Structure-reactivity relationships in glycosylation chemistry
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Chapter 2: Stereoselectivity of S_N1-like reactions of all eight diastereoisomeric pyranosyl and 6-deoxy pyranosyl donors with D- or C-nucleophiles

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Introduction

Despite significant progress over the last decades, the construction of a glycosidic bond in a stereoselective and high yielding way remains a challenging, time consuming and resource intensive operation for which no universal guidelines exist.[1-3] The outcome of a glycosylation reaction is dependent on properties inherent to the used building blocks, as well as on environmental factors, including but not limited to solvent, temperature and concentration.[4] The reason that the outcome of a reaction between a donor and an acceptor remains hard to predict, is the continuum of reaction mechanisms that can be followed to lead to two products (***Figure 1***). When a glycosyl donor (**I**) is activated by a promotor (E-X) a variety of reactive species can form (**II-VIII**), including α- or β-covalent species (**VIII** and **II** respectively) which react predominantly via a S_N2 mechanism and oxocarbenium ion like species (**III-VII**) which react in a S_N1-type fashion. Which pathways are followed depends on the reactivity of the donor and the incoming nucleophile (NuH) and the S_N2- and S_N1-type pathways can yield the α-product (**IX**), the β-product (**X**) or a mixture of the two.[5-8] In order to better understand, and eventually predict the outcome of a glycosylation reaction, it is essential to know which products can be formed by following the different mechanistic pathways. The covalent species involved in the S_N2 reactions can be studied by spectroscopic techniques and over the years multiple covalent species, such as triflates and oxosulfonium triflates, have been observed by the use of variable temperature NMR (VT-NMR).[9-16] On the other hand, oxocarbenium ions are more difficult to study due to their high reactivity and short lifetime, and currently no spectroscopic method exists to observe, let alone characterise oxocarbenium ions of relevant donors, in reaction-like media.

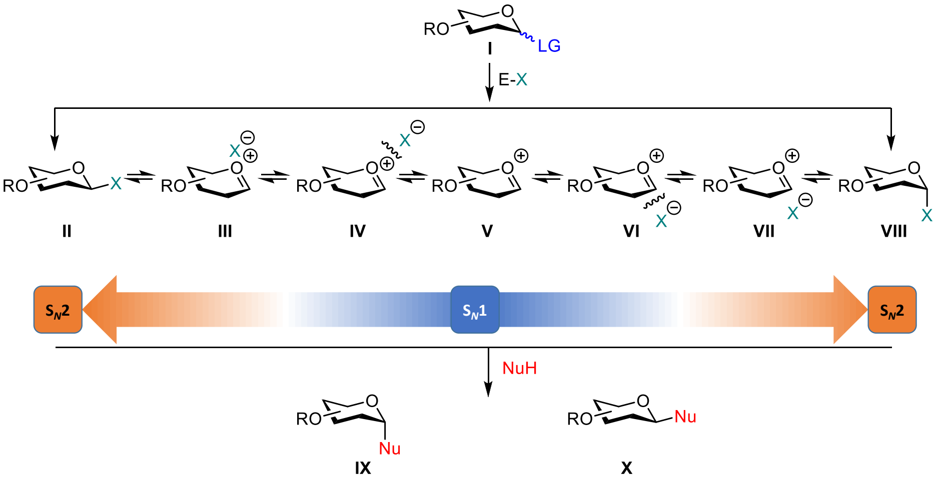
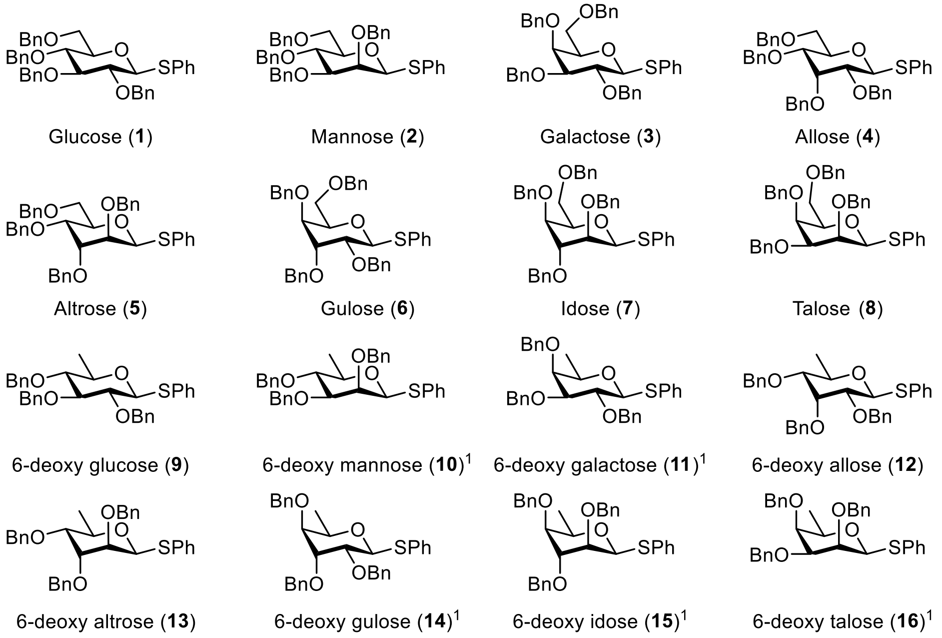


***Figure 1**: Mechanistic continuum of a glycosylation reaction, **II**, **VIII:** covalent species; **III**, **VII:** contact ion pair; **IV**, **VI:** solvent separated ion pair; **V:** oxocarbenium ion. this work investigates **V.** **LG:** leaving group, **E-X:** activator, **NuH**: nucleophile*

Over the last years, tremendous progress has been made in the understanding of glycosyl cations and their reactivity thanks to a combination of mechanistic experiments, NMR experiments in superacid media, IR spectroscopy, computational chemistry, or a combination thereof.[17-31] Understanding, and predicting the (stereochemical) outcome of S_N1 like glycosylation reactions remains challenging nonetheless. While it has long been clear that the conformational behaviour of oxocarbenium ions –and by extension the stereochemical outcome of S_N1 like reactions- is heavily dependent on the substitution pattern on the carbohydrate ring,[19, 31, 32] there is a need for more quantitative data on how the effects of the functional groups on C-2, C-3, C-4 and C-6 together impact the ions. In order to systematically investigate the combined effect of the ring substituents on fully decorated glycosyl oxocarbenium ions, here all 8 possible diastereoisomeric β-thiophenol 2,3,4,6-tetra-*O*-benzyl pyranosyl donors, as well their 6-deoxy counterparts (***Figure 2***) are probed in reactions that typically follow an S_N1-like pathway. To this end, the addition reactions of two nucleophiles, TES-D and allyl-TMS were studied. To investigate the conformational preferences of the involved oxocarbenium ions, conformational energy landscape (CEL) maps were generated using density functional theory (DFT) according to the recently published method by Hansen *et al.*[26] It has previously been reported that the outcome of addition reactions of TES-D to (partially stripped) glycosyl oxocarbenium ions can be rationalized using the most relevant conformers of the glycosyl oxocarbenium ions.[26] For some fully decorated glycosyl cations, however, the addition reactions of allyl-TMS proceeded with different selectivity that what would be expected based on the conformational preference of the intermediate glycosyl cations.

For example, the mannosyl donor **2** reacts with TES-D to selectively gives the β-product, which can be accounted for by the diastereoselective attack of the nucleophile on the β-face of the $^{3}H_{4}$-half chair oxocarbenium ion,[26] but the reaction with allyl-TMS under the same conditions gives a 66:34 α:β mixture. The systematic investigation of all possible diastereoisomeric pyranosyl oxocarbenium ions reported here reveals that the addition of TES-D to the oxocarbenium ions, in most cases, proceeds in a stereoselective fashion to provide the products derived from the most favourable oxocarbenium ions. However, when significant steric interactions develop between the incoming nucleophile and the ions and between substituents on the pyranosyl ring, additions to higher energy ions can become more favorable. The complete set of all eight possible pyranosyl diastereoisomers and the use of the two different nucleophiles has allowed to define these Curtin-Hammett kinetic scenarios, which all together provide a detailed picture of the interplay between oxocarbenium ion stability/reactivity, steric interactions in the developing transition states and nucleophile reactivity. These will be instrumental in the understanding and optimisation of the stereochemical outcome of glycosylation reactions.



Glucose (**1**)

Mannose (**2**)

Galactose (**3**)

Allose (**4**)

Altrose (**5**)

Gulose (**6**)

Idose (**7**)

Talose (**8**)

6-deoxy glucose (**9**)

6-deoxy mannose (**10**)[1]

6-deoxy galactose (**11**)[1]

6-deoxy allose (**12**)

6-deoxy altrose (**13**)

6-deoxy gulose (**14**)[1]

6-deoxy idose (**15**)[1]

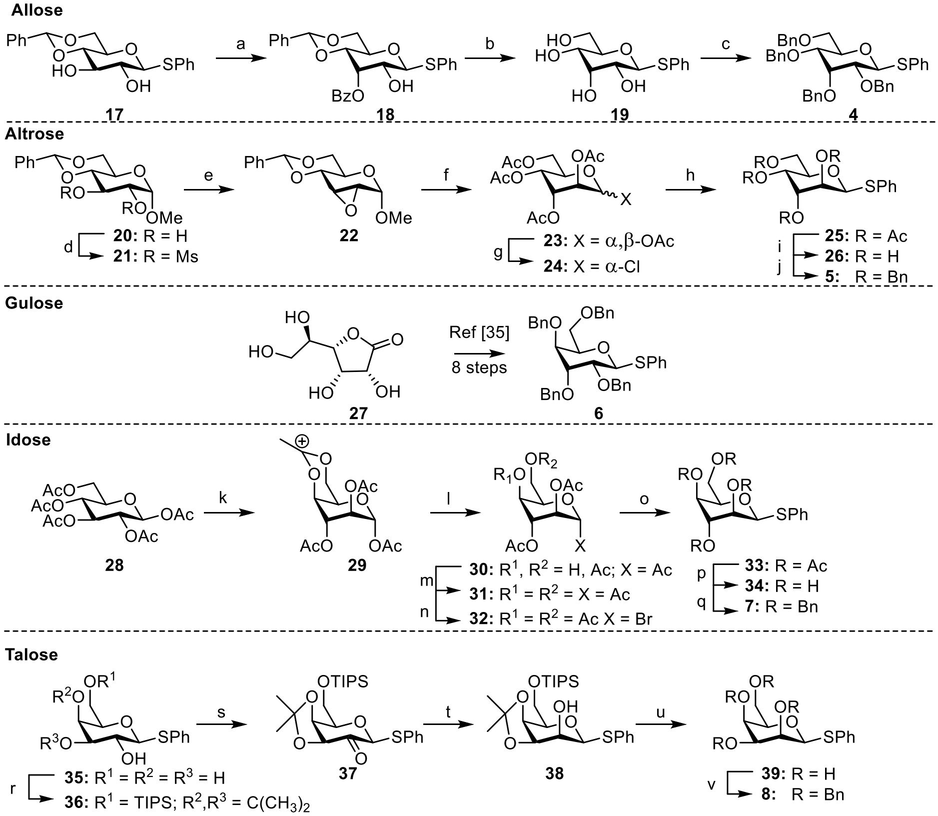
6-deoxy talose (**16**)[1]

Figure 2*: structures of the donors (**1-16**) used in this study. [1]: The* D*-isomer is shown for ease of comparison, but the* L*-isomer is used in the experiments.*

Results and discussion:

Donor synthesis

The glycosyl donors, derived from monosaccharides that are commercially readily available (*i.e.* glucose, mannose, galactose, rhamnose and fucose), was achieved using the following (well-established) reaction sequence: acetylation, installation of the anomeric thiophenol group, deacetylation and benzylation.[26] The synthesis of the other diastereomers is depicted in ***Scheme 1*** (the 6-*O*-benzyl donors) and ***Scheme 2*** (the 6-deoxy sugars). Allose donor **4** was synthesized by the regioselective inversion of the C-3-OH of benzylidene protected glucose **17** via a Mitsunobu reaction with benzoic acid, followed by global deprotection and benzylation. Altrose **5** was synthesised by formation of 2,3-anhydro allose **22** from methyl 4,6-*O*-benzylidene-α-D-glucopyranose (**20**),[12] followed by sulfuric acid catalysed acetolysis.[33] The β-thiophenol moiety was installed by converting the anomeric acetyl group to a chloride using $SOCl_2/SnCl_4$,[34] followed by treatment with NaH/PhSH in DMF. Finally, the acetyl esters were replaced by benzyl ethers under standard conditions. D-Gulose donor **6** was prepared as previously described for the L-isomer,[35] using D-gulonic acid 1,4-lactone (**27**) as starting material. Idose donor **7** was synthesised by antimony(V) chloride mediated inversion of the C-1, C-2, C-3 and C-4 stereocenters of peracetylated glucose (**28**).[36] The β-thiophenol moiety was installed by converting the anomeric acetyl group to the anomeric α-bromide with HBr in acetic acid, followed by treatment with NaH/PhSH in DMF. Next the acetyl groups were replaced by benzyl groups. Finally, talose donor **8** was synthesised from partially protected galactose building block **36** by inversion of C-2 via an oxidation and reduction sequence, followed by acid catalysed deprotection of the TIPS-ether and isopropylidene groups and benzylation. The 6-deoxy glucose, allose and altrose donors were synthesised by deoxygenation of the C-6-*O*-tosyl precursors with lithium aluminium hydride, as shown in ***Scheme 2***. The 6-deoxy gulose donor **14** was synthesised from fucose building block **49**, which was transformed into 6-deoxygulose **50** in 5 steps according to literature procedure,[37] followed by deprotection and benzylation. Both the 6-deoxy idose and 6-deoxy talose donors were synthesised from 3,4-isopropylidene protected fucose building block **52**. The C-2-OH was inverted by oxidation with Dess-Martin periodinane followed by reduction with $NaBH_4$ to give talose configured building block **54**. The idose donor was obtained by removal of the isopropylidene, followed by regioselective benzoylation of the resulting diol, yielding compound **56**. Inversion of the free C-3-OH was then achieved by triflation followed by substitution with $TBANO_2$[38]. Unfortunately, the substitution reaction was accompanied by the formation of elimination products leading to a low yield of compound **58.**[*] Sufficient material could be generated nonetheless for the upcoming glycosylation studies. Debenzoylation followed by benzylation yielded donor **15**. Acidic deprotection followed by benzylation of compound **54** yielded talose donor **16**.



***Scheme 1**: synthesis of per-benzylated Allose (**4**), altrose (**5**), gulose (**6**), idose (**7**) and talose (**8**) β-thiophenol donors. Reagents and conditions: a) BzOH, Ph_3P, DIAD, THF, 70 °C, 52%; b) i: pTsOH, MeOH, 50 °C, ii: NaOMe, MeOH, 81%; c) NaH, BnBr, DMF, 83 %; d) MsCl, pyridine; e) KOH, THF/MeOH 3:2, reflux, 43% over 2 steps; f) Ac_2O, H_2SO_4, 70%; g) $SOCl_2$, $SnCl_4$, DCM; h) NaH, PhSH, DMF, 49% over 2 steps; i) NaOMe, MeOH; j) BnBr, NaH, DMF, 84% over 2 steps; k) $SbCl_5$, DCM; l) NaOAc, H_2O; m) Ac_2O, pyridine, 38% over 3 steps; n) HBr/HOAc, DCM; o) NaH, PhSH, DMF, 56% over 2 steps; p) NaOMe, MeOH, q) BnBr, NaH, DMF, 73% r) i: TIPS-Cl, imidazole, DMF, ii: 2,2,-dimetoxypropane, pTsOH, 57% over 2 steps; s) Dess-Martin, DCM, 94%; t) $NaBH_4$, MeOH, 0 °C, 67%; u) pTsOH, MeOH, 50 °C; v) BnBr, NaH, DMF, 64% over 2 steps*

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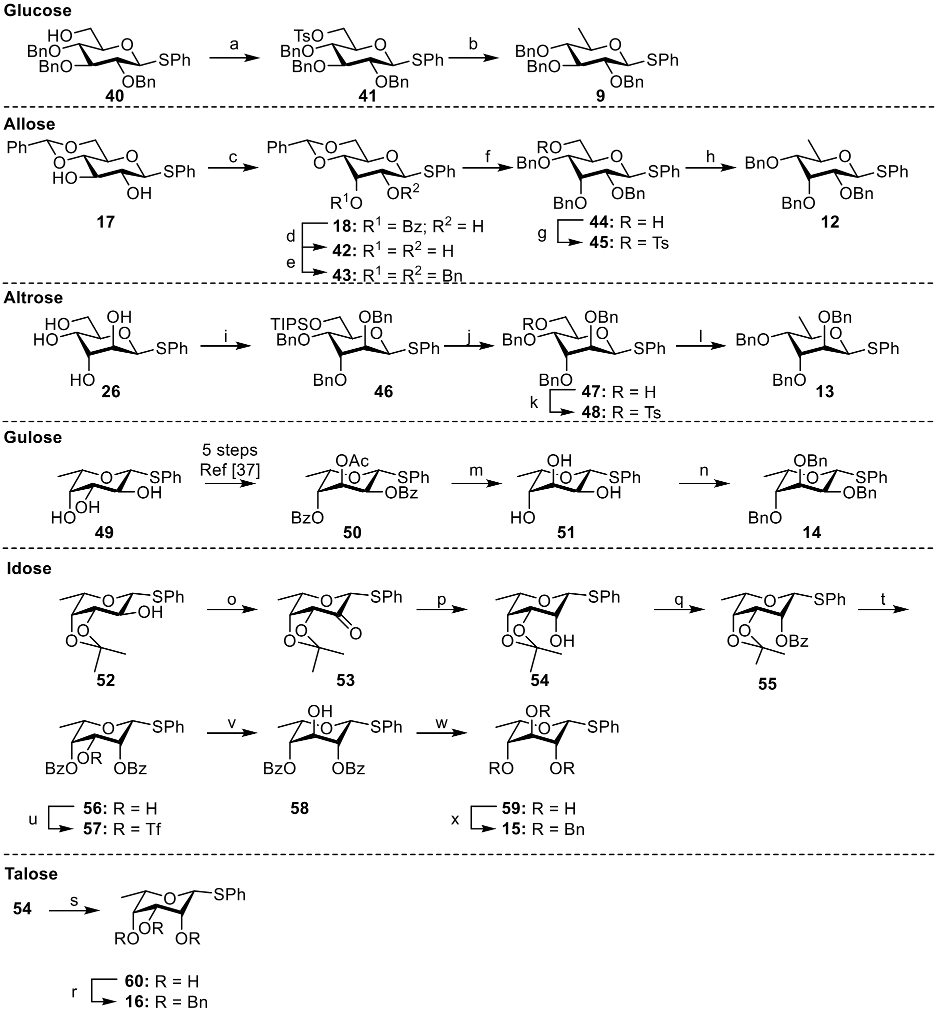
[*] Sanapala and Kulkarni have reported that inversion of the C-3-OH, of a very similar building block carrying a C-4-O-2,2,2-trichloroethoxycarbonyl (Troc) group, under the same conditions proceeds in 54% yield, see ref 38.



***Scheme 2**: synthesis of 6-deoxy donors **9, 12, 13, 14, 15** and **16**. Reagents and conditions: a) pyridine, pTsCl; b) $LiAlH_4$, THF reflux, 47% over 2 steps; c) Ph_3P, BzOH, DIAD, THF reflux; d) NaOMe, MeOH; e) BnBr, NaH, DMF, 32% over 3 steps; f) BH_3-THF, $CoCl_2$, THF; g) pTsCl, pyridine; h) $LiAlH_4$, THF reflux, 48% over 3 steps; i) i: TIPS-Cl, imidazole, DMF, ii: BnBr, NaH, DMF, 85% over 2 steps; j) TFA, THF/H_2O 4:1, 84%; k) pTsCl, pyridine; l) $LiAlH_4$, THF reflux, 64% over 2 steps; m) NaOMe, MeOH; n) BnBr, NaH, DMF, 65% over 2 steps; o) Dess-Martin periodinane, DCM; p) $NaBH_4$, MeOH, -10 °C, 33% over 2 steps; r) BzCl, pyridine, DCM, 79%; r) i: MeOH, amberlite, reflux, ii: $PhC(OMe)_3$, CSA, DCM, iii: H_2O, 54% over 3 steps; s) Tf_2O, pyridine, DCM, -10 °C; t) $TBANO_2$, ACN, 80 °C; u) NaOMe, MeOH; v) BnBr, NaH, DMF, 9% over 4 steps; w) i: PTSA, MeOH, 50 °C; x) BnBr, NaH, DMF, 75% over 2 steps*

CEL maps and stereoselectivity of glycosylations with TES-D and Allyl-TMS

The generation of the oxocarbenium ion CEL maps and the prediction of the stereochemical outcome of S_N1 reactions to these was done as previously described by Hansen *et al.*[26] In order to reduce the required calculation time, the benzyl (OBn) protecting groups were changed for smaller, electronically similar methyl (OMe) groups. The workflow is depicted in ***Figure 3***. The starting conformation for the CEL map was determined by first generating a conformational library using the *'conformation distribution search'* included in spartan '14[39] using the B3LYP as hybrid functional in the gas phase with 6-31G(d) as the basis set. Next, the found structures were re-optimised using Gaussian 09[40] using DFT/B3LYP/6-311G(d,p), including an optimisation with a polarisable continuum solvent model (PCM) to account for the solvation in dichloromethane. The structure with the lowest energy was used as starting point for the CEL map generation. In order to make sure that the entire conformational space was scanned, three dihedral angles, C1-C2-C3-C4 (D1), C3-C4-C5-O (D3) and C5-O-C1-C2 (D5) were changed from -60° to 60° in steps of 15°, giving a total of 729 structures. For donors **1-8**, three different O5-C5-C6-O6 rotamers (the *gg*, *gt* and *tg* structures) were taken into account, as it has been shown that the stability and reactivity of the ions is significantly impacted by the orientation of the C-6-group.[41] The three CEL maps were generated separately and subsequently the maps were merged using the structures that were lowest in energy.

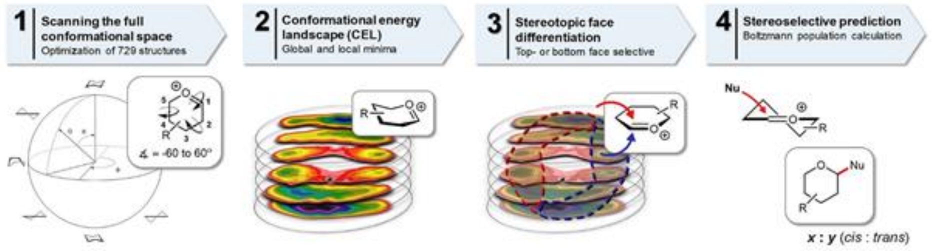


Figure 3: *Overview of the workflow to map the conformational and stereoselective preference of pyranosyl oxocarbenium ions. (1) The complete conformational space of a six-membered ring was scanned by computing 729 prefixed structures. A few canonical conformations (chair, half-chair, envelope, and boat) are depicted. (2) The associated energies were graphed on slices dividing the Cremer–Pople sphere. (3) Top- and bottom-face selective conformers lie in separate areas of the sphere. The family of the top face-selective (^3E, $^3H_4$, E_4, and $B_{2,5}$)-like structures is found in the area contoured with the red-dashed line, while the bottom face-selective family of (^4E, $^4H_3$, E_3, and $^{2,5}B$)-like conformers is found on the opposite side of the sphere, grouped within the blue-dashed line. (4) On the basis of the Boltzmann distribution of the top- and bottom-face selective structures, the stereochemical outcome of nucleophilic addition reactions to pyranosyl oxocarbenium ions can be computed**.** The picture and description are reprinted from ACS Central Science by T. Hansen et al.*[26]

In order to visualise the energy levels of the conformations on the Cremer-Pople sphere,[42] the sphere was dissected in slices that combine closely associated conformers. The OriginPro software[43] was employed to produce the energy heat maps, contoured at 0.5 kcal/mol. The CEL maps revealed that the ^3E, $^3H_4$, E_4, and $B_{2,5}$ conformations together with the opposing ^4E, $^4H_3$, E_3, and $^{2,5}B$ conformations are generally energetially most favourable. To predict the stereoselectivity of the oxocarbenium ions the conformations were divided in top-face (the ^3E, $^3H_4$, E_4, and $B_{2,5}$-type conformations) and bottom-face (^4E, $^4H_3$, E_3, and $^{2,5}B$-type conformations) selective families, based on the most likely mode of attack by the nucleophile. The most favourable reaction path for the half chair-type structures leads to the products via a chair-like structure, while the most favourable approach of the boat-like ions is from the convex face of the structures. To calculate the theoretical α:β ratio based on a given CEL map, the Boltzmann distribution (eq. 1) was used to determine the relative population of the α- and β-selective conformations. Only the conformations with a relative energy lower than 5 kcal/mol were included in the calculations.

$$\frac{N_i}{N_{total}} = \frac{e^{-E_{rel}/RT}}{\sum_{k=1}^{N_{total}} e^{-E_k/RT}} \quad \textit{(eq. 1)}$$

The CEL maps for the 6-deoxy pyranosyl oxocarbenium ions and the C-6-OMe ions are depicted in ***Figure 4*** and ***Figure 5***, respectively. The collection of CEL maps clearly illustrates how changing the configuration of one, two or three stereocenters impacts the conformational preference of the ions. When comparing the structures of the 6-deoxy ions to their C-6-OMe counterparts is becomes apparent that similar families of favourable conformers are found for both pyranosyl classes but that there is a difference between the relative energy of the conformations. The stability of the conformations identified by the CEL maps may be rationalised by taking into account the individual 'preferences' of the susbtituents to best stabilise (or least destabilise) the ions, as experimentally determined by Woerpel and co-workers[19, 20, 31, 32] and computationally substantiated by Hansen *et al.*[26] Pyranosyl oxocarbenium ions placing alkoxy groups at the C-3 and C-4 positions in a *pseudo*-axial orientation are more stable than their *pseudo*-equatorial counterparts. For steric reasons, the C-5 group is placed preferentially in a pseudo-equatorial orientation, just like the C-2-alkoxy group. This orientation of the C-2-group also enables stabilisation of the oxocarbenium ion by hyperconjugative stabilization by the *pseudo*-axial C-2-H atom. When all these preferences can be achieved in concert, as is the case for the 6-deoxy gulosyl oxocarbenium ion, the ion shows a very strong preference for a single well-defined conformation, *i.e.* the $^4H_3$ half chair. The structures that are capable of placing three out of the four substituents in their favorable orientation (6-deoxy mannose/galactose/allose/idose) also show a relatively strong preference for the structure with the three substituents placed in a stereoelectronic favourable orientation. The structures where only two substituents can be placed in a favourable manner show the most 'filled' CEL maps with multiple structures being relatively close in energy.

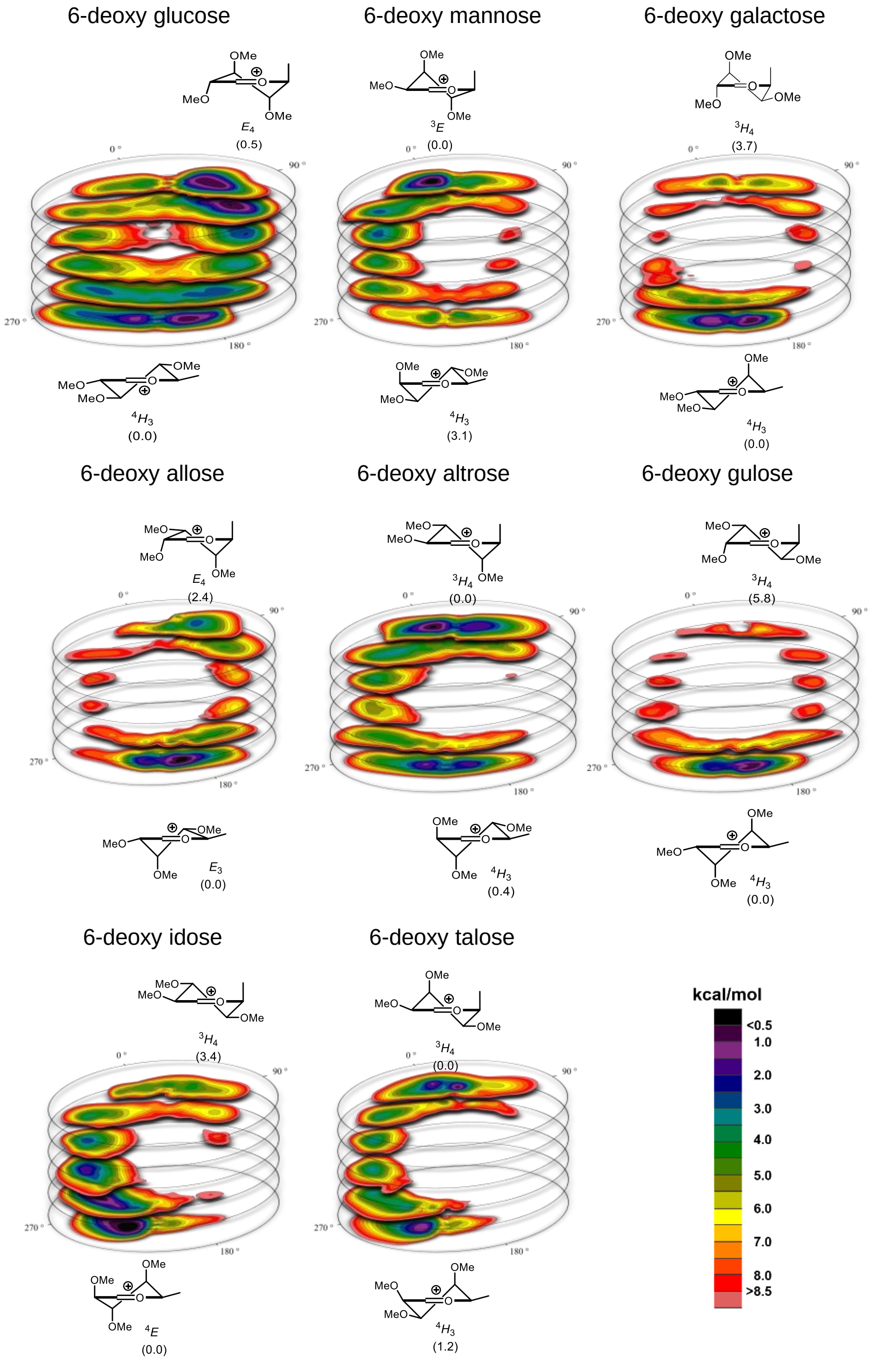
The results of the glycosylations of the eight 6-deoxy pyranosyl and eight C-6-*O*-benzyl donors are summarized in ***Table 1***, and ***Table 2***, respectively, where they are also compared to the calculated α:β ratio based on the CEL maps of the oxocarbenium ions. It has previously been described for a large set of "stripped" pyranosyl oxocarbeniums, that the CEL maps could be used well to rationalise the stereoselectivity of reactions of these with TES-D. From the results in ***Table 1*** it becomes apparent that in the 6-deoxy series the theoretically predicted and experimentally observed selectivities for the addition of TES-D to the mannose-, galactose-, allose-, altrose-, gulose- and talose-configured ions match well. Discrepancies are found for the 6-deoxy glucose and 6-deoxy idose ions. While the 6-deoxy glucose CEL-map predicts an unselective addition reaction, the experiment delivers the α-product with excellent stereoselectivity. Based on the ground-state energy of the different conformers of the 6-deoxy idose ion an α-selective addition could be expected, where a β-selective addition is experimentally observed. The deviation in the selectivity predicted based on the ground-state energy of the ions and the experimentally determined stereoselectivity may be rationalded by steric interactions that develop in the transition states leading to the products, between the oxocarbenium ion and the incoming nucleophile and the interactions of the axial susbtituents of the ions/products. For the 6-deoxy glucose ion, the E_4 conformer is relatively close in energy to the $^4H_3$ half chair ion (ΔG = 0.5 kcalmol^{-1}) but attack on the top face of the E_4 conformer will lead to significant steric interactions with the *pseudo*-axial C-3 and C-5 substituents. In addition, transformation from the envelope structure to a $^4C_1$ chair will increase the 1,3-diaxial interactions between the groups at C-2 and C-4. For the addition of TES-D to the 6-deoxy idose ion a similar analysis can be made. Even though there is a significant difference in stability between the $^3H_4$ half chair and the ^4E envelope (ΔG = 3.4 kcalmol^{-1}), attack at the latter conformer is hindered by the axial C-3-group and, in line with the analysis above, the ^4E to $^1C_4$ transformation will lead to the development of significant 1,3-diaxial interactions of the C-2 and C-4 groups.

The developing steric interactions are even more important in the additions of allyl-TMS to the oxocarbenium ions. Allyl-TMS is a weaker nucleophile than TES-D and therefore the transition state of the reactions of this nucleophile (Mayr nucleophilicity parameter 1.96 (TES-D) *vs* 3.58 (allyl-TMS)) are expected to be later on the reaction coordinate. Thus, for the 6-deoxy mannose case this leads to erosion of β-selectivity, as attack on the β-face of the ^3E envelope generates 1,3-diaxial interactions with the substituents at the C-3 and C-5 position and a gauche interaction with the C-2-substituent. Even though the ground state energy difference between the ^3E envelope and the $^{4}H_{3}$ half chair ions is significant (ΔG = 3.1 kcalmol^{-1}), the developing steric interactions counterbalance this energy gap. For 6-deoxy altrose the ground state energy difference between the two half chairs on either side of the CEL is relatively small. With the reactive and small nucleophile TES-D the intrinsic difference between the $^{3}H_{4}$ and $^{4}H_{3}$ half chair ions (ΔG = 0.4 kcalmol^{-1}) is mirrored in the stereoselectivity of the addition reaction (α:β = 12:88), while the less reactive allyl-TMS provides an α-selective reaction (α:β = 89:11). The developing 1,3-diaxial interaction between the nucleophile and the C-5 methyl group and gauche interaction with the C-2-substituent raise the transition state energy for the addition on the β-face of the $^{3}\mathrm{H}_{4}$ half chair ion such that addition to the α-face of the opposite half chair becomes more favorable. For 6-deoxy idose, these steric interactions also make addition to the less stable ^{4}E oxocarbenium ion less favorable than top-face addition to the $^{4}H_{3}$ half chair. As the addition of allyl-TMS to this ion proceeds with lower β-selectivity than the addition of the smaller and more reactive TES-D it appears that the steric interactions of the incoming allyl-TMS with the substituent at C-2 and C-5 make the transition state for the allyl-TMS addition on the top face more unfavorable leading to the formation of relatively more of the α-product. For 6-deoxy talose a complete shift in stereoselectivity is observed when comparing the TES-D and allyl-TMS additions, again indicating important steric gauche and di-axial interactions in top-face attack of the most stable $^{3}H_{4}$ half chair ion. As the difference in ground state energy between the 6-deoxy talose $^{3}H_{4}$ and $^{4}H_{3}$ half chair ions (ΔG = 1.2 kcalmol^{-1}) is smaller than that of the 6-deoxy mannose ions (ΔG = 3.1 kcalmol^{-1}) and therefore the change in stereoselectivity observed for addition to the 6-deoxy talose ion is more significant (<2:98 to >98:2 *vs* <2:98 to 77:23).

***Table 1:** predicted and experimental stereoselectivities of all 8 6-deoxy pyranosyl donors*

Donor	Calculated α:β selectivity	TES-D		Allyl-TMS	
		Product (Yield)	α:β	Product (Yield)	α:β
9 (6-deoxy glucose)	**55:45**	**9A** (59%)	**>98:2**	**9B** (64%)	**>98:2**
10 (6-deoxy mannose)	**<2:98**	**10A** (79%)	**<2:98**	**10B** (83%)	**77:23**
11 (6-deoxy galactose)	**>98:2**	**11A** (74%)	**>98:2**	**11B** (76%)	**>98:2**
12 (6-deoxy allose)	**>98:2**	**12A** (57%)	**>98:2**	**12B** (57%)	**>98:2**
13 (6-deoxy altrose)	**23:77**	**13A** (85%)	**12:88**^{a}	**13B** (67%)	**89:11**
14 (6-deoxy gulose)	**>98:2**	**14A** (86%)	**>98:2**	**14B** (75%)	**>98:2**
15 (6-deoxy idose)	**>98:2**	**15A** (50%)	**<2:98**	**15B** (48%)	**21:79**
16 (6-deoxy talose)	**12:88**	**16A** (68%)	**<2:98**^{a}	**16B** (55%)	**>98:2**

*a: determined after debenzylation followed by benzoylation. Calculated α:β ratios are based on methylated oxocarbenium ions, experimental α:β values are based on benzylated donors. The CEL maps and TES-D results of donors **10** and **11** were previously reported.*[26]



6-deoxy glucose

6-deoxy mannose

6-deoxy galactose

6-deoxy allose

6-deoxy altrose

6-deoxy gulose

6-deoxy idose

6-deoxy talose

Figure 4: *CEL maps of all 6-deoxy pyranosyl oxocarbenium ions*

Table 2 summarises the results for the reactions of the C-6-OMe/OBn pyranosyl donors. When these results are compared to the experimental results of the 6-deoxy series it becomes apparent that these are very similar and thus that in most cases the C-6-substituent has relatively little influence on the stereoselectivity of the reactions. As mentioned above, the CEL maps of the C-6-OMe and 6-deoxy pyranosyl oxocarbenium ions reveal similar conformations to be relevant and this translates into comparable stereoselectivities in the addition reactions. A notable difference can be observed for the glucopyranosyl ion, where there is a significantly larger difference in stability between the $^4H_3$ half chair ion and the $E_4/^2S_O$ (ΔG = 2.3 kcalmol^{-1}) than found for the 6-deoxyglucosyl ions (ΔG = 0.5 kcalmol^{-1}). This however does not lead to a different stereochemical outcome of the addition reactions, as the sterically least hindered mode of attack can now take place on the most stable oxocarbenium ion conformer. For the talose ion a significant difference is observed as well, with the $^3H_4$ and $^4H_3$ half chair ions being of comparable stability, which translates to a theoretical 1:1 α:β-ratio. The TES-D addition however provides solely the β-product. This would indicate that the 1,3-diaxial interactions between the C-2 and C-4 groups, that develop in the transition state of the reaction of TES-D on the bottom face of the ^{4}E envelope, are prohibitively large to favour attack of the nucleophile on the top face of the ^{3}H$_4$ half chair ion. When allyl-TMS is used as a nucleophile the steric interactions of the nucleophile with the electrophile will become more important (*i.e.* the 1,3-diaxial type interaction with the groups at C-3 and C-5 as well as the gauche interaction with the group at C-2) making the top face attack less favourable and thus leading to the formation of an α/β-mixture.

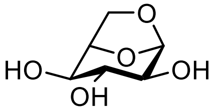
In all, the above-described analyses show that, in line with the study of Hansen *et al.*, the conformational preference of a pyranosyl oxocarbenium ion translates well into the selectivity observed in the addition of TES-D to these ions. TES-D experiences relatively little steric interactions with the substituents on the ring during the addition reaction. If, however, 1,3-diaxial interactions develop between the substituents on the ring in the transition state of the addition reaction (as in the β-face attack on the 6-deoxy glucose ^{4}E-ion, the α-face attack on the 6-deoxy idose ^{4}E-ion and the α-face attack on the 6-deoxy talose ^{4}H$_3$-ion), these can significantly increase the hight of the transition states. Allyl-TMS, a larger and less reactive nucleophile, in contrast can experiences significant 1,3-diaxial type interactions with axial substitutions at the C-3 and C-5 position of the pyranosyl ion as well as gauche interactions with the group at C-2. These interactions can induce a Curtin-Hammett kinetic scenario, in which the higher energy oxocarbenium ion conformer becomes the most relevant product forming intermediate.

Table 2: *predicted and experimental stereoselectivities of all 8 pyranosyl donors*

Donor	Calculated α:β selectivity	TES-D		Allyl-TMS	
		Product (Yield)	α:β	Product (Yield)	α:β
1 (Glucose)	**>98:2**	**1A** (70%)	**>98:2**	**1B** (71%)	**>98:2**
2 (Mannose)	**3:97**	**2A** (93%)	**3:97**	**2B** (80%)	**66:34**
3 (Galactose)	**>98:2**	**3A** (86%)	**>98:2**	**3B** (80%)	**>98:2**
4 (Allose)	**>98:2**	**4A** (74%)	**>98:2**	**4B** (46%)	**>98:2**
5 (Altrose)	**4:96**	**5A** (55%)	**20:80**	**5B** (68%)	**89:11**
6 (Gulose)	**>98:2**	**6A** (83%)	**>98:2**	**6B** (71%)	**>98:2**
7 (Idose)	**90:10**	**7A** (74%)	**<2:98**[a]	**7B** (n.d.)[b]	**13:87**
8 (Talose)	**52:48**	**8A** (51%)	**<2:98**[a]	**8B** (67%)	**57:43**

[a] determined after debenzylation followed by benzoylation. [b] an accurate determination of the yield is not possible due to poor separation from a side product.[†] Calculated α:β ratios are based on methylated oxocarbenium ions, experimental α:β values are based on benzylated donors. The CEL maps and TES-D results of donors ***1-3*** *were previously reported.*[26]

[†]



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The side product is the 1,6-anhydro product from donor ***7****, compound* ***61****. This product forms in 81% yield when donor* ***7*** *is activated, but no nucleophile is added.*

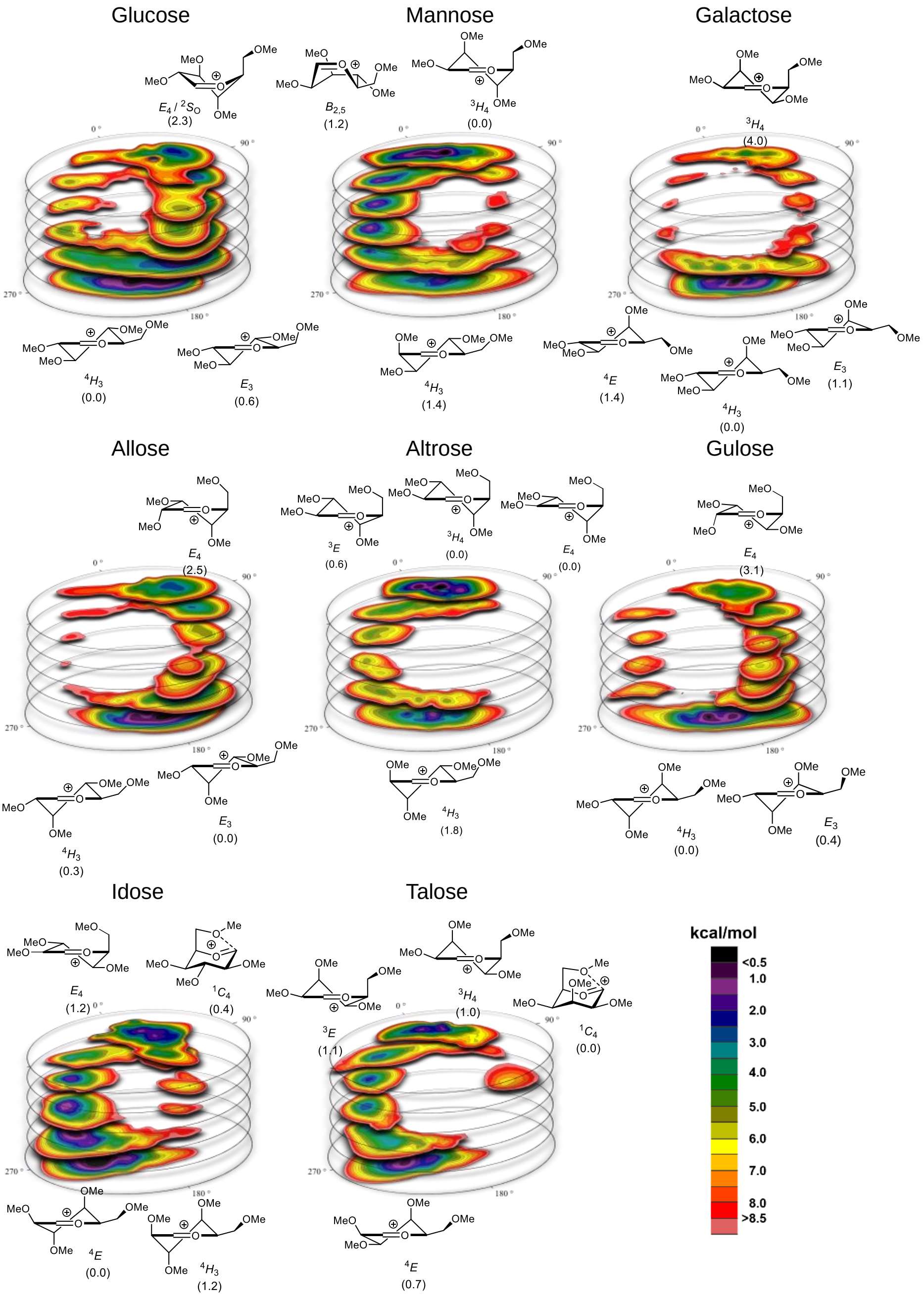


Figure 5: *CEL maps of all pyranosyl oxocarbenium ions*

Conclusion

In conclusion, this chapter has investigated S_N1-like glycosylation reaction mechanisms and the influence of the substitution pattern of the glycosyl donor on the conformational preference of the involved oxocarbenium ions. To fuel these studies, synthetic routes towards all 8 possible diastereoisomeric β-thiophenol 2,3,4,6-tetra-*O*-benzyl pyranosyl donors, and their 6-deoxy-counterparts were developed. Next, the conformational preference of the oxocarbenium ions was mapped by the generation of CEL maps and the donors were reacted with both TES-D and allyl-TMS in order to trap the oxocarbenium ions. These results show that the stereochemical outcome of C-6-deoxy and C-6-OBn donors to be very similar. Even for idose and talose, where the $^1C_4$ conformation of the C-6-OBn oxocarbenium ions was found to be found relatively favorable, the C-6-substituents does not significantly contribute to the stereochemical outcome. Another observation is that the stereochemistry of C-2 is a very important factor for the stereochemical outcome of the reactions with TES-D, since all TES-D reactions were highly *1,2-cis* selective, even when the CEL maps predict a mixture or *1,2-trans* selectivity. This *1,2-cis* selectivity is correctly predicted in 12 out of 16 cases by the CEL maps. A striking difference in the stereoselectivity of the reactions with TES-D and allyl-TMS were observed for the pyranosides having an axial C-2-OBn. Where the TES-D reactions are all highly β-selective, the allyl-TMS reactions are either α-selective or proceed with relatively poor β-selectivity. For the reactions in which the ground state energy of the oxocarbenium ions proved to be a poor predictor of the stereoselectivity of the glycosylation reactions, Curtin Hammett kinetic scenarios were invoked to rationalize the outcome of the reactions. When developing steric interactions between the incoming nucleophile and the electrophile, as well as interactions developing between the substituents on the pyranosyl ring become prohibitively large, reactions on less favorable oxocarbenium ions can become attractive. To better understand the steric and electronic factors at play during the transition state of the reactions, future research will have to focus on computationally studying the transition state of these reactions, in which the donor oxocarbenium ions are systematically varied and paired with *C*-nucleophiles, of gradually changing nucleophilicity.

Experimental

Generation of CEL-maps and calculation of the expected stereochemistry based on the CEL-maps

The generation of CEL-maps and the calculation of the expected stereoselectivity of the oxocarbenium ions based on the CEL-maps was performed as previously described by T. Hansen *et al.*[26]

General experimental procedures

General experimental procedures: All chemicals were of commercial grade and used as received unless stated otherwise. Dichloromethane (DCM) was stored over activated 4 Å molecular sieves for at least 24 h before use. Trifluoromethanesulfonic anhydride (Tf_2O) was distilled over P_2O_5 and stored at -20°C under a nitrogen atmosphere. Overnight temperature control was achieved by a FT902 Immersion Cooler (Julabo). Flash column chromatography was performed on silica gel 60 Å (0.04 – 0.063 mm, Screening Devices B.V.). Thin-layer chromatography (TLC) analysis was conducted on TLC silica gel 60 plates (Kieselgel 60 F254, Merck) with UV detection by (254 nm) and by spraying with 20% sulfuric acid in ethanol or by spraying with a solution of $(NH_4)_6Mo_7O_{24}{\cdot}H_2O$ (25 g/L) and $(NH_4)_4Ce(SO4)_4{\cdot}2H_2O$ (10 g/L) in 10% aq. sulfuric acid followed by charring at ±250 °C. High-resolution mass spectrometry (HRMS) was performed on a Thermo Finnigan LTQ Orbitrap mass spectrometer equipped with an electrospray ion source in positive-ion mode (source voltage 3.5 kV, sheath gas flow 10, capillary temperature 275 °C) with resolution R = 60.000 at m/z 400 (mass range of 150-4000) and dioctylphtalate (m/z=391.28428) as lock mass, or on a Waters Synapt G2-Si (TOF) equipped with an electrospray ion source in positive mode (source voltage 3.5 kV) and LeuEnk (m/z = 556.2771). as internal lock mass. 1H and 13C NMR spectra were recorded on Bruker AV-400, Bruker DMX-400, and Bruker AV-500 NMR instruments. Chemical shifts (δ) are given in parts per million (ppm) relative to tetramethylsilane as an internal standard or the residual signal of the deuterated solvent. Coupling constants (J) are given in Hertz (Hz). All presented 13C-APT spectra are proton-decoupled. NMR peak assignments were made using COSY and HSQC. When necessary, additional NOESY, HMBC and HMBC-GATED experiments were used to further elucidate the structure. The anomeric product ratios were based on careful analysis of the crude reaction mixture and the purified reaction product by integration of representative 1H NMR signals. IR spectra were recorded on a Shimadzu FTIR-8300 IR spectrometer and are reported in cm-1. Specific rotations were measured on a Propol automatic polarimeter or an Anton-Paar MCP-100 modular circular polarimeter at 589 nm unless otherwise stated.

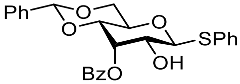
General procedure for Ph_2SO/Tf_2O meditated glycosylations

Donor (0.1 mmol, 1 eq), Ph_2SO (0.13 mmol, 1.3 eq) and TTBP (0.25 mmol, 2.5 eq) were coevaporated twice with toluene, dissolved in 2 mL DCM and stirred for 30 min at RT with 3Å molecular sieves. The solution was cooled to -80 ^{0}C and Tf_2O (22 μL, 0.13 mmol, 2 eq) was added. The reaction mixture was allowed to warm to −60 ^{0}C and then recooled to −78 ^{0}C, after which the acceptor (2-6 eq) was added. The reaction mixture was allowed to warm to −60 ^{0}C for and stirred between 1-24 hr at that temperature. The reaction was quenched with 2 mL sat aq $NaHCO_3$ or 0.2 mL 1M Et_3N in DCM, and the mixture was diluted with DCM. The solution was transferred to a separatory funnel, water was added, the layers were separated, and the water phase was extracted once more with DCM. The combined organic layers were dried over MgSO4, filtered, and concentrated in vacuo. Purification by silica gel flash column chromatography yielded the glycosylation product as a mixture of anomers.

General procedure for debenzylation followed by benzoylation

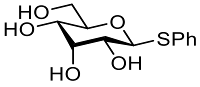
Benzylated product was dissolved in EtOH (0.05 M) with an equal weight of 5% Pd/C. the reaction mixture was flushed with N_2 (2x) and H_2 (2x) and kept under H_2 atmosphere overnight, after which it was flushed twice with N_2, filtered over a plug of celite and concentrated under reduced pressure. The crude tri- or tetra-ol was coevaporated 3x with toluene and dissolved in pyridine (1 mL) and treated with BzCl (2 eq per OH). After 24 hr, the reaction mixture was diluted with EA and washed with 1M HCl and bicarb. The organic phase was dried with $MgSO_4$ and concentrated. Silica chromatography yields the benzoylated product.

Phenyl 3-*O*-benzoyl-4,6-*O*-benzylidene-1-thio-β-D-allopyranose (18)



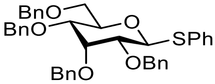
Phenyl 4,6-*O*-benzylidene-1-thio-β-D-glucopyranose[44] (**17**, 7.21 g, 20 mmol), benzoic acid (3.66 g, 30 mmol, 1.5 eq) and triphenylphosphine (7.87 g, 30 mmol,1.5 eq) were dissolved in THF and heated to a gentle reflux. DIAD (5.91 mL, 30 mmol,1.5 eq) was added dropwise over 5 min, after which TLC showed full conversion of the starting material. The reaction mixture was cooled to RT and concentrated under reduced pressure. The residue was dissolved in EtOAc and washed with sat. aq. $NaHCO_3$. The organic phase was dried with $MgSO_4$ and concentrated under reduced pressure. Purification over silica (10%→25% acetone in pentane) yields the title compound as off-white foam. Yield: 4.87 g, 10.5 mmol, 52%. ^1H NMR (400 MHz, $CDCl_3$) δ 8.09 – 8.02 (m, 2H, CH_{arom}), 7.70 – 7.63 (m, 2H, CH_{arom}), 7.60 – 7.51 (m, 4H, CH_{arom}), 7.49 – 7.41 (m, 4H, CH_{arom}), 7.39 – 7.34 (m, 5H, CH_{arom}), 7.28 (dd, *J* = 5.1, 1.9 Hz, 3H, CH_{arom}), 6.01 (t, *J* = 2.8 Hz, 1H, H-3), 5.55 (s, 1H, C*H*Ph), 5.00 (d, *J* = 9.8 Hz, 1H, H-1), 4.46 (dd, *J* = 10.6, 5.0 Hz, 1H, H-6), 4.15 (td, *J* = 9.9, 5.1 Hz, 1H, H-5), 3.80 (t, *J* = 10.4 Hz, 1H, H-6), 3.75 (dd, *J* = 9.5, 2.6 Hz, 2H, H-2, H-4), 2.75 (s, 1H, OH); ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.5 (C=O), 136.9 (C_q), 133.6, 133.5, 132.3, 132.2 (CH_{arom}), 132.1, 132.1 (C_q), 131.1, 130.0, 129.2, 128.7, 128.7, 128.6, 128.6, 128.4, 126.2 (CH_{arom}), 101.8 (CHPh), 86.5 (C-1), 77.0 (C-4), 70.4 (C-3), 69.2 (C-6), 69.0 (C-5), 67.8 (C-2);); HRMS: $[M+NH_4]^+$ calcd for $C_{26}H_{24}O_6SNH_4$ 482.16318, found 487.16258

Phenyl 1-thio-β-D-allopyranose (19)



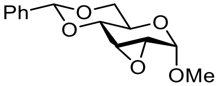
Compound **18** (3.17 g, 6.82 mmol) and pTsOH hydrate (130 mg, 0.68 mmol, 0.1 eq) were dissolved in methanol and heated to 50 °C. After TLC shows full removal of the benzylidene, the reaction mixture was cooled to RT and NaOMe (184 mg, 3.41 mmol, 0.5 eq) was added. After full deprotection, the solution was neutralised with Amberlite IR-120(H), filtered over celite and concentrated. The residue was purified over silica (50% acetone in DCM), to yield the title compound as colourless oil. Yield: 1.51 g, 5.55 mmol, 81%. ^{1}H NMR (400 MHz, Acetone) δ 7.55 – 7.49 (m, 2H, CH$_{arom}$), 7.33 – 7.27 (m, 2H, CH$_{arom}$), 7.27 – 7.21 (m, 1H, CH$_{arom}$), 4.94 (d, *J* = 9.8 Hz, 1H, H-1), 4.14 (t, *J* = 3.0 Hz, 1H, H-3), 3.88 – 3.79 (m, 1H, H-6), 3.70 – 3.60 (m, 2H, H-5, H-6), 3.53 (dd, *J* = 9.7, 3.0 Hz, 1H, H-4), 3.41 (d, *J* = 10.1 Hz, 1H, H-2); ^{13}C NMR (101 MHz, Acetone) δ 135.7 (C$_q$), 131.7, 129.6, 127.5 (CH$_{arom}$), 85.6 (C-1), 77.8 (C-5), 72.4 (C-3), 70.7 (C-2), 68.6 (C-4), 63.1 (C-6); HRMS: [M+Na]$^+$ calcd for $C_{12}H_{16}O_5S$ 295.06107, found 295.06054

Phenyl 2,3,4,6-tetra-*O*-benzyl-1-thio-β-D-allopyranose (4)



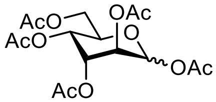
Compound **19** (1.63 g, 6 mmol, 1 eq) was dissolved in 50 mL DMF and cooled to 0°C, after which sodium hydride (60% dispersion in mineral oil, 1.44 g, 36 mmol, 6 eq.) was added portionwise. After stirring for an additional 30 minutes, benzyl bromide (4.28 mL, 36 mmol, 6 eq) was added and the mixture was allowed to warm to RT. Upon completion of the reaction, excess sodium hydride was destroyed carefully with water. The aqueous phase was extracted with diethyl ether, the organic phase washed with distilled water and brine, dried with Na_2SO_4 and concentrated under reduced pressure. The residue was purifed over silica (5% EtOAc in pentane) to give the title compound as a colourless oil that solidifies over time. Yield: 2.80 g, 4.42 mmol, 74%.$[\alpha]_D^{25}$ = -0.6° (c = 0.85, $CHCl_3$); IR (thin film): 697, 737, 1050, 1089; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.64 – 7.49 (m, 2H, H-Ar), 7.40 – 7.14 (m, 23H, CH$_{arom}$), 5.24 (d, *J* = 9.7 Hz, 1H, H-1), 4.83 (d, *J* = 11.9 Hz, 1H, C*H*H Bn), 4.77 (d, *J* = 11.9 Hz, 1H, CH*H* Bn), 4.62 – 4.57 (m, 2H, 2x C*H*H Bn), 4.55 – 4.51 (m, 2H, 2x CH*H* Bn), 4.49 (d, *J* = 7.9 Hz, 1H, C*H*H Bn), 4.41 (d, *J* = 11.6 Hz, 1H, CH*H* Bn), 4.13 (t, *J* = 2.5 Hz, 1H, H-3), 4.09 (ddd, *J* = 9.8, 4.5, 1.9 Hz, 1H, H-5), 3.80 (dd, *J* = 10.9, 1.9 Hz, 1H, H-6), 3.71 (dd, *J* = 10.9, 4.5 Hz, 1H, H-6), 3.49 (dd, *J* = 9.8, 2.4 Hz, 1H, H-4), 3.31 (dd, *J* = 9.8, 2.4 Hz, 1H, H-2); ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.0, 138.6, 138.0, 137.9, 134.1 (C$_q$), 131.9, 128.8, 128.6, 128.5, 128.5, 128.5, 128.4, 128.3, 128.3, 128.1, 128.1, 128.0, 128.0, 127.9, 127.9, 127.7, 127.5, 127.5, 127.2 (C-Ar), 83.9 (C-1), 78.0 (C-2), 75.6 (C-4), 75.2 (C-5), 74.4 (CH_2 Bn), 73.7 (C-3), 73.5 (CH_2 Bn), 72.5 (CH_2 Bn), 71.7 (CH_2 Bn), 69.4 (C-6); HRMS: [M+NH$_4$]$^+$ calcd for $C_{40}H_{40}O_5SNH_4$ 650.29347, found 650.29182

Methyl 2,3-anhydro-4,6-*O*-benzylidene-α-D-allopyranoside (22)



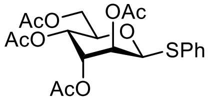
Compound **20**[44] (25.7 g, 91.2 mmol) was dissolved in pyridine (150 mL) and cooled to 0°C. methane sulfonyl chloride (21,2 mL, 273 mmol, 3 eq.) was added dropwise. The mixture was diluted with EA and washed with water and twice with brine. The organic layer was dried with $MgSO_4$ and concentrated in vacuo to obtain the crude dimesylate **21** which was used without further purification. Crude compound **21** (≤91.2 mmol) was dissolved in THF/MeOH (750 mL, 2:3, v:v). KOH (15.3 g, 273 mmol, 3 eq.) was added. The reaction mixture was refluxed overnight at 70°C. The mixture was concentrated to about 20% of the volume. Water was added, and the compound was extracted with EA. The organic fraction was washed with water 3 times. The organic layer was dried with $MgSO_4$ and concentrated in vacuo. The crude product was concentrated in vacuo. The residue was purified by multiple crystallizations in an EA/pentane mixture and yielded the title compound as a fluffy off-white solid. Yield: 10.5 g, 39.8 mmol, 43% over 2 steps. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.55 – 7.45 (m, 2H, CH_{arom}), 7.43 – 7.31 (m, 3H, CH_{arom}), 5.57 (s, 1H, C*H*Ph), 4.89 (d, *J* = 2.70 Hz, 1H, H-1), 4.24 (dd, *J* = 10.3, 5.0, 1H, H-6), 4.09 (ddd, *J* = 10.3, 9.1, 5.0 Hz, 1H, H-5), 3.96 (dd, *J* = 9.1, 1.2 Hz, 1H, H-4), 3.69 (t, *J* = 10.3 Hz, 1H, H-6), 3.53 (dt, *J* = 4.2, 1.1 Hz, 1H, H-3), 3.49 (dd, *J* = 4.3, 2.8 Hz, 1H, H-2), 3.47 (s, 3H, CH_3 OMe), ^{13}C NMR (101 MHz, $CDCl_3$) δ 137.2 (C_q), 129.4, 128.5, 126.4 (CH_{arom}), 102.9 (CHPh), 95.4 (C-1), 78.0 (C-4), 69.0 (C-6), 60.1 (C-5), 56.0 (OMe), 53.3 (C-2), 50.9 (C-3). Spectra in agreement with literature.[12]

1,2,3,4,6-penta-*O*-acetyl-α,β-D-altropyranoside (23)



Compound **22** (5.29 g, 20 mmol) was suspended in 30 mL Ac_2O and cooled to 0 °C. After dropwise addition of 0.6 mL H_2SO_4 in 30 mL Ac_2O, the reaction mixture was allowed to warm to RT and stirred overnight. The reaction mixture was poured in ice water and extracted twice with diethyl ether. Combined organic phases were washed with sat. aq. $NaHCO_3$, dried with $MgSO_4$ and concentrated. Purification with silica chromatography (15→25% acetone in pentane) yields the title compound as yellow oil which solidifies over time. Yield: 5.83 g, 14.9 mmol, 75%, major anomer (1): minor anomer (2) = 1 : 0.6, with traces of furanosides. ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.16 (d, *J* = 2.0 Hz, 0.6H, H-1_2), 6.01 (t, *J* = 1.2 Hz, 1H, H-1_1), 5.44 (dd, *J* = 5.6, 3.3 Hz, 0.6H), 5.32 (td, *J* = 3.6, 1.0 Hz, 1H), 5.24 – 5.21 (m, 1H), 5.19 (dd, *J* = 5.7, 2.4 Hz, 1H), 4.99 (dd, *J* = 3.7, 1.5 Hz, 1H), 4.39 (td, *J* = 4.6, 2.0 Hz, 0.6H), 4.37 – 4.27 (m, 2H), 4.23 (t, *J* = 3.1 Hz, 0.6H), 4.20 (t, *J* = 2.8 Hz, 0.3H), 4.16 (dd, *J* = 12.1, 2.1 Hz, 1H), 2.21 – 2.00 (m, 24H, CH_3 Ac), ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.8, 170.7, 169.6, 169.6, 169.5, 169.5, 169.3, 169.1, 168.8, 168.4 (C=O), 90.5 (C-1_1), 90.1 (C-1_2), 72.2, 68.4, 67.4, 66.7, 66.6, 66.6, 65.5, 64.6, 62.8 (C-6_2), 62.4 (C-6_1), 21.0, 20.9, 20.9, 20.8, 20.8, 20.7 (CH_3 Ac). Spectra in agreement with literature.[33]

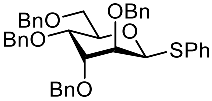
Phenyl 2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-altropyranoside (25)



Compound **23** (5.80 g, 14.9 mmol) was dissolved in DCM and cooled to 0 °C. $SOCl_2$ (2.10 mL, 29.7 mmol, 2 eq) was added, followed by $SnCl_4$ (1M in DCM, 14.9 mL, 14.9 mmol, 1 eq). After TLC shows full conversion, the reaction mixture was quenched with ice water and extracted twice with DCM. Combined organic phases were washed with sat. aq. $NaHCO_3$, dried with $MgSO_4$ and concentrated, yielding chloride **24**, which was immediately dissolved in DMF. The solution was cooled to 0 °C, and thiophenol (2.12 mL, 20.8 mmol, 1.4 eq) and sodium hydride (60% dispersion in mineral oil, 713 mg, 17.8 mmol, 1.2 eq) were added. After full conversion, the reaction mixture was diluted with water and extracted twice with diethyl ether. The organic phases were dried with $MgSO_4$ and concentrated, yielding crude **25** as an α,β-mixture from which the desired β-anomer was isolated as white solid by silica chromatography (10→20% acetone in pentane), followed by recrystallization from the same solvents. Yield: 3.78 g, 8.58 mmol, 58%. ^{1}H

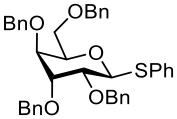
NMR (400 MHz, $CDCl_3$) δ 7.58 – 7.53 (m, 2H, CH_{arom}), 7.36 – 7.30 (m, 3H, CH_{arom}), 5.41 (t, *J* = 3.4 Hz, 1H, H-3), 5.22 (dd, *J* = 3.7, 1.5 Hz, 1H, H-2), 5.19 (d, *J* = 1.5 Hz, 1H, H-1), 5.12 (dd, *J* = 10.4, 3.2 Hz, 1H, H-4), 4.28 – 4.20 (m, 2H, 2x H-6), 4.09 (ddd, *J* = 10.4, 5.5, 3.5 Hz, 1H, H-5), 2.22 (s, 3H, CH_3 Ac), 2.12 (s, 3H, CH_3 Ac), 2.11 (s, 3H, CH_3 Ac), 1.99 (s, 3H, CH_3 Ac); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.8, 169.6, 169.6, 169.0 (C=O), 133.9 (C_q), 131.7, 129.1, 128.0 (CH_{arom}), 83.9 (C-1), 72.8 (C-5), 71.2 (C-2), 67.2 (C-3), 65.5 (C-4), 63.3 (C-6), 20.9, 20.9, 20.8, 20.7 (CH_3 Ac); ^{13}C-HMBC-GATED NMR (101 MHz, $CDCl_3$): δ 83.9 ($J_{H1\text{-}C1}$ = 157 Hz, β); HRMS: $[M+NH_4]^+$ calcd for $C_{20}H_{24}O_9SNH_4$ 458.14793, found 458.14698

<u>Phenyl 2,3,4,6-tetra-*O*-benzyl-1-thio-β-D-altropyranoside (5)</u>



Compound **25** (1.50 g, 3.41 mmol) was dissolved in methanol with NaOMe (46 mg, 0.85 mmol, 0.25 eq). After TLC shows full deacetylation, the reaction mixture was neutralised with amberlite IR-120(H), filtered and concentrated under reduced pressure to yield crude tetra-ol **26**, which was used without further purification. Compound **26** was dissolved in DMF, and NaH (60% dispersion in mineral oil, 0.681 g, 17.03 mmol, 5 eq) and benzyl bromide (2.02 mL, 17.03 mmol, 5 eq) were added. After completion, the reaction was quenched with water and extracted with diethyl ether. The organic phase was dried with Na_2SO_4 and concentrated under reduced pressure. The residue was purified over silica (5% EtOAc in pentane), obtaing the title compound as colourless oil. Yield: 1.82 g, 2.88 mmol, 84% over 2 steps. $[\alpha]_D^{25}$ = -12.2° (c = 0.88, $CHCl_3$); IR (thin film): 698, 750, 1027, 1070, 1454; ^1H NMR (400 MHz, $CDCl_3$) δ 7.55 – 7.50 (m, 2H, CH_{arom}), 7.36 – 7.25 (m, 16H, CH_{arom}), 7.24 – 7.16 (m, 7H, CH_{arom}), 5.23 (d, *J* = 1.4 Hz, 1H, H-1), 4.65 – 4.59 (m, 2H, 2x C*H*H Bn), 4.56 (d, *J* = 11.6 Hz, 2H, C*H*H Bn ,CH*H* Bn), 4.47 – 4.41 (m, 2H, 2x CH*H* Bn), 4.34 (s, 2H, CH_2 Bn), 4.12 (ddd, *J* = 10.1, 6.6, 1.9 Hz, 1H, H-5), 3.87 (dd, *J* = 11.0, 1.9 Hz, 1H, H-6), 3.79 (dd, *J* = 10.1, 2.7 Hz, 1H, H-4), 3.73 (dd, *J* = 3.7, 1.4 Hz, 1H, H-2), 3.72 – 3.67 (m, 2H, H-3, H-6); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.8, 138.2, 138.0, 137.9, 136.0 (C_q), 130.5, 128.9, 128.6, 128.5, 128.5, 128.5, 128.3, 128.3, 128.2, 128.0, 128.0, 127.9, 127.9, 127.5, 126.8 (CH_{arom}), 85.0 (C-1), 78.8 (C-2), 75.8 (C-5), 73.7, 73.6 (CH_2 Bn), 73.1 (C-4), 73.1 (CH_2 Bn), 72.6 (C-3), 71.8 (CH_2 Bn), 70.3 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{40}H_{40}O_5SNH_4$ 650.29347, found 650.29153

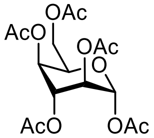
<u>Phenyl-2,3,4,6-tetra-O-benzyl-1-thio-β-D-gulopyranoside (6)</u>



The title compound was synthesised in 8 steps as previously described for the L-isomer from L-gulonolactone,[35] but with D-gulonolactone **27** as starting material. $[\alpha]_D^{25}$ = -9.2° (c = 0.20, $CHCl_3$); IR (thin film): 741, 1001, 1028, 1076, 1101, 1207, 1360, 1439, 1454, 1497; ^1H NMR (400 MHz, $CDCl_3$) δ 7.67 – 7.60 (m, 2H, CH_{arom}), 7.41 – 7.25 (m, 21H, CH_{arom}), 7.18 – 7.12 (m, 2H, CH_{arom}), 5.30 (d, *J* = 9.9 Hz, 1H, H-1), 4.72 (d, *J* = 12.1 Hz, 1H, C*H*H Bn), 4.65 (d, *J* = 11.7 Hz, 1H, C*H*H Bn), 4.58 – 4.52 (m, 2H, C*H*H Bn, CH*H* Bn), 4.49 (d, *J* = 11.9 Hz, 1H, CH*H* Bn), 4.45 (d, *J* =

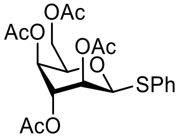
11.8 Hz, 1H, CH*H* Bn), 4.37 (d, *J* = 12.0 Hz, 1H, C*H*H Bn), 4.32 (d, *J* = 12.0 Hz, 1H, CH*H* Bn), 4.20 (td, *J* = 6.4, 1.5 Hz, 1H, H-5), 3.82 (dd, *J* = 9.9, 2.9 Hz, 1H, H-2), 3.77 (t, *J* = 3.4 Hz, 1H, H-3), 3.72 (dd, *J* = 9.8, 6.3 Hz, 1H, H-6), 3.66 (dd, *J* = 9.8, 6.5 Hz, 1H, H-6), 3.57 (dd, *J* = 3.8, 1.4 Hz, 1H, H-4); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.3, 138.3, 138.0, 138.0, 134.5 (C_q), 131.5, 128.7, 128.4, 128.4, 128.4, 128.0, 127.9, 127.9, 127.9, 127.8, 127.8, 127.6, 126.9 (CH_{arom}), 84.4 (C-1), 74.9, 74.8 (C-2, C-4), 74.5 (C-5), 73.4, 73.3 (CH_2 Bn), 73.1 (C-3), 72.8, 72.5 (CH_2 Bn), 69.0 (C-6); HRMS: calcd for $C_{40}H_{40}O_5SNH_4$ 650.29347, found 650.29166

1,2,3,4,6-Penta-*O*-acetyl-α-D-idopyranoside (31)



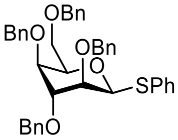
1,2,3,4,6-Penta-*O*-acetyl-β-D-glucopyranoside (**28**, 39.0 g, 100 mmol) was dissolved in 200 mL DCM and cooled to 0 °C after which $SbCl_5$ (15.4 mL, 120 mmol, 1.2 eq) was added. When dioxolenium ion **29** precipitated, the reaction mixture was warmed to RT and stirred for a further 15 minutes. The solids were filtered off, washed 3x with diethyl ether and suspended in 500 mL water with NaOAc (98 g, 1.2 mol, 12 eq). After 1 hr, the reaction mixture was extracted 3x with DCM. Combined organic phases were washed twice with sat. aq. $NaHCO_3$ and once with brine. After drying with $MgSO_4$ and concentration under reduced pressure, a mixture of tetra-acetates **30a** and **30b** was obtained. The residue was dissolved in 60 mL pyridine and 20 mL Ac_2O and stirred overnight. The reaction mixture was diluted with DCM and washed with 1M HCl and sat. aq. $NaHCO_3$. Drying and concentration of the organic phase yields the pure title compound as yellowish oil. Yield: 13 g, 33 mmol, 33%. ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.05 (d, *J* = 1.6 Hz, 1H, H-1), 5.06 (td, *J* = 3.8, 1.1 Hz, 1H, H-3), 4.93 (dd, *J* = 3.8, 2.4 Hz, 1H, H-4), 4.87 (ddd, *J* = 3.9, 2.2, 0.8 Hz, 1H, H-2), 4.47 (td, *J* = 6.3, 2.3 Hz, 1H, H-5), 4.25 – 4.13 (m, 2H, H-6), 2.13 – 2.11 (m, 9H, 3x CH_3 Ac), 2.11 (s, 3H, CH_3 Ac), 2.07 (s, 3H, CH_3 Ac); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.5, 169.7, 169.1, 168.8, 168.5 (C=O), 90.6 (C-1), 66.6 (C-3), 66.3, 66.1, 66.1 (C-2, C-4, C-5), 61.8 (C-6), 20.8, 20.7, 20.7, 20.6 (CH_3 Ac). Spectra in agreement with literature.[36]

Phenyl 2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-idopyranoside (33)



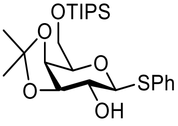
Compound **31** (13 g, 33.3 mmol) was dissolved in 100 mL DCM, after which HBr (33% in AcOH, 29 mL, 167 mmol, 5 eq) was added. After full conversion, as indicated by TLC, the reaction mixture was diluted with DCM and washed twice with cold water. The organic phase was dried with $MgSO_4$ and concentrated under reduced pressure. The residue was coevaporated twice with toluene to yield crude bromide **32**, which was immediately dissolved in DMF. The solution was cooled to 0 °C and PhSH (5.10 mL, 50 mmol, 1.5 eq) and NaH (60% dispersion in mineral oil, 1.87g, 46.6 mmol, 1.4 eq) were added. The reaction mixture was allowed to warm to RT and stirred for a further 2 hr, after which the reaction was quenched with water and extracted with diethyl ether. The organic phase was dried with $MgSO_4$ and concentrated under reduced pressure and the residue purified over silica (10%→20% acetone) to obtain the title compound as yellow oil. Yield: 8.16 g, 18.5 mmol, 56%. ^1H NMR (400 MHz, $CDCl_3$) δ 7.61 – 7.54 (m, 2H, CH_{arom}), 7.38 – 7.29 (m, 3H, CH_{arom}), 5.14 (d, J = 1.7 Hz, 1H, H-1), 5.12 (t, J = 2.7 Hz, 1H, H-3) 5.08 (ddd, J = 2.6, 1.7, 1.0 Hz, 1H, H-2), 4.86 (ddd, J = 2.8, 1.6, 1.0 Hz, 1H, H-4), 4.31 – 4.21 (m, 2H, H-6), 4.18 (ddd, J = 7.9, 4.8, 1.6 Hz, 1H, H-5), 2.20 (s, 3H, CH_3 Ac), 2.16 (s, 3H, CH_3 Ac), 2.14 (s, 3H, CH_3 Ac), 2.09 (s, 3H, CH_3 Ac); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.5, 169.6, 169.4, 168.0 (C=O), 134.0 (C_q), 131.7, 131.5, 129.0, 127.9 (CH_{arom}), 84.4 (C-1), 73.5 (C-5), 68.2 (C-4), 66.7 (C-3), 64.8 (C-2), 62.6 (C-6), 20.8, 20.7, 20.7, 20.6 (CH_3 Ac); ^{13}C-HMBC-GATED NMR (101 MHz, $CDCl_3$): δ 84.4 ($J_{H1\text{-}C1}$ = 157 Hz, β); HRMS: $[M+NH_4]^+$ calcd for $C_{20}H_{24}O_9SNH_4$ 458.14793, found 458.14678

Phenyl 2,3,4,6-tetra-*O*-benzyl-1-thio-β-D-idopyranoside (7)



Compound **33** was deactylated and benzylated as described for compound **5,** yielding the title compound as colourless oil. Yield: 3.40 g, 5.37 mmol, 73%; $[\alpha]_D^{25}$ = -42.7° (c = 0.54, $CHCl_3$); IR (thin film): 698, 753, 1027, 1049 ; ^1H NMR (400 MHz, $CDCl_3$) δ 7.60 – 7.55 (m, 2H, CH_{arom}), 7.45 – 7.32 (m, 16H, CH_{arom}), 7.30 – 7.21 (m, 5H, CH_{arom}), 7.20 – 7.16 (m, 2H, CH_{arom}), 5.19 (d, J = 1.7 Hz, 1H, H-1), 4.68 (s, 2H, CH_2 Bn), 4.62 – 4.56 (m, 2H, 2x C*H*H Bn), 4.52 (d, J = 11.6 Hz, 1H, CH*H* Bn), 4.41 (d, J = 12.2 Hz, 1H, CH*H* Bn), 4.32 (d, J = 2.4 Hz, 2H, CH_2 Bn), 4.10 (ddd, J = 6.9, 5.3, 1.8 Hz, 1H, H-5), 3.89 (dd, J = 10.1, 6.8 Hz, 1H, H-6), 3.73 (dd, J = 10.2, 5.3 Hz, 1H, H-6), 3.71 – 3.67 (m, 2H, H-2, H-3), 3.40 (dt, J = 2.9, 1.4 Hz, 1H, H-4); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.5 138.0, 137.8, 137.5, 136.5 (C_q), 130.3, 128.8, 128.7, 128.5, 128.5, 128.4, 128.4, 128.1, 128.0, 127.9, 127.9, 127.8, 127.6, 126.6 (CH_{arom}), 86.5 (C-1), 76.4 (C-5), 75.8 (C-2/C-3), 73.6, 73.4, 72.2, 72.1 (CH_2 Bn), 71.7 (C-4), 71.1 (C-2/C-3), 70.1 (C-6); HRMS: calcd for $C_{40}H_{40}O_5SNH_4$ 650.29347, found 650.29149

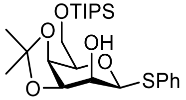
Phenyl 3,4-*O*-isopropylidene-6-*O*-triisopropylsilyl-1-thio-β-D-galactopyranoside (36)



Phenyl 1-thio-β-D-galactopyranoside (**35**, 8.17 g, 30 mmol) was dissolved in DMF with imidazole (5.11 g, 75 mmol, 2.5 eq) and TIPS-Cl (8.35 mL, 39 mmol, 1.3 eq). After 3 hr, the reaction mixture was quenched with 10 mL methanol and concentrated under reduced pressure. The residue was dissolved in DCM and washed with 1M HCl and with sat. aq. $NaHCO_3$. The organic phase was dried with $MgSO_4$ and concentrated under reduced pressure. The residue was dissolved in 150 mL 2,2-dimethoxypropane with PTSA-H_2O (0.57 g, 3 mmol, 0.1 eq). After full conversion, triethylamine (0.82 mL, 6 mmol, 0.2 eq) was added and solvent removed *in vacuo.* Silica chromatography (15% EtOAc in pentane) yield the title compound as colourless oil. Yield: 8.00 g, 17.0 mmol, 57% over 2 steps. ^1H NMR (400 MHz, $CDCl_3$) δ 7.57 – 7.53 (m, 2H, CH_{arom}), 7.30 (dd, J = 5.1, 2.0 Hz, 3H, CH_{arom}), 4.46 (d, J = 10.3 Hz, 1H, H-1), 4.28 (dd, J = 5.4, 2.0 Hz, 1H, H-4), 4.08 (dd, J = 6.9, 5.3 Hz, 1H, H-3), 4.00 – 3.95 (m, 2H, 2x H-6), 3.85 (ddd, J = 6.9, 5.9, 2.1

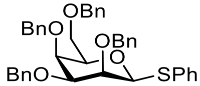
Hz, 1H, H-5), 3.57 (ddd, *J* = 10.3, 6.9, 1.8 Hz, 1H, H-2), 2.50 (d, *J* = 2.0 Hz, 1H, OH), 1.43 (s, 3H, CH_3 isopropylidene), 1.33 (s, 3H, CH_3 isopropylidene), 1.17 – 1.03 (m, 21H, 6x CH_3 TIPS, 3x CH TIPS); ^{13}C NMR (101 MHz, $CDCl_3$) δ 132.6 (C_q), 132.4, 129.1, 129.1, 128.1 (CH_{arom}), 110.2 (C_q isopropylidene), 88.5 (C-1), 79.0 (C-3), 77.6 (C-5), 73.3 (C-4), 71.8 (C-2), 62.6 (C-6), 28.3, 26.4 (CH_3 isopropylidene), 18.1, 18.1, 12.0 (CH_3 TIPS, CH TIPS); HRMS: $[M+NH_4]^+$ calcd for $C_{24}H_{40}O_5SSiNH_4$ 486.27040, found 486.26949

Phenyl 3,4-*O*-isopropylidene-6-*O*-triisopropylsilyl-1-thio-β-D-talopyranoside (38)



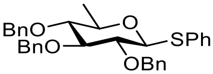
Compound **36** (8.00 g, 17.0 mmol) was dissolved in DCM and Dess-Martin periodiane (10.9g, 25.6 mmol, 1.5 eq) was added. After full conversion, the reaction mixture was diluted with DCM and washed with sat. aq. $Na_2S_2O_3$. The organic phase was dried with $MgSO_4$ and concentrated to obain crude ketone **37** (94% yield) which was used without further purification. The ketone was dissolved in 1:1 THF/MeOH and cooled to 0 °C, after which $NaBH_4$ (1.21 g, 31.9 mmol, 2 eq) was added. After full conversion, the reaction mixture was concentrated. The residue was dissolved in ethyl acetate and washed with water. The organic phase was dried with $MgSO_4$ and concentrated under reduced pressure. Silica chromatography (10% EtOAc in pentane) yields the title compound as colourless oil that solidifies upon standing. Yield: 5.02g, 10.7 mmol, 67% based on ketone **37**. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54 – 7.46 (m, 2H, CH_{arom}), 7.34 – 7.17 (m, 3H, CH_{arom}), 4.77 (d, *J* = 1.4 Hz, 1H, H-1), 4.30 – 4.18 (m, 2H, H-3, H-4), 4.05 – 3.96 (m, 3H, H-2, 2x H-6), 3.89 – 3.82 (m, 1H, H-5), 2.57 (d, *J* = 9.0 Hz, 1H, OH), 1.62 (s, 3H, CH_3 isopropylidene), 1.38 (s, 3H, CH_3 isopropylidene), 1.16 – 0.98 (m, 21H, 6x CH_3 TIPS, 3x CH TIPS); ^{13}C NMR (101 MHz, $CDCl_3$) δ 135.8 (C_q), 130.8, 129.0, 127.2 (CH_{arom}), 110.1(C_q isopropylidene), 88.0 (C-1), 77.3 (C-5), 74.0 (C-3), 71.0 (C-4), 68.1 (C-2), 62.7 (C-6), 25.9, 25.5(CH_3 isopropylidene), 18.1, 18.1, 12.0 (CH_3 TIPS, CH TIPS); HRMS: $[M+NH_4]^+$ calcd for $C_{24}H_{40}O_5SSiNH_4$ 486.27040, found 486.26972

Phenyl 2,3,4,6-tetra-*O*-benzyl-1-thio-β-D-talopyranoside (8)



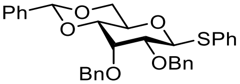
Compound **38** (4.90 g, 10.5 mmol) and PTSA-H_2O (0.40 g, 2.10 mmol, 0.2 eq) were dissolved in methanol and heated to a reflux. After TLC shows full deprotection, triethylamine (0.43 mL, 3.14 mmol, 0.3 eq) was added and the reaction mixture was concentrated under reduced pressure, yielding crude tetra-ol **39**, which was coevaporated twice with toluene, dissolved in DMF and treated with benzyl bromide (6.8 mL, 57.5 mmol, 5.5 eq) and sodium hydride (60% dispersion in mineral oil, 2.30 g, 57.5 mmol, 5.5 eq). After full conversion, the reaction mixture was quenched with water and extracted with diethyl ether. The organic phase was dried with $MgSO_4$ and concentrated. Recrystallization from EtOAc/pentane yields the title compound as white powder. Yield: 4.20 g, 6.64 mmol, 64% over 2 steps. $[\alpha]_D^{25}$ = -38.7° (c = 0.30, $CHCl_3$); IR (thin film): 695, 737, 1027, 1069, 1362, 1454; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49 (ddt, *J* = 11.0, 7.7, 1.6 Hz, 4H, CH_{arom}), 7.38 – 7.16 (m, 21H, CH_{arom}), 5.06 (d, *J* = 11.7 Hz, 1H, C*H*H Bn), 5.01 – 4.91 (m, 2H, C*H*H Bn, CH*H* Bn), 4.80 – 4.71 (m, 2H, H-1, CH*H* Bn), 4.59 (d, *J* = 1.5 Hz, 2H, CH_2 Bn), 4.51 (d, *J* = 11.5 Hz, 1H, C*H*H Bn), 4.44 (d, *J* = 11.5 Hz, 1H, CH*H* Bn), 4.12 (dt, *J* = 2.9, 1.3 Hz, 1H, H-2), 3.91 (dt, *J* = 3.0, 1.4 Hz, 1H, H-4), 3.84 (dd, *J* = 9.8, 6.2 Hz, 1H, H-6), 3.76 (dd, *J* = 9.8, 5.8 Hz, 1H, H-6), 3.60 (td, *J* = 6.1, 1.5 Hz, 1H, H-5), 3.50 (t, *J* = 3.0 Hz, 1H, H-3); ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.0, 138.7, 138.2, 137.8, 136.3 (C_q), 130.7, 128.8, 128.6, 128.4, 128.4, 128.3, 128.1, 128.0, 127.9, 127.8, 127.7, 127.4, 127.3, 127.3, 126.9 (CH_{arom}), 89.0 (C-1), 81.0 (C-3), 79.1 (C-5), 76.3 (C-2), 74.8, 74.0, 73.7 (CH_2 Bn), 72.1 (C-4), 71.0 (CH_2 Bn), 69.9 (C-6); HRMS: calcd for $C_{40}H_{40}O_5SNH_4$ 650.29347, found 650.29169

Phenyl 6-deoxy-2,3,4-tri-*O*-benzyl-1-thio-β-D-glucopyranoside (9)



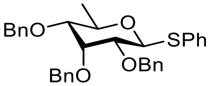
Phenyl 2,3,4-tri-*O*-benzyl-1-thio-β-D-glucopyranoside[45] (**40,** 0.95 g, 1.75 mmol) was dissolved in 5 mL pyridine with p-TsCl (0.50 g, 2.63 mmol, 1.5 eq). After full conversion, the reaction mixture was diluted with EtOAc and washed with 1M HCl and sat. aq. $NaHCO_3$. The organic phase was dried with $MgSO_4$ and concentrated under reduced pressure, yielding the crude tosylate **41**, which was dissolved in THF with $LiAlH_4$ (1M sln in THF, 7 mL, 7 mmol, 4 eq) and heated to 70 °C. After full conversion, the reaction mixture was cooled to 0 °C and carefully quenched with 1M HCl, after which the reaction mixture was extracted with EtOAc. The organic phase was washed with sat. aq. $NaHCO_3$, dried with $MgSO_4$ and concentrated under reduced pressure. Silica chromatography (10% Et_2O in pentane) yields the title compound as white solid. Yield: 0.43 g, 0.82 mmol, 47% over 2 steps. ^1H NMR (400 MHz, $CDCl_3$) δ 7.56 – 7.52 (m, 2H, CH_{arom}), 7.39 (dd, *J* = 8.0, 1.5 Hz, 2H, CH_{arom}), 7.36 – 7.25 (m, 16H, CH_{arom}), 4.93 – 4.82 (m, 4H, 3x C*H*H Bn, CH*H* Bn), 4.75 (d, *J* = 10.2 Hz, 1H, CH*H* Bn), 4.68 – 4.63 (m, 2H, H-1, CH*H* Bn), 3.67 (t, *J* = 8.9 Hz, 1H, H-3), 3.49 (dd, *J* = 9.7, 9.0 Hz, 1H, H-2), 3.42 (dq, *J* = 9.5, 6.1 Hz, 1H, H-5), 3.23 (t, *J* = 9.2 Hz, 1H, H-4), 1.35 (d, *J* = 6.1 Hz, 3H, H-6); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.5, 138.2, 134.0 (C_q), 132.0, 129.0, 128.6, 128.5, 128.3, 128.1, 128.0, 128.0, 128.0, 127.9, 127.6 (CH_{arom}), 87.6 (C-1), 86.7 (C-3), 83.4 (C-4), 81.4 (C-2), 75.9 (CH_2 Bn), 75.7 (C-5), 75.6, 75.5 (CH_2 Bn), 18.3 (C-6). Spectra in agreement with literature.[46]

Phenyl 2,3-di-*O*-benzyl-4,6-*O*-benzylidene-1-thio-β-D-allopyranose (43)



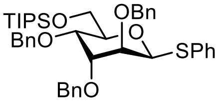
Phenyl 4,6-*O*-benzylidene-1-thio-β-D-glucopyranose (**17**, 2.74 g, 7.60 mmol), benzoic acid (1.39 g, 11.4 mmol, 1.5 eq) and triphenylphosphine (2.99 g, 11.4 mmol,1.5 eq) were dissolved in THF and heated to a gentle reflux. DIAD (2.25 mL, 11.4 mmol,1.5 eq) was added dropwise over 5 min, after which TLC showed full conversion of the starting material. The reaction mixture was cooled to RT and concentrated under reduced pressure. The residue was filtered over a short plug of silica (25% EA) to remove triphenylphosphine oxide, yielding impure product **18**. This was then dissolved in methanol and treated with NaOMe (0.5g). After debenzoylation, the reaction mixture was neutralised with acetic acid and concentrated under reduced pressure. The residue was dissolved in DMF and NaH (60% dispersion in mineral oil, 1.21 g, 30.1 mmol, 4 eq) and benzyl bromide (3.58 mL, 30.1 mmol 4 eq) were added. After 4 hr, the reaction was quenched with water and extracted with diethyl ether. The organic phase was dried with $MgSO_4$ and concentrated. The residue was purified over silica (100% toluene) to give the title compound as colourless oil. Yield: 1.30 g, 2.40 mmol, 32% over 3 steps. ^1H NMR (400 MHz, $CDCl_3$) δ 7.55 – 7.25 (m, 20H, CH_{arom}), 5.47 (s, 1C*H*Ph), 5.25 (d, *J* = 9.8 Hz, 1H, H-1), 4.89 (d, *J* = 12.0 Hz, 1H, C*H*H Bn), 4.78 (d, *J* = 12.0 Hz, 1H, CH*H* Bn), 4.54 (d, *J* = 2.5 Hz, 2H, C*H₂* Bn), 4.38 (dd, *J* = 10.4, 5.2 Hz, 1H, H-6), 4.21 – 4.12 (m, 2H, H-3, H-5), 3.72 (t, *J* = 10.4 Hz, 1H, H-6), 3.52 (dd, *J* = 9.5, 2.1 Hz, 1H, H-4), 3.38 (dd, *J* = 9.8, 2.7 Hz, 1H, H-2); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.7, 137.6, 137.5 (C_q), 133.3, 132.2, 129.3, 128.9, 128.6, 128.5, 128.3, 128.2, 128.2, 128.0, 127.6, 127.6, 126.3 (CH_{arom}), 102.1 (CHPh), 84.7 (C-1), 79.9 (C-4), 77.1 (C-2), 74.1 (CH_2 Bn), 73.8 (C-3), 72.1 (CH_2 Bn), 69.4 (C-6), 66.4 (C-5); HRMS: $[M+NH_4]^+$ calcd for $C_{33}H_{32}O_5SNH_4$ 558.23087, found 558.22995

Phenyl 6-deoxy-2,3,4-tri-*O*-benzyl-1-thio-β-D-allopyranose (12)



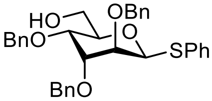
Phenyl 2,3-di-*O*-benzyl-4,6-*O*-benzylidene-1-thio-β-D-allopyranose (**43**, 1.25 g, 2.31 mmol) was dissolved in 7 mL of a 1M BH_3-THF solution in THF (7 mL, 6.94 mmol, 3 eq) and $CoCl_2$ (900 mg, 6.94 mmol, 3 eq) was added. After TLC shows full conversion of the stm, the reaction was diluted with ethyl acetate and filtered over celite. Water was added, and under vigorous stirring, excess $CoCl_2$ was reduced with $NaBH_4$. Solids were filtered off and the phases were separated. The organic phase was dried with $MgSO_4$ and concentrated, yielding crude Phenyl 2,3,4-tri-*O*-benzyl-1-thio-β-D-allopyranose (**44**) which was used without further purification. This compound was dissolved in DCM with DMAP (1.13 g, 9.25 mmol, 4 eq) and p-TsCl (881 mg, 4.62 mmol, 2 eq). After full conversion, the reaction mixture was diluted with EtOAc and washed with 1M HCl and sat. aq. $NaHCO_3$. The organic phase was dried with $MgSO_4$ and concentrated under reduced pressure, yielding the crude tosylate, which was dissolved in THF with $LiAlH_4$ (1M sln in THF, 9.3 mL, 9.3 mmol, 4 eq) and heated to 70 °C. After full conversion, the reaction mixture was cooled to 0 °C and carefully quenched with 1M HCl, after which the reaction mixture was extracted with EtOAc. The organic phase was washed with sat. aq. $NaHCO_3$, dried with $MgSO_4$ and concentrated under reduced pressure. Silica chromatography (10% Et_2O in pentane) yields the title compound as colourless oil. Yield: 588 mg, 1.12 mmol, 48% over 3 steps. $[\alpha]_D^{25}$ = 21.2° (c = 1.44, $CHCl_3$); IR (thin film): 697, 750, 1049, 1089, 1454 ; ^1H NMR (400 MHz, $CDCl_3$) δ 7.55 – 7.50 (m, 2H, CH_{arom}), 7.39 – 7.21 (m, 18H, CH_{arom}), 5.24 (d, *J* = 9.8 Hz, 1H, H-1), 4.84 (d, *J* = 11.9 Hz, 1H, C*H*H Bn), 4.77 (d, *J* = 11.9 Hz, 1H, CH*H* Bn), 4.63 (d, *J* = 11.6 Hz, 1H, C*H*H Bn), 4.56 (d, *J* = 11.6 Hz, 1H, CH*H* Bn), 4.52 (d, *J* = 11.7 Hz, 1H, C*H*H Bn), 4.39 (d, *J* = 11.7 Hz, 1H, CH*H* Bn), 4.13 (t, *J* = 2.4 Hz, 1H, H-3), 4.01 (dq, *J* = 9.5, 6.2 Hz, 1H, H-5), 3.30 (dd, *J* = 9.8, 2.5 Hz, 1H, H-2), 3.02 (dd, *J* = 9.5, 2.3 Hz, 1H, H-4), 1.28 (d, *J* = 6.2 Hz, 3H, H-6); ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.0, 137.9, 134.2 (C_q), 131.6, 128.8, 128.5, 128.3, 128.1, 128.0, 128.0, 127.9, 127.5, 127.2 (CH_{arom}), 83.8 (C-1), 80.9 (C-4), 78.5 (C-2), 74.4 (CH_2 Bn), 73.2 (C-3), 72.6 (CH_2 Bn), 71.6 (C-5), 71.6 (CH_2 Bn), 18.3 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{33}H_{34}O_4SNH_4$ 544.25161, found 544.25045

Phenyl 2,3,4-tri-*O*-benzyl-6-*O*-triisopropylsilyl-1-thio-β-D-altropyranoside (46)



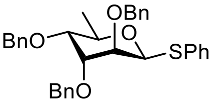
Compound **26** (1.47 g, 5.39 mmol) was dissolved in dry DMF (15 mL). Imidazole (917 mg, 13.5 mmol, 2.5 eq.) and then TIPS-Cl (1.49 mL, 7.01 mmol, 1.3 eq.) where added to the mixture. The reaction was stirred until TLC showed full conversion. The mixture was then quenched with methanol (743 µL, 18.4 mmol, 10 eq.) and diluted in water. The aqueous layer was then 3 times extracted with DCM. The combined organic layers where then washed with 0.1 M aq. HCl and sat. aq. bicarb. The organic layer was diluted dried with MgSO4 and concentrated in vacuo. This yielded a crude TIPS compound which was not characterized and immediately used in the next reaction. The TIPS compound was dissolved in dry DMF (20 mL) and cooled to 0°C. NaH (60% dispersion in mineral oil, 1.08 g, 26.6 mmol, 5 eq.) was added in portions. The mixture was stirred for 30 minutes. Benzyl Bromide (3.20 mL, 26.6 mmol, 5 eq.) was added. The mixture was stirred for 30 minutes before being allowed to warm to room temperature. The reaction was stirred until TLC showed full conversion. The mixture was slowly quenched with water and extracted with a diethyl ether/pentane (1:1) mixture. The organic layer was washed with water and brine. After which it was dried using MgSO4 and concentrated in vacuo. The residue was purified over silica (1% EA in pentane) to yield the title compound as a colourless oil. Yield: 3.13 g, 4.57 mmol, 85%. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.55 – 7.49 (m, 2H,CH$_{arom}$), 7.39 – 7.14 (m, 18H, CH$_{arom}$), 5.22 (d, *J* = 1.4 Hz, 1H, H-1), 4.64 (d, *J* = 12.2 Hz, 1H, C*H*H Bn), 4.58 (d, *J* = 12.2 Hz, 1H, C*H*H Bn), 4.56 (s, 2H, CH*2* Bn), 4.46 (d, *J* = 12.3 Hz, 1H, CH*H* Bn), 4.43 (d, *J* = 12.2 Hz, 1H, CH*H* Bn), 4.36 (d, *J* = 1.6 Hz, 2H, CH_2 Bn), 4.03 (dd, *J* = 10.7, 1.8 Hz, 1H, H-6), 3.96 (ddd, *J* = 9.8, 6.1, 1.8 Hz, 1H, H-5), 3.83 (dd, *J* = 10.8, 6.1 Hz, 1H, H-6), 3.77 – 3.69 (m, 3H, H-2, H-3, H-4), 1.15 – 1.01 (m, 21H, CH_3 TIPS, CH TIPS); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.3, 138.2, 138.1, 136.6 (C$_q$), 130.2, 128.8, 128.5, 128.2, 128.2, 128.1, 128.0, 127.9, 126.6 (CH$_{arom}$), 85.1 (C-1), 79.3 (C-2), 77.2 (C-5), 73.7, 73.1 (CH_2 Bn), 73.0, 72.8 (C-3, C-4), 71.8 (CH_2 Bn), 63.8 (C-6), 18.2, 18.2 (CH_3 TIPS), 12.1 (CH TIPS).

Phenyl 2,3,4-tri-*O*-benzyl-1-thio-β-D-altropyranoside (47)



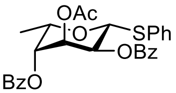
Compound **46** (3.13 g, 4.57 mmol) was dissolved in THF (30 mL). A mixture of TFA/H_2O (1:1, 20 mL) was then added. The reaction was allowed to stir until the TLC showed full conversion. It was quenched with bicarb, extracted with EA and washed with brine. The organic layer was dried using $MgSO_4$ and concentrated in vacuo. The residue was purified over silica (20% EA in pentane) to yield the title compound as a colourless oil. Yield: 1.66 g, 3.05 mmol, 84%. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 (dd, *J* = 7.2, 1.8 Hz, 2H, CH$_{arom}$), 7.38 – 7.19 (m, 18H, CH$_{arom}$), 5.25 (d, *J* = 1.3 Hz, 1H, H-1), 4.58 (dd, *J* = 12.1, 4.2 Hz, 2H, CH_2 Bn), 4.45 (t, *J* = 11.7 Hz, 2H, CH_2 Bn), 4.39 (s, 2H, CH_2 Bn), 3.95 (ddd, *J* = 9.8, 5.4, 3.1 Hz, 1H, H-3), 3.89 (ddd, *J* = 11.8, 6.3, 3.1 Hz, 1H, H-6), 3.81 (dd, *J* = 9.8, 2.5 Hz, 1H, H-4), 3.78 – 3.68 (m, 3H, H-2, H-5, H-6), 2.16 (t, *J* = 6.7 Hz, 1H, OH); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.1, 137.8, 137.6, 135.3 (C$_q$), 130.5, 129.1, 128.6, 128.6, 128.5, 128.5, 128.3, 128.3, 128.1, 128.1, 128.0, 127.1 (CH$_{arom}$), 84.9 (C-1), 78.7 (C-5), 75.5 (C-3), 73.7, 73.2 (CH_2 Bn), 73.0 (C-4), 72.5 (C-2), 71.8 (CH_2 Bn), 63.0 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{33}H_{34}O_5SNH_4$ 560.24652, found 560.24545

Phenyl 6-deoxy-2,3,4-tri-*O*-benzyl-1-thio-β-D-altropyranoside (13)



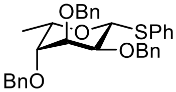
Compound **47** (1.66 g, 3.05 mmol) was dissolved in pyridine (5 mL) and cooled to 0°C. Tosylchloride (871 mg, 4.57 mmol, 1.5 eq.) was added after which the mixture was allowed to warm to room temperature. The reaction was stirred till the TLC showed full conversion. The reaction was quenched with 0.1 M aq. HCl and extracted with diethyl ether. The organic layer was then washed with bicarb and brine. The organic layer was then dried using $MgSO_4$ and concentrated in vacuo. This yielded a crude tosylate **48** which was immediately used in the next reaction. The tosylate was dissolved in THF (30 mL) and $LiAlH_4$ (2.3 M in 2-methylhydrofuran, 5.30 mL, 12.2 mmol, 4 eq.) was added. The mixture was heated to reflux temperature and stirred till TLC showed full conversion. After which the mixture was cooled to 0°C and quenched with 1 M aq. HCl. The aqueous phase was then extracted twice with EA. The combined organic layers where then washed with bicarb and brine. The organic phase was then dried using $MgSO_4$ and concentrated in vacuo. The residue was purified over silica (5% EA in pentane) to yield the title compound as a colourless oil. Yield: 1.03 g, 1.94mmol, 64%. $[\alpha]_D^{25}$ = 14.1° (c = 0.35, $CHCl_3$); IR (thin film): 697, 748, 1027, 1088, 1454; ^1H NMR (400 MHz, $CDCl_3$) δ 7.51 – 7.45 (m, 2H, CH_{arom}), 7.38 – 7.19 (m, 18H, CH_{arom}), 5.19 (d, *J* = 1.5 Hz, 1H, H-1), 4.63 (d, *J* = 12.1 Hz, 1H, C*H*H Bn), 4.55 (d, *J* = 12.2 Hz, 1H, C*H*H Bn), 4.51 – 4.40 (m, 2H, CH*H* Bn, CH*H* Bn), 4.37 (s, 2H, CH_2 Bn), 3.95 (dq, *J* = 9.7, 6.2 Hz, 1H, H-5), 3.73 (dd, *J* = 3.7, 1.5 Hz, 1H, H-2), 3.68 (t, *J* = 3.2 Hz, 1H, H-3), 3.51 (dd, *J* = 9.6, 2.7 Hz, 1H, H-4), 1.33 (d, *J* = 6.2 Hz, 3H, H-6), ^{13}C NMR (101 MHz, $CDCl_3$) δ 130.6, 128.9, 128.6, 128.6, 128.5, 128.3, 128.2, 128.1, 128.0, 128.0, 127.0 (CH_{arom}), 84.9 (C-1), 78.9 (C-2), 77.8 (C-4), 73.8, 73.1 (CH_2 Bn), 72.5 (C-3), 72.0 (CH_2 Bn), 71.8 (C-5), 18.4 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{33}H_{34}O_4SNH_4$ 544.25161, found 544.25007

Phenyl 6-deoxy-3-*O*-acetyl-2,4-di-*O*-benzoyl-1-thio-β-L-gulopyranoside(50)



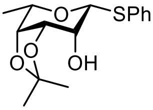
The title compound was synthesises in 5 steps from fucose building block **49** according to literature procedure.[37] ^1H NMR (400 MHz, $CDCl_3$) δ 8.01 – 7.93 (m, 4H, CH_{arom}), 7.65 – 7.53 (m, 4H, CH_{arom}), 7.50 – 7.42 (m, 4H, CH_{arom}), 7.41 – 7.30 (m, 3H, CH_{arom}), 5.60 (dd, *J* = 2.5, 1.4 Hz, 1H, H-3), 5.28 – 5.23 (m, 2H, H-1, H-2), 5.18 (dd, *J* = 3.8, 1.3 Hz, 1H, H-4), 4.33 (qd, *J* = 6.3, 1.2 Hz, 1H, H-5), 2.13 (s, 3H, CH_3 Ac), 1.30 (d, *J* = 6.5 Hz, 3H, H-6); ^{13}C NMR (101 MHz, $CDCl_3$) δ 169.0, 165.3, 164.9 (C=O), 134.0, 133.7, 133.4 (CH_{arom}), 131.3 (C_q), 130.1, 129.8 (CH_{arom}), 129.6, 129.1 (C_q), 128.9, 128.7, 128.6, 128.4 (CH_{arom}), 82.3 (C-1), 71.7 (C-5), 70.9 (C-4), 68.1 (C-3), 67.0 (C-2), 20.9 (CH_3 Ac), 16.5 (C-6).

Phenyl 6-deoxy-2,3,4-tri-*O*-benzyl-1-thio-β-L-gulopyranoside(14)



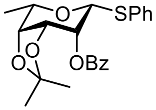
Compound **50** (1.60 g, 3.16 mmol) was dissolved in methanol with NaOMe (171 mg, 3.16 mmol, 1 eq) and stirred until TLC shows full deprotection. The reaction mixture was neutralised with amberlite, filtered and concentrated. The crude triol (**51**) was coevaporated twice with toluene and dissolved in DMF, after which NaH (60% dispersion in mineral oil, 505 mg, 12.6 mmol, 4 eq) and benzyl bromide (1.50 mL, 12.6 mmol, 4 eq) were added. After full conversion, the reaction was quenched with water and extracted with diethyl ether. The organic phase was dried with $MgSO_4$ and concentrated. Silica chromatography (5% to 10% diethyl ether in pentane) yields the title compound as colourless oil. Yield: 1.08 g, 2.05 mmol, 65%. $[\alpha]_D^{25}$ = -0.4° (c = 0.48, $CHCl_3$); IR (thin film): 698, 753, 1042, 1454; ^1H NMR (400 MHz, $CDCl_3$) δ 7.62 – 7.55 (m, 2H, CH_{arom}), 7.36 – 7.21 (m, 16H, CH_{arom}), 7.14 (dd, *J* = 7.0, 2.6 Hz, 2H, CH_{arom}), 5.19 (d, *J* = 9.6 Hz, 1H, H-1), 4.70 (d, *J* = 12.1 Hz, 1H, C*H*H Bn), 4.60 (d, *J* = 11.7 Hz, 1H, C*H*H Bn), 4.48 (d, *J* = 12.2 Hz, 1H, CH*H* Bn), 4.39 (d, *J* = 11.7 Hz, 1H, CH*H* Bn), 4.33 (s, 2H, CH_2 Bn), 4.03 (qd, *J* = 6.5, 1.2 Hz, 1H, H-5), 3.78 – 3.68 (m, 2H, H-2, H-3), 3.20 (dd, *J* = 3.4, 1.4 Hz, 1H, H-4), 1.20 (d, *J* = 6.6 Hz, 3H, H-6); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.5, 138.2, 138.2, 134.8 (C_q), 131.6, 128.7, 128.5, 128.5, 128.4, 128.0, 127.9, 127.9, 127.9, 126.9 (CH_{arom}), 84.4 (C-1), 77.7 (C-4), 74.8 (C-2), 73.6 (C-3), 73.5, 73.0, 72.7 (CH_2 Bn), 71.5 (C-5), 16.5 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{33}H_{34}O_4SNH_4$ 544.25161, found 544.25079

Phenyl 6-deoxy-3,4-*O*-isopropylidene-1-thio-β-L-talopyranoside(54)



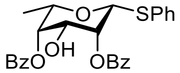
Known fucose intermediate **52**[47] (5.93 g, 20 mmol) was dissolved in DCM with Dess-Martin periodinane (12.7 g, 30 mmol, 1.5 eq) and $NaHCO_3$ (8.40 g, 100 mmol, 5 eq) were dissolved in dichloromethane. After TLC shows full conversion, the reaction mixture was washed with sat. aq. $Na_2S_2O_3$, dried with $MgSO_4$ and concentrated, yielding the crude ketone (**53**) which was used without further purification. The ketone was dissolved in 1:1 MeOH/THF and cooled to -10 °C, after which $NaBH_4$ (2.27 g, 60 mmol, 3 eq) was added in portions. After full conversion, the reaction mixture was concentrated, dissolved in ethyl acetate and washed with water. The organic phase was dried with $MgSO_4$ and concentrated. The residue was purified with silica chromatography, yielding the title compound as colourless oil. Yield: 1.97 g, 6.65 mmol, 33%. ^1H NMR (400 MHz, $CDCl_3$) δ 7.54 – 7.47 (m, 2H, CH_{arom}), 7.34 – 7.22 (m, 3H, CH_{arom}), 4.73 (d, *J* = 1.4 Hz, 1H, H-1), 4.20 (dd, *J* = 5.8, 5.0 Hz, 1H, H-3), 4.02 (dd, *J* = 5.8, 2.6 Hz, 1H, H-4), 3.96 (ddd, *J* = 9.1, 4.7, 1.2 Hz, 1H, H-2), 3.86 (qd, *J* = 6.6, 2.7 Hz, 1H, H-5), 2.57 (d, *J* = 9.1 Hz, 1H, OH), 1.63 (s, 3H, CH_3 isopropylidene), 1.45 (d, *J* = 6.6 Hz, 3H, H-6), 1.40 (s, 3H, CH_3 isopropylidene); ^{13}C NMR (101 MHz, $CDCl_3$) δ 135.5 (C_q), 131.2, 129.1, 127.4 (CH_{arom}), 109.8 (C_q isopropylidene), 87.6 (C-1), 74.2 (C-3), 73.9 (C-4), 72.5 (C-5), 67.8 (C-2), 25.9, 25.6 (CH_3 isopropylidene), 17.0 (C-6);); HRMS: $[M+NH_4]^+$ calcd for $C_{15}H_{20}O_4SNH_4$ 314.14206, found 314.14148.

Phenyl 6-deoxy-2-*O*-benzoyl-3,4-*O*-isopropylidene-1-thio-β-L-talopyranoside(55)



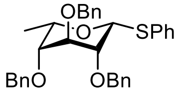
Product **54** (1.95 g, 6.58 mmol) was dissolved in 20 mL 1:1 DCM/pyridine and BzCl (1.15 mL, 9.87 mmol, 1.5 eq) was added. After TLC shows full conversion, the reaction mixture was diluted with DCM and washed twice with a 1 M $CuSO_4$ sln. The organic phase was dried with $MgSO_4$ and concentrated. Silica chromatography (10 to 15% acetone in pentane) yields the title compound as white solid. Yield: 2.08 g, 5.19 mmol, 79%. ^1H NMR (400 MHz, $CDCl_3$) δ 8.27 – 8.19 (m, 2H, CH_{arom}), 7.65 – 7.56 (m, 1H, CH_{arom}), 7.49 (ddd, *J* = 8.0, 5.4, 1.5 Hz, 4H, CH_{arom}), 7.36 – 7.22 (m, 3H, CH_{arom}), 5.60 (dd, *J* = 5.7, 1.9 Hz, 1H, H-2), 4.94 (d, *J* = 1.9 Hz, 1H, H-1), 4.49 (t, *J* = 5.9 Hz, 1H, H-3), 4.10 (dd, *J* = 6.1, 2.7 Hz, 1H, H-4), 3.98 (qd, *J* = 6.5, 2.7 Hz, 1H, H-5), 1.57 (d, *J* = 6.6 Hz, 3H, H-6), 1.34 (s, 3H, CH_3 isopropylidene), 1.27 (s, 3H, CH_3 isopropylidene); ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.1 (C=O), 135.2, 133.3 (C_q), 131.0, 130.4, 129.9, 129.1, 128.5, 127.5 (CH_{arom}), 110.2 (C_q isopropylidene), 85.8 (C-1), 73.2 (C-4), 72.9 (C-5), 72.5 (C-3), 68.2 (C-2), 26.0, 25.5 (CH_3 isopropylidene), 17.2 (C-6); HRMS: $[M+Na]^+$ calcd for $C_{22}H_{24}O_5SNa$ 423.12367, found 423.12293.

Phenyl 6-deoxy-2,4-di-*O*-benzoyl -1-thio-β-L-talopyranoside(56)



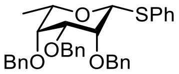
Product **55** (2.00 g, 4.99 mmol) was dissolved in methanol with 400 mg amberlite and heated to a gentle reflux. After isopropylidene removal, the reaction mixture was cooled to RT and filtered over celite. The filtrate was concentrated, coevaporated twice with toluene and dissolved in DCM. CSA (116 mg, 0.50 mmol, 0.1 eq) and trimethylorthobenzoate (1.29 mL, 7.49 mmol, 1.5 eq) were added and the reaction mixture was stirred for 24 hr, after which 10 mL of water was added. After vigorously stirring for another 24 hr, the reaction mixture was washed with sat. aq. $NaHCO_3$. The organic phase was dried with $MgSO_4$ and concentrated. Silica chromatography (25% EtOAc in pentane) yields the title compound as white solid. Yield: 1.24 g, 2.67 mmol 54%. ^1H NMR (400 MHz, $CDCl_3$) δ 8.21 – 8.16 (m, 2H, CH_{arom}), 8.05 – 8.00 (m, 2H, CH_{arom}), 7.61 – 7.56 (m, 1H, CH_{arom}), 7.55 – 7.50 (m, 2H, CH_{arom}), 7.45 (tt, *J* = 7.7, 1.3 Hz, 1H, CH_{arom}), 7.41 – 7.35 (m, 2H, CH_{arom}), 7.34 – 7.26 (m, 3H, CH_{arom}), 7.19 – 7.12 (m, 2H, CH_{arom}), 5.73 (ddd, *J* = 3.8, 1.3, 0.8 Hz, 1H, H-2), 5.41 (dd, *J* = 2.8, 1.1 Hz, 1H, H-4), 5.04 (d, *J* = 1.5 Hz, 1H, H-1), 4.24 (q, *J* = 3.9 Hz, 1H, H-3), 3.92 (qd, *J* = 6.3, 1.2 Hz, 1H, H-5), 3.32 (d, *J* = 5.1 Hz, 1H, OH), 1.41 (d, *J* = 6.5 Hz, 3H, H-6); ^{13}C NMR (101 MHz, $CDCl_3$) δ 167.7, 167.2 (C=O), 134.4 (C_q), 133.6, 133.3, 131.2, 130.5, 130.2 (CH_{arom}), 129.4, 129.2 (C_q), 128.5, 128.2, 127.8 (CH_{arom}), 86.5 (C-1), 74.4 (C-5), 72.3 (C-2), 70.9 (C-3), 70.2 (C-2), 17.2 (C-6); HRMS: $[M+Na]^+$ calcd for $C_{26}H_{24}O_6SNa$ 487.11858, found 487.11790.

Phenyl 6-deoxy-2,3,4-tri-*O*-benzyl -1-thio-β-L-idopyranoside(15)



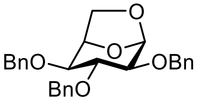
Compound **56** (1.20 g, 2.58 mmol) was dissolved in DCM and cooled to -10 °C, after which pyridine (0.63 mL, 7.75 mmol, 3 eq) and Tf_2O (0.65 mL, 3.87 mmol, 1.5 eq) were added. After full conversion, the reaction mixture was washed with 1M HCl and sat. aq. $NaHCO_3$, dried with $MgSO_4$ and concentrated at 25 °C. The triflate **57** was then dissolved in ACN and treated with $TBANO_2$ (1.49 g, 5.17 mmol, 2 eq) and heated to 80 °C. After 24 hr, the reaction mixture was cooled to RT and concentrated. Silica chromatography yields ca 0.4 g of very impure inverted product **58**. This was then treated with 50 mg NaOMe in MeOH. After debenzoylation, the reaction mixture was quenched with amberlite, filtered and concentrated under reduced pressure. The crude triol was coevaporated 3x with toluene and dissolved in DMF, after which BnBr and NaH, both 4 eq based on pure compound **58**, were added. After 4 hr, the reaction was quenched with water and extracted twice with Et_2O. Silica chromatography (5% Et_2O in pentane) yields the title compound as yellowish oil. Yield: 122 mg, 0.232 mmol, 9% over 4 steps. $[\alpha]_D^{25}$ = 20.8° (c = 0.07, $CHCl_3$); IR (thin film): 697, 1050, 1076, 1076, 1088, 1455; ^1H NMR (400 MHz, $CDCl_3$) δ 7.50 – 7.09 (m, 20H, CH_{arom}), 5.10 (d, *J* = 1.8 Hz, 1H, H-1), 4.64 (d, *J* = 1.8 Hz, 2H, CH_2 Bn), 4.58 (d, *J* = 12.4 Hz, 1H, C*H*H Bn), 4.38 (d, *J* = 12.4 Hz, 1H, CH*H* Bn), 4.31 (d, *J* = 12.1 Hz, 1H, C*H*H Bn), 4.23 (d, *J* = 12.1 Hz, 1H, CH*H* Bn), 3.88 (qd, *J* = 6.5, 1.7 Hz, 1H, H-5), 3.65 (t, *J* = 2.6 Hz, 1H, H-3), 3.61 (d, *J* = 2.7 Hz, 1H, H-2), 3.08 (s, 1H, H-4), 1.29 (d, *J* = 6.6 Hz, 3H, H-6); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.2, 138.0, 137.6, 136.8 (C_q), 130.4, 128.8, 128.7, 128.6, 128.6, 128.4, 128.4, 128.1, 128.0, 127.9, 127.9, 126.6 (CH_{arom}), 86.4 (C-1), 75.5 (C-2), 74.0 (C-4), 73.4 (CH_2 Bn), 72.8 (C-5), 72.4, 72.1 (CH_2 Bn), 71.6 (C-3), 17.0 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{33}H_{34}O_4S$ 544.25161, found 544.25040.

Phenyl 6-deoxy-2,3,4-tri-*O*-benzyl-1-thio-β-L-talopyranoside(16)



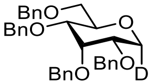
Compound **54** (0.60 g, 2.02 mmol) and PTSA-H_2O (0.04 g, 0.20 mmol, 0.1 eq) were dissolved in methanol and heated to 50 °c. After TLC shows full deprotection, the reaction mixture was concentrated under reduced pressure, yielding crude tri-ol **nr**, which was coevaporated twice with toluene, dissolved in DMF and treated with benzyl bromide (0.96 mL, 8.10 mmol, 4 eq) and sodium hydride (60% dispersion in mineral oil, 0.32 g, 8.10 mmol, 4 eq). After full conversion, the reaction mixture was quenched with water and extracted with diethyl ether. The organic phase was dried with $MgSO_4$ and concentrated under reduced pressure. Silica chromatography (5 to 10% acetone) yields the title compound as colourless oil. Yield: 800 mg, 1.52 mmol, 75%. $[\alpha]_D^{25}$ = 35.6° (c = 0.92, $CHCl_3$); IR (thin film): 695, 738, 1066, 1362, 1454; ^1H NMR (400 MHz, $CDCl_3$) δ 7.51 – 7.45 (m, 4H, CH_{arom}), 7.41 – 7.18 (m, 16H, CH_{arom}), 5.07 (d, *J* = 11.8 Hz, 1H, C*H*H Bn), 5.00 (d, *J* = 12.1 Hz, 1H, C*H*H Bn), 4.95 (d, *J* = 11.8 Hz, 1H, CH*H* Bn), 4.83 (d, *J* = 12.0 Hz, 1H, CH*H* Bn), 4.69 (d, *J* = 1.5 Hz, 1H, H-1), 4.59 (s, 2H, CH_2 Bn), 4.09 (dt, *J* = 2.8, 1.3 Hz, 1H, H-2), 3.64 – 3.60 (m, 1H, H-4), 3.52 – 3.44 (m, 2H, H-3, H-5), 1.34 (d, *J* = 6.4 Hz, 3H, H-6); ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.2, 138.9, 138.0, 136.5 (C_q), 130.9, 128.8, 128.6, 128.5, 128.4, 128.1, 128.1, 127.9, 127.4, 127.4, 126.9 (CH_{arom}), 88.8 (C-1), 81.6 (C-3), 76.0 (C-5), 75.8 (C-2), 74.8 (CH_2 Bn), 74.6 (C-4), 74.3, 71.0 (CH_2 Bn), 17.6 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{33}H_{34}O_4SNH_4$ 544.25161, found 544.25024.

1,6-anhydro-2,3,4-tri-*O*-benzyl-D-idopyranoside (61)



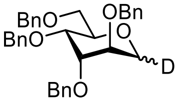
Title compound was formed as side product in reactions **7A** and **7B**. When the idose donor **7** was reacted according to the general procedure for Ph$_2$SO/Tf$_2$O mediated glycosylations, but no nucleophile was added, the product was formed in 81% yield after quenching after 24 hr. ^{1}H NMR (500 MHz, CDCl$_3$) δ 7.36 – 7.26 (m, 15H, CH$_{arom}$), 5.30 (d, J = 1.8 Hz, 1H, H-1), 4.84 (d, J = 2.2 Hz, 2H, CH$_2$ Bn), 4.73 – 4.70 (m, 2H, 2x C*H*H Bn), 4.68 (d, J = 11.9 Hz, 1H, CH*H* Bn), 4.62 (d, J = 11.8 Hz, 1H, CH*H* Bn), 4.39 (t, J = 4.6 Hz, 1H, H-5), 4.13 (dd, J = 7.7, 0.9 Hz, 1H, H-6), 3.78 (t, J = 8.1 Hz, 1H, H-3), 3.72 – 3.66 (m, 2H, H-4, H-6), 3.47 (dd, J = 7.9, 1.8 Hz, 1H, H-2); ^{13}C NMR (126 MHz, CDCl$_3$) δ 138.8, 138.2, 138.1 (C$_q$), 128.7, 128.6, 128.5, 128.5, 128.1, 128.1, 128.0, 128.0, 127.8, 127.8 (CH$_{arom}$), 99.8 (C-1), 82.6 (C-2), 82.0 (C-3), 79.5 (C-4), 75.6 (CH$_2$ Bn), 73.4 (C-5), 73.2, 73.2 (CH$_2$ Bn), 65.6 (C-6). Spectra in agreement with literature.[48]

1-deutero-1-deoxy-2,3,4,6-tetra-*O*-benzyl-α-D-allopyranoside (4A)



Title compound was prepared according to the general procedure for Ph$_2$SO/Tf$_2$O mediated glycosylations with donor **4** and TES-D, yielding compound **4A** (39 mg, 74 µmol, 74%, colourless oil, α:β >98:2) ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.42 – 7.17 (m, 20H, CH$_{arom}$), 4.88 (d, J = 12.1 Hz, 1H, C*H*H Bn), 4.82 (d, J = 12.1 Hz, 1H, CH*H* Bn), 4.59 (d, J = 12.3 Hz, 1H, C*H*H Bn), 4.55 (d, J = 12.2 Hz, 1H, C*H*H Bn), 4.53 – 4.47 (m, 3H, CH*H* Bn, CH$_2$ Bn), 4.37 (d, J = 11.5 Hz, 1H, CH*H* Bn), 4.21 (t, J = 2.5 Hz, 1H, H-3), 3.89 (ddd, J = 9.8, 4.0, 2.1 Hz, 1H, H-5), 3.84 – 3.81 (m, 1H, H-1), 3.70 (dd, J = 10.5, 2.2 Hz, 1H, H-6), 3.65 (dd, J = 10.5, 4.1 Hz, 1H, H-6), 3.51 (dd, J = 5.1, 2.3 Hz, 1H, H-2), 3.46 (dd, J = 9.8, 2.4 Hz, 1H, H-4); ^{13}C NMR (101 MHz, CDCl$_3$) δ 139.3, 138.3, 138.2, 138.1 (C$_q$), 128.6, 128.5, 128.4, 128.3, 128.1, 127.9, 127.8, 127.8, 127.7, 127.5, 127.4 (CH$_{arom}$), 75.9, 75.8 (C-2, C-4), 74.0 (CH$_2$ Bn), 73.9 (C-5), 73.7 (CH$_2$ Bn), 73.1 (C-3), 71.4, 71.3 (CH$_2$ Bn), 69.4 (C-6), 64.0 (t, J = 22.0 Hz, C-1); HRMS: [M+NH$_4$]$^+$ calcd for C$_{34}$H$_{35}$DO$_5$NH$_4$ 543.29638, found 543.29537.

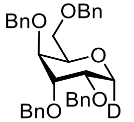
1-deutero-1-deoxy-2,3,4,6-tetra-*O*-benzyl-α,β-D-altropyranoside (5A)



Title compound was prepared according to the general procedure for Ph$_2$SO/Tf$_2$O mediated glycosylations with donor **5** and TES-D, yielding compound **5A** (29 mg, 55 µmol, 55%, colourless oil, α:β = 20:80) ^{1}H NMR (500 MHz, CDCl$_3$) δ 7.37 – 7.17 (m, 20H, CH$_{arom}$), 4.66 – 4.61 (m, 2H, 2x C*H*H Bn), 4.57 (d, J = 9.4 Hz, 1H, C*H*H Bn), 4.55 (d, J = 9.4 Hz, 1H, CH*H* Bn), 4.52 (d, J = 12.2 Hz, 1H, CH*H* Bn), 4.44 (d, J = 11.6 Hz, 1H, C*H*H Bn), 4.42 – 4.36 (m, 2H, 2x CH*H* Bn), 3.96 (ddd, J = 9.7, 5.7, 2.0 Hz, 1H, H-5), 3.88 (d, J = 1.5 Hz, 0.2H, H-1α), 3.86 – 3.81 (m, 1H, H-3), 3.80 (dd, J = 9.8, 2.9 Hz, 1H, H-4), 3.79 (d, J = 1.4 Hz, 0.8H, H-1β), 3.76 (dd, J = 10.6, 2.0 Hz, 1H, H-6), 3.66 (dd, J = 10.6, 5.7 Hz, 1H, H-6), 3.50 (dd, J = 3.8, 1.5 Hz, 1H, H-2); ^{13}C

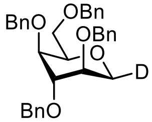
NMR (126 MHz, CDCl$_3$) δ 138.5, 138.5, 138.3, 138.3 (C$_q$), 128.5, 128.5, 128.4, 128.4, 128.1, 128.0, 127.9, 127.8, 127.8, 127.6 (CH$_{arom}$), 74.8 (C-2), 74.7 (C-5), 73.9 (C-4), 73.7, 72.9 (CH$_2$ Bn), 72.7 (C-3), 71.8, 71.0 (CH$_2$ Bn), 70.3 (C-6), 64.5 (t, J = 22.0 Hz, C-1); HRMS: $[M+NH_4]^+$ calcd for $C_{34}H_{35}DO_5NH_4$ 543.29638, found 543.29526.

1-deutero-1-deoxy-2,3,4,6-tetra-*O*-benzyl-α-D-gulopyranoside (6A)



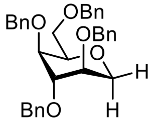
Title compound was prepared according to the general procedure for Ph$_2$SO/Tf$_2$O mediated glycosylations with donor **6** and TES-D, yielding compound **6A** (44 mg, 83 μmol, 83%, colourless oil, α:β >98:2); ^{1}H NMR (500 MHz, CDCl$_3$) δ 7.35 – 7.25 (m, 18H, CH$_{arom}$), 7.15 – 7.11 (m, 2H, CH$_{arom}$), 4.70 (d, J = 12.2 Hz, 1H, C*H*H Bn), 4.56 – 4.50 (m, 3H, 2x C*H*H Bn, CH*H* Bn), 4.47 (d, J = 12.1 Hz, 1H, CH*H* Bn), 4.43 (d, J = 12.1 Hz, 1H, CH*H* Bn), 4.39 (d, J = 12.0 Hz, 1H, C*H*H Bn), 4.35 (d, J = 12.0 Hz, 1H, CH*H* Bn), 3.96 (ddd, J = 7.1, 5.8, 1.6 Hz, 1H, H-5), 3.86 (dd, J = 5.1, 2.7 Hz, 1H, H-2), 3.83 (dd, J = 5.1, 1.2 Hz, 1H, H-1), 3.80 (ddd, J = 4.0, 2.6, 1.3 Hz, 1H, H-3), 3.56 (dd, J = 9.7, 6.8 Hz, 1H, H-6), 3.50 (dd, J = 3.9, 1.6 Hz, 1H, H-4), 3.42 (dd, J = 9.8, 5.9 Hz, 1H); ^{13}C NMR (126 MHz, CDCl$_3$) δ 138.7, 138.5, 138.2, 138.0 (C$_q$), 128.6, 128.5, 128.5, 128.5, 128.3, 128.0, 128.0, 127.9, 127.8, 127.8, 127.7 (CH$_{arom}$), 75.3 (C-4), 73.6 (CH$_2$ Bn), 73.6 (C-5), 73.0 (CH$_2$ Bn), 73.0 (C-2), 72.9 (CH$_2$ Bn), 72.4 (C-3), 71.5 (CH$_2$ Bn), 69.5 (C-6), 64.1 (t, J = 22.0 Hz, C-1); HRMS: $[M+NH_4]^+$ calcd for $C_{34}H_{35}DO_5NH_4$ 543.29638, found 543.29537.

1-deutero-1-deoxy-2,3,4,6-tetra-*O*-benzyl-β-D-idopyranoside (7A)



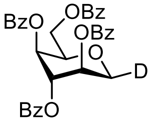
Title compound was prepared according to the general procedure for Ph$_2$SO/Tf$_2$O mediated glycosylations with donor **7** and TES-D, yielding compound **7A.** (39 mg, 74 μmol, 74%, colourless oil, α:β <2:98); ^{1}H NMR (500 MHz, CDCl$_3$) δ 7.38 – 7.22 (m, 20H, CH$_{arom}$), 4.66 – 4.59 (m, 4H, 4x C*H*H Bn), 4.55 – 4.47 (m, 4H, CH*H* Bn), 4.01 (ddd, J = 7.6, 4.6, 3.1 Hz, 1H, H-5), 3.82 – 3.76 (m, 2H, H-1, H-6), 3.71 (t, J = 4.6 Hz, 1H, H-3), 3.62 (dd, J = 10.3, 4.6 Hz, 1H, H-6), 3.52 (dd, J = 4.8, 3.2 Hz, 1H, H-4), 3.42 (t, J = 3.9 Hz, 1H, H-2); ^{13}C NMR (126 MHz, CDCl$_3$) δ 138.4, 138.3, 138.3, 138.2 (C$_q$), 128.5, 128.5, 128.5, 128.4, 128.3, 128.0, 127.9, 127.9, 127.9, 127.8, 127.7 (CH$_{arom}$), 74.9 (C-4), 74.6 (C-5), 74.2 (C-2), 74.0 (C-3), 73.6, 73.1, 72.7, 71.9 (CH$_2$ Bn), 68.6 (C-6), 65.2 (t, J = 22.0 Hz, C-1); HRMS: $[M+NH_4]^+$ calcd for $C_{34}H_{35}DO_5NH_4$ 543.29638, found 543.29518. Comparison with **7A-H** confirms the formation of a single diastereomer, which is characterised as the β-anomer from the benzoylated derivative **7A-Bz**

1-deoxy-2,3,4,6-tetra-*O*-benzyl-D-idopyranoside (7A-H)



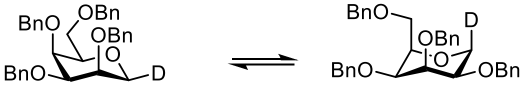
Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **7** and TES-H, yielding compound **7A.** (45 mg, 86 μmol, 86%, colourless oil). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 – 7.24 (m, 20H, CH_{arom}), 4.67 – 4.61 (m, 4H, C*H*H Bn), 4.58 – 4.48 (m, 4H, CH*H* Bn), 4.04 (ddd, *J* = 7.6, 4.6, 3.1 Hz, 1H, H-5), 3.96 – 3.90 (m, 1H, H-1eq), 3.87 – 3.79 (m, 2H, H-1ax, H-6), 3.73 (t, *J* = 4.6 Hz, 1H, H-3), 3.64 (dd, *J* = 10.3, 4.6 Hz, 1H, H-6), 3.54 (ddd, *J* = 4.6, 3.2, 0.8 Hz, 1H, H-4), 3.45 (tdd, *J* = 4.2, 3.1, 0.8 Hz, 1H, H-2); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.4, 138.3, 138.2, 138.2 (C_q), 128.5, 128.5, 128.5, 128.4, 128.3, 128.0, 127.9, 127.9, 127.8, 127.8, 127.8, 127.7 (CH_{arom}, 74.9 (C-4), 74.6 (C-5), 74.2 (C-2), 73.9 (C-3), 73.6, 73.0, 72.7, 71.9 (CH_2 Bn), 68.6 (C-6), 65.5 (C-1); HRMS: $[M+NH_4]^+$ calcd for $C_{34}H_{36}O_5NH_4$ 542.29010, found 542.28852.

1-deutero-1-deoxy-2,3,4,6-tetra-*O*-benzoyl-β-D-idopyranoside (7A-Bz)



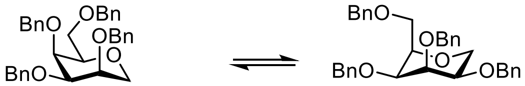
Title compound was prepared according to the general procedure for debenzylation and benzoylation of glycosylated products with **8A** in 60% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.16 – 8.13 (m, 2H, CH_{arom}), 8.12 – 8.09 (m, 2H, CH_{arom}), 8.06 – 8.02 (m, 2H, CH_{arom}), 7.95 – 7.91 (m, 2H, CH_{arom}), 7.65 – 7.58 (m, 2H, CH_{arom}), 7.58 – 7.54 (m, 1H, CH_{arom}), 7.53 – 7.46 (m, 3H, CH_{arom}), 7.45 – 7.37 (m, 4H, CH_{arom}), 7.22 – 7.16 (m, 2H, CH_{arom}), 5.70 (t, *J* = 3.1 Hz, 1H, H-3), 5.40 (ddd, *J* = 3.2, 2.0, 1.0 Hz, 1H, H-4), 5.16 (ddd, *J* = 3.1, 2.1, 1.0 Hz, 1H, H-2), 4.70 (dd, *J* = 11.6, 7.5 Hz, 1H, H-6), 4.53 (dd, *J* = 11.6, 4.9 Hz, 1H, H-6), 4.46 (ddd, *J* = 7.2, 4.9, 2.0 Hz, 1H, H-5), 4.17 (d, *J* = 2.1 Hz, 1H, H-1); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.4, 165.7, 165.5, 164.3 (C=O), 133.9, 133.7, 133.4, 133.4, 130.3, 130.1, 129.9 (CH_{arom}), 129.7, 129.4, 129.3, 129.1 (C_q), 128.8, 128.7, 128.6, 128.4 (CH_{arom}), 73.1 (C-5), 67.3, 67.2 (C-2, C-4), 66.6 (C-3), 63.5 (C-6). C-1 is invisible in the 13C-spectrum, but shows a cross-peak at 66.1 in the HSQC spectrum; HRMS: $[M+Na]^+$ calcd for $C_{34}H_{27}DO_9Na$ 604.16883, found 604.16860.

1-deutero-1-deoxy-2,3,4,6-tetra-*O*-benzyl-β-D-talopyranoside (8A)



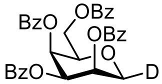
Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **8** and TES-D, yielding compound **8A.** (27 mg, 51 μmol, 51%, colourless oil, α:β <2:98); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 – 7.16 (m, 20H, CH_{arom}), 4.81 (d, *J* = 11.9 Hz, 1H, C*H*H Bn), 4.74 (d, *J* = 12.5 Hz, 1H, C*H*H Bn), 4.69 – 4.54 (m, 5H, 2x C*H*H Bn, 3x CH*H* Bn), 4.48 (d, *J* = 12.0 Hz, 1H, CH*H* Bn), 3.91 (dd, *J* = 10.4, 7.2 Hz, 1H, H-6), 3.75 (tdt, *J* = 8.9, 6.2, 3.1 Hz, 3H, H-3, H-4, H-5), 3.70 – 3.60 (m, 2H, H-2, H-6), 3.48 (d, *J* = 3.0 Hz, 1H, H-1); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.8, 138.7, 138.6, 138.4 (C_q), 128.5, 128.4, 128.4, 128.4, 128.3, 128.3, 128.1, 127.9, 127.7, 127.6, 127.6, 127.5 (CH_{arom}), 77.3, 74.6 (C-3, C-4, C-5), 73.6 (CH_2 Bn), 73.4 (C-2), 72.9, 72.0, 71.8 (CH_2 Bn), 68.4 (C-6); C-1 is invisible in the 13C-spectrum, but shows a cross-peak at 64.6 in the HSQC spectrum; HRMS: $[M+NH_4]^+$ calcd for $C_{34}H_{35}DO_5NH_4$ 543.29638, found 543.29541. Comparison with **8A-H** shows that one diastereomer is selectively formed, which is characterised as the β-anomer from the benzoylated derivative **8A-Bz**

1-deoxy-2,3,4,6-tetra-*O*-benzyl-β-D-talopyranoside (8A-H)



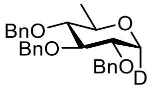
Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **8** and TES-H, yielding compound **8A.** (28 mg, 53 µmol, 53%, colourless oil) ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.52 – 6.88 (m, 20H, CH_{arom}), 4.81 (d, *J* = 11.9 Hz, 1H, C*H*H Bn), 4.74 (d, *J* = 12.4 Hz, 1H, C*H*H Bn), 4.68 – 4.54 (m, 5H, 2x C*H*H Bn, 3x CH*H* Bn), 4.48 (d, *J* = 12.0 Hz, 1H, CH*H* Bn), 4.04 (dd, *J* = 12.0, 5.4 Hz, 1H, H-1), 3.92 (dd, *J* = 10.6, 7.4 Hz, 1H, H-6), 3.83 – 3.72 (m, 3H, H-3, H-4, H-5), 3.69 – 3.60 (m, 2H, H-2, H-6), 3.50 (dd, *J* = 12.0, 3.1 Hz, 1H, H-1); ^{13}C NMR (126 MHz, $CDCl_3$) δ 138.8, 138.7, 138.6, 138.4 (C_q), 128.5, 128.4, 128.4, 128.4, 128.3, 128.3, 128.1, 127.9, 127.7, 127.6, 127.6, 127.5 (CH_{arom}), 77.3, 74.6 (C-3, C-4, C-5), 73.6 (CH_2 Bn), 73.4 (C-2), 72.9, 72.0, 71.8 (CH_2 Bn), 68.4 (C-6); C-1 is invisible in the 13C-spectrum, but shows a cross-peak at 64.6 in the HSQC spectrum; HRMS: $[M+NH_4]^+$ calcd for $C_{34}H_{36}O_5NH_4$ 542.29010, found 542.28886.

1-deutero-1-deoxy-2,3,4,6-tetra-*O*-benzoyl-β-D-talopyranoside (8A-Bz)



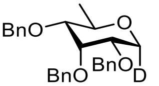
Title compound was prepared according to the general procedure for debenzylation and benzoylation of glycosylated products with **8A** in 36% yield. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14 (ddd, *J* = 8.3, 6.6, 1.3 Hz, 4H, CH_{arom}), 8.07 – 8.04 (m, 2H, CH_{arom}), 8.03 – 7.99 (m, 2H, CH_{arom}), 7.85 – 7.80 (m, 2H, CH_{arom}), 7.68 – 7.55 (m, 4H, CH_{arom}), 7.54 – 7.44 (m, 6H, CH_{arom}), 7.42 – 7.37 (m, 2H, CH_{arom}), 7.33 – 7.22 (m, 6H, CH_{arom}), 5.96 (dt, *J* = 3.9, 1.2 Hz, 1H, H-4), 5.65 (t, *J* = 4.0 Hz, 1H, H-3), 5.62 (dt, *J* = 4.4, 1.2 Hz, 1H, H-2), 4.74 (dd, *J* = 11.5, 7.1 Hz, 1H, H-6), 4.49 (dd, *J* = 11.5, 5.8 Hz, 1H, H-6), 4.27 (ddd, *J* = 7.2, 5.8, 1.6 Hz, 1H, H-5), 4.02 (d, *J* = 1.6 Hz, 1H, H-1); ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.3, 166.2, 166.0, 165.2 (C=O), 133.8, 133.3, 133.3, 133.1, 130.2, 130.1, 129.9, 129.8, 129.8 (CH_{arom}), 129.5, 129.3, 129.1, 128.5 (C_q), 128.5, 128.5, 128.3, 128.3 (CH_{arom}), 75.6 (C-5), 68.6 (C-1, C-3), 67.6 (C-2), 66.9 (C-4), 62.9 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{34}H_{27}DO_9NH_4$ 599.21343, found 599.21225.

1-deutero-1,6-dideoxy-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside (9A)



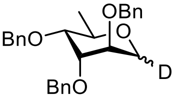
Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **9** and TES-D, yielding compound **9A** (25 mg, 59 µmol, 59%, colourless oil, α:β >98:2); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40 – 7.24 (m, 15H, CH_{arom}), 4.97 (d, *J* = 11.0 Hz, 1H, C*H*H Bn), 4.89 (d, *J* = 10.8 Hz, 1H, C*H*H Bn), 4.85 (d, *J* = 11.0 Hz, 1H, CH*H* Bn), 4.72 (d, *J* = 11.5 Hz, 1H, C*H*H Bn), 4.66 – 4.58 (m, 2H, 2x CH*H* Bn), 3.93 (d, *J* = 4.5 Hz, 1H, H-1), 3.64 – 3.55 (m, 2H, H-2, H-3), 3.31 (dq, *J* = 9.4, 6.1 Hz, 1H, H-5), 3.16 – 3.07 (m, 1H, H-4), 1.26 (d, *J* = 6.1 Hz, 3H, H-6); ^{13}C NMR (126 MHz, $CDCl_3$) δ 138.9, 138.4, 138.3 (C_q), 128.6, 128.6, 128.5, 128.1, 128.1, 128.0, 127.9, 127.8 (CH_{arom}), 86.3 (C-4), 83.8 (C-3), 79.0 (C-2), 76.2 (C-5), 75.7, 75.6, 73.4 (CH_2 Bn), 67.7 (t, *J* = 22.0 Hz, C-1) 18.4 (C-1); HRMS: $[M+NH_4]^+$ calcd for $C_{27}H_{29}DO_4NH_4$ 437.25451, found 437.25374.

1-deutero-1,6-dideoxy-2,3,4-tri-*O*-benzyl-α-D-allopyranoside (12A)



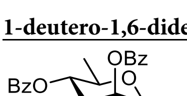
Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **12A** and TES-D, yielding compound **12A** (24 mg, 57 μmol, 57%, colourless oil, α:β >98:2); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.42 – 7.25 (m, 15H, CH_{arom}), 4.89 (d, *J* = 12.0 Hz, 1H, C*H*H Bn), 4.83 (d, *J* = 12.0 Hz, 1H, CH*H* Bn), 4.59 – 4.52 (m, 3H, 2x C*H*H Bn, CH*H* Bn), 4.40 (d, *J* = 11.7 Hz, 1H, CH*H* Bn), 4.21 (bs, 1H, H-3), 3.83 (dq, *J* = 9.4, 6.2 Hz, 1H, H-5), 3.74 (d, *J* = 4.8 Hz, 1H, H-1), 3.47 (dd, *J* = 4.9, 2.2 Hz, 1H, H-2), 2.97 (dd, *J* = 9.4, 2.4 Hz, 1H, H-4), 1.21 (d, *J* = 6.2 Hz, 3H, H-6); ^{13}C NMR (126 MHz, $CDCl_3$) δ 139.3, 138.4, 138.1 (C_q), 128.6, 128.5, 128.3, 128.1, 128.0, 127.9, 127.9, 127.9, 127.5, 127.4 (CH_{arom}), 81.3 (C-4), 76.4 (C-2), 74.0 (CH_2 Bn), 72.7 (C-3), 71.3 (2x CH_2 Bn), 70.7 (C-5), 63.82 (t, *J* = 22.0 Hz, C-1), 18.3 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{27}H_{29}DO_4NH_4$ 437.25451, found 437.25365.

1-deutero-1,6-dideoxy-2,3,4-tri-*O*-benzyl-α,β-D-allopyranoside (13A)



Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **12A** and TES-D, yielding compound **12A** (36 mg, 85 μmol, 85%, colourless oil, α:β = 12:88) ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.59 – 6.76 (m, 15H, CH_{arom}), 4.67 (d, *J* = 12.2 Hz, 1H, C*H*H Bn), 4.58 (t, *J* = 12.8 Hz, 2H, C*H*H Bn, CH*H* Bn), 4.53 (d, *J* = 11.7 Hz, 1H, C*H*H Bn), 4.49 (d, *J* = 11.7 Hz, 1H, CH*H* Bn), 4.45 (d, *J* = 12.4 Hz, 1H, CH*H* Bn), 3.91 – 3.86 (m, 1H, H-5), 3.85 (t, *J* = 3.3 Hz, 1H, H-3), 3.82 – 3.79 (m, 1H, H-1αβ), 3.53 (dd, *J* = 3.8, 1.5 Hz, 1H, H-2), 3.49 (dd, *J* = 9.4, 2.8 Hz, 1H, H-4), 1.32 (d, *J* = 6.2 Hz, 3H, H-6); ^{13}C NMR (126 MHz, $CDCl_3$) δ 138.6, 138.4, 138.3 (C_q), 128.5, 128.5, 128.5, 128.1, 127.9, 127.9, 127.8, 127.8, 127.8 (CH_{arom}), 79.0 (C-4), 75.0 (C-2), 72.8 (CH_2 Bn), 72.4 (C-3), 71.9, 71.2 (CH_2 Bn), 71.2 (C-5), 64.6 (t, *J* = 22.0 Hz, C-1), 18.3 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{27}H_{29}DO_4NH_4$ 437.25451, found 437.25365. Because of overlap of H-1α and H-1β, the ratio was determined from the benzoylated derivate **13A-Bz**

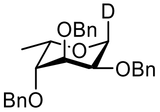
1-deutero-1,6-dideoxy-2,3,4-tri-*O*-benzoyl-α,β-D-allopyranoside (13A-Bz)



Title compound was prepared according to the general procedure for debenzylation and benzoylation of glycosylated products with **13A** in 80% yield. ^{1}H NMR (850 MHz, $CDCl_3$) δ 8.14 (dd, *J* = 8.3, 1.2 Hz, 2H, CH_{arom}), 8.06 (dd, *J* = 8.3, 1.2 Hz, 2H, CH_{arom}), 7.91 (dd, *J* = 8.4, 1.3 Hz, 2H, CH_{arom}), 7.64 – 7.59 (m, 2H, CH_{arom}), 7.52 (tt, *J* = 7.4, 1.3 Hz, 1H, CH_{arom}), 7.51 – 7.47 (m, 4H,

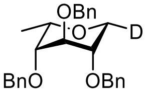
CH_{arom}), 7.38 – 7.33 (m, 2H, CH_{arom}), 5.86 (t, *J* = 3.6 Hz, 1H, H-3), 5.42 (dd, *J* = 9.4, 3.2 Hz, 1H, H-4), 5.32 (dd, *J* = 4.1, 1.7 Hz, 1H, H-2), 4.18 (dq, *J* = 9.4, 6.3 Hz, 1H, H-5), 4.15 (s, 0.12Hα), 4.13 (d, *J* = 1.6 Hz, 0.88H, H-1β), 1.36 (d, *J* = 6.3 Hz, 3H, H-6); ^{13}C NMR (126 MHz, $CDCl_3$) δ 165.6, 165.5, 165.1 (C=O), 133.7, 133.6, 133.4, 130.1, 129.9, 129.8 (CH_{arom}), 129.6, 129.5 (C_q), 128.8, 128.7, 128.5 (CH_{arom}), 71.7 (C-4), 71.0 (C-3), 70.2 (C-2), 68.0 (C-3), 65.4 (t, *J* = 22.0 Hz, C-1), 18.0 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{27}H_{23}DO_7NH_4$ 479.19231, found 479.19118.

1-deutero-1,6-dideoxy-2,3,4-tri-*O*-benzyl-α-L-gulopyranoside (14A)



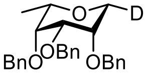
Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **14A** and TES-D, yielding compound **14A** (36 mg, 86 µmol, 86%, colourless oil, α:β >98:2); ^1H NMR (400 MHz, $CDCl_3$) δ 7.37 – 7.26 (m, 13H, CH_{arom}), 7.22 – 7.18 (m, 2H, CH_{arom}), 4.74 (d, *J* = 12.2 Hz, 1H, C*H*H Bn), 4.56 – 4.52 (m, 2H, C*H*H Bn, CH*H* Bn), 4.49 (d, *J* = 10.3 Hz, 1H, CH*H* Bn), 4.46 (d, *J* = 10.3 Hz, 1H, C*H*H Bn), 4.41 (d, *J* = 12.1 Hz, 1H, CH*H* Bn), 3.89 – 3.83 (m, 2H, H-2, H-5), 3.82 (dd, *J* = 4.6, 2.0 Hz, 1H, H-2), 3.79 (d, *J* = 4.9 Hz, 1H, H-1), 3.25 (dd, *J* = 3.8, 1.4 Hz, 1H, H-4), 1.12 (d, *J* = 6.6 Hz, 3H, H-6); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.7, 138.5, 138.1 (C_q), 128.5, 128.5, 128.5, 128.3, 128.0, 127.9, 127.8, 127.8, 127.7 (CH_{arom}), 77.8 (C-4), 73.1 (2x CH_2 Bn), 73.0 (C-2), 72.7 (C-3), 71.5 (CH_2 Bn), 70.5 (C-5), 64.1 (t, *J* = 22.0 Hz, C-1) 16.4 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{27}H_{29}DO_4NH_4$ 437.25451, found 437.25364.

1-deutero-1,6-dideoxy-2,3,4-tri-*O*-benzyl-β-L-idopyranoside (15A)



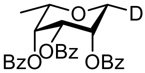
Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **15** and TES-D on 50 µmol scale, yielding compound **15A**. (11 mg, 25 µmol, 50%, colourless oil, α:β <2:98); ^1H NMR (500 MHz, $CDCl_3$) δ 7.40 – 7.08 (m, 15H, CH_{arom}), 4.68 – 4.62 (m, 4H, 2x C*H*H Bn, CH_2 Bn), 4.60 (d, *J* = 12.1 Hz, 1H, CH*H* Bn), 4.55 (d, *J* = 11.9 Hz, 1H, CH*H* Bn), 3.96 (qd, *J* = 6.7, 3.9 Hz, 1H, H-5), 3.73 – 3.69 (m, 2H, H-1, H-3), 3.42 (dd, *J* = 5.7, 4.1 Hz, 1H, H-2), 3.39 (dd, *J* = 6.2, 3.9 Hz, 1H, H-4), 1.26 (d, *J* = 6.8 Hz, 3H, H-6); ^{13}C NMR (126 MHz, $CDCl_3$) δ 138.5, 138.5, 138.5 (C_q), 128.6, 128.5, 128.5, 128.2, 128.0, 128.0, 127.9, 127.8 (CH_{arom}), 77.8 (C-4), 76.4 (C-3), 75.5 (C-2), 73.9, 72.9, 72.5 (CH_2 Bn), 71.0 (C-5), 63.7 (t, *J* = 22.0 Hz, C-1), 14.4 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{27}H_{29}DO_4NH_4$ 437.25451, found 437.25369

1-deutero-1,6-dideoxy-2,3,4-tri-*O*-benzyl-β-L-talopyranoside (16A)



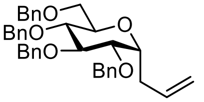
Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **16** and TES-D, yielding compound **16A**. (29 mg, 68 µmol, 68%, colourless oil, α:β <2:98); ^1H NMR (500 MHz, $CDCl_3$) δ 7.60 – 6.99 (m, 15H, CH_{arom}), 4.90 (d, *J* = 12.0 Hz, 1H, C*H*H Bn), 4.80 (d, *J* = 12.6 Hz, 1H, C*H*H Bn), 4.75 (d, *J* = 12.0 Hz, 1H, CH*H* Bn), 4.68 – 4.63 (m, 2H, C*H*H Bn, CH*H* Bn), 4.59 (d, *J* = 12.1 Hz, 1H, CH*H* Bn), 3.70 (bs, 1H, H-4), 3.65 (t, *J* = 2.5 Hz, 1H, H-2), 3.63 – 3.55 (m, 2H, H-3, H-5), 3.41 (d, *J* = 2.4 Hz, 1H, H-1), 1.34 (d, *J* = 6.5 Hz, 3H, H-6); ^{13}C NMR (126 MHz, $CDCl_3$) δ 139.1, 138.9, 138.7 (C_q), 128.4, 128.3, 128.2, 128.2, 127.9, 127.6, 127.5, 127.5, 127.4 (CH_{arom}), 78.7 (C-4), 76.2 (C-3), 73.2 (CH_2 Bn), 72.9 (C-2), 71.8, 71.6 (CH_2 Bn), 16.4 (C-6), C-3 and C-1 are invisible in the 13C spectrum, but show cross-peaks at 74.1 and 65.4 respectively in the HSQC spectrum. HRMS: $[M+NH_4]^+$ calcd for $C_{27}H_{29}DO_4NH_4$ 437.25451, found 437.25372. The product is characterised as the β-anomer form **16A-Bz**

1-deutero-1,6-dideoxy-2,3,4-tri-*O*-benzoyl-β-L-talopyranoside (16A-Bz)



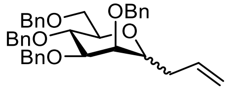
Title compound was prepared according to the general procedure for debenzylation and benzoylation of glycosylated products with **16A** in 91% yield. ^{1}H NMR (850 MHz, $CDCl_3$) δ 8.12 (dd, *J* = 8.4, 1.2 Hz, 2H, CH_{arom}), 8.01 – 7.97 (m, 2H, CH_{arom}), 7.81 – 7.75 (m, 2H, CH_{arom}), 7.58 (tt, *J* = 7.4, 1.3 Hz, 1H, CH_{arom}), 7.50 (tt, *J* = 7.5, 1.3 Hz, 1H, CH_{arom}), 7.46 (ddt, *J* = 8.7, 7.4, 1.5 Hz, 1H, CH_{arom}), 7.37 – 7.33 (m, 2H, CH_{arom}), 7.28 – 7.24 (m, 2H, CH_{arom}), 7.24 – 7.20 (m, 2H, CH_{arom}), 5.65 (dt, *J* = 3.9, 1.1 Hz, 2H, H-4), 5.57 (t, *J* = 4.1 Hz, 1H, H-3), 5.55 (dt, *J* = 4.1, 1.2 Hz, 2H, H-2), 3.95 (qd, *J* = 6.4, 1.3 Hz, 1H, H-5), 3.93 (d, *J* = 1.2 Hz, 1H, H-1), 1.37 (d, *J* = 6.5 Hz, 3H, H-6); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.6, 166.5, 165.5 (C=O), 133.8, 133.3, 133.3, 133.1, 130.3, 130.2, 130.1 (CH_{arom}), 130.1, 129.9 (C_q), 129.9 (CH_{arom}), 129.4 (C_q), 128.6 , 128.5, 128.4, 128.3 (CH_{arom}), 74.2 (C-5), 69.8 (C-4), 69.2 (C-3), 68.8 (t, *J* = 22.0 Hz, C-1), 67.5 (C-2), 17.1 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{27}H_{23}DO_7NH_4$ 479.19231, found 479.19112.

1-allyl-1-deoxy-2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside (1B)



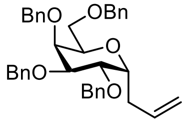
Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **1** and Allyl-TMS, yielding compound **1B** (40 mg, 71 μmol, 71%, colourless oil, α:β >98:2); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.38 – 7.13 (m, 20H, CH_{arom}), 5.81 (dddd, *J* = 16.6, 10.2, 7.4, 6.3 Hz, 1H, CH_2-C*H*=CH_2), 5.17 – 4.98 (m, 2H, CH_2-CH=C*H₂*), 4.93 (d, *J* = 11.0 Hz, 1H, C*H*H Bn), 4.84 – 4.76 (m, 2H, C*H*H Bn, CH*H* Bn), 4.69 (d, *J* = 11.6 Hz, 1H, C*H*H Bn), 4.67 – 4.58 (m, 2H, C*H*H Bn, CH*H* Bn), 4.50 – 4.44 (m, 2H, 2x CH*H* Bn), 4.13 (dt, *J* = 10.4, 5.0 Hz, 1H, H-1), 3.80 (dd, *J* = 9.4, 7.5 Hz, 1H, H-3), 3.76 (dd, *J* = 9.4, 5.5 Hz, 1H, H-2) 3.70 (dd, *J* = 10.6, 3.4 Hz, 1H, H-6), 3.67 – 3.59 (m, 3H, H-4, H-5, H-6), 2.56 – 2.44 (m, 2H, C*H₂*-CH=CH_2); ^{13}C NMR (126 MHz, $CDCl_3$) δ 138.9, 138.4, 138.3, 138.2 (C_q), 134.9 (CH_2-CH=CH_2), 128.6, 128.5, 128.5, 128.1, 128.1, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 127.7 (CH_{arom}), 117.6(CH_2-CH=CH_2), 82.6 (C-2), 79.8 (C-3), 78.2 (C-4), 75.6, 75.2 (CH_2 Bn), 73.8 (C-1), 73.6, 73.2 (CH_2 Bn), 71.2 (C-5), 69.0 (C-6), 29.9 (CH_2-CH=CH_2); HRMS: $[M+Na]^+$ calcd for $C_{37}H_{40}NaO_5$ 587.2768, found 587.2770

1-allyl-1-deoxy-2,3,4,6-tetra-*O*-benzyl-α,β-D-mannopyranoside (2B)



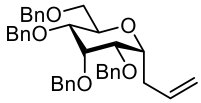
Title compound was prepared according to the general procedure for Ph$_2$SO/Tf$_2$O mediated glycosylations with donor **2** and Allyl-TMS, yielding compound **2B** (45 mg, 80 µmol, 80%, colourless oil, α:β >66:34); data of the α-anomer: ^{1}H NMR (500 MHz, CDCl$_3$): δ 7.41 – 7.23 (m, 20H, CH$_{arom}$), 5.81 – 5.69 (m, 1H, CH$_2$-C*H*=CH$_2$), 5.06 – 4.98 (m, 2H, CH$_2$-CH=C*H*$_2$), 4.74 – 4.65 (m, 2H, C*H*H Bn, CH*H* Bn), 4.61 – 4.48 (m, 6H, 3x C*H*H Bn, 3x CH*H*), 4.04 (ddd, J = 7.8, 6.1, 4.7 Hz, 1H, H-1), 3.88 – 3.81 (m, 2H, H-4, H-5), 3.80 – 3.74 (m, 2H, H-3, H-6), 3.71 (dd, J = 10.3, 3.5 Hz, 1H, H-6), 3.62 (dd, J = 4.9, 2.9 Hz, 1H, H-2), 2.39 – 2.27 (m, 2H, C*H*$_2$-CH=CH$_2$); 13C NMR (126 MHz, CDCl3, HSQC): δ 138.6, 138.4, 138.4, 138.3 (C$_q$), 134.0 (CH$_2$-*C*H-CH$_2$), 128.5, 128.4, 128.4, 128.4, 128.4, 128.3, 128.2, 128.2, 128.1, 128.1, 128.1, 128.0, 127.8, 127.7, 127.7, 127.6 (CH$_{arom}$), 117.3 (CH$_2$-CH=*C*H$_2$), 77.0 (C-3), 75.3 (C-2), 75.0, 74.0 (CH$_2$ Bn), 73.9 (C-5), 73.4 (CH$_2$ Bn), 72.5 (C-1), 72.2, 71.7 (CH$_2$ Bn), 69.3 (C-6), 33.9 (CH$_2$-CH=CH$_2$); diagnostic signals of the β-anomer: 1H NMR (500 MHz, CDCl$_3$): δ 4.87 (d, J = 10.8 Hz, 1H, C*H*H Bn), 4.78 (d, J = 11.7 Hz, 1H, C*H*H Bn), 3.46 (ddd, J = 9.7, 5.8, 1.8 Hz, 1H, H-5), 3.36 – 3.30 (m, 1H, H-1), 2.50 (dtt, J = 12.7, 6.4, 1.6 Hz, 1H, C*H*H-CH=CH$_2$); 13C NMR (126 MHz, CDCl3): δ 134.8 (CH$_2$-*C*H=CH$_2$), 117.4 (CH$_2$-CH=*C*H$_2$), 80.0 (C-5), 78.4 (C-1), 75.4, 74.5, 73.6, 72.6 (CH$_2$ Bn), 69.9 (C-6). HRMS: [M+Na]+ calcd for C$_{37}$H$_{40}$NaO$_5$ 587.2768, found 587.2781.

1-allyl-1-deoxy-2,3,4,6-tetra-*O*-benzyl-α-D-galactopyranoside (3B)



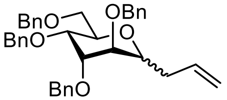
Title compound was prepared according to the general procedure for Ph$_2$SO/Tf$_2$O mediated glycosylations with donor **3** and Allyl-TMS, yielding compound **3B** (46 mg, 80 µmol, 80%, colourless oil, α:β >98:2); ^{1}H NMR (500 MHz, CDCl$_3$) δ 7.91 – 6.50 (m, 20H, CH$_{arom}$), 5.75 (ddt, *J* = 17.1, 10.2, 6.9 Hz, 1H, CH$_2$-C*H*=CH$_2$), 5.13 – 4.98 (m, 2H, CH$_2$-CH=C*H*$_2$), 4.80 – 4.63 (m, 2H, 2x C*H*H Bn), 4.65 – 4.39 (m, 6H, 2x C*H*H Bn, 4x CH*H* Bn), 4.05 (bs, 1H, H-5), 4.03 – 3.97 (m, 1H, H-3), 4.00 (dd, J = 4.0, 2.6 Hz, 1H, H-1), 3.88 – 3.81 (m, 1H, H-6), 3.75 (s, 1H, H-4), 3.72 (dd, *J* = 6.9, 2.8 Hz, 1H, H-2), 3.66 (dd, *J* = 10.6, 4.7 Hz, 1H, H-6), 2.47 – 2.38 (m, 1H, C*H*H-CH=CH$_2$), 2.38 – 2.29 (m, 1H, CH*H*-CH=CH$_2$); 13C NMR (126 MHz, CDCl3, HSQC): δ 138.8, 138.7, 138.7, 138.5 (C$_q$), 135.4 (CH$_2$-CH=CH$_2$), 128.6, 128.6, 128.6, 128.5, 128.2, 128.1, 128.0, 128.0, 127.8, 127.8, 127.7 (CH$_{arom}$), 117.0 (CH$_2$-CH=CH$_2$), 76.7 (C-2), 76.7 (C-4), 74.5 (C-3), 73.4, 73.3, 73.3, 73.2 (CH$_2$ Bn), 73.0 (C-5), 70.8 (C-1), 67.5 (C-6), 33.9 (*C*H$_2$-CH=CH$_2$); HRMS: [M+Na]$^+$ calcd for C$_{37}$H$_{40}$NaO$_5$ 587.2768, found 587.2776.

1-allyl-1-deoxy-2,3,4,6-tetra-*O*-benzyl-α-D-allopyranoside (4B)



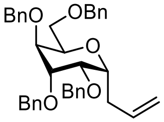
Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **4** and Allyl-TMS, yielding compound **4B** (26 mg, 46 μmol, 46%, colourless oil, α:β >98:2); ^1H NMR (400 MHz, $CDCl_3$) δ 7.38 – 7.18 (m, 20H, CH_{arom}), 5.93 – 5.81 (m, 1H, CH_2-C*H*-CH_2), 5.07 (dq, *J* = 17.2, 1.6 Hz, 1H, CH_2-CH=C*H*H), 5.02 (ddt, *J* = 10.2, 2.3, 1.1 Hz, 1H, CH_2-CH=CH*H*), 4.82 (d, *J* = 3.4 Hz, 2H, CH_2 Bn), 4.62 (d, *J* = 12.2 Hz, 1H, C*H*H Bn), 4.56 (s, 2H, CH_2 Bn), 4.50 (d, *J* = 6.9 Hz, 1H, C*H*H Bn), 4.47 (d, *J* = 8.3 Hz, 1H, CH*H* Bn), 4.38 (d, *J* = 11.4 Hz, 1H, CH*H* Bn), 4.21 (t, *J* = 2.8 Hz, 1H, H-3), 4.11 (ddd, *J* = 11.3, 6.1, 3.1 Hz, 1H, H-1), 4.00 (ddd, *J* = 9.7, 3.6, 2.1 Hz, 1H, H-5), 3.76 (dd, *J* = 10.4, 3.4 Hz, 1H, H-6), 3.67 (dd, *J* = 10.4, 2.1 Hz, 1H, H-6), 3.62 (dd, *J* = 6.0, 2.6 Hz, 1H, H-2), 3.56 (dd, *J* = 9.7, 2.8 Hz, 1H, H-4), 3.13 – 2.94 (m, 1H, C*H*H-CH=CH_2), 2.54 (dddt, *J* = 15.4, 6.2, 2.8, 1.4 Hz, 1H, CH*H*-CH=CH_2); ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.3, 138.4, 138.2 (C_q), 136.8 (CH_2-*C*H=CH_2), 128.6, 128.4, 128.4, 128.4, 128.3, 128.0, 127.9, 127.9, 127.8, 127.8, 127.6, 127.5, 127.4 (CH_{arom}), 116.3 (CH_2-CH=*C*H_2), 77.2 (C-4), 75.1 (C-2), 74.5 (C-1), 74.2 (C-3), 74.1, 73.7, 71.4, 71.3 (CH_2 Bn), 69.4 (C-6), 67.2 (C-5), 31.5 (*C*H_2-CH=CH_2); HRMS: $[M+NH_4]^+$ calcd for $C_{37}H_{40}O_5NH_4$ 582.32140, found 582.32030.

1-allyl-1-deoxy-2,3,4,6-tetra-*O*-benzyl-α,β-D-altropyranoside (5B)



The title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **5** and Allyl-TMS, yielding compound **5B** (38 mg, 68 μmol, 68%, colourless oil, α:β = 89:11) Data for the α-anomer: ^1H NMR (400 MHz, $CDCl_3$) δ 7.35 – 7.22 (m, 20H, CH_{arom}), 5.85 (ddt, *J* = 17.1, 10.2, 6.9 Hz, 1H, CH_2-C*H*=CH_2), 5.12 – 5.00 (m, 2H, CH_2-CH=C*H_2*), 4.68 (d, *J* = 11.3 Hz, 1H, C*H*H Bn), 4.59 – 4.53 (m, 3H, 3x C*H*H Bn), 4.53 – 4.47 (m, 4H, 4x CH*H* Bn), 4.17 (q, *J* = 5.2 Hz, 1H, H-5), 3.86 (dd, *J* = 5.3, 3.1 Hz, 1H, H-4), 3.77 – 3.71 (m, 2H, H-1, H-3), 3.66 – 3.61 (m, 2H, H-2, H-6), 3.57 (dd, *J* = 10.3, 4.8 Hz, 1H, H-6), 2.63 – 2.43 (m, 2H, C*H_2*-CH=CH_2); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.4, 138.4, 138.3 (C_q), 135.3 (CH_2=*C*H=CH_2), 128.5, 128.5, 128.4, 128.4, 128.3, 128.3, 128.2, 128.2, 128.1, 128.0, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 127.7, 127.7 (CH_{arom}), 117.0 (CH_2-CH=*C*H_2), 77.3, 77.2 (C-2, C-3), 74.8 (C-1), 73.7, 73.4 (CH_2 Bn), 73.4 (C-4), 72.2, 71.7 (CH_2 Bn), 71.7 (C-5), 69.1 (C-6), 35.9 (*C*H_2-CH=CH_2); diagnostic peaks for the β-anomer: ^1H NMR (400 MHz, $CDCl_3$) δ 5.68 (dddd, *J* = 16.4, 10.1, 7.9, 6.1 Hz, 1H, CH_2-C*H*=CH_2), 4.02 – 3.94 (m, 2H), 3.32 (dd, *J* = 3.5, 1.5 Hz, 1H), 2.31 – 2.21 (m, 2H, C*H_2*-CH=CH_2); ^{13}C NMR (101 MHz, $CDCl_3$) δ 135.1 (CH_2-CH=CH_2), 75.9, 75.2, 74.3, 73.0, 72.7, 71.8, 70.2 (C-6), 35.2 (*C*H_2-CH=CH_2); HRMS: $[M+NH_4]^+$ calcd for $C_{37}H_{40}O_5NH_4$ 582.32140, found 582.31959.

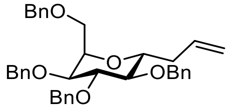
1-allyl-1-deoxy-2,3,4,6-tetra-*O*-benzyl-α-D-gulopyranoside (6B)



Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **6** and Allyl-TMS, yielding compound **6B** (40 mg, 71 μmol, 71%, colourless oil, α:β >98:2); ^1H NMR (400 MHz, $CDCl_3$) δ 7.36 – 7.19 (m, 20H, CH_{arom}), 5.78 (ddt, *J*

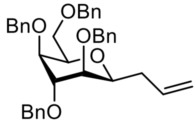
= 17.1, 10.2, 7.0 Hz, 1H, CH_2-C*H*=CH_2), 5.07 (dq, *J* = 17.2, 1.6 Hz, 1H, CH_2-CH=C*H*H), 5.01 (ddt, *J* = 10.2, 2.2, 1.2 Hz, 1H, CH_2-CH=CH*H*), 4.74 (d, *J* = 11.8 Hz, 1H, C*H*H Bn), 4.69 (d, *J* = 12.1 Hz, 1H, C*H*H Bn), 4.64 (d, *J* = 12.1 Hz, 1H, CH*H* Bn), 4.61 – 4.55 (m, 2H, 2x C*H*H Bn), 4.54 – 4.47 (m, 3H, 3x CH*H* Bn), 4.22 (dt, *J* = 6.6, 4.7 Hz, 1H, H-5), 3.94 – 3.87 (m, 2H, H-1, H-4), 3.85 (t, *J* = 3.4 Hz, 1H, H-3), 3.79 (dd, *J* = 6.8, 3.0 Hz, 1H, H-2), 3.69 (dd, *J* = 10.3, 6.6 Hz, 1H, H-6), 3.64 (dd, *J* = 10.3, 5.1 Hz, 1H, H-6), 2.73 (dt, *J* = 15.6, 8.0 Hz, 1H, C*H*H-CH=CH_2), 2.36 (dddt, *J* = 14.9, 7.4, 4.9, 1.3 Hz, 1H, CH*H*-CH=CH_2); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.8, 138.7, 138.5, 138.4 (C_q), 135.9 (CH_2=*C*H=CH_2), 128.5, 128.4, 128.4, 128.1, 128.0, 127.8, 127.8, 127.7, 127.7, 127.6, 127.6 (CH_{arom}), 116.7 (CH_2-CH=*C*H_2), 75.9 (C-4), 75.1 (C-3), 73.7 (C-1), 73.4, 73.3, 73.1, 73.1 (CH_2 Bn), 68.2 (C-6), 33.4 (*C*H_2-CH=CH_2); C-2 and C-5 are invisible in the 13C-spectrum, but show cross-peaks at 77.0 and 69.9 respectively in the HSQC spectrum; HRMS: $[M+NH_4]^+$ calcd for $C_{37}H_{40}O_5NH_4$ 582.32140, found 582.32010

1-allyl-1-deoxy-2,3,4,6-tetra-*O*-benzyl-α-D-idopyranoside (7B-α)



An analytical amount was isolated as the minor product from reaction between donor **7** and allyl-TMS according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 – 7.22 (m, 20H, CH_{arom}), 5.89 (dddd, *J* = 17.6, 10.3, 7.4, 6.1 Hz, 1H, CH_2-C*H*=CH_2), 5.16 – 5.02 (m, 2H, CH_2-CH=C*H₂*), 4.90 – 4.83 (m, 2H, 2x C*H*H Bn), 4.74 (d, *J* = 10.9 Hz, 1H, CH*H* Bn), 4.66 (d, *J* = 11.5 Hz, 1H, C*H*H Bn), 4.63 – 4.55 (m, 4H, 2x CH*H* Bn, CH_2 Bn), 4.24 (ddd, *J* = 8.5, 5.6, 3.3 Hz, 1H, H-5), 3.84 (dd, *J* = 11.0, 8.2 Hz, 1H, H-6), 3.80 – 3.69 (m, 4H, H-1, H-3, H-4, H-6), 3.27 (dd, *J* = 9.4, 7.8 Hz, 1H, H-2), 2.58 (dddt, *J* = 14.7, 6.3, 3.3, 1.5 Hz, 1H, C*H*H-CH=CH_2), 2.27 (dtt, *J* = 14.8, 7.4, 1.2 Hz, 1H, CH*H*-CH=CH_2); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.7, 138.4, 138.3, 138.2 (C_q), 134.8 (CH_2-*C*H=CH_2), 128.6, 128.5, 128.5, 128.0, 127.9, 127.9, 127.8, 127.7 (CH_{arom}), 117.2 (CH_2-CH=*C*H_2), 82.7 (C-3/C-4), 81.3 (C-2), 79.5 (C-3/C-4), 75.4, 75.0 (CH_2 Bn), 73.4 (C-5), 73.4, 73.3 (CH_2 Bn), 72.2 (C-1), 66.0 (CH_2 Bn), 36.3 (CH_2-CH=CH_2); HRMS: $[M+NH_4]^+$ calcd for $C_{37}H_{40}O_5NH_4$ 582.32140, found 582.31962.

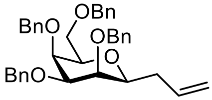
1-allyl-1-deoxy-2,3,4,6-tetra-*O*-benzyl-β-D-idopyranoside (7B-β)

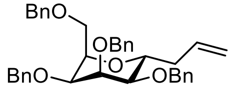


An analytical amount was isolated as the major product from reaction between donor **7** and allyl-TMS according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 – 7.32 (m, 18H, CH_{arom}), 7.27 – 7.23 (m, 2H, CH_{arom}), 5.82 (dddd, *J* = 16.7, 10.2, 7.7, 6.3 Hz, 1H, CH_2-C*H*=CH_2), 5.13 (dq, *J* = 17.1, 1.6 Hz, 1H, CH_2-CH=C*H*H), 5.08 (ddt, *J* = 10.2, 2.2, 1.1 Hz, 1H, CH_2-CH=CH*H*), 4.69 – 4.64 (m, 2H, 2x C*H*H Bn), 4.62 (d, *J* = 12.3 Hz, 1H, C*H*H Bn), 4.57 (d, *J* = 12.0 Hz, 1H, CH*H* Bn), 4.52 – 4.46 (m, 2H, 2x CH*H* Bn), 4.43 (d, *J* = 12.3 Hz, 1H, C*H*H Bn), 4.36 (d, *J* = 12.3 Hz, 1H, CH*H* Bn), 4.04 (td, *J* = 6.2, 1.8 Hz, 1H, H-5), 3.84 – 3.77 (m, 2H, H-1, H-6), 3.75 – 3.70 (m, 2H, H-3, H-6), 3.49 (dt, *J* = 2.8, 1.4 Hz, 1H, H-4), 3.30 (dt, *J* = 2.9, 1.5 Hz, 1H, H-2), 2.68 (dddt, *J* = 14.0, 7.8, 6.3, 1.5 Hz, 1H, C*H*H-CH=CH_2), 2.36

(dddt, *J* = 14.2, 7.6, 6.4, 1.2 Hz, 1H, CH*H*-CH=CH$_2$); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.5, 138.2, 138.1, 137.9 (C$_q$), 135.2 (CH$_2$-*C*H=CH$_2$), 128.7, 128.7, 128.5, 128.5, 128.4, 128.3, 128.3, 127.9, 127.8, 127.8, 127.7, 127.7, 127.5 (CH$_{arom}$), 116.7 (CH$_2$-CH=*C*H), 76.0 (C-1), 75.7 (C-5), 73.5 (CH$_2$ Bn), 73.4 (C-2), 72.4 (CH$_2$ Bn), 72.2 (C-4), 72.2 (CH$_2$ Bn, 71.8 (CH$_2$ Bn), 70.0 (C-3), 69.9 (C-6), 35.4 (*C*H$_2$-CH=CH$_2$); HRMS: [M+NH$_4$]$^+$ calcd for $C_{37}H_{40}O_5NH_4$ 582.32140, found 582.31991.

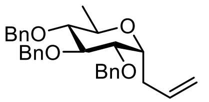
1-allyl-1-deoxy-2,3,4,6-tetra-*O*-benzyl-α,β-D-talopyranoside (8B)





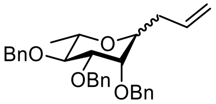
The title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **8** and Allyl-TMS, yielding compound **8B** (38 mg, 68 μmol, 68%, colourless oil, α:β = 57:43). Data reported for a 1:1 mixture: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 – 7.16 (m, 40H, CH$_{arom}$), 5.89 (dddd, *J* = 17.7, 10.2, 7.6, 6.2 Hz, 1H, CH$_2$-C*H*=CH$_2$), 5.71 (dddd, *J* = 16.7, 10.2, 7.7, 6.4 Hz, 1H, CH$_2$-C*H*=CH$_2$), 5.10 (dt, *J* = 17.2, 1.7 Hz, 1H, CH$_2$-CH=C*H*H), 5.07 – 4.96 (m, 4H, CH$_2$-CH=C*H*H, 2x CH$_2$-CH=CH*H*, C*H*H Bn), 4.94 (d, *J* = 12.0 Hz, 1H, C*H*H Bn), 4.85 – 4.77 (m, 2H, CH$_2$ Bn), 4.75 (d, *J* = 12.0 Hz, 1H, C*H*H Bn), 4.71 (d, *J* = 12.0 Hz, 1H, CH*H* Bn), 4.61 – 4.53 (m, 6H, 4x C*H*H Bn, 2x CH*H* Bn), 4.53 – 4.48 (m, 2H, 2x CH*H* Bn), 4.45 (d, *J* = 11.7 Hz, 1H, CH*H* Bn), 4.39 – 4.30 (m, 2H, H-5α, CH*H* Bn), 4.17 (dd, *J* = 11.9, 8.8 Hz, 1H, H-6α), 4.12 (t, *J* = 2.5 Hz, 1H, H-3α), 3.95 – 3.89 (m, 2H, H-1α, H-2β), 3.80 (dd, *J* = 12.0, 2.0 Hz, 1H, H-6α), 3.74 (dt, *J* = 2.9, 1.4 Hz, 1H, H-4β), 3.69 (dd, *J* = 6.1, 1.7 Hz, 2H, 2x H-6β), 3.59 (dd, *J* = 6.3, 2.3 Hz, 1H, H-4α), 3.52 (td, *J* = 6.2, 1.5 Hz, 1H, H-3β), 3.47 (t, *J* = 3.0 Hz, 1H, H-1β), 3.29 (ddd, *J* = 7.5, 6.4, 1.4 Hz, 1H, H-5β), 3.12 (dd, *J* = 9.4, 2.6 Hz, 1H, H-2α), 2.66 – 2.51 (m, 2H, 2x C*H*H-CH=CH$_2$), 2.36 – 2.27 (m, 1H, CH*H*-CH=CH$_2$), 2.27 – 2.18 (m, 1H, CH*H*-CH=CH$_2$); ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.2, 138.9, 138.8, 138.3, 138.3, 138.1, 137.9 (C$_q$), 135.1, 135.0 (CH$_2$-C*H*=CH$_2$), 128.7, 128.6, 128.6, 128.6, 128.5, 128.5, 128.4, 128.4, 128.3, 128.2, 128.2, 128.2, 128.1, 128.0, 127.9, 127.9, 127.8, 127.8, 127.8, 127.7, 127.6, 127.5, 127.5, 127.5, 127.4, 127.3 (CH$_{arom}$), 117.1, 117.1 (CH$_2$-CH=*C*H$_2$), 82.3 (C-1β), 80.0 (C-5β), 79.0 (C-3β), 78.1 (C-2α), 76.8 (C-4α), 75.2 (C-5α), 74.3, 74.2, 74.0 (CH$_2$ Bn), 74.0 (C-4β), 73.7, 73.2 (CH$_2$ Bn), 73.1 (C-3α), 72.7 (C-2β), 71.4, 71.1, 71.0 (CH$_2$ Bn), 69.9 (C-6β), 67.4 (C-1α), 66.4 (C-6α), 35.9, 35.8 (*C*H$_2$-CH=CH$_2$); HRMS: [M+NH$_4$]$^+$ calcd for $C_{37}H_{40}O_5NH_4$ 582.32140, found 582.31986.

1-allyl-1,6-dideoxy-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside (9B)



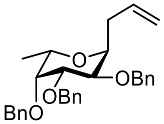
Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **9** and Allyl-TMS, yielding compound **9B** (29 mg, 64 μmol, 64%, colourless oil, α:β >98:2); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 – 7.27 (m, 15H, CH$_{arom}$), 5.86 – 5.70 (m, 1H, CH$_2$-C*H*=CH$_2$), 5.15 – 5.04 (m, 2H, CH$_2$-CH=C*H$_2$*), 4.93 (d, *J* = 10.9 Hz, 1H, C*H*H Bn), 4.89 (d, *J* = 10.7 Hz, 1H, C*H*H Bn), 4.81 (d, *J* = 10.9 Hz, 1H, CH*H* Bn), 4.70 (d, *J* = 11.6 Hz, 1H, C*H*H Bn), 4.65 – 4.60 (m, 2H, 2x CH*H* Bn), 4.06 – 3.97 (m, 1H, H-1), 3.81 – 3.69 (m, 2H, H-2, H-3), 3.63 – 3.55 (m, 1H, H-5), 3.16 – 3.09 (m, 1H, H-4), 2.56 – 2.40 (m, 2H, C*H$_2$*-CH=CH$_2$), 1.23 (d, *J* = 6.1 Hz, 3H, H-6); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.9, 138.4 (C$_q$), 134.9 (CH$_2$-*C*H=CH$_2$), 131.2, 129.5, 129.3, 128.6, 128.6, 128.5, 128.2, 128.1, 127.9, 127.8, 124.9 (CH_{arom}), 117.0 (CH_2-CH=*C*H_2), 84.4 (C-4), 82.4, 80.6 (C-2, C-3), 75.6, 75.6 (CH_2 Bn), 73.8 (C-1), 73.2 (CH_2 Bn), 67.6 (C-5), 30.1 (*C*H_2-CH=CH_2), 18.5 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{30}H_{34}O_4NH_4$ 476.27954, found 476.27873.

1-allyl-1-deoxy-2,3,4-tri-*O*-benzyl-α,β-L-rhamnopyranoside (10B)



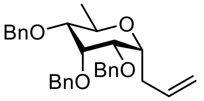
Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **10** and Allyl-TMS, yielding compound **10B** (38 mg, 83 μmol, 83%, colourless oil, α:β 77:23); Data for the α-anomer: ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.48 – 7.13 (m, 15H, CH_{arom}), 5.77 – 5.58 (m, 1H, CH_2-C*H*=CH_2), 5.05 – 4.91 (m, 2H, CH_2-CH=C*H₂*), 4.84 (d, J = 11.1 Hz, 1H, C*H*H Bn), 4.81 – 4.55 (m, 5H, 2x C*H*H Bn, 3x CH*H* Bn,), 4.01 (ddd, J = 8.2, 6.6, 3.4 Hz, 1H, H-1), 3.74 (dd, J = 7.9, 3.1 Hz, 1H, H-3), 3.67 (dd, J = 7.7, 6.1 Hz, 1H, H-5), 3.66 – 3.59 (m, 1H, H-2), 3.58 (t, J = 7.8 Hz, 1H, H-4), 2.34 (tdd, J = 8.2, 6.5, 1.4 Hz, 1H, C*H*H-CH=CH_2), 2.23 (dqd, J = 14.2, 6.9, 1.6 Hz, 1H, CH*H*-CH=CH_2), 1.33 (d, J = 6.2 Hz, 3H, H-6); ^{13}C NMR (126 MHz, CDCl3): δ 138.9, 138.6, 138.4 (C_q), 134.4 (CH_2-*C*H=CH_2), 128.6, 128.6, 128.5, 128.5, 128.2, 128.2, 128.0, 127.9, 127.8, 127.8, 127.7, 127.6 (CH_{arom}), 117.9 (CH_2-CH=*C*H_2), 80.3 (C-4), 78.1 (C-3), 75.3 (C-2), 74.8 (CH_2 Bn), 73.2 (C-1), 72.1, 71.8 (CH_2 Bn), 69.8 (C-5), 34.1 (*C*H_2-CH=CH_2), 18.2 (C-6); diagnostic signals for the β-anomer: 1H NMR (500 MHz, $CDCl_3$): δ 3.78 (dd, J = 2.7, 1.0 Hz, 1H, H-2), 3.36 – 3.28 (m, 2H, H-1, H-5), 2.50 – 2.39 (m, 1H, C*H*H-CH=CH_2); 13C NMR (126 MHz, CDCl3): δ 134.9 (CH_2-*C*H=CH_2), 117.3 (CH_2-CH=CH_2), 78.3 (C-1), 76.1 (C-5), 74.9 (C-2), 35.9 (*C*H_2-CH=CH_2), 19.6 (C-6); HRMS: $[M+Na]^+$ calcd for $C_{30}H_{34}NaO_4$ 481.2349, found 481.2355.

1-allyl-1-deoxy-2,3,4-tri-*O*-benzyl-α-L-fucopyranoside (11B)



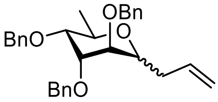
Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **11** and Allyl-TMS, yielding compound **11B** (35 mg, 76 μmol, 76%, colourless oil, α:β >98:2); ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.06 – 6.84 (m, 15H, CH_{arom}), 5.76 (ddt, J = 17.1, 10.2, 6.9 Hz, 1H, CH_2-C*H*=CH_2), 5.14 – 4.93 (m, 2H, CH_2-CH=C*H₂*), 4.80 – 4.53 (m, 5H, 3x C*H*H Bn, 2x CH*H* Bn), 4.52 (d, J = 11.8 Hz, 1H, CH*H* Bn), 4.06 (ddd, J = 8.5, 5.2, 2.4 Hz, 1H, H-1), 3.95 (dd, J = 6.7, 3.8 Hz, 1H, H-5), 3.82 – 3.70 (m, 3H, H-2, H-3, H-4), 2.40 (dddt, J = 14.7, 9.4, 6.8, 1.4 Hz, 1H, C*H*H-CH=CH_2), 2.31 (dddd, J = 13.4, 6.9, 4.1, 1.4 Hz, 1H, CH*H*-CH=CH_2), 1.29 (d, J = 6.7 Hz, 3H, H-6); 13C NMR (126 MHz, $CDCl_3$): δ 139.0, 138.7, 138.5 (C_q), 135.5 (CH_2-*C*H=CH_2), 128.5, 128.4, 128.3, 128.1, 127.9, 127.7, 127.7, 127.7, 127.6 (CH_{arom}), 117.9 (CH_2-CH=CH_2), 76.9 (C-3), 76.7 (C-4), 76.0 (C-2), 73.2, 73.1, 73.1(CH_2 Bn), 70.3, (C-1), 68.8 (C-5), 31.2 (*C*H_2-CH=CH_2), 14.5 (C-6); HRMS: $[M+Na]^+$ calcd for $C_{30}H_{34}NaO_4$ 481.2349, found 481.2347.

1-allyl-1,6-dideoxy-2,3,4-tri-*O*-benzyl-α-D-allopyranoside (12B)



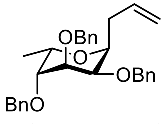
Title compound was prepared according to the general procedure for Ph$_2$SO/Tf$_2$O mediated glycosylations with donor **12** and Allyl-TMS, yielding compound **12B** (26 mg, 57 μmol, 57%, colourless oil, α:β >98:2); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.40 – 7.25 (m, 15H, CH$_{arom}$), 5.92 – 5.78 (m, 1H, CH$_2$-C*H*=CH$_2$), 5.14 – 4.99 (m, 2H, CH$_2$-CH=C*H$_2$*), 4.86 (d, *J* = 11.7 Hz, 1H, C*H*H Bn), 4.82 (d, *J* = 12.1 Hz, 1H, CH*H* Bn), 4.58 (s, 2H, CH$_2$ Bn), 4.55 (d, *J* = 11.7 Hz, 1H, C*H*H Bn), 4.40 (d, *J* = 11.7 Hz, 1H, CH*H* Bn), 4.19 (t, *J* = 2.6 Hz, 1H, H-3), 4.05 – 3.94 (m, 2H, H-1, H-5), 3.59 (dd, *J* = 6.0, 2.7 Hz, 1H, H-2), 3.11 – 2.99 (m, 2H, H-4, C*H*H-CH=CH$_2$), 2.58 – 2.48 (m, 1H, CH*H*-CH=CH$_2$), 1.22 (d, *J* = 6.2 Hz, 3H, H-6); ^{13}C NMR (101 MHz, CDCl$_3$) δ 139.2, 138.4, 138.1 (C$_q$), 136.8 (CH$_2$-CH=CH$_2$), 128.6, 128.5, 128.3, 128.3, 128.1, 127.9, 127.8, 127.8, 127.5, 127.4 (CH$_{arom}$), 116.4 (CH$_2$-CH=CH$_2$), 80.6 (C-4), 77.6 (C-2), 74.3 (C-1), 74.0 (CH$_2$ Bn), 73.7 (C-3), 71.4, 71.2 (CH$_2$ Bn), 63.6 (C-5), 31.8 (*C*H$_2$-CH=CH$_2$), 18.2 (C-6); HRMS: [M+NH$_4$]$^+$ calcd for $C_{30}H_{34}O_4NH_4$ 476.27954, found 476.27879.

1-allyl-1,6-dideoxy-2,3,4-tri-*O*-benzyl-α,β-D-altropyranoside (13B)



Title compound was prepared according to the general procedure for Ph$_2$SO/Tf$_2$O mediated glycosylations with donor **12** and Allyl-TMS, yielding compound **13B**. (31 mg, 67 μmol, 67%, colourless oil, α:β 89:11) Data for the α-anomer: ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.37 – 7.26 (m, 15H, CH$_{arom}$), 5.84 (ddt, *J* = 17.1, 10.2, 6.9 Hz, 1H, CH$_2$-C*H*=CH$_2$), 5.13 – 5.02 (m, 2H, CH$_2$-CH=C*H$_2$*), 4.74 (d, *J* = 11.3 Hz, 1H, C*H*H Bn), 4.62 – 4.55 (m, 5H, 2x C*H*H Bn, 3x CH*H* Bn), 4.21 – 4.11 (m, 1H, H-5), 3.79 (dd, *J* = 6.8, 3.1 Hz, 1H, H-3), 3.72 – 3.62 (m, 2H, H-1, H-2), 3.52 (dd, *J* = 4.8, 3.1 Hz, 1H, H-4), 2.62 – 2.45 (m, 2H, C*H$_2$*-CH=CH$_2$), 1.19 (d, *J* = 6.8 Hz, 3H, H-6); ^{13}C NMR (101 MHz, CDCl$_3$) δ 138.5, 138.5, 138.4 (C$_q$), 135.4 (CH$_2$-CH=CH$_2$), 128.5, 128.5, 128.5, 128.1, 128.0, 128.0, 127.9, 127.8, 127.7 (CH$_{arom}$), 116.9 (CH$_2$-CH=CH$_2$), 77.6 (C-2), 77.3 (C-4), 77.3 (C-3), 74.0 (CH$_2$ Bn), 73.4 (C-1), 72.3, 71.7 (CH$_2$ Bn), 68.4 (C-5), 36.9 (*C*H$_2$-CH=CH$_2$), 13.1 (C-6); diagnostic peaks for the β-anomer: ^{1}H NMR (400 MHz, CDCl$_3$) δ 5.74 – 5.61 (m, 1H, CH$_2$-C*H*=CH$_2$), 2.39 (dt, *J* = 13.1, 6.9 Hz, 1H, C*H*H-CH=CH$_2$), 2.26 – 2.15 (m, 1H, CH*H*-CH=CH$_2$); ^{13}C NMR (101 MHz, CDCl$_3$) δ 135.1 (CH$_2$-CH=CH$_2$), 117.0 (CH$_2$-CH=CH$_2$), 34.1 (*C*H$_2$-CH=CH$_2$), 18.3 (C-6); HRMS: [M+NH$_4$]$^+$ calcd for $C_{30}H_{34}O_4NH_4$ 476.27954, found 476.27867.

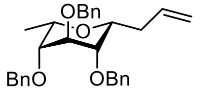
1-allyl-1,6-dideoxy-2,3,4-tri-*O*-benzyl-α-L-gulopyranoside (14B)

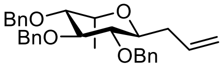


Title compound was prepared according to the general procedure for Ph$_2$SO/Tf$_2$O mediated glycosylations with donor **14** and Allyl-TMS, yielding compound **14B** (35 mg, 75 μmol, 75%, colourless oil, α:β >98:2); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.38 – 7.26 (m, 15H, CH$_{arom}$), 5.73 (ddt, *J*

= 17.1, 10.2, 7.0 Hz, 1H, CH_2-C*H*=CH_2), 5.08 – 4.97 (m, 2H, CH_2-CH=C*H₂*), 4.86 (d, *J* = 11.6 Hz, 1H, C*H*H Bn), 4.74 (s, 2H, CH_2 Bn), 4.67 (d, *J* = 11.8 Hz, 1H, C*H*H Bn), 4.61 (d, *J* = 11.7 Hz, 1H, CH*H* Bn), 4.58 (d, *J* = 11.8 Hz, 1H, CH*H* Bn), 4.28 – 4.20 (m, 1H, H-5), 3.91 (bs, 1H, H-4), 3.81 (t, *J* = 2.7 Hz, 1H, H-3), 3.78 – 3.67 (m, 2H, H-1, H-2), 2.57 (dt, *J* = 14.6, 7.5 Hz, 1H, C*H*H-CH=CH_2), 2.28 (dt, *J* = 14.1, 6.3 Hz, 1H, CH*H*-CH=CH_2), 1.20 (d, *J* = 6.8 Hz, 3H, H-6); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.9, 138.7, 138.6 (C_q), 135.6 (CH_2-*C*H=CH_2), 128.5, 128.4, 128.4, 128.2, 128.0, 127.8, 127.7, 127.6, 127.6 (CH_{arom}), 116.8 (CH_2-CH=*C*H₂), 78.1 (C-2), 77.2 (C-4), 75.7 (C-3) 73.7, 73.2, 73.2 (CH_2 Bn), 72.1 (C-1), 34.4 (*C*H₂-CH=CH_2), 13.5 (C-6), C-5 is invisible in the 13C-spectrum, but shows a cross-peak at 68.0 in the HSQC-spectrum; HRMS: $[M+NH_4]^+$ calcd for $C_{30}H_{34}O_4NH_4$ 476.27954, found 476.27877

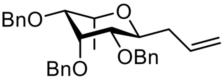
1-allyl-1,6-dideoxy-2,3,4-tri-*O*-benzyl-α,β-L-idopyranoside (15B)





Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor **15** and Allyl-TMS on 50 µmol scale, yielding compound **15B**. (11 mg, 24 µmol, 48%, colourless oil, α:β 21:79) Data for the β-anomer: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 – 7.02 (m, 15H, CH_{arom}), 5.79 – 5.65 (m, 1H, CH_2-C*H*=CH_2), 5.06 – 4.94 (m, 2H, CH_2-CH=C*H₂*), 4.61 – 4.53 (m, 2H, 2x C*H*H Bn), 4.41 (d, *J* = 12.3 Hz, 2H, 2x CH*H* Bn), 4.32 (s, 2H, CH_2 Bn), 3.77 (qd, *J* = 6.6, 1.7 Hz, 1H, H-5), 3.70 – 3.60 (m, 2H, H-1, H-3), 3.19 (q, *J* = 2.7, 2.2 Hz, 1H, H-2), 3.10 (t, *J* = 2.8 Hz, 1H, H-4), 2.57 – 2.48 (m, 1H, C*H*H-CH=CH_2), 2.33 – 2.24 (m, 1H, CH*H*-CH=CH_2), 1.21 (d, *J* = 6.6 Hz, 3H, H-6); ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.4, 138.4, 138.1 (C_q), 135.5 (CH_2-*C*H=CH_2), 128.8, 128.7, 128.6, 128.4, 128.4, 128.1, 128.0, 127.9, 127.9, 127.8 (CH_{arom}), 116.7 (CH_2-CH=*C*H₂), 76.1 (C-1), 74.8 (C-4), 73.2 (C-2), 72.5, 72.3 (CH_2 Bn), 72.2 (C-5), 71.9 (CH_2 Bn), 70.5 (C-3), 35.6 (*C*H₂-CH=CH_2), 17.0 (C-6); diagnostic peaks for the α-anomer: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.88 – 5.79 (m, 1H, CH_2-C*H*=CH_2), 4.90 (d, *J* = 10.8 Hz, 1H, C*H*H Bn), 4.80 (d, *J* = 10.8 Hz, 1H, CH*H* Bn), 4.68 (d, *J* = 11.6 Hz, 1H, C*H*H Bn), 4.19 (p, *J* = 6.5 Hz, 1H, H-5), 3.24 (dd, *J* = 9.7, 8.7 Hz, 1H), 1.27 (d, *J* = 7.0 Hz, 3H, H-6); ^{13}C NMR (101 MHz, $CDCl_3$) δ 134.7 (CH_2-*C*H=CH_2), 117.5 (CH_2-CH=*C*H₂), 81.9, 80.6, 75.3, 73.2, 70.8, 70.0, 11.0 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{30}H_{34}O_4NH_4$ 476.27954, found 476.27867.

1-allyl-1,6-dideoxy-2,3,4-tri-*O*-benzyl-α-L-talopyranoside (16B)



Title compound was prepared according to the general procedure for Ph_2SO/Tf_2O mediated glycosylations with donor 1**6** and Allyl-TMS, yielding compound **16B** (25 mg, 55 µmol, 55%, colourless oil, α:β >98:2); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40 – 7.23 (m, 15H, CH_{arom}), 5.90 – 5.77 (m, 1H, CH_2-C*H*=CH_2), 5.09 (dq, *J* = 17.2, 1.6 Hz, 1H, CH_2-CH=C*H*H), 5.06 – 5.02 (m, 1H, CH_2-CH=CH*H*), 4.87 (d, *J* = 12.0 Hz, 1H, C*H*H Bn), 4.80 (d, *J* = 12.0 Hz, 1H, CH*H* Bn), 4.58 (s, 2H, CH_2 Bn), 4.54 (d, *J* = 11.5 Hz, 1H, C*H*H Bn), 4.38 (d, *J* = 11.5 Hz, 1H, CH*H* Bn), 4.22 (t, *J* = 2.6 Hz, 1H, H-3), 4.18 (p, *J* = 6.9 Hz, 1H, H-5), 4.07 – 4.00 (m, 1H, H-1), 3.51 (dd, *J* = 6.0, 2.7 Hz, 1H, H-4), 3.13 (dd, *J* = 9.4, 2.8 Hz, 1H, H-2), 2.61 (dddd, *J* = 13.1, 6.0, 3.2, 1.6 Hz, 1H, C*H*H=CH=CH_2), 2.18 (dt, *J* = 14.9, 7.8 Hz, 1H, CH*H*-CH=CH_2), 1.49 (d, *J* = 7.0 Hz, 3H, H-6);

^{13}C NMR (126 MHz, $CDCl_3$) δ 139.3, 138.5, 138.1 (C_q), 135.2 (CH_2-*C*H=CH_2), 128.5, 128.5, 128.3, 128.0, 127.9, 127.9, 127.8, 127.5, 127.4 (CH_{arom}), 116.8 (CH_2-CH=*C*H_2), 78.5 (C-2), 77.5 (C-4), 74.0 (CH_2 Bn), 73.8 (C-3), 71.3, 71.0 (CH_2 Bn), 70.5 (C-5), 66.7 (C-1), 36.1 (*C*H_2-CH=CH_2), 14.1 (C-6); HRMS: $[M+NH_4]^+$ calcd for $C_{30}H_{34}O_4NH_4$ 476.27954, found 476.27866.

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