



Glycuronamide Synthesis

An Oxidation–Amidation Approach for the Synthesis of Glycuronamides

Sicheng Lin,^{[a][‡]} Roger A. Ashmus,^{[a][‡]} and and Todd L. Lowary*^[a]

Abstract: A route for the synthesis of glycuronamides via the intermediacy of 6-*S*-tolyl-substituted glycosides and uronic acid thioesters, is reported. The route, which is compatible with a

Introduction

Glycuronamides, amidated uronic acid derivatives, are commonly found in bacterial lipopolysaccharides (LPS) and capsular polysaccharides (CPS).^[1–5] These structures frequently consist of glucuronic acid, galacturonic acid, mannuronic acid, or 2-acetamido-2-deoxy-D-galacturonic acid amidated with a range of different amines including ammonia,^[1] ethanolamine,^[6] L-alanine,^[2] L-serine,^[3] L-lysine,^[7] L-threonine,^[4] and serinol.^[8] Examples include *Escherichia coli* K54 CPS, which has a repeating unit possessing a L-threonine-containing glucuronamide^[9] and *Proteus mirabilis* O28 LPS, which contains two galacturonamide residues, one incorporating L-lysine and the other L-serine (Figure 1).^[7] Polysaccharides containing glycuronamide residues play essential roles in the organisms that produce them. For instance, the L-threonine-containing galacturonamide in the variety of carbohydrate residues and protecting groups, was used to synthesize the repeating unit of the *E. coli* K54 capsular polysaccharide.

Colwellia psychrerythraea 34H CPS has been suggested to be important for the survival of the organism in subfreezing marine environments.^[4] Other studies have shown that CPS possessing uronic acids amidated with amino acids are important in the induction of protective immunity against abscess formation.^[10] In addition, molecules containing these structures have often been targeted in the development of vaccines.^[7,11–13] Consequently, the chemical synthesis of glycans possessing glycuronamides is of interest.

The conventional approach for glycuronamide synthesis involves converting a uronic acid to a reactive intermediate (e.g., an activated ester or acyl halide) and then addition of an amine (Scheme 1, compounds $1 \rightarrow 2 \rightarrow 6$).^[14–20] Recently, Crich and Sasaki have developed an alternate method in which uronic acid thiocarboxylates made in situ react with isocyanates or isothiocyanates to produce glycuronamides $(1 \rightarrow 3 \rightarrow 6)$.^[21] In another



Figure 1. Examples of polysaccharide repeating units containing glycuronamide residues.

 [a] Department of Chemistry and Alberta Glycomics Centre, The University of Alberta,
 Edmonton, Alberta T6G 2G2, Canada

E-mail: tlowary@ualberta.ca www.lowarvlab.ca

- [‡] These authors contributed equally to this work.
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alternate approach, treatment of 1,6- and 3,6-carbohydratebased lactones with amines leads to the corresponding glucuronamides $(1\rightarrow 4/5\rightarrow 6)$.^[22–24] These alternative approaches, however have only been demonstrated on glucuronic acid residues. In addition, they are difficult to implement if the glycan of interest contains more than one glycuronamide (e.g., the repeating unit found in *P. mirabilis* O28 LPS, Figure 1).

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2653





Scheme 1. Approaches for glycuronamide synthesis.

In recent efforts to synthesize glycoconjugates containing glucuronamide residues using the conventional approach described above $(1\rightarrow 2\rightarrow 6)$, we encountered an unexpected problem: The generation of a glucuronic acid derivative, either by hydrolysis of an ester or oxidation of a primary alcohol, led to decomposition of the molecule. Thus, we required a method for the formation of a glucuronamide that did not involve a carboxylic acid intermediate. Although methods for the direct conversion of primary alcohols to amides have been described,^[25–36] in our hands these were unsuccessful.

We then turned our attention to a report by Yu and co-workers, which described the preparation of uronic acid esters from 6-S-phenyl-glycosides (Scheme 2, a).^[37,38] In this approach, the first step involves treatment of the sulfide precursor **7** with sulfuryl chloride to generate the corresponding α , α -dichlorosulfide (**8**), which in a second step can be converted into the uronic acid methyl ester (**9**). In other previous work, Fortes and co-workers showed that α , α -dichlorosulfides, when treated with



Scheme 2. a) Synthesis of uronic acid methyl esters by Yu and co-workers.^[37,38] b) proposed route to glycuronamides.



water and acetone in the presence of Na_2CO_3 , generate thioesters.^[39,40] These investigations prompted us to explore the possibility of preparing glycuronamides from **10** via the formation of the uronic acid thioesters (e.g., **11**) and then treatment with amines (Scheme 2, b).

Results and Discussion

In a first series of experiments, we treated 6-S-tolyl-galactose derivative **13** with sulfuryl chloride to produce the dichlorosulfide intermediate **14** (Scheme 3). Without purification, this adduct was stirred with water in acetone in the presence of NaHCO₃, leading to the formation of thioester **15**, which could be isolated in 87 % yield. Subsequent treatment of **15** with *p*-methoxybenzylamine in dichloromethane furnished the glucuronamide **16** in 90 % isolated yield.

Having succeeded in applying this approach to **13**, we then examined the oxidation of various 6-*S*-tolyl-glycosides **17–21**^[41] to the corresponding thioesters **22–26** as illustrated in Scheme 4. In each case, the two-step conversion afforded the desired product in good to excellent yield. Neither the electron-withdrawing nature of the protecting groups, nor the carbohydrate stereochemistry had a significant influence on the reac-



Scheme 4. Synthesis of uronic acid thioesters from 6-S-tolyl-substituted glycosides. *Reagents and conditions:* (a) pyridine, SO_2CI_2 , CCI_4 , 0 °C, 5 h; (b) NaH-CO₃, acetone/H₂O (3:2), room temp., 18 h.



Scheme 3. Synthesis of galacturonamide **16** from thioether **13**. *Reagents and conditions*: (a) pyridine, SO₂Cl₂, CCl₄, 0 °C, 5 h; (b) NaHCO₃, acetone/H₂O (3:2), room temp., 18 h; (c) *p*-methoxybenzylamine, CH₂Cl₂, room temp., 10 h.



Table 1. Amidation of uronic acid thioesters with amines.

Entry	Thioester	Amines ^[a]	Solvent	Time	Product	Yield ^[b]
1	22	PMB-NH ₂	CH ₂ Cl ₂	10 h	BnO BnO BnO OCH ₃ 27	85%
2	22	PMB-NH ₂	DMF	10 h		82%
3	22	NH ₃ OH (aq.)	DMF	40 h		66%
4	22	1,3-Di-O-benzyl-serinol	CH ₂ Cl ₂	72 h	BRO BRO OCH ₃	64%
5	22	1,3-Di-O-benzyl-serinol	CH ₂ Cl ₂	72 h	BRO BRO OCH ₃ 29	67% ^[c]
6	22	HCI∙H₂N-L-Ala-tBu	CH ₂ Cl ₂	24 h	O NH CO2/BU BhO BhO DCH3 30	33% ^[c]
7	22	H₂N-L-Ala-tBu	CH ₂ Cl ₂	24 h	BnO BnO BnO BnO BnO BnO BnO OCH ₃	71%
8	22	H ₂ N-L-Ser(<i>t</i> Bu)- <i>t</i> Bu	CH ₂ Cl ₂	72 h	1800 NH CO ₂ Bu BnO BnO OCH ₃ 31	65%
9	22	H ₂ N-L-Thr- <i>t</i> Bu	CH ₂ Cl ₂	72 h	HO O BnO BnO BnO BnO BnO BnO BnO BnO BnO	63%
10	23	PMB-NH ₂	CH ₂ Cl ₂	10 h	BZO BZO BZO BZO BZO BZO BZO OCH ₃	86%
11	23	ethanolamine	CH ₂ Cl ₂	17 h	BzO BzO BzO BzO BzO OCH ₃	86%
12	23	serinol	CH ₂ Cl ₂	40 h	OCH3 BZO BZO BZO BZO BZO BZO CCH3	73%
13	23	H₂N-L-Thr- <i>t</i> Bu	CH ₂ Cl ₂	87 h	HO VH BZO BZO BZO BZO BZO BZO BZO CCH ₃	41%
14	23	H ₂ N-L-Thr- <i>t</i> Bu	DMF	38 h		71%
15	24	PMB-NH ₂	CH ₂ Cl ₂	8 h		91%
16	24	H₂N-L-Ser(<i>t</i> Bu)- <i>t</i> Bu	DMF	42 h	1800 Ac09 Ac0 Ac0 Ac0 Ac0 CH ₃	64%
17	24	H₂N-L-Ala-tBu	DMF	18 h	AcoQ NH CO ₂ Bu Aco Aco OCH ₃ 39	63%
18	25	PMB-NH ₂	CH ₂ Cl ₂	10 h	BnO - NHPMB BnO - BnO OCH ₃ 40	83%
19	26	PMB-NH ₂	CH ₂ Cl ₂	10 h	PMBHN OBz Bzo Bzo Hzo CH ₃	98%

[a] 1.5 equiv. of amine except NH_4OH (aq.). [b] Yield of isolated product. [c] Triethylamine was added to the reaction.



tion yield or reaction time. In addition, the reaction could also be carried out in both milligram and gram scale without difficulty. With the thioesters in hand, we explored their amidation with various amines (Table 1).

In exploring the scope of the amidation reaction (Table 1), we focused on the preparation of naturally occurring glycuronamides in their protected form. We found that varying the carbohydrate residue and their electronic properties (i.e., the electron-withdrawing or donating ability of the protecting groups) did not affect the amidation yield or reaction rate.

When simple amines such as *p*-methoxybenzylamine (Entries 1, 10, 15, 18, 19) and ethanolamine (Entry 11) were used, the amidation proceeded in good yields (> 82 %). Ammonia from concentrated ammonium hydroxide could also be used as the amine, albeit this afforded the glycuronamide **28** in somewhat lower (66 %) yield and longer reactions times were required (Entry 3). The use of amines derived from L-alanine, L-serine, L-threonine as well as serinol, provided the corresponding glycuronamides in 63–73 % yields.

The data in Table 1 also supports a general trend for the reaction rate: simple amines (e.g., p-methoxybenzylamine, ethanolamine) > moderately bulky amines (e.g., protected L-alanine derivatives) > more sterically demanding amines (the serinol analogue, L-threonine derivatives, L-serine derivatives). It was discovered that for L-threonine *tert*-butyl ester changing the solvent from CH₂Cl₂ (Entry 13) to DMF (Entry 14) resulted in the reaction rate increasing nearly twofold and a significantly improved product yield. The same trend is observed with other amino acid-derived amines (Entries 8, 16). In attempts to increase the reaction rate, triethylamine was added (Entries 4, 5); however, no increase in the rate or improvement of the yield was observed. We also explored the use of 2,6-di-tert-butyl-4methylpyridine, but again no improvement in rate or product yield was seen. Indeed, for substrates possessing acyl protecting groups at O-4, the yield deceased (see next paragraph). It was also evident that the free amine (Entry 7) is a substantially better substrate than the corresponding hydrochloric salt, even in the presence of an excess of triethylamine (Entry 6). Not surprisingly, the data in entries 9, 11, and 13 demonstrate that amidation will occur over esterification when competing alcohol nucleophiles are present.

It is important to note that when O-4 in the carbohydrate is protected with an ester, significant elimination can occur in the presence of an excess amine nucleophile or when triethylamine is added to the reaction (Figure 2). Small amounts of the elimination adduct were also observed when a sterically demanding amine was used in the amidation step. However, changing the solvent from dichloromethane to DMF in the amidation of **23** with L-threonine *tert*-butyl ester (Entries 13, 14), led to less elimination. In addition, by carefully controlling the amount of amine in the reaction and avoiding the addition of triethylamine, the formation of the elimination product with O-4 acylated substrates could be largely avoided (e.g., Table 1, Entry 10).

To demonstrate the applicability of the approach to glycan synthesis, we used it to prepare the repeating unit of the *E. coli* K54 CPS, a disaccharide possessing a glucuronamide residue







Figure 2. Example of the elimination product formed from O-4 acylated substrates (e.g., **23**) when an triethylamine is used in the amidation reaction.

linked to L-threonine (52, Scheme 5).^[9] The synthesis started with a TBSOTf-catalyzed glycosylation of glucosyl acceptor 43^[42] with rhamnosyl donor 44,^[43] which led to a 2:1 inseparable mixture of 45 and its O-2 regioisomer in favor of the desired adduct. Subsequent acetylation with acetic anhydride in pyridine and removal of the benzylidene acetal afforded disaccharide 46 and its regioisomer 46a in 34 % and 17 % yield, respectively, over three steps. Treatment of 46 with tolyl disulfide and trimethylphosphine in pyridine selectively afforded the 6-S-tolyl sulfide 47 in 95 % yield. Subsequent acetylation of 47 with acetic anhydride in pyridine afforded an 95 % yield of 48. Oxidation of 48 into thioester 49 proceeded in 85 % yield upon treatment with sulfuryl chloride in carbon tetrachloride and then with water in the presence of NaHCO₃. The amidation of thioester 49 with L-threonine benzyl ester afforded glycuronamide 50 in 83 % yield. With the disaccharide prepared, it was deprotected by first hydrogenolysis of the benzyl ester over 5 % Pd/C, which afforded the free acid 51. Subsequent treatment of



Scheme 5. *Reagents and conditions*: (a) 4 Å MS, TBSOTf, CH_2CI_2 , –78 °C, 20 min (inseparable, **46:46a** = 2:1); (b) Ac₂O, pyridine, DMAP, 3 h; (c) 80 % CH₃COOH/ H₂O, 80 °C, 2 h (separable, **47:47a** = 2:1); (d) (TolS)₂, Me₃P in THF, pyridine, room temp., overnight; (e) Ac₂O, pyridine, DMAP, 3 h; (f) pyridine, SO₂CI₂, CCI₄, 0 °C, 5 h; (g) NaHCO₃, acetone/H₂O (3:2), room temp., 18 h; (h) L-threonine benzyl ester, CH₂CI₂, room temp., 44 h; (i) 5 % Pd/C, CH₃OH, room temp., overnight; (j) 50 mM NaOCH₃/CH₃OH, room temp., 4 h.

51 with sodium methoxide in methanol produced the disaccharide **52** in 90 % yield.

Conclusions

In conclusion, an effective strategy for the preparation of glycuronamides from 6-S-tolyl-glycosides was developed. The method was compatible with a range of carbohydrate residues and amines and the approach could be easily applied to the synthesis of the *E. coli* K54 CPS repeating unit. To the best of our knowledge, the route described here is the first of its kind to completely avoid a carboxylic acid intermediate in the synthesis of complex glycans containing glycuronamides. Moreover, staged introductions of 6-S-tolyl moieties into oligosaccharides should allow the preparation of molecules containing more than one uronic acid derivatives amidated to different amines.

Experimental Section

General Experimental Methods: All reagents were purchased from commercial sources and were used without further purification unless noted. Reaction solvents were purified by successive passage through columns of alumina and copper under argon. Unless stated otherwise, all reactions were carried out at room temperature and under a positive pressure of argon and were monitored by TLC on Silica Gel G-25 F254 (0.25 mm). Visualization of the reaction components was achieved using UV fluorescence (254 nm) and/or by charring with acidified anisaldehyde solution in ethanol, acetic acid and sulfuric acid. Organic solvents were evaporated under reduced pressure, and the products were purified by column chromatography on silica gel (230-400 mesh). Optical rotations were measured in a microcell (1 cm, 1 mL) at 21 °C and are in units of degree-mL/(g-dm). ¹H NMR spectra were recorded at 400 MHz or 500 MHz and chemical shifts are referenced to residual CHCl₃ (δ = 7.26 ppm, CDCl₃) or CHD₂OD (δ =3.30 ppm, CD₃OD). ¹³C NMR spectra were recorded at 125 MHz, and chemical shifts are referenced to CDCl₃ (δ =77.0 ppm) or CD₃OD (δ =49.3 ppm). Reported splitting patterns are abbreviated as s = singlet, d = doublet, t = triplet, m =multiplet, br. = broad, app. = apparent. Assignments of NMR spectra were based on two-dimensional experiments (¹H-¹H COSY, HSQC and HMBC). High-resolution ESI-MS spectra (time-of-flight analyzer) were recorded on samples suspended in THF or CH₃OH and with added NaCl.

General Method 1: Preparation of 6-S-tolyl-Substituted Glycosides:^[37] To a stirred solution of the 6-hydroxy glycopyranoside (1.0 mmol) in dry pyridine (5.0 mL) under argon were added (TolS)₂ (2.0 mmol) and PMe₃ (2.0 mmol, 1.0 m in THF). The reaction mixture was stirred overnight at room temperature. Then, the reaction mixture was concentrated, diluted with EtOAc (30 mL) and washed with brine. The organic layer was dried with MgSO₄, filtered and concentrated.

General Method 2: Preparation of Thio-uronates:^[39,40] To a solution of the thioether (1.0 mmol) in dry CCl₄ (15 mL) at 0 °C under argon were added anhydrous pyridine (2.0 mmol) and then SO₂Cl₂ (2.0 mmol). The reaction mixture was stirred for 5 h at 0 °C, then diluted with CH₂Cl₂ and the mixture was washed with brine. The organic layer dried with MgSO₄, filtered and concentrated. The crude residue was dissolved in 3:2 acetone/H₂O (20 mL), and solid NaHCO₃ (4.0 mmol) was added. The reaction mixture was stirred for





18 h at room temperature, diluted with brine, and then extracted with EtOAc (3 \times 30 mL). The organic layer was dried with MgSO₄, filtered and concentrated.

General Method 3: Preparation of Uronamides: To a solution of the thioester (0.1 mmol) in CH_2Cl_2 (or DMF) (1 mL) was added the amine (0.15 mmol). The reaction mixture was monitored by TLC until the consumption of starting material and then diluted with CH_2Cl_2 (5 mL), washed with satd. NH_4Cl (aq.) and brine. The organic layer dried with MgSO₄, filtered and concentrated.

1,2:3,4-Di-O-isopropylidene-6-thio-6-S-p-tolyl-α-D-galactopyranose (13): Scale 1.0 mmol. Prepared as described in general method 1. The crude residue was purified by flash chromatography (5:1→4:1 hexane/EtOAc) to afford 13 (330 mg, 90 %) as a clear viscous oil. $R_f = 0.39$ (4:1 hexane/EtOAc). $[\alpha]_D = -84.3$ (c = 0.4, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.33–7.31 (m, 2 H, Ar), 7.11–7.09 (m, 2 H, Ar), 5.53 (d, J = 5.0 Hz, 1 H, 1-H), 4.61 (dd, J = 7.9, 2.4 Hz, 1 H, 3-H), 4.39 (dd, J = 7.9, 1.8 Hz, 1 H, 4-H), 4.29 (dd, J = 5.0, 2.4 Hz, 1 H, 2-H), 3.83 (td, J = 7.0, 1.7 Hz, 1 H, 5-H), 3.14 (d, J = 7.0 Hz, 2 H, 6-H), 2.31 (s, 3 H, ArCH₃), 1.47 [s, 3 H, C(CH₃)₂], 1.36 [s, 3 H, C(CH₃)₂], 1.30 [s, 3 H, C(CH₃)₂], 1.26 [s, 3 H, C(CH₃)₂] ppm. ¹³C NMR (125 MHz, $CDCl_3$): $\delta = 136.4$ (Ar), 131.9 (Ar), 130.4 (Ar), 129.7 (Ar), 109.3 [C(CH₃)₂], 108.6 [C(CH₃)₂], 96.7 (C-1), 71.3 (C-4), 70.9 (C-3), 70.6 (C-2), 66.2 (C-5), 34.0 (C-6), 26.0 [C(CH₃)₂], 25.6 [C(CH₃)₂], 25.0 [C(CH₃)₂], 24.5 [C(CH₃)₂], 21.0 (ArCH₃) ppm. HRMS (ESI) calcd. for [M + Na] C₁₉H₂₆NaO₅S: 389.1393, found 389.1397.

S-p-Tolyl Thio(1,2:3,4-Di-O-isopropylidene-α-D-galactopyranose)uronate (15): Scale: 1.0 mmol. Prepared as described in general method 2. The crude residue was purified by flash chromatography (4:1 hexane/EtOAc) to afford 15 (331 mg, 87 %) as a white amorphous solid. $R_{\rm f} = 0.29$ (4:1 hexane/EtOAc). $[\alpha]_{\rm D} = -179.5$ (c = 0.7, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.35–7.32 (m, 2 H, Ar), 7.24– 7.22 (m, 2 H, Ar), 5.75 (d, J = 4.9 Hz, 1 H, 1-H), 4.69 (dd, J = 7.7, 2.6 Hz, 1 H, 3-H), 4.65 (dd, J = 7.7, 2.2 Hz, 1 H, 4-H), 4.49 (d, J = 1.9 Hz, 1 H, 5-H), 4.43 (dd, J = 4.9, 2.5 Hz, 1 H, 2-H), 2.39 (s, 3 H, ArCH₃), 1.56 [s, 3 H, C(CH₃)₂], 1.55 [s, 3 H, C(CH₃)₂], 1.38 [s, 3 H, $C(CH_3)_2$, 1.36 [s, 3 H, $C(CH_3)_2$] ppm. ¹³C NMR (125 MHz, $CDCl_3$): $\delta =$ 197.9 (C-6), 139.5 (Ar), 134.7 (Ar), 130.0 (Ar), 123.6 (Ar), 110.1 [C(CH₃)₂], 109.3 [C(CH₃)₂], 96.7 (C-1), 74.2 (C-5), 72.3 (C-4), 70.8 (C-3), 70.7 (C-2), 26.1 [C(CH₃)₂], 26.0 [C(CH₃)₂], 24.8 [C(CH₃)₂], 24.6 $[C(CH_3)_2]$, 21.4 (ArCH₃) ppm. HRMS (ESI) calcd. for [M + Na] C₁₉H₂₄NaO₆S: 403.1186, found 403.1186.

N-(4-Methoxybenzyl) 1,2:3,4-Di-O-Isopropylidene-α-D-galactopyranosiduronamide (16): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (2:1 hexane/EtOAc) to afford 16 (35 mg, 90 %) as a white solid. $R_{\rm f}$ = 0.18 (2:1 hexane/EtOAc). $[\alpha]_{\rm D}$ = -78.2 (c = 0.5, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.24–7.21 (m, 2 H, Ar), 6.85– 6.82 (m, 2 H, Ar), 6.78 (app. t, J = 5.5, 5.5 Hz, 1 H, CONHCH₂), 5.54 (d, J = 4.9 Hz, 1 H, 1-H), 4.72 (dd, J = 7.9, 2.1 Hz, 1 H, 3-H), 4.68-4.64 (m, 2 H, 4-H, NHCH₂Ar), 4.34 (m, 2 H, 2-H, 5-H), 4.23 (dd, J = 14.8, 4.7 Hz, 1 H, NHCH2Ar), 3.78 (s, 3 H, ArOCH3), 1.51 [s, 3 H, C(CH₃)₂], 1.39 [s, 3 H, C(CH₃)₂], 1.35 [s, 3 H, C(CH₃)₂], 1.32 [s, 3 H, C(CH₃)₂] ppm. ¹³C NMR (175 MHz, CDCl₃): δ = 168.2 (C-6), 158.9 (Ar), 130.0 (Ar), 128.9 (Ar), 113.9 (Ar), 109.4 [C(CH₃)₂], 109.2 [C(CH₃)₂], 96.2 (C-1), 71.6 (C-3), 70.7 (C-2), 70.4 (C-4), 68.8 (C-5), 55.3 (ArOCH₃), 42.2 (NHCH₂Ar), 26.0 [C(CH₃)₂], 25.9 [C(CH₃)₂], 24.8 [C(CH₃)₂], 24.2 $[C(CH_3)_2]$ ppm. HRMS (ESI) calcd. for $[M + Na] C_{20}H_{27}NNaO_7$: 416.1680, found 416.1678.

Methyl 2,3,4-Tri-O-benzyl-6-thio-6-S-*p***-tolyl-α-D-glucopyranoside (17):** Scale 1.0 mmol. Prepared from methyl 2,3,4-tri-O-benzyl-α-D-glucopyranoside^[44] as described in general method 1. The crude residue was purified by flash chromatography (5:1 \rightarrow 4:1 hexane/ EtOAc) to afford **17** (542 mg, 95 %) as a clear viscous oil. The ¹H NMR spectroscopic data for the product was consistent with that reported in the literature.^[45]

Methyl 2,3,4-Tri-O-benzoyl-6-thio-6-S-p-tolyl-α-D-glucopyranoside (18): Scale 1.0 mmol. Prepared from methyl 2,3,4-tri-O-benzoyl- α -D-glucopyranoside^[46]as described in general method 1. The crude residue was purified by flash chromatography (5:1→4:1 hexane/EtOAc) to afford **18** (576 mg, 94 %) as a clear viscous oil. $R_{\rm f}$ = 0.44 (4:1 hexane/EtOAc). $[\alpha]_{D} = +40.8$ (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 8.00–7.98 (m, 2 H, Ar), 7.96–7.94 (m, 2 H, Ar), 7.88-7.86 (m, 2 H, Ar), 7.57-7.51 (m, 2 H, Ar), 7.46-7.38 (m, 5 H, Ar), 7.32–7.26 (m, 4 H, Ar), 7.06 (d, J = 7.9 Hz, 2 H, Ar), 6.11 (app. t, J = 9.8 Hz, 1 H, 3-H), 5.49 (app. t, J = 9.7 Hz, 1 H, 4-H), 5.29 (dd, J = 10.2, 3.7 Hz, 1 H, 2-H), 5.24 (d, J = 3.7 Hz, 1 H, 1-H), 4.24 (ddd, J = 9.5, 9.4, 2.5 Hz, 1 H, 5-H), 3.50 (s, 3 H, OCH₃), 3.23 (dd, J = 14.0, 2.5 Hz, 1 H, 6-Ha), 3.13 (dd, J = 14.0, 9.1 Hz, 1 H, 6-Hb), 2.33 (s, 3 H, ArCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 165.8 (2 × C=O), 165.5 (C=O), 136.6 (Ar), 133.5 (Ar), 133.4 (Ar), 133.1 (Ar), 132.3 (Ar), 130.2 (Ar), 130.0 (Ar), 129.9 (Ar), 129.8 (Ar), 129.7 (Ar), 129.3 (Ar), 129.1 (Ar), 128.0 (Ar), 128.4 (2 × Ar), 128.3 (Ar), 96.8 (C-1), 72.3 (C-4), 72.2 (C-2), 70.4 (C-3), 68.9 (C-5), 55.5 (OCH₃), 36.6 (C-6), 21.0 (ArCH₃) ppm. HRMS (ESI) calcd. for [M + Na] C₂₅H₃₂NaO₈S: 635.1710, found 635.1707.

Methyl 2,3,4-Tri-O-acetyl-6-thio-6-S-p-tolyl-α-D-galactopyranoside (19): Scale 1.0 mmol. Prepared from methyl 2,3,4-tri-O-acetyl- α -D-galactopyranoside^[47] as described in general method 1. The crude residue was purified by flash chromatography (3:2→2:1 hexane/EtOAc) to afford **19** (363 mg, 85 %) as a clear viscous oil. $R_f =$ 0.44 (2:1 hexane/EtOAc). $[\alpha]_{D} = +82.7$ (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.29 (d, J = 8.1 Hz, 2 H, Ar), 7.13 (d, J = 7.9 Hz, 2 H, Ar), 5.49 (dd, J = 3.4, 1.2 Hz, 1 H, 4-H), 5.33 (dd, J = 10.9, 3.4 Hz, 1 H, 3-H), 5.15 (dd, J = 10.9, 3.6 Hz, 1 H, 2-H), 5.00 (d, J = 3.6 Hz, 1 H, 1-H), 4.05 (ddd, J = 7.8, 5.5, 1.0 Hz, 1 H, 5-H), 3.39 (s, 3 H, OCH₃), 3.07 (dd, J = 13.8, 8.0 Hz, 1 H, 6-Ha), 2.90 (dd, J = 13.8, 5.4 Hz, 1 H, 6-Hb), 2.35 (s, 3 H, ArCH₃), 2.15 (s, 3 H, COCH₃), 2.09 (s, 3 H, COCH₃), 2.00 (s, 3 H, COCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 170.4 (C= O), 170.3 (C=O), 169.9 (C=O), 137.0 (Ar), 131.6 (Ar), 130.6 (Ar), 129.9 (Ar), 97.2 (C-1), 69.6 (C-3), 68.2 (C-2), 67.8 (C-4), 67.5 (C-5), 55.4 (OCH₃), 35.2 (C-6), 21.0 (COCH₃), 20.8 (COCH₃), 20.7 (COCH₃) ppm. HRMS (ESI) calcd. for $[M + NH_4] C_{20}H_{30}NO_8S$: 444.1687, found 444,1679

Methyl 2,3,4-Tri-O-benzyl-6-thio-6-S-p-tolyl-α-D-galactopyranoside (20): Scale 1.0 mmol. Prepared from methyl 2,3,4-tri-Obenzyl- α -D-galactopyranoside^[48] as described in general method 1. The crude residue was purified by flash chromatography (6:1→4:1 hexane/EtOAc) to afford 20 (479 mg, 82 %) as a clear viscous oil. $R_{\rm f} = 0.44$ (4:1 hexane/EtOAc). $[\alpha]_{\rm D} = -13.0$ (c = 0.3, CHCl₃). ¹H NMR (400 MHz, CDCl₃): δ = 7.40–7.26 (m, 15 H, Ar), 7.18–7.16 (m, 2 H, Ar), 7.07 (d, J = 8.3 Hz, 2 H, Ar), 5.00 (d, J = 11.4 Hz, 1 H, PhCH₂O), 4.87 (d, J = 11.7 Hz, 1 H, PhCH₂O), 4.82 (d, J = 12.1 Hz, 1 H, PhCH₂O), 4.75 (d, J = 11.7 Hz, 1 H, PhCH₂O), 4.69–4.65 (m, 2 H, PhCH₂O, 1-H), 4.55 (d, J = 11.4 Hz, 1 H, PhCH₂O), 4.02 (dd, J = 10.0, 3.6 Hz, 1 H, 2-H), 3.97 (d, J = 2.5 Hz, 1 H, 4-H), 3.89 (dd, J = 10.0, 2.5 Hz, 1 H, 3-H), 3.77-3.73 (m, 1 H, 5-H), 3.32 (s, 3 H, OCH₃), 3.07 (dd, J = 13.4, 6.5 Hz, 1 H, 6-Ha), 2.89 (dd, J = 13.4, 7.1 Hz, 1 H, 6-Hb), 2.31 (s, 3 H, ArCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 138.8 (Ar), 138.5 (2 × Ar), 136.2 (Ar), 132.4 (Ar), 129.8 (Ar), 129.6 (Ar), 128.4 (3 × Ar), 128.3 (Ar), 128.1 (Ar), 127.7 (2 × Ar) 127.6 (Ar), 127.5 (Ar), 98.9 (C-1), 79.4 (C-3), 76.3 (C-2), 75.7 (C-4), 74.9 (PhCH₂O), 73.5 (2 × PhCH₂O), 69.4 (C-5), 55.3 (OCH₃), 34.7 (C-6), 21.0 (ArCH₃) ppm. HRMS (ESI) calcd. for [M + NH₄] C₃₅H₄₂NO₅S: 588.2778, found 588.2764.





Methyl 2,3,4-Tri-O-benzoyl-6-thio-6-S-p-tolyl-α-D-mannopyranoside (21): Scale: 1.0 mmol. Prepared from methyl 2,3,4-tri-O-ben $zoyl-\alpha$ -D-mannopyranoside^[49] as described in general method 1. The crude residue was purified by flash chromatography (6:1 \rightarrow 2:1 hexane/EtOAc) to afford 21 (594 mg, 97 %) as a white amorphous solid. $R_{\rm f} = 0.42$ (4:1 hexane/EtOAc). $[\alpha]_{\rm D} = -112.0$ (c = 1.0, CHCl₃). ¹H NMR (400 MHz, CDCl₃): δ = 8.13–8.11 (m, 2 H, Ar), 7.96–7.94 (m, 2 H, Ar), 7.84-7.82 (m, 2 H, Ar), 7.64-7.38 (m, 7 H, Ar), 7.28-7.24 (m, 4 H, Ar), 7.05 (d, J = 8.0 Hz, 2 H, Ar), 5.87–5.80 (m, 2 H, H3, H4), 5.67 (app. t, J = 1.7 Hz, 1 H, 2-H), 4.99 (d, J = 1.7 Hz, 1 H, 1-H), 4.27-4.22 (m, 1 H, 5-H), 3.53 (s, 3 H, OCH₃), 3.29 (dd, J = 13.8, 2.5 Hz, 1 H, 6-Ha), 3.20 (dd, J = 13.8, 8.7 Hz, 1 H, 6-Hb), 2.31 (s, 3 H, ArCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 165.7 (C=O), 165.6 (C=O), 165.4 (C= O), 136.5 (Ar), 133.5 (2 × Ar), 133.1 (Ar), 132.3 (Ar), 130.2 (Ar), 130.0 (Ar), 129.9 (2 × , Ar), 129.8 (Ar), 129.4 (Ar), 129.2 (Ar), 129.0 (Ar), 128.6 (Ar), 128.5 (Ar), 128.2 (Ar), 98.5 (C-1), 70.6 (C-2), 70.0 (2 × C3 & C4), 69.7 (C5), 55.4 (OCH₃), 36.8 (C-6), 21.0 (ArCH₃) ppm. HRMS (ESI) calcd. for [M + Na] C₃₅H₃₂NaO₈S: 635.1710, found 635.1706.

S-p-Tolyl Thio(methyl 2,3,4-Tri-O-benzyl-α-D-glucopyranosid)uronate (22): Scale 1.0 mmol. Prepared as described in general method 2. The crude residue was purified by flash chromatography (6:1->4:1 hexane/EtOAc) to afford 22 (456 mg, 78 %) as a colorless oil. $R_{\rm f} = 0.40$ (4:1 hexane/EtOAc). $[\alpha]_{\rm D} = +15.5$ (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.38–7.25 (m, 19 H, Ar), 4.97 $(d, J = 10.9 Hz, 1 H, PhCH_2O), 4.86 (d, J = 10.9 Hz, 1 H, PhCH_2O),$ 4.85 (d, J = 12.4 Hz, 1 H, PhCH₂O), 4.78 (d, J = 10.4 Hz, 1 H, PhCH₂O), 4.73 (d, J = 3.5 Hz, 1 H, 1-H), 4.69 (d, J = 12.4 Hz, 1 H, PhCH₂O), 4.68 (d, J = 10.4 Hz, 1 H, PhCH₂O), 4.37 (d, J = 9.7 Hz, 1 H, 5-H), 4.05 (app. t, J = 9.3 Hz, 1 H, 3-H), 3.82 (dd, J = 9.7, 9.3 Hz, 1 H, 4-H), 3.62 (dd, J = 9.3, 3.5 Hz, 1 H, 2-H), 3.49 (s, 3 H, OCH₃), 2.40 (s, 3 H, ArCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 195.4 (C-6), 140.0 (Ar), 138.6 (Ar), 138.0 (2 \times Ar), 134.5 (Ar), 130.2 (Ar), 128.6 (Ar), 128.4 (2 \times Ar), 128.2 (Ar), 128.1 (2 × Ar), 128.0 (Ar), 127.8 (Ar), 127.7 (Ar), 123.1 (Ar), 98.8 (C-1), 81.5 (C-3), 79.9 (C-4), 79.3 (C-2), 76.0 (PhCH₂O), 75.5 (C5), 75.3 (PhCH₂O), 73.7 (PhCH₂O), 55.9 (OCH₃), 21.4 (ArCH₃) ppm. HRMS (ESI) calcd. for $[M + NH_4] C_{35}H_{40}O_6S$: 602.2571, found 602.2572.

S-p-Tolyl Thio(methyl 2,3,4-Tri-O-benzoyl-α-D-glucopyranosid)uronate (23): Scale 1.0 mmol. Prepared as described in general method 2. The crude residue was purified by flash chromatography (dry loading) (4:1→3:1 hexane/EtOAc) to afford 23 (539 mg, 86 %) as a white amorphous solid. $R_f = 0.31$ (4:1 hexane/EtOAc). $[\alpha]_{\rm D}$ = +52.9 (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 8.03– 8.01 (m, 2 H, Ar), 7.97-7.95 (m, 2 H, Ar), 7.93-7.90 (m, 2 H, Ar), 7.57-7.30 (m, 11 H, Ar), 7.22 (dd, J = 8.5, 0.6 Hz, 2 H, Ar), 6.21 (app. t, J = 9.8 Hz, 1 H, 3-H), 5.85 (app. t, J = 9.7 Hz, 1 H, 4-H), 5.44 (d, J = 3.6 Hz, 1 H, 1-H), 5.38 (dd, J = 10.1, 3.6 Hz, 2-H), 4.71 (d, J = 9.7 Hz, 1 H, 5-H), 3.59 (s, 3 H, OCH_3), 2.37 (s, 3 H, ArCH_3) ppm. $^{13}\mathrm{C}$ NMR (125 MHz, CDCl₃): δ = 194.7 (C-6), 165.8 (C=O), 165.6 (C=O), 165.1 (C=O), 140.0 (Ar), 134.8 (Ar), 133.5 (Ar), 133.3 (Ar), 133.2 (Ar), 130.2 (Ar), 130.0 (Ar), 129.9 (Ar), 129.7 (Ar), 129.1 (Ar), 129.0 (Ar), 128.9 (Ar), 128.5 (Ar), 128.3 (2 × Ar), 122.6 (Ar), 97.6 (C-1), 74.0 (C-5), 71.6 (C-2), 70.1 (C-4), 69.9 (C-3), 56.4 (OCH₃), 21.4 (ArCH₃) ppm. HRMS (ESI) calcd. for [M + Na] C₃₅H₃₀NaO₉S: 649.1503, found 649.1497.

S-*p*-**Tolyl Thio(methyl 2,3,4-Tri-O-acetyl-α-D-galactopyranosid)uronate (24):** Scale 1.0 mmol. Prepared as described in general method 2. The crude residue was purified by flash chromatography (2:1 hexane/EtOAc) to afford **24** (396 mg, 90%) as a clear viscous oil. $R_f = 0.36$ (2:1 hexane/EtOAc). $[\alpha]_D = +72.8$ (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): $\delta = 7.27-7.23$ (m, 4 H, Ar), 5.82 (dd, J = 3.3, 1.6 Hz, 1 H, 4-H), 5.43–5.39 (m, 1 H, 3-H), 5.27–5.24 (m, 2 H, 1-H, 2-H), 4.66 (d, J = 1.6 Hz, 1 H, 5-H), 3.55 (s, 3 H, OCH₃), 2.39 (s, 3 H, ArCH₃), 2.12 (s, 6 H, COCH₃, COCH₃), 2.00 (s, 3 H, COCH₃)

ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 195.0 (C-6), 170.3 (C=O), 169.8 (C=O), 169.5 (C=O), 140.1 (Ar), 134.5 (Ar), 130.2 (Ar), 122.6 (Ar), 97.8 (C-1), 74.2 (C-5), 68.8 (C-4), 67.9 (C-2), 67.2 (C-3), 56.3 (OCH₃), 21.4 (COCH₃), 20.8 (COCH₃), 20.6 (COCH₃), 20.5 (ArCH₃) ppm. HRMS (ESI) calcd. for [M + NH₄] C₂₀H₂₈NO₉S: 458.1479, found 458.1472.

S-p-Tolyl Thio(methyl 2,3,4-Tri-O-benzyl-α-D-galactopyranosid)uronate (25): Scale 1.0 mmol. Prepared as described in general method 2. The crude residue was purified by flash chromatography (4:1 hexane/EtOAc) to afford 25 (439 mg, 75 %) as a clear viscous oil. $R_{\rm f} = 0.42$ (4:1 hexane/EtOAc). $[\alpha]_{\rm D} = -41.0$ (c = 0.2, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.40–7.29 (m, 15 H, Ar), 7.23– 7.21 (m, 4 H, Ar), 4.92 (d, J = 11.1 Hz, 1 H, PhCH₂O), 4.91 (d, J = 3.6 Hz, 1 H, 1-H), 4.88 (d, J = 12.0 Hz, 1 H, PhCH₂O), 4.84 (d, J = 11.7 Hz, 1 H, PhCH₂O), 4.75 (d, J = 11.7 Hz, 1 H, PhCH₂O), 4.71 (d, J = 12.0 Hz, 1 H, PhCH₂O), 4.56 (d, J = 11.1 Hz, 1 H, PhCH₂O), 4.43 (d, J = 1.4 Hz, 1 H, 5-H), 4.39 (dd, J = 2.8, 1.4 Hz, 1 H, 4-H), 4.16 (dd, J = 10.1, 3.6 Hz, 1 H, 2-H), 3.97 (dd, J = 10.1, 2.8 Hz, 1 H, 3-H), 3.49 (s, 3 H, OCH₃), 2.40 (s, 3 H, ArCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 198.2 (C-6), 139.8 (Ar), 138.5 (Ar), 138.4 (2 × Ar), 134.8 (Ar), 130.1 (Ar), 128.4 (Ar), 128.1 (2 × Ar), 127.8 (Ar), 127.6 (Ar), 127.5 (2 × Ar), 123.4 (Ar), 99.4 (C-1), 78.3 (C-3), 76.4 (C-4), 76.1 (2×C-5, C-2), 75.6 (PhCH₂O), 73.9 (PhCH₂O), 73.2 (PhCH₂O), 56.1 (OCH₃), 21.4 (ArCH₃) ppm. HRMS (ESI) calcd. for $[M + NH_4] C_{35}H_{40}NO_6S$: 602.2571, found 602.2557.

S-p-Tolyl Thio(methyl 2,3,4-Tri-O-benzoyl-α-D-mannopyranosid)uronate (26): Scale 1.0 mmol. Prepared as described in general method 2. The crude residue was purified by flash chromatography (4:1-3:1 hexane/EtOAc) to afford 26 (464 mg, 74 %) as a white amorphous solid. $R_{\rm f} = 0.31$ (4:1 hexane/EtOAc). $[\alpha]_{\rm D} = -100.5$ $(c = 1.0, CHCl_3)$. ¹H NMR (500 MHz, CDCl_3): $\delta = 8.21-8.19$ (m, 2 H, Ar), 8.01–7.99 (m, 2 H, Ar), 7.90–7.88 (m, 2 H, Ar), 7.66–7.45 (m, 5 H, Ar), 7.40-7.28 (m, 6 H, Ar), 7.24 (d, J = 8.0 Hz, 2 H, Ar), 6.20 (app. t, J = 9.7 Hz, 1 H, 4-H), 5.96 (dd, J = 9.7, 3.2 Hz, 1 H, 3-H), 5.77 (dd, J = 3.2, 2.2 Hz, 1 H, 2-H), 5.21 (d, J = 2.2 Hz, 1 H, 1-H), 4.76 (d, J = 9.7 Hz, 1 H, 5-H), 3.65 (s, 3 H, OCH₃), 2.38 (s, 3 H, ArCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 194.9 (C-6), 165.50 (C=O), 165.35 (C=O), 165.29 (C=O), 140.0 (Ar), 134.8 (Ar), 133.7 (Ar), 133.3 (2 × Ar), 130.2 (Ar), 130.1 (Ar), 129.9 (Ar), 129.8 (Ar), 129.2 (2 × Ar), 129.0 (Ar), 128.7 (Ar), 128.4 (Ar), 122.7 (Ar), 99.1 (C-1), 75.4 (C-5), 69.9 (C-2), 69.4 (C-3), 67.8 (C-4), 56.3 (OCH₃), 21.4 (ArCH₃) ppm. HRMS (ESI) calcd. for $[M + NH_4] C_{35}H_{34}NO_9S: 644.1949$, found 644.1935.

N-(4-Methoxybenzyl) (Methyl 2,3,4-Tri-O-benzyl-α-D-glucopyranosid)uronamide (27): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (2:1 hexane/EtOAc) to afford 27 (51 mg, 85 %) as a white solid. $R_{\rm f} = 0.18$ (2:1 hexane/EtOAc). $[\alpha]_{\rm D} = -6.1$ (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.38–7.25 (m, 15 H, Ar), 7.15 (d, J = 8.6 Hz, 2 H, Ar), 6.82 (d, J = 8.6 Hz, 2 H, Ar), 6.33 (app. t, J = 5.5 Hz, 1 H, CONHCH₂), 4.97 (d, J = 10.9 Hz, 1 H, PhCH₂O), 4.85 (d, J = 10.9 Hz, 1 H, PhCH₂O), 4.82 (d, J = 12.0 Hz, 1 H, PhCH₂O), 4.78 (d, J = 10.5 Hz, 1 H, PhCH₂O), 4.67 (d, J = 12.0 Hz, 1 H, PhCH₂O), 4.64– 4.61 (m, 2 H, 1-H, PhCH₂O), 4.43 (dd, J = 14.4, 5.5 Hz, 1 H, NHCH₂Ar), 4.34 (dd, J = 14.4, 5.5 Hz, 1 H, NHCH₂Ar), 4.10 (d, J = 9.9 Hz, 1 H, 5-H), 4.02 (app. t, J = 9.3 Hz, 1 H, 3-H), 3.79 (s, 3 H, ArOCH₃), 3.63 (dd, J = 9.9, 9.3 Hz, 1 H, 4-H), 3.57 (dd, J = 9.3, 3.5 Hz, 1 H, 2-H), 3.40 (s, 3 H, OCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 168.6 (C-6), 159.1 (Ar), 138.6 (Ar), 138.0 (Ar), 137.9 (Ar), 129.8 (Ar), 129.3 (Ar), 128.5 (Ar), 128.4 (3 × Ar), 128.2 (Ar), 128.1 (2 × Ar), 128.0 (Ar), 127.8 (Ar), 127.7 (Ar), 114.1 (Ar), 98.5 (C-1), 81.5 (C-3), 80.3 (C-4), 79.2 (C-2), 75.9 (PhCH₂O), 75.2 (PhCH₂O), 73.6 (PhCH₂O), 70.8 (C-5), 55.8 (OCH₃), 55.3 (ArOCH₃), 43.0 (NHCH₂Ar) ppm. HRMS (ESI) calcd. for [M + H] C₃₆H₄₀NO₇: 598.2799, found 598.2790.

Eur. J. Org. Chem. 2016, 2653–2664 www.e

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Methyl 2,3,4-Tri-O-benzyl- α -D-glucopyranosiduronamide (28): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (1:2 hexane/ EtOAc) to afford **28** (32 mg, 66 %) as a white solid. $R_f = 0.24$ (1:2 hexane/EtOAc). $[\alpha]_{D} = -8.2$ (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.39–7.28 (m, 15 H), 6.12 (br. s, 1 H, CONH_a), 5.79 (br. s, 1 H, CONH_b), 4.98 (d, J = 10.9 Hz, 1 H, PhCH₂O), 4.87–4.81 (m, 3 H, PhCH₂O), 4.71-4.65 (m, 3 H, PhCH₂O, 1-H), 4.12 (d, J = 9.7 Hz, 1 H, 5-H), 4.02 (app. t, J = 9.5 Hz, 1 H, 3-H), 3.61 (dd, J = 9.7, 9.5 Hz, 1 H, 4-H), 3.57 (dd, J = 9.5, 3.5 Hz, 1 H, 2-H), 3.41 (s, 3 H, OCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 171.4 (C-6), 138.5 (Ar), 138.0 (Ar), 137.7 (Ar), 128.6 (Ar), 128.5 (2 × Ar), 128.4 (2 × Ar), 128.3 (Ar), 128.2 $(3 \times Ar)$, 128.1 (Ar), 128.0 (Ar), 127.9 (Ar), 127.7 (Ar), 98.4 (C-1), 81.6 (C-3), 80.2 (C-4), 79.2 (C-2), 75.9 (PhCH2O), 75.4 (PhCH2O), 73.6 (PhCH₂O), 70.0 (C-5), 55.8 (OCH₃) ppm. HRMS (ESI) calcd. for [M + H] C₂₈H₃₂NO₆: 478.2224, found 478.2217.

2-N-(Methyl 2,3,4-Tri-O-benzyl-α-D-glucopyranosiduronoyl)-1,3di-O-benzyl-2-deoxy-glycerol (29): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (4:1→2:1 hexane/EtOAc) to afford 29 (47 mg, 64 %) as a white solid. $R_{\rm f} = 0.24$ (2:1 hexane/EtOAc). $[\alpha]_{\rm D} = -6.3$ (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.40–7.26 (m, 25 H, Ar), 6.49 (d, J = 8.4 Hz, 1 H, CONHCH), 4.96 (d, J = 10.9 Hz, 1 H, PhCH₂O), 4.85–4.82 (m, 2 H, PhCH₂O), 4.74 (d, J = 10.6 Hz, 1 H, PhCH₂O), 4.69– 4.64 (m, 3 H, PhCH₂O, 1-H), 4.52-4.44 (m, 4 H, PhCH₂O), 4.37-4.33 (m, 1 H, NHCH), 4.07 (d, J = 9.9 Hz, 1 H, 5-H), 4.01 (app. t, J = 9.3 Hz, 1 H, 3-H), 3.65–3.56 (m, 4 H, CHCH₂OBn, 2-H, 4-H), 3.53 (dd, J = 9.3, 5.9 Hz, 1 H, CHCH₂OBn), 3.46 (dd, J = 9.3, 5.9 Hz, 1 H, CHCH₂OBn), 3.40 (s, 3 H, OCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 168.7 (C-6), 138.7 (Ar), 138.1 (2 × Ar), 138.0 (2 × Ar), 128.5 (Ar), 128.4 (2 × Ar), 128.3 (Ar), 128.2 (Ar), 128.0 (3 × Ar), 127.7 (4 × Ar), 127.6 (Ar), 98.5 (C-1), 81.5 (C-3), 80.4 (C-4), 79.2 (C-2), 75.9 (PhCH₂O), 75.1 (PhCH₂O), 73.6 (PhCH₂O), 73.1 (2 × PhCH₂O), 70.9 (C-5), 68.3 (CHCH₂OBn), 68.2 (CHCH₂OBn), 55.8 (OCH₃), 48.4 (NHCH) ppm. HRMS (ESI) calcd. for [M + H] C₄₅H₅₀NO₈: 732.3531, found 732.3516.

N-(Methyl 2,3,4-Tri-O-benzyl- α -D-glucopyranosiduronoyl)-Lalanine tert-Butyl Ester (30): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (2:1 hexane/EtOAc) to afford 30 (43 mg, 71 %) as a viscous oil. $R_{\rm f} = 0.27$ (2:1 hexane/EtOAc). $[\alpha]_{\rm D} = -4.64$ $(c = 1.0, CHCl_3)$. ¹H NMR (500 MHz, CDCl₃): $\delta = 7.39-7.27$ (m, 15 H, Ar), 6.83 (d, J = 7.0 Hz, 1 H, CONHCH), 4.96 (d, J = 10.9 Hz, 1 H, PhCH₂O), 4.85 (d, J = 11.8 Hz, 1 H, PhCH₂O), 4.83 (d, J = 12.7 Hz, 1 H, PhCH₂O), 4.76 (d, J = 10.3 Hz, 1 H, PhCH₂O), 4.73 (d, J = 10.4 Hz, 1 H, PhCH₂O), 4.67 (d, J = 12.1 Hz, 1 H, PhCH₂O), 4.66 (d, J = 3.5 Hz, 1 H, 1-H) 4.46 [dt, J = 14.2, 7.2 Hz, 1 H, NHCHCO₂C(CH₃)₃], 4.11 (d, J = 9.9 Hz, 1 H, 5-H), 4.02 (app. t, J = 9.3 Hz, 1 H, 3-H), 3.61 (dd, J = 9.9, 8.9 Hz, 1 H, 4-H), 3.56 (dd, J = 9.7, 3.5 Hz, 1 H, 2-H), 3.41 (s, 3 H, OCH₃), 1.48 [s, 9 H, NHCHCO₂C(CH₃)₃], 1.36 (d, J = 7.1 Hz, 3 H, CHCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 172.0 (C=O), 168.5 (C= O), 138.7 (Ar), 138.0 (Ar), 138.0 (Ar), 128.5 (Ar), 128.4 (Ar), 128.3 (Ar), 128.3 (Ar), 128.2 (Ar), 128.0 (Ar), 127.9 (Ar), 127.7 (Ar), 127.6 (Ar), 98.4 (C-1), 82.2 [NHCHCO2C(CH3)3], 81.5 (C-3), 80.4 (C-4), 79.2 (C-2), 75.9 (PhCH₂O), 75.2 (PhCH₂O), 73.6 (PhCH₂O), 70.7 (C-5), 55.8 (OCH₃), 48.5 [NHCHCO₂C(CH₃)₃], 28.0 [NHCHCO₂C(CH₃)₃], 18.6 (CHCH₃) ppm. HRMS (ESI) calcd. for [M + Na] C₃₅H₄₃NNaO₈: 628.2881, found 628.2876.

N-(Methyl 2,3,4-Tri-O-benzyl-α-D-glucopyranosiduronoyl)-Otert-butyl-L-serine tert-Butyl Ester (31): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (4:1 \rightarrow 2:1 hexane/EtOAc) to afford 31 (42 mg, 70 %) as a clear viscous oil. $R_f = 0.47$ (2:1 hexane/EtOAc). $[\alpha]_{\rm D}$ = +11.3 (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.39– 7.25 (m, 15 H, Ar), 7.02 (d, J = 7.8 Hz, 1 H, CONHCH), 4.94 (d, J = 10.8 Hz, 1 H, PhCH₂O), 4.83 (d, J = 10.8 Hz, 1 H, PhCH₂O), 4.83 (d, J = 12.3 Hz, 1 H, PhCH₂O), 4.78 (d, J = 10.2 Hz, 1 H, PhCH₂O), 4.73 (d, J = 10.3 Hz, 1 H, PhCH₂O), 4.68 (d, J = 3.5 Hz, 1 H, 1-H), 4.68 (d, J = 12.3 Hz, 1 H, PhCH₂O), 4.65–4.62 (m, 1 H, NHCHCH₂), 4.15 (d, J = 9.9 Hz, 1 H, 5-H), 4.02 (app. t, J = 9.3 Hz, 1 H, 3-H), 3.77 (dd, J = 8.8, 2.9 Hz, 1 H, CHCH₂O), 3.63 (app. t, J = 9.4 Hz, 1 H, 4-H), 3.59-3.57 (m, 2 H, 2-H, CHCH₂O), 3.42 (s, 3 H, OCH₃), 1.48 [s, 9 H, C(CH₃)₃], 1.11 [s, 9 H, C(CH₃)₃] ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 169.2 (C= O), 168.7 (C=O), 138.7 (Ar), 138.1 (2 × Ar), 128.5 (Ar), 128.4 (Ar), 128.3 (2 × Ar), 128.2 (Ar), 128.0 (2 × Ar), 127.6 (Ar), 98.4 (C-1), 82.0 [C(CH₃)₃], 81.5 (C-3), 80.6 (C-3), 79.3 (C-2), 76.0 (PhCH₂O), 75.1 (PhCH₂O), 73.6 (PhCH₂O), 73.0 [C(CH₃)₃], 70.9 (C-5), 62.1 (CHCH₂O), 55.7 (OCH₃), 53.1 (NHCH), 28.1 [C(CH₃)₃], 27.4 [C(CH₃)₃] ppm. HRMS (ESI) calcd. for [M + H] C₃₉H₅₂NO₉: 678.3637, found 678.3631.

N-(Methyl 2,3,4-Tri-O-benzyl- α -D-glucopyranosiduronoyl)-Lthreonine tert-Butyl Ester (32): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (2:1 hexane/EtOAc) to afford 32 (40 mg, 63 %) as a oil. $R_{\rm f}$ = 0.22 (2:1 hexane/EtOAc). [α]_D = -14.6 (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.39–7.25 (m, 15 H, Ar), 6.97 (d, J = 8.6 Hz, 1 H, CONHCH), 4.96 (d, J = 10.8 Hz, 1 H, PhCH₂O),4.84 (d, J = 10.8 Hz, 1 H, PhCH₂O), 4.83 (d, J = 12.4 Hz, 1 H, PhCH₂O), 4.78–4.74 (m, 2 H, PhCH₂O), 4.68 (d, J = 12.4 Hz, 1 H, PhCH₂O), 4.68 (d, J = 3.5 Hz, 1 H, 1-H), 4.54 (dd, J = 8.6, 2.9 Hz, 1 H, NHCHCH), 4.30-4.29 (m, 1 H, CHCHOH), 4.20 (d, J = 10.0 Hz, 1 H, 5-H), 4.04 (app. t, J = 9.2 Hz, 1 H, 3-H), 3.65 (dd, J = 9.8, 9.0 Hz, 1 H, 4-H), 3.58 (dd, J = 9.7, 3.5 Hz, 1 H, 2-H), 3.41 (s, 3 H, OCH₃), 2.05 (s, 1 H, CHOH), 1.49 [s, 9 H, C(CH₃)₃], 1.21 (d, J = 6.4 Hz, 3 H, CHCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 169.8 (C=O), 169.7 (C=O), 138.6 (Ar), 138.0 (2 × Ar), 128.6 (Ar), 128.4 (Ar), 128.3 (Ar), 128.2 (2 × Ar), 128.1 (Ar), 127.9 (Ar), 127.7 (Ar), 127.6 (Ar), 98.4 (C-1), 82.7 [C(CH₃)₃], 81.5 (C-3), 80.6 (C-4), 79.2 (C-2), 76.0 (PhCH2O), 75.2 (PhCH2O), 73.6 (PhCH2O), 70.6 (C-5), 68.4 (CHCHOH), 57.5 (NHCH), 55.8 (OCH₃), 28.0 [C(CH₃)₃], 20.0 (CHCH₃) ppm. HRMS (ESI) calcd. for $[M + H] C_{36}H_{46}NO_9$: 636.3167, found 636.3161.

N-(4-Methoxybenzyl) (Methyl 2,3,4-Tri-O-benzoyl-α-D-glucopyranosid)uronamide (33): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (3:2-)1:1 hexane/EtOAc) to afford 33 (55 mg, 86 %) as a clear viscous oil. $R_{\rm f}$ = 0.43 (1:1 hexane/EtOAc). [α]_D = +99.7 (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 8.04–7.99 (m, 4 H, Ar), 7.91-7.89 (m, 2 H, Ar), 7.56-7.50 (m, 2 H, Ar), 7.48-7.38 (m, 5 H, Ar), 7.34-7.30 (m, 2 H, Ar), 7.29-7.26 (m, 2 H, Ar), 6.93-6.91 (m, 2 H, Ar), 6.71 (app. t, J = 5.6 Hz, 1 H, CONHCH₂), 6.20 (app. t, J = 9.9 Hz, 1 H, 3-H), 5.68 (app. t, J = 9.9 Hz, 1 H, 4-H), 5.30 (d, J = 3.6 Hz, 1 H, 1-H), 5.24 (dd, J = 10.2, 3.6 Hz, 1 H, 2-H), 4.56 (d, J = 10.2 Hz, 1 H, 5-H), 4.49 (dd, J = 14.5, 6.0 Hz, 1 H, NHCH₂Ar), 4.35 (dd, J = 14.5, 5.4 Hz, 1 H, NHCH₂Ar), 3.84 (s, 3 H, ArOCH₃), 3.50 (s, 3 H, OCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 166.9 (C=O), 165.9 (C=O), 165.6 (C=O), 165.5 (C=O), 159.2 (Ar), 133.5 (Ar), 133.2 (Ar), 133.1 (Ar), 130.0 (2 × Ar), 129.8 (Ar), 129.7 (Ar), 129.4 (Ar), 129.3 (Ar), 129.2 (Ar), 128.9 (Ar), 128.5 (Ar), 128.3 (2 × Ar), 114.2 (Ar), 97.2 (C-1), 71.9 (C-2), 70.4 (C-4), 69.8 (C-3), 68.7 (C-5), 56.2 (OCH₃), 55.3 (ArOCH₃), 42.7 (NHCH₂Ar) ppm. HRMS (ESI) calcd. for [M + H] C₃₆H₃₄NO₁₀: 640.2168, found 640.2177.

N-(2-Hydroxyethyl) (Methyl 2,3,4-Tri-*O*-benzoyl-α-*D*-glucopyranosid)uronamide (34): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (20:1 CH₂Cl₂/CH₃OH) to afford 34 (48 mg, 86 %) as a clear viscous oil. $R_f = 0.31$ (1:1 CH₂Cl₂/CH₃OH). $[\alpha]_D = +75.0$ (c = 1.0,

Eur. J. Org. Chem. 2016, 2653–2664 www.eu

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CHCl₃). ¹H NMR (600 MHz, CDCl₃): δ = 8.01–7.99 (m, 4 H, Ar), 7.90–7.88 (m, 2 H, Ar), 7.56–7.50 (m, 2 H, Ar), 7.46–7.38 (m, 5 H, Ar), 7.32–7.29 (m, 2 H, Ar), 6.89 (app. t, *J* = 5.8 Hz, 1 H, CON*H*CH₂), 6.22 (app. t, *J* = 9.9 Hz, 1 H, 3-H), 5.62 (app. t, *J* = 9.9 Hz, 1 H, 4-H), 5.34 (d, *J* = 3.6 Hz, 1 H, 1-H), 5.29 (dd, *J* = 10.1, 3.6 Hz, 1 H, 2-H), 4.50 (d, *J* = 10.2 Hz, 1 H, 5-H), 3.84–3.81 (m, 1 H, CH₂CH₂OH), 3.71–3.69 (m, 1 H, CH₂CH₂O), 3.60 (dddd, *J* = 14.2, 5.8, 5.8, 3.2 Hz, 1 H, NHCH₂CH₂), 3.50 (s, 3 H, OCH₃), 3.30 (dddd, *J* = 13.9, 8.1, 5.6, 3.4 Hz, 1 H, NHCH₂CH₂), 2.76 (s, 1 H, CH₂OH) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 168.2 (C=O), 166.1 (C=O), 165.9 (C=O), 165.6 (C=O), 133.6 (Ar), 133.4 (Ar), 133.2 (Ar), 130.0 (2 × Ar) 129.7 (Ar), 129.1 (Ar), 128.9 (Ar), 128.8 (Ar), 128.5 (Ar), 128.4 (Ar), 128.3 (Ar), 97.3 (C-1), 71.9 (C-2), 71.0 (C-4), 69.5 (C-3), 69.1 (C-5), 61.2 (CH₂CH₂O), 56.2 (OCH₃), 42.2 (NHCH₂CH₂) ppm. HRMS (ESI) calcd. for [M + H] C₃₀H₃₀NO₁₀: 564.1864, found 564.1859.

2-N-(Methyl 2,3,4-Tri-O-benzoyl-α-D-glucopyranosiduronoyl)-1,3-di-O-benzyl-2-deoxy-glycerol (35): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (2:1 hexane/EtOAc) to afford 35 (56 mg, 73 %) as a clear viscous oil. $R_{\rm f}$ = 0.23 (2:1 hexane/EtOAc). $[\alpha]_{\rm D}$ = +70.6 (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): $\delta = 8.03-7.99$ (m, 4 H, Ar), 7.92–7.90 (m, 2 H, Ar), 7.57–7.30 (m, 19 H, Ar), 6.88 (d, J = 8.5 Hz, 1 H, CONHCH), 6.20 (app. t, J = 9.9 Hz, 1 H, 3-H), 5.63 (app. t, J = 9.9 Hz, 1 H, 4-H), 5.34 (d, J = 3.6 Hz, 1 H, 1-H), 5.29 (dd, J = 10.2, 3.6 Hz, 1 H, 2-H), 4.62 (d, J = 12.0 Hz, 1 H, PhCH₂O), 4.59 (d, J = 12.0 Hz, 1 H, PhCH₂O), 4.54 (d, J = 12.0 Hz, 1 H, PhCH₂O), 4.51 (d, J = 12.0 Hz, 1 H, PhCH₂O), 4.50 (d, J = 10.1 Hz, 1 H, 5-H), 4.31-4.28 (m, 1 H, NHCH), 3.73 (dd, J = 9.3, 3.9 Hz, 1 H, CHCH₂OBn), 3.69 (dd, J = 9.4, 4.3 Hz, 1 H, CHCH₂OBn), 3.65 (dd, J = 9.3, 6.2 Hz, 1 H, CHCH₂OBn), 3.56 (dd, J = 9.4, 5.9 Hz, 1 H, CHCH₂OBn), 3.50 (s, 3 H, OCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 166.9 (C=O), 165.9 (C= O), 165.6 (C=O), 165.4 (C=O), 138.2 (Ar), 138.1 (Ar), 133.5 (Ar), 133.2 (Ar), 133.1 (Ar), 130.0 (2 × Ar), 129.7 (Ar), 129.3 (Ar), 129.2 (Ar), 128.9 (Ar), 128.5 (Ar), 128.4 (2 \times Ar), 128.3 (2 \times Ar), 127.8 (Ar), 127.7 (2 \times Ar), 127.6 (Ar), 97.2 (C-1), 73.2 (PhCH₂O), 73.1 (PhCH₂O), 71.9 (C-2), 70.4 (C-4), 69.9 (C-3), 68.8 (C-5), 68.2 (CHCH2OBn), 68.1 (CHCH2OBn), 56.2 (OCH₃), 48.2 (NHCH) ppm. HRMS (ESI) calcd. for [M + H] C₄₅H₄₄NO₁₁: 774.2909, found 774.2893.

N-(Methyl 2,3,4-Tri-O-benzoyl-α-D-glucopyranosiduronoyl)-Lthreonine tert-Butyl Ester (36): Scale 0.1 mmol. Following the general method 3, the crude residue was purified by flash chromatography (3:2->1:1 hexane/EtOAc) to afford 36 (28 mg, 41 %) as a clear viscous oil. $R_{\rm f} = 0.52$ (1:1 hexane/EtOAc). $[\alpha]_{\rm D} = +67.1$ (c = 1.0, CHCl₃). ¹H NMR (600 MHz, CDCl₃): δ = 8.02–7.97 (m, 4 H, Ar), 7.90– 7.88 (m, 2 H, Ar), 7.56-7.36 (m, 7 H, Ar), 7.32-7.29 (m, 2 H, Ar), 7.23 (d, J = 8.7 Hz, 1 H, CONHCH), 6.21 (app. t, J = 9.9 Hz, 1 H, 3-H), 5.68 (app. t, J = 9.9 Hz, 1 H, 4-H), 5.37 (d, J = 3.6 Hz, 1 H, 1-H), 5.31 (dd, J = 10.2, 3.6 Hz, 1 H, 2-H), 4.56 (d, J = 10.2 Hz, 1 H, 5-H), 4.47 (dd, J = 8.7, 3.2 Hz, 1 H, NHCH), 4.31-4.30 (m, 1 H, CHCHOH), 3.52 (s, 3 H, OCH₃), 2.27 (s, 1 H, CHOH), 1.50 [s, 9 H, C(CH₃)₃], 1.31 (d, J = 6.5 Hz, 3 H, CHCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 169.6 (C= O), 167.7 (C=O), 165.8 (C=O), 165.7 (C=O), 165.6 (C=O), 133.5 (Ar), 133.2 (2 \times Ar) 130.0 (Ar), 129.7 (Ar), 129.1 (2 \times Ar), 128.9 (Ar), 128.5 (Ar), 128.4 (Ar), 128.3 (2 × Ar), 97.3 (C-1), 82.8 [C(CH₃)₃], 71.8 (C-2), 70.7 (C-4), 69.8 (C-3), 68.9 (2 × C-5, CHCHOH), 57.5 (NHCH), 56.3 (OCH₃), 28.0 [C(CH₃)₃], 20.1 (CHCH₃) ppm. HRMS (ESI) calcd. for [M + H] C₃₆H₄₀NO₁₂: 678.2545, found 678.2531.

N-(4-Methoxybenzyl) (Methyl 2,3,4-Tri-O-acetyl- α -D-galactopyranoside)uronamide (37): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (3:2 EtOAc/hexane) to afford 37 (41 mg, 91 %) as a clear viscous oil. $R_{\rm f} = 0.25$ (3:2 EtOAc/hexane). $[\alpha]_{\rm D} =$ +116.5 (*c* = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.24–7.21 (m, 2 H, Ar), 6.90–6.87 (m, 2 H, Ar), 6.81 (app. t, *J* = 5.8 Hz, 1 H, CON*H*CH₂), 5.88 (dd, *J* = 3.4, 1.7 Hz, 1 H, 4-H), 5.44 (dd, *J* = 10.5, 3.4 Hz, 1 H, 3-H), 5.12–5.08 (m, 2 H, 1-H, 2-H), 4.62 (dd, *J* = 14.6, 7.0 Hz, 1 H, NHCH₂Ar), 4.51 (d, *J* = 1.6 Hz, 1 H, 5-H), 4.22 (dd, *J* = 14.6, 5.0 Hz, 1 H, NHCH₂), 3.82 (s, 3 H, ArOCH₃), 3.43 (s, 3 H, OCH₃), 2.10 (s, 3 H, COCH₃), 1.99 (s, 3 H, COCH₃), 1.95 (s, 3 H, COCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 170.5 (C=O), 169.7 (C=O), 169.3 (C=O), 166.3 (C=O), 159.2 (Ar), 130.1 (Ar), 129.2 (Ar), 114.1 (Ar), 97.5 (C-1), 69.5 (C-5), 69.0 (C-4), 68.0 (C-2), 67.1 (C-3), 56.1 (OCH₃), 55.3 (ArOCH₃), 42.5 (NHCH₂), 20.8 (COCH₃), 20.6 (COCH₃), 20.4 (COCH₃) ppm. HRMS (ESI) calcd. for [M + Na] C₂₁H₂₇NNaO₁₀: 476.1527, found 476.1516.

N-(Methyl 2,3,4-Tri-O-acetyl-α-D-galactopyranosiduronoyl)-Otert-butyl-L-serine tert-Butyl Ester (38): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography $(3:2\rightarrow 1:1 \text{ hexane/EtOAc})$ to afford **38** (34 mg, 64 %) as a clear viscous oil. $R_f = 0.48$ (1:1 hexane/EtOAc). $[\alpha]_{\rm D} = +101.8 \ (c = 1.0, \ {\rm CHCl}_3).$ ¹H NMR (500 MHz, ${\rm CDCl}_3$): $\delta = 7.29$ (d, J = 8.1 Hz, 1 H, CONHCH), 5.87 (dd, J = 3.4, 1.6 Hz, 1 H, 4-H), 5.44 (dd, J = 10.7, 3.4 Hz, 1 H, 3-H), 5.18 (dd, J = 10.7, 3.6 Hz, 1 H, 2-H), 5.15 (d, J = 3.6 Hz, 1 H, 1-H), 4.63 (app. dt, J = 8.6, 3.0 Hz, 1 H, NHCHCH₂), 4.51 (d, J = 1.5 Hz, 1 H, 5-H), 3.82 (dd, J = 8.8, 3.1 Hz, 1 H, CHCH₂O), 3.48 (dd, J = 8.8, 3.0 Hz, 1 H, CHCH₂O), 3.47 (s, 3 H, OCH₃), 2.12 (s, 3 H, COCH₃), 2.08 (s, 3 H, COCH₃), 2.00 (s, 3 H, COCH₃), 1.49 [s, 9 H, C(CH₃)₃], 1.19 [s, 9 H, C(CH₃)₃] ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 170.5 (C=O), 169.7 (C=O), 169.3 (C=O), 169.0 (C=O), 166.2 (C=O), 97.4 (C-1), 82.0 [OC(CH3)3], 73.2 [OC(CH3)3], 69.3 (C-5), 68.9 (C-4), 68.0 (C-2), 67.3 (C-3), 62.5 (CHCH2O), 56.1 (OCH3), 52.9 (NHCHCH₂), 28.0 [C(CH₃)₃], 27.4 [C(CH₃)₃], 20.8 (COCH₃), 20.7 (COCH₃), 20.6 (COCH₃) ppm. HRMS (ESI) calcd. for [M + H] C₂₄H₄₀NO₁₂: 534.2545, found 534.2538.

N-(Methyl 2,3,4-Tri-O-acetyl-α-D-galactopyranosiduronoyl)-Lalanine tert-Butyl Ester (39): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (3:2→1:1 hexane/EtOAc) to afford 39 (29 mg, 63 %) as a clear viscous oil. $R_{\rm f}$ = 0.20 (3:2 hexane/EtOAc). $[\alpha]_{\rm D}$ = +92.7 (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.15 (d, J = 7.6 Hz, 1 H, CONHCH), 5.84 (dd, J = 3.4, 1.7 Hz, 1 H, 4-H), 5.44 (dd, J = 10.1, 3.4 Hz, 1 H, 3-H), 5.16–5.12 (m, 2 H, 1-H, 2-H), 4.52–4.46 (m, 2 H, 5-H, NHCHCH₃), 3.45 (s, 3 H, OCH₃), 2.11 (s, 3 H, COCH₃), 2.07 (s, 3 H, COCH₃), 1.99 (s, 3 H, COCH₃), 1.49 [s, 9 H, C(CH₃)₃], 1.38 (d, J = 7.1 Hz, 3 H, CHCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): $\delta =$ 171.7 (C=O), 170.5 (C=O), 169.7 (C=O), 169.2 (C=O), 165.9 (C=O), 97.5 (C-1), 82.3 [C(CH₃)₃], 69.4 (C-5), 69.0 (C-4), 68.0 (C-2), 67.1 (C-3), 56.1 (OCH₃), 48.3 (NHCHCH₃), 28.0 [C(CH₃)₃], 20.8 (COCH₃), 20.6 (COCH₃), 20.4 (COCH₃), 18.7 (CHCH₃) ppm. HRMS (ESI) calcd. for [M + Na] C₂₀H₃₁NNaO₁₁: 484.1789 Found 484.1779.

N-(4-Methoxybenzyl) (2,3,4-Tri-O-benzyl-α-D-galactopyranosid)uronamide (40): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (2:1 hexane/EtOAc) to afford 40 (50 mg, 83 %) as a clear viscous oil. R_f = 0.20 (2:1 hexane/EtOAc). [α]_D = +60.1 (c = 1.0, CHCl₃). ¹H NMR (400 MHz, CDCl₃): δ = 7.39–7.26 (m, 15 H, Ar), 7.11 (d, J = 8.5 Hz, 2 H, Ar), 6.79 (app. t, J = 5.6 Hz, 1 H, CONHCH₂), 6.73 (d, J = 8.6 Hz, 2 H, Ar), 4.92 (d, J = 10.9 Hz, 1 H, PhCH₂O), 4.85 (d, J = 12.1 Hz, 1 H, PhCH₂O), 4.81 (d, J = 11.8 Hz, 1 H, PhCH₂O), 4.76 (d, J = 11.8 Hz, 1 H, PhCH₂O), 4.70–4.67 (m, 2 H, PhCH₂O, 1-H), 4.58 (d, J = 10.9 Hz, 1 H, PhCH₂O), 4.48–4.42 (m, 2 H, 3-H, NHCH₂Ar), 4.35–4.29 (m, 2 H, NHCH₂Ar, 5-H), 4.05–3.98 (m, 2 H, 2-H, 4-H), 3.76 (s, 3 H, ArOCH₃), 3.36 (s, 3 H, OCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 168.6 (C-6), 159.0 (Ar), 138.7 (Ar), 138.5 (2 × Ar), 129.7 (Ar), 129.1





 $\begin{array}{l} (Ar), \ 128.4 \ (2 \times Ar), \ 128.2 \ (Ar), \ 128.1 \ (Ar), \ 128.0 \ (Ar), \ 127.8 \ (Ar), \ 127.6 \\ (Ar), \ 127.5 \ (2 \times Ar), \ 114.0 \ (Ar), \ 99.2 \ (C-1), \ 78.4 \ (C-4), \ 76.6 \ (C-3), \ 75.7 \\ (C-2), \ 75.4 \ (PhCH_2O), \ 73.7 \ (PhCH_2O), \ 73.0 \ (PhCH_2O), \ 71.3 \ (C-5), \ 55.9 \\ (OCH_3), \ 55.3 \ (ArOCH_3), \ 42.6 \ (NHCH_2Ar) \ ppm. \ HRMS \ (ESI) \ calcd. \ for \\ [M + H] \ C_{36}H_{40}NO_7: \ 598.2799, \ found \ 598.2790. \end{array}$

N-(4-Methoxybenzyl) (2,3,4-Tri-O-benzoyl-α-D-mannopyranosid)uronamide (41): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (3:2->1:1 hexane/EtOAc) to afford 41 (63 mg, 98 %) as a clear viscous oil. $R_{\rm f} = 0.43$ (1:1 hexane/EtOAc). $[\alpha]_{\rm D} = -19.0$ (c = 1.0, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 8.07–8.05 (m, 4 H, Ar), 7.87 (d, J = 7.4 Hz, 2 H, Ar), 7.64–7.39 (m, 7 H, Ar), 7.31–7.26 (m, 4 H, Ar), 6.89 (d, J = 8.5 Hz, 2 H, Ar), 6.80 (app. t, J = 5.5 Hz, 1 H, CONHCH₂), 6.04 (dd, J = 10.0, 10.0 Hz, 1 H, 4-H), 5.93 (dd, J = 10.1, 3.2 Hz, 1 H, 3-H), 5.69 (dd, J = 2.9, 1.9 Hz, 1 H, 2-H), 5.04 (d, J = 1.3 Hz, 1 H, 1-H), 4.58 (d, J = 10.0 Hz, 1 H, 5-H), 4.50 (dd, J = 14.5, 6.0 Hz, 1 H, NHCH₂Ar), 4.38 (dd, J = 14.6, 5.4 Hz, 1 H, NHCH₂Ar), 3.82 (s, 3 H, ArOCH₃), 3.55 (s, 3 H, OCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 167.3 (C=O), 165.7 (C=O), 165.41 (C=O), 165.37 (C=O), 159.1 (Ar), 133.6 (Ar), 133.3 (Ar), 133.1 (Ar), 130.0 (Ar), 129.9 (2 × Ar), 129.8 (Ar), 129.5 (Ar), 129.2 (2 × Ar), 129.1 (Ar), 128.7 (Ar), 128.4 (Ar), 128.3 (Ar), 114.2 (Ar), 98.8 (C-1), 70.2 (C-2), 69.7 (C-5), 69.5 (C-3), 67.8 (C-4), 56.1 (OCH₃), 55.3 (ArOCH₃), 42.6 (NHCH₂Ar) ppm. HRMS (ESI) calcd. for [M + H] C₃₆H₃₄NO₁₀: 640.2177 Found 640.2163.

N-(4-Methoxybenzyl) (Methyl 2,3-Di-O-Benzoyl-4-deoxy- β -Lthreo-hex-4-enopyranosid)uronamide (42): To a solution of 23 (63 mg, 0.1 mmol) in CH₂Cl₂ (1 mL) was added p-methoxybenzylamine (19 µL, 0.15 mmol), followed by triethylamine (62 µL, 0.45 mmol). The reaction mixture was stirred for 10 h at room temperature, then diluted with CH_2CI_2 (10 mL), washed with satd. NH_4CI_2 (ag.), brine, dried with MgSO₄ and concentrated. The crude reside was purified by flash chromatography (2:1→3:2 hexane/EtOAc) to afford 42 (39 mg, 75 %) as a clear viscous oil. $R_f = 0.19$ (2:1 hexane/ EtOAc). $[\alpha]_D = +75.3$ (c = 1.2, CHCl₃). ¹H NMR (500 MHz, CDCl₃): $\delta =$ 8.06-8.01 (m, 4 H, Ar), 7.59-7.54 (m, 2 H, Ar), 7.46-7.41 (m, 4 H, Ar), 7.29–7.26 (m, 2 H, Ar), 6.93–6.90 (m, 2 H, Ar), 6.80 (app. t, J = 5.8 Hz, 1 H, CONHCH₂), 6.30 (d, J = 3.0 Hz, 1 H, 4-H), 6.13 (dd, J = 8.0, 3.0 Hz, 1 H, 3-H), 5.54 (dd, J = 8.0, 2.5 Hz, 1 H, 2-H), 5.35 (d, J = 2.6 Hz, 1 H, 1-H), 4.57 (dd, J = 14.6, 6.1 Hz, 1 H, NHCH₂Ar), 4.46 (dd, J = 14.6, 5.5 Hz, 1 H, NHCH₂Ar), 3.83 (s, 3 H, ArOCH₃), 3.54 (s, 3 H, OCH₃) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 165.8 (C=O), 165.6 (C= O), 160.5 (C=O), 159.2 (Ar), 143.7 (C-5), 133.6 (Ar), 133.3 (Ar), 130.0 (Ar), 129.8 (Ar), 129.8 (Ar), 129.5 (Ar), 129.3 (Ar), 129.0 (Ar), 128.5 (Ar), 128.4 (Ar), 114.2 (Ar), 104.9 (C-4), 98.9 (C-1), 69.9 (C-2), 66.8 (C-3), 57.1 (OCH₃), 55.3 (ArOCH₃), 43.0 (NHCH₂Ar) ppm. HRMS (ESI) calcd. for [M + Na] C₂₉H₂₇NNaO₈: 540.1629, found 540.1633.

2-(Trimethylsilyl)ethyl 2,3,4-Tri-O-acetyl-α-L-rhamnopyranosyl- $(1\rightarrow 3)$ -4,6-O-benzylidene- β -D-glucopyranoside and 2-(Trimethylsilyl)ethyl 2,3,4-Tri-O-acetyl- α -L-rhamnopyranosyl-(1 \rightarrow 2)-4,6-**O-benzylidene-β-D-glucopyranoside (45/45a):** A mixture of trichloroacetimidate 44^[43] (854 mg, 1.96 mmol), alcohol 43^[42] (869 mg, 2.36 mmol), and 4 Å molecular sieves (4 g) in CH₂Cl₂ (80 mL) was stirred for 30 min at room temperature under an argon atmosphere. The mixture was cooled to -78 °C, then TBSOTf (46 µL, 0.2 mmol) was added. The reaction mixture was stirred for 20 min at -78 °C, then the TBSOTf was quenched by the addition of Et₃N (28 μL). The mixture was filtered through Celite and concentrated. The crude residue was purified by flash chromatography (2:1 hexane/EtOAc) to afford 45/45a (904 mg, 72 %, 45:45a = 2:1) as a white solid, which was an inseparable mixture. $R_{\rm f} = 0.27$ (2:1 hexane/EtOAc). ¹H NMR (400 MHz, CDCl₃): δ = 7.49–7.45 (m, 6 H), 7.39– 7.36 (m, 3 H), 7.34-7.31 (m, 6 H), 5.55 (s, 2 H), 5.51 (s, 1 H), 5.355.27 (m, 9 H), 5.20 (d, J = 1.5 Hz, 2 H, 1'-H of 45), 5.07 (t, J = 10.0 Hz, 1 H), 4.97 (t, J = 10.0 Hz, 2 H), 4.49 (d, J = 7.7 Hz, 1 H, 1-H of 45a), 4.40–4.32 (m, 7 H), 4.20 (dq, J = 9.9, 6.3 Hz, 2 H), 4.03–3.74 (m, 9 H), 3.66–3.54 (m, 9 H), 3.51–3.38 (m, 4 H), 2.71 (d, J = 2.8 Hz, 1 H), 2.41 (d, J = 2.7 Hz, 1 H), 2.14 (s, 3 H), 2.13 (s, 6 H), 2.03 (s, 3 H), 1.99 (s, 6 H), 1.97 (s, 3 H), 1.95 (s, 6 H), 1.20 (d, J = 6.3 Hz, 3 H), 1.06–0.92 (m, 6 H), 0.85 (d, J = 6.2 Hz, 6 H), 0.04 (s, 9 H), 0.03 (s, 18 H) ppm. ¹³C NMR (125 MHz, CDCl₃): $\delta = 170.2$, 170.2, 170.2, 170.0, 169.9, 137.2, 137.0, 129.3, 129.0, 128.4, 128.0, 126.3, 126.2, 103.0 (C-1 of 45), 101.8, 101.7 (C-1 of 45a), 101.6, 97.7 (C-1' of 45), 97.6 (C-1' of 45a), 80.7, 79.0, 77.1, 76.4, 75.7, 74.9, 71.3, 71.17, 69.7, 69.7, 69.3, 69.3, 68.8, 68.7, 68.2, 68.0, 66.8, 66.4, 66.0, 65.9, 21.0, 21.0, 20.8, 20.8, 18.5, 18.3, 17.3, 16.8, -1.4, -1.5 ppm. HRMS (ESI) calcd. for [M + Na] C₃₀H₄₄NaO₁₃Si: 663.2443, found 663.2440.

2-(Trimethylsilyl)ethyl 2,3,4-Tri-O-acetyl-α-L-rhamnopyranosyl- $(1\rightarrow 3)$ -2-O-acetyl-4,6-O-benzylidene- β -D-glucopyranoside (S1) and 2-(Trimethylsilyl)ethyl 2,3,4-Tri-O-acetyl-α-L-rhamnopyranosyl-(1 \rightarrow 2)-3-O-acetyl-4,6-O-benzylidene- β -D-glucopyranoside (S1a): To a solution of 45/45a (904 mg, 1.41 mmol) in pyridine (14 mL) and Ac₂O (7 mL) was added DMAP (17 mg, 0.14 mmol). The reaction mixture was stirred for 3 h at room temperature, then the Ac₂O was quenched by addition of CH₃OH (7 mL). Then, the mixture was co-concentrated with toluene (3 ×). The crude residue was purified by flash chromatography (1:1 hexane/EtOAc) to afford S1/S1a (934 mg, 97 %, S1:S1a = 2:1) as a white solid, which was an inseparable mixture. $R_f = 0.56$ (1:1 hexane/EtOAc). ¹H NMR (500 MHz, CDCl₃): δ = 7.50–7.48 (m, 5 H), 7.45–7.43 (m, 2 H), 7.38– 7.33 (m, 11 H), 5.57 (s, 2 H), 5.48 (s, 1 H), 5.40 (t, J = 9.4 Hz, 1 H), 5.34-5.29 (m, 4 H), 5.11-5.05 (m, 5 H), 5.04 (d, J = 1.9 Hz, 1 H, 1'-H of S1a), 4.99 (dd, J = 3.4, 1.8 Hz, 2 H), 4.95 (t, J = 9.9 Hz, 2 H), 4.91 (d, J = 1.7 Hz, 2 H, 1'-H of **S1**), 4.57 (d, J = 7.6 Hz, 1 H, 1-H of **S1a**), 4.49 (d, J = 8.0 Hz, 2 H, 1-H of **S1**), 4.41–4.37 (m, 3 H), 4.32 (dq, J = 10.2, 6.3 Hz, 1 H), 4.10 (dq, J = 10.0, 6.2 Hz, 2 H), 4.04–3.88 (m, 5 H), 3.87-3.75 (m, 3 H), 3.75-3.62 (m, 4 H), 3.62-3.44 (m, 6 H), 2.15 (s, 3 H), 2.14 (s, 6 H), 2.14 (s, 3 H), 2.12 (s, 6 H), 2.05 (s, 3 H), 2.02 (s, 3 H), 2.00 (s, 6 H), 1.98 (s, 6 H), 1.21 (d, J = 6.2 Hz, 3 H), 1.05–0.89 (m, 6 H), 0.68 (d, J = 6.2 Hz, 6 H), 0.06 (s, 9 H), 0.03 (s, 18 H) ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 170.0, 170.0, 169.8, 169.4, 137.1, 136.9, 129.2, 129.0, 128.2, 128.1, 126.4, 126.1, 102.0, 101.7 (C-1 of S1a), 101.4, 101.0 (C-1 of S1), 97.7 (C-1' of S1a), 97.6 (C-1' of S1), 79.1, 78.7, 73.9, 73.5, 71.4, 71.4, 70.6, 70.3, 68.8, 68.7, 68.6, 68.4, 68.1, 67.6, 66.6, 66.6, 66.3, 66.2, 25.0, 20.9, 20.9, 20.8, 20.8, 20.8, 18.4, 18.1, 17.3, 16.5, -1.42, -1.49 ppm. HRMS (ESI) calcd. for [M + Na] C₃₂H₄₆NaO₁₄Si: 705.2549, found 705.2541.

2-(Trimethylsilyl)ethyl 2,3,4-Tri-O-acetyl-α-L-rhamnopyranosyl- $(1\rightarrow 3)$ -2-O-acetyl- β -D-glucopyranoside (46) and 2-(Trimethylsilyl)ethyl 2,3,4-Tri-O-acetyl-α-L-rhamnopyranosyl-(1→3)-3-Oacetyl-β-D-glucopyranoside (46a): To a solution of S1/S1a (767 mg, 1.12 mmol) in 80 % CH₃COOH/H₂O (10 mL) was heated at 80 °C for 2 h and then cooled to room temperature. The mixture was concentrated and then co-evaporated with toluene (3×). The crude residue was purified by flash chromatography $(1:1\rightarrow 1:2 \text{ hex-})$ ane/EtOAc) to afford 46 (326 mg, 49 %) as a white amorphous solid and 46a (166 mg, 25 %) as a white amorphous solid. Data for 46: $R_{\rm f} = 0.45$ (1:2 hexane/EtOAc). $[\alpha]_{\rm D} = -17.7$ (c = 1.5, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 5.22 (dd, J = 10.1, 3.3 Hz, 1 H, 3'-H), 5.15 (dd, J = 3.3, 2.1 Hz, 1 H, 2'-H), 5.11 (app. t, J = 9.9 Hz, 1 H, 4'-H), 4.96 (dd, J = 9.5, 8.1 Hz, 1 H, 2-H), 4.90 (d, J = 2.0 Hz, 1 H, 1'-H), 4.47 (d, J = 8.1 Hz, 1 H, 1-H), 4.15 (dq, J = 9.8, 6.5 Hz, 1 H, 5'-H), 4.00–3.93 [m, 2 H, 6-Ha, OCH₂CH₂Si(CH₃)₃], 3.84 (ddd, J = 11.7, 7.4, 4.8 Hz, 1 H, 6-Hb), 3.65 (app. td, J = 9.0, 2.4 Hz, 1 H, 4-H), 3.61-3.54 [m, 3 H, 3-H, OCH₂CH₂Si(CH₃)₃, 4-OH], 3.38 (ddd, J = 8.2, 4.6, 3.4 Hz, 1 H, 5'-H), 2.16 (s, 3 H, COCH₃), 2.16 (s, 3 H, COCH₃), 2.09 (t, J = 7.2 Hz, 1



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H, 6-OH), 2.06 (s, 3 H, COCH₃), 2.00 (s, 3 H, COCH₃), 1.26 (d, J = 6.3 Hz, 3 H, 6'-H), 0.98 [ddd, J = 14.1, 10.6, 6.7 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 0.91 [ddd, J = 14.0, 10.2, 5.6 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 0.03 [s, 9 H, OCH₂CH₂Si(CH₃)₃] ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 170.1 (C=O), 169.9 (C=O), 169.6 (C=O), 169.4 (C=O), 100.3 (C-1), 99.1 (C-1'), 85.9 (C-3), 75.1 (C-5), 71.3 (C-2), 70.6 (C-4'), 70.2 (C-4), 69.8 (C-2'), 68.6 (C-3'), 67.9 (C-5'), 67.4 [OCH₂CH₂Si(CH₃)₃], 62.4 (C-6), 20.9 (COCH₃), 20.8 (COCH₃), 20.7 (COCH₃), 20.7 (COCH₃), 18.0 [OCH₂CH₂Si(CH₃)₃], 17.5 (C-6'), -1.4 [OCH₂CH₂Si(CH₃)₃] ppm. HRMS (ESI) calcd. for [M + Na] $C_{25}H_{42}NaO_{14}Si: 617.2236$ found 617.2228. Data for **46a**: $R_f = 0.42$ (1:2 hexane/EtOAc). $[\alpha]_D = -28.0 \ (c = 3.2, CHCl_3)$. ¹H NMR (500 MHz, CDCl₃): δ = 5.27 (dd, J = 10.1, 3.4 Hz, 1 H, 3'-H), 5.08 (app. t, J = 10.1 Hz, 1 H, 4'-H), 5.06 (dd, J = 3.7, 1.8 Hz, 1 H, 2'-H), 5.02 (app. t, J = 9.4 Hz, 1 H, 3-H), 5.00 (d, J = 1.8 Hz, 1 H, 1'-H) 4.48 (d, J = 7.8 Hz, 1 H, 1-H), 4.33 (dq, J = 10.1, 6.2 Hz, 1 H, 5'-H), 3.98 [td, J = 9.8, 8.1 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 3.93 (dd, J = 11.9, 3.5 Hz, 1 H, 6-Ha), 3.83 (dd, J = 11.9, 4.7 Hz, 1 H, 6-Hb), 3.65-3.60 [m, 3 H, 2-H, 4-H, $OCH_2CH_2Si(CH_3)_3$], 3.41 (ddd, J = 9.5, 4.6, 3.7 Hz, 1 H, 5-H), 3.16 (br. s, 1 H, 4-OH) 2.18-2.14 (m, 7 H, 2× COCH3, 6-OH), 2.04 (s, 3 H, COCH₃), 2.01 (s, 3 H, COCH₃), 1.19 (d, J = 6.2 Hz, 3 H, 6'-H), 1.04-0.98 [m, 2 H, OCH₂CH₂Si(CH₃)₃], 0.04 [s, 9 H, OCH₂CH₂Si(CH₃)₃] ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 172.7 (C=O), 170.1 (C=O), 170.0 (C= O), 169.9 (C=O), 101.0 (C-1), 97.6 (C-1'), 78.8 (C-3), 76.1 (C-2), 75.6 (C-5), 71.3 (C-4'), 70.2 (C-2'), 70.2 (C-4), 68.7 (C-3'), 67.9 [OCH₂CH₂Si(CH₃)₃], 66.5 (C-5'), 62.3 (C-6), 20.9 (COCH₃), 20.9 (COCH₃), 20.8 (COCH₃), 20.7 (COCH₃), 18.4 [OCH₂CH₂Si(CH₃)₃], 17.3 (C-6'), -1.5 [OCH₂CH₂Si(CH₃)₃] ppm. HRMS (ESI) calcd. for [M + Na] C₂₅H₄₂NaO₁₄Si: 617.2236, found 617.2230.

2-(Trimethylsilyl)ethyl 2,3,4-Tri-O-Acetyl-α-L-rhamnopyranosyl- $(1\rightarrow 3)$ -2-O-acetyl-6-thio-6-S-*p*-tolyl- β -D-glucopyranoside (47): To a stirred solution of 46 (128 mg, 0.216 mmol) in dry pyridine (1.1 mL) were added $(TolS)_2$ (108 mg, 0.44 mmol) and P(CH₃)₃ (0.44 mL, 0.44 mmol, 1.0 м in THF) under argon. The reaction mixture was stirred overnight at room temperature. Then, the reaction mixture was concentrated, diluted with EtOAc (30 mL) and washed with brine. The organic layer was dried with MgSO₄, filtered and concentrated. The crude residue was purified by flash chromatography (2:1 hexane/EtOAc) to afford 47 (144 mg, 95 %) as a viscous oil. $R_{\rm f} = 0.18$ (2:1 hexane/EtOAc). $[\alpha]_{\rm D} = +1.7$ (c = 0.3, CHCl₃). ¹H NMR $(500 \text{ MHz, CDCl}_3)$: $\delta = 7.34-7.32 \text{ (m, 2 H, Ar)}, 7.12-7.09 \text{ (m, 2 H, Ar)},$ 5.22 (dd, J = 10.0, 3.3 Hz, 1 H, 3'-H), 5.14 (dd, J = 3.2, 2.1 Hz, 1 H, 2'-H), 5.10 (app. t, J = 9.9 Hz, 1 H, 4'-H), 4.98 (dd, J = 9.1, 8.4 Hz, 1 H, 2-H), 4.87 (d, J = 2.1 Hz, 1 H, 1'-H), 4.39 (d, J = 8.1 Hz, 1 H, 1-H), 4.12 (dq, J = 9.8, 6.3 Hz, 1 H, 5'-H), 3.92 [td, J = 9.9, 5.7 Hz, 1 H, OCH2CH2Si(CH3)3], 3.57-3.41 [m, 6 H, OCH2CH2Si(CH3)3, 3-H,4-H,5-H,6-Ha, 4-OH], 3.09 (dd, J = 13.7, 7.7 Hz, 1 H, 6-Hb), 2.33 (s, 3 H, Ar-CH₃), 2.16 (s, 3 H, COCH₃), 2.15 (s, 3 H, COCH₃), 2.07 (s, 3 H, COCH₃), 2.00 (s, 3 H, COCH₃), 1.25 (d, J = 6.3 Hz, 3 H, 6'-H), 0.96 [ddd, J = 14.0, 10.3, 6.8 Hz, 1 H, $OCH_2CH_2Si(CH_3)_3]$, 0.90 [ddd, J = 13.7, 9.9, 5.6 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 0.02 [s, 9 H, OCH₂CH₂Si(CH₃)₃] ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 170.0 (C=O), 169.9 (C=O), 169.5 (C= O), 169.4 (C=O), 136.1 (Ar), 132.9 (Ar), 129.8 (Ar), 129.7 (Ar), 100.0 (C-1), 99.2 (C-1'), 86.3 (C-3), 74.7 (C-5), 72.7 (C-4), 71.4 (C-2), 70.6 (C-4'), 69.8 (C-2'), 68.6 (C-3'), 67.9 (C-5'), 67.0 [OCH₂CH₂Si(CH₃)₃], 36.2 (C-6), 21.0 (Ar-CH₃), 20.9 (COCH₃), 20.8 (COCH₃), 20.7 (COCH₃), 20.7 (COCH₃), 17.9 [OCH₂CH₂Si(CH₃)₃], 17.5 (C-6'), -1.4 [OCH₂CH₂Si(CH₃)₃] ppm. HRMS (ESI) calcd. for $[M + Na] C_{32}H_{48}NaO_{13}SSi: 723.2477$, found 723.2472.

2-(Trimethylsilyl)ethyl 2,3,4-Tri-O-acetyl-α-L-rhamnopyranosyl-(1 \rightarrow **3)-2,4-di-O-acetyl-6-thio-6-***S***-***p***-tolyl-**β**-D**-**glucopyranoside** (**48):** To a solution of **47** (143.6 mg, 0.205 mmol) in pyridine (2 mL) and Ac₂O (1 mL) was added DMAP (2.6 mg, 0.021 mmol). The reaction mixture was stirred for 3 h at room temperature, then the Ac₂O was quenched by addition of CH₃OH (1 mL). Then the mixture was co-concentrated with toluene (3×). The crude reside was purified by flash chromatography (2:1 hexane/EtOAc) to afford 48 (145 mg, 95 %) as a white amorphous solid. $R_f = 0.19$ (2:1 hexane/EtOAc). $[\alpha]_{\rm D} = -10.7$ (c = 0.3, CHCl₃). ¹H NMR (500 MHz, CDCl₃): $\delta = 7.28-$ 7.26 (m, 2 H, Ar), 7.12-7.10 (m, 2 H, Ar), 5.12-5.09 (m, 2 H, 3'-H, 2'-H), 5.03 (dd, J = 9.7, 8.1 Hz, 1 H, 2-H), 5.02 (app. t, J = 9.8 Hz, 1 H, 4'-H), 4.98 (app. t, J = 9.4 Hz, 1 H, 4-H), 4.80 (d, J = 1.2 Hz, 1 H, 1'-H), 4.38 (d, J = 8.0 Hz, 1 H, 1-H), 3.93-3.86 [m, 2 H, 5'-H, OCH₂CH₂Si(CH₃)₃], 3.75 (app. t, J = 9.3 Hz, 1 H, 3-H), 3.55 [td, J = 9.9, 6.6 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 3.46 (ddd, J = 9.7, 8.3, 3.4 Hz, 1 H, 5-H), 3.05 (dd, J = 14.0, 8.2 Hz, 1 H, 6-Ha), 2.99 (dd, J = 13.9, 3.4 Hz, 1 H, 6-Hb), 2.33 (s, 3 H, Ar-CH₃), 2.16 (s, 3 H, COCH₃), 2.15 (s, 3 H, COCH₃), 2.11 (s, 3 H, COCH₃), 2.05 (s, 3 H, COCH₃), 1.96 (s, 3 H, COCH₃), 1.16 (d, J = 6.2 Hz, 3 H, 6'-H), 0.96 [ddd, J = 13.9, 10.3, 6.8 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 0.90 [ddd, J = 14.0, 10.0, 5.8 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 0.02 [s, 9 H, OCH₂CH₂Si(CH₃)₃] ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 170.2 (C=O), 170.1 (C=O), 169.8 (C=O), 169.5 (C=O), 169.4 (C=O), 136.5 (Ar), 132.5 (Ar), 130.1 (Ar), 129.7 (Ar), 100.1 (C-1), 99.5 (C-1'), 81.9 (C-3), 73.5 (C-5), 73.2 (C-4), 71.9 (C-4'), 70.6 (C-2), 69.9 (C-2'), 68.9 (C-3'), 67.5 (C-5'), 67.1 [OCH₂CH₂Si(CH₃)₃], 36.5 (C-6), 21.3 (COCH₃), 21.0 (Ar-CH₃), 20.9 (COCH₃), 20.8 (COCH₃), 20.8 (COCH₃), 20.6 (COCH₃), 17.9 [OCH₂CH₂Si(CH₃)₃], 17.2 (C-6'), -1.4 $[OCH_2CH_2Si(CH_3)_3]$ ppm. HRMS (ESI) calcd. for [M + Na]C₃₄H₅₀NaO₁₄SSi: 765.2583, found 765.2580.

2-(Trimethylsilyl)ethyl 2,3,4-Tri-O-acetyl-α-L-rhamnopyranosyl- $(1 \rightarrow 3)$ -S-p-tolyl Thio(2,4-di-O-acetyl- β -D-glucopyranosid)uronate (49): To a solution of 48 (136 mg, 0.18 mmol) in dry CCl₄ (2.7 mL) at 0 °C were added anhydrous pyridine (29 µL, 0.36 mmol) followed by the addition of SO_2Cl_2 (29 µL, 0.36 mmol) under argon. The reaction mixture was stirred for 5 h at 0 °C and then diluted with CH₂Cl₂ and was washed with brine. The organic layer was dried with MgSO₄, filtered and concentrated. The crude residue was dissolved in 3:2 acetone/H₂O (3.6 mL), and solid NaHCO₃ (60.5 mg, 0.72 mmol) was added. The reaction mixture was stirred overnight at room temperature, diluted with brine and then extracted with EtOAc (3×5 mL). The organic layer was dried with MgSO₄, filtered and concentrated. The crude residue was purified by flash chromatography (2:1 hexane/EtOAc) to afford 49 (116 mg, 85 %) as a white amorphous solid. $R_{\rm f} = 0.45$ (1:1 hexane/EtOAc). $[\alpha]_{\rm D} = -66.8$ (c = 0.6, CHCl₃). ¹H NMR (500 MHz, CDCl₃): δ = 7.31–7.29 (m, 2 H, Ar), 7.25– 7.23 (m, 2 H, Ar), 5.32 (dd, J = 9.7, 9.3 Hz, 1 H, 4-H), 5.16 (dd, J = 9.3, 7.9 Hz, 1 H, 2-H), 5.13-5.11 (m, 2 H, 2'-H, 3'-H), 5.04 (app. t, J = 9.8 Hz, 1 H, 4'-H), 4.86 (d, J = 1.5 Hz, 1 H, 1'-H), 4.56 (d, J = 7.9 Hz, 1 H, 1-H), 4.08 [td, J = 9.6, 6.7 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 3.99 (d, J = 9.9 Hz, 1 H, 5-H), 3.92 (dq, J = 9.7, 6.1 Hz, 1 H, 5'-H), 3.86 (app. t, J = 9.2 Hz, 1 H, 3-H), 3.68 [td, J = 9.5, 6.8 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 2.39 (s, 3 H, Ar-CH₃), 2.19 (s, 3 H, COCH₃), 2.15 (s, 3 H, COCH₃), 2.06 (s, 3 H, COCH₃), 2.05 (s, 3 H, COCH₃), 1.98 (s, 3 H, COCH₃), 1.16 (d, J = 6.2 Hz, 3 H, 6'-H), 1.03 [ddd, J = 14.0, 9.4, 6.8 Hz, 1 H, $OCH_2CH_2Si(CH_3)_3$], 0.99 [ddd, J = 14.0, 9.4, 6.8 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 0.06 [s, 9 H, OCH₂CH₂Si(CH₃)₃] ppm. ¹³C NMR (125 MHz, CDCl_3): δ = 195.5 (C-6), 170.2 (C=O), 170.1 (C=O), 169.5 (C=O), 169.4 (C=O), 169.3 (C=O), 139.9 (Ar), 134.8 (Ar), 130.2 (Ar), 122.8 (Ar), 100.2 (C-1), 99.4 (C-1'), 81.1 (C-3), 77.7 (C-5), 71.4 (C-2), 70.8 (C-4), 70.6 (C-4'), 69.9 (C-2'), 68.8 (C-3'), 67.5 [OCH₂CH₂Si(CH₃)₃], 67.5 (C-5'), 21.4 (Ar-CH₃), 21.0 (COCH₃), 21.0 (COCH₃), 20.8 (COCH₃), 20.8 (COCH₃), 20.7 (COCH₃), 18.0 [OCH₂CH₂Si(CH₃)₃], 17.3 (C-6'), -1.3 $[OCH_2CH_2Si(CH_3)_3]$ ppm. HRMS (ESI) calcd. for $[M + NH_4]$ C₃₄H₅₂NO₁₅SSi: 774.2807 Found 774.2821.

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nine Benzyl Ester (50): To a solution of 49 (79.8 mg, 0.105 mmol) in CH₂Cl₂ (2.1 mL) was added L-threonine benzyl ester (33.1 mg, 0.158 mmol). The reaction mixture was stirred for 44 h at room temperature, then diluted with CH₂Cl₂ (10 mL), washed with satd. NH_4CI (ag.) and brine. The organic layer was dried with $MgSO_4$, filtered and concentrated. The crude residue was purified by flash chromatography (2:1→1:1 hexane/EtOAc) to afford 50 (73.5 mg, 83 %) as a white amorphous solid. $R_f = 0.29$ (1:1 hexane/EtOAc). $[\alpha]_{\rm D}$ = -23.1 (c = 0.6, CHCl₃). ¹H NMR (400 MHz, CDCl₃): δ = 7.38-7.31 (m, 5 H, Ar), 7.19 (d, J = 8.8 Hz, 1 H, NHCHCO₂Bn), 5.22 (d, J = 12.3 Hz, 1 H, CH₂Ph), 5.17 (d, J = 12.3 Hz, 1 H, CH₂Ph), 5.14 (app. t, J = 9.4 Hz, 1 H, 4-H), 5.11–5.06 (m, 3 H, 2-H, 2'-H, 3'-H), 5.01 (app. t, J = 9.7 Hz, 1 H, 4'-H), 4.86 (d, J = 1.2 Hz, 1 H, 1'-H), 4.55 (dd, J = 8.7, 3.3 Hz, 1 H, NHCHCO₂Bn), 4.50 (d, J = 8.0 Hz, 1 H, 1-H), 4.29 (ddq, J = 6.3, 5.5, 3.7 Hz, 1 H, HOCHCH₃), 3.97 [td, J = 9.7, 6.4 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 3.91–3.84 (m, 3 H, 5'-H, 3-H, 5-H), 3.58 [td, J = 9.6, 6.8 Hz, 1 H, OCH2CH2Si(CH3)3], 2.16 (s, 3 H, COCH3), 2.13 (s, 3 H, $COCH_3$), 2.10 (s, 3 H, $COCH_3$), 2.06 (d, J = 5.5 Hz, 1 H, $HOCHCH_3$), 2.02 (s, 3 H, COCH₃), 1.95 (s, 3 H, COCH₃), 1.24 (d, J = 6.4 Hz, 3 H, HOCHCH₃), 1.14 (d, J = 6.2 Hz, 3 H, 6'-H), 0.97 [ddd, J = 14.2, 9.7, 6.7 Hz, OCH₂CH₂Si(CH₃)₃], 0.92 [ddd, J = 14.4, 10.0, 6.6 Hz, OCH₂CH₂Si(CH₃)₃], 0.02 [s, 9 H, OCH₂CH₂Si(CH₃)₃] ppm. ¹³C NMR (125 MHz, CDCl₃): δ = 170.1 (C=O), 170.1 (C=O), 170.0 (C=O), 169.9 (C=O), 169.6 (C=O), 169.4 (C=O), 167.6 (C-6), 135.2 (Ar), 128.65 (Ar), 128.50 (Ar), 128.2 (Ar), 100.2 (C-1), 99.1 (C-1'), 80.4 (C-3), 72.8 (C-5), 71.7 (C-2), 71.1 (C-4), 70.6 (C-4'), 69.9 (C-2'), 68.8 (HOCHCH₃), 68.5 (C-3'), 68.0 [OCH₂CH₂Si(CH₃)₃], 67.4 (C-5'), 67.3 (CH₂Ph), 57.2 (NHCHCO₂Bn), 21.0 (COCH₃), 20.9 (COCH₃), 20.8 (COCH₃), 20.8 (COCH₃), 20.7 (COCH₃), 19.9 (HOCHCH₃), 18.0 [OCH₂CH₂Si(CH₃)₃], 17.3 (C-6'), -1.4 [OCH₂CH₂Si(CH₃)₃] ppm. HRMS (ESI) calcd. for [M + Na] C₃₈H₅₅NNaO₁₈Si: 864.3081, found 864.3076.

N-[2-(Trimethylsilyl)ethyl 2,3,4-Tri-O-acetyl-α-L-rhamnopyranosyl- $(1 \rightarrow 3)$ -(2, 4-di-O-acetyl- β -D-glucopyranosiduronoyl)]-L-threo**nine (51):** To a solution of **50** (67.4 mg, 0.08 mmol) in CH_3OH was added palladium on charcoal (5 %, 10 mg). The flask was flushed with H₂ gas, and then the reaction mixture was stirred at room temperature overnight under a H₂ atmosphere. The mixture was filtered through Celite, and the filtrate was concentrated to afford **51** (60.2 mg, quant.) as a white solid. $R_f = 0.30$ (5:1 CH₂Cl₂/CH₃OH). $[\alpha]_{\rm D} = -30.2$ (c = 1.6, CHCl₃). ¹H NMR (500 MHz, CD₃OD): $\delta = 5.14$ (app. t, J = 9.6 Hz, 1 H, 4-H), 5.08 (dd, J = 3.3, 2.0 Hz, 1 H, 2'-H), 5.04 (dd, J = 10.1, 3.3 Hz, 1 H, 3'-H), 5.00 (dd, J = 9.6, 8.1 Hz, 1 H, 2-H), 4.96 (app. t, J = 9.6 Hz, 1 H, 4-H) 4.92 (d, J = 1.9 Hz, 1 H, 1'-H), 4.68 (d, J = 8.1 Hz, 1 H, 1-H), 4.31-4.28 (m, 2 H, NHCHCO₂H, HOCHCH₃), 4.07 (app. t, J = 9.5 Hz, 1 H, 3-H), 4.04 [td, J = 9.8, 5.9 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 4.02 (d, J = 9.9 Hz, 1 H, 5-H), 3.85 (dq, J = 9.7, 6.2 Hz, 1 H, 5'-H), 3.64 [td, J = 9.6, 6.7 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 2.12 (s, 3 H, COCH₃), 2.12 (s, 3 H, COCH₃), 2.06 (s, 3 H, s, 3 H, COCH₃), 2.02 (s, 3 H, s, 3 H, COCH₃), 1.93 (s, 3 H, s, 3 H, COCH₃), 1.19 (d, J = 6.3 Hz, 3 H, HOCHCH₃), 1.12 (d, J = 6.2 Hz, 3 H, 6'-H), 0.97 [ddd, J = 14.0, 9.9, 6.7 Hz, 1 H, $OCH_2CH_2Si(CH_3)_3$], 0.89 [ddd, J = 14.0, 9.6, 5.8 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 0.02 [s, 9 H, OCH₂CH₂Si(CH₃)₃] ppm. ¹³C NMR (125 MHz, CD₃OD): δ = 174.5 (C=O), 171.7 (C=O), 171.7 (C=O), 171.4 (C=O), 171.4 (C=O), 171.3 (C=O), 169.6 (C-6), 101.3 (C-1), 100.6 (C-1'), 81.9 (C-3), 73.7 (C-5), 73.4 (C-2), 72.5 (C-4), 71.9 (C-4'), 71.1 (C-2'), 70.3 (C-3'), 68.7 (HOCHCH₃), 68.6 [OCH₂CH₂Si(CH₃)₃], 58.9 (NHCHCO2H), 21.4 (COCH3), 21.1 (COCH3), 20.7 (COCH3), 20.6 (COCH₃), 20.6 (COCH₃), 20.3 (HOCHCH₃), 18.9 [OCH₂CH₂Si(CH₃)₃], 17.7 (C-6'), -1.3 [OCH₂CH₂Si(CH₃)₃] ppm. HRMS (ESI) calcd. for [M + Na] C₃₁H₄₉NNaO₁₈Si: 774.2611, found 774.2600.

N-[2-(Trimethylsilyl)ethyl α-L-Rhamnopyranosyl-(1→3)-(β-D-Glucopyranosiduronoyl)]-L-threonine (52): To a solution of 51 (60.2 mg, 0.08 mmol) in CH₃OH (1 mL) was added a solution of



NaOCH₃ in CH₃OH (1 mL, 0.1 M). The reaction mixture was stirred for 4 h at room temperature and then neutralized by addition of Amberlite® IR-120 (H⁺) cation exchange resin. The mixture was filtered and the filtrate was concentrated. The residue was dissolved in water and then lyophilized to afford 52 (39.0 mg, 90 %) as a white solid. $R_{\rm f}$ = 0.24 (1:2:4 H₂O/2-propanol/EtOAc). [α]_D = -53.2 (c = 0.3, CH₃OH). ¹H NMR (500 MHz, CD₃OD): δ = 5.18 (d, J = 1.6 Hz, 1 H, 1'-H), 4.45 (br. s, 1 H, NHCHCO₂H), 4.39 (d, J = 7.9 Hz, 1 H, 1-H), 4.36 (br. s, 1 H, HOCHCH₃), 4.07 (dq, J = 9.6, 6.2 Hz, 1 H, 5'-H), 4.00 [ddd, J = 11.0, 9.7, 6.0 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 3.92 (dd, J = 3.3, 1.7 Hz, 1 H, 2'-H), 3.87 (d, J = 9.3 Hz, 1 H, 5-H), 3.71–3.65 [m, 2 H, 3'-H, OCH₂CH₂Si(CH₃)₃], 3.59 (app. t, J = 8.7 Hz, 1 H, 3-H), 3.54 (app. t, J = 9.0 Hz, 1 H, 4-H), 3.37 (app. t, J = 9.7 Hz, 1 H, 4'-H), 3.34 (dd, J = 8.5 Hz, 1 H, 2-H), 1.23 (d, J = 6.2 Hz, 3 H, 6'-H), 1.19 (d, J = 6.3 Hz, 3 H, HOCHCH₃), 1.05 [ddd, J = 13.8, 11.0, 5.8 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 0.99 [ddd, J = 13.8, 11.0, 6.0 Hz, 1 H, OCH₂CH₂Si(CH₃)₃], 0.03 [s, 9 H, OCH₂CH₂Si(CH₃)₃] ppm. ¹³C NMR (125 MHz, CD₃OD): δ = 173.4 (C=O), 172.2 (C-6), 103.8 (C-1), 102.5 (C-1'), 83.0 (C-3), 76.0 (C-5), 75.5 (C-2), 74.1 (C-4'), 72.4 (C-4), 72.4 (C-2'), 72.3 (C-3'), 69.9 (C-5'), 68.6 [OCH₂CH₂Si(CH₃)₃], 68.4 (HOCHCH₃), 58.6 (NHCHCO₂H), 20.6 (HOCHCH₃), 19.2 [OCH₂CH₂Si(CH₃)₃], 17.9 (C-6'), -1.4 [OCH₂CH₂Si(CH₃)₃] ppm. HRMS (ESI) calcd. for [M – H] C₂₁H₃₈NO₁₃Si: 540.2118, found 540.2113.

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Keywords: Synthetic methods · Oxidation · Amidation · Polysaccharides · Glycuronamides

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