CHEMISTRY
A EUROPEAN JOURNAL

DOI: 10.1002/chem.200800960

# Stereoselective Synthesis of L-Guluronic Acid Alginates

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*Dedicated to Professor Jan Reedijk on the occasion of his 65th birthday and his retirement*

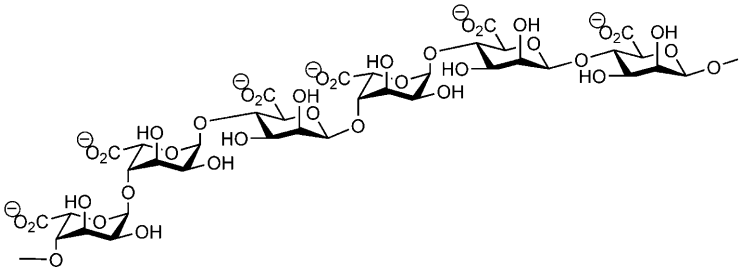
**Abstract:** The glycosylation properties of gulopyranosides have been mapped out, and it is shown that gulose has an intrinsic preference for the formation of 1,2-*cis*-glycosidic bonds. It is postulated that this glycosylation behaviour originates from nucleophilic attack at the oxacarbenium ion, which adopts the most favourable $^3H_4$ conformation. Building on the stereoselectivity of gulose, a guluronic acid alginate trisaccharide was assembled for the first time by using gulopyranosyl building blocks.

**Keywords:** glycosylation · gulose · oligosaccharides · oxacarbenium ions · oxidation · thioglycosides

## Introduction

Alginates are naturally occurring polysaccharides composed of 1,2-*cis*-linked L-guluronic and D-mannuronic acid residues that are arranged in homopolymer (i.e., polyguluronate and polymannuronate) or heteropolymer (a mixed sequence of these residues) sections (Scheme 1). Alginate polymers, isolated from marine brown algae (Phaeophyta),[1] are used for food, textile, and pharmaceutical purposes.[2] Bacteria, such as *Pseudomonas aeruginosa*, also produce alginates as exopolysaccharides, and alginate oligomers appear to have cytokine-inducing activities by binding to Toll-like receptors (TLRs) 2 and 4.[3] As part of a program to evaluate the immunomodulating properties of carbohydrate structures, we set out to develop synthetic routes towards well-defined alginate fragments.

In this framework, we recently reported the synthesis of a 1,2-*cis*-linked D-mannuronic acid trimer by the use of 1-(*S*)-phenylmannuronic acid pyranosides.[4] The present study is focused on the development of a synthetic route to the corresponding 1,2-*cis*-linked L-guluronic acid oligomers. Analogously to other acidic oligosaccharides,[5] the carboxylate function in L-guluronic acid oligomers can be introduced at the monosaccharide stage by the use of suitably protected L-guluronate ester building blocks or at the oligomer level by selective deprotection and oxidation of the incorporated orthogonally protected L-gulose residues. Which route of synthesis is more efficient relies on the glycosylation properties of the L-guluronate ester and L-gulose donors, respectively. Up until now, L-gulose donors have only been employed in the total synthesis of bleomycin,[6] in which L-guluronate ester donors are completely unexplored.



Scheme 1. Alginate oligosaccharide.

Herein, we describe an evaluation of the glycosylating properties of gulose and guluronate ester donors and the first synthesis of a guluronic acid trimer. It is revealed that gulopyranose has a very high tendency to form 1,2-*cis*-linkages without the need to incorporate stereodirecting groups, as is the case for most other pyranosides.

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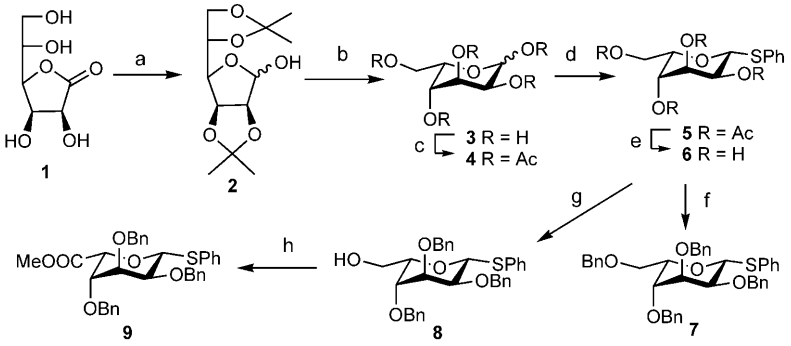
Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/chem.200800960.

## Results and Discussion

The rare L-gulose and L-guluronic acid are C-5-epimers of D-mannose and mannuronic acid, respectively, and not readily commercially available. Therefore, our first aim was to develop a scalable route of a synthesis for L-gulopyranose, provided with an anomeric thio function for ensuing glycosylations. A practical approach was found in the use of L-gulonic acid γ-lactone (**1**), commercially available at reasonable cost. The transformation of this lactone into β-*S*-phenyl-gulopyranose **6** is depicted in Scheme 2 and started with protection of the four hydroxy groups by treatment of **1** with dimethoxypropane. The lactone was reduced by using DIBAL-H in toluene to yield **2**,[7] and acidic hydrolysis of both acetonides delivered the hygroscopic L-gulose **3**, which was immediately acetylated to give per-acetyl gulose **4**. A Lewis acid-mediated introduction of the anomeric thiophenol resulted in an inseparable α/β mixture of thioglycosides. Alternatively, the transformation of **4** into the anomeric bromide moiety and ensuing treatment with PhSH under phase-transfer conditions[8] gave thioguloside **5** as a single anomer, which was deacetylated to furnish key β-(*S*)-phenyl-gulopyranoside **6**. The sequence of reactions to furnish **6** required only one chromatographic purification and can be performed on a 500-mmol scale (100 g). Standard protecting-group manipulations on **6** delivered gulose donor **7** and guluronate ester **9**[9] devoid of any stereodirecting protecting groups.

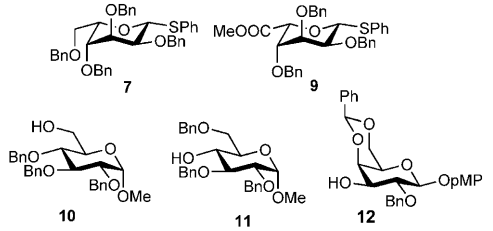



Scheme 2. Synthesis of β-(*S*)-phenyl-L-guloses **6**, **7**, and **9**. a) i. Acetone, dimethoxypropane, $H_2SO_4$; ii. toluene, DIBAL-H, 0 °C (84 %, over 2 steps); b) 20 % TFA in $H_2O$ (quant.); c) pyridine, $Ac_2O$ (72 %); d) i. AcOH, HBr; ii. EtOAc, $Bu_4NHSO_4$, $Na_2CO_3$, PhSH, $H_2O$ (66 %, over 2 steps); e) MeOH, NaOMe (cat.; 97 %); f) DMF, BnBr, NaH, 0 °C→room temperature (89 %); g) i. pyridine, TrCl; ii. DMF, BnBr, NaH, 0 °C→room temperature; iii. MeOH, *p*-TsOH (cat.; 88 %, over 3 steps); h) i. $CH_2Cl_2$, $H_2O$, TEMPO, BAIB; ii. DMF, $K_2CO_3$, MeI (72 %, over 2 steps). BAIB = [bis(acetoxy)iodo]benzene, DIBAL-H = diisobutylaluminium hydride, TEMPO = 2,2,6,6-tetramethylpiperidin-1-oxyl, TFA = trifluoroacetic acid, TrCl = triphenylmethyl chloride, *p*-TsOH = *para*-toluenesulfonic acid.

The glycosylating properties of these donors were examined in the condensation with acceptors **10**–**12**.[10] Each donor was activated with diphenyl sulfoxide ($Ph_2SO$) and triflic anhydride ($Tf_2O$) in the presence of TTBP in dichloromethane at −78 or −45 °C for donors **7** and **9**, respectively. After complete activation, the temperature was adjusted to −78 °C, 1.5 equivalents of the acceptor was added, and the reaction mixture was allowed to warm to 0 °C. The condensation of primary acceptor **10** with gulose **7** almost exclusively gave the 1,2-*cis* product, whereas the reaction of guluronate ester donor **9** with **10** proceeded slightly less stereoselectively (Table 1). Gulosylation of the secondary acceptors **11** and **12** proceeded in a highly α-selective manner for both gulose and guluronate ester. Apparently, gulose and guluronate ester have an unusually strong preference for the formation of 1,2-*cis* glycosidic bonds.

To explore the influence of different protecting groups on the α-selectivity and to find the most convenient building block for the synthesis of guluronic acid alginates, we next investigated one guluronate ester (i.e., **22**) and three differently protected gulose donors (i.e., **19**, **24**, and **25**). The conformationally constrained 4,6-*O*-benzylidene gulose **19** and 4,6-*O*-di-*tert*-butylsilylidene (DTBS) gulose **25** were selected on the basis of their reputation to influence the stereochemical outcome of glycosylations.[11,12] Gulose donor **24** and guluronate ester donor **22**, with a selectively removable levulinoyl (Lev) group at the C-4 position, allow elongation to alginate oligomers with minimal protective-group manipulation. All four donor building blocks were assembled from phenyl-1-thio-β-L-gulopyranoside (**6**; Scheme 3). The instalment of the 4,6-*O*-benzylidene group on **6** and subsequent benzylation yielded 4,6-*O*-benzylidenegulose donor **19**. Guluronate

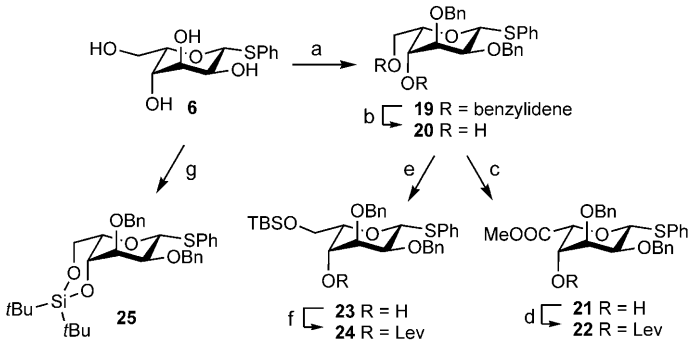
Table 1. Glycosylations of β-*S*-phenyl-L-gulose donors **7**[a] and **9**[b].




| Entry | Donor | Acceptor | Yield [%] | (α/β) | Product |
|---|---|---|---|---|---|
| 1 | **7**[a] | **10** | 71 | (13:1) | **13** |
| 2 | **7**[a] | **11** | 91 | (10:1) | **14** |
| 3 | **7**[a] | **12** | 73 | (>20:1) | **15** |
| 4 | **9**[b] | **10** | 73 | (3:1) | **16** |
| 5 | **9**[b] | **11** | 94 | (>20:1) | **17** |
| 6 | **9**[b] | **12** | 79 | (10:1) | **18** |

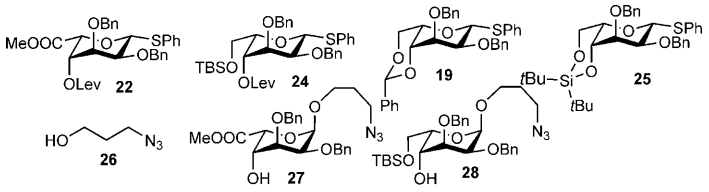
[a] $Ph_2SO$, TTBP, $CH_2Cl_2$, −78 °C, $Tf_2O$, 10 min, nucleophile, to 0 °C. [b] $Ph_2SO$, TTBP, $CH_2Cl_2$, −45 °C, $Tf_2O$, 10 min, then −78 °C, nucleophile, to 0 °C.




Scheme 3. Synthesis of gulose building blocks **19**, **22**, **24**, and **25**. a) i. MeCN, $PhCH(OMe)_2$, *p*-TsOH (cat.); ii. DMF, BnBr, NaH, 0 °C→ room temperature (70%, over 2 steps); b) MeOH, *p*-TsOH (cat.; quant.); c) i. $CH_2Cl_2$, $H_2O$, TEMPO, BAIB; ii. $Et_2O$, TMS diazomethane (49%, over 2 steps); d) pyridine, dioxane, $Lev_2O$ (95%); e) DMF, TBDMSCl, imidazole, 0 °C→room temperature (90%); f) pyridine, dioxane, $Lev_2O$ (94%); g) i. pyridine, $(tBu)_2Si(OTf)_2$, −20 °C→room temperature; ii. DMF, BnBr, NaH, 0 °C→room temperature (88%, over 2 steps). DMF = *N*,*N*-dimethylformamide, TBDMSCl = *tert*-butyldimethylsilyl chloride.

Table 2. Glycosylations of orthogonally protected β-*S*-phenyl-L-gulose donors.[a,b]



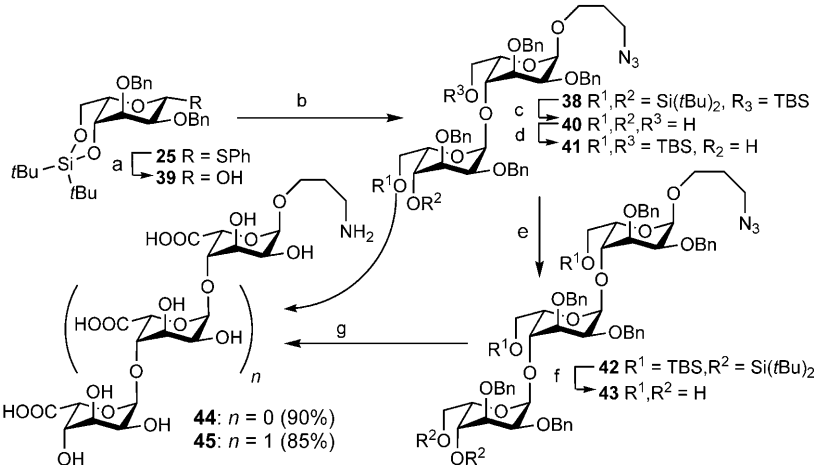

| Entry | Donor | Acceptor | Yield [%] | (α/β) | Product |
|---|---|---|---|---|---|
| 1 | **22**[a] | **10** | 66 | (1:3) | **29** |
| 2 | **22**[a] | **11** | 64 | (>20:1) | **30** |
| 3 | **22**[a] | **26** | 77 | (1:3) | **31** |
| 4 | **22**[a] | **27** | 34 | (3:1) | **32** |
| 5 | **24**[b] | **26** | 86 | (3:1) | **33** |
| 6 | **24**[b] | **28** | 48 | (6:1) | **34** |
| 7 | **19**[b] | **26** | 88 | (3:1) | **35** |
| 8 | **19**[b] | **28** | 45 | (6:1) | **36** |
| 9 | **25**[b] | **26** | 75 | (5:1) | **37** |
| 10 | **25**[b] | **28** | 48 | (10:1) | **38** |

[a] $Ph_2SO$, TTBP, $CH_2Cl_2$, −45 °C, $Tf_2O$, 10 min, then −78 °C, nucleophile, to 0 °C. [b] $Ph_2SO$, TTBP, $CH_2Cl_2$, −78 °C, $Tf_2O$, 10 min, nucleophile, to 0 °C.

ester donor **22** was accessible by the acidic cleavage of the benzylidene group in **19**, regio- and chemoselective oxidation of the primary hydroxy group in diol **20** with TEMPO/BAIB, methylation of the carboxylic acid with trimethylsilyl (TMS) diazomethane, and levulinoylation of the hydroxy group at C-4 in **21**. Protection of the hydroxy group at C-6 in diol **20** with the *tert*-butyldimethylsilyl (TBDMS) group and levulinoylation of the remaining alcohol furnished donor **24**. Treatment of tetraol **6** with di-*tert*-butylsilyl bistriflate in pyridine at −20 °C followed by benzylation of the crude product afforded di-*O*-*tert*-butylsilylidene gulose **25** (Scheme 3).

With the thioglycoside donors (i.e., **19**, **22**, **24**, and **25**) in hand, we first focused on the glycosylating properties of thioguluronate ester **22** (Table 2). For comparative reasons, **22** was condensed with model acceptors **10** and **11**. In line with the glycosylations of donor **9**, levulinoyl donor **22** was moderately α-selective with the primary alcohol **10** and completely α-selective with secondary acceptor **11** (Table 2, entries 1 and 2, respectively). Next, donor **22** was coupled with 3-azidopropanol (**26**) and 3-azidopropyl-methyl-2,3-*O*-benzyl-α-L-gulopyranoside uronate (**27**). In contrast to the gulosylations described above, the β product prevailed in the condensation of **22** and the rather reactive primary alcohol **26** (Table 2, entry 3). Diuronate **30** was formed in low yield from **22** and **27**, again with α-selectivity (Table 2, entry 4). The gulose donors **19**, **24**, and **25** all predominantly provided the 1,2-*cis* linked products, with both the primary and secondary alcohol acceptors. Thus, the presence of the carboxylic acid ester at C-5 does not contribute favourably to the formation of the 1,2-*cis* gulosidic linkage. Because the DTBS donor **25** shows the best α-selectivity of the three thioguloses examined, this guloside was further examined in the synthesis of a guluronic alginate trimer (Scheme 4).

It is clear that the guluronate ester and hydroxy group at C-4 in gulose are poor nucleophiles, thus leading to moder-



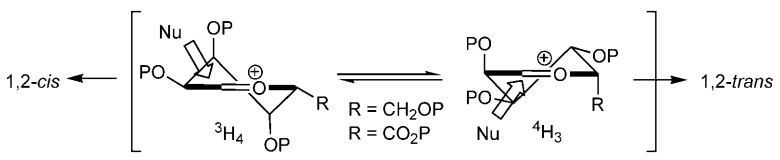

Scheme 4. Synthesis of the alginate trisaccharide **45**. a) $CH_2Cl_2$, NIS, TFA (95%); b) $Ph_2SO$, TTBP, −60 °C, $Tf_2O$, **28**, −60 °C→room temperature (84%; α/β = 10:1); c) THF, TBAF (87%); d) DMF, TBDMSCl, imidazole (78%); e) **37**, $Ph_2SO$, TTBP, −60 °C, $Tf_2O$, then **41**, −60 °C→room temperature (42%; α); f) THF, TBAF (83%); g) i. $CH_2Cl_2$, *t*BuOH, $H_2O$, TEMPO, BAIB; ii. *t*BuOH, Pd/C, $H_2$ (**44**: 90%, **45**: 85%, over 2 steps). NIS = *N*-iodosuccinimide, TTBP = tri-*tert*-butylpyrimidine.

ate yields in the gulosylations (Table 2, entries 4, 6, 8, and 10). We attribute these moderate yields to a reactivity mismatch of the coupling partners[13] because in the condensation reactions all the donor guloside was consumed, whereas some of the acceptor remained untouched. Other promoter systems were investigated to modulate the reactivity of the activated donor species. Iodonium-mediated glycosylations with NIS/trimethylsilyl trifluoromethanesulfonate (TMSOTf) and iodonium dicollidine perchlorate (IDCP)[4,14] resulted in the same stereoselectivity, although the yield did not improve (results not shown). Next, a dehydrative condensation strategy, originally devised by Gin and co-workers,[15] was explored. In our experience, this type of glycosylation is well suited to unreactive nucleophiles because the activated sulfoxonium species is relatively stable and survives longer at higher temperatures.[16] Therefore, we hydrolyzed thiogulose **25** by using NIS/TFA[17] to give hemiacetal donor **39** (Scheme 4). This lactol was activated by $Ph_2SO$/$Tf_2O$ and coupled to gulose **28** to provide disaccharide **38** in a slightly improved yield (55%). Importantly, the excellent α-stereoselectivity of DTBS-protected gulose **25** was maintained and was thus shown to be independent of the activation method. Changing the donor/acceptor ratio (1.2:1 to 2:1) further increased the yield to 84%.

Next, we elongated disaccharide **38** by liberation of the hydroxy group at C-4′ and subsequent glycosylation with two equivalents of **39**. Trimer **42** was obtained as a single diastereomer, albeit in a moderate 42% yield. The introduction of the carboxylate functions was achieved by desilylation of dimer **38** and trimer **42** and subsequent oxidation mediated with TEMPO/BAIB. It was observed that primary alcohols **40** and **43** were smoothly transformed into the corresponding aldehydes, but that ensuing oxidation to the acid was troublesome. The addition of *t*BuOH to homogenise the biphasic reaction mixture of dichloromethane and water enhanced the rate of aldehyde hydration, thereby allowing the efficient oxidation of the lipophilic substrates.[18] Hydrogenolysis completed the synthesis, and the di- and triacids **44** and **45** were isolated in excellent yield over the two final steps.

Finally, it is appropriate to comment on the unusually high α-selectivity displayed by the gulopyranosides described herein. In most pyranosides, an alkoxide aglycon prefers to adopt an axial position as dictated by the anomeric effect.[19] In gulose, however, the anomeric effect will be largely offset by the 1,3-diaxial interaction of the α-oriented aglycon and the substituent at C-3.[20] Therefore, we dismiss the anomeric effect to be the basis of the observed selectivities. Anomeric triflates have convincingly been demonstrated to be intermediates in sulfonium-mediated glycosylations, as practiced herein.[21] In most cases, the anomeric α-triflates serve as a reservoir for the actual glycosylation species, being a close ion pair (CIP) or a solvent-separated ion pair (SSIP). In the gulosylations at hand, it is difficult to predict which anomeric triflate will be the most stable, because also in this case the anomeric effect is counterbalanced by steric interactions and both the α- and β-triflates may exist in solution. It is unlikely that the α-stereoselectivity in gulosylation arises from the selective $S_N2$-type displacement on the β-triflate or β-CIP.

Rather, we believe that the high 1,2-*cis* selectivity originates form the conformational preferences of the intermediate solvent-separated oxacarbenium ion. Lemieux and Huber postulated that the relative stabilities of the oxacarbenium conformers can influence the stereochemical outcome of glycosylation reactions.[22] Recently, the conformational restriction of oxacarbenium ions was exploited in the stereoselective synthesis of β-arabinofuranoses.[23] Computational[24] and experimental[25] data have established that substituents on the pyranose ring influence the stability of the oxacarbenium intermediate and thereby affect the outcome of a glycosylation reaction. It was shown that electronegative substituents at C-3 and C-4 prefer to adopt a pseudoaxial orientation, thereby minimizing their electron-withdrawing nature. Substituents at C-2 and C-5 prefer to adopt a pseudoequatorial orientation because of hyperconjugative effects for the former[26] and steric reasons for the latter.[25] When we apply these findings to the two likely half-chair conformations of the L-gulose oxacarbenium ion intermediate, it becomes clear that all substituents occupy their preferred orientation in the $^3H_4$ conformer (Scheme 5). On the contrary, all the substituents are in disfavoured positions in the $^4H_3$ conformer. An incoming nucleophile will approach the oxacarbenium ion in a pseudoaxial trajectory, with a preference for the diastereotopic face that leads to the more favourable chair-like product.[27] If no prohibitive steric interactions evolve in the transition state, thus leading to the coupled product, the L-gulose oxacarbenium ion will react from the $^3H_4$ conformer to form the α product. The protecting-group pattern on the gulosides only has a marginal effect on the stereochemical outcome of the condensation reactions. Although the cyclic protecting groups in **19** and **25** restrict the conformational freedom of the gulopyranoses, they do not a priori rule out either of the two half-chair oxacarbenium ion conformers because they can be accommodated in both constellations. Participation of the acyl group at C-4 in **24**, as has been suggested in α-galactosylations,[28] does not play a decisive role in the gulosylations described herein. In comparison with the gulose donors, the stereoselectivity of the guluronate esters is somewhat decreased. The counterproductive effect of the carboxylic ester could suggest that this electron-withdrawing group at C-5 prefers




Scheme 5. Proposed oxacarbenium ion conformers.

to adopt a pseudoaxial orientation in the oxacarbenium ion, thereby shifting the ratio of the two half-chair intermediates and the stereochemical outcome of the glycosylations.

## Conclusion

In closing, we have mapped out the glycosylation properties of gulopyranosides and have shown that gulose has an intrinsic preference for the formation of a 1,2-*cis*-glycosidic bond. It is postulated that this glycosylation behaviour originates from nucleophilic attack at the oxacarbenium ion, which adopts the most favourable conformation, that is, $^3H_4$. Building on the stereoselectivity of gulose, a guluronic acid alginate trisaccharide has been assembled for the first time. Insight into the influence of the stereochemistry of substituents on the pyranoside ring on the stereochemical outcome of a glycosylation will aid the future development of stereoselective glycosylation reactions.

## Experimental Section

Dichloromethane was heated to reflux with $P_2O_5$ and distilled before use. Trifluoromethanesulfonic anhydride was distilled from $P_2O_5$. Traces of water in the donor and acceptor glycosides, diphenyl sulfoxide, and TTBP were removed by coevaporation with toluene. All other chemicals were used as received from Acros, Fluka, Merck, and Schleicher & Schue. Column chromatography was performed on Merck silica gel 60 (0.040–0.063 mm). Analysis by TLC was conducted on HPTLC aluminum sheets (Merck; silica gel 60, F245). Compounds were visualised by UV absorption ($\lambda = 245$ nm) by spraying with 20% $H_2SO_4$ in ethanol or with a solution of $[Mo_7(NH_4)_6O_{24}]\cdot 4H_2O$ (25 g $L^{-1}$), $[Ce(NH_4)_4(SO_4)_4]\cdot 2H_2O$ (10 g $L^{-1}$), or 10% $H_2SO_4$ in $H_2O$ followed by charring at +/−140 °C. $^1H$ and $^{13}C$ NMR spectra were recorded on Bruker AV 400 (400 and 100 MHz, respectively), AV 500 (500 and 125 MHz, respectively), or DMX 600 (600 and 150 MHz, respectively) spectrometers. NMR spectra were recorded in $CDCl_3$ with the chemical shift $\delta$ relative to trimethylsilane (TMS) unless stated otherwise. Optical rotations were measured on a Propol automatic polarimeter. High-resolution (HR) mass spectra were recorded on a LTQ-orbitrap (thermoelectron). IR spectra were recorded on a Shimadzu FTIR-8300 spectrometer and are reported in $cm^{-1}$.

**2,3–5,6-Di-*O*-isopropylidene-α,β-L-gulofuranose (2)**: $H_2SO_4$ (5 drops) was added to a suspension of L-gulonic acid γ-lactone (**1**; 40.0 g, 225 mmol) and 2,2-dimethoxypropane (71 mL, 788 mmol) in acetone (800 mL). The reaction mixture was stirred overnight and quenched with $Et_3N$ until neutral pH. The acetone was removed in vacuo, and the residue was taken up in $Et_2O$ and washed twice with $H_2O$. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. The residue was dissolved in toluene (2.0 L) and DIBAL-H (137 mL, 1.7 m solution in toluene) was slowly added at 0 °C. The reaction was quenched with EtOAc (20 mL) after 20 min, 2 M NaOH (215 mL) was added under vigorous stirring, and the reaction mixture was filtered over Hyflo Gel. The aqueous layer was extracted twice with EtOAc and the combined organic layers dried over $MgSO_4$ and concentrated in vacuo to afford **2** as a white solid (49 g, 84%). $^1H$ NMR (400 MHz, $CDCl_3$): $\delta = 1.29$ (s, 3H, $CH_3$ isoprop), 1.39 (s, 3H, $CH_3$ isoprop), 1.45 (s, 6H, 2×$CH_3$ isoprop), 3.44 (d, 1H, $J$ = 2.0 Hz, OH), 3.74 (dd, 1H, $J = 7.2$, 8.4 Hz, H-6), 4.13 (dd, 1H, $J = 3.6$, 8.4 Hz, H-4), 4.21 (dd, 1H, $J = 6.4$, 8.4 Hz, H-6), 4.37 (dd, 1H, $J = 6.8$, 8.4 Hz, H-5), 4.63 (d, 1H, $J = 5.6$ Hz, H-2), 4.70 (dd, 1H, $J = 3.8$, 5.8 Hz, H-3), 5.46 ppm (d, 1H, $J = 2.0$ Hz, H-1); $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta = 24.7$ ($CH_3$ isoprop), 25.4 ($CH_3$ isoprop), 25.9 ($CH_3$ isoprop), 26.7 ($CH_3$ isoprop), 66.0 (C-6), 75.5 (C-5), 79.8 (C-3), 82.1 (C-4), 85.6 (C-2), 101.3 (C-1), 109.7 ($C_q$ isoprop), 112.8 ppm ($C_q$ isoprop); HRMS: *m/z*: calcd for $C_{12}H_{20}O_6 + H^+$: 261.1333; found: 261.1313; IR (neat): $\tilde{\nu} = 1091$, 1263, 1380, 1454, 2986, 3445 $cm^{-1}$.

**α,β-L-Gulose (3)**: Compound **2** (75.5 g, 290 mmol) was added to $H_2O$ (870 mL) and TFA (174 mL) at 0 °C, after which the reaction mixture was allowed to warm to room temperature. After stirring for 5 h, approximately half of the volume was evaporated in vacuo. The solution was diluted with $H_2O$ (500 mL) and evaporated to half the volume. This process was repeated twice, and the remaining TFA was quenched with $Et_3N$ until neutral pH. The reaction mixture was concentrated in vacuo to obtain **3** as a colourless oil (52.2 g, quantitative). $^1H$ NMR (500 MHz, $D_2O$): $\delta = 3.65$ (dd, 1H, $J = 3.3$, 8.3 Hz, H-2), 3.74–3.79 (m, 2H, H-6, H-6), 3.83 (d, 1H, $J = 3.5$ Hz, H-4), 4.02 (t, 1H, $J = 6.0$ Hz, H-5), 4.09 (t, 1H, $J = 3.3$ Hz, H-3), 4.90 ppm (d, 1H, $J = 8.0$ Hz, H-1); $^{13}C$ NMR (125 MHz, $CDCl_3$): $\delta = 60.56$ (C-6), 68.64–73.66 (C-2, C-3, C-4, C-5), 93.39 ppm (C-1); HRMS: *m/z*: calcd for $C_6H_{12}O_6 + Na^+$: 203.05261; found: 203.05262.

**Penta-*O*-acetyl-α,β-L-gulopyranose (4)**: Gulose (**3**; 52.2 g, 290 mmol) was dissolved in pyridine (1 L) and cooled to 0 °C. After the addition of $Ac_2O$ (200 mL), the reaction mixture was allowed to stir overnight at room temperature. The reaction was quenched with MeOH and concentrated in vacuo. The reaction mixture was diluted with EtOAc, washed with 1 m HCl (aq), $NaHCO_3$ (aq), and brine. The organic layer was dried over $MgSO_4$ and concentrated in vacuo to yield **4** as a dark-yellow oil (96.6 g, 72%). $^1H$ NMR major anomer (400 MHz, $CDCl_3$): $\delta = 2.05$–2.17 (5×s, 15H, 5×$CH_3$ acetyl), 4.11 (m, 1H, H-6), 4.17 (m, 1H, H-6), 4.37 (m, 1H, H-5), 5.00 (dd, 1H, $J = 1.2$, 4.0 Hz, H-4), 5.12 (dd, 1H, $J = 3.6$, 8.6 Hz, H-2), 5.44 (t, 1H, $J = 3.6$ Hz, H-3), 6.00 ppm (d, 1H, $J = 8.4$ Hz, H-1); $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta = 20.5$–20.9 ($CH_3$ acetyl), 61.5 (C-6), 67.2 (C-3), 67.3 (C-2), 67.5 (C-4), 71.3 (C-5), 89.9 (C-1), 168.9–170.4 ppm (CO); HRMS: *m/z*: calcd for $C_{16}H_{22}O_{11} + Na^+$: 413.10543; found: 413.10544; IR (neat): $\tilde{\nu} = 1065$, 1207, 1369, 1744 $cm^{-1}$.

**Phenyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-L-gulopyranoside (5)**: Per acetyl gulose (**4**; 83.8 g, 215 mmol) was dissolved in AcOH (86 mL) and cooled to 0 °C. HBr/AcOH (33%, 102 mL) was added slowly and the reaction mixture was stirred at 0 °C for 2 h. The reaction mixture was then poured into icewater and extracted with EtOAc (2×250 mL). The organic layers were carefully washed with $NaHCO_3$ (aq) and added to a solution of $Bu_4NHSO_4$ (730 g, 215 mmol), $Na_2CO_3$ (286 g, 1.00 mol), and PhSH (26.4 mL, 258 mmol) in $H_2O$ (1 L). When analysis by TLC showed complete consumption of the starting material, the layers were separated and the organic layer was washed with 1 m NaOH and brine. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Column chromatography yielded **5** as a slightly yellow oil (62.5 g, 66%). $[\alpha]_D^{22} = -20.6$ ($c = 1$, $CHCl_3$); $^1H$ NMR (600 MHz, $CDCl_3$): $\delta = 2.01$–2.22 (m, 12H, $CH_3$ acetyl), 4.145–4.25 (m, 3H, H-5, H-6, H-6), 4.98 (dd, 1H, $J = 0.8$, 4.0 Hz H-4), 5.05 (m, 2H, H-1, H-2), 5.37 (dd, 1H, $J = 2.0$, 3.2 Hz, H-3), 7.26–7.33 (m, 3H, Ar-H SPh), 7.50–7.54 ppm (m, 2H, Ar-H SPh); $^{13}C$ NMR (150 MHz, $CDCl_3$): $\delta = 20.6$–21.0 ($CH_3$ acetyl), 62.0 (C-6), 66.3 (C-2), 66.8 (C-3), 67.8 (C-4), 72.7 (C-5), 83.0 (C-1), 127.4–132.4 (Ar-CH), 132.6 ($C_q$ SPh), 168.8–170.4 ppm (CO); HRMS: *m/z*: calcd for $C_{20}H_{24}O_9S + Na^+$: 463.10332; found: 463.10311; IR (neat): $\tilde{\nu} = 1026$, 1059, 1209, 1369, 1736 $cm^{-1}$.

**Phenyl-1-thio-β-L-gulopyranoside (6)**: Compound **5** (62.5 g, 142 mmol) was dissolved in MeOH (750 mL) and a catalytic amount of NaOMe was added. The reaction mixture was stirred overnight, quenched with Amberlite $H^+$, and concentrated in vacuo. Crystallisation from acetone yielded **6** as white crystals (37.5 g, 97%). $[\alpha]_D^{22} = +48.6$ ($c = 1$, $CHCl_3$); $^1H$ NMR (400 MHz, MeOD): $\delta = 3.67$–3.79 (m, 4H, H-2, H-4, H-6, H-6), 3.92 (t, 1H, $J = 5.8$ Hz, H-4), 3.97 (t, 1H, $J = 3.6$ Hz, H-3), 5.02 (d, 1H, $J = 10.4$ Hz, H-1), 7.19–7.29 (m, 3H, Ar-H), 7.53–7.56 ppm (m, 2H, Ar-H); $^{13}C$ NMR (150 MHz, $CDCl_3$): $\delta = 62.7$ (C-6), 68.1 (C-2), 71.2 (C-5), 72.6 (C-4), 77.3 (C-3), 87.3 (C-1), 127.8, 129.8, 131.9 (Ar-CH), 136.3 ppm ($C_q$ SPh); HRMS: *m/z*: calcd for $C_{12}H_{16}O_5S + Na^+$: 295.06107; found: 295.06130; IR (neat): $\tilde{\nu} = 974$, 1034, 1051, 1412, 3234, 3440 $cm^{-1}$.

**Phenyl-2,3,4,6-tetra-*O*-benzyl-1-thio-β-L-gulopyranoside (7)**: Thiogulose (**6**; 1.54 g, 5.66 mmol) was dissolved in DMF (56 mL) and cooled to 0 °C. Respectively, BnBr (3.2 mL, 27 mmol) and NaH (1.08 g, 27 mmol, 60% dispersion in oil) were added. After stirring overnight, the reaction mixture was quenched with MeOH and concentrated in vacuo. The residue

was taken up in $Et_2O$ and washed three times with $H_2O$. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Column chromatography yielded **7** as a colourless oil (3.19 g, 89%). $[\alpha]_D^{22} = +9.17$ (c = 0.024, $CH_2Cl_2$); $^1$H NMR (400 MHz, $CDCl_3$): $\delta = 3.51$ (m, 1H, H-4), 3.57–3.67 (m, 2H, H-6), 3.71 (t, 1H, $J = 3.2$ Hz, H-3), 3.75 (dd, 1H, $J = 2.8$, 10 Hz, H-2), 4.13 (t, 1H, $J = 6.4$ Hz, H-5), 4.26 (d, 1H, $J = 12$ Hz, $CH_2$ Bn), 4.31 (d, 1H, $J = 12$ Hz, $CH_2$ Bn), 4.37 (d, 1H, $J = 10.8$ Hz, $CH_2$ Bn), 4.40 (d, 1H, $J = 8.8$ Hz, $CH_2$ Bn), 4.47–4.52 (m, 2H, $CH_2$ Bn), 4.59 (d, 1H, $J = 11.6$ Hz, $CH_2$ Bn), 4.66 (d, 1H, $J = 12$ Hz, $CH_2$ Bn), 5.23 (d, 1H, $J = 10$ Hz, H-1), 7.08–7.10 (m, 2H, Ar-H), 7.12–7.35 (m, 21H, Ar-H), 7.51–7.60 ppm (m, 2H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta = 69.0$ (C-6), 72.4 ($CH_2$ Bn), 72.8 ($CH_2$ Bn), 73.1 (C-3), 73.2 ($CH_2$ Bn), 73.4 ($CH_2$ Bn), 74.4 (C-5), 74.8 (C-2), 74.9 (C-4), 84.3 (C-1), 126.8–128.6 (Ar-CH), 131.4 (Ar-CH), 138.2 ppm ($C_q$ Bn); HRMS: *m/z*: calcd for $C_{40}H_{40}O_5S + Na^+$: 655.24887; found: 655.24860; IR (neat): $\tilde{\nu} = 741$, 1001, 1028, 1076, 1101, 1207, 1360, 1439, 1454, 1497, 2866, 3032, 3061 cm$^{-1}$.

**Phenyl-2,3,4-tri-*O*-benzyl-1-thio-β-L-gulopyranoside (8)**: Compound **6** (5.45 g, 20 mmol) was dissolved in pyridine (100 mL) and trityl chloride (8.36 g, 30 mmol) was added, and the reaction mixture was stirred for 3 days. The reaction was quenched with MeOH and concentrated in vacuo. The mixture was diluted with EtOAc, washed with 1 M HCl (aq), $NaHCO_3$ (aq), and brine. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. The residue was dissolved in DMF (100 mL) and cooled to 0 °C. Respectively, BnBr (8.55 mL, 72 mmol) and NaH (2.88 g, 72 mmol, 60% dispersion in oil) were added. After stirring overnight, the reaction mixture was quenched with MeOH and concentrated in vacuo. The residue was taken up in $Et_2O$ and washed three times with $H_2O$. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. The residue was dissolved in $CH_2Cl_2$ (50 mL) and MeOH (200 mL) and a catalytic amount of *p*-TsOH was added. The reaction mixture was stirred overnight. The reaction mixture was neutralised with $Et_3N$ and concentrated in vacuo. Column chromatography yielded **8** as a colourless oil (9.58 g, 88%). $[\alpha]_D^{22} = +11.8$ ($c = 0.024$, $CH_2Cl_2$); $^1$H NMR (400 MHz, $CDCl_3$): $\delta =$ 3.40 (m, 1H, H-3), 3.45–3.53 (m, 1H, H-6), 3.76 (m, 2H, H-2, H-4), 3.80–3.85 (m, 1H, H-6), 3.94–3.97 (m, 1H, H-5), 4.22 (d, 1H, $J = 12$ Hz, $CH_2$ Bn), 4.29 (d, 1H, $J = 12$ Hz, $CH_2$ Bn), 4.40 (d, 1H, $J = 12$ Hz, $CH_2$ Bn), 4.49 (d, 1H, $J = 12$ Hz, $CH_2$ Bn), 4.61 (d, 1H, $J = 11.6$ Hz, $CH_2$ Bn), 4.71 (d, 1H, $J = 12$ Hz, $CH_2$ Bn), 5.23 (d, 1H, $J = 9.6$ Hz, H-1), 7.07–7.10 (m, 2H, Ar-H), 7.23–7.36 (m, 16H, Ar-H), 7.55–7.57 ppm (m, 2H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta = 62.5$ (C-6), 72.1 ($CH_2$ Bn), 72.7 (C-2 or C-4), 72.9 ($CH_2$ Bn), 73.4 ($CH_2$ Bn), 74.9 (C-2 or C-4), 75.2 (C-3), 75.8 (C-5), 84.0 (C-1), 127.0–128.8 (Ar-CH), 131.6 (Ar-CH), 134.0 ($C_q$ Bn), 137.5 ($C_q$ Bn), 137.8 ($C_q$ Bn), 138.1 ppm ($C_q$ Bn); HRMS: *m/z*: calcd for $C_{33}H_{34}O_5S + H^+$: 543.21997; found: 543.22015; IR (neat): $\tilde{\nu} = 739$, 922, 1001, 1026, 1042, 1074, 1207, 1358, 1439, 1454, 1477, 1497, 2878, 3030, 3063 cm$^{-1}$.

**Methyl (phenyl-2,3,4-tri-*O*-benzyl-1-thio-β-D-gulopyranosyluronate) (9)**: Compound **8** (1.95 g, 3.6 mmol) was taken up in $CH_2Cl_2$ (24 mL) and $H_2O$ (12 mL) and TEMPO (0.115 g, 0.74 mmol) and BAIB (2.89 g, 9.0 mmol) were added. The reaction mixture was stirred vigorously until analysis by TLC showed complete conversion of the starting material. $Na_2S_2O_3$ (50 mL, aq) was added and the resulting mixture was stirred for 15 min. The layers were separated and the aqueous phase acidified with 1 M HCl and extracted three times with $CH_2Cl_2$. The combined organic layers were dried over $MgSO_4$ and concentrated in vacuo. The residue was taken up in DMF (20 mL) and $K_2CO_3$ (2.49 g, 18 mmol) and MeI (0.56 mL, 9.0 mmol) was added. After 2 h, the reaction mixture was diluted with $Et_2O$ (50 mL) and washed three times with $H_2O$. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Purification by column chromatography yielded **9** as a white solid (1.48 g, 72%). $[\alpha]_D^{22} = +17.0$ ($c = 1$, $CH_2Cl_2$); $^1$H NMR (400 MHz, $CDCl_3$): $\delta = 3.72$–$3.75$ (m, 4H, H-3, $CH_3CO_2Me$), 3.83 (dd, 1H, $J = 3.2$, $J = 10$ Hz, H-2), 3.91 (dd, 1H, $J = 3.6$, 1.6 Hz, H-4), 4.31 (d, 1H, $J = 12$ Hz, $CH_2$ Bn), 4.39 (d, 1H, $J = 12$ Hz, $CH_2$ Bn), 4.41 (d, 1H, $J = 12$ Hz, $CH_2$ Bn), 4.56 (d, 1H, $J =$ 12 Hz, $CH_2$ Bn), 4.60 (s, 1H, H-5), 4.61 (d, 1H, $J = 12$ Hz, $CH_2$ Bn), 4.71 (d, 1H, $J = 12.4$ Hz, $CH_2$ Bn), 5.23 ppm (d, 1H, $J = 10$ Hz, H-1); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta = 52.1$ ($CH_3CO_2Me$), 72.5 ($CH_2$ Bn), 72.7 ($CH_2$ Bn), 72.7 (C-3), 72.2 ($CH_2$ Bn), 73.9 (C-2), 74.7 (C-5), 76.2 (C-4),84.4 (C-1), 127.2–128.6 (Ar-C), 132.4 (Ar-C), 133.7 ($C_q$ Bn), 137.4 ($C_q$ Bn), 137.7 ($C_q$ Bn), 137.8 ($C_q$ Bn), 169.1 ppm (COOMe); HRMS: *m/z*: calcd for $C_{34}H_{34}O_6S + NH_4^+$: 588.24144; found: 588.24210; IR (neat): $\tilde{\nu} =$ 731, 897, 814, 939, 1026, 1074, 1126, 1209, 1265, 1304, 1358, 1420, 1439, 1454, 1477, 1497, 1734, 1765, 2876 cm$^{-1}$.

**Methyl-2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzyl-α,β-L-gulopyranoside)-α-D-glucopyranoside (13)**: A solution of donor **7** (0.127 g, 0.2 mmol), diphenyl sulfoxide (0.045 g, 0.22 mmol), and tri-*tert*-butylpyrimidine (0.124 g, 0.5 mmol) in $CH_2Cl_2$ (4 mL) was stirred over activated 3-Å molecular sieves (MS) for 30 min. The reaction mixture was cooled to −78 °C before triflic acid anhydride (37 μL, 0.22 mmol) was added. The reaction mixture was stirred for 10 min at −78 °C followed by the addition of acceptor **10** (0.139 g, 0.3 mmol) in $CH_2Cl_2$ (3 mL). Stirring was continued and the reaction mixture was allowed to warm to 0 °C and $Et_3N$ (0.15 mL) was added. The reaction mixture was diluted with $CH_2Cl_2$ and washed with $NaHCO_3$ (aq). The aqueous layer was extracted twice with $CH_2Cl_2$. The collected organic layers were dried over $MgSO_4$ and concentrated in vacuo. Purification by size exclusion and column chromatography yielded **13** as a colourless oil (71%, 0.140 g, $\alpha/\beta = 13{:}1$). Determination of the α/β ratio by $^1$H NMR: $\delta =$ 3.25 (s, 3H, $OCH_3$ α), 3.33 ppm (s, 0.22H, $OCH_3$ β). α isomer: $^1$H NMR (400 MHz, $CDCl_3$): $\delta =$ 3.25 (s, 3H, $OCH_3$), 3.38 (dd, 1H, $J = 3.6$, $J = 9.6$ Hz, H-2), 3.53–3.62 (m, 2H, H-6′), 3.63–3.85 (m, 6H, H-3′, H-4, H-6, H-5, H-2′, H-4′), 3.96 (t, 1H, $J = 9.2$ Hz, H-3), 4.01 (d, 1H, $J = 10$ Hz, H-6′), 4.33–4.55 (m, 9H, H-5′, $CH_2$ Bn), 4.57 (d, 1H, $J = 3.6$ Hz, H-1), 4.68 (d, 1H, $J = 12.4$ Hz, $CH_2$ Bn), 4.71 (d, 1H, $J = 12.4$ Hz, $CH_2$ Bn), 4.80 (d, 1H, $J = 10.8$ Hz, $CH_2$ Bn), 4.83 (d, 1H, $J = 12$ Hz, $CH_2$ Bn), 4.93 (d, 1H, $J = 10.8$ Hz, $CH_2$ Bn), 4.98 ppm (d, 1H, $J = 3.2$ Hz, H-1′); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta = 54.8$ ($OCH_3$), 65.5 (C-5), 67.2 (C-6′), 68.8 (C-6), 70.1 (C-4′), 71.1 ($CH_2$ Bn), 72.7 (C-2′), 72.7 ($CH_2$ Bn), 72.8 ($CH_2$ Bn), 73.0 ($CH_2$ Bn), 73.1 ($CH_2$ Bn), 74.2 (C-5′), 74.8 ($CH_2$ Bn), 75.5 ($CH_2$ Bn), 75.6 (C-3′), 77.9 (C-4′), 80.2 (C-2), 82.0 (C-3), 97.7 (C-1′), 97.8 (C-1), 127.1–128.3 (Ar-CH), 138.1 ($C_q$ Bn), 138.3 ($C_q$ Bn), 138.4 ($C_q$ Ph), 138.5 ($C_q$ Bn), 138.8 ($C_q$ Bn), 139.1 ($C_q$ Bn), 139.4 ppm ($C_q$ Bn); HRMS: *m/z*: calcd for $C_{62}H_{66}O_{11} + NH_4^+$: 1004.49434; found: 1004.49579; IR (neat): $\tilde{\nu} = 733$, 820, 908, 1026, 1047, 1069, 1194, 1207, 1310, 1327, 1360, 1454, 1497, 2870, 3030, 3063 cm$^{-1}$.

**Methyl-2,3,6-tri-*O*-benzyl-4-*O*-(2,3,4,6-tetra-*O*-benzyl-α,β-L-gulopyranoside)-α-D-glucopyranoside (14)**: As described for the synthesis of **13** using acceptor **11** (0.139 g, 0.3 mmol). Purification by size exclusion and column chromatography yielded **14** as a colourless oil (91%, 0.179 g, $\alpha/\beta = 10{:}1$). Determination of the α/β ratio by $^1$H NMR: $\delta = 5.11$ (d, 1H, $J = 4.0$ Hz, H-1′ α), 5.38 ppm (d, 0.09H, $J = 8.0$ Hz, H-1′ β). α isomer: $^1$H NMR (400 MHz, $CDCl_3$): $\delta = 3.34$ (s, 3H, $CH_3$ OMe), 3.45 (m, 1H), 3.51 (dd, 1H, $J = 3.6$ Hz, 8.8 Hz), 3.60 (m, 1H), 3.68 (t, 1H, $J = 3.2$ Hz), 3.73 (m, 1H, H-2′), 3.76–3.89 (m, 4H), 4.09 (d, 1H, $J = 11.6$ Hz, $CH_2$ Bn), 4.15 (d, 1H, $J = 11.6$ Hz, $CH_2$ Bn), 4.26–4.40 (m, 7H), 4.51–4.56 (m, 3H, H-1), 4.66 (d, 1H, $J = 8.8$ Hz, $CH_2$ Bn), 4.68 (d, 1H, $J = 8.8$ Hz, $CH_2$ Bn), 4.88 (d, 1H, $J = 11.2$ Hz, $CH_2$ Bn), 4.95 (d, 1H, $J = 11.2$ Hz, $CH_2$ Bn), 5.11 (d, 1H, $J = 4.0$ Hz, H-1′), 7.08–7.30 ppm (m, 35H, Ar-CH); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta = 54.9$ ($CH_3$ OMe), 65.3, 68.1, 68.9, 70.1, 71.3, 72.6, 72.7, 72.8, 72.9, 73.0, 73.1, 73.3, 73.9, 74.5, 75.8, 80.3, 80.5, 97.6 (C-1′), 97.8 (C-1), 126.8–128.7 (Ar-CH), 137.9–139.5 ppm ($C_q$ Bn); ESI-MS: *m/z*: 987.5 [$M+H^+$]; IR (neat): $\tilde{\nu} = 732$, 909, 1027, 1454, 2866, 3030 cm$^{-1}$.

***para*-Methoxyphenyl-2-*O*-benzyl-(2,3,4,6-tetra-*O*-benzyl-α-L-gulopyranoside)-4,6-benzylidene-β-D-galactopyranoside (15)**: As described for the synthesis of **13** using acceptor **12** (0.139 g, 0.3 mmol). Purification by size exclusion and column chromatography yielded **15** as a colourless oil (73%, 0.144 g). Determination of the α/β ratio by $^1$H NMR: $\delta = 5.47$ (s, 0.07H, CH benzylidene β), 5.55 ppm (s, 1H, CH benzylidene α). α anomer: $^1$H NMR (400 MHz, $CDCl_3$): $\delta = 3.28$ (s, 1H, H-6), 3.43 (dd, 1H, $J = 10$ Hz, H-6), 3.57–3.60 (m, 1H, H-4′), 3.62 (t, 1H, $J = 10$ Hz, H-5′), 3.68 (dd, 1H, $J = 10$, 3.6 Hz, H-3), 3.71 (s, 1H, H-6′), 3.86 (m, 1H, H-2′), 3.90 (m, 1H, H-3′), 4.03–4.10 (m, 2H, H-2, H-6), 4.30–4.49 (m, 6H, $CH_2$ Bn), 4.58–4.63 (m, 2H, H-4, $CH_2$ Bn), 4.71–4.72 (m, 1H, H-5), 4.76 (d, 1H, $J = 11.2$ Hz, $CH_2$ Bn), 4.87–4.90 (m, 2H, H-1, $CH_2$ Bn), 5.23 (d, 1H, $J = 3.6$ Hz, H-1′), 5.55 (s, 1H, CH benzylidene), 6.74–6.76 (m, 2H, Ar-H), 6.99–7.01 (m, 2H, Ar-H), 7.12–7.31 (m, 35H, Ar-H), 7.38–7.40 (m, 3H, Ar-H), 7.50–7.52 ppm (m, 2H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta =$ 55.5 ($OCH_3$ *p*MP (*p*-methoxyphenyl)), 66.6 (C-5), 68.5 (C-6), 70.9 (C-6′),

70.9 (C-4), 72.0 (C-3′), 72.5 ($CH_2$ Bn), 72.8 ($CH_2$ Bn), 73.8 ($CH_2$ Bn), 74.3 (C-2′), 75.1 (C-5′), 75.1 ($CH_2$ Bn), 76.8 (C-4′), 77.0 (C-2), 82.8 (C-3), 99.5 (CH benzylidene), 100.7 (C-1′), 102.7 (C-1), 114.2 ($C_{pMP}$), 118.9 ($C_{pMP}$), 125.2–128.3 (Ar-CH), 137.7 ($C_q$ Bn), 138.9 ($C_q$ Bn), 138.1 ($C_q$ Bn), 138.3 ($C_q$ Bn), 138.9 ($C_q$ Bn), 139.0 ($C_q$ Bn), 151.6 ($C_q$ Bn), 155.0 ppm ($C_q$ Bn); HRMS: *m/z*: calcd for $C_{61}H_{62}O_{12}+NH_4^+$: 1004.45795; found: 1004.45946; IR (neat): $\tilde{\nu}$ = 731, 824, 872, 910, 997, 1026, 1065, 1080, 1173, 1217, 1265, 1308, 1367, 1454, 1506, 2866, 3030 $cm^{-1}$.

**Methyl-2,3,4-tri-*O*-benzyl-6-*O*-[methyl (2,3,4-tri-*O*-benzyl-α,β-L-gulopyranosyl)uronate]-α-D-glucopyranoside (16)**: A solution of donor **7** (0.114 g, 0.2 mmol), diphenyl sulfoxide (0.045 g, 0.22 mmol), and tri-*tert*-butylpyrimidine (0.124 g, 0.5 mmol) in $CH_2Cl_2$ (4 mL) was stirred over activated 3-Å MS for 30 min. The mixture was cooled to −60 °C before triflic acid anhydride (37 μL, 0.22 mmol) was added. The mixture was warmed to −45 °C then cooled to −78 °C followed by the addition of acceptor **10** (0.139 g, 0.3 mmol) in $CH_2Cl_2$ (3 mL). Stirring was continued and the reaction mixture was allowed to warm to 0 °C and $Et_3N$ (0.15 mL) was added. The reaction mixture was diluted with $CH_2Cl_2$ and washed with $NaHCO_3$ (aq). The aqueous layer was extracted twice with $CH_2Cl_2$. The collected organic layers were dried over $MgSO_4$ and concentrated in vacuo. Purification by size exclusion and column chromatography yielded **16** as a colourless oil (115 mg, 73 %, α/β = 3:1). Determination of the α/β ratio by $^1$H NMR (400 MHz, $CDCl_3$): δ = 3.60 (s, 1.15 H, $CH_3$ $CO_2$Me β), 3.64 (s, 3.62 H, $CH_3$ $CO_2$Me α), 4.96 (d, 0.33 H, *J* = 8 Hz, H-1′β), 5.08 ppm (d, 1 H, *J* = 3.6 Hz, H-1); $^{13}$C NMR (100 MHz, $CDCl_3$): δ = 97.8 (C-1α), 98.0 (C-1′α), 100.6 ppm (C-1′β); HRMS: *m/z*: calcd for $C_{56}H_{60}O_{12}+NH_4^+$: 942.44230; found: 942.44351; IR (neat): $\tilde{\nu}$ = 731, 808, 910, 1026, 1047, 1070, 1207, 1265, 1304, 1358, 1439, 1454, 1497, 1732, 1765, 2876, 3030 $cm^{-1}$.

**Methyl-2,3,6-tri-*O*-benzyl-4-*O*-[methyl (2,3,4-tri-*O*-benzyl-α-L-gulopyranosyl)uronate]-α-D-glucopyranoside (17)**: As described for the synthesis of **16** using acceptor **11** (0.139 g, 0.3 mmol). Purification by size exclusion and column chromatography yielded **17** as a colourless oil (189 mg, 94 %). $^1$H NMR (400 MHz, $CDCl_3$): δ = 3.31 (s, 3 H, $CH_3$ $CO_2$Me), 3.42 (s, 3 H, $CH_3$ OMe), 3.63 (dd, 1 H, *J* = 3.6, 8.8 Hz, H-2), 3.72–3.75 (m, 2 H, H-6, H-3′), 3.85–3.97 (m, 5 H, H-3, H-5, H-6, H-2′, H-4′), 4.35 (s, 2 H, $CH_2$ Bn), 4.40–4.53 (m, 4 H, $CH_2$ Bn), 4.57 (d, 1 H, *J* = 12 Hz, $CH_2$ Bn), 4.63 (d, 1 H, *J* = 3.6 Hz, H-1), 4.69 (d, 1 H, *J* = 12 Hz, $CH_2$ Bn), 4.83 (d, 1 H, *J* = 12 Hz, $CH_2$ Bn) 4.99 (m, 2 H, H-5′, $CH_2$ Bn), 5.26 (d, 1 H, *J* = 3.6 Hz, H-1′), 7.16–7.40 ppm (m, 30 H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): δ = 51.4 ($CH_3$ COOMe), 54.9 ($CH_3$ OMe), 67.6 (C-5′), 68.3 (C-6), 70.2, 71.5, 72.2, 72.6, 72.9, 73.1, 73.2, 73.3, 74.2, 75.0, 76.6, 76.7, 77.3, 79.8, 80.1, 97.4 (C-1′), 97.8 (C-1), 126.5–128.3 (CH Bn), 137.5–139.2 ($C_q$ Bn), 169.6 ppm (COOMe); ESI-MS: 925.4 [*M*+H$^+$]; IR (neat): $\tilde{\nu}$ = 533, 732, 910, 1027, 1208, 1554, 1797, 1734, 1764, 2892, 3031 $cm^{-1}$.

***para*-Methoxyphenyl-2-*O*-benzyl-3-*O*-[methyl (2,3,4-tri-*O*-benzyl-α,β-L-gulopyranosyl)uronate]-4,6-benzylidene-β-D- galactopyranoside (18)**: As described for the synthesis of **13** using acceptor **12** (0.139 g, 0.3 mmol). Purification by size exclusion and column chromatography yielded **18** as a colourless oil (124 mg, 79 %, α/β = 10:1). Determination of the α/β ratio by $^1$H NMR (400 MHz, $CDCl_3$): δ = 5.21 (d, 0.11 H, *J* = 8 Hz, H-1′β), 5.34 ppm (d, 1 H, *J* = 3.6 Hz, H-1′α); $^{13}$C NMR (100 MHz, $CDCl_3$): δ = 100.2 (C-1′α), 102.6 ppm (C-1α); HRMS: *m/z*: calcd for $C_{55}H_{56}O_{13}+Na^+$: 947.36131; found: 947.36190; IR (neat): $\tilde{\nu}$ = 731, 826, 908, 997, 1026 1065, 1078, 1175, 1217, 1265, 1306, 1366, 1439, 1454, 1506, 175, 2870, 3030 $cm^{-1}$.

**Phenyl-2,3-di-*O*-benzyl-4,6-*O*-benzylidene-1-thio-β-L-gulopyranoside (19)**: Compound **6** (10.88 g, 40.0 mmol) was dissolved in MeCN (400 mL) and benzaldehyde dimethylacetal (6.32 mL, 42.0 mmol) and a catalytic amount of *p*-TsOH were added. After stirring for 15 h, the reaction mixture was quenched with $Et_3N$ until neutral pH and concentrated in vacuo. The residue was dissolved in DMF (200 mL) and cooled to 0 °C. Respectively, BnBr (11.4 mL, 96 mmol) and NaH (3.84 g, 96 mmol, 60 % dispersion in oil) were added. After stirring overnight, the reaction mixture was quenched with MeOH and concentrated in vacuo. The residue was taken up in $Et_2O$ and washed three times with $H_2O$. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Column chromatography yielded **19** as a colourless oil (15.12 g, 70 %). $[\alpha]_D^{22}$ = +39.2 (*c* = 1, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$): δ = 3.81 (dd, 1 H, *J* = 2.8, 10.0 Hz, H-2), 3.83 (s, 1 H, H-5), 3.92 (t, 1 H, *J* = 3.2 Hz), 3.97 (dd, 1 H, *J* = 1.6, 12.4 Hz, H-6), 4.05 (d, 1 H, *J* = 3.6 Hz, H-4), 4.33 (d, 1 H, *J* = 12.8 Hz, H-6), 4.36 (d, 1 H, *J* = 11.6 Hz, $CH_2$ Bn), 4.47 (d, 1 H, *J* = 11.2 Hz, $CH_2$ Bn), 4.63 (d, 1 H, *J* = 12.0 Hz, $CH_2$ Bn), 4.79 (d, 1 H, *J* = 12.0 Hz, $CH_2$ Bn), 5.27 (d, 1 H, *J* = 9.6 Hz, H-1), 5.47 (s, 1 H, CH benzylidene), 7.15–7.72 ppm (m, 20 H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): δ = 67.5 (C-5), 69.5 (C-6), 72.5 ($CH_2$ Bn), 73.6 ($CH_2$ Bn), 74.0 (C-2), 74.3 (C-3), 75.0 (C-4), 83.1 (C-1), 100.9 (CHPh), 126.4–132.7 (Ar-CH), 133.0 ($C_q$ SPh), 137.8, 137.9, 138.1 ppm ($C_q$ Bn, $C_q$ benzylidene); HRMS: *m/z*: calcd for $C_{33}H_{32}O_5S+H^+$: 541.20432; found: 541.20440; IR (neat): $\tilde{\nu}$ = 995, 1080, 1394, 1454, 2870, 3032 $cm^{-1}$.

**Phenyl-2,3-*O*-benzyl-1-thio-β-L-gulopyranoside (20)**: A solution of **3** (10.8 g, 20 mmol) in MeOH (200 mL) with a catalytic amount of *p*-TsOH was stirred overnight at room temperature. The reaction mixture was quenched with $Et_3N$ until neutral pH and concentrated in vacuo. Purification of the residue by column chromatography afforded **20** as a colourless oil (9.05 g, quantitative). $[\alpha]_D^{22}$ = +27.6 (*c* = 1, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$): δ = 2.38 (bs, 1 H, 6-OH), 3.45 (d, 1 H, *J* = 3.6 Hz, 4′-OH), 3.81 (dd, 1 H, *J* = 2.8, 10.0 Hz, H-2), 3.85–3.98 (m, 5 H, H-3, H-4, H-5, H-6, H-6), 4.55 (d, 1 H, *J* = 11.6 Hz, $CH_2$ Bn), 4.60 (d, 1 H, *J* = 12.0 Hz, $CH_2$ Bn), 4.64 (d, 1 H, *J* = 11.6 Hz, $CH_2$ Bn), 4.77 (d, 1 H, *J* = 12.0 Hz, $CH_2$ Bn), 5.28 (d, 1 H, *J* = 10.0 Hz, H-1), 7.24–7.38 (m, 13 H, Ar-H), 7.52–7.54 ppm (m, 2 H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): δ = 64.0 (C-6), 70.8 (C-5), 72.7 ($CH_2$ Bn), 73.5 ($CH_2$ Bn), 74.2 (C-4), 75.0 (C-2), 75.5 (C-3), 84.7 (C-1), 127.2–131.5 (Ar-CH), 133.8 ($C_q$ SPh), 137.9 ($C_q$ Bn), 138.2 ppm ($C_q$ Bn); HRMS: *m/z*: calcd for $C_{26}H_{28}O_5S+H^+$: 453.17302; found: 453.17296; IR (neat): $\tilde{\nu}$ = 956, 1026, 1454, 2889, 3402 $cm^{-1}$.

**Methyl (phenyl-2,3-*O*-benzyl-1-thio-β-L-guluronate) (21)**: Compound **20** (0.538 g, 1.18 mmol) was taken up in $CH_2Cl_2$ (10 mL) and $H_2O$ (4 mL). TEMPO (0.038 g, 0.24 mmol) and BAIB (0.955 g, 2.96 mmol) were added to this mixture, and the reaction mixture was stirred vigorously until analysis by TLC showed complete conversion of the starting material. $Na_2S_2O_3$ (50 mL, aq) was added and the resulting mixture was stirred for 15 min. The layers were separated and the aqueous phase was acidified with 1 M HCl and extracted three times with $CH_2Cl_2$. The combined organic layers were dried over $MgSO_4$ and concentrated in vacuo. The resulting syrup was then dissolved in $Et_2O$ (20 mL) and cooled to 0 °C, after which TMS diazomethane (0.5 m in $Et_2O$) was added until the solution turned bright yellow. AcOH was added until the yellow colour disappeared. The mixture was concentrated in vacuo. Purification by column chromatography yielded **21** as a colourless oil (0.280 g, 49 %). $[\alpha]_D^{22}$ = −98.8 (*c* = 1, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$): δ = 2.76 (bs, 1 H, 4′-OH), 3.73–3.74 (m, 1 H, H-2), 3.75 (s, 3 H, $CH_3$ $CO_2$Me), 3.95 (t, 1 H, *J* = 3.4 Hz, H-3), 4.16 (bs, 1 H, H-4), 4.51 (d, 1 H, *J* = 11.2 Hz, $CH_2$ Bn), 4.58–4.64 (m, 3 H, $CH_2$ Bn, H-5), 4.75 (d, 1 H, *J* = 12.0 Hz, $CH_2$ Bn), 5.21 (d, 1 H, *J* = 10.0 Hz), 7.24–7.62 ppm (m, 15 H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): δ = 52.4 ($CH_3$ $CO_2$Me), 69.4 (C-4), 72.7 ($CH_2$ Bn), 73.4 ($CH_2$ Bn), 74.3 (C-2), 74.9 (C-3), 75.1 (C-5), 85.1 (C-1), 127.5–132.3 (Ar-CH), 133.3 ($C_q$ Bn), 137.7 ($C_q$ Bn), 137.9 ($C_q$ Bn), 169.4 ppm (COOMe); HRMS: *m/z*: calcd for $C_{27}H_{28}O_6S+Na^+$: 503.1499; found: 503.1488; IR (neat): $\tilde{\nu}$ = 1069, 1118, 1744, 2855, 2920, 3445 $cm^{-1}$.

**Methyl (phenyl-2,3-*O*-benzyl-4-*O*-levulinoyl-1-thio-β-L-guluronate) (22)**: A solution of $Lev_2O$ in dioxane (0.5 m, 8.0 mL, 4.0 mmol) was added to a solution of **21** (0.96 g, 2.00 mmol) in pyridine (20 mL). The reaction mixture was diluted with EtOAc after 16 h and washed with 1 M HCl (aq), $NaHCO_3$ (aq), and brine. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Purification by column chromatography yielded **22** as a colourless oil (1.10 g, 95 %). $[\alpha]_D^{22}$ = −105.6 (*c* = 1, $CHCl_3$); $^1$H NMR (600 MHz, $CDCl_3$): δ = 2.16 (s, 3 H, $CH_3$ Lev), 2.45–2.48 (m, 2 H, $CH_2$ Lev), 2.64–2.73 (m, 2 H, $CH_2$ Lev), 3.60 (dd, 1 H, *J* = 3.0, 10.2 Hz, H-2), 3.76 (s, 3 H, $CH_3$ $CO_2$Me), 3.93 (t, 1 H, *J* = 3.3 Hz, H-3), 4.47–4.76 (m, 5 H, $CH_2$ Bn, H-5), 5.21 (d, 1 H, *J* = 10.2 Hz, H-1), 5.29 (dd, 1 H, *J* = 1.5, 3.9 Hz, H-4), 7.26–7.66 ppm (m, 15 H, Ar-H); $^{13}$C NMR (150 MHz, $CDCl_3$): δ = 27.9 ($CH_2$ Lev), 29.7 ($CH_3$ Lev), 37.7 ($CH_2$ Lev), 52.3 ($CH_3$ $CO_2$Me), 70.2 (C-4), 72.4 ($CH_2$ Bn), 72.5 (C-3), 73.2 (C-5), 73.4 ($CH_2$ Bn), 73.7 (C-2), 84.6 (C-1), 127.5–132.6 (Ar-CH), 133.4 ($C_q$ SPh), 137.5 ($C_q$ Bn), 137.6 ($C_q$ Bn), 167.9 (COOMe), 171.3 (COO Lev), 206.0 ppm (CO Lev); HRMS: *m/z*: calcd for $C_{32}H_{34}O_8S+Na^+$: 601.1867;

found: 601.1843; IR (neat): $\tilde{\nu}$ = 1026, 1064, 1111, 1250, 1713, 1740, 2873 $cm^{-1}$.

**Phenyl-2,3-*O*-benzyl-6-*O*-*tert*-butyldimethylsilyl-1-thio-β-L-gulopyranoside (23)**: A solution of **20** (0.869 g, 1.92 mmol) in DMF (10 mL) was cooled to 0 °C. Respectively, imidazole (0.136 g, 2.00 mmol) and TBDMSCl (0.301 g, 2.00 mmol) were added and the reaction mixture was warmed to room temperature. After stirring for 4 h, the reaction mixture was quenched with MeOH and concentrated in vacuo. The residue was taken up in $Et_2O$ and washed three times with $H_2O$. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Column chromatography yielded **23** as a colourless oil (0.978 g, 90 %). $[\alpha]_D^{22}$ = +32.4 ($c$ = 1, $CHCl_3$); $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 0.08 (s, 3H, $CH_3$), 0.11 (s, 3H, $CH_3$), 0.91 (s, 9H, *t*Bu), 3.79 (dd, 1H, $J$ = 3.0, 10.2 Hz, H-2), 3.82 (bs, 1H, OH), 3.87–3.91 (m, 3H, H-3, H-5, H-6), 3.97 (dd, 1H, $J$ = 3.6, 10.8 Hz, H-6), 4.00 (bs, 1H, H-4), 4.46 (d, 1H, $J$ = 11.4 Hz, $CH_2$ Bn), 4.55 (d, 1H, $J$ = 11.4 Hz, $CH_2$ Bn), 4.57 (d, 1H, $J$ = 12.0 Hz, $CH_2$ Bn), 4.74 (d, 1H, $J$ = 12.0 Hz, $CH_2$ Bn), 5.18 (d, 1H, $J$ = 10.2 Hz, H-1), 7.23–7.59 ppm (m, 15H, Ar-H); $^{13}$C NMR (300 MHz, $CDCl_3$): $\delta$ = −5.7 ($CH_3$), −5.5 ($CH_3$), 18 ($C_q$ TBDMS), 25.8 (*t*Bu), 65.2 (C-6), 70.8 (C-4), 72.7 ($CH_2$ Bn), 73.5 ($CH_2$ Bn), 73.9 (C-5), 74.7 (C-2), 75.6 (C-3), 84.6 (C-1), 127.2–132.3 (Ar-CH), 133.8 ($C_q$ SPh), 138.1 ($C_q$ Bn), 138.4 ppm ($C_q$ Bn); ESI-MS: 567.3 [$M$+$H^+$]; IR (neat): $\tilde{\nu}$ = 833, 1026, 1103, 1254, 2855, 2928, 3456 $cm^{-1}$.

**Phenyl-2,3-*O*-benzyl-6-*O*-*tert*-butyldimethylsilyl-4-*O*-levulinoyl-1-thio-β-L-gulopyranoside (24)**: A solution of $Lev_2O$ in dioxane (0.5 m, 6.92 mL, 3.46 mmol) was added to a solution of **23** (0.978 g, 1.73 mmol) in pyridine (10 mL). The reaction mixture was diluted with EtOAc after 16 h and washed with 1 M HCl (aq), $NaHCO_3$ (aq), and brine. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Purification by column chromatography yielded **24** as a colourless oil (1.08 g, 94 %). $[\alpha]_D^{22}$ = +35.6 ($c$ = 1, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ = −0.01 (s, 3H, $CH_3$ TBDMS), −0.01 (s, 3H, $CH_3$ TBDMS), 0.83 (s, 9H, *t*Bu TBDMS), 2.13 (s, 3H, $CH_3$ Lev), 2.45–2.48 (m, 2H, $CH_2$ Lev), 2.64–2.67 (m, 2H, $CH_2$ Lev), 3.55–3.60 (m, 2H, H-2, H-6), 3.68 (dd, 1H, $J$ = 6.4 Hz, 10.0 Hz, H-6), 3.90 (t, 1H, $J$ = 3.6 Hz, H-3), 4.10 (t, 1H, $J$ = 6.8 Hz, H-5), 4.48 (d, 1H, $J$ = 11.6 Hz, $CH_2$ Bn), 4.56 (d, 1H, $J$ = 11.6 Hz, $CH_2$ Bn), 4.64 (d, 1H, $J$ = 12.0 Hz, $CH_2$ Bn), 4.69 (d, 1H, $J$ = 12.0 Hz, $CH_2$ Bn), 5.06 (d, 1H, $J$ = 3.6 Hz, H-4), 5.23 (d, 1H, $J$ = 10.0 Hz, H-1), 7.18–7.54 ppm (m, 15H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ = −5.7 ($CH_3$ TBDMS), −5.5 ($CH_3$ TBDMS), 18 ($C_q$ TBDMS), 25.7 (*t*Bu TBDMS), 27.9 ($CH_2$ Lev), 29.7 ($CH_3$ Lev), 37.8 ($CH_2$ Lev), 61.0 (C-6), 68.7 (C-4), 72.2 ($CH_2$ Bn), 72.7 (C-3) 73.1 ($CH_2$ Bn), 74.4, 74.5 (C-2, C-5), 84.4 (C-1), 126.9–131.2 (Ar-CH), 134.2 ($C_q$ SPh), 137.7 ($C_q$ Bn), 137.8 ($C_q$ Bn), 171.6 (COO Lev), 205.9 ppm (CO Lev); HRMS: $m/z$: calcd for $C_{37}H_{48}O_7SSi$+$H^+$: 665.29628; found: 665.29699; IR (neat): $\tilde{\nu}$ = 1026, 1096, 1362, 1717, 1740, 2858, 2928 $cm^{-1}$.

**Phenyl-2,3-di-*O*-benzyl-4,6-*O*-di-*tert*-butylsilylidene-1-thio-β-L-gulopyranoside (25)**: $(tBu)_2Si(OTf)_2$ (3.24 mL, 10.0 mmol) was added to a solution of **6** (2.72 g, 10.0 mmol) in pyridine (100 mL) at −20 °C, after which the reaction mixture was warmed to room temperature. The reaction mixture was quenched with MeOH, concentrated in vacuo, taken up in EtOAc, and washed with 1 M HCl (aq), $NaHCO_3$ (aq), and brine. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. The residue was dissolved in DMF (50 mL) and cooled to 0 °C. Respectively, BnBr (2.87 mL, 24.0 mmol) and NaH (0.96 g, 24.0 mmol, 60 % dispersion in oil) were added. After stirring for 15 h, the mixture was quenched with MeOH and concentrated in vacuo. The residue was taken up in $Et_2O$ and washed three times with $H_2O$. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Column chromatography yielded **25** as a colourless oil (5.20 g, 88 %). $[\alpha]_D^{22}$ = +26.6 ($c$ = 1, $CHCl_3$); $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 1.00 (s, 9H, *t*Bu), 1.04 (s, 9H, *t*Bu), 3.74 (bs, 1H, H-5), 3.87–3.89 (m, 2H, H-2, H-3), 4.11 (dd, 1H, $J$ = 2.4, 12.6 Hz, H-6), 4.15–4.18 (m, 2H, H-4, H-6), 4.59 (d, 1H, $J$ = 12.0 Hz, $CH_2$ Bn), 4.66 (d, 1H, $J$ = 11.4 Hz, $CH_2$ Bn), 4.75 (d, 1H, $J$ = 11.4 Hz, $CH_2$ Bn), 4.84 (d, 1H, $J$ = 12.0 Hz, $CH_2$ Bn), 5.27 (d, 1H, $J$ = 9.6 Hz, H-1), 7.18–7.54 ppm (m, 15H, Ar-H); $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 20.4 ($C_q$ *t*Bu), 23.2 ($C_q$ *t*Bu), 27.5 ($CH_3$ *t*Bu), 67.2 (C-6), 72.0 (C-4), 72.1 (C-5), 72.7 ($CH_2$ Bn), 73.7 ($CH_2$ Bn), 75.2 (C-2), 76.3 (C-3), 84.9 (C-1), 126.9–134.7 (Ar-CH), 134.7 ($C_q$ SPh), 137.8 ($C_q$ Bn), 138.4 ppm ($C_q$ Bn); HRMS: $m/z$: calcd for $C_{34}H_{44}O_5SSi$+$H^+$: 593.27515; found: 593.27527; IR (neat): $\tilde{\nu}$ = 853, 937, 1088, 1474, 2858, 2932 $cm^{-1}$.

**3-Azidopropyl [methyl (2,3-*O*-benzyl-α-L-gulopyranoside)uronate] (27)**: Hydrazine (76 μL, 1.6 mmol) was added to a solution of **29** (178 g, 0.31 mmol) in pyridine/AcOH (4:1, 3.5 mL). The reaction mixture was stirred for 10 min, diluted with EtOAc, and washed with 1 M HCl, water, and $NaHCO_3$ (aq). The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Column chromatography afforded **27** as a colourless oil (116 mg, 80 %). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ = 1.81–1.96 (m, 2H, $CH_2$ $C_3H_6N_3$), 2.39 (d, 1H, $J$ = 5.6 Hz, 4′-OH), 3.35–3.38 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.47–3.53 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.78 (s, 3H, $CH_3$ $CO_2Me$), 3.82–3.88 (m, 2H, H-2, $C_3H_6N_3$), 3.90 (t, 1H, $J$ = 3.4 Hz, H-3), 4.19 (bs, 1H, H-4), 4.57–4.67 (m, 3H, $CH_2$ Bn), 4.79 (d, 1H, $J$ = 1.2 Hz, H-5), 4.87 (d, 1H, $J$ = 12.0 Hz, $CH_2$ Bn), 4.95 (d, 1H, $J$ = 3.6 Hz, H-1), 7.25–7.38 ppm (m, 10H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ = 28.9 ($CH_2$ $C_3H_6N_3$), 48.2 ($CH_2$ $C_3H_6N_3$), 52.4 ($CH_3$ $CO_2Me$), 65.5 ($CH_2$ $C_3H_6N_3$), 67.7 (C-5), 69.8 (C-4), 71.8 ($CH_2$ Bn), 72.9 (C-2), 73.1 ($CH_2$ Bn), 75.4 (C-3), 98.1 (C-1), 127.6–128.4 (Ar-CH), 137.9 ($C_q$ Bn), 138.6 ($C_q$ Bn), 170.5 ppm (COOMe); HRMS: $m/z$: calcd for $C_{24}H_{29}N_3O_7$+$H^+$: 472.2078; found: 472.2081; IR (neat): $\tilde{\nu}$ = 1034, 1088, 1450, 2095, 2870, 2924 $cm^{-1}$.

**3-Azidopropyl-2,3-*O*-benzyl-6-*O*-*tert*-butyldimethylsilyl-α-L-gulopyranoside (28)**: A solution of **35** (0.576 g, 0.988 mmol) in THF (10 mL) was cooled to 0 °C and TBAF (3 mL, 3 mmol, 1 M in THF) was added. The reaction mixture was diluted with EtOAc after 4 h and washed with water and brine. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. The residue was taken up in DMF (5.0 mL) was cooled to 0 °C. Imidazole (0.073 g, 1.08 mmol) and TBDMSCl (0.162 g, 1.08 mmol) were added and the reaction mixture was warmed to room temperature. After stirring for 4 h, the reaction mixture was quenched with MeOH and concentrated in vacuo. The residue was taken up in $Et_2O$ and washed three times with $H_2O$. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Column chromatography yielded **28** as a colourless oil (0.414 g, 75 %). $[\alpha]_D^{22}$ = −23.0 ($c$ = 1, $CHCl_3$); $^1$H NMR (500 MHz, $CDCl_3$): $\delta$ = 0.09 (s, 6H, $CH_3$ TBDMS), 0.89 (s, 9H, *t*Bu TBDMS), 1.78–1.98 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.37 (t, 2H, $J$ = 6.5 Hz, 2H, $CH_2$ $C_3H_6N_3$), 3.44–3.48 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.76–3.83 (m, 2H, OH, $CH_2$ $C_3H_6N_3$), 3.86–3.87 (m, 1H, H-5), 3.91–3.92 (m, 3H, H-2, H-6, H-6), 4.03–4.05 (m, 2H, H-3, H-4), 4.57–4.66 (m, 3H, $CH_2$ Bn), 4.86–4.89 (m, 2H, H-1, $CH_2$ Bn), 7.24–7.37 ppm (m, 10H, Ar-H); $^{13}$C NMR (125 MHz, $CDCl_3$): $\delta$ = −5.7 ($CH_3$ TBDMS), −5.6 ($CH_3$ TBDMS), 18.1 ($C_q$ *t*Bu TBDMS), 25.7 ($CH_3$ *t*Bu TBDMS), 28.9 ($CH_2$ $C_3H_6N_3$), 48.3 ($CH_2$ $C_3H_6N_3$), 64.5 ($CH_2$ $C_3H_6N_3$), 65.1 (C-3), 65.5 (C-6), 70.9 (C-4), 71.4 ($CH_2$ Bn), 72.9 ($CH_2$ Bn), 73.5 (C-2), 75.5 (C-5), 97.9 (C-1), 127.3–128.3 (Ar-CH), 138.3 ($C_q$ Bn), 139.0 ppm ($C_q$ Bn); HRMS: $m/z$: calcd for $C_{29}H_{43}N_3O_6Si$+$H^+$: 558.29939; found: 558.29985; IR (neat): $\tilde{\nu}$ = 1042, 1107, 2095, 2858, 2928 $cm^{-1}$.

**Methyl-2,3,4-tri-*O*-benzyl-6-*O*-[methyl (2,3-di-*O*-benzyl-4-*O*-levulinoyl-α,β-L-gulopyranosyl)uronate]-α-D- glucopyranoside (29)**: As described for the synthesis of **13** using donor **22** (0.061 g, 0.105 mmol) and acceptor **10** (0.073 g, 0.158 mmol). Purification by size exclusion and column chromatography yielded **29** as a colourless oil (0.064 g, 66 %, $\alpha/\beta$ = 3:1). Determination of the α/β ratio by $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ = 3.27 (s, 3H, OMe), 3.33 (s, 0.33H, OMe), 4.99 (d, 0.33H, $J$ = 8.4 Hz, H-1′β), 5.05 ppm (bs, 1H, H-1′α); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ = 55.0 ($CH_3$ OMe αα), 55.0 ($CH_3$ OMe βα), 97.9 (C-1′α), 100.6 ppm (C-1′β).

**Methyl-2,3,6-tri-*O*-benzyl-4-*O*-[methyl (2,3-di-*O*-benzyl-4-*O*-levulinoyl-α-L-gulopyranosyl)uronate]-α-D-glucopyranoside (30)**: As described for the synthesis of **13** using donor **22** (0.065 g, 0.112 mmol) and acceptor **11** (0.078 g, 0.168 mmol). Purification by size exclusion and column chromatography yielded **30** as a colourless oil (0.066 g, 64 %). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ = 2.14 (s, 3H, $CH_3$ Lev), 2.38–2.48 (m, 2H, $CH_2$ Lev), 2.59–2.72 (m, 2H, $CH_2$ Lev), 3.25 (s, 3H, $CH_3$ $CO_2Me$), 3.36 (s, 3H, $CH_3$ OMe), 3.57–3.58 (m, 1H, H-2), 3.63 (bs, 1H, H-2′), 3.65 (bs, 1H, H-4), 3.88–3.91 (m, 5H, H-3, H-5, H-6, H-6, H-3′), 4.39–4.52 (m, 5H, $CH_2$ Bn), 4.57 (bs, 1H, H-1), 4.62 (m, 3H, $CH_2$ Bn), 5.01 (s, 1H, H-5′), 5.16 (bs, 1H, H-1′), 5.19 (s, 1H, H-4′), 7.11–7.43 ppm (m, 25H, Ar-H); $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 27.9 ($CH_2$ Lev), 29.7 ($CH_3$ Lev), 37.7 ($CH_2$ Lev), 51.8 ($CH_3$ $CO_2Me$), 55.0 ($CH_3$ OMe), 66.0 (C-5′), 68.2 (C-6), 70.2, 70.7 (C-4′), 71.2 ($CH_2$ Bn), 71.8 (C-3′), 72.5 (C-2′), 73.8 ($CH_2$ Bn),

73.3 ($CH_2$ Bn), 74.2 ($CH_2$ Bn), 74.9, 79.7, 80.3 (C-2), 97.4 (C-1′), 97.9 (C-1), 126.5–128.4 (Ar-CH), 137.5–139.2 ($C_q$ arom), 168.7 ($CO_2Me$), 171.5 (CO Lev), 206.1 ppm (COO Lev).

**3-Azidopropyl [methyl(2,3-di-*O*-benzyl-4-*O*-levulinoyl-α-L-gulopyranoside)uronate] (31)**: A solution of **22** (0.116 g, 0.20 mmol), diphenyl sulfoxide (0.049 g, 0.24 mmol), and tri-*tert*-butylpyrimidine (0.129 g, 0.52 mmol) in $CH_2Cl_2$ (4 mL) was stirred over activated 3-Å MS for 30 min. The reaction mixture was cooled to −60 °C before triflic acid anhydride (40 μL, 0.24 mmol) was added, then warmed to −45 °C. The reaction mixture was stirred for 10 min at −45 °C followed by the addition of azidopropanol (0.061 g, 0.6 mmol) in $CH_2Cl_2$ (1.5 mL). Stirring was continued and the reaction mixture was allowed to warm to 0 °C and $Et_3N$ (0.14 mL) was added. The reaction mixture was diluted with $CH_2Cl_2$ and washed with $NaHCO_3$ (aq). The aqueous layer was extracted twice with $CH_2Cl_2$. The collected organic layers were dried over $MgSO_4$ and concentrated in vacuo. Purification by column chromatography yielded **31** as a colourless oil (0.098 g, 86 %, $\alpha/\beta$ = 1:3). The anomers could be separated by column chromatography; the spectral data for the α anomer are given. $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ = 1.80–1.96 (m, 2H, $C_3H_6N_3$), 2.17 (s, 3H, $CH_3$ Lev), 2.45–2.49 (m, 2H, $CH_2$ Lev), 2.66–2.73 ($CH_2$ Lev), 3.33–3.37 (m, 2H, $C_3H_6N_3$), 3.48–3.53 (m, 1H, $C_3H_6N_3$), 3.70 (t, 1H, $J$ = 3.8 Hz, H-2), 3.71 (s, 3H, $CO_2Me$), 3.81–3.86 (m, 1H, $C_3H_6N_3$), 3.92 (t, 1H, $J$ = 3.4 Hz, H-3), 4.52 (d, 1H, $J$ = 12.4 Hz, $CH_2$ Bn), 4.62 (d, 1H, $J$ = 12.4 Hz, $CH_2$ Bn), 4.72 (d, 1H, $J$ = 12.0, $CH_2$ Bn), 4.82–4.86 (m, 2H, H-5, $CH_2$ Bn), 4.95 (d, 1H, $J$ = 4.0 Hz, H-1), 5.32 (dd, 1H, $J$ = 1.6 Hz, 3.2 Hz, H-4), 7.26–7.41 ppm (m, 10H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ = 28.0 ($CH_2$ Lev), 28.9 ($CH_2$ $C_3H_6N_3$), 29.7 ($CH_3$ Lev), 37.8 ($CH_2$ Lev), 48.2 ($CH_2$ $C_3H_6N_3$), 52.4 ($CH_3$ $CO_2Me$), 65.4 (C-5), 70.8 (C-4), 71.5 ($CH_2$ Bn), 72.5, 72.5 (C-2, C-3), 73.1 ($CH_2$ Bn), 97.9 (C-1), 127.6–128.4 (Ar-CH), 137.8 ($C_q$ Bn), 138.3 ($C_q$ Bn), 169.1 (COOMe), 171.4 (COO Lev), 206.0 ppm (CO Lev); HRMS: $m/z$: calcd for $C_{29}H_{35}N_3O_9+H^+$: 570.2446; found: 570.2447; IR (neat): $\tilde{\nu}$ = 1141, 1744, 2095, 2870, 2924 $cm^{-1}$.

**3-Azidopropyl (methyl{2,3-di-*O*-benzyl-4-*O*-[methyl (2,3-di-*O*-benzyl-4-*O*-levulinoyl-α-L-gulopyranosyl)uronate]-α-L-gulopyranoside}uronate] (32)**: A solution of **22** (0.116 g, 0.20 mmol), diphenyl sulfoxide (0.049 g, 0.24 mmol), and tri-*tert*-butylpyrimidine (0.129 g, 0.52 mmol) in $CH_2Cl_2$ (4 mL) was stirred over activated 3-Å MS for 30 min. The reaction mixture was cooled to −60 °C before triflic acid anhydride (40 μL, 0.24 mmol) was added, then warmed to −45 °C. The reaction mixture was stirred for 10 min at −45 °C followed by the addition of **27** (0.078 g, 0.166 mmol) in $CH_2Cl_2$ (1.6 mL). Stirring was continued, the reaction mixture was allowed to warm to 0 °C, and $Et_3N$ (0.14 mL) was added. The reaction mixture was diluted with $CH_2Cl_2$ and washed with $NaHCO_3$ (aq). The aqueous layer was extracted twice with $CH_2Cl_2$ and the collected organic layers were dried over $MgSO_4$ and concentrated in vacuo. Purification by size exclusion and column chromatography yielded **32** as a colourless oil (0.053 g, 34 %, $\alpha/\beta$ = 3:1). The anomers could be separated by column chromatography; the spectral data for the α anomer are given. $[\alpha]_D^{22}$ = −64.4 ($c$ = 1, $CH_2Cl_2$); $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = 1.81–1.94 (m, 2H, $CH_2$ $C_3H_6N_3$), 2.17 (s, 3H, $CH_3$ Lev), 2.45–2.48 (m, 2H, $CH_2$ Lev), 2.67–2.72 (m, 2H, $CH_2$ Lev), 3.32–3.38 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.52–3.55 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.56 (s, 3H, $CH_3$ $CO_2Me$), 3.66 (t, 1H, $J$ = 3.3 Hz, H-2′), 3.70–3.72 (m, 4H, H-2, $CH_3$ $CO_2Me$), 3.86–3.90 (m, 3H, H-3, H-3′, $CH_2$ $C_3H_6N_3$), 4.18 (d, 1H, $J$ = 12.6 Hz, $CH_2$ Bn), 4.27 (m, 1H, H-4), 4.30 (d, 1H, $J$ = 12.0 Hz, $CH_2$ Bn), 4.47 (d, 1H, $J$ = 12.0 Hz, $CH_2$ Bn), 4.56 (d, 1H, $J$ = 12.0 Hz, $CH_2$ Bn), 4.59–4.61 (m, 3H, H-5′, $CH_2$ Bn), 4.78–4.81 (m, 3H, H-5, $CH_2$ Bn), 4.97 (d, 1H, $J$ = 3.6 Hz, H-1), 5.17 (d, 1H, $J$ = 3.6 Hz, H-1′), 5.27 (dd, 1H, $J$ = 1.8, 4.2 Hz, H-4′), 7.09–7.42 ppm (m, 20H, Ar-H); $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = 27.9 ($CH_2$ Lev), 28.9 ($CH_2$ $C_3H_6N_3$), 29.7 ($CH_3$ Lev), 37.8 ($CH_2$ Lev), 48.2 ($CH_2$ $C_3H_6N_3$), 52.1 ($CH_3$ $CO_2Me$), 52.4 ($CH_3$ $CO_2Me$), 65.3 ($CH_2$ $C_3H_6N_3$), 66.8 (C-5′), 67.1 (C-5), 70.9 (C-4′), 71.4 ($CH_2$ Bn), 71.6 ($CH_2$ Bn), 71.7 (C-3′), 72.8 ($CH_2$ Bn), 73.0 ($CH_2$ Bn), 73.1 (C-2′), 73.5 (C-2), 75.1 (C-3), 77.7 (C-4), 97.6 (C-1), 99.7 (C-1′), 127.4–128.3 (Ar-CH), 137.7 ($C_q$ Bn), 137.9 ($C_q$ Bn), 138.5 ($C_q$ Bn), 138.6 ($C_q$ Bn), 168.5, 169.9, 171.4 (COOMe, COO Lev), 206.10 ppm (CO Lev); HRMS: $m/z$: calcd for $C_{50}H_{57}N_3O_{15}+Na^+$: 962.36955; found: 962.36819; IR (neat): $\tilde{\nu}$ = 1038, 1142, 1454, 1744, 2095, 2870, 2924 $cm^{-1}$.

**3-Azidopropyl-2,3-*O*-benzyl-6-*O*-*tert*-butyldimethylsilyl-4-*O*-levulinoyl-α,β-L-gulopyranoside (33)**: A solution of donor **24** (0.133 g, 0.2 mmol), diphenyl sulfoxide (0.045 g, 0.22 mmol), and tri-*tert*-butylpyrimidine (0.124 g, 0.5 mmol) in $CH_2Cl_2$ (4 mL) was stirred over activated 3-Å MS for 30 min. The reaction mixture was cooled to −70 °C before triflic acid anhydride (37 μL, 0.22 mmol) was added. The reaction mixture was stirred for 10 min at −70 °C followed by the addition of azidopropanol (0.061 g, 0.6 mmol) in $CH_2Cl_2$ (1.5 mL). Stirring was continued, the reaction mixture was allowed to warm to 0 °C, and $Et_3N$ (0.15 mL) was added. The reaction mixture was diluted with $CH_2Cl_2$ and washed with $NaHCO_3$ (aq). The aqueous layer was extracted twice with $CH_2Cl_2$, and the collected organic layers were dried over $MgSO_4$ and concentrated in vacuo. Purification by column chromatography yielded **33** as a colourless oil (0.098 g, 86 %, $\alpha/\beta$ = 3:1). The anomers could not be separated by column chromatography. $^1$H NMR (600 MHz, $CDCl_3$): $\delta$ = −0.01–0.01 (m, 7.8H, $CH_3$ TBDMS), 0.83 (s, 9H, *t*Bu TBDMS), 0.84 (s, 3H, *t*Bu TBDMS), 1.78–1.93 (m, 2.6H, $CH_2$ $C_3H_6N_3$), 2.13 (s, 1H, $CH_3$ Lev), 2.14 (s, 3H, $CH_3$ Lev), 2.47–2.49 (m, 2.6H, $CH_2$ Lev), 2.61–2.73 (m, 2.6H, $CH_2$ Lev), 3.32–3.40 (m, 4H), 3.43–3.47 (m, 1.3H, $CH_2$ $C_3H_6N_3$), 3.51 (dd, 1H, $J$ = 6.6 Hz, 9.6 Hz), 3.57–3.62 (m, 2.9H), 3.65–3.70 (m, 1.6H), 3.77–3.81 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.84–3.87 (m, 1.3H), 3.93–3.96 (m, 0.3H, $CH_2$ $C_3H_6N_3$), 4.06 (t, 0.3H, $J$ = 6.6 Hz), 4.24 (t, 1H, $J$ = 7.2 Hz), 4.50–4.79 (m, 7.1H, H-1 α, $CH_2$ Bn), 4.81 (d, 0.3H, $J$ = 7.8 Hz, H-1 β), 5.01 (d, 0.3H, $J$ = 1.6 Hz, H-4), 5.06 (d, 1H, $J$ = 1.6 Hz, H-4), 7.23–7.62 ppm (m, 13H, Ar-H); $^{13}$C NMR (150 MHz, $CDCl_3$): $\delta$ = −5.6 ($CH_3$ TBDMS), −5.5 ($CH_3$ TBDMS), 18.2 ($C_q$ TBDMS), 25.8 (*t*Bu TBDMS), 26.7, 26.8, 28.0, 29.0, 29.3, 29.8, 31.5, 37.9, 48.5, 59.8, 60.9, 61.4, 64.8, 66.0, 66.5, 68.7, 69.2, 71.2, 72.2, 72.6, 72.9, 73.0, 73.3, 74.7, 76.2, 97.4 (C-1α), 100.9 (C-1 β), 124.8–135.6 (Ar-CH), 138.1 ($C_q$ Bn), 138.1 ($C_q$ Bn), 138.6 ($C_q$ Bn), 138.6 ($C_q$ Bn), 171.8 (COO lev), 171.9 (COO lev), 206.1 (CO Lev), 206.2 ppm (CO Lev); HRMS: $m/z$: calcd for $C_{34}H_{49}N_3O_8Si+Na^+$: 678.31811; found: 678.31810; IR (neat): $\tilde{\nu}$ = 1026, 1096, 1717, 1740, 2095, 2858, 2928 $cm^{-1}$.

**3-Azidopropyl-2,3-*O*-benzyl-6-*O*-*tert*-butyldimethylsilyl-4-*O*-(2,3-*O*-benzyl-6-*O*-*tert*-butyldimethylsilyl-4-*O*-levulinoyl-α-L-gulopyranosyl)-α-L-gulopyranoside (34)**: A solution of donor **24** (0.133 g, 0.2 mmol), diphenyl sulfoxide (0.045 g, 0.22 mmol), and tri-*tert*-butylpyrimidine (0.124 g, 0.5 mmol) in $CH_2Cl_2$ (4 mL) was stirred over activated 3-Å MS for 30 min. The reaction mixture was cooled to −70 °C before triflic acid anhydride (37 μL, 0.22 mmol) was added. The reaction mixture was stirred for 10 min at −70 °C followed by the addition of acceptor **28** (0.093 g, 0.166 mmol) in $CH_2Cl_2$ (1.6 mL). Stirring was continued, the reaction mixture was allowed to warm to 0 °C, and $Et_3N$ (0.15 mL) was added. The reaction mixture was diluted with $CH_2Cl_2$ and washed with $NaHCO_3$ (aq). The aqueous layer was extracted twice with $CH_2Cl_2$, and the collected organic layers were dried over $MgSO_4$ and concentrated in vacuo. Purification by size exclusion and column chromatography yielded **34** as a colourless oil (48 %, 0.089 g, $\alpha/\beta$ = 6:1). The anomers could be separated by column chromatography; the spectral data for the α anomer are given. $[\alpha]_D^{22}$ = −88.0 ($c$ = 0.1, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ = −0.03 (s, 3H, $CH_3$ TBDMS), −0.01 (s, 3H, $CH_3$ TBDMS), 0.00 (s, 3H, $CH_3$ TBDMS), 0.01 (s, 3H, $CH_3$ TBDMS), 0.83 (s, 9H, *t*Bu TBDMS), 0.87 (s, 9H, *t*Bu TBDMS), 1.83–1.92 (m, 2H, $CH_2$ $C_3H_6N_3$), 2.18 (s, 3H, $CH_3$ Lev), 2.45–2.53 (m, 2H, $CH_2$ Lev), 2.67–2.73 ($CH_2$ Lev), 3.34–3.38 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.42–3.53 (m, 3H, H-6, H-6, $CH_2$ $C_3H_6N_3$), 3.60 (t, 1H, $J$ = 3.6 Hz, H-2′), 3.70–3.82 (m, 3H, H-2, H-6′, $CH_2$ $C_3H_6N_3$), 3.88–3.99 (m, 4H, H-3, H-4, H-3′, H-6′), 4.13 (t, $J$ = 7.2 Hz, H-5′), 4.19 (t, $J$ = 6.8 Hz, H-5), 4.23 (d, 1H, $J$ = 12.4 Hz, $CH_2$ Bn), 4.30 (d, 1H, $J$ = 12.4 Hz, $CH_2$ Bn), 4.53 (d, 1H, $J$ = 12.4 Hz, $CH_2$ Bn), 4.59 (d, 1H, $J$ = 11.6 Hz, $CH_2$ Bn), 4.64–4.677 (m, 2H, $CH_2$ Bn), 4.87 (d, 1H, $J$ = 3.6 Hz, H-1), 4.81 (d, 1H, $J$ = 11.6 Hz, $CH_2$ Bn), 4.86 (d, 1H, $J$ = 12.4 Hz, $CH_2$ Bn), 5.07–5.09 (m, 2H, H-1′, H-4′), 7.16–7.38 ppm (m, 20H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ = −5.5 ($CH_3$ TBDMS), −5.4 ($CH_3$ TBDMS), −5.3 ($CH_3$ TBDMS), 18.1 ($C_q$ *t*Bu TBDMS), 18.3 ($C_q$ *t*Bu TBDMS), 25.9 (*t*Bu TBDMS), 28.1 ($CH_2$ Lev), 29.2 ($CH_2$ $C_3H_6N_3$), 29.8 ($CH_3$ Lev), 37.9 ($CH_2$ Lev), 48.6 ($CH_2$ $C_3H_6N_3$), 61.0, 61.1 (C-6, C-6′), 64.8 ($CH_2$ $C_3H_6N_3$), 66.2 (C-5), 67.0 (C-5′), 69.8 (C-4′), 71.1 ($CH_2$ Bn), 71.2 ($CH_2$ Bn), 72.0 (C-3′), 72.5 ($CH_2$ Bn), 72.8 ($CH_2$ Bn), 74.3 (C-2′), 74.3 (C-2), 74.7 (C-3), 75.8 (C-4), 97.5 (C-1), 99.6 (C-1′), 127.2–128.4 (Ar-CH), 138.2 ($C_q$ Bn) , 138.3 ($C_q$ Bn) , 139.1 ($C_q$ Bn) , 139.2 ($C_q$ Bn), 171.8 (COO Lev), 206.1 ppm (CO

Lev); HRMS: *m/z*: calcd for $C_{60}H_{85}N_3O_{13}Si_2+Na^+$: 1134.55131; found: 1134.55163; IR (neat): $\tilde{\nu}$=1003, 1092, 1454, 1744, 2095, 2858, 2928 $cm^{-1}$.

**3-Azidopropyl-2,3-di-*O*-benzyl-4,6-*O*-benzylidene-α,β-L-gulopyranoside (35)**: As described for the synthesis of **33** using donor **19** (0.108 g, 0.20 mmol). Purification by column chromatography yielded **35** as a colourless oil (0.094 g, 88%, $\alpha/\beta$=3:1). The anomers could not be separated by column chromatography. $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=1.84–1.96 (m, 2.6H, $CH_2$ $C_3H_6N_3$), 3.36–3.39 (m, 2.6H, $CH_2$ $C_3H_6N_3$), 3.45–3.50 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.60–3.66 (m, 0.3H, $CH_2$ $C_3H_6N_3$), 3.72 (dd, 0.3H, *J*= 2.8, 8.0 Hz, H-2 β), 3.77 (s, 0.3H), 3.82–3.88 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.91–3.97 (m, 3.6H), 4.00–4.05 (m, 2H), 4.10 (d, 1H, *J*=2.4 Hz), 4.23 (d, 1H, *J*=12.4 Hz, $CH_2$ Bn), 4.28 (d, 0.3H, *J*=12.4 Hz, $CH_2$ Bn), 4.57–4.69 (m, 3.9H, $CH_2$ Bn), 4.83–4.88 (m, 0.6H, $CH_2$ Bn), 4.92 (d, 1H, *J*=12.0 Hz, $CH_2$ Bn), 4.94 (d, 0.3H, *J*=8.4 Hz, H-1 β), 4.98 (d, 1H, *J*=4.0 Hz, H-1 α), 5.48 (s, 0.3H, CH benzylidene), 5.50 (s, 1H, CH benzylidene), 7.23–7.65 ppm (m, 19.5H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$=29.0 ($CH_2$ $C_3H_6N_3$), 29.3 ($CH_2$ $C_3H_6N_3$), 48.3 ($CH_2$ $C_3H_6N_3$), 48.4 ($CH_2$ $C_3H_6N_3$), 59.8, 64.7, 65.5, 66.2, 69.4, 69.7, 71.6, 73.2, 73.5, 73.7, 73.9, 74.2, 75.3, 75.6, 76.4, 76.6, 97.8 (C-1 α), 100.7 (C-1 β), 101.0 (CHPh), 124.7–131.0 (Ar-CH), 137.7 ($C_q$ Bn), 138.1 ($C_q$ Bn), 138.8 ppm ($C_q$ Bn); HRMS: *m/z*: calcd for $C_{30}H_{33}N_3O_6+H^+$: 532.24212; found: 532.24421; IR (neat): $\tilde{\nu}$= 1088, 1109, 2095, 2874 $cm^{-1}$.

**3-Azidopropyl-2,3-*O*-benzyl-6-*O*-*tert*-butyldimethylsilyl-4-*O*-(2,3-di-*O*-benzyl-4,6-*O*-benzylidene-α-L-gulopyranosyl)-α-L-gulopyranoside (36)**: As described for the synthesis of **34** using donor **19** (0.108 g, 0.20 mmol). Purification by size exclusion and column chromatography yielded **36** as a colourless oil (45%, 0.074 g, $\alpha/\beta$=6:1). The anomers could be separated by column chromatography; the spectral data for the α anomer are given. $[\alpha]_D^{22}=-78.0$ (*c*=0.5, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$= −0.04 (s, 3H, $CH_3$ TBDMS), 0.01 (s, 3H, $CH_3$ TBDMS), 0.86 (s, 9H, *t*Bu TBDMS), 1.86–2.01 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.11 (bs, 1H, H-4′), 3.35–3.44 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.55–3.58 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.63 (t, 1H, *J*= 3.6 Hz, H-3′), 3.69–3.76 (m, 4H, H-2, H-6, H-6′, H-6′), 3.84–3.95 (m, 4H, H-3, H-2′, H-5′, $CH_2$ $C_3H_6N_3$), 3.95–3.99 (m, 2H, H-4, H-6), 4.13 (d, 1H, *J*=7.2 Hz, H-5), 4.45 (d, 1H, *J*=12.8 Hz, $CH_2$ Bn), 4.54 (d, 1H, *J*= 12.0 Hz, $CH_2$ Bn), 4.59 (d, 1H, *J*=10.8 Hz, $CH_2$ Bn), 4.67–4.76 (m, 3H, $CH_2$ Bn), 4.91 (d, 1H, *J*=3.6 Hz, H-1), 5.00 (d, 1H, *J*=11.2 Hz, $CH_2$ Bn), 5.19 (d, 1H, *J*=3.6 Hz, H-1′), 5.02 (d, 1H, *J*=10.8 Hz, $CH_2$ Bn), 5.45 (s, 1H, CH benzylidene), 6.94–7.48 ppm (m, 25H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$=−5.4 ($CH_3$ TBDMS), −5.3 ($CH_3$ TBDMS), 18.2 ($C_q$ *t*Bu TBDMS), 25.8 (*t*Bu TBDMS), 29.2 ($CH_2$ $C_3H_6N_3$), 48.6 ($CH_2$ $C_3H_6N_3$), 60.1 (C-4′), 61.1 (C-6), 64.8 ($CH_2$ $C_3H_6N_3$), 66.8 (C-5), 69.5 (C-6′), 71.5 ($CH_2$ Bn), 71.5 ($CH_2$ Bn), 72.2 ($CH_2$ Bn), 73.3 ($CH_2$ Bn), 73.4 (C-2), 73.8 (C-4), 75.1 (C-3), 75.3 (C-5′), 75.5 (C-3′), 76.1 (C-2′), 97.0 (C-1), 99.9 (C-1′), 100.9 (CH benzylidene), 126.2–129.1 (Ar-CH), 137.7–139.5 ppm ($C_q$ arom); HRMS: *m/z*: calcd for $C_{56}H_{69}N_3O_{11}Si+Na^+$: 1010.45936; found: 1010.46006; IR (neat): $\tilde{\nu}$=1088, 1109, 2095, 2874 $cm^{-1}$.

**3-Azidopropyl-2,3-di-*O*-benzyl-4,6-*O*-di-*tert*-butylsilylidene-α-L-gulopyranoside (37)**: As described for the synthesis of **33** using donor **25** (0.118 g, 0.20 mmol). Purification by column chromatography yielded **37** as a colourless oil (0.088 g, 75%, $\alpha/\beta$=5:1). The anomers could be separated by column chromatography; the spectral data for the α anomer are given. $[\alpha]_D^{22}=-57.6$ (*c*=1, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=0.91 (s, 9H, *t*Bu), 0.98 (s, 9H, *t*Bu), 1.82–1.85 (m, 1H, $CH_2$ $C_3H_6N_3$), 1.91–1.94 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.37 (t, 2H, *J*=6.8 Hz, $CH_2$ $C_3H_6N_3$), 3.44–3.49 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.78–82 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.83–3.88 (m, 2H, H-2, H-3), 3.93 (bs, 1H, H-5), 4.09 (dd, 1H, *J*=1.6, 12.4 Hz, H-6), 4.18–4.19 (m, 2H, H-4, H-6), 4.58–4.62 (m, 2H, $CH_2$ Bn), 4.67 (d, 1H, *J*=12.4 Hz, $CH_2$ Bn), 4.80 (d, 1H, *J*=3.6 Hz, H-1), 4.96 (d, 1H, *J*=12.0 Hz, $CH_2$ Bn), 7.26–7.39 ppm (m, 10H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$= 20.4 ($C_q$ *t*Bu), 23.3 ($C_q$ *t*Bu), 27.2 ($CH_3$ *t*Bu), 27.6 ($CH_3$ *t*Bu), 29.0 ($CH_2$ $C_3H_6N_3$), 48.4 ($CH_2$ $C_3H_6N_3$), 64.1 (C-5), 64.6 ($CH_2$ $C_3H_6N_3$), 67.2 (C-6), 71.3 ($CH_2$ Bn), 72.4 (C-4), 72.6 (C-2), 73.3 ($CH_2$ Bn), 76.1 (C-3), 97.8 (C-1), 127.5–128.4 (Ar-CH), 138.0 ($C_q$ Bn), 139.1 ppm ($C_q$ Bn); HRMS: *m/z*: calcd for $C_{31}H_{45}N_3O_6Si+H^+$: 584.31504; found: 584.31479; IR (neat): $\tilde{\nu}$= 1089, 1138, 2095, 2858, 2931 $cm^{-1}$.

**3-Azidopropyl-2,3-*O*-benzyl-6-*O*-*tert*-butyldimethylsilyl-4-*O*-(2,3-di-*O*-benzyl-4,6-*O*-di-*tert*-butylsilylidene-α-L-gulopyranosyl)-α-L-gulopyranoside (38)**: Compound **38** was synthesised by two pathways: 1) As described for the synthesis of **34** using donor **25** (0.118 g, 0.20 mmol). Purification by size exclusion and column chromatography yielded **38** as a colourless oil (0.083 g, 48%, $\alpha/\beta$=10:1). 2) A solution of hemiacetal **39** (0.235 g, 0.47 mmol), diphenyl sulfoxide (0.237 g, 1.17 mmol), and tri-*tert*-butylpyrimidine (0.233 g, 0.939 mmol) in $CH_2Cl_2$ (10 mL) was stirred over activated 3-Å MS for 30 min. The reaction mixture was cooled to −60°C before triflic acid anhydride (83 μL, 0.493 mmol) was added. The reaction mixture was warmed to −40°C and stirred for 1 h followed by the addition of acceptor **28** (0.131 g, 0.234 mmol) in $CH_2Cl_2$ (2.5 mL). Stirring was continued and the reaction mixture was allowed to warm to room temperature, after which $Et_3N$ (5 equiv) was added. The reaction mixture was diluted with $CH_2Cl_2$ and washed with $NaHCO_3$ (aq). The aqueous layer was extracted twice with $CH_2Cl_2$, and the collected organic layers were dried over $MgSO_4$ and concentrated in vacuo. Purification by size exclusion and column chromatography yielded **38** as a colourless oil (0.205 g, 84%, $\alpha/\beta$=10:1). The anomers could be separated by column chromatography; the spectral data for the α anomer are given. $[\alpha]_D^{22}=-75.0$ (*c*=1, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=−0.03 (s, 3H, $CH_3$ TBDMS), 0.01 (s, 3H, $CH_3$ TBDMS), 0.86 (s, 9H, *t*Bu silylidene), 0.91 (s, 9H, *t*Bu silylidene), 1.03 (s, 9H, *t*Bu TBDMS), 1.84–1.97 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.29–3.40 (m, 3H, H-4′, $CH_2$ $C_3H_6N_3$), 3.50–3.52 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.60 (t, 1H, *J*=3.6 Hz, H-3), 3.67 (t, 1H, *J*=3.6 Hz, H-2), 3.71 (dd, 1H, *J*=1.2, 12.4 Hz, H-6′), 3.76–3.81 (m, 3H, H-4, H-6, H-5′), 3.82–3.86 (m, 3H, H-2′, H-6′, $CH_2$ $C_3H_6N_3$), 3.89–3.95 (m, 2H, H-6, $CH_2$ Bn), 4.09–4.13 (m, 2H, H-5, H-3′), 4.37 (d, 1H, *J*=12.4 Hz, $CH_2$ Bn), 4.55–4.59 (m, 2H, $CH_2$ Bn), 4.69 (d, 1H, *J*=12.0 Hz, $CH_2$ Bn), 4.77 (d, 1H, *J*=12.0 Hz, $CH_2$ Bn), 4.87 (d, 1H, *J*=3.6 Hz, H-1) 4.98 (d, 1H, *J*= 3.6 Hz, H-1′), 5.02 (d, 1H, *J*=10.8 Hz, $CH_2$ Bn), 6.96–7.48 ppm (m, 20H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$=−5.4 ($CH_3$ TBDMS), −5.3 ($CH_3$ TBDMS), 18.2 ($C_q$ *t*Bu TBDMS), 20.4 ($C_q$ *t*Bu silylidene), 23.3 ($C_q$ *t*Bu silylidene), 25.9 (*t*Bu TBDMS), 27.2 ($CH_3$ *t*Bu silylidene), 27.6 ($CH_3$ *t*Bu silylidene), 29.2 ($CH_2$ $C_3H_6N_3$), 48.6 ($CH_2$ $C_3H_6N_3$), 61.4 (C-6), 64.5 (C-4′), 64.7 ($CH_2$ $C_3H_6N_3$), 66.9 (C-6′), 67.1 (C-5), 71.2 ($CH_2$ Bn), 71.5 ($CH_2$ Bn), 72.9 ($CH_2$ Bn), 73.1 (C-3′), 73.2 ($CH_2$ Bn), 73.8 (C-2′), 73.9 (C-2), 75.5 (C-4), 75.6 (C-5′), 76.1 (C-3), 97.0 (C-1), 99.7 (C-1′), 127.3–128.5 (Ar-CH), 138.1 ($C_q$ Bn), 138.5 ($C_q$ Bn), 139.0 ($C_q$ Bn), 139.7 ppm ($C_q$ Bn); HRMS: *m/z*: calcd for $C_{57}H_{81}N_3O_{11}Si_2+Na^+$: 1062.53018; found: 1062.53082; IR (neat): $\tilde{\nu}$=1084, 1138, 1454, 1474, 2095, 2859, 2932 $cm^{-1}$.

**2,3-Di-*O*-benzyl-4,6-*O*-di-*tert*-butylsilylidene-α,β-L-gulopyranoside (39)**: NIS (0.243 g, 1.08 mmol) and TFA (83 μL, 1.08 mmol) were added to a solution of **25** (0.638 g, 1.08 mmol) in $CH_2Cl_2$ (10 mL) at 0°C. After analysis by TLC showed complete consumption of the starting material, the reaction was quenched with $Et_3N$. Saturated $Na_2S_2O_3$ (aq) was added to the reaction mixture, which was then stirred for 30 min. The aqueous layer was extracted twice with $CH_2Cl_2$, and the combined organic layers were dried over $MgSO_4$ and concentrated in vacuo. Purification by column chromatography yielded **39** as a colourless oil (0.514 g, 95%, $\alpha/\beta$=3:1). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=0.91 (s, 3H, *t*Bu), 0.99 (s, 9H, *t*Bu), 3.48 (d, 0.3H, *J*=5.2 Hz, OH β), 3.65 (dd, 0.3H, *J*=2.8, 8.0 Hz, H-2 β), 3.80 (bs, 0.3H), 3.88–3.89 (m, 1H, H-2 α), 3.98 (m, 1.3H), 4.13–4.23 (m, 3H), 4.57–4.71 (m, 2.6H, $CH_2$ Bn), 4.80 (d, 0.3H, *J*=12.0 Hz, $CH_2$ Bn), 4.85 (d, 1H, *J*=11.6 Hz, $CH_2$ Bn), 5.16 (dd, 0.3H, *J*=5.2, 2.6 Hz, H-1 β), 5.22 (m, 1H, H-1 α), 7.21–7.37 ppm (m, 10.6H, Ar-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$=20.3 ($C_q$ *t*Bu), 20.4 ($C_q$ *t*Bu), 23.2 ($C_q$ *t*Bu), 27.1 ($CH_3$ *t*Bu), 27.3 ($CH_3$ *t*Bu), 27.4 ($CH_3$ *t*Bu), 27.8 ($CH_3$ *t*Bu), 62.3, 67.0, 67.1, 70.2, 70.5, 70.6, 71.6, 72.0, 72.7, 73.6, 74.6, 76.9, 77.6, 78.2, 92.9, 94.8 (C-1, α/β), 127.5–128.5 (Ar-CH), 137.2 ($C_q$ Bn), 137.5 ($C_q$ Bn), 138.3 ($C_q$ Bn), 138.5 ppm ($C_q$ Bn); HRMS: *m/z*: calcd for $C_{28}H_{40}O_6Si+H^+$: 501.26669; found: 501.26671; IR (neat): $\tilde{\nu}$=826, 1045, 1084, 1138, 1474, 1736, 2858, 2932, 3472 $cm^{-1}$.

**3-Azidopropyl-2,3-*O*-benzyl-4-*O*-(2,3-*O*-benzyl-α-L-gulopyranosyl)-α-L-gulopyranoside (40)**: A solution of **38** (0.233 g, 0.244 mmol) in THF (2.5 mL) was cooled to 0°C and TBAF (0.74 mL, 0.74 mmol, 1 m in THF) was added. The reaction mixture was diluted with EtOAc after 4 h, and washed with water and brine. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Purification by column chromatogra-

phy yielded **40** as a colourless oil (0.153 g, 87%). $[\alpha]_D^{22}=-73.2$ ($c=1$, $CHCl_3$); $^1H$ NMR (400 MHz, $CDCl_3$): $\delta=1.81$–$2.01$ (m, 2H, $CH_2$ $C_3H_6N_3$), 3.37–3.43 (m, 3H, H-6, $CH_2$ $C_3H_6N_3$), 3.49–3.54 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.58 (dd, 1H, $J=2.8$, 12 Hz, H-6), 3.70 (bs, 1H, OH), 3.77–3.77 (m, 5H), 3.83–3.88 (m, 5H), 4.12 (bs, 1H), 4.18 (d, 1H, $J=12.6$ Hz, $CH_2$ Bn), 4.27 (m, 1H, H-4), 4.33 (d, 1H, $J=12.0$ Hz, $CH_2$ Bn), 4.37 (d, 1H, $J=12.4$ Hz, $CH_2$ Bn), 4.43 (d, 1H, $J=12.0$ Hz, $CH_2$ Bn), 4.54–4.61 (m, 3H, $CH_2$ Bn), 4.65 (d, 1H, $J=12.0$ Hz, $CH_2$ Bn), 4.80 (d, 1H, $J=2.4$ Hz, H-1), 4.85 (d, 1H, $J=12.0$ Hz, $CH_2$ Bn), 4.98 (d, 1H, $J=3.6$ Hz, H-1′), 7.17–7.41 ppm (m, 20H, Ar-H); $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta=29.0$ ($CH_2$ $C_3H_6N_3$), 48.4 ($CH_2$ $C_3H_6N_3$), 62.6, 64.3 (C-6, C-6′), 64.8 ($CH_2$ $C_3H_6N_3$), 65.8, 65.9, 70.8, 71.3, 71.4, 72.7, 72.7, 72.9, 73.3, 73.6, 74.6, 80.4, 97.1 (C-1), 99.8 (C-1′), 127.3–129.1 (Ar-CH), 137.4 ($C_q$ Bn), 138.2 ($C_q$ Bn), 138.3 ($C_q$ Bn), 138.7 ppm ($C_q$ Bn); ESI-MS: $m/z$: 786.4 $[M+H^+]$; IR (neat): $\tilde{\nu}=1069$, 1109, 1454, 2095, 2878 $cm^{-1}$.

**3-Azidopropyl-2,3-*O*-benzyl-6-*O*-*tert*-butyldimethylsilyl-4-*O*-(2,3-*O*-benzyl-6-*O*-*tert*-butyldimethylsilyl-α-L-gulopyranosyl)-α-L-gulopyranoside (41)**: A solution of **40** (0.278 g, 0.35 mmol) in DMF (5 mL) was cooled to 0°C. Imidazole (0.049 g, 0.725 mmol) and TBDMSCl (0.109 g, 0.725 mmol) were added respectively and the reaction mixture was warmed to room temperature. After stirring for 4 h, the reaction mixture was quenched with MeOH and concentrated in vacuo. The residue was taken up in $Et_2O$ and washed three times with $H_2O$. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Column chromatography yielded **41** as a colourless oil (0.273 g, 78%). $[\alpha]_D^{22}=-60.2$ ($c=1$, $CHCl_3$); $^1H$ NMR (400 MHz, $CDCl_3$): $\delta=-0.01$ (s, 3H, $CH_3$), 0.02 (s, 3H, $CH_3$), 0.11 (s, 3H, $CH_3$), 0.12 (s, 3H, $CH_3$), 0.89 (s, 9H, *t*Bu), 0.93 (s, 9H, *t*Bu), 1.88–1.99 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.32–3.46 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.53–3.57 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.60–3.66 (m, 3H, H-5′, H-6′, H-6′), 3.70 (t, 1H, $J=3.2$ Hz, H-3), 3.74–3.78 (m, 2H, H-2, H-6), 3.83–3.87 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.88–4.04 (m, 5H, H-4, H-6, H-2′, H-4′, $CH_2$ Bn), 4.09 (s, 1H, H-3′), 4.16 (t, 1H, $J=6.8$ Hz, H-5), 4.42 (d, 1H, $J=12.4$ Hz, $CH_2$ Bn), 4.58–4.62 (m, 2H, $CH_2$ Bn), 4.65 (d, 1H, $J=12.0$ Hz, $CH_2$ Bn), 4.73 (d, 1H, $J=12.0$ Hz, $CH_2$ Bn), 4.80 (d, 1H, $J=12.0$ Hz, $CH_2$ Bn), 4.87 (d, 1H, $J=3.6$ Hz, H-1), 5.00 (d, 1H, $J=11.2$ Hz, $CH_2$ Bn), 5.15 (d, 1H, $J=3.6$ Hz, H-1′), 7.04–7.49 ppm (m, 20H, Ar-H); $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta=-5.6$ ($CH_3$), −5.5 ($CH_3$), −5.4 ($CH_3$), 18.0 ($C_q$ *t*Bu), 18.2 ($C_q$ *t*Bu), 25.8 (*t*Bu), 29.1 ($CH_2$ $C_3H_6N_3$), 48.5 ($CH_2$ $C_3H_6N_3$), 61.1 (C-6), 64.6 ($CH_2$ $C_3H_6N_3$), 65.3 (C-5′), 65.6 (C-6′), 67.0 (C-5), 71.4 ($CH_2$ Bn), 71.5 ($CH_2$ Bn), 72.5 ($CH_2$ Bn), 73.1 ($CH_2$ Bn), 72.1, 74.1, 74.9, 75.1, 75.2 (C-2, C-4, C-2′, C-3′, C-4′), 76.1 (C-3), 97.0 (C-1), 99.9 (C-1′), 127.0–128.3 (Ar-CH), 138.4 ($C_q$ Bn), 138.5 ($C_q$ Bn), 139.0 ($C_q$ Bn), 139.6 ppm ($C_q$ Bn); HRMS: $m/z$: calcd for $C_{55}H_{79}N_3O_{11}Si_2+Na^+$: 1036.51453; found: 1036.51517; IR (neat): $\tilde{\nu}=1003$, 1092, 1454, 2095, 2858, 2928 $cm^{-1}$.

**3-Azidopropyl-2,3-*O*-benzyl-6-*O*-*tert*-butyldimethylsilyl-4-*O*-[2,3-*O*-benzyl-6-*O*-*tert*-butyldimethylsilyl-4-*O*-(2,3-di-*O*-benzyl-4,6-*O*-di-*tert*-butylsilylidene-α-L-gulopyranosyl)-α-L-gulopyranosyl]-α-L-gulopyranoside (42)**: A solution of **39** (0.162 g, 0.324 mmol), diphenyl sulfoxide (0.164 g, 0.81 mmol), and tri-*tert*-butylpyrimidine (0.504 g, 0.125 mmol) in $CH_2Cl_2$ (6 mL) was stirred over activated 3-Å MS for 30 min. The reaction mixture was cooled to −60°C before triflic acid anhydride (57 μL, 0.340 mmol) was added. The reaction mixture was allowed to warm to −40°C and stirred for 1 h followed by the addition of acceptor **41** (0.164 g, 0.162 mmol) in $CH_2Cl_2$ (1.6 mL). Stirring was continued, the reaction mixture was allowed to warm to 10°C, and $Et_3N$ (0.1 mL) was added. The reaction mixture was diluted with $CH_2Cl_2$ and washed with $NaHCO_3$ (aq). The aqueous layer was extracted twice with $CH_2Cl_2$, and the collected organic layers were dried over $MgSO_4$ and concentrated in vacuo. Purification by column chromatography yielded **42** as a colourless oil (0.102 g, 42%). $[\alpha]_D^{22}=-75.8$ ($c=1$, $CHCl_3$); $^1H$ NMR (400 MHz, $CDCl_3$): $\delta=-0.02$ (s, 3H, $CH_3$), −0.01 (s, 3H, $CH_3$), 0.01 (s, 3H, $CH_3$), 0.06 (s, 3H, $CH_3$), 0.87 (s, 9H, *t*Bu), 0.93 (s, 9H, *t*Bu), 0.96 (s, 9H, *t*Bu), 1.08 (s, 9H, *t*Bu), 1.88–1.93 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.32–3.37 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.39–3.45 (m, 2H), 3.69–3.86 (m, 8H), 3.89–3.98 (m, 7H), 4.03 (t, 1H, $J=9.6$ Hz), 4.09–4.20 (m, 5H), 4.28 (d, 1H, $J=12.4$ Hz, $CH_2$ Bn), 4.45 (d, 1H, $J=12.4$ Hz, $CH_2$ Bn), 4.59–4.66 (m, 3H, $CH_2$ Bn), 4.70 (d, 1H, $J=4.0$ Hz, H-1), 4.73 (d, 1H, $J=12.0$ Hz, $CH_2$ Bn), 4.79 (d, 1H, $J=12.4$ Hz, $CH_2$ Bn), 4.96 (d, 1H, $J=12.0$ Hz, $CH_2$ Bn), 5.03 (d, 1H, $J=12.0$ Hz, $CH_2$ Bn), 5.08 (d, 1H, $J=11.2$ Hz, $CH_2$ Bn), 5.11 (d, 1H, $J=2.8$ Hz) , 5.16 (d, 1H, $J=2.4$ Hz) (H-1′, H-1″), 6.97–7.55 ppm (m, 30H, Ar-H); $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta=-5.4$ ($CH_3$), −5.3 ($CH_3$), −5.2 ($CH_3$), 18.1 ($C_q$ *t*Bu), 18.2 ($C_q$ *t*Bu), 20.3 ($C_q$ *t*Bu), 23.3 ($C_q$ *t*Bu), 25.9 (*t*Bu), 25.9 (*t*Bu), 27.2 ($CH_3$ *t*Bu), 27.6 ($CH_3$ *t*Bu), 29.1 ($CH_2$ $C_3H_6N_3$), 48.5 ($CH_2$ $C_3H_6N_3$), 61.0, 61.3 (C-6, C-6′), 64.5 (4″), 64.6 ($CH_2$ $C_3H_6N_3$), 66.8 (C-6″), 67.6 (C-5, C-5′), 71.0 ($CH_2$ Bn), 71.1 ($CH_2$ Bn), 71.1 ($CH_2$ Bn), 72.5 ($CH_2$ Bn), 72.9 ($CH_2$ Bn), 73.3 ($CH_2$ Bn), 73.0, 73.6, 74.9, 75.1, 75.4, 75.7, 75.8, 76.2, 97.2 (C-1), 99.3, 99.7 (C-1′, C-1″), 127.0–128.4 (Ar-CH), 138.0 ($C_q$ Bn), 138.4 ($C_q$ Bn), 138.6 ($C_q$ Bn), 139.5 ($C_q$ Bn), 139.6 ($C_q$ Bn), 138.7 ppm ($C_q$ Bn); HRMS: $m/z$: calcd for $C_{83}H_{117}N_3O_{16}Si_3+Na^+$: 1518.76338; found: 1518.76503; IR (neat): $\tilde{\nu}=1084$, 1138, 1454, 1474, 2095, 2859, 2932 $cm^{-1}$.

**3-Azidopropyl-2,3-*O*-benzyl-4-*O*-[2,3-*O*-benzyl-4-*O*-(2,3-*O*-benzyl-α-L-gulopyranosyl)-α-L-gulopyranosyl]-α-L-gulopyranoside (43)**: A solution of **42** (0.094 g, 0.063 mmol) in THF (2 mL) was cooled to 0°C and TBAF (0.28 mL, 0.28 mmol, 1 M in THF) was added. The reaction mixture was diluted with EtOAc after 4 h, and washed with water and brine. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Purification by column chromatography yielded **43** as a colourless oil (0.067 g, 83%). $^1H$ NMR (400 MHz, $CDCl_3$): $\delta$ 1.88–1.96 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.34–3.39 (m, 3H), 3.47–3.59 (m, 4H), 3.64–3.67 (m, 4H), 3.73–3.79 (m, 4H), 3.82–3.87 (m, 7H), 3.97 (bs, 1H), 4.05 (bs, 1H), 4.14 (bs, 1H), 4.23 (d, 1H, $J=12.4$ Hz, $CH_2$ Bn), 4.32 (d, 1H, $J=11.6$ Hz, $CH_2$ Bn), 4.34 (d, 1H, $J=10.8$ Hz, $CH_2$ Bn), 4.43 (d, 1H, $J=12.0$ Hz, $CH_2$ Bn), 4.49 (d, 1H, $J=12.4$ Hz, $CH_2$ Bn), 4.55 (d, 1H, $J=12.4$ Hz, $CH_2$ Bn), 4.57–4.68 (m, 5H, $CH_2$ Bn), 4.70 (d, 1H, $J=3.2$ Hz, H-1), 4.91 (d, 1H, $J=12.0$ Hz, $CH_2$ Bn), 4.95 (d, 1H, $J=3.6$ Hz), 4.97 (d, 1H, $J=3.6$ Hz, H-1′, H-1″), 7.10–7.42 ppm (m, 30H, Ar-H); $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta=29.1$ ($CH_2$ $C_3H_6N_3$), 48.4 ($CH_2$ $C_3H_6N_3$), 62.5, 62.8, 64.2, 64.7, 65.7, 66.0, 66.5, 70.7, 71.2, 71.3, 71.5, 72.1, 72.6, 72.7, 72.7, 73.1, 73.2, 73.3, 74.0, 74.8, 79.7, 80.9, 97.3, 99.2, 99.9 (C-1, C-1′, C-1″), 127.4–128.5 (Ar-CH), 137.4 ($C_q$ Bn), 137.6 ($C_q$ Bn), 138.2 ($C_q$ Bn), 138.2 ($C_q$ Bn), 138.3 ($C_q$ Bn), 139.0 ppm ($C_q$ Bn); ESI-MS: 1128.5 $[M+Na^+]$; IR (neat): $\tilde{\nu}=1069$, 1109, 1454, 2095, 2878 $cm^{-1}$.

**3-Aminopropyl {[4-*O*-(α-L-gulopyranosyl)uronate]-α-L-gulopyranoside}-uronic acid (44)**: Compound **40** (0.243 g, 0.310 mmol) was taken up in $CH_2Cl_2$ (2 mL), *t*BuOH (2 mL), and $H_2O$ (0.5 mL) and TEMPO (0.019 g, 0.124 mmol) and BAIB (0.496 g, 1.55 mmol) were added. The reaction mixture was stirred vigorously until analysis by TLC showed complete conversion of the starting material. $Na_2S_2O_3$ (10 mL, aq) was added and the resulting mixture was stirred for 15 min. The layers were separated and the aqueous phase was acidified with 1 M HCl and extracted three times with $CH_2Cl_2$. The combined organic layers were dried over $MgSO_4$ and concentrated in vacuo. The resulting syrup was then dissolved in *t*BuOH (2 mL) and $H_2O$ (2 mL) before a catalytic amount of Pd on charcoal was added. The reaction mixture was stirred overnight in an $H_2$ atmosphere and filtered. Gel filtration (HW-40) afforded the desired disaccharide **44** (0.086 g, 90%). $^1H$ NMR (400 MHz, $D_2O$): $\delta=1.98$–$2.06$ (m, 2H, $CH_2$ $C_3H_6N_3$), 3.14–3.23 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.65–3.71 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.92–3.99 (m, 4H, H-2, H-2′, H-3′, $CH_2$ $C_3H_6N_3$), 4.09–4.16 (m, 3H, H-3, H-4, H-4′), 4.41 (d, 1H, $J=1.2$ Hz, H-5′), 4.47 (s, 1H, H-5), 4.96 (d, 1H, $J=3.6$ Hz), 5.02 ppm (d, 1H, $J=4.0$ Hz) (H-1, H-1′); $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta=26.0$ ($CH_2$ $C_3H_6N_3$), 39.0 ($CH_2$ $C_3H_6N_3$), 64.5, 65.1 (C-2, C-2′), 66.7 (C-5), 67.8 ($CH_2$ $C_3H_6N_3$), 68.1 (C-5′), 69.1, 70.3 (C-3, C-3′), 70.8 (C-4′), 80.5 (C-4), 98.4, 100.9 (C-1, C-1′), 175.7 (COOH), 176.1 ppm (COOH); HRMS: $m/z$: calcd for $C_{15}H_{25}NO_{13}+Na^+$: 450.12181; found: 450.12170.

**3-Aminopropyl {4-*O*-[4-*O*-(α-L-gulopyranosyl)uronate]-α-L-gulopyranosyl)uronate]-α-L-gulopyranoside}uronic acid (45)**: Compound **43** (0.039 g, 0.034 mmol) was taken up in $CH_2Cl_2$ (1 mL), *t*BuOH (1 mL), and $H_2O$ (0.5 mL) and TEMPO (0.003 g, 0.021 mmol) and BAIB (0.082 g, 0.257 mmol) were added. The reaction mixture was stirred vigorously until analysis by TLC showed complete conversion of the starting material. $Na_2S_2O_3$ (2 mL, aq) was added and the resulting mixture was stirred for 15 min. The layers were separated and the aqueous phase was acidified with 1 M HCl and extracted three times with $CH_2Cl_2$. The combined organic layers were dried over $MgSO_4$ and concentrated in vacuo. The re-

sulting syrup was then dissolved in *t*BuOH (1 mL) and $H_2O$ (1 mL) before a catalytic amount of Pd on charcoal was added. The reaction mixture was stirred overnight in an $H_2$ atmosphere and filtered. Gel filtration (HW-40) afforded the desired trisaccharide **45** (0.018 g, 85 %). $^1$H NMR (400 MHz, $D_2O$): $\delta$ = 1.98–2.02 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.14–3.19 (m, 2H, $CH_2$ $C_3H_6N_3$), 3.65–3.71 (m, 1H, $CH_2$ $C_3H_6N_3$), 3.91–4.00 (m, 5H, H-2, H-2′, H-2″, H-3″, $CH_2$ $C_3H_6N_3$), 4.04–4.07 (m, 2H, H-3, H-3′), 4.14 (bs, 3H, H-4, H-4′, H-4″), 4.41 (s, 1H), 4.46 (s, 1H), 4.47 (s, 1H, H-5, H-5′, H-5″), 4.96 (d, 1H, $J$ = 4.0 Hz), 5.02 (d, 1H, $J$ = 3.6 Hz), 5.06 ppm (d, 1H, $J$ = 4.0 Hz) (H-1, H-1′, H-1″); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ = 26.2 ($CH_2$ $C_3H_6N_3$), 39.0 ($CH_2$ $C_3H_6N_3$), 64.6, 65.2, 65.2 (C-2, C-2′, C-2″), 66.6, 67.3, 68.2 (C-5, C-5′, C-5″), 67.8 ($CH_2$ $C_3H_6N_3$), 69.1, 69.2, 70.4 (C-3, C-3′, C-3″), 70.8 (C-4″), 80.0, 80.5 (C-4, C-4′), 98.4, 100.7, 100.9 (C-1, C-1′, C-1″), 175.5 (COOH), 175.6 (COOH), 176.1 ppm (COOH); HRMS: $m/z$: calcd for $C_{21}H_{33}NO_{19}+Na^+$: 626.15390; found: 626.15384.

## Acknowledgements

This work was supported by the Council for Chemical Sciences of the Netherlands Organisation for Scientific Research (NWO).

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Received: May 20, 2008
Revised: July 14, 2008
Published online: September 3, 2008

  