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# A New Method of Carbohydrate Synthesis in Both Solution and Solid Phases Using a Special Hydroxy Protecting Group

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A new carbohydrate synthesis method using a special hydroxy protecting group (uni-chemo protection = UCP) in both solution and solid phases was developed. The UCP group was comprised of polymerized amino acid derivatives. Each hydroxyl group was protected by a UCP group with a different degree of polymerization, which allowed them to be uniquely identified. To deprotect the UCP group, one cycle of Edman degradation was performed as follows: 1) removal of the amino protecting group; 2) phenyl isothiocyanate coupling; 3) removal of the *N*-terminal phenyl thiocarbamoyl mono-amino acid derivative by treatment with trifluoroacetic acid; and 4) re-protection of the newly exposed amino group with a Boc group. The hydroxyl groups were deprotected successively from the UCP group with the lowest to the highest degree of polymerization by repeating this Edman degradation cycle. First, commercially available *N*-α-*t*-Boc-sarcosine, *N*-α-*t*-Boc-*N*-α-methyl-L-alanine, and *N*-α-*t*-Boc-L-phenylglycine were examined as UCP groups. Despite successfully protecting and selectively deprotecting the hydroxyl groups, there were problems with stability or reactivity. To address these problems, *N*-α-1-ethylpropylglycine was chosen as the UCP group, and we successfully synthesized two sialyl-T antigen analogues. Tri-UCP and mono-UCP were attached to the 6- and 3-positions of the D-galactosamine (GalN) derivative, respectively, using cyanuric chloride. To selectively deprotect the mono-UCP group on the 3-position of the GalN derivative, one cycle of Edman degradation was performed. As a result of this cycle, the tri-UCP on the 6-position of the GalN derivative was degraded to di-UCP, and the mono-UCP on the 3-position was selectively deprotected to yield a GalN derivative with a free 3-position. Glycosylation of this selectively deprotected free 3-position GalN derivative with a suitably protected D-galactose (Gal) derivative in which the 3-position was protected by a mono-UCP group using *N*-iodosuccinimide (NIS) and trifluoromethanesulfonic acid (TfOH) in dichloromethane yielded the desired disaccharide in high yield in both a position- and stereoselective manner. By repeating one cycle of Edman degradation, the 3′-position-free disaccharide in which the 6-position was protected by a mono-UCP group was prepared selectively. Subsequent acetylation and a final cycle of Edman degradation (except the third and fourth steps) yielded the 6-position-free disaccharide selectively. Two disaccharides, one with a free 3′-position and another with a free 6-position, were coupled with a sialic acid donor using NIS and TfOH in acetonitrile to obtain sialyl (2→3) T and sialyl (2→6) T antigen derivatives, respectively. Solid-phase synthesis was demonstrated using polystyrene-type beads and a new linker, 2-{4-(hydroxymethyl)benzamido}acetic acid (HMBA-Gly), to synthesize Galβ (1→3) Gal from a suitably protected Gal derivative in which the 3-position was protected by mono-UCP. Solid-phase glycosylation was successfully monitored by measuring the removal of the Fmoc group, which protected the amino group on UCP, similar to the method for monitoring solid-phase Fmoc peptide synthesis. This UCP hydroxy protecting group was suitable for solid-phase synthesis, and will be the key technique in both automated oligosaccharide synthesis and oligosaccharide library synthesis. 

## 1. Introduction

A large number of hydroxy protecting groups for carbohydrate synthesis have been developed and used successfully for oligosaccharide synthesis.[1–4] Despite the availability of such large numbers of protecting groups, oligosaccharide synthesis is still quite laborious. For glycosylation reactions, the hydroxyl groups on both the acceptor and donor must be differentiated and protected selectively. The product must then be selectively deprotected for the next round of reactions. At present, the best method for synthesis of oligosaccharides is the orthogonal method.[1,5,6] For orthogonal synthesis of oligosaccharides, a hydroxy protecting group that can be deprotected using a special reagent is used. These special reagents do not influence other protecting groups, and selectively react with and remove the desired protecting group. However, increasing the number of saccharide coupling steps also increases the number of orthogonal protecting groups. Unsurprisingly, because of the limited number of such orthogonal protecting groups, these can not be applied to complicated, branched oligosaccharide synthesis. For this reason, there is no generally applicable method for oligosaccharide synthesis. The develop-

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ment of an optimal hydroxy protecting group for solid-phase carbohydrate synthesis would facilitate both carbohydrate library synthesis and automated carbohydrate synthesis. To establish a general method for solid-phase carbohydrate synthesis, a new concept of hydroxy group protection is required.

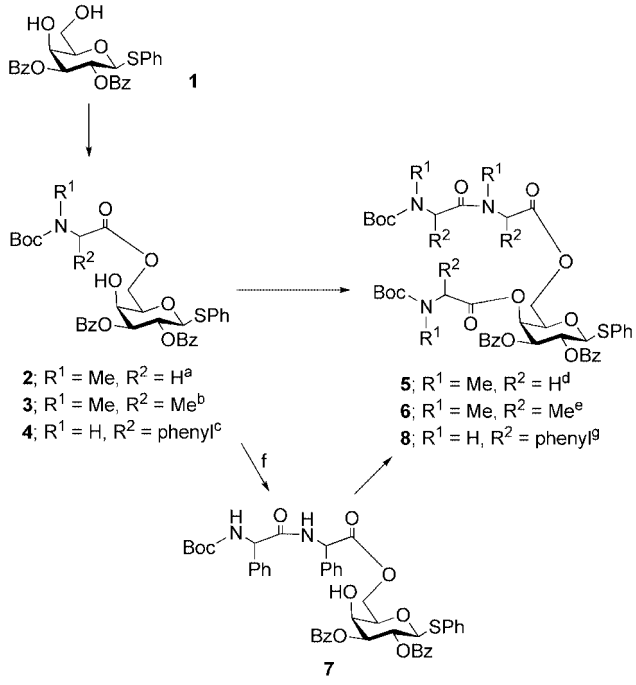
Recently, Miranda and Meldal reported the concept of uni-chemo protection (UCP).[7] UCP is comprised of an amino acid polymer, which attaches to and protects the amino group. The individual amino groups have a different degree of amino acid polymerization. Deprotection of this protecting group is performed by Edman degradation,[8] which removes only the *N*-terminal amino acid from all UCP groups. Depending on the degree of polymerization of the amino acid protecting group, each amino group can be characterized and controlled. We applied this concept to hydroxy protection for oligosaccharide synthesis. To protect individual hydroxyl groups on the carbohydrate, amino acids with different degrees of polymerization were attached by ester linkages. In addition, the polymerized amino acid protecting groups were removed successively from the *N*-terminus using the Edman degradation method. Each hydroxyl group can be characterized and controlled using only one kind of protecting group and one deprotection method.[9]

To demonstrate the utility of this concept, three experiments were performed. In the first experiment, we examined the reactivity of the amino acid derivatives that comprise the UCP group. In the second experiment, we examined the synthesis of two kinds of sialyl-T antigens[10] using a UCP group. The third experiment was performed to examine solid-phase oligosaccharide synthesis using a UCP group.

## 2. Results and Discussion

### 2.1. Examination of the Reactivity of the Amino Acid Derivatives that Comprise the UCP Group

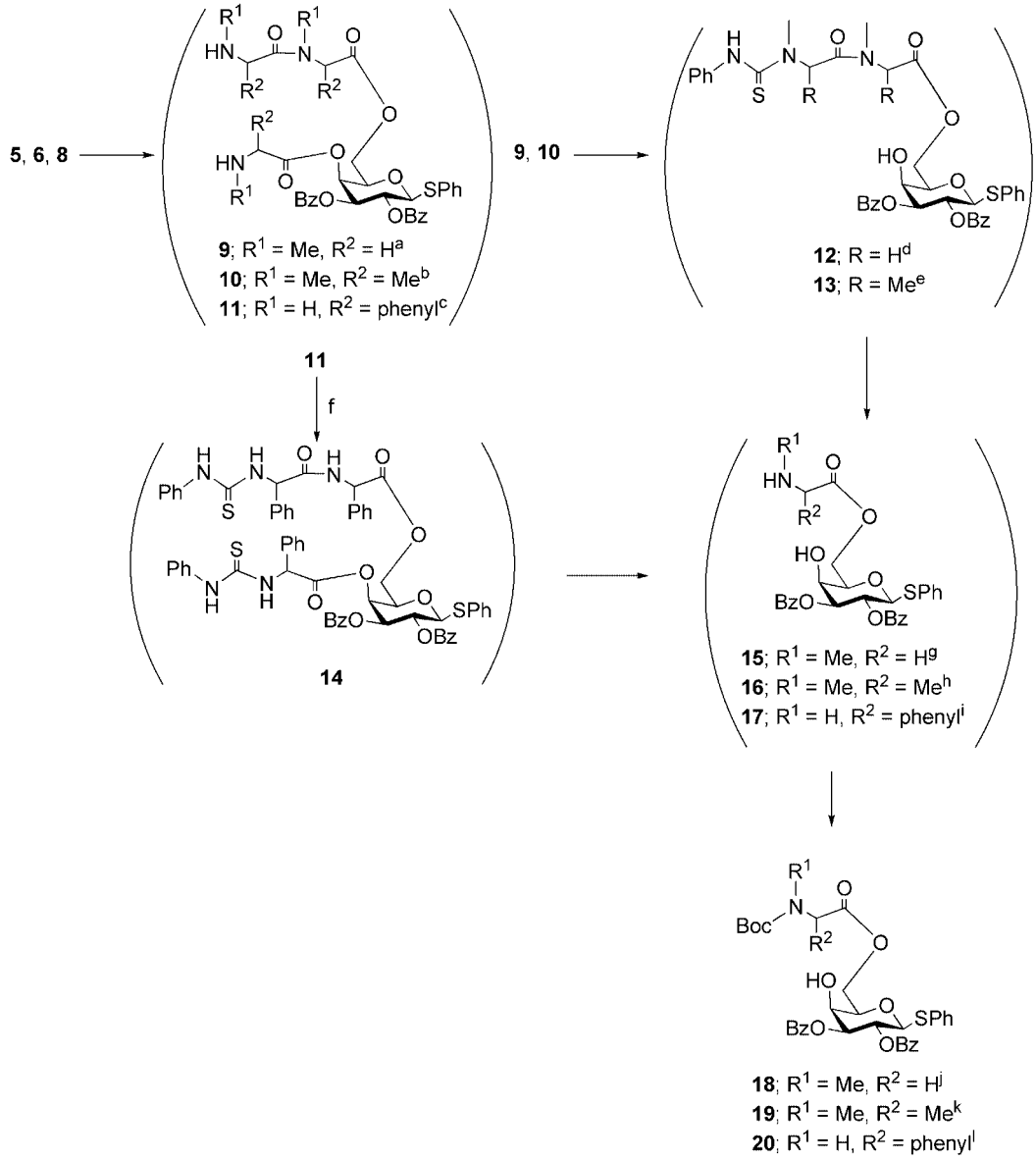
We used commercially available *N*-α-*t*-Boc-sarcosine, *N*-α-*t*-Boc-*N*-α-methyl-L-alanine, and *N*-α-*t*-Boc-L-phenylglycine as amino acids comprising the UCP group. Phenyl 2,3-di-*O*-benzoyl-1-thio-β-D-galactose (**1**), which was prepared from phenyl 4,6-*O*-benzylidene-1-thio-β-D-galactose (**36**)[11] in two steps, was chosen and used to protect the 4- and 6-positions with a mono-UCP group and a di-UCP group, respectively (Scheme 1). Each amino acid that was protected with a Boc group on the amine was selectively introduced into the 6-position of the Gal residue by an ester linkage using DIC and DMAP via symmetrical anhydride or cyanuric chloride. Subsequently, the Boc group was removed by TFA, and additional amino acid derivatives were attached by amide linkages to the amino terminus of the amino acid protected with 6-OH, using DIC and DMAP via the same symmetrical anhydride. During this reaction, the hydroxyl group on the 4-position of the Gal derivative was also esterified by the amino acid, except in the case of the phenylglycine derivative. The sterically large phenylglycine protecting the 6-position of the Gal derivative covered the hydroxyl group on the 4-position, decreasing its reactivity. To attack the sterically hindered 4-OH of the Gal derivative, the reaction mixture was heated to 50 °C in pyridine. The resultant Gal derivatives **5**, **6**, and **8**, in which the 4- and 6-positions were protected with a mono- and a di-UCP group, respectively, were treated with one cycle of Edman degradation (Scheme 2). One cycle of Edman degradation was comprised of a total of four steps: 1) deprotection of the amino protecting group; 2) coupling of PITC (phenyl isothiocyanate; Edman reagent) to all amino termini; 3) cleavage of the *N*-terminal phenyl thiocarbamoyl monoamino acid derivative from all UCP groups; 4) re-protection of all newly exposed *N*-terminal amino groups with Boc groups. In the first step, three suitably protected Gal derivatives **5**, **6**, and **8** were treated with TFA in $CH_2Cl_2$ at room temperature for 30 min, and the Boc group was completely removed. The reaction mixtures were then evaporated and co-evaporated with toluene. In the second step, the resultant three Gal derivatives with unprotected amino groups were treated with phenyl isothiocyanate (PITC) and *N*-methylmorpholine in DMF at room temperature for 30 min. Subsequently, the organic layer was extracted with water and evaporated, and the phenylthiocarbamoyl com-




Scheme 1. Reagents and conditions. [a] **1**, Boc-Sar-OH, cyanuric chloride, pyr., room temp., 1 h, 97%; [b] **1**, symmetrical anhydride (Boc-*N*-Me-Ala-OH, DIC, $CH_2Cl_2$, 0 °C, 40 min.), DMAP, DMF, room temp., 1 h, 78%; [c] **1**, symmetrical anhydride (Boc-Phg-OH, DIC, $CH_2Cl_2$, 0 °C, 40 min.), DMAP, DMF, room temp., 1 h, 94%; [d] i), **2**, TFA, $CH_2Cl_2$, room temp., 30 min. ii), symmetrical anhydride (Boc-Sar-OH, DIC, $CH_2Cl_2$, 0 °C, 40 min.), DMAP, DMF, room temp., 1 h, 73%; [e] i), **3**, TFA, $CH_2Cl_2$, room temp., 30 min. ii), symmetrical anhydride (Boc-*N*-Me-Ala-OH, DIC, $CH_2Cl_2$, 0 °C, 40 min.), DMAP, DMF, room temp., 1 h, 75%; [f] i), **4**, TFA, $CH_2Cl_2$, room temp., 30 min. ii), symmetrical anhydride (Boc-Phg-OH, DIC, $CH_2Cl_2$, 0 °C, 40 min.), DMAP, DMF, room temp., 1 h, 92%; [g] **7**, symmetrical anhydride (Boc-Phg-OH, DIC, $CH_2Cl_2$, 0 °C, 40 min.), DMAP, pyr., 50 °C, 5 h, 68%.

pounds **12**, **13**, and **14** were roughly separated by column chromatography. During this step, the mono-UCP group on the 4-position of the Gal derivatives was cleaved immediately owing to the electron-withdrawing effect, except in the case of the phenyl glycyl compound; the phenyl group on the phenylglycine residue neutralized this electron-withdrawing effect and stabilized the ester linkage. These results were confirmed by ESI-MS spectroscopy in positive ion mode. In the third step, phenylthiocarbamoyl compounds were treated with TFA in $CH_2Cl_2$ at room temperature for 30 min. The terminal phenylthiocarbamoyl mono-amino acid derivatives were removed selectively in this step. In the fourth step, the resultant free amines **15**, **16**, and **17** were protected with Boc groups using di-*tert*-butyl dicarbonate in saturated aqueous $NaHCO_3$ and DMF at room temperature for 30 min. Subsequently, the organic layer was extracted with water and evaporated, and the selectively 4-position-deprotected Gal derivatives **18**, **19**, and **20**, in which the 6-position was selectively protected by the mono-UCP group, were purified by column chromatography. The Boc re-protection of this final step was the most important step. Using a saccharide that was protected by amino-unprotected UCP for glycosylation yielded no glycosylated product because of problems with the stability of the UCP containing a free amine (unpublished data). The yields of one cycle of Edman degradation for the three amino acid



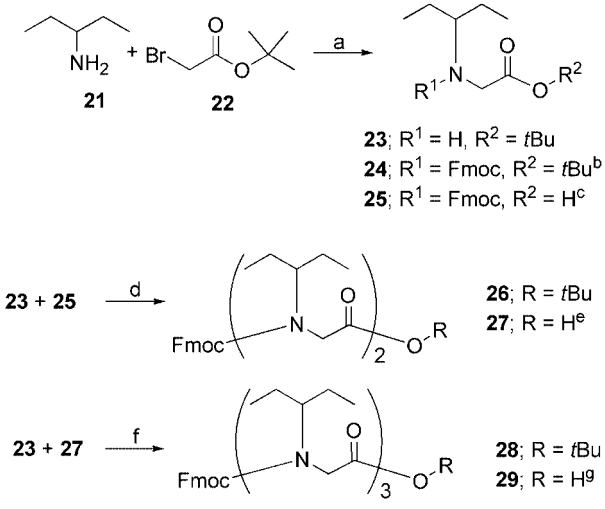

Scheme 2. Reagents and conditions. [a] **5**, TFA, $CH_2Cl_2$, room temp., 30 min; [b] **6**, TFA, $CH_2Cl_2$, room temp., 30 min; [c] **8**, TFA, $CH_2Cl_2$, room temp., 30 min; [d] **9**, PITC, NMM, DMF, room temp. 30 min; [e] **10**, PITC, NMM, DMF, room temp. 30 min; [f] **11**, PITC, NMM, DMF, room temp. 30 min; [g] **12**, TFA, $CH_2Cl_2$, room temp., 30 min; [h] **13**, TFA, $CH_2Cl_2$, room temp., 30 min; [i] **14**, TFA, $CH_2Cl_2$, room temp., 30 min; [j] **15**, $Boc_2O$, satd. aq. $NaHCO_3$, DMF, room temp., 30 min, 47% (4 steps); [k] **16**, $Boc_2O$, satd. aq. $NaHCO_3$, DMF, room temp., 30 min, 62% (4 steps); [l] **17**, $Boc_2O$, satd. aq. $NaHCO_3$, DMF, room temp., 30 min, 69% (4 steps).

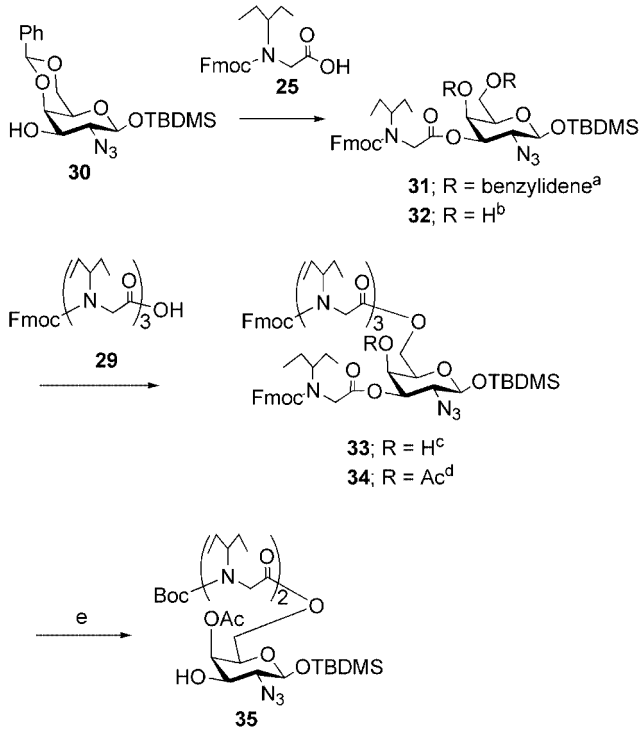
derivatives, sarcosine (**5**), *N*-methyl alanine (**6**), and phenylglycine (**8**), were 47%, 62%, and 69%, respectively. Despite the success of one cycle of Edman degradation, these three amino acid derivatives were not suitable for complex oligosaccharide synthesis because of the low reaction yield due to poor stability (sarcosine), complicated NMR peaks from the chiral center and the rotamers of carbamate (*N*-methyl alanine), and the reaction of the hydroxyl group being disturbed due to the sterically large phenyl group (phenylglycine).

### 2.2. Examination of the Synthesis of Two Kinds of Sialyl-T Antigens Using a UCP Group

*N*-α-1-Ethylpropylglycine was chosen as the amino acid for UCP. To achieve greater stability, a 1-ethylpropyl group was introduced as an amino protecting group compared with the methyl group in sarcosine or *N*-methyl alanine. As the backbone amino acid, glycine was chosen because it has no chiral center and no sterically large groups. Meldal et al. used *N*-α-1-methylpropylglycine as the amino acid for the UCP group.[7] However, this amino protecting group has a chiral carbon atom. To avoid the presence of a chiral center, we chose a 1-ethylpropyl group as an amino protecting group. However, the NMR spectrum was still complicated due to the rotamers of carbamate. This *N*-α-1-ethylpropylglycine was synthesized according to Meldal's method[7] (Scheme 3). The *N*-α-1-ethylpropylglycine derivative was prepared by the coupling of 3-aminopentane (**21**) with *tert*-butyl bromoacetate (**22**). Subsequently, the amine was protected by the Fmoc group and the *tert*-butyl group was removed, thus the Fmoc-protected mono-UCP **25** was prepared. The coupling reagent PyBroP was used to polymerize this UCP group, and successful coupling was obtained. The *tert*-butyldimethylsilyl 2-azido-4,6-*O*-benzylidene-2-deoxy-β-D-galactopyranoside (**30**) was used as the GalN residue in which the 1-position was protected by a *tert*-butyldimethylsilyl group for selective deprotection for future steps, and the 2-position had an azido group to introduce an anomeric α-configuration for future coupling with serine or threonine[12] (Scheme 4). The mono-UCP was selectively introduced into the 3-position of the GalN residue using the in situ activating reagent cyanuric chloride in pyridine at 40 °C. After deprotection of the benzylidene group, the 6-position of GalN derivative was selectively esterified by the tri-UCP group according to the same method. Subsequently, the 4-position of the GalN derivative was protected by an acetyl group to prepare the suitably protected GalN residue **34**. Subsequent treatment with one cycle of Edman degradation yielded the selectively deprotected 3-OH GalN derivative **35**, in which the 6-position was protected by the di-UCP group in high yield (four steps, total yield of 69%). In comparison with previously tested commercially available amino acids, sarcosine, *N*-methyl alanine, and phenylglycine, this *N*-α-1-ethylpropylglycine was highly stable and deprotected in high yield. The final step of one cycle of Edman degradation was the Boc re-protection step. The reason we chose the Boc group instead of the Fmoc group for amine protection was for the next round



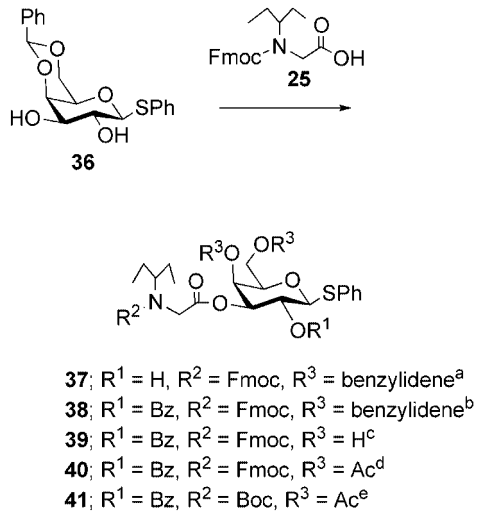

Scheme 3. Reagents and conditions. [a] THF, room temp., 4 h, 98%; [b] Fmoc-Cl, 1,4-dioxane/satd. aq. $NaHCO_3$, room temp., 2 h, 86%; [c] 90% formic acid, 40 °C, 7 h, 90%; [d] DIPEA, PyBroP, DMF, room temp., 30 min, 91%; [e] 90% formic acid, 50 °C, 3 h, 93%; [f] DIPEA, PyBroP, DMF, room temp., 30 min, 85%; [g] 90% formic acid, 50 °C, 2 h, 98%.



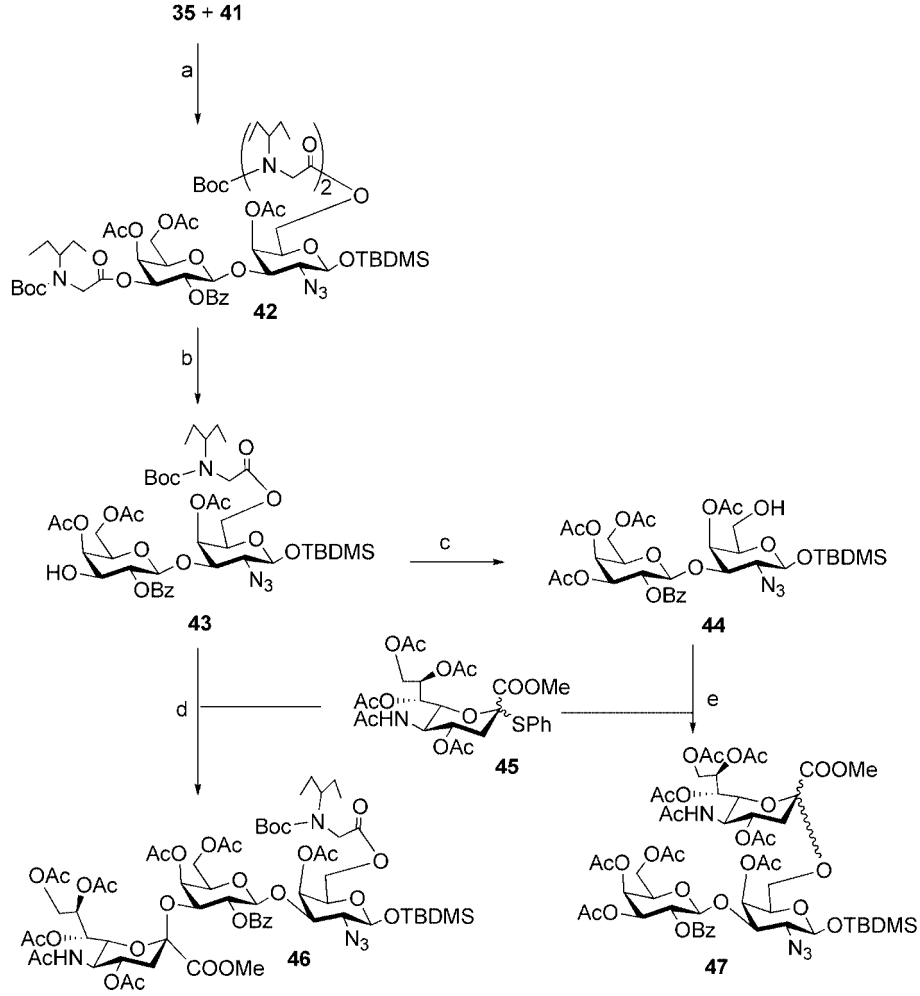

Scheme 4. Reagents and conditions. [a] **25**, cyanuric chloride, pyr., 40 °C, 2 h, 90%; [b] 80% aq. AcOH, 60 °C, 2 h, 79%; [c] **29**, cyanuric chloride, pyr., 40 °C, 2 h, 65%; [d] $Ac_2O$, pyr., 40 °C, 2 h, 91%; [e] i), 20% piperidine in DMF, room temp., 20 min. ii), PITC, NMM, room temp., 30 min. iii), TFA, $CH_2Cl_2$, room temp., 30 min. iv), $Boc_2O$, satd. aq. $NaHCO_3$, DMF, room temp., 30 min, 69% (4 steps).

of Edman degradation. If the di-UCP were protected by an Fmoc group, subsequent treatment with piperidine in basic solution to remove Fmoc would result in attack by the free amino group on the carbonyl carbon at the C-terminus of the UCP group, resulting in formation of cyclic di-UCP by removal of the hydroxyl group. To avoid this cyclization, the amino protecting group must be acid-cleavable, such as a Boc group. Phenyl 4,6-*O*-benzylidene-1-thio-β-D-galactopyranoside (**36**)[11] was used as the Gal residue (Scheme 5). To selectively protect the 3-position of the Gal derivative, the mono-UCP was initially treated with cyanuric chloride in pyridine at 40 °C for 30 min to convert it into the activated ester. This activated ester was added in a dropwise manner to the Gal derivative in pyridine at 0 °C, and the mixture was stirred for 1 h at 0 °C. Subsequently protected by benzoyl group on the 2-position of the Gal residue, the 4, 6-protecting group was exchanged from a benzylidene group to two acetyl groups. To match the amino protecting group of UCP on the GalN derivative, the Fmoc group was exchanged for a Boc group in high yield. The resultant Gal donor **41** was selectively coupled with the 3-position on the




Scheme 5. Reagents and conditions. [a] **25**, cyanuric chloride, pyr., 0 °C, 1 h, 73%; [b] BzCl, pyr., room temp., 2 h, 97%; [c] 80% aq. AcOH, 60 °C, 2 h, 65%; [d] $Ac_2O$, pyr., room temp., 2 h, 76%; [e] 20% piperidine in DMF, room temp., 20 min then $Boc_2O$, satd. aq. $NaHCO_3$, room temp., 1 h, 83% (2 steps).




Scheme 6. Reagents and conditions. [a] NIS, TfOH, MS 4 Å, $CH_2Cl_2$, –40 °C, 2 h, 89%; [b] i), TFA, $CH_2Cl_2$, room temp., 30 min. ii), PITC, NMM, room temp., 30 min. iii), TFA, $CH_2Cl_2$, room temp., 30 min. iv), $Boc_2O$, satd. aq. $NaHCO_3$, DMF, room temp., 30 min, 70% (4 steps); [c] i), $Ac_2O$, pyr., room temp. 2 h, 99%. ii), TFA, $CH_2Cl_2$, room temp., 30 min. iii), PITC, NMM, room temp., 30 min, 98% (2 steps); [d] NIS, TfOH, MS 3 Å, $CH_3CN$, –30 °C, 48 h, 13%; [e] NIS, TfOH, MS 3 Å, $CH_3CN$, –30 °C, 10 h, 67% ($\alpha/\beta$ = 71:29).

$GalN_3$ acceptor (**35**) using *N*-iodosuccinimide (NIS) and trifluoromethanesulfonic acid (TfOH) in $CH_2Cl_2$ at –40 °C in a yield of 89% (Scheme 6). In the $^1$H-NMR spectrum of the anomeric protons on the Gal residue, peaks were observed at $\delta$ (ppm) 4.87, 4.88, 4.91, and 4.92 (4d, 1 H, $J_{1,2}$ = 7.9, 8.1, 7.9, and 7.8 Hz). The peaks were very complicated due to the rotamers of carbamate, but it was suggested to be in the β-configuration. Following treatment with one cycle of Edman degradation, the 3′-free disaccharide **43** in which the 6-position was protected by mono-UCP was prepared. This was an acceptor for the synthesis of sialyl (2–3) T antigen. After protection by adding an acetyl group to the 3′-position of the disaccharide, one cycle of Edman degradation was repeated, except the third step (TFA treatment to remove the *N*-terminal amino acid) and the fourth step (re-protecting the amino group with Boc). This produced the disaccharide **44** selectively deprotected at the 6-position in high yield. Disaccharide **44** was an acceptor for the synthesis of sialyl (2–6) T antigen. These two disaccharides **43** and **44** were sialylated with the sialyl SPh donor **45**[13] using NIS and TfOH as promoters in acetonitrile[14,15] at –30 °C. The sialyl (2–3) T antigen **46** was prepared in a yield of 13%. Unfortunately, the anomeric configuration of sialic acid was shown to be β by NMR spectroscopy.[16] In this case, no α configuration was observed. On the other hand, sialyl (2–6) T antigen **47** was prepared in a yield of 67% (α/β = 71:29 mixture).[16] The ratio of the anomeric configuration was calculated from the integration of the equatorial proton at the 3-position on the sialic acid residue. Despite using acetonitrile as the solvent in both coupling reactions, the α anomer was lost selectively because of steric problems (sialyl 2–3 T) and the high reactivity of the primary hydroxyl group (sialyl 2–6 T), respectively. Nevertheless, this new method for oligosaccharide synthesis using a UCP group is quite promising, because of the selective cleavage of the desired hydroxyl group and stepwise deprotection using only one deprotection method.

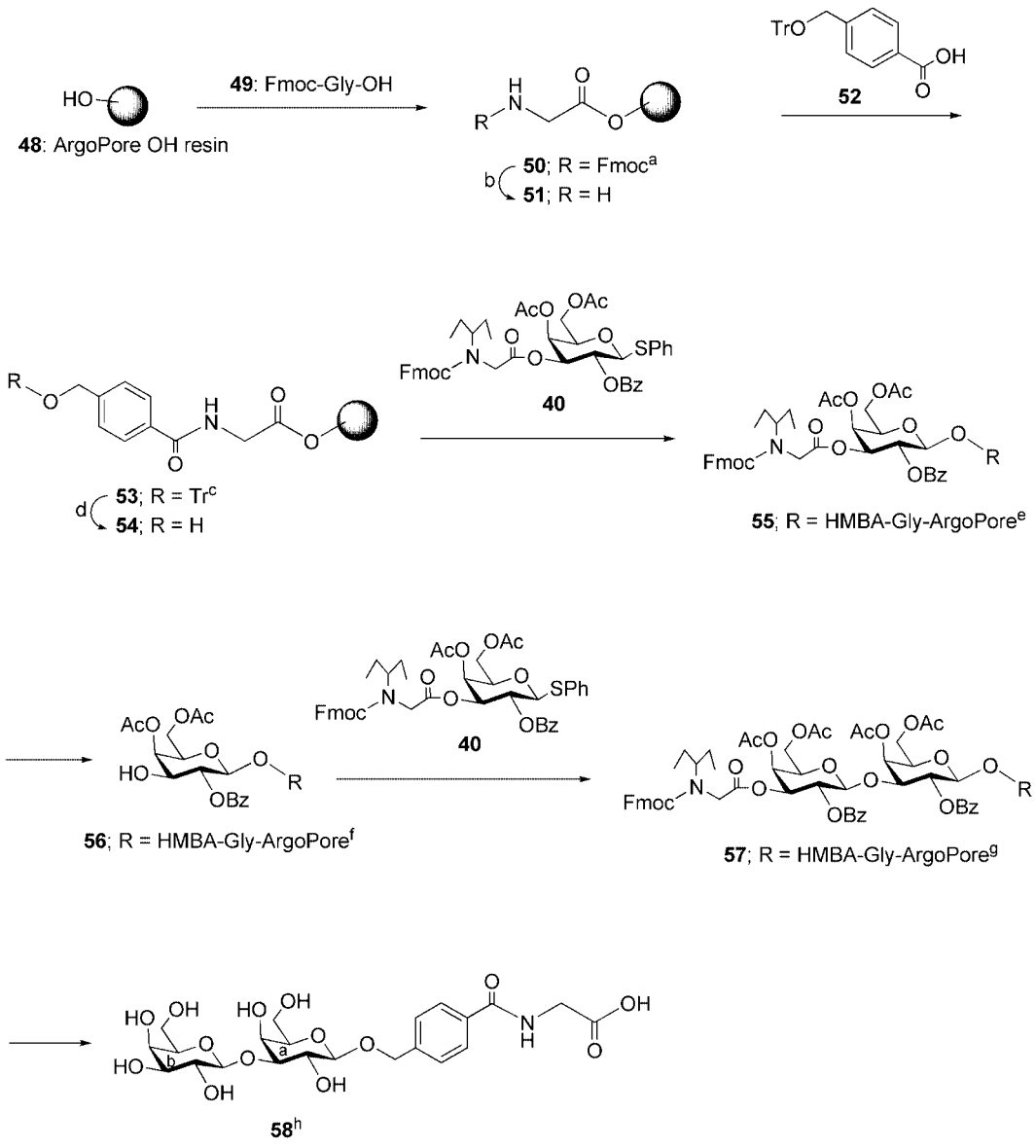
### 2.3. Examination of Solid-Phase Oligosaccharide Synthesis Using a UCP Group

Galβ (1→3) Gal was synthesized by a solid-phase reaction using a UCP group (Scheme 7). *N*-Fmoc-protected *N*-α-1-ethylpropylglycine was chosen as the amino acid for the UCP group. The previously prepared Gal derivative **40**, in which the 3-position was protected by an Fmoc-protected mono-UCP group, was used and coupled together on a solid support consisting of a polystyrene-type resin [ArgoPore OH (**48**); Argonaut Technologies Inc., Foster City, CA, USA].[17] A new type of linker for solid-phase oligosaccharide synthesis was designed, 2-[4-(hydroxymethyl)benzamido]acetic acid (HMBA-Gly), to make it easy to release the carbohydrate-linker complex from the solid support under basic conditions. In addition, to allow detection of the target compound by UV on HPLC, HMBA-Gly was prepared by coupling of 4-(hydroxymethyl)benzoic acid (HMBA) with glycine via a peptide linkage. This linker was attached to the hydroxyl group on the solid support by an ester linkage. The sugar anomeric position was attached via a hydroxyl group on the benzyl position of the linker by glycoside linkage formation so the sugar moiety could be released from this linker by hydrogenolysis. Fmoc-protected glycine **49** was coupled to hydroxyl groups on the resin using DIC and DMAP in $CH_2Cl_2$ at room temperature. Fmoc loading was measured by 290 nm UV spectrometry in 20% piperidine/DMF; the loading was estimated to be 0.449 mmol/g. Following cleavage of the Fmoc group using 20% piperidine/DMF, HMBA derivative **52**, in which the hydroxyl was protected by a trityl group, was coupled to the amino terminus of the glycine on the resin using the TBTU and NEM coupling method. After cleavage of the trityl group using TFA in $H_2O$, the suitably protected Gal donor **40** was coupled using dimethyl(methylthio)sulfonium triflate (DMTST) as a promoter in $CH_2Cl_2$ at room temperature for 1 d. The resin was washed with DMF, $CH_2Cl_2$, and $Et_2O$, dried in vacuo, and the glycosylation procedure was repeated. To measure the coupling yield, aliquots of the resins were treated with 20% piperidine/DMF to cleave the Fmoc group protecting the UCP group on the 3-position of Gal, and the eluate was examined by UV spectrometry at 290 nm. For a single coupling, the loading was estimated as 0.076 mmol/g, and after a double coupling, the loading was increased to 0.103 mmol/g. After the four steps (Fmoc deprotection, Tr-HMBA coupling, Tr deprotection, and glycosylation), the yields of single coupling and double coupling were estimated as 22% and 29%, respectively, with theoretical loading of 0.352 mmol/g. In addition, aliquots of the double-coupled resin were treated with NaOMe in MeOH and $CH_2Cl_2$ at room temperature for 4 h. In addition, following the addition of water, the reaction was continued for a further 4 h at room temperature. The eluate of the aqueous layer was analyzed by analytical HPLC (Figure 1, A). The peaks were detected at 254 nm using a UV detector. The yield was calculated from the area under the peaks. The coupling yield of Gal was determined as 31%. This demonstrated that Fmoc measurement allowed determination of the coupling yield. Following treatment with acetic anhydride in pyridine and $CH_2Cl_2$ at room temperature for 2 h, one cycle of Edman degradation was performed except for the third (TFA treatment) and fourth (Boc reprotection) steps. The resultant Gal residue in which the 3-position hydroxyl group was free was glycosylated with the same Gal donor **40** in which the 3-position was protected by the Fmoc-protected mono-UCP group, using the same double coupling conditions. After single coupling, the loading was estimated as 0.041 mmol/g. After double coupling, the loading was increased to 0.046 mmol/g, as estimated from Fmoc measurement. The glycosylation yields of both single and double coupling, which included the UCP deprotection step, were estimated as 36% and 41%, respectively, with theoretical loading of 0.113 mmol/g. Aliquots of the double-coupled resin were treated with NaOMe in MeOH and $CH_2Cl_2$ at room temperature for 4 h.

Water was then added, and the reaction was continued for a further 4 h at room temperature. The eluate of the aqueous layer was analyzed by analytical HPLC (Figure 1, A). The glycosylation yield was estimated as 42%. Again, Fmoc measurement was confirmed to be a good method to determine yield. Cleavage of the disaccharide-HMBA-Gly complex from the resin was performed with NaOMe in $CH_2Cl_2$ and MeOH for one day at room temperature, water was added, and the resultant mixture was mixed for one more day.[18] The cleaved disaccharide derivative was purified by HPLC. The target disaccharide **58** was obtained in a yield of 1.8 mg, and the total yield of cleavage from the resin was estimated as 4% over 8 steps (Fmoc deprotection, Tr-HMBA coupling, Tr deprotection, glycosylation, Fmoc deprotection, UCP deprotection, glycosylation, and cleavage from the resin). These results demonstrated that this method is applicable to solid-phase oligosaccharide synthesis, including solid-phase oligosaccharide library synthesis or solid-phase automated oligosaccharide synthesis.

In conclusion, the results of the present study clearly demonstrated that this hydroxyl-protecting UCP method is a useful technique for oligosaccharide synthesis, which is applicable to both automated oligosaccharide synthesis and library synthesis.




Scheme 7. Reagents and conditions. [a] **49**, DIC, DMAP, $CH_2Cl_2$, room temp., 7 h, then $Ac_2O$, pyr., $CH_2Cl_2$, room temp., 2 h; [b] 20% piperidine in DMF, room temp., 22 min; [c] **52**, NEM, TBTU, DMF, room temp., 4 h; [d] 90% TFA in $H_2O$, room temp., 3 h; [e] **40**, DMTST, $CH_2Cl_2$, room temp., 1 d. This was repeated once more, then $Ac_2O$, pyr., $CH_2Cl_2$, room temp., 2 h; [f], i), 20% piperidine in DMF, room temp., 22 min, ii), PITC, NMM, DMF, room temp., 2 h; [g] **40**, DMTST, $CH_2Cl_2$, room temp., 1 d, this was repeated once more; [h] NaOMe in MeOH, $CH_2Cl_2$, MeOH, room temp., 1 d, then added $H_2O$, room temp., 1 d, 4% (8 steps from **50**).

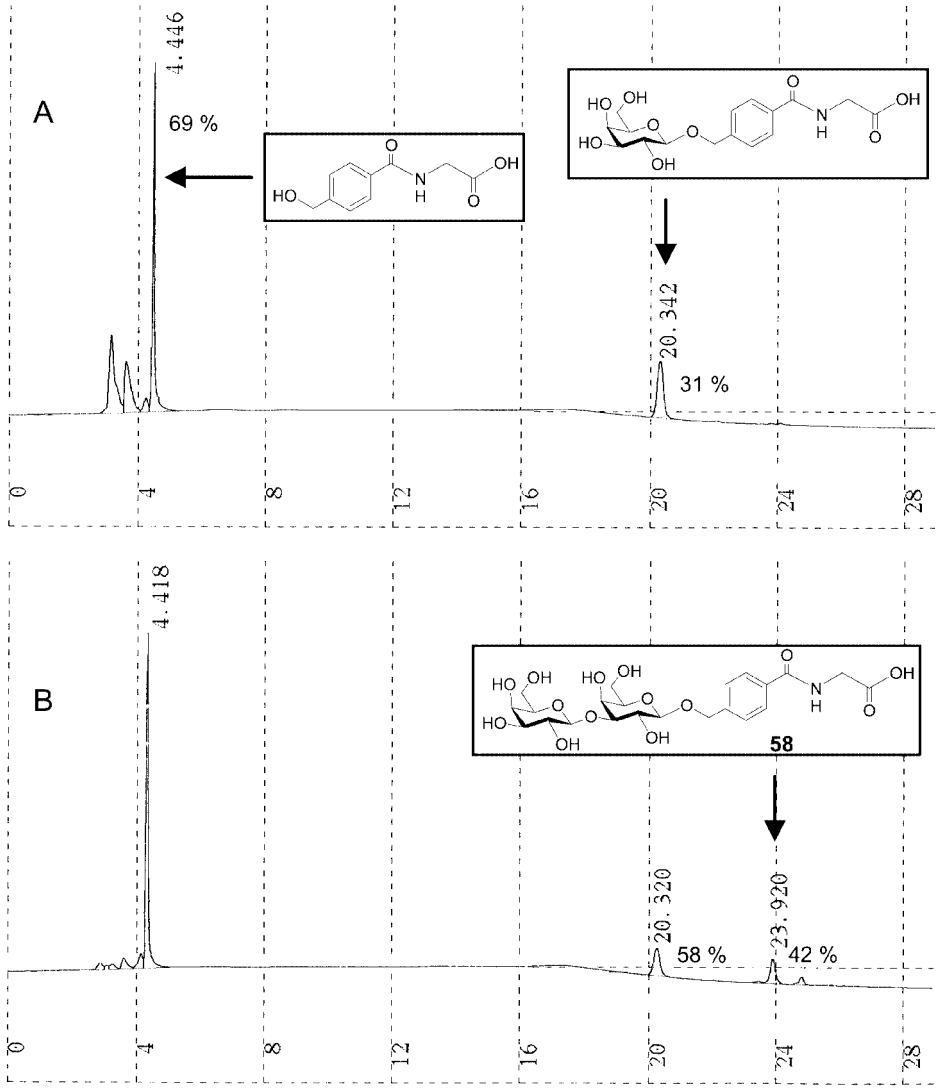



Figure 1. HPLC traces: A) After double coupling of initial sugar to the resin. B) After double coupling of secondary sugar to the resin. The yield was calculated by peak area.

## Experimental Section

**General Procedures:** $^1$H- and $^{13}$C-NMR spectra were obtained on a Bruker DRX-600 spectrometer in $CDCl_3$ or $D_2O$. Chemical shifts are expressed in parts per million relative to the signal of either $CHCl_3$ or $Me_4Si$ in $CDCl_3$, adjusted to 7.24 or 0.00 ppm, respectively, or MeOH in $D_2O$, adjusted to 3.30 ppm. ESI-FT-MS spectra were recorded in the positive ion mode on a Bruker APEX II 70e mass spectrometer. Optical rotations were determined with a JASCO P-1020-GT polarimeter in $CHCl_3$ or $H_2O$ at ambient temperature. Preparative chromatography was performed on silica gel [silica gel 60 (230–400 mesh); Nacalai Tesque Inc., Kyoto, Japan] with the solvent systems specified. Analytical normal-phase HPLC separation was performed on a Shimadzu HPLC system, using a TSK-gel Amide-80 column (4.6×250 mm, 5 μm, Tosoh Co. Ltd.), with a flow rate of 1 mL min$^{-1}$ and detection at 254 nm. The solvent system was as follows: solvent A, TFA/acetonitrile/water (1:900:100); solvent B, TFA/water (1:1000). All reagents and solvents were of reagent grade.

**Abbreviations Used:** DIC: 1,3-diisopropylcarbodiimide, DMAP: 4-(dimethylamino)pyridine, THF: tetrahydrofuran, *t*Bu: *tert*-butyl, Fmoc: fluorenylmethoxycarbonyl, Ac: acetyl, Bz: benzoyl, Boc: butoxycarbonyl, DIPEA: *N*,*N*-diisopropylethylamine, PyBroP™: bromo-Tris-pyrrolidino-phosphonium hexafluorophosphate, DMF: *N*,*N*-dimethylformamide, TBDMS: *tert*-butyldimethylsilyl, pyr.: pyridine, $Ac_2O$: acetic anhydride, PITC: phenyl isothiocyanate, TFA: trifluoroacetic acid, $Boc_2O$: di-*tert*-butyl dicarbonate, SPh: thiophenyl, NIS: *N*-iodosuccinimide, TfOH: trifluoromethanesulfonic acid. MS: molecular sieves, room temp.: room temperature, aq.: aqueous, satd.: saturated, GalN: D-galactosamine, Gal: D-galactose, SA: sialic acid, NEM: *N*-ethylmorpholine, NMM: *N*-methylmorpholine, TBTU: 2-(1*H*-benzotriazole-1-yl)-1,1,3,3-tetramethyluronium tetrafluoroborate, DMTST: dimethyl(methylthio)sulfonium triflate.

**Phenyl 2,3-Di-*O*-benzoyl-6-*O*-{2-[*tert*-butoxycarbonyl(methyl)-amino]acetyl}-1-thio-β-D-galactopyranoside (2):** To a solution of **1** (100 mg, 208 μmol) in pyridine (3 mL) was added *N*-α-*t*-Boc-sarco-

sine (43 mg, 227 μmol) and cyanuric chloride (115 mg, 624 μmol), and the mixture was stirred for one hour at room temp. After concentration, the product was purified by chromatography on a column of silica gel with 1:2 ethyl acetate/hexane to give **2** (131 mg, 97%). Owing to the rotamers of carbamate, some peaks of both $^1$H NMR and $^{13}$C NMR appeared as double peaks. In addition, all other compounds that had a tertiary amino group gave complicated NMR signals because of their rotamers. $[\alpha]_D$ = 52.0 (*c* = 1.3, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 1.40, 1.43 (2 s, 9 H, *Me*$_3$CO), 2.90 (s, 3 H, *Me*N), 3.91, 3.93, 3.94, 4.05 (4 d, $J_{gem}$ = 17.7, 17.4, 17.7, 17.7 Hz, 2 H, N*CH*$_2$CO), 3.99 (br. d, 1 H, 5-H), 4.33, 4.35 (2 br. s, 1 H, 4-H), 4.47 (m, 2 H, 6-H), 4.96 (d, $J_{1,2}$ = 10.0 Hz, 1 H, 1-H), 5.36 (br. d, $J_{2,3}$ = 10.0 Hz, 1 H, 3-H), 5.79 (t, $J_{1,2}$ = $J_{2,3}$ = 9.9 Hz, 1 H, 2-H), 7.29–7.97 (m, 15 H, 2 *Ph*COO and SPh) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 28.19 (*Me*$_3$CO), 35.45, 35.61 (MeN), 50.17, 50.71 (N*CH*$_2$CO), 63.02, 63.38 (C-6), 67.08, 67.27 (C-4), 67.72, 67.83 (C-2), 75.13 (C-3), 75.97 (C-5), 80.29 (Me$_3$*C*O), 86.54 (C-1), 127.92, 128.04, 128.31, 128.36, 128.78, 128.83, 128.90, 129.31, 129.69, 129.76, 132.40, 132.61, 133.14, 133.20, 133.31, 133.42 (2 *Ph*COO and SPh), 155.28, 156.07 (C=O Boc), 165.24, 165.66 (2 Ph*C*OO), 169.70 (NCH$_2$*C*O) ppm. ESI-FT-MS: calcd. for $C_{34}H_{37}NO_{10}SNa^+$ [M + $Na^+$] 674.20304; found 674.20387.

**Phenyl 2,3-Di-*O*-benzoyl-6-*O*-{2-[*tert*-butoxycarbonyl(methyl)-amino]propionyl}-1-thio-β-D-galactopyranoside (3):** To a solution of *N*-α-*t*-Boc-*N*-α-methyl-L-alanine (127 mg, 625 μmol) in dichloromethane (500 μL) was added 1,3-diisopropylcarbodiimide (49 μL, 313 μmol) at 0 °C, and the mixture was stirred for 40 min at 0 °C. After concentration, the product was dissolved in DMF (500 μL). To the resultant solution was added **1** (100 mg, 208 μmol) and 4-(dimethylamino)pyridine (3 mg, 25 μmol), and the mixture was stirred for 1 h at room temp. After concentration, the product was purified by chromatography on a column of silica gel with ethyl acetate/hexane (1:1) to give **3** (108 mg, 78%). $[\alpha]_D$ = 38.8 (*c* = 1.2, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 1.40 [d, $J_{CH3,CH}$ = 7.3 Hz, 3 H, NCH(*Me*)CO], 1.42, 1.46 (2 s, 9 H, *Me*$_3$CO), 2.81, 2.85 (2 s, 3 H, MeN), 4.00 (br. s, 1 H, 5-H), 4.34 (br. d, 1 H, 4-H), 4.36–4.54 (m, 2 H, 6-H), 4.43, 4.76, 4.82 [3 m, 1 H, N*CH*(Me)CO], 4.96 (d, $J_{1,2}$ = 10.0 Hz, 1 H, 1-H), 5.37, 5.40 (2 dd, $J_{2,3}$ = 9.9, 10.0 Hz, $J_{3,4}$ = 3.1, 3.2 Hz, 1 H, 3-H), 5.79 (t, $J_{1,2}$ = $J_{2,3}$ = 10.0 Hz, 1 H, 2-H), 7.28–7.97 (m, 15 H, 2 *Ph*COO and SPh) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 14.49, 14.65, 14.97, 15.17 [NCH(*Me*)CO], 28.23 (*Me*$_3$CO), 30.51, 30.66, 31.09, 31.28 (MeN), 53.44, 53.68, 54.86, 55.10 [N*CH*(Me)CO], 63.08, 63.47 (C-6), 67.09, 67.30 (C-4), 67.83 (C-2), 73.03, 75.02 (C-3), 76.02 (C-5), 80.30 (Me$_3$*C*O), 86.64 (C-1), 127.88, 128.28, 128.84, 129.31, 129.69, 129.77, 132.24, 132.55, 133.14, 133.30 (2 *Ph*COO and SPh), 155.17, 156.02 (C=O Boc), 165.24, 165.65 (2 Ph*C*OO), 171.97, 172.17 [NCH(Me)*C*O] ppm. ESI-FT-MS: calcd. for $C_{35}H_{39}NO_{10}SNa^+$ [M + $Na^+$] 688.21869; found 688.21912.

**Phenyl 2,3-Di-*O*-benzoyl-6-*O*-[2-(*tert*-butoxycarbonylamino)-2-phenylacetyl]-1-thio-β-D-galactopyranoside (4):** To a solution of *N*-α-*t*-Boc-L-phenylglycine (345 mg, 1.37 mmol) in dichloromethane (2 mL) was added DIC (108 μL, 690 μmol) at 0 °C, and the mixture was stirred for 40 min at 0 °C. After concentration, the product was dissolved in DMF (3 mL). To the resultant solution was added **1** (300 mg, 624 μmol) and DMAP (7.6 mg, 62 μmol), and the mixture was stirred for one hour at room temp. The work-up as described for **3** yielded **4** (420 mg, 94%). $[\alpha]_D$ = 55.5 (*c* = 1.9, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 1.43, 1.45 (2 s, 9 H, *Me*$_3$CO), 3.89, 3.95 (2 t, $J_{5,6}$ = $J_{5,6'}$ = 6.2, 6.2 Hz, 1 H, 5-H), 4.13, 4.26 (2 br. s, 1 H, 4-H), 4.41–4.57 (m, 2 H, 6-H), 4.94 (d, $J_{1,2}$ = 10.0 Hz, 1 H, 1-H), 5.33, 5.36 (2 dd, $J_{2,3}$ = 9.9, 10.0 Hz, $J_{3,4}$ = 3.0, 3.1 Hz, 1 H, 3-H), 5.39, 5.42 [2 d, $J_{gem}$ = 7.2, 7.2 Hz, 1 H, N*CH*(Ph)CO], 5.83, 5.84 (2 t, $J_{1,2}$ = $J_{2,3}$ = 10.0, 9.9 Hz, 1 H, 2-H), 7.29–8.00 [m, 20 H, 2 *Ph*COO, NCH(*Ph*)CO and SPh] ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 28.00, 28.05 (*Me*$_3$CO), 57.22, 57.56 [N*CH*(Ph)CO], 63.54, 63.76 (C-6), 66.74, 66.88 (C-4), 67.77 (C-2), 74.90 (C-3), 75.69, 75.73 (C-5), 79.90, 80.20 (Me$_3$*C*O), 86.28 (C-1), 126.89, 126.99, 127.76, 127.84, 128.13, 128.27, 128.41, 128.57, 128.66, 128.78, 129.15, 129.17, 129.52, 129.60, 129.84, 132.30, 132.48, 133.00, 133.11, 133.16, 133.19 [2 *Ph*COO, NCH(*Ph*)CO and SPh], 154.77, 156.36 (C=O Boc), 165.13, 165.52 (2 Ph*C*OO), 170.00, 171.26 [NCH(Ph)*C*O] ppm. ESI-FT-MS: calcd. for $C_{39}H_{39}NO_{10}SNa^+$ [M + $Na^+$] 736.21869; found 736.21754.

**Phenyl 2,3-Di-*O*-benzoyl-6-*O*-[2-{2-[*tert*-butoxycarbonyl(methyl)-amino]-*N*-methylacetamido}acetyl]-4-*O*-{2-[*tert*-butoxycarbonyl-(methyl)amino]acetyl}-1-thio-β-D-galactopyranoside (5):** To a solution of **2** (249 mg, 382 μmol) in dichloromethane (5 mL) was added trifluoroacetic acid (1 mL). The mixture was stirred for 30 min at room temp., and then concentrated (A). To a solution of *N*-α-*t*-Boc-sarcosine (578 mg, 3.05 mmol) in dichloromethane (2 mL) was added DIC (240 μL, 1.53 mmol) at 0 °C. The mixture was stirred for 40 min at 0 °C, and then concentrated (B). To a solution of A and B in DMF (3.2 mL) was added DMAP (5 mg, 41 μmol), and the mixture was stirred for one hour at room temp. The work-up as described for **3** yielded **5** (248 mg, 73%). $[\alpha]_D$ = 29.9 (*c* = 1.2, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 1.35, 1.43, 1.47 (3 s, 18 H, 2 *Me*$_3$CO), 2.71, 2.72, 2.75, 2.87, 2.87, 2.92, 2.93, 3.00, 3.02 (9 s, 9 H, 3 MeN), 3.89–4.27 (m, 6 H, 3 N*CH*$_2$CO), 4.20–4.40 (m, 2 H, 6-H), 4.21 (m, 1 H, 5-H), 5.01, 5.04, 5.07 (3 d, $J_{1,2}$ = 9.3, 10.3, 9.9 Hz, 1 H, 1-H), 5.44–5.54 (m, 1 H, 3-H), 5.65, 5.67 (2 t, $J_{1,2}$ = $J_{2,3}$ = 10.0, 10.2 Hz, 1 H, 2-H), 5.71, 5.74 (2 d, $J_{3,4}$ = 2.5, 2.4 Hz, 1 H, 4-H), 7.32–7.98 (m, 15 H, 2 *Ph*COO and SPh) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 27.99, 28.08, 28.13, 28.22 (2 *Me*$_3$CO), 34.79, 35.17, 35.42 (3 MeN), 49.31, 49.56, 49.80, 49.85, 50.12, 50.37 (3 *CH*$_2$CO), 61.43, 61.57 (C-6), 67.59, 67.75 (C-2), 67.87, 68.03 (C-4), 72.37, 72.69 (C-3), 74.04, 74.14 (C-5), 79.76, 80.03, 80.15 (2 Me*C*O), 86.51 (C-1), 128.30, 128.48, 128.62, 128.82, 128.85, 128.99, 129.43, 129.58, 129.62, 132.73, 133.05, 133.23 (2 *Ph*COO and SPh), 154.94, 155.55, 155.65, 156.10 (C=O 2 Boc), 165.02, 165.14, 165.18 (2 Ph*C*OO), 168.30, 168.37, 168.94, 169.03, 169.18, 169.33 (3 NCH$_2$*C*O) ppm. ESI-FT-MS: calcd. for $C_{45}H_{55}N_3O_{14}SNa^+$ [M + $Na^+$] 916.32970; found 916.32999.

**Phenyl 2,3-Di-*O*-benzoyl-4-*O*-{2-[*tert*-butoxycarbonyl(methyl)-amino]propionyl}-6-*O*-[2-{2-[*tert*-butoxycarbonyl(methyl)amino]-*N*-methylpropanamido}propionyl]-1-thio-β-D-galactopyranoside (6):** To a solution of **3** (217 mg, 326 μmol) in dichloromethane (5 mL) was added trifluoroacetic acid (1 mL). The mixture was stirred for 30 min at room temp., and then concentrated (A). To a solution of *N*-α-*t*-Boc-*N*-α-methyl-L-alanine (530 mg, 2.61 mmol) in dichloromethane (4 mL) was added DIC (204 μL, 1.30 mmol) at 0 °C. The mixture was stirred for 40 min at 0 °C, and then concentrated (B). To a solution of A and B in DMF (6 mL) was added DMAP (4 mg, 33 μmol), and the mixture was stirred for one hour at room temp. The work-up as described for **3** yielded **6** (228 mg, 75%). $[\alpha]_D$ = –19.1 (*c* = 0.5, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 1.25–1.39 [m, 9 H, 3 NCH(*Me*)CO], 1.42, 1.47 (2 s, 18 H, 2 Boc), 2.49–2.93 (m, 9 H, 3 *Me*N), 4.12–4.39 (m, 2 H, 6-H), 4.17 (m, 1 H, 5-H), 4.71–5.17 [m, 3 H, 3 N*CH*(Me)CO], 4.96 (br. d, $J_{1,2}$ = 10.0 Hz, 1 H, 1-H), 5.36 (br. d, $J_{2,3}$ = 9.5 Hz, 1 H, 3-H), 5.55 (br. t, $J_{1,2}$ = $J_{2,3}$ = 9.6 Hz, 1 H, 2-H), 5.66 (br. s, 1 H, 4-H), 7.32–7.99 (m, 15 H, 2 OBz and SPh). $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 14.13, 14.39, 14.60, 14.67, 15.09, 15.59, 16.26 [3 NCH(*Me*)CO], 28.33, 28.39 (2 *Me*$_3$CO), 29.16, 29.33, 29.49, 29.66, 29.71, 30.00, 31.08 (3 *Me*N), 50.87, 52.48, 52.51, 52.77, 53.11, 53.19, 53.41, 53.55 [3 N*CH*(Me)-

CO], 62.04, 62.35 (C-6), 67.25, 67.32, 67.40 (C-2), 67.79, 67.96 (C-4), 73.11, 73.17 (C-3), 74.30, 74.46 (C-5), 80.06, 80.33, 80.45 ($Me_3CO$), 85.64, 86.07 (C-1), 128.37, 128.49, 128.92, 129.66, 129.81, 133.41, 133.54, 133.79 (2 *Ph*CO and SPh), 155.40, 155.77 (C=O 2 Boc), 165.23 (2 Ph*C*OO), 171.07, 171.38, 172.19 [3 NCH(Me)*C*O]. ESI-FT-MS: calcd. for $C_{48}H_{61}N_3O_{14}SNa^+$ [M + $Na^+$] 958.37665; found 958.37740.

**Phenyl 2,3-Di-*O*-benzoyl-6-*O*-{2-[2-(*tert*-butoxycarbonylamino)-2-phenylacetylamido]-2-phenylacetyl}-1-thio-β-D-galactopyranoside (7):** To a solution of **4** (321 mg, 450 μmol) in dichloromethane (5 mL) was added trifluoroacetic acid (1 mL). The mixture was stirred for 30 min at room temp., and then concentrated (A). To a solution of *N*-α-*t*-Boc-L-phenylglycine (904 mg, 3.60 mmol) in dichloromethane (9 mL) was added DIC (282 μL, 1.80 mmol) at 0 °C. The mixture was stirred for 40 min at 0 °C, and then concentrated (B). To a solution of A and B in DMF (10 mL) was added DMAP (5.5 mg, 45 μmol), and the mixture was stirred for 6 h at room temp. The work-up as described for **3** yielded **7** (349 mg, 92%). $[\alpha]_D$ = 69.7 (*c* = 1.0, $CHCl_3$). $^1H$ NMR (600 MHz, $CDCl_3$): $\delta$ = 1.30, 1.31 (2 s, 9 H, $Me_3$CO), 3.81 (br. t, $J_{5,6} = J_{5,6'}$ = 6.1 Hz, 1 H, 5-H), 4.13 (br. s, 1 H, 4-H), 4.31–4.40 (m, 2 H, 6-H), 4.85, 4.87 (2 d, $J_{1,2}$ = 10.1, 10.6 Hz, 1 H, 1-H), 5.21, 5.24 (2 dd, $J_{2,3}$ = 9.9, 9.9 Hz, $J_{3,4}$ = 3.0, 3.1 Hz, 1 H, 3-H), 5.34–5.56 [m, 2 H, 2 N*CH*(Ph)CO], 5.71, 5.73 (2 t, $J_{1,2} = J_{2,3}$ = 10.0, 9.8 Hz, 1 H, 2-H), 7.14–7.95 [m, 25 H, 2 *Ph*COO, 2 NCH(*Ph*)CO and SPh] ppm. $^{13}C$ NMR (150 MHz, $CDCl_3$): $\delta$ = 28.09 ($Me_3$CO), 56.58, 56.92, 58.05 [N*CH*(Ph)CO], 63.69 (C-6), 66.79 (C-4), 67.77 (C-2), 74.94, 75.07 (C-3), 75.53, 75.67 (C-5), 80.48 ($Me_3CO$), 86.38, 86.52 (C-1), 127.07, 127.13, 127.14, 127.18, 127.96, 128.29, 128.32, 128.41, 128.79, 128.82, 128.84, 128.85, 128.90, 128.93, 129.05, 129.16, 129.45, 129.68, 129.73, 132.43, 132.67, 133.17, 133.32, 133.36 [2 *Ph*COO, 2 NCH(*Ph*)CO and SPh], 152.38, 152.40, 155.29, 155.34 (C=O Boc), 165.25, 165.27, 165.67 (2 Ph*C*OO), 168.02, 170.08, 171.33, 172.30 [NCH(Ph)*C*O] ppm. ESI-FT-MS: calcd. for $C_{47}H_{46}N_2O_{11}SNa^+$ [M + $Na^+$] 869.27145; found 869.27256.

**Phenyl 2,3-Di-*O*-benzoyl-4-*O*-[2-(*tert*-butoxycarbonylamino)-2-phenylacetyl]-6-*O*-{2-[2-(*tert*-butoxycarbonylamino)-2-phenylacetamido]-2-phenylacetyl}-1-thio-β-D-galactopyranoside (8):** To a solution of *N*-α-*t*-Boc-L-phenylglycine (119 mg, 474 μmol) in dichloromethane (1 mL) was added DIC (37 μL, 236 μmol) at 0 °C, and the mixture was stirred for 40 min at 0 °C. After concentration, the product was dissolved in pyridine. To the resultant solution was added **7** (100 mg, 118 μmol) and DMAP (43 mg, 354 μmol), and the mixture was stirred for 5 h at 50 °C. After concentration, the product was purified by chromatography on a column of silica gel with ethyl acetate/hexane (1:2) to give **8** (87 mg, 68%). $[\alpha]_D$ = 32.7 (*c* = 0.9, $CHCl_3$). $^1H$ NMR (600 MHz, $CDCl_3$): $\delta$ = 1.37, 1.40, 1.41 (3 s, 18 H, 2 $Me_3$CO), 3.47, 4.03, 4.21, 4.38, 4.42 (5 m, 2 H, 6-H), 3.82–3.99 (m, 1 H, 5-H), 4.78, 4.80, 4.85 (3 d, $J_{1,2}$ = 9.9, 9.9, 10.1 Hz, 1 H, 1-H), 5.22, 5.28, 5.50 [3 m, 3 H, 3 N*CH*(Ph)CO], 5.27, 5.35, 5.42 (3 m, 1 H, 3-H), 5.36, 5.58 (2 t, $J_{1,2} = J_{2,3}$ = 9.9, 10.1 Hz, 1 H, 2-H), 5.41, 5.44 (2 br. s, 1 H, 4-H), 7.17–7.97 [m, 30 H, 2 *Ph*COO, 3 NCH(*Ph*)CO and SPh] ppm. $^{13}C$ NMR (150 MHz, $CDCl_3$): $\delta$ = 28.04, 28.28 (2 $Me_3$CO), 56.91, 58.46 [3 N*CH*(Ph)CO], 62.07, 62.81 (C-6), 67.35, 67.45 (C-2), 68.52, 68.80 (C-4), 72.45 (C-3),74.20, 74.55 (C-5), 80.15, 80.30 ($Me_3CO$), 85.33, 85.55 (C-1), 126.55, 127.14, 127.27, 127.37, 127.45, 128.21, 128.29, 128.35, 128.39, 128.52, 128.59, 128.86, 128.91, 129.08, 129.15, 129.20, 129.70, 129.80, 133.13, 133.27, 134.35 [2 *Ph*COO, 3 NCH(*Ph*)CO and SPh], 154.67, 155.13 (C=O Boc), 164.54, 165.24 (2 Ph*C*OO), 169.63 [3 NCH(Ph)*CO*] ppm. ESI-FT-MS: calcd. for $C_{60}H_{61}N_3O_{14}SNa^+$ [M + $Na^+$] 1102.37665; found 1102.37514.

**General Procedure for One Cycle of Edman Degradation:** One cycle of Edman degradation is explained for the synthesis of compound **18**. First step: deprotection of the amino protecting group (Boc or Fmoc). Second step: coupling of phenyl isothiocyanate (PITC). During this step, a mono-UCP group was removed, except for phenylglycyl-UCP. Third step: removal of the *N*-terminal amino acid derivative. Fourth step: Boc protection of the newly exposed amino group.

**Phenyl 2,3-Di-*O*-benzoyl-6-*O*-{2-[*tert*-butoxycarbonyl(methyl)-amino]acetyl}-1-thio-β-D-galactopyranoside (18):** To a solution of **5** (117 mg, 131 μmol) in dichloromethane (3 mL) was added trifluoroacetic acid (600 μL), and the mixture was stirred for 30 min at room temp. After concentration, the product (**9**) was dissolved in DMF (1 mL). To the resultant solution was added phenyl isothiocyanate (500 μL, 4.18 mmol) and *N*-methylmorpholine (120 μL), and the mixture was stirred for 30 min at room temp. To the mixture was added ethyl acetate, and the organic layer was washed with water, dried ($Na_2SO_4$), and concentrated. Column chromatography (ethyl acetate/hexane, 2:1) of the residue over silica gel gave phenylthiocarbamoyl complex **12**, which was dried in vacuo. To a solution of phenylthiocarbamoyl complex **12** in dichloromethane (2 mL) was added trifluoroacetic acid (400 μL), and the mixture was stirred for 30 min at room temp. After concentration in vacuo, the product **15** was dissolved in DMF (1 mL). In addition, di-*tert*-butyl dicarbonate (400 mg, 1.83 mmol) and saturated aqueous $NaHCO_3$ (1 mL) were added to the resultant solution, and the mixture was stirred for 30 min at room temp. To the mixture was added ethyl acetate and the organic layer was washed with water, dried ($Na_2SO_4$), and concentrated. Column chromatography (ethyl acetate/hexane, 1:1) of the residue over silica gel gave **18** (40 mg, 4 steps 47%). $^1H$ NMR and $^{13}C$ NMR signals were observed as described for compound **2**. ESI-FT-MS: calcd. for $C_{34}H_{37}NO_{10}SNa^+$ [M + $Na^+$] 674.20304; found 674.20350.

**Phenyl 2,3-Di-*O*-benzoyl-6-*O*-{2-[*tert*-butoxycarbonyl(methyl)-amino]propionyl}-1-thio-β-D-galactopyranoside (19):** Using the general procedure for one cycle of Edman degradation, compound **6** (50 mg, 53 μmol) was degraded to compound **19** (22 mg, 4 steps 62%) via compounds **10**, **13**, and **16**. $^1H$ NMR and $^{13}C$ NMR signals were observed as described for compound **3**. ESI-FT-MS: calcd. for $C_{35}H_{39}NO_{10}SNa^+$ [M + $Na^+$] 688.21869; found 688.21898.

**Phenyl 2,3-Di-*O*-benzoyl-6-*O*-[2-(*tert*-butoxycarbonylamino)-2-phenylacetyl]-1-thio-β-D-galactopyranoside (20):** Using the general procedure for one cycle of Edman degradation, compound **8** (44 mg, 41 μmol) was degraded to compound **20** (20 mg, 4 steps 69%) via compounds **11**, **14**, and **17**. $^1H$ NMR and $^{13}C$ NMR signals were observed as described for compound **4**. ESI-FT-MS: calcd. for $C_{39}H_{39}NO_{10}SNa^+$ [M + $Na^+$] 736.21869; found 736.21800.

***tert*-Butyl (1-Ethylpropylamino)acetate (23):** A solution of *tert*-butyl bromoacetate (**22**, 5 mL, 33.9 mmol) in THF (20 mL) was added dropwise to a cooled solution of 3-amino pentane (**21**, 8.7 mL, 74.7 mmol) in THF (20 mL) over 5 min. The solution was stirred for 4 h at room temp. and concentrated. The product was suspended in diethyl ether; the residue of the hydrobromide salt was removed by filtration. The residue was washed with diethyl ether, and the filtrate was concentrated in vacuo to give **23** (6.7 g, 98%) as a colorless oil. $[\alpha]_D$ = –0.2 (*c* = 1.2, $CHCl_3$). $^1H$ NMR (600 MHz, $CDCl_3$): $\delta$ = 0.89 (t, $J_{CH3,CH} = J_{CH3,CH'}$ = 7.5 Hz, 6 H, 2 $CH_3CH_2$), 1.42 (m, 4 H, 2 $CH_3CH_2$), 1.47 (s, 9 H, *t*Bu), 1.67 (s, 1 H, NH), 2.35 [quint, $J_{CH,CHa} = J_{CH,CHa'} = J_{CH,CHb} = J_{CH,CHb'}$ = 5.9 Hz, 1 H, $(CH_3CH_2)_2CH$], 3.30 (s, 2 H, N$HCH_2$CO) ppm. $^{13}C$

NMR (150 MHz, $CDCl_3$): $\delta$ = 9.74 (2 $CH_3CH_2$), 25.73 (2 $CH_3CH_2$), 28.10 ($Me_3CO$), 49.46 ($NHCH_2CO$), 59.70 [$(CH_3CH_2)_2CH$], 81.00 ($Me_3CO$), 172.08 (C=O) ppm. ESI-FT-MS: calcd. for $C_{11}H_{24}NO_2^+$ [M + H$^+$] 202.18016; found 202.18082.

***tert*-Butyl [(1-Ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]-acetate (24):** A solution of 9-fluorenylmethyl chloroformate (9.4 g, 36.3 mmol) in 1,4-dioxane (100 mL) was added dropwise to a cooled solution of **23** (7.37 g, 36.6 mmol) in satd. aq. $NaHCO_3$ (100 mL) over 5 min. After stirring for 2 h at room temp., ethyl acetate was added and the mixture was washed with water, dried ($Na_2SO_4$), and concentrated. Column chromatography (ethyl acetate/hexane, 1:4) of the residue on silica gel gave **24** (13.34 g, 86%). $[\alpha]_D$ = –1.0 ($c$ = 1.1, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.77, 0.90 (2 t, $J_{CH3,CH}$ = $J_{CH3,CH'}$ = 7.4, 7.4 Hz, 6 H, 2 $CH_3CH_2$), 1.25–1.50 (m, 4 H, 2 $CH_3CH_2$), 1.42, 1.45 (2 s, 9 H, *t*Bu), 3.62, 4.00 [2 ttt, $J_{CH,CHa}$ = $J_{CH,CHb}$ = 6.0, 5.6 Hz, $J_{CH,CHa'}$ = $J_{CH,CHb'}$ = 8.9, 9.1 Hz, 1 H, $(CH_3CH_2)_2CH$], 3.66, 3.67 (2 s, 2 H, $NCH_2CO$), 4.22, 4.25 (2 t, $J_{9\text{-}H,CH}$ = $J_{9\text{-}H,CH'}$ = 7.0, 6.3 Hz, 1 H, 9-H Fmoc), 4.42, 4.51 (2 d, $J_{CH2,9\text{-}H}$ = 7.0, 6.2 Hz, 2 H, $CH_2$ Fmoc), 7.29–7.77 (m, 8 H, Ar Fmoc) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 11.00, 11.05 (2 $CH_3CH_2$), 25.75, 25.99 (2 $CH_3CH_2$), 28.00, 28.03 ($Me_3CO$), 44.48, 44.78 ($NCH_2CO$), 47.35, 47.50 (C-9 Fmoc), 59.58, 59.88 [$(CH_3CH_2)_2CH$], 67.18, 67.47 ($CH_2$ Fmoc), 81.24, 81.47 ($Me_3CO$), 119.87, 119.89, 124.88, 125.16, 126.98, 127.05, 127.56, 127.62, 141.28, 141.38, 144.11, 144.16 (Ar Fmoc), 156.71, 156.89 (C=O Fmoc), 168.86, 169.03 ($NCH_2CO$) ppm. ESI-FT-MS: calcd. for $C_{26}H_{33}NO_4Na^+$ [M + Na$^+$] 446.23018; found 446.22838.

**[(1-Ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetic Acid (25):** A solution of **24** (13.058 g, 30.8 mmol) in 90% aq. formic acid (100 mL) was stirred for 7 h at 40 °C. After concentration, the product was purified by chromatography on a column of silica gel with ethyl acetate/hexane (1:5) to give **25** (10.159 g, 90%). $[\alpha]_D$ = –0.4 ($c$ = 0.8, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.71, 0.85 (2 t, $J_{CH3,CH}$ = $J_{CH3,CH'}$ = 7.4 Hz, 6 H, 2 $CH_3CH_2$), 1.24–1.44 (m, 4 H, 2 $CH_3CH_2$), 3.56, 3.97 [2 m, 1 H, $(CH_3CH_2)_2CH$], 3.66, 3.77 (2 s, 2 H, $NCH_2CO$), 4.17, 4.24 (2 m, 1 H, 9-H Fmoc), 4.49, 4.58 (2 d, $J_{CH2,9\text{-}H}$ = 6.2, 5.8 Hz, 2 H, $CH_2$ Fmoc), 7.27–7.76 (m, 8 H, Ar Fmoc) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 10.84, 10.93 (2 $CH_3CH_2$), 25.71, 25.88 (2 $CH_3CH_2$), 43.09, 44.22 ($NCH_2CO$), 47.32, 47.38 (C-9 Fmoc), 59.55, 60.24 [$(CH_3CH_2)_2CH$], 67.32, 67.53 ($CH_2$ Fmoc), 119.89, 119.95, 124.76, 124.82, 127.02, 127.07, 127.57, 127.70, 141.34, 141.43, 143.84, 143.97 (Ar Fmoc), 156.50, 157.82 (C=O Fmoc), 173.78, 174.91 ($NCH_2CO$). ESI-FT-MS: calcd. for $C_{22}H_{26}NO_4^+$ [M + H$^+$] 368.18563; found 368.18691.

***tert*-Butyl [(1-Ethylpropyl){2-[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetyl}amino]acetate (26):** *N*,*N*-Diisopropylethylamine (948 µmol, 5.44 mmol) and PyBroP (1.9 g, 4.08 mmol) were added to a mixture of **23** (1 g, 4.97 mmol) and **25** (1 g, 2.72 mmol) in DMF (5 mL), and the mixture was stirred for 30 min at room temp. The product was dissolved in chloroform and the solution was washed with 2 N HCl and water, dried ($Na_2SO_4$), and concentrated. Column chromatography (ethyl acetate/hexane, 1:3) of the residue on silica gel gave **26** (1.364 g, 91%). $[\alpha]_D$ = –0.2 ($c$ = 1.2, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.77–1.00 (m, 12 H, 4 $CH_3CH_2$), 1.24–1.53 (m, 8 H, 4 $CH_3CH_2$), 1.43, 1.43, 1.47, 1.49 (4 s, 9 H, *t*Bu), 3.39, 3.45, 3.65, 3.91, 4.03 [5 m, 2 H, 2 $(CH_3CH_2)_2CH$], 3.42, 3.56, 3.70, 3.75, 3.89, 3.94, 3.95 (7 s, 4 H, 2 $NCH_2CO$), 4.25 (m, 1 H, 9-H Fmoc), 4.40, 4.47, 4.49 (3 d, $J_{CH2,9\text{-}H}$ = 6.9, 6.3, 6.3 Hz, 2 H, $CH_2$ Fmoc), 7.28–7.76 (m, 8 H, Ar Fmoc) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 10.93, 10.95, 11.08, 11.18, 11.21, 11.25, 11.31, 11.35 (4 $CH_3CH_2$), 25.17, 25.30, 25.62, 25.65, 25.87, 25.96, 26.46, 26.49 (4 $CH_3CH_2$), 27.92, 27.95 ($Me_3CO$), 43.25, 43.50, 43.81, 43.87 (2 $NCH_2CO$), 47.34, 47.42, 47.87 (C-9 Fmoc), 59.62, 59.95, 60.11, 60.23, 60.26 [2 $(CH_3CH_2)_2CH$], 67.17, 67.35 ($CH_2$ Fmoc), 81.11, 81.18 ($Me_3CO$), 119.70, 119.74, 119.81, 119.83, 124.94, 125.21, 126.89, 126.96, 127.02, 127.39, 127.48, 127.81, 141.19, 141.29, 141.35, 144.21, 144.28, 144.41 (Ar Fmoc), 156.57, 156.89, 156.98, 157.02 (C=O Fmoc), 168.22, 168.50, 168.64, 168.76, 169.34, 169.81, 170.03 (2 $NCH_2CO$) ppm. ESI-FT-MS: calcd. for $C_{33}H_{46}N_2O_5Na^+$ [M + Na$^+$] 573.32989; found 573.33263.

**[(1-Ethylpropyl){2-[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetyl}amino]acetic Acid (27):** A solution of **26** (500 mg, 907.8 µmol) in 90% aq. formic acid (5 mL) was stirred for 3 h at 50 °C. The work-up as described for **25** gave **27** (403 mg, 93%). $[\alpha]_D$ = –0.3 ($c$ = 1.0, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.75, 0.87, 0.88, 0.94 (4 t, 12 H, 4 $CH_3CH_2$), 1.25–1.59 (m, 8 H, 4 $CH_3CH_2$), 3.37, 3.49, 3.62, 4.01 [4 m, 2 H, 2 $(CH_3CH_2)_2CH$], 3.80, 3.88, 3.88, 3.93 (4 s, 4 H, 2 $NCH_2CO$), 4.23 (m, 1 H, 9-H Fmoc), 4.46, 4.52 (2 d, $J_{CH2,9\text{-}H}$ = 6.5, 6.1 Hz, 2 H, $CH_2$ Fmoc), 7.27–7.76 (m, 8 H, Ar Fmoc) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 10.90, 11.11, 11.15, 11.18 (4 $CH_3CH_2$), 25.59, 25.84, 25.90, 26.18, 26.20 (4 $CH_3CH_2$), 43.40, 43.67, 43.74, 43.90, 43.99 (2 $NCH_2CO$), 47.30, 47.47 (C-9 Fmoc), 59.61, 60.18, 60.44, 60.86, 61.09 [2 $(CH_3CH_2)_2CH$], 67.13, 67.35, 67.46 ($CH_2$ Fmoc), 119.78, 119.88, 124.57, 124.88, 124.95, 125.07, 125.19, 126.93, 127.02, 127.48, 127.58, 141.24, 141.40, 144.10, 144.22 (Ar Fmoc), 156.80, 157.13, 157.35 (C=O Fmoc), 170.73, 171.16, 172.00, 172.28, 173.51 (2 $NCH_2CO$) ppm. ESI-FT-MS: calcd. for $C_{29}H_{39}N_2O_5^+$ [M + H$^+$] 495.28535; found 495.28670.

***tert*-Butyl [(1-Ethylpropyl){2-[(1-ethylpropyl){2-[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetyl}amino]acetyl}-amino]acetate (28):** *N*,*N*-Diisopropylethylamine (603 µmol, 3.46 mmol) and PyBroP (1.2 g, 2.57 mmol) were added to a mixture of **23** (522 mg, 2.59 mmol) and **27** (829 mg, 1.73 mmol) in DMF (4 mL), and the mixture was stirred for 30 min at room temp. The work-up described for **26** gave **28** (975 mg, 85%). $[\alpha]_D$ = –0.2 ($c$ = 1.2, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.74–0.96 (m, 18 H, 6 $CH_3CH_2$), 1.26–1.52 (m, 12 H, 6 $CH_3CH_2$), 1.43, 1.44, 1.46, 1.47, 1.47, 1.48 (6 s, 9 H, *t*Bu), 3.38, 3.46, 3.68, 3.95 [4 m, 3 H, 3 $(CH_3CH_2)_2CH$], 3.60–3.96 (m, 6 H, 3 $NCH_2CO$), 4.18–4.28 (m, 1 H, 9-H Fmoc), 4.37–4.50 (m, 2 H, $CH_2$ Fmoc), 7.28–7.76 (m, 8 H, Ar Fmoc) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 10.78, 10.82, 10.87, 10.93, 10.97, 11.02, 11.10, 11.24, 11.32, 11.56 (6 $CH_3CH_2$), 25.16, 25.24, 25.32, 25.44, 25.48, 25.67, 25.73, 26.44, 26.51 (6 $CH_3CH_2$), 27.90, 27.94, 27.99 ($Me_3CO$), 43.42, 43.50, 43.96 (3 $NCH_2CO$), 47.33, 47.49, 47.71 (C-9 Fmoc), 60.05, 60.12, 60.40, 60.46, 60.57, 60.77 [3 $(CH_3CH_2)_2CH$], 66.43, 67.19 ($CH_2$ Fmoc), 81.28, 81.41, 81.75, 81.93, 82.52, 82.85 ($Me_3CO$), 119.59, 119.68, 119.78, 119.85, 125.02, 125.06, 125.26, 125.36, 126.86, 126.96, 127.36, 127.42, 127.53, 141.22, 141.26, 141.35, 141.37, 144.25, 144.44, 144.47 (Ar Fmoc), 156.92, 157.15 (C=O Fmoc), 168.50, 168.95, 169.34, 169.88, 169.91, 170.00 (3 $NCH_2CO$) ppm. ESI-FT-MS: calcd. for $C_{40}H_{60}N_3O_6^+$ [M + H$^+$] 678.44766; found 678.44615.

**[(1-Ethylpropyl){2-[(1-ethylpropyl){2-[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetyl}amino]acetyl}amino]acetic Acid (29):** A solution of **28** (171 mg, 258.3 µmol) in 90% aq. formic acid (2 mL) was stirred for 2 h at 50 °C. The work-up as described for **25** gave **29** (154 mg, 98%). $[\alpha]_D$ = –0.2 ($c$ = 1.2, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.74–0.99 (m, 18 H, 6 $CH_3CH_2$), 1.21–1.63 (m, 12 H, 6 $CH_3CH_2$), 3.36, 3.44, 3.51, 3.65, 3.95, 4.01 [6 m, 3 H, 3 $(CH_3CH_2)_2CH$], 3.59–4.16 (m, 6 H, 3 $NCH_2CO$), 4.23 (m, 1 H, 9-H Fmoc), 4.39–4.53 (m, 2 H, $CH_2$ Fmoc), 7.27–7.77 (m, 8 H, Ar

Fmoc) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 10.79, 10.83, 10.89, 10.98, 11.05, 11.11, 11.16, 11.19, 11.21, 11.40, 11.50 (6 $CH_3CH_2$), 25.18, 25.26, 25.43, 25.53, 25.70, 25.81, 25.85, 26.07, 26.36 (6 $CH_3CH_2$), 42.02, 42.79, 44.03, 44.10 (3 $NCH_2CO$), 47.22, 47.26, 47.45, 47.75 (C-9 Fmoc), 60.55, 60.66, 60.70 [3 $(CH_3CH_2)_2CH$], 67.36, 67.44, 67.74 ($CH_2$ Fmoc), 119.66, 119.78, 119.86, 119.88, 124.88, 124.96, 124.99, 125.04, 125.24, 125.34, 126.92, 126.99, 127.01, 127.38, 127.43, 127.56, 127.59, 141.22, 141.36, 141.38, 144.12, 144.18 (Ar Fmoc), 157.29, 157.34 (C=O Fmoc), 170.81, 171.57, 172.79 (3 $NCH_2CO$) ppm. ESI-FT-MS: calcd. for $C_{36}H_{52}N_3O_6^+$ [M + H$^+$] 622.38506; found 622.38370.

***tert*-Butyldimethylsilyl 2-Azido-4,6-*O*-benzylidene-2-deoxy-3-*O*-{[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetyl}-β-D-galactopyranoside (31):** To a solution of **30**[12] (496 mg, 1.22 mmol) in pyridine (9 mL) was added **25** (671 mg, 1.83 mmol) and cyanuric chloride (1.12 g, 6.07 mmol), and the mixture was stirred for 2 h at 40 °C. After concentration, the product was purified by chromatography on a column of silica gel with ethyl acetate/hexane (1:2) to give **31** (830 mg, 90%). $[\alpha]_D$ = 19.8 ($c$ = 0.9, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.16, 0.17, 0.17, 0.18 (4 s, 6 H, $Me_2Si$), 0.74, 0.89 (2 m, 6 H, 2 $CH_3CH_2$), 0.94, 0.95 (2 s, 9 H, $Me_3CSi$), 1.24–1.50 (m, 4 H, 2 $CH_3CH_2$), 3.35, 3.41 (2 s, 1 H, 5-H), 3.62, 4.03 [2 m, 1 H, $(CH_3CH_2)_2CH$], 3.78, 3.79 (2 dd, $J_{1,2}$ = 7.6, 7.5 Hz, $J_{2,3}$ = 11.1z, 11.0 Hz, 1 H, 2-H), 3.79, 3.88 (2 m, 2 H, $NCH_2CO$), 3.88, 4.02, 4.18, 4.25 (4 dd, $J_{gem}$ = 12.3 Hz, $J_{6,5}$ = 1.4 Hz, 2 H, 6-H), 4.06, 4.31 (2 d, $J_{3,4}$ = 3.2, 3.7 Hz, 1 H, 4-H), 4.06, 4.36, 4.44, 4.49 (4 dd, $J_{gem}$ = 10.7, 10.7, 10.7, 10.7 Hz, $J_{CH2,9\text{-}H}$ = 7.5, 6.3, 6.8, 6.1 Hz, 2 H, $CH_2$ Fmoc), 4.19 (m, 1 H, 9-H Fmoc), 4.60, 4.62 (2 d, $J_{1,2}$ = 7.6, 7.6 Hz, 1 H, 1-H), 4.66, 4.76 (2 dd, $J_{2,3}$ = 10.9, 10.9 Hz, $J_{3,4}$ = 3.6, 3.5 Hz, 1 H, 3-H), 5.08, 5.50 (2 s, 1 H, Ph$CH$), 7.23–7.77 (m, 13 H, Ar Fmoc and $Ph$CH) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = –4.93, –4.16 ($Me_2Si$), 10.88, 10.92, 10.95, 11.03 (2 $CH_3CH_2$), 17.99, 18.01 ($Me_3CSi$), 25.58, 25.69, 25.76, 25.90, 26.00 (2 $CH_3CH_2$), 25.64, 25.65 ($Me_3CSi$), 43.66, 43.86 ($NCH_2CO$), 47.20, 47.25 (C-9 Fmoc), 59.57, 59.94 [$(CH_3CH_2)_2CH$], 62.60, 62.70 (C-2), 66.18, 66.28 (C-5), 67.21, 67.83 ($CH_2$ Fmoc), 68.95, 69.04 (C-6), 72.12, 72.34 (C-3), 72.47, 72.70 (C-4), 97.33, 97.40 (C-1), 100.85 (Ph$CH$), 119.71, 119.86, 119.90, 119.96, 120.97, 124.79, 124.82, 124.98, 125.40, 126.15, 126.26, 126.96, 127.03, 127.55, 127.57, 128.08, 128.11, 129.01, 129.03 (Ar Fmoc and $Ph$CH), 156.50, 156.88 (C=O Fmoc), 169.39, 169.68 ($NCH_2CO$) ppm. ESI-FT-MS: calcd. for $C_{41}H_{53}N_4O_8Si^+$ [M + H$^+$] 757.36272; found 757.36288.

***tert*-Butyldimethylsilyl 2-Azido-2-deoxy-3-*O*-{[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetyl}-β-D-galactopyranoside (32):** A solution of **31** (780 mg, 1.03 mmol) in 80% aq. acetic acid (50 mL) was stirred for 2 h at 60 °C. After concentration, the product was purified by chromatography on a column of silica gel with ethyl acetate/hexane (1:1) to give **32** (542 mg, 79%). $[\alpha]_D$ = 14.9 ($c$ = 1.3, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.17, 0.17 (2 s, 6 H, $Me_2Si$), 0.69, 0.72 (2 t, $J_{CH3,CH}$ = $J_{CH3,CH'}$ 7.4, 7.4 Hz, 6 H, 2 $CH_3CH_2$), 0.95 (s, 9 H, $Me_3CSi$), 1.18–1.41 (m, 4 H, 2 $CH_3CH_2$), 3.49 [m, 1 H, $(CH_3CH_2)_2CH$], 3.51 (m, 1 H, 5-H), 3.64, 3.78 (2 d, $J_{gem}$ = 17.0, 17.0 Hz, 2 H, $NCH_2CO$), 3.66 (dd, $J_{1,2}$ = 7.7 Hz, $J_{2,3}$ = 10.7 Hz, 1 H, 2-H), 3.78, 3.94 (2 m, 2 H, 6-H), 4.19 (d, $J_{3,4}$ = 2.3 Hz, 1 H, 4-H), 4.21 (t, $J_{9\text{-}H,CH}$ = $J_{9\text{-}H,CH'}$ = 5.5 Hz, 1 H, 9-H Fmoc), 4.47 (dd, $J_{2,3}$ = 10.7 Hz, $J_{3,4}$ = 3.1 Hz, 1 H, 3-H), 4.55 (d, $J_{1,2}$ = 8.2 Hz, 1 H, 1-H), 4.57 (d, $J_{CH2,9\text{-}H}$ = 5.5 Hz, 2 H, $CH_2$ Fmoc), 7.30–7.77 (m, 8 H, Ar Fmoc) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = –5.18, –4.13 ($Me_2Si$), 10.74, 10.76 (2 $CH_3CH_2$), 17.93 ($Me_3CSi$), 25.61 ($Me_3CSi$), 25.87, 25.98 (2 $CH_3CH_2$), 44.48, 44.51, 44.54 ($NCH_2CO$), 47.17 (C-9 Fmoc), 60.35 [$(CH_3CH_2)_2CH$], 62.45 (C-6), 62.78 (C-2), 65.61 (C-4), 67.49 ($CH_2$ Fmoc), 74.22 (C-5), 74.97 (C-3), 97.65 (C-1), 119.98, 124.58, 124.69, 127.07, 127.28, 127.74, 127.82, 141.44, 141.50, 143.67 (Ar Fmoc), 158.12 (C=O Fmoc), 168.52 ($NCH_2CO$) ppm. ESI-FT-MS: calcd. for $C_{34}H_{49}N_4O_8Si^+$ [M + H$^+$] 669.33142; found 669.33028.

***tert*-Butyldimethylsilyl 2-Azido-2-deoxy-6-*O*-{[(1-ethylpropyl){2-[(1-ethylpropyl){2-[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)-amino]acetyl}amino]acetyl}-3-*O*-{[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetyl}-β-D-galactopyranoside (33):** To a solution of **32** (100 mg, 149.5 μmol) in pyridine (2 mL) was added **29** (100 mg, 165 μmol) and cyanuric chloride (138 mg, 748.3 μmol), and the mixture was stirred for 2 h at 40 °C. After concentration, the product was purified by chromatography on a column of silica gel with ethyl acetate/hexane (1:1) to give **33** (122 mg, 65%). $[\alpha]_D$ = 7.9 ($c$ = 1.5, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.16, 0.17, 0.17, 0.18 (4 s, 6 H, $Me_2Si$), 0.67–1.01 (m, 24 H, 8 $CH_3CH_2$), 0.95 (s, 9 H, $Me_3CSi$), 1.18–1.63 (m, 16 H, 8 $CH_3CH_2$), 3.49, 3.70 [2 m, 4 H, 4 $(CH_3CH_2)_2CH$], 3.61, 3.63, 3.81 (3 m, 8 H, 4 $NCH_2CO$), 3.63 (m, 1 H, 5-H), 3.66 (m, 1 H, 2-H), 4.15 (m, 1 H, 4-H), 4.23 (m, 2 H, 9-H 2 Fmoc), 4.33 (m, 2 H, 6-H), 4.42, 4.47, 4.58 (3 m, 4 H, 2 $CH_2$ Fmoc), 4.45 (m, 1 H, 3-H), 4.53 (d, $J_{1,2}$ = 7.7 Hz, 1 H, 1-H), 7.27–7.77 (m, 16 H, Ar 2 Fmoc) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = –5.26, –4.22 ($Me_2Si$), 10.74, 11.14, 11.19, 11.31 (8 $CH_3CH_2$), 17.94 ($Me_3CSi$), 25.48, 25.58, 25.85, 26.00 (8 $CH_3CH_2$), 25.63 ($Me_3CSi$), 42.50, 43.36, 43.92, 44.57 (4 $NCH_2CO$), 47.17, 47.33 (C-9 2 Fmoc), 59.79, 60.02, 60.34, 60.48, 60.56 [4 $(CH_3CH_2)_2CH$], 62.63 (C-2), 63.27 (C-6), 64.56 (C-4), 67.21, 67.43 ($CH_2$ 2 Fmoc), 71.87, 71.92 (C-5), 74.74, 74.83 (C-3), 97.57 (C-1), 119.69, 119.85, 119.98, 124.56, 124.71, 125.05, 125.34, 126.97, 127.07, 127.31, 127.37, 127.53, 127.74, 127.82, 141.25, 141.34, 141.44, 141.51, 143.65, 144.24 (Ar, 2 Fmoc), 157.18, 158.16 (C=O 2 Fmoc), 168.38, 168.44, 168.46, 169.57, 170.61 (4 $NCH_2CO$) ppm. ESI-FT-MS: calcd. for $C_{70}H_{98}N_7O_{13}Si^+$ [M + H$^+$] 1272.69864; found 1272.69712.

***tert*-Butyldimethylsilyl 4-*O*-Acetyl-2-azido-2-deoxy-6-*O*-{[(1-ethylpropyl){2-[(1-ethylpropyl){2-[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetyl}amino]acetyl}amino]acetyl}-3-*O*-{[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetyl}-β-D-galactopyranoside (34):** To a solution of **33** (287 mg, 228.3 μmol) in pyridine (3 mL) was added acetic anhydride (3 mL), and the mixture was stirred for 2 h at 40 °C. The product was dissolved in chloroform and the solution was washed with 2 N HCl and water, dried ($Na_2SO_4$), and concentrated. Column chromatography (ethyl acetate/hexane, 1:3) of the residue on silica gel gave **34** (269 mg, 91%). $[\alpha]_D$ = 0.5 ($c$ = 1.0, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.15, 0.15, 0.16, 0.17 (4 s, 6 H, $Me_2Si$), 0.72–0.97 (m, 24 H, 8 $CH_3CH_2$), 0.93 (s, 9 H, $Me_3CSi$), 1.33–1.51 (m, 16 H, 8 $CH_3CH_2$), 2.04 (s, 3 H, OAc), 3.58 (m, 1 H, 2-H), 3.60, 3.66 [2 m, 4 H, 4 $(CH_3CH_2)_2CH$], 3.61, 3.70, 3.83 (3 m, 8 H, 4 $NCH_2CO$), 3.83 (m, 1 H, 5-H), 4.02–4.19 (m, 2 H, 6-H), 4.24 (m, 2 H, 9-H 2 Fmoc), 4.32–4.54 (m, 4 H, $CH_2$ 2 Fmoc), 4.57, 4.58 (2 d, $J_{1,2}$ = 7.6, 7.6 Hz, 1 H, 1-H), 4.75, 4.80 (2 dd, $J_{2,3}$ = 11.1, 11.1 Hz, $J_{3,4}$ = 3.4, 3.4 Hz, 1 H, 3-H), 5.14–5.36 (m, 1 H, 4-H), 7.28–7.76 (m, 16 H, Ar 2 Fmoc) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = –5.15, –5.09, –4.41, –4.39 ($Me_2Si$), 10.81, 10.89, 10.90, 10.98, 11.01, 11.08, 11.14, 11.18, 11.22, 11.33, 11.50 (8 $CH_3CH_2$), 18.00 ($Me_3CSi$), 20.57, 20.66, 21.05 ($CH_3COO$), 25.23, 25.42, 25.46, 25.69, 25.74, 25.89, 26.00, 26.30, 26.34, 26.38, 26.45 (8 $CH_3CH_2$), 25.58 ($Me_3CSi$), 42.44, 42.51, 43.32, 43.58, 43.88, 44.00 (4 $NCH_2CO$), 47.31 (C-9 2 Fmoc), 59.69, 59.94, 60.06, 60.39, 60.48, 60.53, 60.59 [4 $(CH_3CH_2)_2CH$], 61.25, 61.37 (C-6), 63.16, 63.22 (C-2), 66.22, 66.29, 66.42, 66.57 (C-4), 67.21, 67.32 ($CH_2$ 2 Fmoc), 70.56, 70.65, 70.76 (C-5), 71.33, 71.39 (C-3), 97.38, 97.42, 97.49 (C-1), 119.69, 119.85, 119.91, 124.79, 124.83, 125.02, 125.13, 125.33, 126.96, 127.01, 127.36,

127.53, 127.61, 128.22, 129.03, 141.24, 141.27, 141.32, 141.34, 141.37, 141.40, 143.99, 144.05, 144.11, 144.23, 144.38 (Ar, 2 Fmoc), 156.50, 156.87, 157.15 (C=O 2 Fmoc), 168.19, 168.22, 168.78, 168.89, 169.06, 169.62 (4 $NCH_2CO$), 170.07, 170.14 (C=O Ac) ppm. ESI-FT-MS: calcd. for $C_{72}H_{100}N_7O_{14}Si^+$ [M + $H^+$] 1314.70920; found 1314.70920.

***tert*-Butyldimethylsilyl 4-*O*-Acetyl-2-azido-2-deoxy-6-*O*-{[{2-[*tert*-butoxycarbonyl(1-ethylpropyl)amino]acetyl}(1-ethylpropyl)-amino]acetyl}-β-D-galactopyranoside (35):** To a solution of **34** (300 mg, 230.9 μmol) in DMF (1.6 mL) was added piperidine (400 μL, 4.04 mmol), and the mixture was stirred for 20 min at room temp. After cooling to 0 °C, phenyl isothiocyanate (1 mL, 8.36 mmol) and *N*-methylmorpholine (200 μL) were added to the mixture, followed by stirring for 30 min at room temp. Subsequently, work-up (extraction and purification), trifluoroacetic acid treatment, amino group reprotection procedures, and work-up (extraction and purification) were performed according to the general procedure for one cycle of Edman degradation to yield GalN derivative **35** (114 mg, 4 steps 69%). $[\alpha]_D$ = –2.0 (*c* = 2.1, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.16, 0.17, 0.17 (3 s, 6 H, $Me_2Si$), 0.83–1.00 (m, 12 H, 4 $CH_3CH_2$), 0.94, 0.94 (2 s, 9 H, $Me_3CSi$), 1.33–1.53 (m, 8 H, 4 $CH_3CH_2$), 1.41, 1.46 (2 s, 9 H, Boc), 2.15, 2.16 (2 s, 3 H, OAc), 3.41, 3.53, 3.63, 3.96 [4 m, 2 H, 2 $(CH_3CH_2)_2CH$], 3.46 (m, 1 H, 2-H), 3.60 (m, 1 H, 3-H), 4.52, 4.52 (2 d, $J_{1,2}$ = 7.6, 7.7 Hz, 1 H, 1-H), 5.29, 5.30 (2 d, $J_{3,4}$ = 3.5, 3.6 Hz, 1 H, 4-H) ppm $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = –5.12, –4.31, –4.29 ($Me_2Si$), 10.82, 11.21, 11.22, 11.25, 11.32, 11.33, 11.39, 11.60 (4 $CH_3CH_2$), 18.03 ($Me_3CSi$), 20.82, 20.84 ($CH_3COO$), 25.61, 25.67, 25.69, 25.92, 25.97, 26.26, 26.52, 26.59 (4 $CH_3CH_2$), 25.64, 25.65 ($Me_3CSi$), 28.25, 28.54 ($Me_3CO$), 42.55, 43.33, 43.65 (2 $NCH_2CO$), 60.07, 60.24 [2 $(CH_3CH_2)_2CH$], 61.04, 61.82 (C-6), 65.75, 66.21 (C-2), 68.50, 68.74 (C-4), 70.20, 70.61 (C-5), 70.71, 70.78 (C-3), 79.52, 79.79 ($Me_3CO$), 97.36 (C-1), 156.14, 156.49 (C=O Boc), 168.76, 168.91, 169.41, 169.79 (2 $NCH_2CO$), 170.98, 171.17 (C=O Ac) ppm. ESI-FT-MS: calcd. for $C_{33}H_{62}N_5O_{10}Si^+$ [M + $H^+$] 716.42605; found 716.42647.

**Phenyl 4,6-*O*-Benzylidene-3-*O*-{[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetyl}-1-thio-β-D-galactopyranoside (37):** To a solution of **25** (1.12 g, 3.05 mmol) in pyridine (20 mL) was added cyanuric chloride (2.56 g, 13.88 mmol), and the mixture was stirred for 30 min at 40 °C. This mixture was added dropwise to a cooled solution (0 °C) of **36**[11] (1 g, 2.77 mmol) in pyridine (20 mL) over 5 min. The combined mixture was stirred for a further 1 h at 0 °C. After adding ice to the mixture, the product was dissolved in ethyl acetate, and the solution was washed with water, dried ($Na_2SO_4$), and concentrated. Column chromatography (ethyl acetate/hexane, 1:1) of the residue on silica gel gave **37** (1.439 g, 73%). $[\alpha]_D$ = 11.4 (*c* = 1.0, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.55, 0.66, 0.81, 0.82 (4 t, $J_{CH3,CH} = J_{CH3,CH'}$ = 7.3, 7.3, 7.3, 7.3 Hz, 6 H, 2 $CH_3CH_2$), 1.14–1.43 (m, 4 H, 2 $CH_3CH_2$), 3.49, 3.54 (br. 2 s, 1 H, 5-H), 3.51, 3.96 [2 m, 1 H, $(CH_3CH_2)_2CH$], 3.66, 3.79 (2 d, $J_{gem}$ = 17.2, 17.1 Hz, 2 H, $NCH_2CO$), 3.85, 3.97, 4.27, 4.33 (4 dd, $J_{5,6}$ = 1.4, 1.5, 1.4, 1.5 Hz, $J_{gem}$ = 12.3, 12.3, 12.5, 12.3 Hz, 2 H, 6-H), 3.90, 3.90 (2 t, $J_{1,2} = J_{2,3}$ = 9.7, 9.5 Hz, 1 H, 2-H), 4.05, 4.37, 4.44, 4.47 (4 dd, $J_{CH2,9-H}$ = 7.6, 6.1, 6.7, 6.0 Hz, $J_{gem}$ = 10.6, 10.7, 10.6, 10.7 Hz, 2 H, $CH_2$ Fmoc), 4.13, 4.18 (2 t, $J_{9\text{-}H,CH} = J_{9\text{-}H,CH'}$ = 7.0, 7.3 Hz, 1 H, 9-H Fmoc), 4.17, 4.28 (2 d, $J_{3,4}$ = 2.4, 2.7 Hz, 1 H, 4-H), 4.53, 4.61 (2 d, $J_{1,2}$ = 9.5, 9.5 Hz, 1 H, 1-H), 4.90, 5.03 (2 dd, $J_{2,3}$ = 9.8, 9.6 Hz, $J_{3,4}$ = 3.4, 3.4 Hz, 1 H, 3-H), 5.06, 5.44 (2 s, 1 H, Ph*CH*), 7.12–7.76 (m, 18 H, Ar Fmoc, *Ph*CH and SPh) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 11.21, 11.22, 11.41 (2 $CH_3CH_2$), 26.18, 26.25, 26.40 (2 $CH_3CH_2$), 44.21, 44.64 ($NCH_2CO$), 47.64 (C-9 Fmoc), 60.03, 60.50 [$(CH_3CH_2)_2CH$], 66.03, 66.26 (C-2), 67.88, 68.20 ($CH_2$ Fmoc), 69.48, 69.62 (C-6), 70.10, 70.14 (C-5), 73.89, 74.30 (C-4), 75.83, 76.35 (C-3), 87.33, 87.85 (C-1), 101.29, 101.37 (Ph*CH*), 120.35, 120.42, 125.21, 125.24, 125.47, 125.91, 126.74, 126.88, 127.49, 127.50, 127.53, 127.56, 128.02, 128.09, 128.11, 128.13, 128.37, 128.43, 128.49, 128.73, 129.18, 129.43, 129.48, 131.45, 134.02, 134.16, 138.17, 141.80, 141.82, 144.32, 144.36 (Ar Fmoc, *Ph*CH and SPh), 157.04, 157.82 (C=O Fmoc), 169.90, 170.45 ($NCH_2CO$) ppm. ESI-FT-MS: calcd. for $C_{41}H_{44}NO_8S^+$ [M + $H^+$] 710.27821; found 710.27645.

**Phenyl 2-*O*-Benzoyl-4,6-*O*-benzylidene-3-*O*-{[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetyl}-1-thio-β-D-galactopyranoside (38):** To a solution of **37** (521 mg, 733.9 μmol) in pyridine (3 mL) was added benzoyl chloride (128 μL, 1.103 mmol), and the mixture was stirred for 2 h at room temp. After adding ice to the mixture, the product was dissolved in chloroform and the solution was washed with 2 N HCl and water, dried ($Na_2SO_4$), and concentrated. Column chromatography (ethyl acetate/hexane, 1:1) of the residue on silica gel gave **38** (582 mg, 97%). $[\alpha]_D$ = –16.9 (*c* = 1.1, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.46, 0.60, 0.64, 0.72 (4 t, $J_{CH3,CH} = J_{CH3,CH'}$ = 7.4, 7.4, 7.4, 7.4 Hz, 6 H, 2 $CH_3CH_2$), 0.85–1.31 (m, 4 H, 2 $CH_3CH_2$), 3.45, 3.55, 3.80, 3.82 (4 d, $J_{gem}$ = 17.7, 18.3, 18.3, 17.7 Hz, 2 H, $NCH_2CO$), 3.48, 3.85 [2 m, 1 H, $(CH_3CH_2)_2CH$], 3.59, 3.61 (2 d, $J_{5,6}$ = 1.1, 1.1 Hz, 1 H, 5-H), 3.92, 4.04 (2 dd, $J_{5,6}$ = 1.5, 1.6 Hz, $J_{gem}$ = 12.2, 12.3 Hz, 2 H, 6-H), 3.94, 4.24, 4.27, 4.33 (4 dd, $J_{CH2,9-H}$ = 7.8, 6.7, 6.3, 6.4 Hz, $J_{gem}$ = 10.6, 10.6, 10.7, 10.6 Hz, 2 H, $CH_2$ Fmoc), 4.04, 4.12 (2 t, $J_{9\text{-}H,CH} = J_{9\text{-}H,CH'}$ = 7.2, 6.2 Hz, 1 H, 9-H Fmoc), 4.21, 4.40 (2 dd, $J_{3,4}$ = 3.4, 3.3 Hz, $J_{4,5}$ = 0.8, 0.7 Hz, 1 H, 4-H), 4.85, 4.85 (2 d, $J_{1,2}$ = 9.8, 9.8 Hz, 1 H, 1-H), 5.21, 5.49 (2 s, 1 H, Ph*CH*), 5.23, 5.31 (2 dd, $J_{2,3}$ = 9.9, 9.9 Hz, $J_{3,4}$ = 3.4, 3.4 Hz, 1 H, 3-H), 5.55, 5.57 (2 dd, $J_{1,2}$ = 7.6, 7.6 Hz, $J_{2,3}$ = 9.8, 9.8 Hz, 1 H, 2-H), 7.18–8.01 (m, 23 H, Ar Fmoc, *Ph*CH, OBz and SPh) ppm. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 10.63, 10.71, 10.73, 10.76 (2 $CH_3CH_2$), 25.34, 25.47, 25.82 (2 $CH_3CH_2$), 43.25, 43.44 ($NCH_2CO$), 47.06, 47.17 (C-9 Fmoc), 59.26, 59.56 [$(CH_3CH_2)_2CH$], 67.12, 67.39, 67.48, 67.59 ($CH_2$ Fmoc and C-2), 68.93, 69.01 (C-6), 69.70, 69.78 (C-5), 73.17, 73.51 (C-3), 73.53, 73.68 (C-4), 85.07, 85.22 (C-1), 101.01, 101.03 (Ph*CH*), 119.81, 119.83, 124.78, 124.94, 125.21, 126.43, 126.47, 126.89, 126.91, 126.94, 126.98, 127.51, 127.53, 127.61, 128.04, 128.11, 128.24, 128.32, 128.34, 128.70, 128.72, 129.06, 129.12, 129.73, 129.85, 133.13, 133.23, 133.77, 134.00, 137.19, 141.15, 141.19, 141.26, 143.70, 143.95 (Ar Fmoc, *Ph*CH, *Ph*COO and SPh), 156.34, 156.73 (C=O Fmoc), 164.72, 164.83 (C=O Bz), 169.31, 169.66 ($NCH_2CO$) ppm. ESI-FT-MS: calcd. for $C_{48}H_{47}NO_9SNa^+$ [M + $Na^+$] 836.28637; found 836.28760.

**Phenyl 2-*O*-Benzoyl-3-*O*-{[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetyl}-1-thio-β-D-galactopyranoside (39):** A solution of **38** (432 mg, 530.7 μmol) in 80% aq. acetic acid (5 mL) was stirred for 2 h at 60 °C. After concentration, the product was purified by chromatography on a column of silica gel with ethyl acetate/hexane (1:1) to give **39** (250 mg, 65%). $[\alpha]_D$ = 15.0 (*c* = 1.3, $CHCl_3$). $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.57, 0.61 (2 t, $J_{CH3,CH} = J_{CH3,CH'}$ = 7.4, 7.4 Hz, 6 H, 2 $CH_3CH_2$), 0.94–1.31 (m, 4 H, 2 $CH_3CH_2$), 3.48, 3.61, 3.65, 3.71 (4 d, $J_{gem}$ = 18.4, 17.1, 17.1, 17.8 Hz, 2 H, $NCH_2CO$), 3.51, 3.82 [2 m, 1 H, $(CH_3CH_2)_2CH$], 3.70 (m, 1 H, 5-H), 3.84, 3.87, 3.96, 4.02 (4 dd, $J_{5,6}$ = 4.4, 4.6, 5.7, 6.4 Hz, $J_{gem}$ = 11.9, 11.9, 11.8, 11.9 Hz, 2 H, 6-H), 4.04, 4.20 (2 t, $J_{9\text{-}H,CH} = J_{9\text{-}H,CH'}$ = 4.5, 5.9 Hz, 1 H, 9-H Fmoc), 4.36 (dd, $J_{3,4}$ = 3.1 Hz, $J_{4,5}$ = 1.1 Hz, 1 H, 4-H), 4.45, 4.50 (2 dd, $J_{CH2,9-H}$ = 6.2, 5.9 Hz, $J_{gem}$ = 10.6, 10.6 Hz, 2 H, $CH_2$ Fmoc), 4.85, 4.86 (2 d, $J_{1,2}$ = 10.0, 10.0 Hz, 1 H, 1-H), 5.09, 5.18 (2 dd, $J_{2,3}$ = 9.8, 9.7 Hz, $J_{3,4}$ = 3.1, 3.1 Hz, 1 H, 3-H), 5.53, 5.64 (2 t, $J_{1,2} = J_{2,3}$ = 9.9, 9.9 Hz, 1 H, 2-H), 7.21–8.02 (m, 18 H, Ar Fmoc, OBz and SPh) ppm. $^{13}$C

NMR (150 MHz, $CDCl_3$): $\delta$ = 10.67, 10.71 (2 $CH_3CH_2$), 25.44, 25.79 (2 $CH_3CH_2$), 43.11, 44.26 ($NCH_2CO$), 47.15, 47.34 (C-9 Fmoc), 59.30, 59.88 [$(CH_3CH_2)_2CH$], 62.62 (C-6), 66.96, 67.15 (C-4), 67.68 ($CH_2$ Fmoc), 67.96, 68.26 (C-2), 74.81, 76.09 (C-3), 78.00, 78.28 (C-5), 86.52, 86.92 (C-1), 124.76, 124.90, 124.93, 127.04, 127.08, 127.17, 127.65, 127.71, 127.79, 128.35, 128.40, 128.89, 128.98, 129.56, 129.77, 129.86, 132.08, 132.59, 133.14, 133.27, 141.34, 141.42, 143.66, 143.86 (Ar Fmoc, *Ph*COO and SPh), 157.69 (C=O Fmoc), 165.02, 165.12 (C=O Bz), 168.97, 169.12 ($NCH_2CO$) ppm. ESI-FT-MS: calcd. for $C_{41}H_{43}NO_9SNa^+$ [M + $Na^+$] 748.25507; found 748.25643.

**Phenyl 4,6-Di-*O*-acetyl-2-*O*-benzoyl-3-*O*-{[(1-ethylpropyl)(9*H*-fluoren-9-ylmethoxycarbonyl)amino]acetyl}-1-thio-β-D-galactopyranoside (40):** To a solution of **39** (197 mg, 271.4 μmol) in pyridine (3 mL) was added acetic anhydride (3 mL), and the mixture was stirred for 2 h at room temp. The work-up as described for **34** gave **40** (168 mg, 76%). $[\alpha]_D$ = 22.8 (*c* = 1.0, $CHCl_3$). $^1H$ NMR (600 MHz, $CDCl_3$): $\delta$ = 0.57, 0.69, 0.69, 0.88 (4 t, $J_{CH3,CH}$ = $J_{CH3,CH'}$ = 7.3, 7.4, 7.3, 7.3 Hz, 6 H, 2 $CH_3CH_2$), 0.99–1.42 (m, 4 H, 2 $CH_3CH_2$), 2.04, 2.06, 2.13, 2.14 (4 s, 6 H, 2 OAc), 3.51, 3.89 [2 m, 1 H, $(CH_3CH_2)_2CH$], 3.56, 3.61, 3.63, 3.67 (4 d, $J_{gem}$ = 17.4, 17.4, 18.1, 18.1 Hz, 2 H, $NCH_2CO$), 3.89, 4.11 (2 t, $J_{9\text{-}H,CH}$ = $J_{9\text{-}H,CH'}$ = 7.3, 6.5 Hz, 1 H, 9-H Fmoc), 3.99 (m, 1 H, 5-H), 4.01, 4.09, 4.19, 4.27 (4 dd, $J_{CH2,9\text{-}H}$ = 7.4, 6.9, 6.2, 6.2 Hz, $J_{gem}$ = 10.6, 10.6, 10.5, 10.6 Hz, 2 H, $CH_2$ Fmoc), 4.16, 4.23 (2 dd, $J_{5,6}$ = 6.2, 6.9 Hz, $J_{gem}$ = 11.5, 11.4 Hz, 2 H, 6-H), 4.85, 4.86 (2 d, $J_{1,2}$ = 9.9, 10.0 Hz, 1 H, 1-H), 5.32, 5.34 (2 dd, $J_{2,3}$ = 10.0, 10.0 Hz, $J_{3,4}$ = 3.3, 3.3 Hz, 1 H, 3-H), 5.42, 5.49 (2 dd, $J_{3,4}$ = 3.3, 3.4 Hz, $J_{4,5}$ = 1.0, 0.9 Hz, 1 H, 4-H), 5.49, 5.50 (2 t, $J_{1,2}$ = $J_{2,3}$ = 10.0, 10.0 Hz, 1 H, 2-H), 7.10–7.99 (m, 18 H, Ar Fmoc, OBz and SPh) ppm. $^{13}C$ NMR (150 MHz, $CDCl_3$): $\delta$ = 10.79, 10.87, 11.07 (2 $CH_3CH_2$), 20.68, 20.70 (2 $CH_3COO$), 25.54, 25.79, 25.82 (2 $CH_3CH_2$), 43.22, 43.67 ($NCH_2CO$), 46.96, 47.19 (C-9 Fmoc), 59.49, 59.77 [$(CH_3CH_2)_2CH$], 61.65, 61.68 (C-6), 67.12, 67.84 ($CH_2$ Fmoc), 67.41, 67.49 (C-4), 67.71, 67.82 (C-2), 72.50, 72.69 (C-3), 74.59, 74.63 (C-5), 86.76, 86.89 (C-1), 119.80, 119.85, 124.85, 124.87, 125.01, 125.12, 126.85, 126.93, 126.95, 127.48, 127.51, 127.56, 127.58, 128.17, 128.22, 128.29, 128.36, 128.63, 128.83, 128.85, 129.32, 129.56, 129.98, 132.19, 132.46, 132.77, 132.95, 133.26, 141.19, 141.24, 141.34, 143.96, 144.00, 144.10, 144.22 (Ar Fmoc, *Ph*COO and SPh), 156.38, 156.66 (C=O Fmoc), 164.97, 165.29 (C=O Bz), 169.08, 169.34 ($NCH_2CO$), 170.07, 170.21, 170.39 (C=O 2 Ac) ppm. ESI-FT-MS: calcd. for $C_{45}H_{48}NO_{11}S^+$ [M + $H^+$] 810.29426; found 810.29461.

**Phenyl 4,6-Di-*O*-acetyl-2-*O*-benzoyl-3-*O*-{[*tert*-butoxycarbonyl(1-ethylpropyl)amino]acetyl}-1-thio-β-D-galactopyranoside (41):** To a solution of **40** (500 mg, 617.3 μmol) in DMF (2.4 mL) was added piperidine (600 μL, 6.06 mmol), and the mixture was stirred for 20 min at room temp. After cooling to 0 °C, di-*tert*-butyl dicarbonate (1.72 g, 7.88 mmol) and satd. aq. $NaHCO_3$ (3 mL) were added, and the mixture was stirred for 1 h at room temp. The product was dissolved in ethyl acetate and the solution was washed with water, dried ($Na_2SO_4$), and concentrated. Column chromatography (ethyl acetate/hexane, 1:2) of the residue on silica gel gave **41** (351 mg, 2 steps 83%). $[\alpha]_D$ = 17.1 (*c* = 1.0, $CHCl_3$). $^1H$ NMR (600 MHz, $CDCl_3$): $\delta$ = 0.65, 0.66, 0.78, 0.85 (4 t, $J_{CH3,CH}$ = $J_{CH3,CH'}$ 7.2, 7.3, 7.4, 7.4 Hz, 6 H, 2 $CH_3CH_2$), 0.88–1.33 (m, 4 H, 2 $CH_3CH_2$), 1.19, 1.34 (2 s, 9 H, Boc), 2.06, 2.06, 2.15, 2.15 (4 s, 6 H, 2 OAc), 3.50, 3.59 (2 s, 2 H, $NCH_2CO$), 3.58, 3.83 [2 m, 1 H, $(CH_3CH_2)_2CH$], 3.98, 4.01 (2 t, $J_{5,6}$ = $J_{5,6'}$ = 6.2, 6.2 Hz, 1 H, 5-H), 4.14, 4.17, 4.21, 4.24, (4 dd, $J_{5,6}$ = 6.1, 5.9, 6.8, 7.0 Hz, $J_{gem}$ = 11.4, 11.4, 11.3, 11.5 Hz, 2 H, 6-H), 4.86, 4.89 (2 d, $J_{1,2}$ = 10.0, 10.0 Hz, 1 H, 1-H), 5.29, 5.33 (2 dd, $J_{2,3}$ = 9.9, 9.9 Hz, $J_{3,4}$ = 3.2, 3.3 Hz, 1 H, 3-H), 5.42, 5.51 (2 d, $J_{3,4}$ = 3.3, 3.3 Hz, 1 H, 4-H), 5.50, 5.52 (2 t, $J_{1,2}$ = $J_{2,3}$ = 9.9, 10.0 Hz, 1 H, 2-H), 7.28–8.04 (m, 10 H, OBz and SPh) ppm. $^{13}C$ NMR (150 MHz, $CDCl_3$): $\delta$ = 10.76, 10.96, 10.99, 11.06 (2 $CH_3CH_2$), 20.69 (2 $CH_3COO$), 25.60, 26.09, 26.10 (2 $CH_3CH_2$), 27.97, 28.27 ($Me_3CO$), 43.09, 43.34 ($NCH_2CO$), 58.15, 59.82 [$(CH_3CH_2)_2CH$], 61.74, 61.79 (C-6), 67.40, 67.52 (C-4), 67.80, 67.95 (C-2), 72.39, 72.50 (C-3), 74.63, 74.74 (C-5), 79.71, 79.84 ($Me_3CO$), 86.75, 86.84 (C-1), 128.19, 128.32, 128.41, 128.49, 128.83, 128.88, 129.10, 129.93, 130.06, 132.19, 132.88, 132.99, 133.30, 133.57 (*Ph*COO and SPh), 155.57, 156.00 (C=O Boc), 165.11, 165.30 (C=O Bz), 169.51, 169.63 ($NCH_2CO$), 170.01, 170.10, 170.40 (C=O 2 Ac) ppm. ESI-FT-MS: calcd. for $C_{35}H_{46}NO_{11}S^+$ [M + $H^+$] 688.27861; found 688.27911.

***tert*-Butyldimethylsilyl *O*-{4,6-Di-*O*-acetyl-2-*O*-benzoyl-3-*O*-{[*tert*-butoxycarbonyl(1-ethylpropyl)amino]acetyl}-β-D-galactopyranosyl}-(1→3)-4-*O*-acetyl-2-azido-2-deoxy-6-*O*-{[{2-[*tert*-butoxycarbonyl-(1-ethylpropyl)amino]acetyl}(1-ethylpropyl)amino]acetyl}-β-D-galactopyranoside (42):** To a solution of **35** (90 mg, 125.7 μmol) and **41** (130 mg, 189 μmol) in dry dichloromethane (2 mL) was added 4-Å molecular sieves (250 mg) and *N*-iodosuccinimide (85 mg, 377.7 μmol), and the mixture was stirred at –40 °C. Trifluoromethanesulfonic acid (5 μL, 56.5 μmol) was added, and the mixture was stirred for 2 h at –40 °C. The solid was filtered off and washed with chloroform. The combined filtrate and washings were washed with satd. aq. $Na_2S_2O_3$ and satd. aq. $NaHCO_3$, then dried ($Na_2SO_4$), and concentrated. Column chromatography (ethyl acetate/hexane, 1:2) of the residue on silica gel gave **42** (145 mg, 89%). $[\alpha]_D$ = 6.1 (*c* = 1.0, $CHCl_3$). $^1H$ NMR (600 MHz, $CDCl_3$): $\delta$ = 0.09, 0.10, 0.10 (3 s, 6 H, $Me_2Si$), 0.67, 0.69, 0.79, 0.97 (4 t, 18 H, 6 $CH_3CH_2$), 0.88, 0.88 (2 s, 9 H, $Me_3CSi$), 1.03–1.56 (m, 12 H, 6 $CH_3CH_2$), 1.18, 1.33, 1.41, 1.46 (4 s, 18 H, 2 Boc), 2.07, 2.09, 2.10, 2.19, 2.19, 2.20 (6 s, 9 H, 3 OAc), 3.37, 3.39 (2 t, $J_{1,2}$ = $J_{2,3}$ = 7.7, 7.7 Hz, 1 H, 2-H GalN), 3.39–3.97 [m, 3 H, 3 $(CH_3CH_2)_2CH$], 3.45–3.95 (m, 6 H, 3 $NCH_2CO$), 3.50 (m, 1 H, 3-H GalN), 3.74 (m, 1 H, 5-H GalN), 3.92 (m, 1 H, 5-H Gal), 3.98, 4.16 (2 m, 4 H, 6-H GalN and 6-H Gal), 4.44, 4.45 (2 d, $J_{1,2}$ = 7.7, 7.7 Hz, 1 H, 1-H GalN), 4.87, 4.88, 4.91, 4.92 (4 d, $J_{1,2}$ = 7.9, 8.1, 7.9, 7.8 Hz, 1 H, 1-H Gal), 5.26 (dd, $J_{2,3}$ = 10.5 Hz, $J_{3,4}$ = 3.5 Hz, 1 H, 3-H Gal), 5.28, 5.30, 5.31 (3 d, $J_{3,4}$ = 3.4, 3.4, 3.4 Hz, 1 H, 4-H GalN), 5.37, 5.46 (br. 2 s, 1 H, 4-H Gal), 5.40 (dd, $J_{1,2}$ = 7.9 Hz, $J_{2,3}$ = 10.4 Hz, 1 H, 2-H Gal), 7.41–8.05 (m, 5 H, OBz) ppm. $^{13}C$ NMR (150 MHz, $CDCl_3$): $\delta$ = –5.20, –5.13, –4.39, –4.35 ($Me_2Si$), 10.75, 10.97, 11.06, 11.09, 11.21, 11.24, 11.31, 11.35, 11.45, 11.47, 11.53 (6 $CH_3CH_2$), 17.95 ($Me_3CSi$), 20.66, 20.74, 20.76 (3 $CH_3COO$), 25.54, 25.58, 25.68 ($Me_3CSi$), 26.11, 26.16, 26.41, 26.46, 26.56, 26.60 (6 $CH_3CH_2$), 27.98, 28.26, 28.34, 28.44, 28.55 (2 $Me_3CO$), 42.48, 42.70, 43.12, 43.40, 43.70 (3 $NCH_2CO$), 58.21, 58.26, 59.87, 60.09, 60.29, 60.43 [3 $(CH_3CH_2)_2CH$], 61.15, 61.19, 62.37, 62.51 (C-6 Gal), 65.12, 65.23 (C-2 GalN), 67.01, 67.13 (C-4 Gal), 68.20 (C-4 GalN), 69.33, 69.41 (C-2 Gal), 70.91, 70.98, 71.06 (C-5 Gal and C-3 Gal), 71.42 (C-5 GalN), 76.13, 76.30 (C-3 GalN), 79.48, 79.57, 79.72, 79.86 (2 $Me_3CO$), 97.42 (C-1 GalN), 101.41, 101.54 (C-1 Gal), 128.44, 128.51, 129.17, 129.70, 129.80, 133.41 (*Ph*COO), 155.61, 156.05, 156.12 (C=O 2 Boc), 165.13, 165.25 (C=O Bz), 168.75, 169.41, 169.62, 169.77, 169.99, 170.17, 170.30, 170.44 (3 $NCH_2CO$ and C=O 3 Ac) ppm. ESI-FT-MS: calcd. for $C_{62}H_{101}N_6O_{21}Si^+$ [M + $H^+$] 1293.67836; found 1293.67847.

***tert*-Butyldimethylsilyl *O*-(4,6-Di-*O*-acetyl-2-*O*-benzoyl-β-D-galactopyranosyl)(1→3)-4-*O*-acetyl-2-azido-6-*O*-{[*tert*-butoxycarbonyl(1-ethylpropyl)amino]acetyl}-2-deoxy-β-D-galactopyranoside (43):** Using the general procedure for one cycle of Edman degradation, compound **42** (163 mg, 126 μmol) was degraded to compound **43** (83 mg, 4 steps 70%) as a selectively 3′-position-free disaccharide.

$[\alpha]_D$ = 2.7 (*c* = 1.3, $CHCl_3$). $^1H$ NMR (600 MHz, $CDCl_3$): $\delta$ = 0.12, 0.12 (2 s, 6 H, $Me_2Si$), 0.90 (m, 6 H, 2 $CH_3CH_2$), 0.90, 0.90 (2 s, 9 H, $Me_3CSi$), 1.28–1.46 (m, 4 H, 2 $CH_3CH_2$), 1.40, 1.46 (2 s, 9 H, Boc), 2.07, 2.08, 2.09, 2.09, 2.21, 2.21 (6 s, 9 H, 3 OAc), 3.44, 3.45 (2 dd, $J_{1,2}$ = 7.5, 7.5 Hz, $J_{2,3}$ = 10.5, 10.4 Hz, 1 H, 2-H GalN), 3.51, 3.51 (2 dd, $J_{2,3}$ = 10.5, 10.4 Hz, $J_{3,4}$ = 3.3, 3.3 Hz, 1 H, 3-H Ga1N), 3.62, 3.66, 3.71 (d, d, s, $J_{gem}$ = 17.6, 17.7 Hz, 2 H, $NCH_2CO$), 3.73, 3.95 [2 m, 1 H, $(CH_3CH_2)_2CH$], 3.74 (m, 1 H, 5-H GalN), 3.87 (br. t, 1 H, 5-H Gal), 3.99 (m, 1 H, 3-H Gal), 4.03, 4.20 (2 m, 2 H, 6-H GalN), 4.15 (m, 2 H, 6-H Gal), 4.46, 4.46 (2 d, $J_{1,2}$ = 7.6 Hz, 7.5 Hz, 1 H, 1-H GalN), 4.84, 4.85 (2 d, $J_{1,2}$ = 7.8, 7.9 Hz, 1 H, 1-H Gal), 5.15 (dd, $J_{1,2}$ = 7.9 Hz, $J_{2,3}$ = 10.0 Hz, 1 H, 2-H Gal), 5.31, 5.32 (br. 2 d, $J_{3,4}$ = 3.8, 4.1 Hz, 1 H, 4-H GalN), 5.36, 5.37 (br. 2 d, $J_{3,4}$ = 4.0, 3.6 Hz, 1 H, 4-H Gal), 7.45–8.09 (m, 5 H, OBz) ppm. $^{13}C$ NMR (150 MHz, $CDCl_3$): $\delta$ = –5.18, –5.15, –4.33 ($Me_2Si$), 10.99, 11.00, 11.19 (2 $CH_3CH_2$), 17.97 ($Me_3CSi$), 20.64, 20.65, 20.74, 20.78, 20.83 (3 $CH_3COO$), 25.57, 25.58 ($Me_3CSi$), 25.91, 25.95, 26.39 (2 $CH_3CH_2$), 28.25, 28.40 ($Me_3CO$), 43.54 ($NCH_2CO$), 58.32, 59.99 [$(CH_3CH_2)_2CH$], 61.52, 61.65 (C-6 Gal), 62.68, 62.90 (C-6 GalN), 65.20, 65.24 (C-2 GalN), 68.28, 68.37 (C-4 GalN), 69.38, 69.45 (C-4 Gal), 71.05, 71.10, 71.17, 71.23 (C-3 Gal and C-5 Gal), 71.58 (C-5 GalN), 73.26, 73.35 (C-2 Gal), 76.22, 76.43 (C-3 GalN), 79.95, 80.05 ($Me_3CO$), 97.42, 97.48 (C-1 GalN), 101.16, 101.20 (C-1 Gal), 128.55, 129.40, 129.42, 129.76, 133.43, 133.46 (*Ph*COO), 155.66, 156.31 (C=O Boc), 166.61, 166.66 (C=O Bz), 169.79, 169.86, 169.94, 170.08, 170.51, 170.55, 170.98, 170.99 ($NCH_2CO$ and C=O 3 Ac) ppm. ESI-FT-MS: calcd. for $C_{43}H_{66}N_4O_{17}SiNa^+$ [M + $Na^+$] 961.40844; found 961.40827.

***tert*-Butyldimethylsilyl *O*-(3,4,6-Tri-*O*-acetyl-2-*O*-benzoyl-β-D-galactopyranosyl)(1→3)-4-*O*-acetyl-2-azido-2-deoxy-β-D-galactopyranoside (44):** To a solution of **43** (53 mg, 56.4 μmol) in pyridine (1 mL) was added acetic anhydride (1 mL), and the mixture was stirred for 2 h at room temp. The work-up described for **34** gave an acetylated intermediate (55 mg, 99%). Subsequent deprotection of the amino protecting group and coupling of PITC as described in the general procedure for one cycle of Edman degradation gave **44** (33 mg, 2 steps 98%) as a selectively 6-position-free disaccharide. $[\alpha]_D$ = 1.8 (*c* = 0.5, $CHCl_3$). $^1H$ NMR (600 MHz, $CDCl_3$): $\delta$ = 0.09 (s, 6 H, $Me_2Si$), 0.87 (s, 9 H, $Me_3CSi$), 1.92, 2.07, 2.19, 2.19 (4 s, 12 H, 4 OAc), 3.40 (dd, $J_{5,6}$ = 8.4 Hz, $J_{gem}$ = 11.0 Hz, 1 H, 6-H GalN), 3.44 (dd, $J_{1,2}$ = 6.6 Hz, $J_{2,3}$ = 10.5 Hz, 1 H, 2-H GalN), 3.47 (dd, $J_{2,3}$ = 10.4 Hz, $J_{3,4}$ = 3.2 Hz, 1 H, 3-H GalN), 3.52 (t, $J_{5,6}$ = $J_{5,6'}$ = 7.9 Hz, 1 H, 5-H GalN), 3.57 (m, 1 H, 6′-H GalN), 3.96 (ddd, $J_{4,5}$ = 1.2 Hz, $J_{5,6}$ = $J_{5,6'}$ = 6.6 Hz, 1 H, 5-H Gal), 4.09, 4.13 (2 dd, $J_{5,6}$ = 6.7, 6.5 Hz, $J_{gem}$ = 11.3, 11.3 Hz, 2 H, 6-H Gal), 4.44 (d, $J_{1,2}$ = 6.4 Hz, 1 H, 1-H GalN), 4.82 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1-H Gal), 5.21 (dd, $J_{2,3}$ = 10.6 Hz, $J_{3,4}$ = 3.4 Hz, 1 H, 3-H Gal), 5.23 (d, $J_{3,4}$ = 2.3 Hz, 1 H, 4-H GalN), 5.42 (dd, $J_{3,4}$ = 3.4 Hz, $J_{4,5}$ = 1.1 Hz, 1 H, 4-H Gal), 5.45 (dd, $J_{1,2}$ = 7.9 Hz, $J_{2,3}$ = 10.6 Hz, 1 H, 2-H Gal), 7.44–8.05 (m, 5 H, OBz) ppm. $^{13}C$ NMR (150 MHz, $CDCl_3$): $\delta$ = –5.17, –4.33 ($Me_2Si$), 17.91 ($Me_3CSi$), 20.56, 20.69, 20.84 (4 $CH_3COO$), 25.53 ($Me_3CSi$), 59.91 (C-6 GalN), 61.17 (C-6 Gal), 65.18 (C-2 GalN), 66.98 (C-4 Gal), 69.18, 69.21 (C-4 GalN and C-2 Gal), 70.53 (C-3 Gal), 70.92 (C-5 Gal), 73.47 (C-5 GalN), 77.70 (C-3 GalN), 97.50 (C-1 GalN), 102.13 (C-1 Gal), 128.52, 129.33, 129.68, 133.37 (*Ph*COO), 165.20 (C=O Bz), 170.19, 170.23, 170.45, 172.62 (C=O 4 Ac). ESI-FT-MS: calcd. for $C_{33}H_{47}N_3O_{15}SiNa^+$ [M + $Na^+$] 776.26687; found 776.26714.

***tert*-Butyldimethylsilyl *O*-(Methyl 5-acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-β-D-*galacto*-2-nonulopyranosylonate)-(2→3)-*O*-(4,6-di-*O*-acetyl-2-*O*-benzoyl-β-D-galactopyranosyl)-(1→3)-4-*O*-acetyl-2-azido-6-*O*-{[*tert*-butoxycarbonyl(1-ethylpropyl)-amino]acetyl}-2-deoxy-β-D-galactopyranoside (46):** To a solution of **43** (10 mg, 10.6 μmol) and **45**[13] (12.6 mg, 21.6 μmol) in dry acetonitrile (150 μL) was added 3-Å molecular sieves (30 mg) and *N*-iodosuccinimide (9.6 mg, 42.6 μmol), and the mixture was stirred at –30 °C. Trifluoromethanesulfonic acid (0.6 μL, 6.7 μmol) was added, and the mixture was stirred at –30 °C for 2 days. The solid was filtered and washed with chloroform. The combined filtrate and washings were washed with satd. aq. $Na_2S_2O_3$ and satd. aq. $NaHCO_3$, dried ($Na_2SO_4$), and concentrated. Column chromatography (ethyl acetate/hexane, 3:1) of the residue on silica gel gave **46** (2 mg, 13%) as the β anomer selectively. $[\alpha]_D$ = 17.6 (*c* = 0.5, $CHCl_3$). $^1H$ NMR (600 MHz, $CDCl_3$): $\delta$ = 0.07, 0.11, 0.11, 0.12 (4 s, 6 H, $Me_2Si$), 0.89 (m, 6 H, 2 $CH_3CH_2$), 0.89, 0.89 (2 s, 9 H, $Me_3CSi$), 1.28–1.44 (m, 4 H, 2 $CH_3CH_2$), 1.39, 1.45 (2 s, 9 H, Boc), 1.72 (br. t, 1 H, 3ax-H SA), 1.90, 1.90 (2 s, 3 H, NAc), 1.98, 1.99, 2.02, 2.04, 2.05, 2.06, 2.07, 2.08, 2.09, 2.09, 2.12 (11s, 21 H, 7 OAc), 2.43 (dd, $J_{3eq,4}$ = 4.6 Hz, $J_{gem}$ = 13.3 Hz, 1 H, 3eq-H SA), 3.11, 3.12 (2 s, 3 H, COO*Me*), 3.32, 3.33 (2 dd, $J_{1,2}$ = 7.8, 7.8 Hz, $J_{2,3}$ = 10.5, 10.4 Hz, 1 H, 2-H Ga1N), 3.50, 3.51 (2 dd, $J_{2,3}$ = 10.7, 10.2 Hz, $J_{3,4}$ = 3.5, 3.7 Hz, 1 H, 3-H GalN), 3.62, 3.65, 3.70 (d, d, s, 2 H, $J_{gem}$ = 17.2, 17.4 Hz, $NCH_2CO$), 3.72, 3.95 [2 m, 1 H, $(CH_3CH_2)_2CH$], 3.73 (m, 1 H, 5-H GalN), 3.83 (m, 2 H, 9-H SA), 3.97 (m, 1 H, 5-H SA), 3.99, 4.17 (2 m, 2 H, 6-H GalN), 4.06, 4.23 (m, 2 H, 6-H Gal), 4.21 (m, 1 H, 5-H Gal), 4.47, 4.47 (2 d, $J_{1,2}$ = 7.7, 7.8 Hz, 1 H, 1-H GalN), 4.65 (dd, $J_{5,6}$ = 10.5 Hz, $J_{6,7}$ = 1.5 Hz, 1 H, 6-H SA), 4.89, 4.89 (2 d, $J_{1,2}$ = 7.9, 8.0 Hz, 1 H, 1-H Gal), 4.94, 4.95 (2 dd, $J_{2,3}$ = 10.1, 9.7 Hz, $J_{3,4}$ = 3.5, 3.1 Hz, 1 H, 3-H Gal), 5.04 (ddd, $J_{3ax,4}$ = $J_{4,5}$ = 11.0 Hz, $J_{3eq,4}$ = 4.5 Hz, 1 H, 4-H SA), 5.27 (m, 1 H, 8-H SA), 5.28 (br. d, $J_{3,4}$ = 2.8 Hz, 1 H, 4-H GalN), 5.31 (dd, $J_{1,2}$ = 8.0 Hz, $J_{2,3}$ = 10.3 Hz, 1 H, 2-H Gal), 5.37 (m, 1 H, 7-H SA), 5.34 (m, 1 H, 4-H Gal), 5.53, 5.53 (2 d, $J_{NH,5}$ 10.2, 10.1 Hz, 1 H, NH), 7.45–8.05 (m, 5 H, OBz) ppm. $^{13}C$ NMR (150 MHz, $CDCl_3$): $\delta$ = –5.18, –4.35 ($Me_2Si$), 10.99, 11.01, 11.19 (2 $CH_3CH_2$), 17.97 ($Me_3CSi$), 20.52, 20.53, 20.66, 20.69, 20.83, 20.96, 20.99, 21.04, 21.06 (7 $CH_3COO$), 23.26 ($CH_3CON$), 25.58, 25.59 ($Me_3CSi$), 25.91, 25.96, 26.39 (2 $CH_3CH_2$), 28.25, 28.40 ($Me_3CO$), 37.26, 37.34 (C-3 SA), 43.54 ($NCH_2CO$), 48.57 (C-5 SA), 52.40 (COO*Me*), 58.31, 59.99 [$(CH_3CH_2)_2CH$], 60.95, 61.10 (C-6 Gal), 62.76 (C-6 GalN), 62.96, 63.01 (C-7 SA and C-9 SA), 64.95, 65.00 (C-2 GalN), 67.70 (C-4 SA), 68.41, 68.47 (C-4 GalN), 69.03, 69.06, 69.51, 70.01, 70.07, 70.12, 70.19, 70.34, 70.38 (C-4 Gal, C-5 Gal, and C-3 Gal), 71.60, 71.62 (C-5 GalN), 71.71 (C-2 Gal), 72.54 (C-8 SA), 73.16 (C-6 SA), 75.08, 75.24 (C-3 GalN), 79.95, 80.04 ($Me_3CO$), 97.55, 97.61 (C-1 GalN), 98.93 (C-2 SA), 100.90, 100.93 (C-1 Gal), 128.61, 129.81, 130.14, 130.17, 133.28, 133.31 (*Ph*COO), 155.66, 156.30 (C=O Boc), 165.71 (C=O Bz), 166.51 (C-1 SA), 169.77, 169.84, 169.86, 169.93, 170.08, 170.27, 170.67, 170.71, 171.17, 171.25, 171.27, 172.35, 172.38 ($NCH_2CO$ and C=O 8 Ac) ppm. ESI-FT-MS: calcd. for $C_{63}H_{93}N_5O_{29}SiNa^+$ [M + $Na^+$] 1434.56177; found 1434.56135.

***tert*-Butyldimethylsilyl *O*-(3,4,6-Tri-*O*-acetyl-2-*O*-benzoyl-β-D-galactopyranosyl)(1→3)-*O*-[(methyl 5-acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-α,β-D-*galacto*-2-nonulopyranosylonate)(2→6)]-4-*O*-acetyl-2-azido-2-deoxy-β-D-galactopyranoside (47):** To a solution of **44** (23 mg, 30.5 μmol) and **45** (27 mg, 46.2 μmol) in dry acetonitrile (400 μL) was added 3-Å molecular sieves (40 mg) and *N*-iodosuccinimide (21 mg, 93.3 μmol), and the mixture was stirred at –30 °C. Trifluoromethanesulfonic acid (1.2 μL, 13.5 μmol) was added and the mixture was stirred at –30 °C for 10 h. The solid was filtered and washed with chloroform. The combined filtrate and washings were washed with satd. aq. $Na_2S_2O_3$ and satd. aq. $NaHCO_3$, then dried ($Na_2SO_4$), and concentrated. Gel filtration column chromatography (chloroform/methanol, 1:1)

Table 1. $^1$H NMR data for trisaccharide **47**.

| GalN | α | | β | |
|---|---|---|---|---|
| H-1 | 4.45 | d, $J_{1,2}$ 7.7 Hz | 4.44 | d, $J_{1,2}$ 7.7 Hz |
| H-2 | 3.39 | dd, $J_{1,2}$ 7.7 Hz, $J_{2,3}$ 10.4 Hz | 3.42 | dd, $J_{1,2}$ 7.7 Hz, $J_{2,3}$ 10.4 Hz |
| H-3 | 3.50 | dd, $J_{2,3}$ 10.4 Hz, $J_{3,4}$ 3.6 Hz | 3.50 | dd, $J_{2,3}$ 10.4 Hz, $J_{3,4}$ 3.3 Hz |
| H-4 | 5.26 | dd, $J_{3,4}$ 3.6 Hz, $J_{4,5}$ 0.7 Hz | 5.54 | d, $J_{3,4}$ 3.3 Hz |
| H-5 | 3.61 | m | 3.65 | m |
| H-6 | 3.25 | dd, $J_{5,6}$ 3.7 Hz, $J_{gem}$ 10.1 Hz | 3.29 | t, $J_{5,6} = J_{gem}$ 9.2 Hz |
| H-6' | 3.76 | dd, $J_{5,6'}$ 2.4 Hz, $J_{gem}$ 10.1 Hz | 3.32 | dd, $J_{5,6'}$ 5.1 Hz, $J_{gem}$ 8.9 Hz |
| Gal | α | | β | |
| H-1 | 4.93 | d, $J_{1,2}$ 7.9 Hz | 4.88 | d, $J_{1,2}$ 7.8 Hz |
| H-2 | 5.39 | dd, $J_{1,2}$ 7.9 Hz, $J_{2,3}$ 10.6 Hz | 5.45 | dd, $J_{1,2}$ 7.8 Hz, $J_{2,3}$ 10.6 Hz |
| H-3 | 5.21 | dd, $J_{2,3}$ 10.6 Hz, $J_{3,4}$ 3.5 Hz | 5.23 | dd, $J_{2,3}$ 10.6 Hz, $J_{3,4}$ 3.4 Hz |
| H-4 | 5.42 | dd, $J_{3,4}$ 3.5 Hz, $J_{4,5}$ 1.0 Hz | 5.47 | dd, $J_{3,4}$ 3.4 Hz, $J_{4,5}$ 0.8 Hz |
| H-5 | 3.94 | broad t, $J_{5,6}$ 7.4 Hz | 4.00 | m |
| H-6 | 4.12 | dd, $J_{5,6}$ 7.8 Hz, $J_{gem}$ 11.2 Hz | 4.19 | m |
| H-6' | 4.18 | dd, $J_{5,6'}$ 6.0 Hz, $J_{gem}$ 11.2 Hz | 4.23 | m |
| SA | α | | β | |
| H-3ax | 1.88 | t, $J_{3ax,4} = J_{gem}$ 12.7 Hz | 1.79 | t, $J_{3ax,4} = J_{gem}$ 12.7 Hz |
| H-3eq | 2.52 | dd, $J_{3eq,4}$ 4.6 Hz, $J_{gem}$ 12.7 Hz | 2.42 | dd, $J_{3eq,4}$ 5.0 Hz, $J_{gem}$ 12.7 Hz |
| H-4 | 4.82 | m | 5.29 | m |
| H-5 | 4.04 | m | 4.20 | m |
| H-6 | 4.25 | dd, $J_{5,6}$ 12.3 Hz, $J_{6,7}$ 2.3 Hz | 3.71 | dd, $J_{5,6}$ 10.6 Hz, $J_{6,7}$ 2.5 Hz |
| H-7 | 5.32 | dd, $J_{6,7}$ 2.3 Hz, $J_{7,8}$ 4.9 Hz | 5.35 | dd, $J_{6,7}$ 2.5 Hz, $J_{7,8}$ 4.5 Hz |
| H-8 | 5.32 | m | 5.50 | dddd, $J_{7,8}$ 4.5 Hz, $J_{8,9}$ 7.6 Hz, $J_{8,9'}$ 3.3 Hz |
| H-9 | 4.00 | m | 4.20 | m |
| H-9' | 4.04 | m | 4.61 | dd, $J_{8,9'}$ 3.3 Hz, $J_{gem}$ 12.3 Hz |

of the residue on Sephadex LH-20 gave the crude product, which was then purified by column chromatography on silica gel with 4:1 ethyl acetate/hexane, to give **47** (25 mg, 67%, $\alpha/\beta$ = 71:29). The α to β ratio was calculated from the 3-H equatorial proton on the sialic acid residue determined by $^1$H NMR spectroscopy. $^1$H NMR (600 MHz, $CDCl_3$, $\alpha/\beta$ = 71:29): $\delta$ = 0.09, 0.13, 0.15 (3 s, $Me_2Si$), 0.87, 0.90 (2 s, $Me_3CSi$), 1.87, 1.92, 1.93, 1.94, 1.97, 2.01, 2.02, 2.03, 2.03, 2.06, 2.06, 2.10, 2.11, 2.14, 2.16, 2.18, 2.19, 2.29 (18s, 8 OAc and NAc), 3.78, 3.79 (2 s, COO*Me*), 7.44–8.05 (m, OBz) ppm. For the remaining $^1$H NMR data, see Table 1. $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = –5.28, –4.18 ($Me_2Si$), 17.89, 17.99 ($Me_3CSi$), 20.57, 20.65, 20.69, 20.72, 20.77, 20.81, 20.85, 20.93, 21.08, 21.37 (8 $CH_3COO$), 23.11, 23.20 ($CH_3CON$), 25.49, 25.65 ($Me_3CSi$), 37.20 (C-3 SA β), 37.63 (C-3 SA α), 47.89 (C-5 SA β), 49.33 (C-5 SA α), 52.60 (COO*Me* β), 52.85 (COO*Me* α), 60.15 (C-6 GalN β), 60.62 (C-6 Gal β), 60.92 (C-6 Gal α), 61.91 (C-9 SA β), 62.28 (C-6 SA α and C-9 SA α), 63.57 (C-6 GalN α), 65.29 (C-2 GalN), 66.82 (C-4 Gal β), 66.92 (C-4 Gal α), 67.11 (C-7 SA α), 67.63 (C-8 SA α), 67.76 (C-8 SA β), 67.97 (C-7 SA β), 68.42 (C-4 GalN α), 68.53 (C-4 GalN β), 68.93 (C-4 SA β), 69.04 (C-4 SA α), 69.40 (C-2 Gal α), 69.54 (C-2 Gal β), 70.58 (C-3 Gal), 70.70 (C-5 Gal β), 70.74 (C-5 Gal α), 71.40 (C-5 GalN β), 71.98 (C-6 SA β), 72.86 (C-5 GalN α), 75.90 (C-3 GalN α), 77.58 (C-3 GalN β), 97.36 (C-1 GalN α), 97.53 (C-1 GalN β), 98.45 (C-2 SA α), 98.75 (C-2 SA β), 101.32 (C-1 Gal α), 101.71 (C-1 Gal β), 128.53, 128.57, 129.33, 129.37, 129.65, 129.69, 133.35, 133.39 (*Ph*COO), 165.11 (C=O Bz α), 165.25 (C=O Bz β), 167.28 (C-1 SA β), 167.75 (C-1 SA α), 169.49, 170.09, 170.19, 170.23, 170.27, 170.29, 170.38, 170.40, 170.46, 170.62, 170.72, 170.95, 171.79 (C=O 9Ac) ppm. ESI-FT-MS: calcd. for $C_{53}H_{75}N_4O_{27}Si^+$ [M + H$^+$] 1227.43825; found 1227.43891.

**2-{4-[Methyl *O*-β-D-galactopyranosyl(1→3)-*O*-β-D-galactopyranoside]benzamido}acetic Acid (58):** ArgoPore OH resin (**48**, 550 mg) was packed into a 20 mL disposable chromatography column (Econo-Pac, Bio-Rad, Hercules, CA). The column was connected to a suction flask through a Teflon tube with a manual two-way Teflon valve; excess reagents, DMF etc., were removed by applying a vacuum. The resin was derivatized with the HMBA-Gly-linker. Briefly, the resin was swelled with dichloromethane (6 mL). *N*-α-Fmoc-glycine (**49**; 358 mg, 1.20 mmol), DMAP (98 mg, 0.80 mmol), and DIC (157 μL, 1.00 mmol) were added to the resin in dichloromethane, and then agitated. After 7 h, the solution was removed. Subsequently, dichloromethane (3 mL), acetic anhydride (3 mL) and pyridine (1 mL) were added to the resin, and then agitated. After 2 h, the solution was removed, and the resin was washed thoroughly with DMF (10 × 10 mL), dichloromethane (5 × 10 mL), and diethyl ether (3 × 10 mL), then dried in vacuo (general washing and drying procedure). The Fmoc group was cleaved from the Gly residue, and the loading of ArgoPore resin was determined as 0.449 mmol/g from the UV absorbance of the eluate. *N*-α-Fmoc deprotection was effected by treatment of the resin for 22 min with 20% piperidine in DMF (28 mL). 4-(Trityloxymethyl) benzoic acid (**52**; Tr-HMBA, 419 mg, 1.06 mmol), NEM (270 μL, 2.12 mmol), and TBTU (329 mg, 1.02 mmol) were dissolved in DMF, and after 3 min, the solution was added to the resin, and then agitated. After 4 h, the solution was removed, and the resin was washed with DMF (6 × 10 mL), and a solution (10 mL) of acetic anhydride/DMF, (1:7) was added. After 20 min, the resin was washed and dried as described in the general washing and drying procedure. Deprotection of the trityl group from the resin was performed using TFA (10.8 mL) and $H_2O$ (1.2 mL) at room temperature. After agitation for 3 h, the resin was washed and dried as described in the general washing and drying procedure to obtain hydroxy-functionalized HMBA-Gly-ArgoPore resin (**54**).

The hydroxy-functionalized HMBA-Gly-ArgoPore resin (**54**; 171 mg) was packed into a 5-mL disposable chromatography column (mini column, Sarstedt, Nümbrecht, Germany). This hydroxy-functionalized resin was glycosylated with thiophenyl galactose (**40**; 100 mg, 0.12 mmol) in which the 3-position was protected by an Fmoc-protected mono-UCP group using DMTST (111 mg,

0.43 mmol) in dichloromethane (1.5 mL) at room temperature. After agitation for 1 d, the resin was washed and dried as described in the general washing and drying procedure. To determine the coupling yield, aliquots of the resin were taken and treated with a solution of 20% piperidine in DMF (14 mL) for 22 min. The eluate was examined by UV at 290 nm and the Fmoc loading and yield were determined to be 0.076 mmol/g and 22%, respectively. Glycosylation coupling was repeated once more according to the same procedure. After double coupling, the glycosylation yield was determined to be 29% by Fmoc UV measurement. To confirm the accuracy of the yield from Fmoc UV measurement, the sugar was cleaved from the resin and analyzed by HPLC. Aliquots of the resin were taken, and treated with a solution of dichloromethane/MeOH/25 wt.-% NaOMe in MeOH (360 μL/40 μL/8 μL). After agitation for 4 h, $H_2O$ (400 μL) was added, and agitation was continued for 4 h. After filtration of the resin, the water layer was analyzed by normal-phase HPLC. Initially, isocratically 100% solvent A was used at 1 mL/ min for 10 min. Then, a linear gradient of 0 to 100% solvent B was used at 1 mL/ min for 30 min. The peaks were detected by UV at 254 nm. The glycosylation yield was determined to be 31%, which was calculated from the area under the peaks.

The unreacted hydroxyl group on the HMBA-Gly linker was subjected to acetyl capping with acetic anhydride and pyridine in dichloromethane for 2 h, to selectively deprotect the 3-position of Gal by one cycle of Edman degradation without the TFA treatment and Boc reprotection steps. The resin was treated with a solution of 20% piperidine in DMF (4 mL). After agitation for 22 min, the solution was removed, and the resin was washed with DMF (10 × 4 mL), followed by dissolving in DMF (2.5 mL), and addition of PITC (1.25 mL) and *N*-methylmorpholine (0.3 mL), and the mixture was then agitated. After 2 h, the resin was washed and dried as described in the general washing and drying procedure to give selectively 3-position-free Gal acceptor (**56**).

This selectively free hydroxyl group on the 3-position of Gal was glycosylated with thiophenyl galactose (**40**; 48 mg, 59.2 μmol) using DMTST (53 mg, 0.21 mmol) in dichloromethane (1.5 mL) at room temp., according to the same procedure as described for the previous Gal coupling. After double coupling, the glycosylation yield was determined to be 41% by Fmoc UV measurement. HPLC measurement indicated the glycosylation yield to be 42%.

The final cleavage of the disaccharide from the resin was performed by treatment with a solution of dichloromethane/MeOH/25 wt.-% NaOMe in MeOH (2 ml/200 μL/10 μL). After agitation for 1 d, $H_2O$ (50 μL) was added and the mixture was agitated for 1 more day. After neutralization with acetic acid, the reaction mixture was filtered. The resin was washed with $CH_2Cl_2$/MeOH, (1:1; 5 × 4 mL), MeOH (5 × 4 mL), and $H_2O$ (5 × 4 mL), and the combined filtrate and washings were concentrated. The disaccharide was purified by analytical HPLC using the same column and solvent system as described above to obtain 1.8 mg of the target disaccharide (**58**). The total yield was determined to be 4% for eight steps from compound **50**. $[\alpha]_D$ = –0.4 (*c* = 0.14, $H_2O$). $^1$H NMR (600 MHz, $D_2O$): $\delta$ = 3.55 (dd, $J_{1,2}$ = 7.7 Hz, $J_{2,3}$ = 9.9 Hz, 1 H, $2_b$-H), 3.61 (dd, $J_{2,3}$ = 9.9 Hz, $J_{3,4}$ = 3.4 Hz, 1 H, $3_b$-H), 3.62–3.66 (m, 2 H, $5_a$-H and $5_b$-H), 3.69 (dd, $J_{1,2}$ = 7.9 Hz, $J_{2,3}$ = 9.9 Hz, 1 H, $2_a$-H), 3.68–3.77 (m, 4 H, $6_a$-H and $6_b$-H), 3.74 (dd, $J_{2,3}$ = 9.9 Hz, $J_{3,4}$ = 3.3 Hz, 1 H, $3_a$-H), 3.86 (d, $J_{3,4}$ = 3.4 Hz, 1 H, $4_b$-H), 4.01 (s, 2 H, N$CH_2$CO), 4.14 (d, $J_{3,4}$ = 3.0 Hz, 1 H, $4_a$-H), 4.48 (d, $J_{1,2}$ = 7.9 Hz, 1 H, $1_a$-H), 4.55 (d, $J_{1,2}$ = 7.7 Hz, 1 H, $1_b$-H), 4.80 (d, $J_{gem}$ = 12.0 Hz, 1 H, *CH*-Ph), 4.97 (d, $J_{gem}$ = 12.4 Hz, 1 H, *CH'*-Ph), 7.54 (d, $J_{o,m}$ = 8.2 Hz, 2 H, $Ph_o$), 7.79 (d, $J_{o,m}$ = 8.1 Hz, 2 H, $Ph_m$) ppm. $^{13}$C NMR (150 MHz, $D_2O$): $\delta$ = 43.12 (N$CH_2$CO), 61.04, 61.10 (C-$6_a$ and C-$6_b$), 68.58 (C-$4_a$), 68.71 (C-$4_b$), 70.06 (C-$2_a$), 70.69 ($CH_2$-Ph), 71.17 (C-$2_b$), 72.64 (C-$3_b$), 74.99, 75.20 (C-$5_a$ and C-$5_b$), 82.46 (C-$3_a$), 101.66 (C-$1_a$), 104.50 (C-$1_b$), 127.62 ($Ph_o$), 128.77 ($Ph_m$), 133.12 (Ph-1), 141.08 ($Ph_p$), 170.68 (Ph-*CO*-N), 175.87 ($CH_2$*C*OOH); HMBC NMR (600 MHz, $D_2O$): $\delta$ = 4.55→82.46 ($1_b$-H→C-$3_a$). ESI-FT-MS: calcd. for $C_{22}H_{31}NO_{14}Na^+$ [M + $Na^+$] 556.16368; found 556.16422.

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