 (4d, *J* = 10.4 Hz, PhCH_2, 1H), 5.35 (d, *J* = 3.6 Hz, H-1^{GalN}, 1H), 5.95 (d, *J* = 3.2 Hz, H-4^{GalN}, 1H), 6.62 (t, *J* = 2.0 Hz, 1H), 7.14–7.41 (m, Ar, 17H), 7.65–7.68 (m, Ar, 5H); MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{51}H_{57}N_9O_{10}SiNa$, 1006.38, found 1006.19; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{51}H_{57}N_9O_{10}SiNa$, 1006.3895, found 1006.3933.

4.15. *tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-(3,4,5-tri-methoxybenzoyl)-α-D-Galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (13g).

The title compound was synthesized from **3g** and **2** in $CHCl_3$ according to the procedure described for the preparation of compound **13a** to furnish the title compound as pasty mass (55%, α:β = 10:1).

^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.09 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.11 (s, *t*-Bu, 9H), 2.81 (qd, *J* = 6.0, 9.2 Hz, H-5^{Bac}, 1H), 3.11 (br t, *J* = 9.2 Hz, H-4^{Bac}, 1H), 3.18 (br t, *J* = 9.2 Hz, H-3^{Bac}, 1H), 3.39 (dd, *J* = 8.0, 9.2 Hz, H-2^{Bac}, 1H), 3.48–3.56 (m, H-6a^{GalN}, H-6b^{GalN}, H-5^{GalN}, 3H), 3.75 (dd, *J*

= 4.0, 10.8 Hz, H-2^{GalN}, 1H), 3.86 (br s, CH_3OAr, 6H), 3.89 (s, CH_3OAr, 3H), 4.08 (dd, *J* = 2.8, 10.8 Hz, H-3^{GalN}, 1H), 4.36 (d, *J* = 7.6 Hz, H-1^{Bac}, 1H), 4.40–4.56 (m, PhCH_2, 3H) 4.90 (d, *J* = 11.6 Hz, PhCH_2, 1H), 5.37 (d, *J* = 4.0 Hz, H-1^{GalN}, 1H), 5.96 (d, *J* = 2.8 Hz, H-4^{GalN}, 1H), 7.15–7.42 (m, Ar, 17H), 7.66–7.69 (m, Ar, 5H); MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{52}H_{59}N_9O_{11}Si$ Na, 1036.35, found 1036.29; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{52}H_{59}N_9O_{11}SiNa$, 1036.4001, found 1036.4006.

4.16. Typical procedure for deprotection of pentafluoropropionyl (PFP) group:

***tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (14).**

To a stirred solution of compound **13a** (2.480 g, 2.569 mmol) in methanol:toluene (2:1, 30 mL) was added NaOMe (12 mg, 0.22 mmol) at room temperature under argon atmosphere. After 13 min, the reaction mixture was neutralized with addition of amberlyst IR resin (plus). Resin was filtered and washed with methanol:toluene (1:1) mixture. Filtrate was concentrated and dried *in vacuo* to obtain the title compound (2.104 g, quant.) as a pasty mass.

$[\alpha]^{28}_D$ +36.73° (*c* 0.49, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.02 (d, *J* = 6.4 Hz, H-6^{Bac}, 3H), 1.04 (s, *t*-Bu, 9H), 2.64 (br s, GalN-4-O*H*, 1H), 2.71 (qd, *J* = 6.0, 10.0 Hz, H-5^{Bac}, 1H), 3.02 (br t,

J = 9.6 Hz, H-4^{Bac}, 1H), 3.10 (dd, *J* = 9.2, 10.0 Hz, H-3^{Bac}, 1H), 3.28 (dd, *J* = 8.0, 9.6 Hz, H-2^{Bac}, 1H), 3.61 (dd, *J* = 4.8, 9.6 Hz, H-3^{GalN}, 1H), 3.69–3.76 (m, H-2^{GalN}, H-6a^{GalN}, 2H), 3.81 (dd, *J* = 2.8, 10.4 Hz, H-6b^{GalN}, 1H), 4.13–4.15 (m, H-5^{GalN}, H-4^{GalN}, 2H), 4.50 (br s, PhCH_2, 2H), 4.65 (br s, PhCH_2, 2H), 5.22 (d, *J* = 3.6 Hz, H-1^{GalN}, 1H), 7.21–7.35 (m, Ar, 16H), 7.58–7.61 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.97, 19.24, 26.92, 59.12, 66.56, 67.64, 68.94, 69.12, 69.26, 70.88, 71.78, 73.72, 76.17, 78.36, 96.70, 98.82, 127.18, 127.43, 127.60, 127.89, 128.01, 128.27, 128.48, 129.63, 129.83, 132.27, 132.88, 135.63, 135.68, 137.04, 137.62; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{42}H_{49}N_9O_7SiNa$, 842.34, found 842.26; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{42}H_{49}N_9O_7SiNa$, 842.3422, found 842.3419.

Anal. Calcd. for $C_{42}H_{49}N_9O_7Si$: C, 61.52; H, 6.02; N, 15.37. Found: C, 62.30; H, 5.98; N, 14.63.

4.17. *tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-pentafluoropropionyl-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (15a).

The title compound was synthesized from compound **14** (0.739 g, 0.902 mmol) and **3a** (0.688 g, 1.29 mmol) according to the procedure described for compound **13a**. The mixture was subjected to flash silica gel chromatography (toluene:ethyl acetate, 50:1) to give the title compound (α

anomer, 1.121 g, 93%; β anomer, 64 mg, 5%) (α:β = 95:5 as isolated).

α-anomer: $[\alpha]^{26}_{D}$ +83.76° (*c* 1.10, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.08 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.11 (s, *t*-Bu, 9H), 2.80 (qd, *J* = 6.4, 9.2 Hz, H-5^{Bac}, 1H), 3.01 (dd, *J* = 5.2, 8.8 Hz, H-6a^{GalNII}, 1H), 3.05–3.16 (m, H-4^{Bac}, H-3^{Bac}, H-6b^{GalNII}, 3H), 3.33 (dd, *J* = 8.0, 9.6 Hz, H-2^{Bac}, 1H), 3.41 (dd, *J* = 3.6, 10.4 Hz, H-2^{GalNII}, 1H), 3.50 (dd, *J* = 5.2, 9.6 Hz, H-6a^{GalNI}, 1H), 3.66 (dd, *J* = 3.6, 10.8 Hz, H-2^{GalNI}, 1H), 3.86 (dd, *J* = 2.8, 10.8 Hz, H-3^{GalNI}, 1H), 3.89–3.99 (m, H-6b^{GalNI}, PhCH_2, H-3^{GalNII}, 4H), 4.21 (m, H-5^{GalNI}, 1H), 4.32 (br s, H-4^{GalNI}, 1H), 4.33 (d, *J* = 7.6 Hz, H-1^{Bac}, 1H), 4.43–4.55 (m, PhCH_2, H-5^{GalNII}, 3H), 4.57 (d, *J* = 5.2 Hz, PhCH_2, 1H), 4.60 (d, *J* = 5.2 Hz, PhCH_2, 1H), 4.73 (d, *J* = 10.4 Hz, PhCH_2, 1H), 4.85 (d, *J* = 12.0 Hz, PhCH_2, 1H), 4.93 (d, *J* = 4.0 Hz, H-1^{GalNII}, 1H), 5.29 (d, *J* = 3.6 Hz, H-1^{GalNI}, 1H), 5.77 (br s, H-4^{GalNII}, 1H), 7.09–7.65 (m, Ar, 24H), 7.64–7.68 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.86, 19.18, 26.87, 59.62, 59.68, 66.06, 66.54, 66.65, 67.58, 69.05, 69.40, 70.95, 71.04, 72.08, 72.74, 73.27, 74.02, 75.98, 78.20, 96.77, 98.56, 98.88, 126.96, 127.27, 127.52, 127.74, 127.82, 128.00, 128.19, 128.21, 128.25, 128.27, 128.44, 128.53, 128.95, 129.73, 129.92, 132.38, 132.94, 135.72, 135.77, 136.45, 137.12, 137.29, 137.40; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{65}H_{69}N_{12}O_{12}SiNa$, 1355.47, found 1355.64; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{65}H_{69}N_{12}O_{12}SiNa$, 1355.4745, found 1355.4762.

β anomer: $[\alpha]^{24}_{D}$ +30.69° (*c* 0.83, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.06 (d, *J* = 6.0 Hz,

H-6^{Bac}, 3H), 1.09 (s, *t*-Bu, 9H), 2.78 (qd, *J* = 6.0, 9.6 Hz, H-5^{Bac}, 1H), 3.07 (br t, *J* = 9.6 Hz, H-4^{Bac}, 1H), 3.13–3.22 (m, H-3^{Bac}, H-3^{GalNII}, H-6a^{GalNII}, 3H), 3.28 (dd, *J* = 5.6, 8.8 Hz, H-6b^{GalNII}, 1H), 3.35 (dd, *J* = 7.6, 9.6 Hz, H-2^{Bac}, 1H), 3.43 (dd, *J* = 7.6, 10.8 Hz, H-2^{GalNII}, 1H), 3.49 (dd, *J* = 5.6, 9.6 Hz, H-6a^{I}, 1H), 3.56 (dd, *J* = 6.8, 10.8 Hz, H-6b^{GalNI}, 1H), 3.90 (dd, *J* = 2.8, 10.4 Hz, H-3^{GalNI}, 1H), 4.01 (dd, *J* = 3.6, 10.4 Hz, H-2^{GalNI}, 1H), 4.19–4.26 (m, H-5^{I}, H-4^{GalNI}, 2H), 4.29–4.33 (m, H-5^{GalNII}, H-1^{Bac}, PhCH_2, 3H), 4.38–4.50 (m, H-1^{GalNII}, PhCH_2, 5H), 4.59 (d, *J* = 12.0 Hz, PhCH_2, 1H), 4.66 (d, *J* = 11.6 Hz, PhCH_2, 1H), 4.80 (d, *J* = 11.6 Hz, PhCH_2, 1H), 5.28 (d, *J* = 3.6 Hz, H-1^{GalNI}, 1H), 5.24 (d, *J* = 2.8 Hz, H-4^{GalNII}, 1H), 7.17–7.41 (m, Ar, 26H), 7.63–7.66 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.88, 19.15, 26.84, 59.67, 62.81, 66.49, 67.69, 68.60, 68.86, 69.87, 70.05, 70.69, 70.78, 71.60, 72.30, 72.68, 73.18, 73.67, 76.43, 78.29, 96.70, 98.63, 101.13, 127.19, 127.23, 127.38, 127.48, 127.80, 127.99, 128.05, 128.18, 128.32, 128.42, 128.47, 129.67, 129.87, 132.33, 132.98, 135.70, 135.75, 136.47, 136.89, 137.62, 138.26; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{65}H_{69}N_{12}O_{12}SiNa$, 1355.47, found 1355.89.

4.18. *tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (15b).

The title compound was obtained from compound **15a** upon treatment with NaOMe according to

the typical procedure described for compound **14** (quant.).

$[\alpha]^{27}_{D}$ +90.67° (*c* 0.60, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 0.99 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.02 (s, *t*-Bu, 9H), 2.70 (qd, *J* = 6.4, 9.2 Hz, H-5^{Bac}, 1H), 2.86 (br s, GalN^{II}-4-O*H*, 1H), 2.96–3.05 (m, H-4^{Bac}, H-3^{Bac}, 2H), 3.11 (dd, *J* = 4.4, 9.6 Hz, H-6a^{GalNII}, 1H), 3.24 (dd, *J* = 8.0, 9.6 Hz, H-2^{Bac}, 1H), 3.33 (dd, *J* = 4.4, 9.6 Hz, H-6b^{GalNII}, 1H), 3.44 (dd, *J* = 5.6, 8.8 Hz, H-6a^{GalNI}, 1H), 3.60 (dd, *J* = 3.6, 10.8 Hz, H-2^{GalNI}, 1H), 3.67 (dd, *J* = 3.6, 10.8 Hz, H-2^{GalNII}, 1H), 3.74–3.79 (m, H-3^{GalNI}, H-3^{GalNII}, 2H), 3.85 (br t, *J* = 9.6 Hz, H-6b^{GalNI}, 1H), 4.05–4.18 (m, H-5^{GalNI}, H-4^{GalNII}, H-5^{GalNII}, PhC*H*$_2$, 5H), 4.24 (d, *J* = 7.6 Hz, H-1^{Bac}, 1H), 4.27 (d, *J* = 2.4 Hz, H-4^{GalNI}, 1H), 4.41–4.63 (m, PhC*H*$_2$, 5H), 4.75 (d, *J* = 12.4 Hz, PhC*H*$_2$, 1H), 4.95 (d, *J* = 3.6 Hz, H-1^{GalNII}, 1H), 5.21 (d, *J* = 4.0 Hz, H-1^{GalNI}, 1H), 7.07–7.12 (m, Ar, 2H), 7.13–7.36 (m, Ar, 24H), 7.56–7.59 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.94, 19.25, 26.93, 59.34, 59.77, 66.48, 66.62, 67.59, 68.26, 69.43, 69.58, 70.94, 71.38, 71.90, 72.29, 73.49, 73.57, 75.77, 76.10, 77.20, 78.11, 96.75, 98.86, 98.91, 127.12, 127.19, 127.44, 127.57, 127.80, 127.85, 127.94, 128.18, 128.34, 129.64, 129.84, 132.31, 132.89, 135.63, 135.69, 137.20, 137.34, 137.42; ESI-TOF MS: $[M+Na]^+$ calcd for $C_{62}H_{70}N_{12}O_{11}SiNa$, 1209.49, found 1209.46. HRMS ESI-TOF : $[M+Na]^+$ calcd for $C_{62}H_{70}N_{12}O_{11}SiNa$, 1209.4954, found 1209.4957.

Anal. Calcd. for $C_{62}H_{70}N_{12}O_{11}Si$: C, 62.71; H, 5.94; N, 13.89. Found: C, 62.81; H, 6.04; N, 13.99.

4.19. *tert*-Butyldiphenylsilyl β-D-glucopyranosyl-(1→3)-2-azido-4,6-*O*-benzylidene-2-deoxy-β-D-galactopyranoside (26).

A solution of compound **25**[14] (2.213 g, 2.567 mmol) in methanol:toluene (1:1) was treated with NaOMe (19 mg, 0.352 mmol) at room tempetature for 2 h. The mixture was neutralized with amberlyst IR resin (plus) and filtered. Evaporation and concentration of the filtrate provided the title compound as glass (1.781 g, quant.).

$[\alpha]^{24}_{D}$ +10.45° (*c* 1.06, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.08 (s, *t*-Bu, 9H), 2.82 (br s, H-5^{GalN}, 1H), 3.03–3.28 (m, H-5^{Glc}, H-6a^{GalN}, H-6b^{GalN}, H-2^{Glc}, 4H), 3.36 (dd, *J* = 2.4, 10.4 Hz, H-3^{GalN}, 1H), 3.50–3.59 (m, H-3^{Glc}, H-6a^{Glc}, 2H), 3.65–3.75 (H-4^{Glc}, H-6b^{Glc}, 2H), 3.78 (dd, *J* = 7.6, 10.4 Hz, H-2^{GalN}, 1H), 4.02 (d, *J* = 2.4 Hz, H-4^{GalN}, 1H), 4.36 (d, *J* = 7.6 Hz, H-1^{GalN}, 1H), 4.41 (d, *J* = 7.2 Hz, H-1^{Glc}, 1H), 5.35 (s, PhC*H*(O)$_2$, 1H), 7.22–7.35 (m, Ar, 9H), 7.40–7.42 (m, Ar, 2H), 7.64–7.66 (m, Ar, 2H), 7.73–7.75 (m, Ar, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 19.40, 27.01, 61.22, 65.33, 66.23, 68.55, 69.33, 73.07, 75.12, 75.82, 97.04, 101.01, 103.85, 126.79, 127.34, 127.59, 128.31, 129.26, 129.71, 129.88, 132.92, 133.32,135.82, 136.00, 137.93; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{35}H_{43}N_3O_{10}SiNa$, 716.26, found 716.62; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{35}H_{43}N_3O_{10}SiNa$, 716.2615, found 716.2586.

4.20. *tert*-Butyldiphenylsilyl 2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)-2-azido-4,6-*O*-benzylidene-2-deoxy-β-D-galactopyranoside (27).

To a solution of compound **26** (1.609 g, 2.322 mmol) in anhydrous THF (15.0 mL) was added NaH (0.279 g, 11.620 mmol), benzyl bromide (1.65 mL, 13.930 mmol) followed by the addition of TBAI (53 mg, 0.143 mmol) at room tempereture. The reaction mixture was stirred for 16 h and then ice chips were added. The reaction mixture was diluted with ethyl acetate followed by addition of Et_3N (1.0 mL). The crude mixture was washed with water and brine and dried over Na_2SO_4. The crude solution was concentrated and subjected to silica gel chromatography (hexane:ethyl acetate, 3:1, $R_f = 0.60$) to afford the title compound as a white solid (1.988 g, 81%), which was crystallized from ethyl acetate and hexane.

mp 106–108 °C; $[\alpha]^{22}_D$ +18.60° (*c* 0.43, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.13 (s, *t*-Bu, 9H), 2.83 (br s, H-5^{GalN}, 1H), 3.40 (dd, *J* = 3.6, 10.8 Hz, H-3^{GalN}, 1H), 3.46–3.52 (m, H-5^{GalN}, H-2^{Glc}, H-4^{Glc} 3H), 3.56-3.64 (m, H-3^{Glc}, H-6a^{Glc}, H-6b^{Glc}, 3H), 3.82 (dd, *J* = 2.0, 12.4 Hz, H-6a^{GalN}, 1H) 3.82 (dd, *J* = 1.6, 12.0 Hz, H-6b^{GalN}, 1H), 3.92 (dd, *J* = 7.6, 10.8 Hz, H-2^{GalN}, 1H), 4.15 (d, *J* = 3.2 Hz, H-4^{GalN}, 1H), 4.42 (d, *J* = 12.0 Hz, PhCH_2, 1H), 4.46 (d, *J* = 7.6 Hz, H-1^{GalN}, 1H), 4.48 (d, *J* = 11.2 Hz, PhCH_2, 1H), 4.50 (d, *J* = 11.6 Hz, PhCH_2, 1H), 4.65 (d, *J* = 7.6 Hz, H-1^{Glc}, 1H), 4.75, (d, *J* = 11.2 Hz, PhCH_2, 1H), 4.76, (d, *J* = 10.8 Hz, PhCH_2, 1H), 4.79, (d, *J* = 10.8 Hz,

PhCH_2, 1H), 4.94 (d, J = 10.8 Hz, PhCH_2, 1H), 5.01 (d, J = 11.2 Hz, PhCH_2, 1H), 5.41 (s, PhCH(O)$_2$, 1H), 7.14–7.16 (m, Ar, 2H), 7.21–7.55 (m, Ar, 27H), 7.70–7.73 (m, Ar, 2H), 7.78–7.80 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 19.23, 26.93, 64.95, 66.40, 68.52, 69.50, 73.37, 74.35, 74.93, 75.07, 75.53, 77.64, 77.79, 81.24, 84.55, 97.29, 100.58, 126.29, 127.13, 127.39, 127.42, 127.55, 127.61, 127.67, 127.89, 128.03, 128.17, 128.21, 128.24, 128.27, 128.28, 128.74, 129.48, 129.65, 132.93, 133.27, 135.74, 135.96, 137.88, 138.13, 138.16, 138.49; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{63}H_{67}N_3O_{10}SiNa$, 1076.44, found 1076.92.

Anal. Calcd. for $C_{63}H_{67}N_3O_{10}Si$: C, 71.77; H, 6.41; N, 3.99. Found: C, 71.64; H, 6.31; N, 4.00.

4.21. *tert*-Butyldiphenylsilyl 2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)-2-azido-6-*O*-benzyl-2-deoxy -β-D-galactopyranoside (28).

A mixture of compound **27** (1.443 g, 1.370 mmol), $NaCNBH_3$ (0.516 g, 8.21 mmol) and dried MS (3 g, 4Å) in THF was cooled to ice-water temperatute. To the solution 4 M HCl solution (2.20 mL, 8.80 mmol) in dioxane was added slowly. The reaction mixture was stirred at ice-bath temperature for 40 min. Ice chips were added to the reaction mixture followed by addition of cooled saturated $NaHCO_3$ solution until the CO_2 bubble formation was stopped. The mixture was diluted with ethyl acetate and filtered through a Celite pad. The filter cake was washed with ethyl

acetate and the filtrate was concentrated under reduced pressure. The residue was subjected to chromatographic purification on silica by using a gradient solvent system (toluene:ethyl acetate,16:1 to 8:1 to 4:1) to provide the compound **28** (1.346 g, 93%) as a white solid, which was crystallized from ethyl acetate and hexane as fine long needles.

mp 109–111 °C; $[\alpha]^{23}_{D}$ +12.56° (*c* 0.64, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.14 (s, *t*-Bu, 9H), 3.13 (br s, H-5^{GalN}, 1H), 3.33 (br t, *J* = 5.6 Hz, H-5^{Glc}, 1H), 3.43 (dd, *J* = 2.8, 10.4 Hz, H-3^{GalN}, 1H), 3.54–3.73 (m, H-3^{Glc}, H-6a^{Glc}, H-6b^{Glc}, H-4^{Glc}, H-6a^{GalN}, H-2^{Glc}, H-6b^{GalN}, 7H), 3.92 (dd, *J* = 8.4, 10.4 Hz, H-2^{GalN}, 1H), 4.09 (br s, H-4^{GalN}, 1H), 4.38 (br s, PhCH_2, 2H), 4.46 (d, *J* = 8.0 Hz, H-1^{GalN}, 1H), 4.49 (d, *J* = 12.4 Hz, PhCH_2, 1H), 4.54 (d, *J* = 12.4 Hz, PhCH_2, 1H), 4.58 (d, *J* = 10.8 Hz, PhCH_2, 1H), 4.60 (d, *J* = 7.2 Hz, H-1^{Glc}, 1H), 4.83 (d, *J* = 10.8 Hz, PhCH_2, 1H), 4.85 (d, *J* = 12.4 Hz, PhCH_2, 1H), 4.88 (d, *J* = 11.2 Hz, PhCH_2, 1H), 5.00 (d, *J* = 10.8 Hz, PhCH_2, 1H), 5.13 (d, *J* = 10.8 Hz, PhCH_2, 1H), 7.22–7.28 (m, Ar, 2H), 7.34–7.45 (m, Ar, 29H), 7.79–7.84 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 19.14, 26.81, 65.25, 67.27, 68.92, 69.32, 73.27, 73.45, 74.49, 74.70, 74.96, 75.65, 76.68, 77.52, 81.17, 81.57, 84.46, 97.03, 103.53, 127.16, 127.42, 127.49, 127.62, 127.70, 127.75, 127.89, 128.05, 128.16, 128.27, 128.31, 129.50, 129.72, 132.51, 133.14, 135.84, 135.95, 137.61, 137.74, 138.02, 138.09, 138.29. MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{63}H_{69}N_3O_{10}SiNa$, 1078.46, found 1078.71.

Anal. Calcd. for $C_{63}H_{69}N_3O_{10}Si$: C, 71.63; H, 6.58; N, 3.98. Found: C, 71.64; H, 6.52; N, 3.92.

4.22. *tert*-Butyldiphenylsilyl 2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)-2-azido-6-*O*-benzyl-2-deoxy-4-*O*-pentafluoropropionyl-β-D-galactopyranoside (29).

A solution of compound **28** (4.931 g, 4.674 mmol) in pyridine was cooled to ice-water temperature. To the solution was added pentafluoropropionic anhydride (1.10 mL, 5.57 mmol) and the solution was stirred for 1.5 h, while being warmed up to room temperature. To the reaction mixture ice chips were added and diluted with ethyl acetate followed by washing with saturated $NaHCO_3$ (aq.), water and brine. The crude solution was dried over Na_2SO_4, concentrated and subjected to silica gel flash chromatography (hexane:ethyl acetate, 4:1) to afford the title compound (5.428 g. 97%) as a semi-solid substance.

$[\alpha]^{24}_D$ +7.50° (*c* 0.16, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.11 (s, *t*-Bu, 9H), 3.13–3.22 (m, H-5^{GalN}, H-3^{Glc}, 2H), 3.28 (br t, *J* = 9.6 Hz, H-4^{Glc}, 1H), 3.34 (dd, *J* = 7.6, 9.2 Hz, H-2^{Glc}, 1H), 3.38–3.46 (m, , H-5^{Glc}, H-6a^{Glc}, H-6b^{Glc}, 3H), 3.53 (dd, *J* = 2.8, 10.4 Hz, H-3^{GalN}, 1H), 3.58–3.67 (m, H-6a^{GalN}, H-2^{GalN}, 3H), 4.19 (d, *J* = 11.6 Hz, PhC*H*$_2$, 1H), 4.23 (d, *J* = 12.0 Hz, PhC*H*$_2$, 1H), 4.40 (d, *J* = 7.6 Hz, H-1^{GalN}, 1H), 4.41–4.52 (m, PhC*H*$_2$, 3H), 4.58 (d, *J* = 7.6 Hz, H-1^{Glc}, 1H), 4.62 (d, *J* = 10.8 Hz, PhC*H*$_2$, 1H), 4.74 (d, *J* = 11.2 Hz, PhC*H*$_2$, 1H), 4.78 (d, *J* = 11.2 Hz, PhC*H*$_2$,

1H), 4.87 (d, J = 11.2 Hz, PhCH_2, 1H), 4.92 (d, J = 10.8 Hz, PhCH_2, 1H), 5.60 (d, J = 2.4 Hz, H-4^{GalN}, 1H), 7.10–7.16 (m, Ar, 2H), 7.23–7.39 (m, Ar, 29H), 7.66–7.70 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 19.13, 26.79, 65.78, 71.48, 73.36, 73.57, 74.13, 74.95, 75.02, 75.07, 75.70, 75.96, 77.86, 82.40, 84.30, 97.29, 104.22, 127.16, 127.38, 127.41, 127.48, 127.52, 127.60, 127.67, 127.71, 127.94, 127.95, 128.21, 128.23, 128.26, 128.32, 129.60, 129.90, 135.77, 137.86, 138.24, 138.39; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{66}H_{68}F_5N_3O_{11}SiNa$, 1224.44, found 1224.69; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{66}H_{68}F_5N_3O_{11}SiNa$, 1224.4441, found 1224.4481.

4.23. 2,3,4,6-Tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)-2-azido-6-*O*-benzyl-2-deoxy-4-*O*-pentafluoropropionyl-D-galactopyranose (30).

To a solution of compound **29** (5.049 g, 4.204 mmol) in THF (20 mL) was added HF–pyridine (70%) (0.5 mL, 17.49 mmol) at room temperature. The solution was stirred for 41 h and the reaction was quenched by addition of ice chips and saturated $NaHCO_3$ (aq.). The mixture was diluted with ethyl acetate and washed with water and brine and then dried over Na_2SO_4. The solvent was evaporated and then silica gel flash chromatographic purification (toluene:ethyl acetate, 8:1) provided the hemi-acetal **30** (3.798 g, 94%) as white solid (α:β = 1.28:1), which was crystallized from ethyl acetate and hexane as needles (α:β = 1:7.4).

mp 103–104 °C; $[\alpha]^{24}_{D}$ +18.14° (*c* 0.84, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz), (β anomer, major): δ 3.31 (dd, *J* = 8.0, 9.6 Hz, H-2^{Glc}, 1H), 3.36–3.63 (m, H-6a^{Glc}, H-6b^{Glc}, H-3^{Glc}, H-6a^{GalN}, H-2^{GalN}, H-4^{Glc}, H-5^{Glc}, H-3^{GalN}, 8H), 3.67–3.73 (m, H-5^{GalN}, H-6b^{GalN}, 2H), 4.40–4.56 (m, PhC*H*$_2$, 5H), 4.57 (d, *J* = 7.2 Hz, H-1^{GalN}, 1H), 4.58 (d, *J* = 7.2 Hz, H-1^{Glc}, 1H), 4.59 (d, *J* = 10.8 Hz, PhC*H*$_2$, 1H), 4.73 (d, *J* = 10.8 Hz, PhC*H*$_2$, 1H), 4.77 (d, *J* = 10.8 Hz, PhC*H*$_2$, 1H), 4.85 (d, *J* = 10.8 Hz, PhC*H*$_2$, 1H), 4.87 (d, *J* = 10.8 Hz, PhC*H*$_2$, 1H), 5.69 (d, *J* = 3.2 Hz, H-4^{GalN}, 1H), 7.13–7.16 (m, Ar, 2H), 7.23–7.39 (m, Ar, 23H); ^{13}C NMR ($CDCl_3$, 100 MHz), (β anomer, major): δ 64.04, 67.77, 69.41, 71.91, 73.37, 73.79, 74.05, 74.93, 74.97, 75.11, 75.73, 76.18, 82.29, 84.28, 96.71, 104.28, 127.51, 127.65, 127.70, 127.77, 127.94, 128.28, 128.34, 128.40, 136.94, 137.77, 138.03, 138.12; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{50}H_{50}F_5N_3O_{11}Na$, 986.32, found 986.48.

Anal. Calcd. for $C_{50}H_{50}F_5N_3O_{11}$: C, 62.30; H, 5.23; N, 4.36. Found: C, 62.21; H, 5.22; N, 4.38.

4.24. 2,3,4,6-Tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)-2-azido-6-*O*-benzyl-2-deoxy-4-*O*-pentafluoropropionyl-D-galactopyranosyl fluoride (4a).

A solution of compound **30** (3.781 g, 3.926 mmol) in CH_2Cl_2 (15.0 mL) was cooled in an ice-methanol bath and then treated with DAST (1.0 mL, 7.6 mmol). The solution was stirred at room temperature for 3.5 h and the reaction was quenched with ice-chips and diluted with CH_2Cl_2 and

washed with saturated $NaHCO_3$ (aq.), water and brine. Then it was dried over Na_2SO_4, filtered and evapotated. The crude products was purified by silica gel flash chromatography (toluene:ethyl acetate, 30:1) to afford the title compound (3.474 g, 92%), (α-anomer, 1.185 g, white solid and β-anomer, 2.289 g, pasty mass).

β-anomer: $[\alpha]^{24}_{D}$ +3.22° (*c* 0.31, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 3.34 (dd , *J* = 7.6, 9.2 Hz, H-2^{Glc}, 1H), 3.41–3.50 (m, H-6a^{Glc}, H-5^{GalN}, H-4^{Glc}, 3H), 3.55–3.64 (m, H-3^{Glc}, H-6b^{Glc}, H-6a^{GalN}, 3H), 3.67–3.71 (m, H-3^{GalN}, H-2^{GalN}, H-6b^{GalN}, 3H), 3.79 (br t, *J* = 6.4 Hz, H-5^{Glc}, 1H), 4.40–4.54 (m, PhC*H*$_2$, 6H), 4.61 (d, *J* = 7.6 Hz, H-1^{Glc}, 1H), 4.65 (d, *J* = 12.4 Hz, PhC*H*$_2$, 1H), 4.75 (d, *J* = 13.6 Hz, PhC*H*$_2$, 1H), 4.81 (d, *J* = 15.2 Hz, PhC*H*$_2$, 1H), 4.86 (d, *J* = 10.8 Hz, PhC*H*$_2$, 1H), 5.07 (dd, *J* = 7.2, 52.0 Hz, H-1^{GalN}, 1H), 5.74 (br s, H-4^{GalN}, 1H), 7.13–7.15 (m, Ar, 2H), 7.23–7.34 (m, Ar, 23H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 55.02, 61.55, 63.01, 66.97, 69.34, 71.91, 73.20, 73.40, 73.88, 75.03, 75.10, 75.74, 78.54, 82.30, 84.29, 104.24, 107.25, 127.51, 127.68, 127.80, 127.85, 127.95, 128.29, 128.36, 128.41, 128.55, 134.07, 136.81, 137.76, 137.94, 138.15, 138.27; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{50}H_{49}F_6N_3O_{10}Na$, 988.32, found 988.29; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{50}H_{49}F_6N_3O_{10}Na$, 988.3220, found 988.3220.

α-anomer: $[\alpha]^{24}_{D}$ +51.86° (*c* 1.20, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 3.35 (dd , *J* = 7.6, 9.2 Hz, H-2^{Glc}, 1H), 3.38 (dd , *J* =6.8, 10.0 Hz, H-6a^{GalN}, 1H), 3.47–3.51 (m, H-6a^{Glc}, H-6b^{Glc}, H-

6b^{GalN}, 3H), 3.58–3.72 (m, H-3^{Glc}, H-2^{GalN}, H-5^{Glc}, H-4^{Glc}, 4H), 4.23 (dd , *J* =3.2,10.8 Hz, H-3^{GalN}, 1H), 4.27 (br t, *J* = 6.4 Hz, H-5^{GalN}, 1H), 4.40–4.59 (m , PhCH_2, 6H), 4.65 (d, *J* = 7.6 Hz, H-1^{Glc}, 1H), 4.74–4.87 (m, PhCH_2, 4H), 5.77 (dd, *J* = 2.8, 52.4 Hz, H-1^{GalN}, 1H), 5.94 (d, *J* = 2.8 Hz, H-4^{GalN}, 1H), 7.14–7.16 (m, Ar, 2H), 7.20–7.32 (m, Ar, 23H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 59.29, 59.53, 67.15, 69.28, 72.83, 73.40, 73.75, 74.45, 75.02, 75.10, 75.75, 77.83, 82.32, 84.30, 104.31, 107.38, 127.47, 127.52, 127.60, 127.68, 127.75, 127.91, 128.04, 128.26, 128.28, 128.35, 128.37, 136.87, 137.83, 138.04, 138.21, 138.30; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{50}H_{49}F_6N_3O_{10}Na$, 988.32, found 988.64.

4.25. 2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)-2-azido-6-*O*-benzyl-2-deoxy-β-D-galactopyranosyl fluoride (4d).

A solution of **4a** (77.0 mg, 0.080 mmol) in pyridine:ethanol (1:1, 4 mL) was stirred at ambient temperature for 49 h. The reaction mixture was evaporated and co-evaporated with toluene and then crude product was purified by preparative thin layer chromatography (toluene:ethyl acetate, 8:1) to obtain the title compound as a foamy solid (59.0 mg, 91%).

$[\alpha]^{24}_D$ +7.69° (*c* 0.26, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 3.48–3.54 (m , H-2^{Glc}, H-3^{GalN}, H-6a^{Glc}, H-5^{Glc}, 4H), 3.57–3.68 (m, H-6b^{Glc}, H-4^{Glc}, 2H), 3.69–3.74 (m, H-3^{Glc}, H-6a^{GalN}, H-5^{GalN},

3H), 3.75–3.86 (m, H-6b^{GalN}, H-2^{GalN}, 2H), 4.04 (br s, H-4^{GalN}, 1H), 4.41(d, *J* = 12.0 Hz, PhCH_2, 1H), 4.43 (d, *J* = 12.0 Hz, PhCH_2, 1H), 4.49 (d, *J* = 11.2 Hz, PhCH_2, 1H), 4.52 (d, *J* = 11.6 Hz, PhCH_2, 1H), 4.54 (d, *J* = 7.6 Hz, H-1^{Glc}, 1H), 4.73 (d, *J* = 11.6 Hz, PhCH_2, 1H), 4.75–4.78 (m, PhCH_2, 3H), 4.95 (d, *J* = 11.2 Hz, PhCH_2, 1H), 4.99 (d, *J* = 10.4 Hz, PhCH_2, 1H), 5.04 (dd, *J* = 7.6, 52.4 Hz, H-1^{GalN}, 1H), 7.14–7.16 (m, Ar, 2H), 7.26–7.35 (m, Ar, 23H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 62.44, 62.67, 66.66, 68.98, 73.50, 74.53, 74.86, 75.04, 75.72, 77.53, 80.55, 81.52, 84.48, 103.35, 109.47, 127.64, 127.68, 127.71, 127.77, 127.96, 128.03, 128.37, 137.95, 138.20; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{47}H_{50}FN_3O_9Na$, 842.34, found 842.49; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{47}H_{50}FN_3O_9Na$, 842.3429, found 842.3385.

4.26. 2,3,4,6-Tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)-4-*O*-acetyl-2-azido-6-*O*-benzyl-2-deoxy-β-D-galactopyranosyl fluoride (4c).

A solution of compound **4d** (49.0 mg, 0.060 mmol) in pyridine (5.0 mL) was treated with Ac_2O (0.1 mL, 0.7 mmol) at room temperature for 14 h. Ice chips were added to the flask and diluted with $CHCl_3$. The organic layer was washed with saturated $NaHCO_3$ (aq.), water and brine successively and dried over Na_2SO_4. The solvent was evaporated and then crude product was purified by preparative thin layer chromatography (toluene:ethyl acetate, 8:1) to obtain the compound **4c** (47.0 mg, 91%) as a semi-solid.

$[\alpha]^{24}_{D}$ +12.86° (*c* 1.57, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 2.02 (s, C*H*$_3$CO, 3H), 3.37–3.41 (m, H-2^{Glc}, H-6a^{GalN}, 2H), 3.50–3.53 (m, H-6b^{GalN}, H-6a^{Glc}, 2H), 3.57–3.66 (m, H-3^{Glc}, H-4^{Glc}, H-3^{GalN}, H-6b^{Glc}, 4H), 3.69–3.78 (m, H-5^{Glc}, H-5^{GalN}, H-2^{GalN}, 3H), 4.40–4.57 (m, PhC*H*$_2$, 6H), 4.58 (d, *J* = 7.2 Hz, H-1^{Glc}, 1H), 4.68 (d, *J* = 11.2 Hz, PhC*H*$_2$, 1H), 4.75 (d, *J* = 11.2 Hz, PhC*H*$_2$, 1H), 4.85 (d, *J* = 10.8 Hz, PhC*H*$_2$, 1H), 4.89 (d, *J* = 10.8 Hz, PhC*H*$_2$, 1H), 5.04 (dd, *J* = 7.6, 52.0 Hz, H-1^{GalN}, 1H), 5.43 (br s, H-4^{GalN}, 1H), 7.11–7.13 (m, Ar, 2H), 7.18–7.28 (m, Ar, 23H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 20.76, 63.28, 63.49, 68.34, 68.57, 68.79, 73.21, 73.34, 73.68, 74.76, 74.92, 74.96, 75.49, 75.77, 75.87, 82.04, 103.39, 107.41, 109.54, 127.46, 127.55, 127.64, 127.67, 127.76, 127.85, 127.87, 128.23, 128.32, 137.31, 137.88, 138.06, 138.18, 138.41, 169.42; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{49}H_{52}FN_3O_{10}Na$, 884.35, found 884.47; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{49}H_{52}FN_3O_{10}Na$, 884.3534, found 884.3497.

4.27. *tert*-Butyldiphenylsilyl 2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)-2-azido-6-*O*-benzyl-2-deoxy-4-*O*-pentafluoropropionyl-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (17a).

A mixture of compound **15b** (0.347 g, 0.292 mmol) and **4a** (0.395 g, 0.409 mmol) was azeotroped with anhydrous toluene *in vacuo* and dissolved in benzene and was transferred to a

stirred mixture of Cp_2HfCl_2 (0.222 g, 0.585 mmol), $AgClO_4$ (0.243 g, 1.170 mmol) and dried MS (2 g, 4Å) in benzene under argon atmosphere. The mixture was stirred for 12 h and then diluted with ethyl acetate followed by filtration through a layer of Celite. The filtrate was successively washed with water and brine and dried over Na_2SO_4. The crude solution was concentrated and pass through a Bio-Beads SX-3 (toluene:ethyl acetate, 2:1). The collected fraction was monitored by t.l.c. and MALDI TOF mass analysis. Concentration of proper fraction and drying under high vacuum provided a pasty solid of the title compound as anomers (0.420 g, 67%, α:β = 14:1). The desired α anomer was obtained through silica gel flash chromatography (toluene:ethyl acetate, 20:1).

α-anomer: $[\alpha]^{26}_{D}$ +142.93° (*c* 0.41, CH_2Cl_2), ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.05 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.09 (s, *t*-Bu, 9H), 2.76 (qd, *J* = 6.0, 8.8 Hz, H-5^{Bac}, 1H), 2.98–3.12 (m, H-6a^{GalNIII}, H-4^{Bac}, H-3^{Bac}, H-6b^{GalNIII}, H-6a^{GalNII}, 5H), 3.28–3.33 (m, H-2^{Bac}, H-2^{Glc}, H-2^{GalNIII}, 3H), 3.48–3.52 (m, H-6a^{GalNI}, H-6a^{Glc}, 2H), 3.54–3.71 (m, H-6b^{Glc}, H-3^{Glc}, H-2^{GalNII}, H-4^{Glc}, H-2^{GalNI}, H-6b^{GalNII}, 6H), 3.81–3.85 (m, H-3^{GalNI}, H-5^{Glc}, H-6b^{GalNI}, 3H), 3.89–4.01 (m, H-3^{GalNII}, PhCH_2, 3H), 4.15–4.20 (m, H-3^{GalNIII}, H-5^{GalNI}, 2H), 4.25–4.31 (m, H-5^{GalNII}, H-4^{GalNII}, H-1^{Bac}, 3H), 4.36 (br s, H-4^{GalNI}, 1H), 4.43–4.57 (m, H-5^{GalNIII}, PhCH_2, 10H), 4.63 (d, *J* = 7.6 Hz, H-1^{Glc}, 1H), 4.70–4.91 (m, PhCH_2, 7H), 4.97 (d, *J* = 3.6 Hz, H-1^{GalNIII}, 1H), 5.04 (d, *J* = 3.6 Hz, H-1^{GalNII}, 1H), 5.22 (d, *J*

= 4.0 Hz, H-1^{GalNI}, 1H), 5.88 (d, *J* = 2.8 Hz, H-4^{GalNIII}, 1H), 7.04–7.06 (m, Ar, 2H), 7.11–7.40 (m, Ar, 49H), 7.62–7.65 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.94, 19.25, 26.93, 59.71, 66.18, 66.43, 66.93, 67.15, 67.53, 68.87, 69.08, 69.47, 70.96, 71.78, 71.85, 71.91, 72.24, 73.03, 73.12, 73.31, 73.54, 73.58, 74.96, 75.08, 75.17, 75.24, 75.47, 75.70, 75.95, 77.21, 77.74, 78.13, 82.42, 82.27, 96.75, 98.68, 98.83, 98.89, 104.11, 126.86, 126.91, 127.19, 127.24, 127.44, 127.48, 127.75, 127.78, 127.86, 127.90, 128.03, 128.05, 128.12, 128.16, 128.23, 128.36, 128.43, 129.65, 129.84, 132.29, 132.86, 135.63, 135.69, 137.12, 137.23, 137.43, 137.91, 138.29, 138.36; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{112}H_{118}F_5N_{15}O_{21}SiNa$, 2154.82, found 2155.91; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{112}H_{118}F_5N_{15}O_{21}SiNa$, 2154.8214, found 2154.8211.

β-anomer: $[\alpha]^{24}_D$ +73.66° (*c* 0.12, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.04 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.07 (s, *t*-Bu, 9H), 2.75 (qd, *J* = 6.4, 8.8 Hz, H-5^{Bac}, 1H), 3.03–3.06 (m, H-4^{Bac}, H-6a^{GalNIII}, 2H), 3.12-3.24 (m, H-6b^{GalNIII}, H-6a^{GalNII}, H-6a^{GalNI}, 3H), 3.26-3.30 (m, H-3^{Bac}, H-2^{Bac}, 2H), 3.34–3.42 (m, H-2^{GalNIII}, H-3^{GalNIII}, H-3^{Glc}, H-6b^{GalNI}, 4H), 3.44–3.52 (m, H-6b^{GalNII}, H-6a^{Glc}, H-2^{Glc}, H-6b^{Glc}, H-3^{GalNII}, 5H), 3.55–3.67 (m, H-4^{Glc}, H-2^{GalNI}, 2H), 3.76 (dd, *J* = 2.4, 10.8 Hz, H-3^{GalNI}, 1H), 3.84–3.94 (m, H-2^{GalNII}, H-5^{Glc}, H-5^{GalNI}, 3H), 4.02 (d, *J* = 12.0 Hz, PhCH_2, 1H), 4.12–4.17 (m, H-1^{GalNIII}, H-5^{GalNII}, PhCH_2, 3H), 4.27–4.36 (m, H-1^{Bac}, H-4^{GalNI}, H-4^{GalNII}, H-5^{GalNIII}, 4H), 4.42–4.59 (m, H-1^{Glc}, PhCH_2, 14H), 4.72 (d, *J* = 11.6 Hz, PhCH_2, 1H), 4.75 (d, *J* = 12.8 Hz,

PhCH_2, 1H), 4.85 (d, J = 12.0 Hz, PhCH_2, 1H), 5.01 (d, J = 2.8 Hz, H-1^{GalNII}, 1H), 5.25 (d, J = 4.0 Hz, H-1^{GalNI}, 1H), 5.59 (d, J = 2.8 Hz, H-$4^{GalNIII}$, 1H), 7.07–7.39 (m, Ar, 51H), 7.61–7.64 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.84, 19.15, 26.84, 59.61, 59.87, 63.33, 66.43, 66.96, 67.48, 68.05, 68.96, 69.07, 69.20, 69.51, 70.91, 71.28, 71.50, 72.03, 72.42, 72.83, 73.40, 73.61, 74.87, 75.11, 75.70, 75.89, 77.78, 78.07, 82.32, 84.26, 96.75, 98.63, 98.88, 101.50, 104.29, 127.10, 127.23, 127.35, 127.46, 127.49, 127.52, 127.61, 127.68, 127.74, 127.85, 127.92, 127.94, 128.03, 128.12, 128.20, 128.26, 128.32, 128.36, 128.42, 129.68, 129.89, 132.35, 132.94, 135.70, 135.75, 137.04, 137.30, 137.51, 137.89, 138.10, 138.23, 138.30, 138.40; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{112}H_{118}F_5N_{15}O_{21}SiNa$, 2154.82, found 2155.75.

4.28. *tert*-Butyldiphenylsilyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyl-(1→3)-2-azido-6-*O*-benzyl-2-deoxy-4-*O*-pentafluoropropionyl-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (17b).

The title compound was synthesized from **15b** and **4b** according to the procedure described for cmpound **17a** except that $CHCl_3$ was used as a solvent and that the reaction was carried out under reflux (49%, α:β = 6.7:1).

$[\alpha]^{24}_{D}$ +90.56° (*c* 1.03, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.07 (d, *J* = 6.4 Hz, H-6^{Bac}, 3H), 1.10 (s, *t*-Bu, 9H), 1.95 (s, CH_3CO, 3H), 1.97 (s, CH_3CO, 3H), 1.98 (s, CH_3CO, 3H), 2.00 (s, CH_3CO, 3H), 2.77 (qd, *J* = 6.4, 9.6 Hz, H-5^{Bac}, 1H), 2.99–3.12 (m, 3 x H-6^{GalN}, H-4^{Bac}, H-3^{Bac}, 5H), 3.28–3.36 (m, H-2^{Bac}, H-$2^{GalNIII}$, 2H), 3.52-3.72 (m, 2 x H-6^{GalN}, H-2^{GalNI}, H-2^{GalNII}, H-5^{Glc}, 5H), 3.84–3.95 (m, H-3^{GalNI}, H-3^{GalNII}, H-6^{GalN}, PhCH_2, 6H), 4.01–4.12 (m, H-6a^{Glc}, PhCH_2, 3H), 4.17–4.22 (m, H-6b^{Glc}, H-5^{GalN}, 2H), 4.28–4.30 (m, H-4^{GalN}, H-5^{GalN}, 2H), 4.31 (d, *J* = 7.6 Hz, H-1^{Bac}, 1H), 4.37–4.42 (m, H-5^{GalN}, H-4^{GalN}, 2H), 4.48 (d, *J* = 12.0 Hz, PhCH_2, 1H), 4.50 (d, *J* = 12.0 Hz, PhCH_2, 1H), 4.56 (d, *J* = 12.0 Hz, PhCH_2, 1H), 4.57 (d, *J* = 12.0 Hz, PhCH_2, 1H), 4.74 (d, *J* = 8.0 Hz, H-1^{Glc}, 1H), 4.80 (d, *J* = 12.0 Hz, PhCH_2, 1H), 4.85–4.90 (m, H-4^{Glc}, PhCH_2, 2H), 4.89 (d, *J* = 4.0 Hz, H-$1^{GalNIII}$, 1H), 5.04 (br t, *J* = 9.6 Hz, H-2^{Glc}, 1H), 5.09 (d, *J* = 3.6 Hz, H-1^{GalNII}, 1H), 5.13 (br t, *J* = 9.6 Hz, H-3^{Glc}, 1H), 5.24 (d, *J* = 3.6 Hz, H-1^{GalNI}, 1H), 5.78 (d, *J* = 2.0 Hz, H-4^{GalNI}, 1H), 7.08–7.43 (m, Ar, 33H), 7.63–7.67 (m, Ar, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.94, 19.25, 20.53, 20.72, 26.92, 29.82, 59.76, 59.82, 61.52, 65.93, 66.50, 66.87, 67.52, 67.99, 69.08, 69.36, 70.96, 71.25, 71.76, 71.92, 72.28, 72.87, 73.14, 73.30, 73.52, 74.13, 75.23, 72.94, 76.02, 78.11, 96.74, 98.06, 98.87, 98.94, 101.13, 126.79, 126.86, 127.19, 127.43, 127.59, 127.63, 127.79, 127.86, 128.09, 128.14, 128.26, 128.36, 128.45, 129.65, 129.84, 132.27, 132.84, 135.63, 135.68, 136.99, 137.06, 137.38, 137.43, 168.82, 168.99, 170.03, 170.48; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{92}H_{102}F_5N_{15}O_{25}SiNa$, 1962.67, found 1962.41; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{92}H_{102}F_5N_{15}O_{25}SiNa$, 1962.6758, found 1962.6753.

4.29. *tert*-Butyldiphenylsilyl 2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)-4-*O*-acetyl-2-azido-6-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (17c).

Compound **15b** was glycosylated with **4c** according to the procedure described for pentasaccharide **17a** to furnish the title compound as a pasty mass (66%, α:β = 5.2:1).

$[\alpha]^{24}_{D}$ +70.96° (*c* 3.05, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.06 (d, *J* = 5.6 Hz, H-6^{Bac}, 3H), 1.10 (s, *t*-Bu, 9H), 1.94 (s, C*H*$_3$CO, 3H), 2.77 (qd, *J* = 5.6, 9.2 Hz, H-5^{Bac}, 1H), 3.05–3.18 (m, H-6a^{GalNIII}, H-4^{Bac}, H-6b^{GalNIII}, H-6a^{GalNII}, 4H), 3.29–3.33 (m, H-2^{Bac}, H-3^{Bac}, 2H), 3.40–3.56 (H-2^{Glc}, H-6b^{GalNII}, H-2^{GalNIII}, 3H), 3.59–3.74 (m, H-3^{Glc}, H-2^{GalNI}, H-2^{GalNII}, H-6a^{GalNI}, H-6b^{GalNI} H-6a^{Glc}, 6H), 3.82–3.96 (m, H-4^{Glc}, H-6b^{Glc}, H-3^{GalNI}, H-3^{GalNII}, 4H), 3.99–4.23 (m, H-5^{Glc}, H-3^{GalNIII}, H-5^{GalNI}, H-5^{GalNII}, 4H), 4.27–4.41 (m, H-1^{Bac}, H-4^{GalNII}, H-4^{GalNI}, H-5^{GalNIII}, PhC*H*$_2$, 6H), 4.45–4.56 (m, PhC*H*$_2$, 7H), 4.64–4.71 (m, H-1^{Glc}, PhC*H*$_2$, 3H), 4.74–4.98 (m, PhC*H*$_2$, 7H), 5.05 (d, *J* = 3.6 Hz, H-1^{GalNII}, 1H), 5.11 (d, *J* = 3.6 Hz, H-1^{GalNIII}, 1H), 5.23 (d, *J* = 3.6 Hz, H-1^{GalNI}, 1H), 5.63 (d, *J* = 2.0 Hz, H-4^{GalNIII}, 1H), 7.14–7.40 (m, Ar, 51H), 7.63–7.67 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.81, 19.13, 20.96, 26.82, 59.63, 59.74, 60.15, 66.38, 66.56, 67.47, 68.10, 68.27, 68.54, 68.92, 68.27, 68.54, 68.92, 69.01, 69.45, 70.32, 70.89, 71.67, 71.75, 71.82, 71.98, 72.94, 73.30, 73.39,

73.51, 74.77, 74.93, 75.28, 75.42, 77.51, 78.03, 82.18, 84.47, 96.73 (2 x C-1), 98.85 (2 x C-1), 103.39, 126.90, 127.16, 127.22, 127.27, 127.32, 127.37, 127.47, 127.51, 127.60, 127.79, 127.87, 127.98, 128.03, 128.06, 128.17, 128.21, 128.29, 128.38, 128.43, 129.67, 129.87, 132.31, 132.89, 135.67, 135.72, 137.29, 137.48, 137.66, 138.08, 138.37, 138.42, 138.58, 169.28; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{111}H_{121}N_{15}O_{21}SiNa$, 2050.85, found 2050.63; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{111}H_{121}N_{15}O_{21}SiNa$, 2050.8528, found 2050.8522.

4.30. *tert*-Butyldiphenylsilyl 2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)-2-azido-6-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (5).

The title compound was obtained from compound **17** in quantitative yield upon deprotection of pentafluoropropionyl ester by NaOMe according to the procedure described for **14**.

$[\alpha]^{26}_{D}$ +133.13° (*c* 0.68, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.07 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.10 (s, *t*-Bu, 9H), 2.78 (qd, *J* = 6.0, 8.8 Hz, H-5^{Bac}, 1H), 3.03–3.11 (m, H-4^{Bac}, H-3^{Bac}, 2H), 3.15 (dd, *J* = 5.6, 8.8 Hz, H-$6a^{GalNIII}$, 1H), 3.21 (dd, *J* = 5.2, 9.2 Hz, H-$6a^{GalNII}$, 1H), 3.31 (dd, *J* = 8.0, 9.8 Hz, H-2^{Bac}, 1H), 3.48–3.56 (m, H-$6b^{GalNIII}$, H-$6a^{GalNI}$, H-2^{Glc}, H-$6a^{Glc}$, H-$6b^{Glc}$, 5H), 3.58–3.67

(m, H-2^{GalNI}, H-2^{GalNII}, H-2^{GalNIII}, H-3^{Glc}, 4H), 3.70 (br t, J = 9.6 Hz, H-6b^{GalNII}, 1H), 3.81–3.87 (m, H-3^{GalNI}, H-4^{Glc}, H-6b^{GalNI}, H-5^{Glc}, 4H), 3.93 (d, J = 12.0 Hz, PhCH_2, 1H), 4.03 (d, J = 12.0 Hz, PhCH_2, 1H), 4.07–4.10 (m, H-3^{GalNIII}, H-3^{GalNII}, 2H), 4.16 (m, H-5^{GalNI}, 1H), 4.27–4.29 (m, H-5^{GalNII}, H-4^{GalNIII}, 2H), 4.31 (d, J = 7.6 Hz, H-1^{Bac}, 1H), 4.33–4.35 (m, H-5^{GalNIII}, H-4^{GalNII}, H-4^{GalNI}, 3H), 4.43–4.55 (m, PhCH_2, 8H), 4.64 (d, J = 7.2 Hz, H-1^{Glc}, 1H), 4.72–4.79 (m, PhCH_2, 4H), 4.85–4.89 (m, PhCH_2, 3H), 5.04–5.08 (m, H-1^{GalNII}, H-1^{GalNIII}, PhCH_2, 3H), 5.23 (d, J = 3.6 Hz, H-1^{GalNI}, 1H), 7.11–7.62 (m, Ar, 51H), 7.64–7.67 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.95, 19.25, 26.94, 59.31, 59.71, 59.82, 66.51, 66.67, 67.55, 67.77, 68.22, 68.70, 69.08, 69.54, 70.97, 71.64, 71.74, 71.85, 73.03, 73.22, 73.44, 73.56, 74.54, 74.82, 74.99, 75.39, 75.63, 75.92, 77.48, 78.09, 81.77, 84.58, 96.76, 98.87, 98.88, 98.91, 103.51, 126.91, 127.20, 127.23, 127.29, 127.40, 127.44, 127.53, 127.61, 127.66, 127.79, 127.85, 127.90, 128.03, 128.15, 128.19, 128.23, 128.26, 128.36, 128.40, 129.64, 129.83, 132.32, 132.89, 135.64, 135.70, 137.32, 137.35, 137.41, 137.48, 137.67, 137.80, 137.94, 138.25, 138.30; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{109}H_{119}N_{15}O_{20}SiNa$, 2008.84, found 2009.75; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{109}H_{119}N_{15}O_{20}SiNa$, 2008.8423, found 2008.8446.

Anal. Calcd. for $C_{109}H_{119}N_{15}O_{20}Si$: C, 65.88; H, 6.04; N, 10.57. Found: C, 65.85; H, 6.15; N, 10.45.

4.31. *tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-pentafluoropropionyl-α-D-galactopyranosyl-(1→4)-[2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)]-2-azido-6-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (18).

This compound was synthesized from compound **5** (1.171 g, 0.590 mmol) and **3a** (0.449 g, 0.842 mmol) according to the procedure described in section **4.3.** (1.310 g, 89%).

$[\alpha]^{24}_{D}$ +156.90° (*c* 0.36, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.09 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.12 (s, *t*-Bu, 9H), 2.79 (qd, *J* = 6.0, 9.2 Hz, H-5^{Bac}, 1H), 3.05–3.12 (m, H-6a^{GalNIII}, H-4^{Bac}, H-3^{Bac}, H-6a^{GalNIV}, 4H), 3.15 (dd, *J* = 3.6, 10.4 Hz, H-2^{GalNIV}, 1H), 3.21 (dd, *J* = 5.2, 8.4 Hz, H-6a^{GalNII}, 1H), 3.31–3.35 (m, H-2^{GalNII}, H-2^{Bac}, 2H), 3.50–3.58 (m, H-2^{Glc}, H-6a^{GalNI}, H-6b^{GalNIII}, H-6a^{Glc}, 4H), 3.63–3.69 (m, H-2^{GalNI}, H-2^{GalNIII}, H-3^{GalNGlc}, H-6b^{GalNII}, 4H), 3.73–3.79 (m, H-6b^{Glc}, H-6b^{GalNIV}, H-4^{Glc}, 3H), 3.82–4.00 (m, H-3^{GalNIII}, H-6b^{Glc},H-3^{GalNI}, H-5^{Glc}, H-3^{GalNIV}, 5H), 4.01–4.10 (m, H-3^{GalNII}, PhCH_2, 3H), 4.21 (m, H-5^{GalNI}, 1H), 4.30–4.37 (m, H-1^{Bac}, H-5^{GalNII}, H-5^{GalNIII}, 3H), 4.37–4.45 (m, H-4^{GalNIII}, H-4^{GalNI}, H-4^{GalNII}, 3H), 4.48–4.58 (m, PhCH_2, 10H), 4.66 (d, *J* = 7.6 Hz, H-1^{Glc}, 1H), 4.69–4.81 (m, H-5^{GalNIV}, PhCH_2, 7H), 4.83 (d, *J* = 4.0 Hz, H-1^{GalNIV}, 1H), 4.85–4.95 (m, PhCH_2, 4H), 5.12 (br s, H-1^{GalNII}, H-1^{GalNIII}, 2H), 5.25 (d, *J* = 4.0 Hz, H-1^{GalNI}, 1H), 5.78 (br s, H-4^{GalNIV},

1H), 7.06–7.45 (m, Ar, 61H), 7.65–7.69 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.93, 19.24, 26.93, 59.46, 59.56, 59.70, 59.76, 65.84, 66.28, 66.55, 66.61, 67.54, 68.70, 68.86, 68.97, 69.05, 69.43, 70.96, 71.20, 71.62, 71.68, 72.01, 72.94, 73.14, 73.59, 73.73, 73.83, 74.22, 75.05, 75.41, 75.81, 76.54, 78.12, 81.90, 84.68, 96.74, 96.96, 98.85, 98.89, 99.10, 105.84, 126.95, 127.19, 127.23, 127.33, 127.43, 127.59, 127.65, 127.70, 127.81, 127.84, 127.95, 127.99, 128.07, 128.16, 128.26, 128.36, 128.40, 129.64, 129.83, 132.31, 132.86, 135.63, 135.68, 136.37, 136.94, 137.01, 137.20, 137.26, 137.40, 137.99, 138.21, 138.49, 138.58; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{132}H_{139}F_5N_{18}O_{25}SiNa$, 2521.97, found 2523.00; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{132}H_{139}F_5N_{18}O_{25}SiNa$, 2521.9746, found 2521.9718.

4.32. *tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-[2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)]-2-azido-6-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (19).

Compound **18** was treated with NaOMe according to the procedure described in section **4.16.** to give **19** as a foamy solid (quant.).

$[\alpha]^{25}_{D}$ +152.24° (*c* 0.98, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.08 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.11 (s, *t*-Bu, 9H), 2.79 (qd, *J* = 6.4, 8.8 Hz, H-5^{Bac}, 1H), 3.04–3.15 (m, H-4^{Bac}, H-3^{Bac}, H-6a^{GalNIII}, 3H), 3.20 (dd, *J* = 5.6, 8.4 Hz, H-6a^{GalNII}, 1H), 3.32 (dd, *J* = 7.6, 9.2 Hz, H-2^{Bac}, 1H), 3.41 (dd, *J* = 3.6, 10.8 Hz, H-2^{GalNII}, 1H), 3.49–3.58 (m, H-2^{GalNIV}, H-2^{Glc}, H-6a^{GalNI}, H-6a^{Glc}, 4H), 3.61–3.73 (m, H-2^{GalNI}, H-2^{GalNIII}, H-3^{Glc}, H-6b^{GalNII}, H-6a^{GalNIV}, H-6b^{GalNIV}, H-4^{Glc}, 7H), 3.79–3.88 (m, H-6b^{Glc}, H-3^{GalNI}, H-5^{Glc}, H-3^{GalNIV}, H-6b^{GalNI}, 5H), 3.91–4.08 (m, H-3^{GalNIII}, PhCH_2, H-3^{GalNII}, 4H), 4.17–4.19 (m, H-5^{GalNI}, H-4^{GalNIV}, 2H), 4.28–4.31 (m, H-5^{GalNII}, 1H), 4.32 (d, *J* = 7.6 Hz, H-1^{Bac}, 1H), 4.34–4.46 (m, H-5^{GalNIII}, H-4^{GalNIII}, H-4^{GalNI}, PhCH_2, H-5^{GalNIV}, 6H), 4.51–4.57 (m, PhCH_2, 8H), 4.61–4.75 (m, H-1^{Glc}, PhCH_2, 5H), 4.77–4.98 (m, PhCH_2, 6H), 4.99 (d, *J* = 4.4 Hz, H-1^{GalNIV}, 1H), 5.09 (d, *J* = 3.6 Hz, H-1^{GalNIII}, 1H), 5.14 (d, *J* = 4.0 Hz, H-1^{GalNII}, 1H), 5.24 (d, *J* = 3.6 Hz, H-1^{GalNI}, 1H), 7.06–7.42 (m, Ar, 61H), 7.65–7.68 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.94, 19.25, 26.93, 59.42, 59.55, 59.69, 59.95, 65.72, 66.42, 66.54, 66.66, 67.88, 68.27, 68.85, 68.99, 69.06, 69.47, 70.96, 71.48, 71.57, 71.62, 71.64, 72.94, 73.13, 73.59, 73.76, 74.34, 74.93, 74.98, 75.03, 75.24, 75.66, 75.79, 75.92, 76.40, 77.54, 78.10, 82.00, 84.62, 96.75, 97.55, 98.84, 98.89, 99.09, 105.88, 126.95, 127.06, 127.19, 127.27, 127.31, 127.44, 127.55, 127.57, 127.61, 127.67, 127.84, 127.91, 128.99, 128.02, 128.06, 128.09, 128.11, 128.17, 128.20, 128.38, 129.64, 129.83, 132.31, 132.88, 135.63, 135.69, 137.15, 137.21, 137.25, 137.43, 137.88, 138.01, 138.30, 138.64, 138.68; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{129}H_{140}N_{18}O_{24}SiNa$, 2375.99, found 2375.98;

HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{129}H_{140}N_{18}O_{24}SiNa$, 2375.9955, found 2375.9996.

Anal. Calcd. for $C_{129}H_{140}N_{18}O_{24}Si$: C, 65.80; H, 6.04; N, 10.57. Found: C, 65.85; H, 6.05; N, 10.61.

4.33. *tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-pentafluoropropionyl-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-[2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)]-2-azido-6-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (20).

Reaction between compound **19** (0.187 g, 0.0794 mmol) and **3a** (0.063 g, 0.118 mmol) was conducted according to the procedure described in section **4.3.** to give the title compound (0.187 g, 82%) as a semi-solid.

$[\alpha]^{26}_D$ +165.8° (*c* 0.32, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.08 (d, *J* = 5.6 Hz, H-6^{Bac}, 3H), 1.11 (s, *t*-Bu, 9H), 2.78 (qd, *J* = 6.0, 8.0 Hz, H-5^{Bac}, 1H), 3.02–3.21 (m, H-$6a^{GalNIV}$, H-4^{Bac}, H-3^{Bac}, H-$6a^{GalNIII}$, H-$6b^{GalNIV}$, H-$6a^{GalNII}$, 6H), 3.24 (dd, *J* = 3.6, 10.8 Hz, H-2^{GalNV}, 1H), 3.29–3.36 (m, H-2^{Bac}, H-2^{GalNIV}, H-2^{GalNII}, 3H), 3.48–3.55 (m, H-$6b^{GalNIII}$, H-$6a^{GalNI}$, H-$6a^{Glc}$, 3H), 3.57–3.67 (m, H-

2^{Glc}, H-2^{GalNI}, H-$2^{GalNIII}$, H-6b^{Glc}, H-6b^{GalNII}, H-3^{Glc}, 6H), 3.70–3.90 (m, H-6a^{GalNV}, H-4^{Glc}, H-6b^{GalNV}, H-6b^{GalNI}, H-3^{GalNI}, H-3^{GalNIV}, H-5^{Glc}, 7H), 3.91–4.07 (m, H-$3^{GalNIII}$, H-3^{GalNIV}, PhCH_2, H-3^{GalNII}, 5H), 4.16–4.19 (m, H-5^{GalNI}, 1H), 4.24 (br s, H-4^{GalNIV}, 1H), 4.27–4.31 (m, H-5^{GalNII}, 1H), 4.32 (d, J = 8.0 Hz, H-1^{Bac}, 1H), 4.35–4.49 (m, H-$5^{GalNIII}$, H-$4^{GalNIII}$, H-4^{GalNI}, PhCH_2, H-4^{GalNII}, 5H), 4.51–4.68 (m, H-5^{GalNIV}, H-5^{GalNV}, PhCH_2, 15H), 4.71–4.76 (m, PhCH_2, H-1^{Glc}, 5H), 4.78 (d, J = 3.6 Hz, H-1^{GalNV}, 1H), 4.81–4.88 (m, PhCH_2, 4H), 4.97 (d, J = 10.8 Hz, PhCH_2, 1H), 5.00 (d, J = 3.2 Hz, H-1^{GalNIV}, 1H), 5.08–5.11 (m, PhCH_2, H-$1^{GalNIII}$, H-1^{GalNII}, 3H), 5.23 (d, J = 3.6 Hz, H-1^{GalNI}, 1H), 5.80 (br s, H-4^{GalNV}, 1H), 7.06–7.41 (m, Ar, 71H), 7.64–7.68 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.94, 19.25, 26.93, 59.45, 59.56, 59.64, 59.85, 60.24, 65.81, 66.52, 67.54, 68.75, 69.00, 69.07, 69.46, 70.97, 71.09, 71.62, 72.03, 72.51, 72.92, 73.16, 73.31, 73.48, 73.59, 73.92, 74.79, 74.93, 75.09, 75.26, 75.67, 75.83, 75.98, 78.11, 82.46, 84.52, 96.75, 97.31, 98.37, 98.86, 99.01, 105.47, 126.93, 127.02, 127.16, 127.19, 127.44, 127.49, 127.58, 127.70, 127.75, 127.78, 127.83, 128.03, 128.07, 128.09, 128.14, 128.17, 128.21, 128.36, 128.41, 128.68, 129.64, 129.84, 132.88, 135.63, 135.69, 136.41, 137.05, 137.09, 137.17, 137.26, 137.44, 137.97, 138.25, 138.59, 138.66; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{152}H_{160}F_5N_{21}O_{29}SiNa$, 2889.12, found 2890.37; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{152}H_{160}F_5N_{21}O_{29}SiNa$, 2889.1278, found 2889.1261.

Anal. Calcd. for $C_{152}H_{160}F_5N_{21}O_{29}Si$: C, 63.65; H, 5.62; N, 10.26. Found: C, 63.63; H, 5.71; N,

10.20.

4.34. *tert*-Butyldiphenylsilyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-[2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)]-2-azido-6-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diazido-2,4,6-trideoxy-β-D-glucopyranoside (6).

The title compound was obtained in quantitative yield from compound **20** upon methanolysis of PFP ester according to the procedure described in section **4.16.**

$[\alpha]^{27}_{D}$ +149.61° (*c* 0.26, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.07 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.11 (s, *t*-Bu, 9H), 2.79 (qd, *J* = 6.4, 8.4 Hz, H-5^{Bac}, 1H), 2.92 (br s, GalN^{V}-4-O*H*, 1H), 3.04–3.12 (m, H-4^{Bac}, H-3^{Bac}, H-6a^{GalNIV}, 3H), 3.17–3.23 (m, H-6a^{GalNIII}, H-6a^{GalNV}, 2H), 3.29–3.33 (m, H-2^{Bac}, H-2^{GalNII}, 2H), 3.38 (dd, *J* = 3.2, 10.8 Hz, H-2^{GalNIV}, 1H), 3.41–3.48 (m, H-6b^{GalNV}, H-6b^{GalNIV}, 2H), 3.50–3.54 (m, H-2^{Glc}, H-6a^{GalNI}, H-6a^{Glc}, 3H), 3.57–3.60 (m, H-3^{Glc}, H-2^{GalNI}, 2H), 3.62–3.67 (m, H-6b^{GalNIII}, H-6b^{Glc}, H-2^{GalNIII}, H-2^{GalNV}, 4H), 3.75–3.92 (m, H-4^{Glc}, H-6a^{GalNV}, H-6b^{GalNI}, H-3^{GalNI}, H-3^{GalNIV}, H-5^{Glc}, H-6b^{GalNV}, H-3^{GalNV}, H-3^{GalNIII}, 9H), 3.94–4.07 (m, H-3^{GalNII}, PhCH_2, 3H), 4.14–4.28 (m, H-5^{GalNI}, H-4^{GalNV}, H-5^{GalNII}, H-4^{GalNI}, H-5^{GalNIII}, PhCH_2, 7H), 4.32 (d, *J* = 8.0 Hz, H-

1^{Bac}, 1H), 4.36–4.39 (m, H-5^{GalNIV}, H-4^{GalNIII}, H-4^{GalNV}, PhCH_2, 5H), 4.42–4.55 (m, PhCH_2, H-2^{GalNIV}, H-4^{GalNV}, 10H), 4.57–4.68 (m, PhCH_2, H-1^{Glc}, 7H), 4.71–4.88 (m, PhCH_2, 5H), 4.89 (d, J = 3.6 Hz, H-1^{GalNV}, 1H), 4.96 (d, J = 10.8 Hz, PhCH_2, 1H), 5.01 (d, J = 4.0 Hz, H-1^{GalNIV}, 1H), 5.09 (br s, H-1^{GalNIII}, H-1^{GalNII}, 2H), 5.23 (d, J = 3.6 Hz, H-1^{GalNI}, 1H), 7.07–7.41 (m, Ar, 71H), 7.64–7.67 (m, Ar, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 17.94, 19.24, 26.93, 59.27, 59.56, 59.68, 60.19, 66.31, 66.56, 66.72, 67.54, 68.17, 68.88, 69.06, 69.15, 69.37, 69.47, 70.96, 71.33, 71.44, 71.59, 72.27, 72.92, 73.16, 73.47, 73.59, 73.91, 74.59, 74.94, 75.15, 75.23, 75.32, 75.75, 76.09, 78.10, 82.52, 84.55, 96.75, 97.35, 98.88, 99.03, 105.53, 126.93, 127.02, 127.19, 127.38, 127.44, 127.57, 127.70, 127.78, 127.82, 128.01, 128.04, 128.07, 128.17, 128.22, 128.36, 128.39, 128.53, 128.65, 128.88, 129.64, 129.83, 130.72, 132.31, 132.88, 135.63, 135.69, 137.09, 137.18, 137.24, 137.47, 137.99, 138.28, 138.63; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{149}H_{161}N_{21}O_{28}SiNa$, 2743.14, found 2744.16; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{149}H_{161}N_{21}O_{28}SiNa$, 2743.1487, found 2744.1447.

4.35. *tert*-Butyldiphenylsilyl 2-acetamido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-acetamido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-[2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl-(1→3)]-2-acetamido-6-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-acetamido-3,6-di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→4)-2-acetamido-3,6-

di-*O*-benzyl-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diacetamido-2,4,6-trideoxy-β-D-glucopyranoside (22).

A solution of compound **6** (29.8 mg, 10.95 μmol) in THF–H_2O (3:1, 6.0 mL) was cooled to ice-water temperature. To the solution was added $CoCl_2 \cdot (H_2O)_6$ (4.4 mg, 0.016 mmol) followed by slow addition of an aqueous solution of $NaBH_4$ (6.0 mg, 0.16 mmol in 1 mL water). The mixture was stirred from ice-bath to ambient temperature for 4 h. Monitoring of the reaction by MALDI-TOF MS revealed the reduction of seven azides to amines. Then reaction mixture was again cooled to ice-bath temperature followed by addition of Ac_2O (1.0 mL). The stirring was continued for 6 h and then THF was removed under reduced pressure. The crude mixture was diluted with $CHCl_3$ and washed with sat. $NaHCO_3$ (aq.), water and brine successively, and dried over Na_2SO_4. The concentrated crude product was purified by preparative thin layer chromatography (chloroform–methanol, 10:1) to afford the title compound (R_f = 0.55) as white solid (19.1 mg, 62%).

$[\alpha]^{24}_D$ +98.95° (*c* 0.42, CH_2Cl_2); ^{1}H NMR (CD_3OD, 400 MHz): δ 0.98 (d, *J* = 5.6 Hz, H-6^{Bac}, 3H), 1.03 (s, *t*-Bu, 9H), 1.76 (s, C*H*$_3$CONH, 3H), 1.83 (s, C*H*$_3$CONH, 3H), 1.84 (s, C*H*$_3$CONH, 3H), 1.86 (s, C*H*$_3$CONH, 3H), 1.89 (s, C*H*$_3$CONH, 3H), 1.91 (s, C*H*$_3$CONH, 3H), 1.99 (s, C*H*$_3$CONH, 3H), 2.98 (qd, *J* = 5.6, 8.8 Hz, H-5^{Bac}, 1H), 3.11–3.25 (m, H-4^{Bac}, H-3^{Bac}, 2 x H-6^{GalNAc}, 4H),

3.29–3.48 (m, H-2^{Bac}, 2 x H-6^{GalNAc}, 3H), 3.50–3.69 (m, H-3^{GalNAcII} , H-2^{Glc}, H-4^{Glc}, H-6^{GalNAc} x 3, 6H), 3.72–3.86 (m, H-3^{GalNAcI}, H-3^{GalNAcIII}, H-6^{Glc}, H-3^{Glc}, H-6^{GalNAc}, 5H), 3.88–4.16 (m, H-4^{GalNAcIII}, H-3^{GalNAcIV}, H-6^{Glc}, H-5^{Glc}, H-6^{GalNAc}, H-5^{GalNAc}, 6H), 4.19–4.38 (m, H-4^{GalNAcIV}, H-4^{GalNAcI}, H-4^{GalNAcII}, H-5^{GalNAc}, 4H), 4.44 (d, *J* = 7.2 Hz, H-1^{Bac}, 1H), 4.45–4.75 (m, 2 x H-6^{GalNAc}, 5 x H-2^{GalNAc}, H-4^{GalNAcV}, H-5^{GalNAc}, 9H), 4.77 (d, *J* = 8.0 Hz, H-1^{Glc}, 1H), 4.78–4.89 (m, H-5^{GalNAc} x 2, 2H), 3.90–4.89 (m, PhCH_2 x 13, 26H), 5.07 (br s, H-1^{GalNAc} x 3, 3H), 5.09 (d, *J* = 3.6 Hz, H-1^{GalNAc}, 1H), 5.12 (d, *J* = 3.2 Hz, H-1^{GalNAc}, 1H), 7.07–7.40 (m, Ar, 69H), 7.62–7.68 (m, Ar, 6H); ^{13}C NMR (CD_3OD, 100 MHz): δ 17.74, 20.05, 22.98, 23.03, 23.08, 23.27, 23.35, 23.42, 23.51, 27.41, 50.29, 51.06, 51.30, 66.55, 67.80, 67.96, 69.47, 69.75, 69.91, 70.01, 70.35, 70.88, 72.03, 72.60, 72.92, 73.02, 73.16, 73.40, 73.61, 74.00, 74.16, 74.37, 75.72, 76.33, 76.40, 76.82, 77.15, 77.33, 77.79, 78.80, 84.00, 85.81, 97.02, 97.67, 99.04, 99.28, 99.56, 106.27, 127.47, 127.68, 128.11, 128.16, 128.18, 128.30, 128.39, 128.42, 128.48, 128.61, 128.81, 128.89, 128.96, 129.00, 129.03, 129.08, 129.15, 129.20, 129.24, 129.32, 129.39, 130.67, 130.73, 134.21, 136.85, 138.66, 138.68, 139.09, 139.20, 139.41, 139.55, 139.69, 139.75, 139.78, 139.83, 139.89, 139.99, 172.55, 172.78, 173.08, 173.19, 173.27, 173.45, 174.00; MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{163}H_{189}N_7O_{35}SiNa$, 2855.28, found 2855.42; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{163}H_{189}N_7O_{35}SiNa$, 2855.2892, found 2855.2841.

4.36. *tert*-Butyldicyclohexylsilyl 2-acetamido-2-deoxy-α-D-galactopyranosyl-(1→4)-2-acetamido-2-deoxy-α-D-galactopyranosyl-(1→4)-[β-D-glucopyranosyl-(1→3)]-2-acetamido-

2-deoxy-α-D-galactopyranosyl-(1→4)-2-acetamido-2-deoxy-α-D-galactopyranosyl-(1→4)-2-acetamido-2-deoxy-α-D-galactopyranosyl-(1→3)-2,4-diacetamido-2,4,6-trideoxy-β-D-glucopyranoside (23).

To a stirred solution of compound **22** (13.6 mg, 4.80 μmol) in CH_3OH–H_2O (1:1, 6 mL) was added 20% $Pd(OH)_2/C$ (28 mg) and the mixture was stirred at 50 °C for 98 h under hydrogen atmosphere and then filtered through Celite pad. The crude was concentrated under reduced pressure and crude product was subjected to reverse phase chromatographic purification (Sep-pak, C_{18}) by using a gradient solvent mixture of degassed water and methanol (1:0 to 0:1). Fraction was monitored by mass spectrum analysis and proper fraction was concentrated to afford the title compound as a white solid (3.4 mg, 42%).

^{1}H NMR (CD_3OD:D_2O, 1:1, 50 °C, 400 MHz): δ 0.95 (s, *t*-Bu, 9H), 1.16 (d, *J* = 6.0 Hz, H-6^{Bac}, 3H), 1.17–1.35 (m, cyclohexyl, 15H), 1.71–1.83 (m, cyclohexyl, 7H), 1.88 (s, C*H*$_3$CONH, 3H), 1.94 (s, C*H*$_3$CONH, 3H), 1.99 (s, C*H*$_3$CONH, 3H), 2.03 (s, C*H*$_3$CONH, 3H), 2.04 (s, C*H*$_3$CONH, 3H), 2.05 (s, C*H*$_3$CONH, 3H), 2.06 (s, C*H*$_3$CONH, 3H), 3.25–3.35 (m, H-5^{Glc}, H-6^{Glc}, H-4^{Bac}, H-5^{Bac}, 5H), 3.50-3.92 (m, H-3^{GalNAcI}, H-6^{GalNAcI}, H-6^{GalNAcII}, H-6^{GalNAcIII}, H-6^{GalNAcIV}, H-6^{GalNAcV}, H-2^{Glc}, H-3^{Glc}, H-4^{Glc}, H-2^{Bac}, H-3^{Bac}, 16H), 3.95 (dd, *J* = 11.2, 3.2 Hz, H-3^{GalNAcIII}, 1H), 4.00–4.15 (m, H-3^{GalNAcII}, H-3^{GalNAcIV}, H-3^{GalNAcV}, H-4^{GalNAcI}, H-4^{GalNAcII}, H-4^{GalNAcIII}, H-4^{GalNAcV}, 7H),

4.22–4.30 (m, H-2^{GalNAcI}, H-2^{GalNAcII}, H-2^{GalNAcIII}, H-2^{GalNAcV}, 4H), 4.30–4.45 (m, H-5^{GalNAc} x 5, 5H), 4.34 (br s, H-4^{GalNAcIV}, 1H), 4.40 (d, J = 7.6 Hz, H-1^{Bac}, 1H), 4.52–4.61 (m, H-2^{GalNAcIV}, 1H), 4.78 (d, J = 8.0 Hz, H-1^{Glc}, 1H), 5.00 (d, J = 2.8 Hz, H-1^{GalNAcV}, 1H), 5.01 (d, J = 2.8 Hz, H-1^{GalNAcIV}, 1H), 5.04 (d, J = 4.0 Hz, H-1^{GalNAcIII}, 1H), 5.11 (d, J = 3.6 Hz, H-1^{GalNAcII}, 1H), 5.17 (d, J = 3.6 Hz, H-1^{GalNAcI}, 1H); MALDI-TOF MS: $[M+Na]^+$ calcd for $C_{72}H_{123}N_7O_{35}SiNa$, 1696.77, found 1696.58; HRMS ESI-TOF: $[M+Na]^+$ calcd for $C_{72}H_{123}N_7O_{35}SiNa$, 1696.7727, found 1696.7768.

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References and Notes

1. Dwek, R. A. *Chem. Rev.* **1996**, *96*, 683-720.

2. Varki, A.; Cummings, R.; Esko, J.; Freeze, H.; Hart, G.; Marth, J. ed. *Essentials in*

Glyocbiology, Cold Spring Harbor Laboratory Press, New York, **1999**.

3. Benz, I.; Schmidt, M. A. *Mol. Microbiol.* **2002**, *45*, 267-276.

4. Wacker, M.; Linton, D.; Hitchen, P. G.; Nita-Lazar, M.; Haslam, S. M.; North, S. J.; Panico, M.; Morris, H. R.; Dell, A.; Wren, B. W.; Aebi, M. *Science* **2002**, *298*, 1790-1793.

5. Young, N. M.; Brisson, J-R.; Kelly, J.; Watson, D. C.; Tessier, L.; Lanthier, P. H.; Jarrell, H. C.; Cadotte, N.; Michael, F. St.; Aberg, E.; Szymanski, C. M. *J. Biol. Chem.* **2002**, *227*, 42530-42539.

6. (a) Nita-Lazar, M.; Wacker, M.; Schegg, B.; Amber, S.; Aebi, M. *Glycobiology* **2005**, *15*, 361-367. (b) Kowarik, M.; Young, N. M.; Numao, S.; Schulz, B. L.; Hug, I.; Callewaert, N.; Mills, D. C.; Hernandez, M.; Kelly, J. F.; Wacker, M.; Aebi, M.*EMBO J.* **2006**, *25*, 1-10.

7. (a) Szymanski, C. M.; Logan, S. M.; Linton, D.; Wren, B. W. *Trends Microbiol.* **2003**, *11*, 233-238. (b) Weerapana, E.; Imperiali, B. *Glycobiology* **2006**, *16*, 91R-101R.

8. (a) Feldman, M. F.; Wacker, M.; Hernandez, M.; Hitchen, P. G.; Marolda, C. L.; Kowarik, M.; Morris, H. R.; Dell, A.; Valvano, M. A.; Aebi, M. *Proc. Nat. Acad. Sci.* **2005**, *102*, 3016-3021. (b) Wacker, M.; Feldman, M. F.; Callewaert, N.; Kowarik, M.; Clarke, B. R.; Pohl, N. L.; Hernandez, M.; Vines, E. D.; Valvano, M. A.; Aebi, M. *Proc. Nat. Acad. Sci.* **2006**, *103*, 7088-

7093.

9. (a) Glover, K. J.; Weerapana, E.; Imperiali, B. *Proc. Nat. Acad. Sci.* **2005**, *102*, 14255-14259.

(b) Weerapana, E.; Glover, K. J.; Chen, M. M.; Imperiali, B. *J. Am. Chem. Soc.* **2005**, *127*, 13766-13767.

10. Glover, K. J.; Weerapana, E.; Numao, S.; Imperiali, B. *Chem. Biol.* **2005**, *12*, 1311-1316.

11. Szymanski, C. M.; Burr, D. H.; Guerry, P. *Infect. Immun.* **2002**, *70*, 2242-2244.

12. van Vliet, A. H. M.; Ketley, J. M. *J. Appl. Microbiol.* **2001**, *90*, 45S-56S.

13. For review, see; Nachamkin, I.; Allos, B. M.; Ho, T. *Clin. Microbiol. Rev.* **1998**, *11*, 555-567.

14. Ishiwata, A.; Ohta, S.; Ito, Y. *Carbohydr. Res.* **2006**, *341*, 1557-1573.

15. Amin, M. N.; Ishiwata, A.; Ito, Y. *Carbohydr. Res.*, **2006**, *341*, 1922-1929.

16. Nakahara, Y.; Iijima, H.; Shibayama, S.; Ogawa, T. *Carbohydr. Res.* **1991**, *216*, 211-225.

17. Lemieux, R. U.; Ratcliffe, M. M. *Can. J. Chem.* **1979**, *57*, 1244-1251.

18. Review, see; Arsequell, G.; Valencia, G. *Tetrahedron Asym.* **1997**, *8*, 2839-2876.

19. Review for the synthesis of 1,2-cis glycoside, see; Demchenko, A. V. *Synlett* **2003**, 1225-1240.

20. (a) Imamura, A.; Ando, H.; Korogi, S.; Tanabe, G.; Muraoka, O.; Ishida, H.; Kiso, M. *Tetrahedron Lett*. **2003**, *44*, 6725-6727. (b) Imamura, A.; Kimura, A.; Ando, H.; Ishida, H.; Kiso, M. *Org*. *Lett*. **2005**, 7, 4415-4418. (c) Imamura, A.; Kimura, A.; Ando, H.; Ishida, H.; Kiso, M. *Chem*. *Eur. J*. **2006**, *12*, 8862-8870.

21. Manabe, S.; Ishii, K.; Ito, Y. *J*. *Am*. *Chem*. *Soc*. **2006**, *128*, 10666-10667.

22. Takatani, M.; Matsuo, I.; Ito, Y. *Carbohydrate Res*. **2003**, *338*, 1073-1081; Takatani, M.; Ito, Y. *Chem*. *Asian J*. **2006**, *1*, 64-75.

23. (a) Matsumoto, T.; Maeta, H.; Suzuki, K.; Tsuchihashi, G. *Tetrahedron Lett*. **1988**, *29*, 3567-3570. (b) Matsumoto, T.; Maeta, H.; Suzuki, K.; Tsuchihashi, G. *Tetrahedron Lett*. **1988**, *29*, 3571-3574. (c) Suzuki, K.; Maeta, H.; Matsumoto, T. *Tetrahedron Lett*. **1989**, *30*, 4853-4856. (d) Suzuki, K.; Maeta, H.; Suzuki, T.; Matsumoto, T. *Tetrahedron Lett*. **1989**, *30*, 6879-6882.

24. For recent examples, see; (a) De Meo, C.; Kamat, M. N.; Demchenko, A. V. *Eur. J*. *Org*. *Chem*. **2005**, 706-711. (b) Chiba, S.; Kitamura, M.; Narasaka, K. *J*. *Am*. *Chem*. *Soc*. **2006**, *128*, 6931-6937.

25. Tsvetkov, Y. E.; Shashkiv, A. S.; Knirel, Y. A. ; Zähringer, U. *Carbohydrate Res*. **2001**, *335*, 221-243.

26. Fristad, W.-E.; Brandvald, T. A.; Peterson, J. R.; Thompson, S. R. *J. Org. Chem.* **1985**, *53*, 1580-1582.

27. Corey, E. J.; Nicolaou, K. C.; Balanson, R. D.; Machida, Y. *Synthesis* **1975**, 590.

28. Fringuelli, F.; Pizzo, F.; Vaccaro, L. *Synthesis* **2000**, *5*, 646-650.

29. Schlesinger, H. I.; Brown, H. C.; Finholt, A. E.; Gilbreath, J. R.; Hoekstra, H. R.; Hyde, E. K. *J. Am. Chem. Soc.* **1953**, *75*, 215-219.

Table 1. Glycosylation of diazide **2** with GalN donor **3**.

entry[a)]	**3**	solvent	time (h)	yield (α:β)	recovery of **5**	Δ_{Rf}[b)]
1	**a**	$CHCl_3$	42	41% (4.3:1)	53%	0.30
2	**a**	toluene	42	67% (4.6:1)	26%	–
3	**a**	CCl_4	96	60% (3.3:1)	31%	–
4	**a**	$(CH_2Cl)_2$	42	46% (6.1:1)	48%	–
5	**a**	benzene	42	63% (8.1:1)	33%	–
6[c)]	**a**	benzene	5.5	83% (7.3:1)	11%	–
7[d)]	**a**	benzene	6	89% (6.1:1)	0%	–
8	**b**	$CHCl_3$	42	58% (3.0:1)	33%	0.02
9	**c**	$CHCl_3$	42	66% (3.5:1)	26%	0.10
10	**e**	$CHCl_3$	42	40% (3.8:1)	54%	0.09
11	**f**	$CHCl_3$	42	15% (8.1:1)	76%	0.07
12	**g**	$CHCl_3$	42	55% (10:1)	41%	0.01
13	**g**	toluene	42	58% (12:1)	33%	–

[a] Cp_2HfCl_2 (2.0~2.6 equiv.) and $AgClO_4$ (4.0~5.2 equiv.) were used. [b] $R_f(\alpha)$–$R_f(\beta)$; TLC was developed with toluene:ethyl acetate, 50:1. [c] A mixture of Cp_2HfCl_2–$AgClO_4$ (1:4) was used. [d] 1.4 equiv. of **3a** was used as a mixture of α- and β-anomers (1:2.2).

Table 2. Glycosylation with **3a** and disaccharide donor **4**.

entry[a)]	donor (equiv.)	acceptor	solvent	temp.	time (h)	product	yield (α:β)
1	**3a** (1.2)	**16a**	$CHCl_3$	r.t.	42	**16b**	80% (19:1)
2	**4b** (1.2)	**16a**	$CHCl_3$	r.t.	42	**16c**	50% (4.0:1)
3	**4b** (1.2)	**16a**	$CHCl_3$	reflux	42	**16c**	72% (4.9:1)
4	**4b** (1.2)	**15b**	$CHCl_3$	reflux	50	**17b**	49% (6.7:1)
5	**4a** (1.4)	**15b**	$CHCl_3$	r.t.	13	**17a**	64% (12:1)
6	**4a** (1.4)	**15b**	benzene	r.t.	12	**17a**	67% (14:1)
7	**4c** (1.4)	**15b**	benzene	r.t.	12	**17c**	66% (5.2:1)

[a]1:2 ratio of Cp_2HfCl_2 (2.0-2.6 equiv.) and $AgClO_4$ (4.0-5.2 equiv.) were used.

Fig. 1. *C. jejuni N*-glycan; structure (**A**) and synthetic design (**B**).

Scheme 1. Reagents and conditions; a) HF, THF, 97%; b) DAST, 91%; b) Cp_2HfCl_2, $AgClO_4$, benzene, r.t., 4 h, 39%, α:β = 3.53:1.

Scheme 2. Reagents and conditions; a) BnBr, NaH, TBAI, 95%; b) $NaBH_3CN$, HCl, 97% (**7**); c) NAPBr, NaH, 91% (**8**); d) HF, THF, 96% (**9**); e) DAST, 91% (**3c**); f) pyridine, EtOH, r.t., 55 h, 92% (**3d**); g) MBzCl, pyridine, r.t., 6 h, 84% (**3e**); h) DMBzCl, pyridine, r.t., 8 h, 74% (**3f**); i) TMBzCl, pyridine, 50 °C, 1 h, 69% (**3g**).

Scheme 3. Reagents and conditions; a) NaOMe, MeOH, quant.; b) **3a**, Cp_2HfCl_2, $AgClO_4$, benzene, r.t., 5.5 h 98%, α:β = 95:5; c) **4a**, Cp_2HfCl_2, $AgClO_4$, benzene, r.t., 12 h, 63%; d) **3a**, Cp_2HfCl_2, $AgClO_4$, benzene, r.t., 8.5 h, 89% (**18**), 82%, (**20**); e) $CoCl_2{\cdot}(H_2O)_6$, $NaBH_4$, THF–H_2O; then Ac_2O, 62%; d) $Pd(OH)_2$, H_2, MeOH–H_2O, 50 °C, 42%.

Scheme 4. Reagents and conditions; a) NaOMe, MeOH, quant; b) BnBr, NaH, 81%; c) $NaBH_3CN$, HCl, 93%; d) PFP_2O, pyridine, 97%; e) HF, THF, 94%; f) DAST, 92%; g) 1) pyridine, EtOH, 91%, 2) Ac_2O, pyridine, 91%.