C7 Epimerization of Benzylidene-Protected *β*-D-Idopyranosides Brings Structural Insights into Idose Conformational Flexibility

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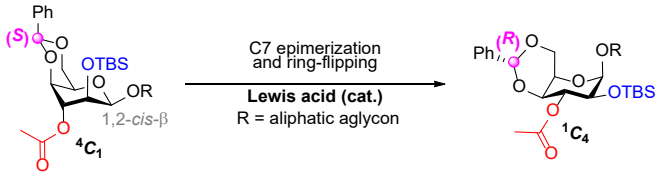


ABSTRACT

Idose is unique among other aldohexoses because of its high conformational flexibility in solution. We herein show that benzylidene acetal-protected 3-*O*-acyl-*β*-D-idopyranosides undergo Lewis acid-catalyzed C7 epimerization with concomitant $^{4}C_{1}$ to $^{1}C_{4}$ ring inversion. The reaction conditions and structural parameters for this transformation to occur have been thoroughly investigated through an extensive glycosylation study combined with NMR analyses, X-ray diffraction, and quantum molecular modeling. In addition to reporting a direct, *β*-stereoselective idosylation approach, our work brings fundamental structural insights into the conformational flexibility of idose.

INTRODUCTION

Idose is a rare, albeit biologically important naturally occurring hexose that stands out from its counterparts by its remarkable ring flexibility in solution. The presence of several axially-oriented substituents induces significant 1,3-*syn*-diaxial interactions that lowers the energy barrier between the $^4C_1$ and $^1C_4$ chairs, increasing the conformational freedom of idose.[1-2] In α-D-idopyranosides, these destabilizing interactions are balanced by the equatorial orientation of the large C5 substituent as well as the anomeric effect. This unique flexibility is denoted by the fact that while D-aldohexoses typically adopt the $^4C_1$ conformation in solution, D-idose exists as a mixture of $^4C_1$ and $^1C_4$ chairs,[2] whose ratio is directly related to the solvent and substitution pattern of its hydroxyl groups (Fig. 1A).[3] Furthermore, Angyal and Kondo reported that intramolecular hydrogen bonds between OH-2/O-4 and OH-3/O-1 stabilize the $^4C_1$ conformation of 4,6-*O*-benzylidene α-D-idopyranosides in solvents with no hydrogen bonding properties, whereas these compounds predominantly adopt a skew-boat ($^{O}S_2$) conformation when dissolved in DMSO and D_2O.[4] Similarly, Nifantiev and co-workers recently reported that the 3-*O*-substituents in such compounds have a significant influence on the $^4C_1/^{O}S_2$ equilibrium.[5]

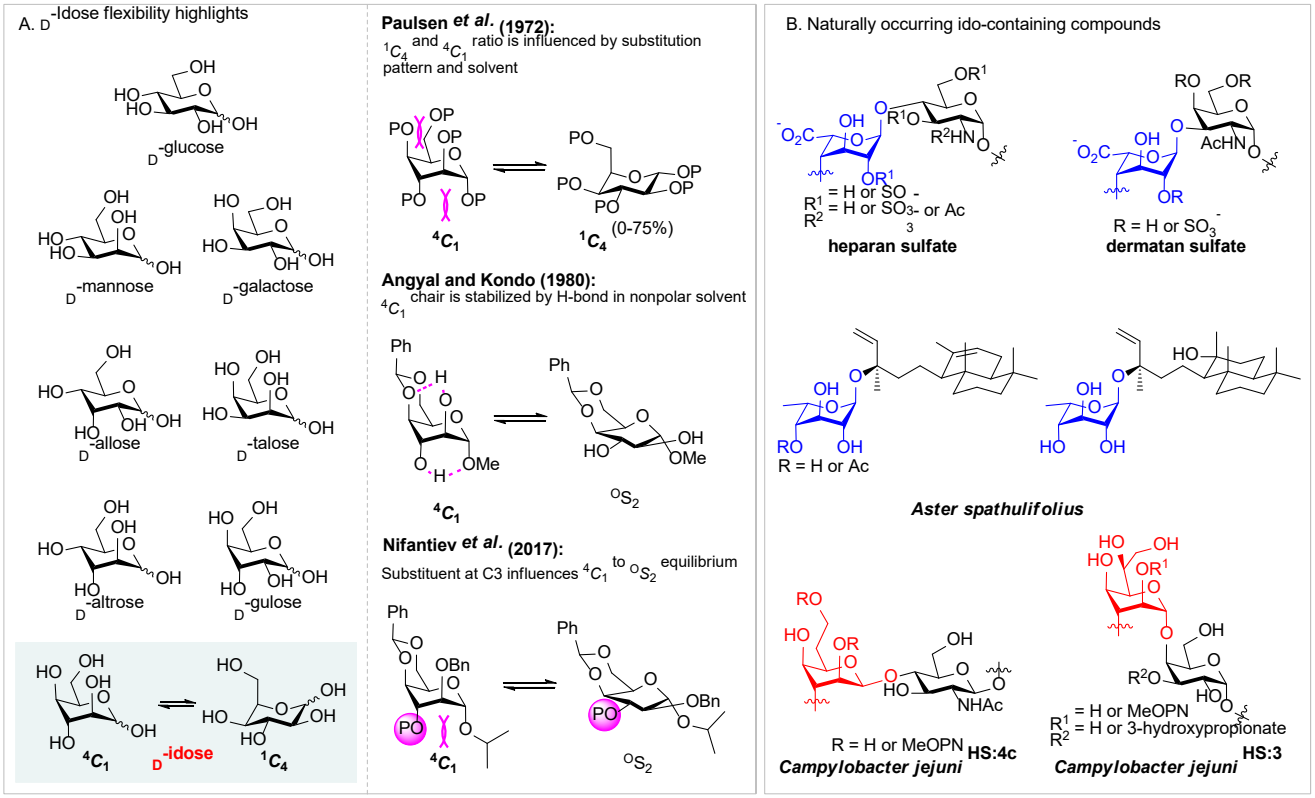


Figure 1. (A) Conformational equilibrium of D-idopyranosides as compared to other D-aldohexoses;[2-5] (B) Examples of naturally occurring glycosides and oligosaccharides containing L- (blue) and D- (red) *ido*-configured sugars.[6-9] P = protecting groups.

These unique conformational properties make *ido*-configured carbohydrates biologically valuable. For instance, L-iduronic acid residues significantly modulate the flexibility of glycosaminoglycans (Fig. 1B), which in turn impacts their ability to interact with biomacromolecules.[6] The biological relevance of idosides is further highlighted by the identification of 6-deoxy-L-idose in labdane-type diterpenes produced by *Aster spathyliofolius*.[9] L-idose was also studied for its inhibitory effect against the growth of *Caenorhabditis elegans*,[10] whereas D-idose was shown to exert an antiproliferative activity against leukemia cell lines.[11] Moreover, L-*glycero*-D-*ido*-heptoses and 6-deoxy-D-*ido*-heptoses are found in the capsular polysaccharide (CPS) of *Campylobacter jejuni* HS:3[12-13] and HS:4c,[14-15] respectively.

Because of the biological importance of *ido*-configured glycosides, along with their unique conformational flexibility, there has been an increased interest in the development of synthetic pathways that would enable access to idose-containing oligosaccharides. More specifically, different research groups have been involved in the preparation of 1,2-*cis*-*β*-linked idopyranosides, as found in *C. jejuni* HS:4c CPS. Preparation of such compounds represents an interesting synthetic challenge: not only does the expensiveness of D-idose implies it must be prepared synthetically (*vide infra*), but access to such 1,2-*cis*-*β*-glycosidic bonds stands as a nontrivial task. To address these challenges, Ling and co-workers optimized an approach based on the C2/C3 inversion of *β*-D-galactosides through the regioselective opening of 2,3-anhydro-*β*-D-talopyranoside intermediates (Fig. 2A).[16-18] Alternatively, Li's group recently reported the preparation of a 6-deoxy-*β*-D-*ido*-heptopyranoside-containing oligosaccharide via the C2 epimerization of a 6-deoxy-*β*-D-*gulo*-heptopyranoside (Fig. 2B).[19] Both approaches thus depended on the formation of a 1,2-*trans*-*β*-glycosidic linkage through neighboring group participation (NGP) of C2 esters, prior to performing the mono (C2) or double (C2/C3) epimerization. *β*-Glycosylation of D-*ido*-configured donors therefore remains an underexplored area of carbohydrate chemistry and an efficient stereoselective method has yet to be disclosed. In this regard, we have been interested to develop a *β*-stereoselective glycosylation method using benzylidene-protected thioidosyl donors. In the course of this work, we have uncovered an unexpected *in situ* epimerization of benzylidene acetals with concomitant $^4C_1$ to $^1C_4$ ring flipping, which is specific to *β*-D-idopyranosides bearing C3 acyl groups (Fig. 2C). We herein report the thorough investigation of this transformation through a glycosylation study combined with NMR experiments and quantum molecular modeling. These experiments have allowed us to identify the reaction conditions and structural requirements needed for the epimerization to occur, thus shedding light on the unusual conformational flexibility of *β*-D-idopyranosides.

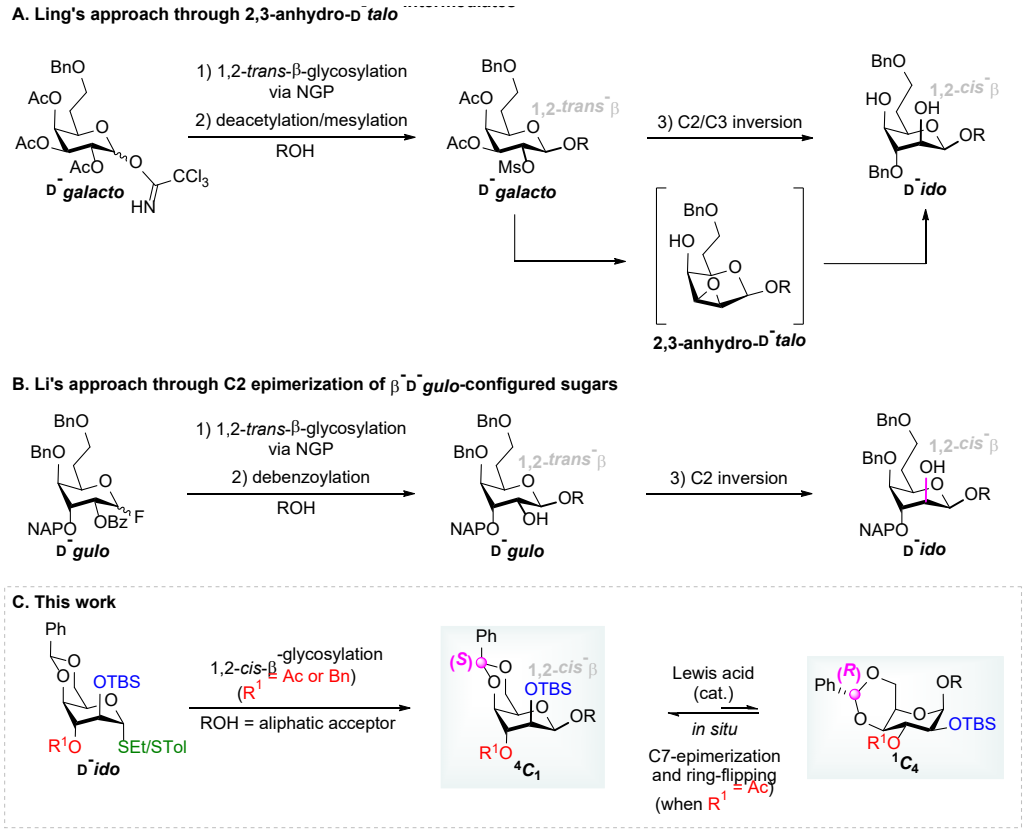


Figure 2. (A) Ling and (B) Li's indirect approaches towards the preparation of 1,2-*cis*-*β*-linked idopyranosides; (C) this work: direct *β*-glycosylation of thioidopyranosyl donors and spontaneous acid-mediated *in situ* C7-epimerization with concomitant chair flip. NGP: neighboring group participation.

RESULTS AND DISCUSSION

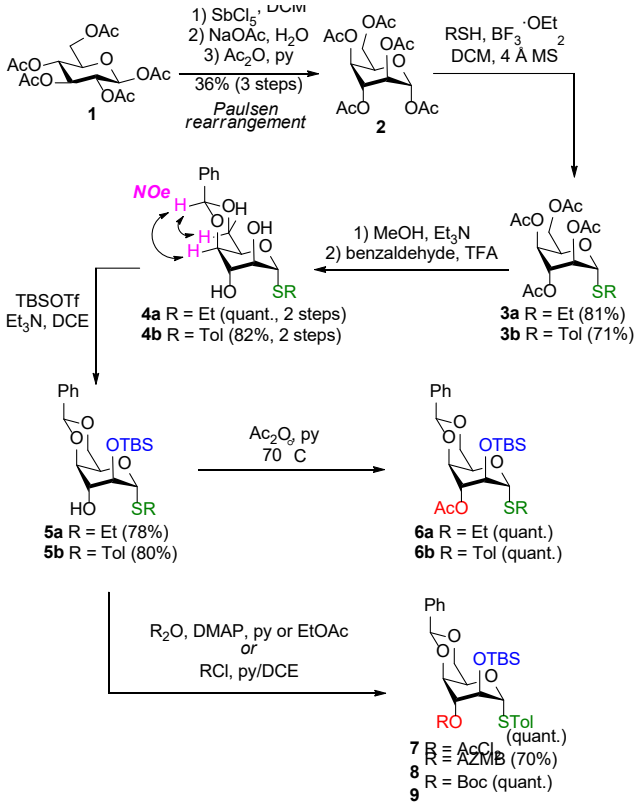
Synthetic Approach. As previously mentioned, whereas the 1,2-*trans* glycosidic linkages can be readily assembled with the help of a participating group at C2, the preparation of 1,2-*cis* bonds is nontrivial. Various synthetic approaches have been developed to circumvent this difficulty, including but not limited to hydrogen bond-mediated aglycon delivery,[20-21] intramolecular aglycon delivery,[22] participation of chiral auxiliaries at C2,[23] and solvent participation.[24] The anchimeric assistance by remote carbonyl groups has also been shown to stand as an exquisite approach to achieve high 1,2-*cis*-stereoselectivity in glycosylation reactions.[25] Of relevance, the potential of axially-oriented C3 carbonyl groups to act as long distance participating groups has been highlighted by the isolation of a 1,3-cyclic carbamate by Wiesner

et al.[26] Similarly, Crich and co-workers demonstrated the remote anchimeric assistance of axial 3-*O*-esters in glycosylation reactions through the trapping of a 1,3-*O*-cyclic carbonate.[27] These results prompted us to hypothesize that 3-O-acylation of benzylidene-protected idosyl donors could enable their *β*-stereoselective glycosylation. Triflates[28] could also be important reactive intermediates in idosylation reactions. In a recent report by Asensio and colleagues,[29] the influence of the orientation of C2 and C3 substituents on the stability of *α*- and *β*-triflates was put forward. Quantum mechanic calculations highlighted that in D-mannosides, axially-oriented substituents at C2 increase the weight of the anomeric effect, thus stabilizing *α*-triflates and consequently reducing their reactivity. In contrast, in the case of D-*allo*-configured sugars, the energy gap between both anomers is diminished due to 1,3-*syn*-diaxial repulsive interactions that destabilize the *α*-triflate, and oppositely noncanonical hydrogen bonding between H-1_{ax} and *O*-3 that stabilizes the *β*-triflate. In D-idosides, the presence of axial substituents at both C2 and C3 implies that all these effects should have an impact on the population of the respective anomers, their reactivity, and their rate of anomerization, which would in turn affect the glycosylation stereoselectivity.

Synthesis of Idopyranosyl Donors. Our first task therefore consisted in the synthesis of orthogonally protected *α*-D-thioidopyranosyl donors. Despite the attractiveness of D-*ido*-configured sugars, limited efforts have been directed towards their synthesis. Dromowicz and Köll reported a two-step protocol involving addition of nitromethane to D-xylose followed by a modified Nef reaction for the synthesis of D-idose.[30] Szekrenyi *et al.* alternatively performed its preparation using biocatalytic conditions.[31] Methods involving the late-stage conversion of functionalized D-galactosides,[16-17] *gluco*-heptonic acid,[32] and more recently *C*-allyl *α*-D-glucosides[19] have additionally been reported. Notwithstanding the success of these approaches, they present some drawbacks such as the need for highly functionalized precursors, large excess of reagents, potentially explosive chemicals, or specialized equipment. As such, these methods show limited synthetic applicability. On the other hand, Paulsen acetoxonium rearrangement provides a

straightforward method for the preparation of α-D-idose pentaacetate **2** from inexpensive peracetylated β-D-glucose **1**[33] through a Lewis acid-mediated C1 to C4 epimerization cascade.[34-35] This three-step approach was successfully employed for the gram-scale synthesis of idoside **2** (Scheme 1) through our optimized protocol. The latter compound was then readily converted into thioidosides **3a** and **3b** under the action of $BF_3 \cdot OEt_2$.

Scheme 1. Synthesis of 3-*O*-Acylated *ido*-Configured Thioglycoside Donors 6–9.

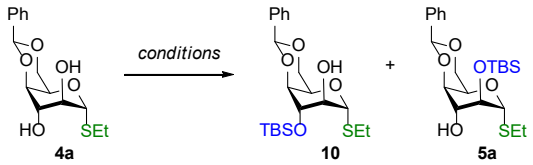


Functionalization of D-*ido*-configured compounds remain a significant challenge because of the presence of three axially-oriented substituents. Furthermore, to the best of our knowledge, methods for the regioselective protection of 1,2-*trans*-diols in carbohydrates are scarce and usually focus on *gluco*-configured compounds.[36] To address this challenge, we first performed the deacetylation of thioidosides **3a** and **3b** followed by their 4,6-O-benzylidenation. The expected (*S*)-stereochemistry[4] of resulting

intermediates **4a** and **4b** was confirmed with the help of NOESY NMR, which highlighted the through-space coupling between the benzylidenic proton and H-6_{axial} and H-4.

We then set out to silylate diol **4a** regioselectively at C2 (Table 1). TBS was chosen as an ideal protecting group because of its enhanced stability compared to other silyl-based groups, its straightforward orthogonal cleavage, and its ability to increase the reactivity of glycosyl donors.[37] We envisioned that, due to the poor nucleophilicity of 3-OH in idosides,[19] silylation would preferentially occur at C2. However, because of the low reactivity of the axial 2-OH, we observed that using TBSCl as a silylating agent was unsuccessful (entries 1-2). Disilylation under the action of TBSOTf and subsequent regioselective monodesilylation using TBAF was also fruitless (entry 3). On the other hand, lowering the number of equivalents of TBSOTf and performing the reaction in DCE allowed isolation of 2-*O*-silylated idoside **5a** in 29% yield (entry 5). Switching from DCE to THF increased the yield of compound **5a**, but significant 3-O-silylation (**10**) nonetheless occurred (entry 6). Using pyridine as base and solvent (entry 7) or a mixture of pyridine and DCE (entry 8) gave similar results while performing the reaction in DCE with 1.5 equivalents of pyridine significantly enhanced the regioselectivity of the reaction (entry 9). Pleasingly, using a combination of TBSOTf and Et_3N in DCE and fine-tuning the number of equivalents (entries 10-12) drastically minimized the 3-O-silylation and enabled isolation of target compound **5a** in a 78% yield (entry 12). On the other hand, lower amounts of TBSOTf and Et_3N (entry 10) led to uncomplete conversion of the starting material, whereas increasing the number of equivalents of both reagents (entry 11) led to significant decomposition. We attributed the latter result to the acidity of the silyl triflate, which could additionally be converted into triflic acid in the presence of moisture in the reaction mixture. The regioselectivity was similar when conducted with thiotolyl **4b**. Finally, an acetyl group was introduced at C3, which could potentially act as a long-distance participating group, thus furnishing orthogonally protected α-D-thioidopyranosides **6a** and **6b**.

Table 1. Optimization of the Regioselective Silylation of Diol 4a.



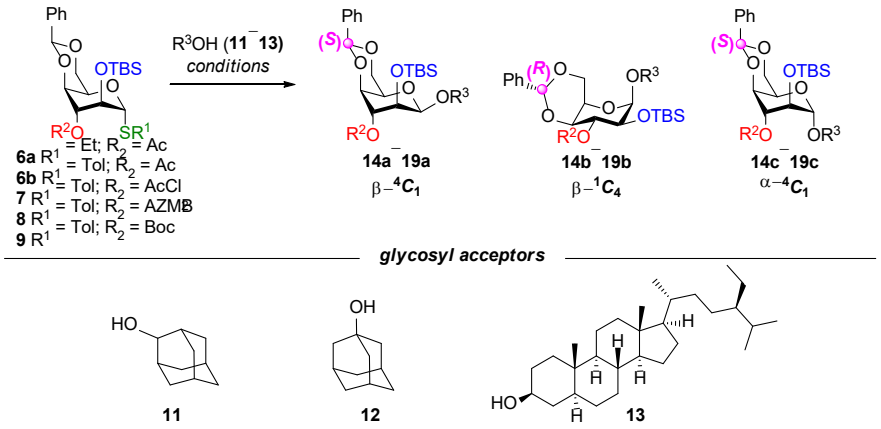
entry	conditions	yield (%)[a]	
		10	5a
1	TBSCl, Im, DMAP, DMF, 60 °C[b]	-	-
2	TBSCl, Im, I_2, DCE, rt	-[c]	-[c]
3	TBSOTf, Et_3N, DCE, 60 °C; then TBAF, THF, 0 °C to rt[b]	-	-
4	TBSOTf, 2,6-lutidine, DMF, 100 °C	-	-
5	TBSOTf (1.0 equiv), 2,6-lutidine (2.4 equiv), DCE, 0 °C to rt	-[c]	22
6	TBSOTf (1.3 equiv), Et_3N (1.5 equiv), THF, 0 °C to rt	29	43
7	TBSOTf (1.3 equiv), py, 0 °C	31	49
8	TBSOTf (1.3 equiv), py/DCE 1:1, 0 °C	28	42
9	TBSOTf (1.3 equiv), py (1.5 equiv), DCE, 0 °C to rt	4	61
10	TBSOTf (1.3 equiv), Et_3N (1.5 equiv), DCE, 0 °C to rt	-[c]	51
11	TBSOTf (2.5 equiv), Et_3N (3.0 equiv), DCE, 0 °C	7	19
12	TBSOTf (1.5 equiv), Et_3N (1.8 equiv), DCE, 0 °C	4	78

[a]Isolated yields; [b]Diol **4a** was recovered; [c]Traces of compounds were detected by TLC.

Glycosylation Study, Characterization, and Molecular Modeling. Having compounds **6a** and **6b** in hand, we then set out to investigate their behavior under glycosylation conditions. As previously mentioned, we hypothesized that the 3-*O*-acetyl group might provide long distance anchimeric assistance, leading to the stereoselective formation of *β*-glycosidic linkages. Simultaneously, destabilization of the plausible *α*-triflate intermediate mediated by 1,3-*syn*-diaxial repulsion could enhance its reactivity towards the acceptors, thus favoring the formation of the *β*-glycosidic linkage. As shown in Table 2, coupling of thioidosyl donor **6a** and 2-adamantanol (**11**) under the promotion of NIS and TMSOTf in DCE was indeed *β*-stereoselective (*β*/*α* 6.6:1.0, entry 1). NMR identification of *β*- and *α*-anomers **14a** and

14c, respectively, was performed on the basis of the small coupling constants between protons H1, H2, H3, and H4, characteristic of their all-axial arrangement, and the $^{1}J_{C1,H1}$ (156 Hz for β, 171 Hz for α).[38] Unexpectedly, a third chromatographically distinct compound (**14b**) was additionally isolated and characterized by a large $^{3}J_{H2,H3}$ (10 Hz) value, which is typical of a D-idoside in the $^{1}C_{4}$ chair conformation. The β-configuration of this compound was revealed through the small coupling constant between H1 and H2 ($^{3}J = 3.7$ Hz) as well as the $^{1}J_{C1,H1}$ (171 Hz), which was distinctive of an equatorially-oriented anomeric proton.[38] HRMS analysis revealed a molecular ion at *m/z* 581.29228 ($[M + Na]^{+}$), correlating with the expected chemical formula $C_{31}H_{46}O_{7}Si$. In addition, as depicted in Scheme 2, both β-glycosides remained distinguishable upon removal of the TBS and acetyl groups while the $^{1}C_{4}$ conformer converted back to the $^{4}C_{1}$ form following benzylidene acetal cleavage.

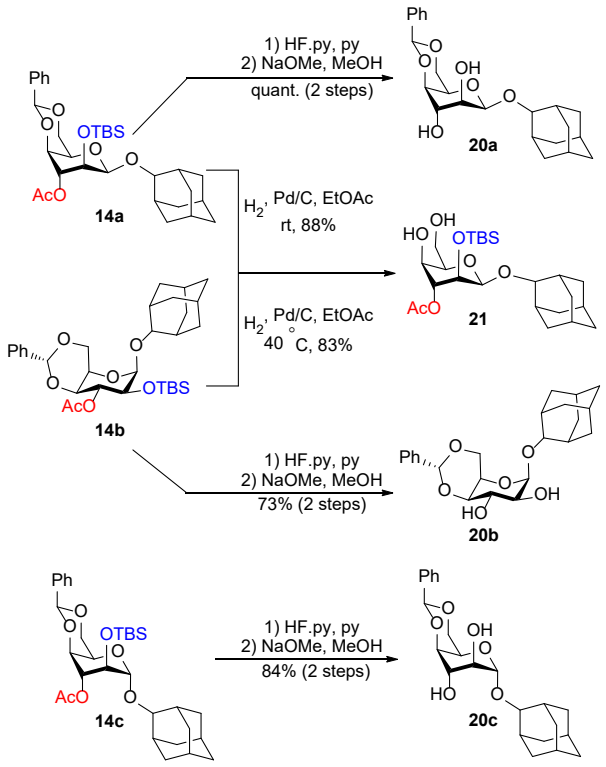
Table 2. Glycosylation Study of *ido*-Configured Thioglycosyl Donors 6−9.



entry	donor	R^3OH	promotor	solvent[a]	T (°C)	NMR ratio			*β*/*α* ratio	NMR conversion (%)	products
						β–$^4C_1$	*β*–$^1C_4$	*α*–$^4C_1$			
1	**6a**	**11**	NIS/TMSOTf	DCE	–10	3.8	2.8	1.0	6.6:1.0	>95	**14a−14c**
2	**6a**	**11**	NIS/TMSOTf	THF	–10	1.0	-	1.5	1.0:1.5	75	**14a−14c**
3	**6a**	**11**	NIS/TMSOTf	Et_2O	–10	6.0	1.0	1.0	7.0:1.0	85	**14a−14c**
4	**6a**	**11**	NIS/TMSOTf	Tol	–10	11.4	4.0	1.0	15.4:1.0	>95	**14a−14c**
5	**6b**	**11**	DMTST	DCE	rt	4.8	1.1	1.0	5.9:1.0	56	**14a−14c**
6	**6b**	**11**	NIS/$Yb(OTf)_3$	DCE	–10	8.0	1.0	2.2	4.1:1.0	>95	**14a−14c**
7	**6b**	**11**	NIS/$AgBF_4$	DCE	–10	4.3	1.0	1.1	4.8:1.0	>95	**14a−14c**
8	**6a**	**11**	$CuBr_2$/Bu_4NBr	DCE	rt	15.7	1.0	11.0	1.5:1.0	62	**14a−14c**
9	**6b**	**12**	NIS/TMSOTf	DCE	–10	12.0	1.0	3.2	4.1:1.0	>95	**15a−15c**
10	**6b**	**13**	NIS/TMSOTf	DCE	–10	5.0	1.0	1.0	6.0:1.0	>95	**16a−16c**
11	**7**	**11**	NIS/TMSOTf	DCE	–10	1.6	1.2	1.0	2.8:1.0	>95	**17a−17c**
12	**8**	**11**	NIS/TMSOTf	DCE	–10	2.5	1.0	1.0	3.5:1.0	>95	**18a−19c**
13	**9**	**11**	NIS/TMSOTf	DCE	–10	4.4	1.0	1.0	5.4:1.0	>95	**19a−19c**

[a]Molar concentration was 0.05 M; donor (1.2 equiv), acceptor (1.0 equiv). DMTST: dimethyl(methylthio)sulfonium trifluoromethanesulfonate.

Scheme 2. Partial Deprotection of Glycosides 14a−14c.



Interestingly, formation of this unanticipated compound occurred systematically, independently of the solvent (entries 1-4), promotor (entries 5-8), and glycosyl acceptor (entries 9-10). Changing the nature of the ester at C3 (**7**−**9**, Scheme 1) also did not significantly affect the outcome of the reaction (entries 11-13). The exception to this observation is when THF was employed as the solvent. Not only was this third unanticipated compound not observed, but the reaction was also slightly α-stereoselective (entry 2; β/α 1.0:1.5). This was not entirely unexpected as ether-based solvents have been shown to participate in glycosylation reactions by equatorially binding transient oxocarbenium intermediates, thus leading to the preferential formation of α-anomers.[24] With the exception of this latter entry, all reactions were performed with some β-stereoselectivity, which could be attributed to the remote participation of the 3-*O*-ester as well as to the formation of transient α-triflate intermediates. 1,3-*Syn*-diaxial repulsion induced by the axially-oriented 3-*O*-ester could increase the reactivity of this triflate towards the studied aliphatic acceptors, preferentially leading to β-glycosides.[29] Another significant observation can be made from the

glycosylation reaction performed in toluene (entry 4): this solvent provided the higher *β*-stereoselectivity (*β*/*α* ratio 15.4:1.0). This could stem from the fact that in nonpolar solvents such as toluene, the destabilization of the oxocarbenium ion is exacerbated, thus favoring S_N2-like reactions involving either the acetoxonium ion or the *α*-triflate.[39] Noteworthy, *n*-butanol was also employed as a highly nucleophilic acceptor for this glycosylation study. Although similar results were achieved with this alcohol, the reaction was poorly reproducible and as such was not included in Table 2. Similarly, glycosylation reactions were attempted using methanol and *para*-methoxybenzyl alcohol as acceptors, but proved unsuccessful due to significant hydrolysis and decomposition of the donor.

Close examination of the 2D spectroscopic data of this third compound (**14b**) revealed strong NOE correlations between the benzylidenic proton and H-3, suggesting an (*R*)-configured benzylidene acetal rather than the initially expected (*S*) configuration. Intrigued by this result, we carried out theoretical calculations to establish its definitive structure, as well as that of *α*- and *β*-glycosides **14a** and **14c**. As such, *in silico* diols **22a** [(*S*)−*β*−$^4C_1$], **(*S*)−22b** [(*S*)−*β*−$^1C_4$], **(*R*)−22b** [(*R*)−*β*−$^1C_4$], and **22c** [(*S*)−*α*−$^4C_1$] bearing a simplified methoxy group at the anomeric position were modeled (Fig. 3A). For each glycoside, a conformational search was performed on Spartan using molecular mechanics (MMFF) and each geometry was optimized on Gaussian using B3LYP/6-31+G(d,p) level of theory. Low abundance conformers were eliminated based on their calculated thermochemical parameters using the Boltzmann equation. ^{1}H and ^{13}C NMR chemical shifts were predicted in chloroform through the calculation of the shielding tensors using the multi-standard approach with the DFT functional mPW1PW91 and basis set 6-311+G(2d,p).[40-41] In parallel, theoretical ^{1}H-^{1}H coupling constants were determined by NMR single-point calculation. Using the previously optimized most abundant geometries, thermochemical parameters were additionally calculated using the higher DFT level of theory B3LYP/6-311++G(2d,2p) to determine their respective abundance, to which theoretical NMR data were correlated. The resulting values were compared with experimentally determined ^{13}C and ^{1}H NMR chemical shifts and coupling constants of

synthetic compounds **20a**−**20c** prepared following cleavage of the TBS and acetyl groups (Scheme 2). Root-mean-square deviation (rmsd) values are reported in Fig. 3A (see Tables S6-S27 for complete data).

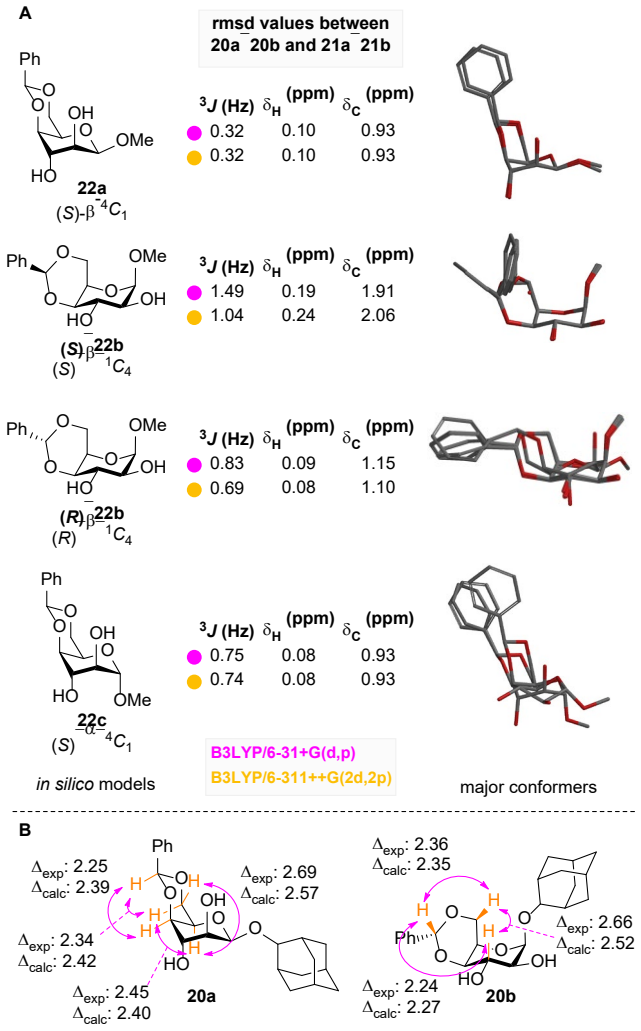


Figure 3. (A) Comparison between theoretical and experimental NMR data; (B) Most relevant NOE correlations and comparison between theoretical and experimental distances.

We found that while theoretical data of *in silico* compounds **22a** and **22c** correlated well with experimental data of corresponding synthetic compounds **20a** and **20c**, respectively, this was not the case for model compound **(*S*)−22b**. Instead, rmsd values were significantly lower for its benzylidenic epimer **(*R*)−22b**, a result that is coherent with our previous observation that strong NOE correlations existed between H3 and the benzylidenic proton. Nonetheless, to further confirm that the third isolated compound indeed consisted in a 4,6-*O*-(*R*)-benzylidene-*β*-D-idopyranoside, relevant interproton distances of synthetic

compound **20b** were measured experimentally by quantitative NOESY using the distance between H14 and H24B (refer to Fig. S1) as a reference and compared to extracted values from the optimized modeled structures **(*S*)−22b** and **(*R*)−22b**. Figure 3B reports the experimental interproton distances of compound **20b** (Δ_{exp}) for the three most significant NOE correlations, *i.e.*, H7/H6b, H7/H3, and H3/H6b, and the corresponding calculated distances of *in silico* model compound **(*R*)−22b**. The quantitative NOESY-derived distance between the benzylidenic proton and H3 (2.24 Å) was an excellent match with the calculated distance for *in silico* model compound **(*R*)−22b** (2.27 Å), as opposed to the one determined for the modeled (*S*)-epimer **(*S*)−22b** (4.06 Å, see Table S17). These results strengthened our hypothesis that following the glycosylation reaction between 3-*O*-acylated 4,6-*O*-benzylidene thioidopyranosyl donors and non-glycosidic acceptors, the third and unexpected compound consists in the benzylidenic C7-(*R*)-epimer. In parallel, the same comparisons were performed between diol **20a** and *in silico* model compound **22a** and we found that experimental interproton distances were in excellent agreement with theoretical values (Fig. 3B). Crystallization of *β*-glycoside **20a** allowed us to obtain an X-ray structure of the compound, which proved the (*S*)-stereochemistry of the benzylidene acetal as well as the $^4C_1$ conformation of the pyranose ring in the solid state (Fig. 4).

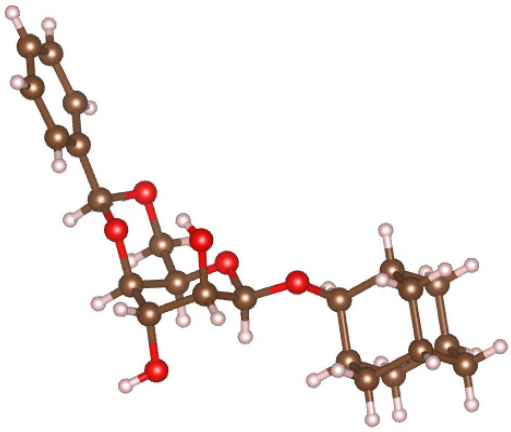
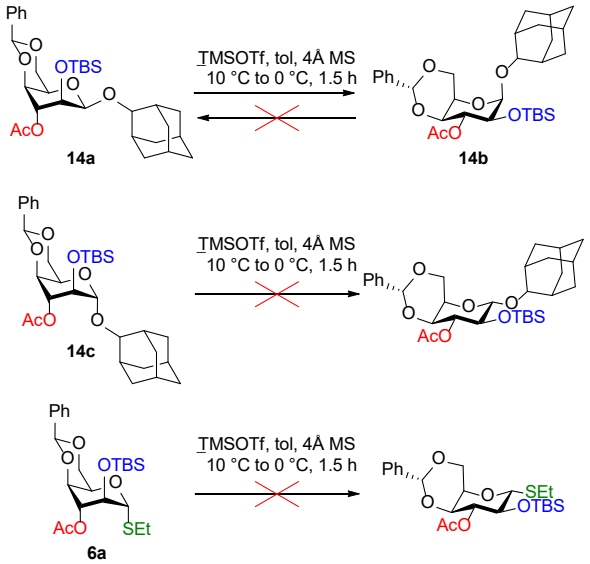


Figure 4. X-ray crystallographic structure of *β*-glycoside **20a**.

Regioselective opening of benzylidene acetals are often performed under the catalysis of Lewis acids such as TMSOTf.[42] On that account, we postulated that formation of the benzylidenic epimer **14b** could occur

post-glycosylation through the acid-catalyzed opening of the benzylidene acetal. Both β- and α-glycosides were therefore subjected to glycosylation conditions (Scheme 3). As expected, we observed that under these conditions, β-glycoside **14a** was transformed into its corresponding C7-epimer **14b** in the $^{1}C_{4}$ conformation (final $^{4}C_{1}/^{1}C_{4}$ NMR ratio 1.0:2.9). On the other hand, when C7-epimer **14b** was subjected to these same conditions, the compound remained stable and no traces of (*S*)-benzylidenated β-glycoside **14a** were detected. Similarly, this ring-flipping/epimerization transformation did not occur when the experiment was performed on α-anomer **14c**. To rule out the possibility that epimerization might occur prior to the glycosylation reaction, the same experiment was performed on α-donor **6a**: apart from slight hydrolysis, no changes were observed, thus suggesting that this transformation indeed takes place post-glycosylation. This result is also coherent with the observation that the ring-flipping/epimerization transformation did not occur when the experiment was performed on α-configured glycoside **14c**. Additional experiments were also performed in which the ring-flipping/epimerization of β-glycoside **14a** was attempted using catalytic and stoichiometric amounts of aliphatic acceptors (*i.e.* MeOH, 2-adamantanol) instead of a Lewis acid. Again, no changes were observed, suggesting that this transformation was catalyzed by the Lewis acid employed for the glycosylation reaction.

Scheme 3. Benzylidene Epimerization Experiments.

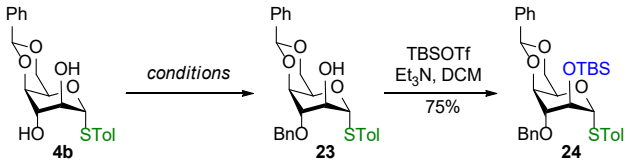


As previously mentioned, D-*ido*-configured compounds are recognized for their low energy barrier between the $^4C_1$ and $^1C_4$ conformation. This flexibility is ascribed to the existence of destabilizing 1,3-*syn*-diaxial interactions, which in the $^4C_1$ conformation are balanced by the equatorial orientation of the large C5 substituent and, in α-D-idosides, by the anomeric effect. We thus propose that the β-configuration of glycoside **14a** significantly decreases the stability of the $^4C_1$ conformer. Subsequently to the glycosylation reaction, the benzylidene acetal could undergo TMSOTf-catalyzed ring opening, leading to a more conformationally labile system. Isomerization into the $^1C_4$ conformation would then be favored because of the anomeric effect. In this thermodynamically favored conformation, ring closing would occur with concomitant (*S*) to (*R*) epimerization of the benzylidenic chiral center as to reduce the steric hindrance caused by the phenyl group. On the other hand, α-glycoside **14c** would not undergo this ring flipping with concomitant epimerization because the $^4C_1$ chair remains the thermodynamically preferred conformer due, in part, to the anomeric effect. Of note, observation of this ring flipping specific to $^4C_1$ β-glycosides is coherent with a recent report from Ling and co-workers who observed that upon reductive opening of a benzylidene-protected β-D-idopyranoside, the resulting compound bearing a 6-hydroxyl group preferentially existed in the $^1C_4$ conformation.[43]

Having highlighted that formation of this benzylidenic epimer occurred independently of the type of ester present at C3 and that it was specific to β-glycosides, we were subsequently interested in the impact of changing the configuration and nature of the substituent at this position. First, we focused our attention on the synthesis of a 3-O-benzylated analogue. Regioselective benzylation of diol **4b** was the main challenge to access this glycosidic donor. As shown in Table 3, standard benzylation conditions (entry 1; BnBr, NaH, DMF) enabled the preparation of target intermediate **23**, albeit in low yield. In contrast, employing silver oxide as a base (entry 2) or attempting benzylation under acidic conditions using benzyl 2,2,2-trichloroacetimidate (BnTCA, entries 3-5) proved unsuccessful. Reductive etherification of the

disilylated derivative of diol **4b** under the conditions reported by Hung *et al.*[44] was also ineffective (entry 6). Finally, we were pleased to find that phase transfer conditions[45] offered excellent regioselectivity and enabled the preparation of 3-O-benzylated idoside **23** in 75% yield (entry 7). 2-O-Silylation under our previously optimized conditions cleanly led to our target donor **24**.

Table 3. Synthesis of 3-O-Benzylated Thioidoside 24 via Regioselective 3-O-Benzylation.



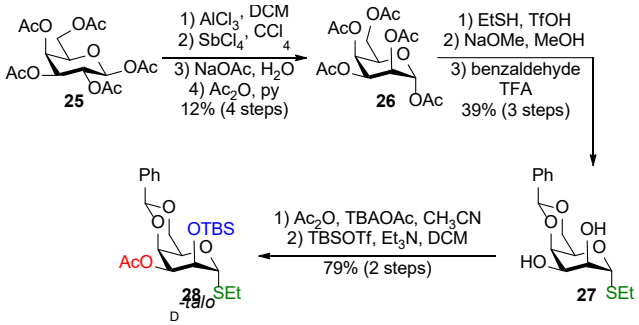
entry	conditions	yield[a] (%)
1	BnBr, NaH, DMF, 0 °C to rt	13
2	BnBr, Ag_2O, Hex/DCE, 4 Å MS, 60 °C	-
3	BnTCA, TMSOTf, DCE, 0 °C to rt	-[b]
4	BnTCA, TfOH, THF, 4 Å MS, rt	-[b]
5	BnTCA, TfOH, Tol/DCE, 4 Å MS	-
6	1) TBSOTf, Et_3N, DCE, 0 °C to rt 2) benzaldehyde, $FeCl_3$, Et_3SiH CH_3CN, 0 °C to rt	-[b]
7	BnBr, NaOH(aq), TBAHS, DCM, 40 °C	75

[a]Isolated yields; [b]Diol **4b** was recovered.

We next tackled the preparation of D-talo derivative **28** bearing an equatorially-oriented acetate at C3 (Scheme 4). We reasoned that inverting this position could affect the formation of the corresponding benzylidenic epimer because destabilizing 1,3-*syn*-diaxial interactions are lessened in this configuration. Once again taking advantage of the Paulsen rearrangement,[35, 46] we were able to prepare peracetylated *α*-D-taloside **26** in four steps from *β*-D-galactose peracetate **25**.[47] We then focused on the thioglycosylation of taloside **26**, which turned out to be surprisingly challenging. Bromination of the latter, as reported by Blanchard *et al.* on the same substrate,[48] proceeded uneventfully but complete decomposition occurred when attempting to introduce the thioethyl moiety under phase transfer conditions.[49] Thioglycosylation under the promotion of TMSOTf or $BF_3{\cdot}OEt_2$ only led to small amounts of the target thioglycoside (<20%). Noteworthy, Bundle and co-workers reported similar difficulties when attempting the

thioglycosylation of taloside **26** using $BF_3 \cdot OEt_2$.[50] Pleasingly, TfOH-mediated thioalkylation under Demchenko's conditions[51] enabled the preparation of our target thiotaloside intermediate, which was subsequently deacetylated and benzylidenated. Acetylation under the catalysis of tetrabutylammonium acetate[52] furnished the expected 3-O-acetylated regioisomer with full selectivity, which was followed by 2-O-silylation to give target D-thiotaloside **28**.

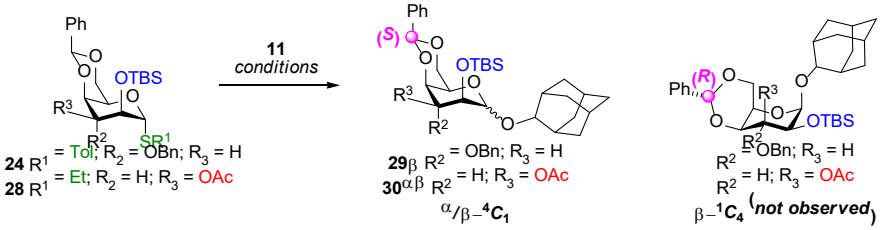
Scheme 4. Synthesis of Thiotaloside 28.



With 3-O-benzylated D-idoside **24** and 3-O-acetylated D-taloside **28** in hand, both compounds were tested in various glycosylation conditions using 2-adamantanol (**11**) as the glycosyl acceptor (Table 4). In the case of the former compound, performing the reaction under the promotion of NIS/AgOTf in DCE led to a mixture of the corresponding *β*-glycoside and its desilylated derivative (entry 1). Switching to toluene (entry 2) or diethyl ether (entry 3) and using TMSOTf as triflate also exclusively furnished *β*-glycoside **29**. Similar results were achieved when using NIS/$AgBF_4$ (entry 4) or dimethyl(methylthio)sulfonium trifluoromethanesulfonate (DMTST) (entry 5) as promotors. Several factors could explain this complete *β*-stereoselectivity. First, it could be attributed to the steric bulkiness of the axial 3-*O*-Bn, shielding the bottom face of the sugar,[53-54] as well as to the potential oxocarbenium ion stabilization by the π-system of this remote aromatic ring, thus favoring the top-face attack of the acceptor.[55] Moreover, if transient triflates intermediates are involved in these glycosylation reactions, the axially-oriented benzyl group at C3 could destabilize the *α*-triflate through 1,3-*syn*-diaxial interaction,[29] thus increasing its reactivity

towards 2-adamantanol. Noteworthy, no traces of the (*R*)-4,6-*O*-benzylidene stereoisomer were detected and no epimerization/chair flip occurred when *β*-glycoside **29** was treated with TMSOTf, highlighting that this transformation did not occur when the 3-*O*-ester is replaced with a benzyl group. Additionally, as expected, no benzylidenic epimer in the $^{1}C_{4}$ conformation was detected when the reaction was carried out with D-talosyl donor **28** (entry 6). This result is coherent with a greater stability of the $^{4}C_{1}$ chair due to the equatorial orientation of the C3 substituent which lessens 1,3-*syn*-diaxial repulsion.

Table 4. Glycosylation Study of *ido*- and *talo*-Configured Thioglycosyl Donors 24 and 28.



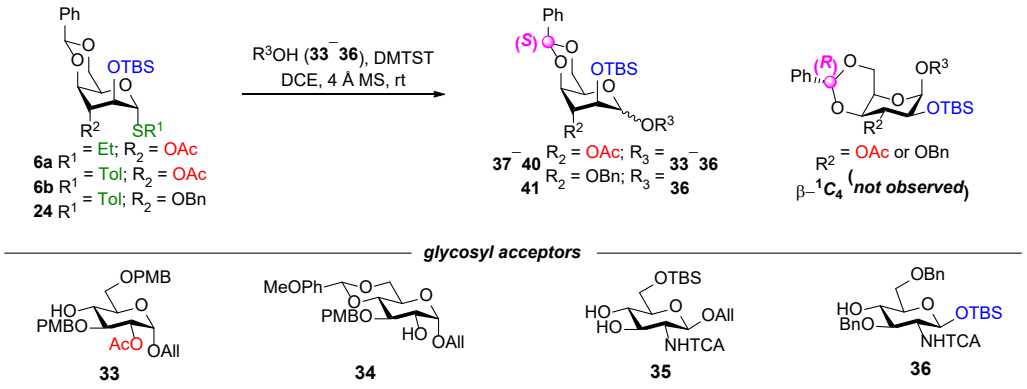
entry	donor	promotor	solvent	T (°C)	isolated ratio			yield
					β–$^{4}C_{1}$	*β*–$^{1}C_{4}$	*α*–$^{4}C_{1}$	(%)[a]
1	**24**	NIS/AgOTf	DCE	–10	1.0	-	-	41[b]
2	**24**	NIS/TMSOTf	Tol	–10	1.0	-	-	39
3	**24**	NIS/TMSOTf	Et_2O	–10	1.0	-	-	51
4	**24**	NIS/$AgBF_4$	DCE	–10	1.0	-	-	57
5	**24**	DMTST	DCE	rt	1.0	-	-	57
6	**28**	NIS/TMSOTf	DCE	–10	1.0	-	8.4	47[c]

[a]Isolated yields; [b]The corresponding desilylated *β*-glycoside (**31**) was also isolated in a 40% yield; [c]The corresponding desilylated *α*-glycoside (**32**) was also isolated in an 18% yield.

Having established a *β*-stereoselective glycosylation method with aliphatic acceptors and uncovered the C7-epimerization of 3-O-acylated *β*-idopyranosides, we were finally interested in the behavior of donors **6a**, **6b**, and **24** when coupled with various glycosidic acceptors (**33**–**36**, Table 5).[56-58] These reactions were performed under the promotion of DMTST, as the latter condition enabled the stereoselective

preparation of β-glycosidic linkages and also led to the formation of the benzylidenic epimer of the corresponding 3-O-acylated β-idosides. Of note, significant decomposition occurred when the following [1 + 1] glycosylations were attempted under the promotion of NIS and TMSOTf, further justifying the use of DMTST.

Table 5. Glycosylation Study of *ido*-Configured Thioglycosyl Donors 6a, 6b, and 24 with Glycosidic Acceptors.



entry	donor	R^3OH	isolated ratio			yield, %[a]
			β–$^4C_1$	β–$^1C_4$	α–$^4C_1$	(products)
1	**6a**	**33**	1.0	-	1.3	37 (**37β**) 51 (**37α**)
2	**6a**	**34**	-	-	1.0	57 (**38**)
3	**6a**	**35**	-	-	(1→4): 1.0 (1→3): 3.8	8 (**39a**) 30 (**39b**)
4	**6b**	**36**	-	-	1.0	29 (**40**)
5	**24**	**36**	1.0	-	7.2	8 (**41β**) 58 (**41α**)

[a]Isolated yields.

As opposed to our previous results with less hindered aliphatic acceptors having a high nucleophilic character, these [1 + 1] glycosylations tended to be α-stereoselective, independently of the nature of the

substituent at C3. Only two instances led to the formation of the target *β*-disaccharides as the minor product (entries 1 and 5), whereas no benzylidenic epimer in the $^{1}C_{4}$ conformation was observed. Because we previously highlighted that this ring-flipping/epimerization transformation was specific to *β*-configured glycosides, it is not surprising that the C7-*(R)*-epimer was not observed in entries 2−4. As for entries 1 and 5, we hypothesize that the presence of esters of amides in the glycoside acceptors could attenuate the promotors acidity and thus prevent the acid-mediated *in situ* epimerization. Additionally, the observed *α*-stereoselectivity is coherent with previous reports on benzylidene-protected pyranosyl donors. If triflates are indeed reactive intermediate in these reactions, the diminished nucleophilic character of these glycosyl acceptors would favor the *α*-glycosylation due to a preferred consumption of the slightly more reactive *β*-triflate.[29, 59] Of note, glycosyl acceptors **33** and **36** that led to the formation of the corresponding *β*-disaccharides are characterized by an enhanced nucleophilic character owing to neighboring alkyl substituents.

In their work on the flexibility of 4,6-*O*-benzylidene idosides, Nifantiev and co-workers estimated that while their reported 3-O-acetylated *β*-D-idopyranosides mainly existed in the $^{4}C_{1}$ conformation in chloroform, the amount of $^{O}S_{2}$ fell between 0% and 19% due to the 1,3-*syn*-diaxial interactions between the substituents at C2 and C4.[5] If *β*-glycoside **14a** adopts such a conformation, even if its population remains small, this would ideally orient the 3-*O*-ester carbonyl to form a chelate with the Lewis acid and the acetal oxygen at C4 (Fig. 5).[60] This would then be followed by opening of the benzylidene ring, $^{4}C_{1}$ to $^{1}C_{4}$ isomerization, and ring closing with concomitant epimerization of the benzylidenic center. This could explain why this transformation does not occur with 3-O-benzylated *β*-glycoside **29**, as the latter does not have the ability to form a chelate with the oxygen at C4. Moreover, as mentioned above, the driving force for this conformational change would be the anomeric effect, explaining why this behavior is specific to *β*-glycosides, which would then adopt their thermodynamically favored $^{1}C_{4}$ conformation.

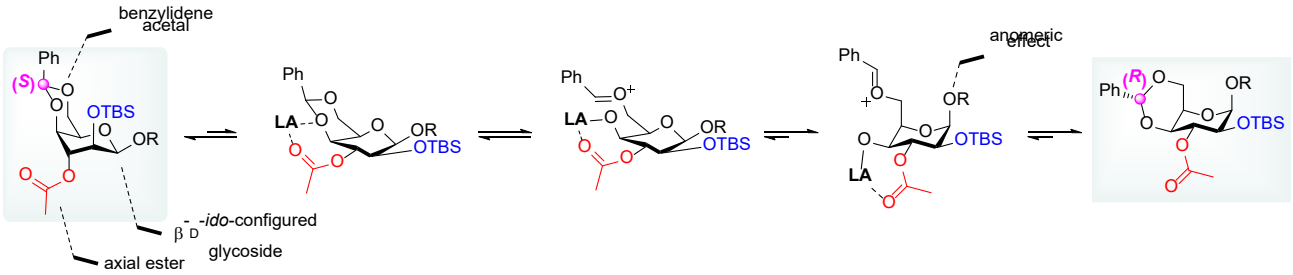


Figure 5. Proposed mechanism for the ring flipping with concomitant benzylidene epimerization.

CONCLUSIONS

In summary, this work presents the glycosylation study of benzylidene-protected thioidosyl donors and describes a unique behavior of *β*-idosides related to their significant flexibility. Access to these thioidosyl donors was accomplished through the development of synthetic approaches enabling the regioselective silylation and benzylation of C2 and C3 hydroxyl groups, respectively. We have highlighted that with glycosyl acceptors having a high nucleophilic character, glycosylation reactions with 3-*O*-acylated 4,6-*O*-benzylidene thioidosyl donors were generally *β*-stereoselective to different extents (*β*/*α* ratio 1.5:1.0 to 15.4:1.0). On the other hand, replacing the 3-*O*-acyl group with a benzyl group led to complete *β*-stereoselectivity, whereas performing these reactions with less nucleophilic glycosidic acceptors favored formation of the *α*-disaccharides. We have uncovered and studied in detail an unusual behavior of *ido*-configured sugars that exemplifies their characteristic flexibility. Through the above-mentioned glycosylation study and with the help of NMR analyses and molecular modeling, we show that post-glycosylation acid-catalyzed benzylidene acetal opening with concomitant ring flipping and C7-epimerization occurs when the following conditions are met: (1) the glycosyl donor is D-*ido*-configured and esterified at C3; (2) the C4 and C6 positions are protected as a benzylidene acetal; (3) the alcohol acceptors are non-glycosidic; and (4) the resulting glycoside is *β*-configured. Our results suggest that the driving force for this transformation is the stabilization of the sugar conformation *via* the anomeric effect that outweighs the presence of axially-oriented substituents. Altogether, our study highlights the unique flexibility of D-idosides and their unusual behavior under glycosylation conditions.

EXPERIMENTAL SECTION

General Methods.

All starting materials and reagents were purchased from commercial sources and used as received without further purification. Air and water sensitive reactions were performed in oven-dried glassware under an Ar atmosphere. Moisture sensitive reagents were introduced *via* a dried syringe. Anhydrous solvents were either prepared from commercial solvents and dried over heat-gun activated 4 Å molecular sieves (MS) or supplied over MS and used as received. Powdered 4 Å MS were activated before use by heating with a heat gun for approx. 15 min under vacuum. Room temperature reactions were performed at 23 °C. Reactions were monitored by thin-layer chromatography (TLC) with silica gel 60 F_{254} 0.25 mm pre-coated aluminum foil plates. Compounds were visualized by using UV_{254} and/or orcinol (1 mg•mL^{-1}) in 10% aqueous H_2SO_4 solution with heating. Normal-phase flash column chromatographies were performed on silica gel 60 Å (15-40 μm). NMR spectra were recorded at 297 K in $CDCl_3$) with a 600 MHz instrument, employing standard softwares given by the manufacturer. ^1H and ^{13}C NMR spectra were referenced to tetramethylsilane (TMS, $\delta_H = \delta_C = 0.00$ ppm) as an internal reference. Assignments were based on ^1H, ^{13}C, COSY, HSQC, undecoupled HSQC, NOESY, and HMBC experiments. NMR spectra of compounds **20a**, **20b** and **20c** were recorded at 298 K with a 500 MHz instruments equipped with a N_2-cooled cryogenic broadband probe. 1D and 2D experiments were recorded using standard pulse program. For the NOESY quantitative experiment, relaxation and mixing time were set to 20 and 0.5 seconds, respectively. Terminal units in disaccharides are designated B, whereas sugars at the non-reducing end are designated A. High-resolution mass spectra (HRMS) were recorded on an ESI-Q-TOF mass spectrometer. Optical rotations $[\alpha]_D^{20}$ were measured on an Anton Paar polarimeter.

1,2,3,4,6-Penta-*O*-acetyl-*α*-D-idopyranose (2).

Compound **2** was synthesized according to our optimized approach. Briefly, *β*-D-glucose pentaacetate **1**[33] (10.0 g, 25.6 mmol, 1.0 equiv) was solubilized in dry DCM (59 mL) under Ar. The solution was cooled to −10 °C and a solution of $SbCl_5$ (4.22 mL, 33.3 mmol, 1.3 equiv) in dry DCM (10 mL) was added dropwise. The solution was brought back to rt and was stirred for 1 h, during which a white precipitate formed. The solvents were removed under inert atmosphere through the cannula filtration technique while maintaining an inert atmosphere. The precipitate was washed once with Et_2O and the solvent was again removed by cannula filtration while maintaining the inert atmosphere. An aqueous solution of NaOAc (156 mL, 2.4 M) was added to the solid and the mixture was stirred at rt for 1 h, after which it was extracted three times with DCM. The combined organic layers were washed with H_2O, a saturated aqueous $NaHCO_3$ solution (2×), and H_2O, then dried over $MgSO_4$, filtered, and evaporated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 3:1 to 1:2) to give a mixture of 4-OH and 6-OH as a colorless oil (3.40 g, 38% in two steps). The latter mixture was solubilized in dry pyridine (21 mL) and cooled to 0 °C. Ac_2O (64 mL) was added, the solution was brought back to rt and was allowed to stir at this temperature for 16 h. The solution was diluted with DCM and ice-cold water was added, followed by the slow addition of a 1 N aqueous HCl solution while stirring. The organic layer was washed again with a 1 N aqueous HCl solution and twice with a saturated aqueous $NaHCO_3$ solution. The organic layers were dried over $MgSO_4$, filtered, evaporated under reduced pressure, and co-evaporated with toluene. The residue was purified by silica gel flash chromatography (Hex/EtOAc 1:0 to 1:1) to give peracetylated *α*-D-idopyranose **2** (3.5 g, 36%, 3 steps) as a white amorphous solid. Physical and analytical data agreed with those published.[35]

Ethyl 2,3,4,6-Tetra-*O*-acetyl-1-thio-*α*-D-idopyranoside (3a).

To a suspension of compound **2** (685 mg, 1.76 mmol, 1.0 equiv), activated 4 Å MS (446 mg) and EtSH (1.3 mL, 17 mmol, 10 equiv) in dry DCM (18 mL) at 0 °C was added dropwise $BF_3.OEt_2$ (0.32 mL, 2.6 mmol, 1.5 equiv). The suspension was stirred at rt for 3.5 h under Ar atmosphere. A saturated aqueous

$NaHCO_3$ solution was added followed by I_2 (until the coloration persisted). A freshly prepared 10% aqueous $Na_2S_2O_3$ solution was added until the coloration disappeared and the aqueous phase was extracted with DCM (3×). The organic layer was then washed with brine, dried over $MgSO_4$, filtered over Celite and concentrated under reduced pressure. The residue was purified by silica gel flash chromatography (Tol/EtOAc 95:5 to 8:2) to give thioglycoside **3a** (556 mg, 81%) as a colorless oil: R_f 0.5 (Tol/EtOAc 6:4); $[\alpha]_D^{20}$ +81 (*c* 0.50, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 5.26 (br s, 1H, H-1), 5.01 (t, J = 3.0 Hz, 1H, H-3), 4.86 (m, 2H, H-2, H-4), 4.77 (td, J = 6.2 Hz, J = 1.7 Hz, 1H, H-5), 4.26−4.19 (m, 2H, H-6a, H-6b), 2.71−2.59 (m, 2H, CH_{2SEt}), 2.14 (s, 3H, CH_{3Ac}), 2.13 (s, 3H, CH_{3Ac}), 2.12 (s, 3H, CH_{3Ac}), 2.07 (s, 3H, CH_{3Ac}), 1.31 (t, J = 7.4 Hz, 3H, CH_{3SEt}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) : δ (ppm) 170.6 (*C*OOR_{Ac}), 169.8 (*C*OOR_{Ac}), 169.4 (*C*OOR_{Ac}), 168.9 (*C*OOR_{Ac}), 82.1 (C-1), 68.6, 66.61, 66.55 (3C, C-2, C-3, C-4), 65.0 (C-5), 62.3 (C-6), 26.4 (*C*H_{2SEt}), 21.0 (*C*H_{3Ac}), 20.9 (*C*H_{3Ac}), 20.84 (*C*H_{3Ac}), 20.80 (*C*H_{3Ac}), 15.0 (*C*H_{3SEt}); HRMS (ESI-TOF) *m/z* $[M + NH_4]^+$ calcd for $C_{16}H_{28}NO_9S$ 410.1479; found 410.1481; *m/z* $[M + Na]^+$ calcd for $C_{16}H_{24}NaO_9S$ 415.1033; found 415.1041.

***para*-Methylphenyl 2,3,4,6-Tetra-*O*-acetyl-1-thio-*α*-D-idopyranoside (3b).**

To a solution of peracetylated idopyranoside **2** (219 mg, 0.560 mmol, 1.0 equiv) in dry DCM (5.6 mL) were added activated 4 Å MS (142 mg) and HSTol (696 mg, 5.60 mmol, 10.0 equiv). The suspension was cooled to 0 °C and BF_3.OEt_2 (104 μL, 0.840 mmol, 1.5 equiv) was added dropwise. The mixture was stirred at rt for 4 h under Ar atmosphere. Then, the reaction was quenched with a saturated aqueous $NaHCO_3$ solution. I_2 was added until the color persisted, followed by a freshly prepared 10% aqueous $Na_2S_2O_3$ solution until the color disappeared. The aqueous layer was extracted with DCM (3×), and the combined organic layers were dried over $MgSO_4$, filtered, and evaporated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 9:1 to 75:25) to give thioglycoside **3b** (180 mg, 71%) as a colorless oil: R_f 0.4 (Hex/EtOAc 1:1); $[\alpha]_D^{20}$ +127 (*c* 2.40, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.42−7.41 (m, 2H, 2 × CH_{STol}), 7.12−7.11 (m, 2H, 2 × CH_{STol}), 5.39 (br s, 1H, H-

1), 5.06−5.05 (m, 1H, H-3), 5.02−5.01 (m, 1H, H-2), 4.93 (ddd, J = 7.3 Hz, J = 5.0 Hz, J = 2.0 Hz, 1H, H-5), 4.90−4.89 (m, 1H, H-4), 4.26 (dd, J = 11.6 Hz, J = 7.6 Hz, 1H, H-6a), 4.22 (dd, J = 11.6 Hz, J = 5.0 Hz, 1H, H-6b), 2.33 (s, 3H, CH_{3STol}), 2.19 (s, 3H, CH_{3Ac}), 2.12 (s, 3H, CH_{3Ac}), 2.09 (s, 3H, CH_{3Ac}), 2.06 (s, 3H, CH_{3Ac}); $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$): δ (ppm) 170.7 (COOR$_{Ac}$), 169.9 (COOR$_{Ac}$), 169.3 (COOR$_{Ac}$), 168.8 (COOR$_{Ac}$), 138.2 (C_{STol}), 132.5 (2C, 2 × CH$_{STol}$), 131.0 (C_{STol}), 129.9 (2C, 2 × CH$_{STol}$), 86.0 (C-1), 68.4 (C-2), 66.5, 66.4 (2C, C-3, C-4), 65.4 (C-5), 62.5 (C-6), 21.3 (CH$_{3STol}$), 20.99 (CH$_{3Ac}$), 20.98 (CH$_{3Ac}$), 20.9 (CH$_{3Ac}$), 20.8 (CH$_{3Ac}$); HRMS (ESI-TOF) m/z $[M + NH_4]^+$ calcd for $C_{21}H_{30}NO_9S$ 472.1636; found 472.1646.

Ethyl 4,6-*O*-Benzylidene-1-thio-*α*-D-idopyranoside (4a).

A neat solution of compound **3a** (50 mg, 0.22 mmol, 1.0 equiv), benzaldehyde (0.73 mL), and TFA (0.04 mL) was stirred at rt for 1 h under Ar atmosphere. The reaction flask was then cooled to 0 °C, slowly quenched with Et_3N, and evaporated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 9:1 to 6:4) to give compound **4a** (69 mg, quant.) as a colorless oil: R_f 0.25 (Hex/EtOAc 6:4); $[\alpha]_D^{20}$ +111 (c 0.960, $CHCl_3$); ^1H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.48−7.46 (m, 2H, 2 × CH_{Ar}), 7.38−7.34 (m, 3H, 3 × CH_{Ar}), 5.51 (s, 1H, CHPh), 5.40 (br s, 1H, H-1), 4.29 (dd, J = 12.6 Hz, 1.3 Hz, 1H, H-6a), 4.23 (br s, 1H, H-5), 4.10 (dd, J = 12.6 Hz, 1.6 Hz, 1H, H-6b), 4.03 (br s, 1H, H-4), 4.00 (br s, 1H, H-3), 3.73 (m, 1H, H-2), 2.70−2.59 (m, 2H, CH_{2SEt}), 1.30 (t, J = 7.4 Hz, 3H, CH_{3SEt}); $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$) : δ (ppm) 137.3 (C_{Ar}), 129.3 (CH$_{Ar}$), 128.4 (2C, 2 × CH$_{Ar}$), 126.0 (2C, 2 × CH$_{Ar}$), 101.5 (CHPh), 84.5 (C-1), 75.7 (C-4), 70.11, 70.06 (2C, C-6, C-2), 68.1 (C-3), 59.4 (C-5), 26.4 (CH$_{2SEt}$), 14.8 (CH$_{3SEt}$); HRMS (ESI-TOF) m/z $[M + H]^+$ calcd for $C_{15}H_{21}O_5S$ 313.1104; found 313.1096; m/z $[M + Na]^+$ calcd for $C_{15}H_{20}NaO_5S$ 335.0924; found 335.0915.

***para*-Methylphenyl 4,6-*O*-Benzylidene-1-thio-*α*-D-idopyranoside (4b).**

Et_3N (434 μL, 3.11 mmol, 8.0 equiv) was added to a solution of compound **3b** (177 mg, 0.389 mmol, 1.0 equiv) in MeOH (3 mL). The mixture was stirred at rt for three days, after which the solvents were co-evaporated with toluene. The crude tetraol (125 mg, 0.437 mmol, 1.0 equiv) was solubilized in benzaldehyde (1.4 mL) and TFA (70 μL) was added to the resulting solution. The mixture was stirred at rt for 1 h, cooled at 0 °C, and quenched with the slow addition of Et_3N. The solvents were co-evaporated with toluene and the residue was purified by silica gel flash chromatography to give diol **4b** (135 mg, 82%) as a white foam: R_f 0.3 (Hex/EtOAc 6:4); $[\alpha]_D^{20}$ +217 (*c* 0.450, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.47−7.46 (m, 2H, 2 × C*H*$_{Ar}$), 7.39−7.35 (m, 5H, 5 × C*H*$_{Ar}$), 7.12−7.10 (m, 2H, 2 × C*H*$_{Ar}$), 5.61 (br s, 1H, H-1), 5.54 (s, 1H, C*H*Ph), 4.39 (br s, 1H, H-5), 4.32 (dd, *J* = 12.6 Hz, *J* = 1.3 Hz, 1H, H-6a), 4.13 (dd, *J* = 12.7 Hz, *J* = 1.5 Hz, 1H, H-6b), 4.11 (br s, 2H, H-2, H-4), 3.90 (br s, 1H, H-3), 3.81 (br s, 1H, O*H*), 2.56 (br s, 1H, O*H*), 2.32 (s, 3H, C*H*$_{3STol}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 137.5−126.1 (12C, 3 × *C*$_{Ar}$, 9 × *C*H$_{Ar}$), 101.7 (*C*HPh), 88.5 (C-1), 75.6 (C-4), 70.4, 70.1 (2C, C-6, C-3), 68.2 (C-2), 60.2 (C-5), 21.2 (*C*H$_{3STol}$); HRMS (ESI-TOF) *m/z* $[M + Na]^+$ calcd for $C_{20}H_{22}NaO_5S$ 397.1080; found 397.1074.

Ethyl 4,6-*O*-Benzylidene-2-*O*-*tert*-butyldimethylsilyl-1-thio-*α*-D-idopyranoside (5a) and Ethyl 4,6-*O*-Benzylidene-3-*O*-*tert*-butyldimethylsilyl-1-thio-*α*-D-idopyranoside (10).

Et_3N (0.76 mL, 5.5 mmol, 1.8 equiv) and TBSOTf (1.1 mL, 4.8 mmol, 1.5 equiv) were sequentially added to a solution of compound **4a** (948 mg, 3.03 mmol, 1.0 equiv) in anhydrous DCM (46 mL) at 0 °C. The solution was stirred at 0 °C for 10 min under Ar atmosphere then quenched with Et_3N and co-evaporated with toluene. The residue was purified by silica gel flash chromatography (Hex/EtOAc 95:5 to 7:3) to give compound **5a** (1014 mg, 78%) as a colorless oil and regioisomer **10** (52 mg, 4%) as a colorless oil.

Data for 2-*O*-silylated 5a: R_f 0.6 (Hex/EtOAc 6:4); $[\alpha]_D^{20}$ +87 (*c* 0.83, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.54−7.53 (m, 2H, 2 × C*H*$_{Ar}$), 7.34−7.32 (m, 3H, 3 × C*H*$_{Ar}$), 5.53 (s, 1H, C*H*Ph), 5.23 (d, *J* = 3.5 Hz, 1H, H-1), 4.28 (d, *J* = 12.6 Hz, 1H, H-6a), 4.16 (dd, *J* = 12.9 Hz, 1.9 Hz, 1H, H-6b),

4.03−4.02 (m, 2H, H-4, H-5), 3.91−3.89 (m, 1H, H-3), 3.64 (dd, *J* = 5.5 Hz, 3.6 Hz, 1H, H-2), 2.71 (dq, *J* = 14.6 Hz, 7.3 Hz, 1H, C*H*HSEt), 2.58 (dq, *J* = 14.9 Hz, 7.5 Hz, 1H, CH*H*SEt), 2.43 (d, *J* = 6.2 Hz, 1H, O*H*-3), 1.31 (t, *J* = 7.4 Hz, 3H, C*H*3SEt), 0.87 (s, 9H, C(C*H*3)3TBS), 0.14 (s, 3H, C*H*3TBS), 0.09 (s, 3H, C*H*3TBS); $^{13}C\{^{1}H\}$ NMR (150 MHz, $CDCl_3$) : δ (ppm) 138.0 (*C*Ar), 129.1 (*C*HAr), 128.2 (2C, 2 × *C*HAr), 126.7 (2C, 2 × *C*HAr), 100.9 (*C*HPh), 85.2 (C-1), 76.4 (C-4), 73.0 (C-3), 72.1 (C-2), 69.7 (C-6), 60.3 (C-5), 25.9 (3C, C(*C*H3)3TBS), 25.3 (*C*H2SEt), 18.3 (*C*(CH3)3TBS), 14.9 (*C*H3SEt), −4.4 (*C*H3TBS), −4.6 (*C*H3TBS); HRMS (ESI-TOF) *m/z* $[M+Na]^+$ calcd for $C_{21}H_{34}NaO_5SSi$ 449.1788; found 449.1800.

Data for 3-*O*-silylated 10: R_f 0.7 (Hex/EtOAc 6:4); $[\alpha]_D^{20}$ +50 (*c* 0.31, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.50−7.48 (m, 2H, 2 × C*H*Ar), 7.38−7.36 (m, 3H, 3 × C*H*Ar), 5.54 (s, 1H, C*H*Ph), 5.33 (br s, 1H, H-1), 4.35 (br s, 1H, H-5), 4.30 (d, *J* = 12.5 Hz, 1H, H-6a), 4.13 (dd, *J* = 12.5 Hz, 1.3 Hz, 1H, H-6b), 3.97 (t, *J* = 2.4 Hz, H-3), 3.85 (d, *J* = 2.6 Hz, 1H, H-4), 3.76 (d, *J* = 12.0 Hz, 1H, O*H*-2), 3.66 (dd, *J* = 11.8 Hz, *J* = 1.1 Hz, 1H, H-2), 2.67−2.58 (m, 2H, C*H*2SEt), 1.30 (t, *J* = 7.4 Hz, 3H, C*H*3SEt), 0.95 (s, 9H, C(C*H*3)3TBS), 0.14 (s, 3H, C*H*3TBS), 0.13 (s, 3H, C*H*3TBS); $^{13}C\{^{1}H\}$ NMR (150 MHz, $CDCl_3$) : δ (ppm) 137.5 (*C*Ar), 129.4 (*C*HAr), 128.5 (2C, 2 × *C*HAr), 126.2 (2C, 2 × *C*HAr), 101.7 (*C*HPh), 86.2 (C-1), 76.6 (C-4), 71.1 (C-2), 70.6 (C-6), 68.4 (C-3), 59.6 (C-5), 27.4 (*C*H2SEt), 25.9 (3C, C(*C*H3)3TBS), 18.2 (*C*(CH3)3TBS), 15.3 (*C*H3SEt), −4.7 (*C*H3TBS), −5.0 (*C*H3TBS). HRMS (ESI-TOF) *m/z* $[M+NH_4]^+$ calcd for $C_{21}H_{38}NO_5SSi$ 444.2234; found 444.2253.

***para*-Methylphenyl 4,6-*O*-Benzylidene-2-*O*-*tert*-butyldimethylsilyl-1-thio-*α*-D-idopyranoside (5b).**

To a solution of diol **4b** (310 mg, 0.823 mmol, 1.0 equiv) in dry DCE (12.4 mL) at 0 °C was successively added Et_3N (208 μL, 1.49 mmol, 1.8 equiv) and TBSOTf (288 μL, 1.25 mmol, 1.5 equiv) dropwise. The solution was stirred at 0 °C for 10 min, quenched with Et_3N, and concentrated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 95:5 to 7:3) to give compound **5b** as a white amorphous solid (323 mg, 80%): R_f 0.55 (Hex/EtOAc 6:4); $[\alpha]_D^{20}$ +76 (*c* 0.42, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.53−7.51 (m, 2H, 2 × C*H*Ar), 7.40−7.39 (m, 2H, 2 × C*H*STol),

7.34−7.32 (m, 3H, 3 × C*H*$_{Ar}$), 7.11−7.10 (m, 2H, 2 × C*H*$_{STol}$), 5.53 (s, 1H, C*H*Ph), 5.37 (d, *J* = 4.1 Hz, 1H, H-1), 4.28 (dd, *J* = 12.8 Hz, *J* = 0.9 Hz, 1H, H-6a), 4.17 (dd, *J* = 12.8 Hz, *J* = 2.5 Hz, 1H, H-6b), 4.13 (br s, 1H, H-5), 4.07 (dd, *J* = 3.3 Hz, *J* = 2.3 Hz, 1H, H-4), 3.95 (br s, 1H, H-3), 3.78 (dd, *J* = 6.1 Hz, *J* = 4.2 Hz, 1H, H-2), 2.32 (s, 3H, C*H*$_{3STol}$), 2.30 (s, 1H, O*H*-3), 0.87 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.16 (s, 3H, C*H*$_{3TBS}$), 0.11 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): *δ* (ppm) 138.0−126.6 (12C, 3 × *C*$_{Ar}$, 9 × *C*H$_{Ar}$), 100.8 (*C*HPh), 89.7 (C-1), 76.7 (C-4), 73.4 (C-3), 72.4 (C-2), 69.5 (C-6), 61.3 (C-5), 26.0 (3C, C(*C*H$_3$)$_{3TBS}$), 21.2 (*C*H$_{3STol}$), 18.3 (*C*(CH$_3$)$_{3TBS}$), −4.2 (*C*H$_{3TBS}$), −4.5 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH_4]$^+$ calcd for $C_{26}H_{40}NO_5SSi$ 506.2391; found 506.2405.

Ethyl 3-*O*-Acetyl-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-1-thio-*α*-D-idopyranoside (6a).

To a solution of alcohol **5a** (525 mg, 1.23 mmol, 1.0 equiv) in dry pyridine (17 mL) was added Ac_2O (17 mL). The solution was heated at 70 °C with an oil bath and stirred at this temperature for 16 h under Ar atmosphere. The solvents were co-evaporated with toluene and the residue was purified by silica gel flash chromatography (Hex/EtOAc 9:1 to 8:2) to give compound **6a** (562 mg, quant.) as a white amorphous solid: *R*$_f$ 0.45 (Hex/EtOAc 7:3); [*α*]$_D^{20}$ +128 (*c* 0.800, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : *δ* (ppm) 7.54−7.53 (m, 2H, 2 × C*H*$_{Ar}$), 7.33−7.31 (m, 3H, 3 × C*H*$_{Ar}$), 5.51 (s, 1H, C*H*Ph), 5.30 (s, 1H, H-1), 4.89 (t, *J* = 2.3 Hz, 1H, H-3), 4.31 (dd, *J* = 12.6 Hz, *J* = 1.2 Hz, 1H, H-6a), 4.20 (m, 1H, H-5), 4.14 (dd, *J* = 12.6 Hz, *J* = 2.0 Hz, 1H, H-6b), 3.92 (t, *J* = 2.1 Hz, 1H, H-4), 3.78−3.77 (m, 1H, H-2), 2.69 (dq, *J* = 13.2 Hz, *J* = 7.4 Hz, 1H, C*H*H$_{SEt}$), 2.60 (dq, *J* = 13.1 Hz, *J* = 7.4 Hz, 1H, CH*H*$_{SEt}$), 2.12 (s, 3H, C*H*$_{3Ac}$), 1.30 (t, *J* = 7.4 Hz, 3H, C*H*$_{3SEt}$), 0.85 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.11 (s, 3H, C*H*$_{3TBS}$), 0.08 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) : *δ* (ppm) 169.4 (*C*OOR$_{Ac}$), 138.0 (*C*$_{Ar}$), 129.0 (*C*H$_{Ar}$), 128.0 (2C, 2 × *C*H$_{Ar}$), 126.8 (2C, 2 × *C*H$_{Ar}$), 101.5 (*C*HPh), 86.0 (C-1), 72.8 (C-4), 70.8 (C-3), 69.9 (C-6), 68.6 (C-2), 59.8 (C-5), 26.3 (*C*H$_{2SEt}$), 25.8 (3C, C(*C*H$_3$)$_{3TBS}$), 21.2 (*C*H$_{3Ac}$), 18.1 (*C*(CH$_3$)$_{3TBS}$), 15.2 (*C*H$_{3SEt}$), −4.75 (*C*H$_{3TBS}$), −4.84 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH_4]$^+$ calcd for $C_{23}H_{40}NO_6SSi$ 486.2340; found 486.2362.

***para*-Methylphenyl 3-*O*-Acetyl-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-1-thio-*α*-D-idopyranoside (6b).**

To a solution of alcohol **5b** (38 mg, 0.078 mmol, 1.0 equiv) in dry pyridine (1.1 mL) was added Ac_2O (1.1 mL). The solution was heated at 70 °C with an oil bath and stirred at this temperature for 16 h under an Ar atmosphere. The solvents were co-evaporated with toluene and the residue was purified by silica gel flash chromatography (Hex/EtOAc 9:1) to give compound **6b** (41 mg, quant.) as a colorless oil: R_f 0.48 (Hex/EtOAc 7:3); $[\alpha]_D^{20}$ +99 (*c* 0.87, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.54−7.52 (m, 2H, 2 × C*H*$_{Ar}$), 7.39−7.38 (m, 2H, 2 × C*H*$_{Ar}$), 7.32−7.31 (m, 3H, 3 × C*H*$_{Ar}$), 7.12−7.10 (m, 2H, 2 × C*H*$_{Ar}$), 5.52 (s, 1H, C*H*Ph), 5.50 (br s, 1H, H-1), 4.94 (t, *J* = 2.5 Hz, 1H, H-3), 4.35−4.33 (m, 2H, H-6a, H-5), 4.16 (dd, *J* = 12.9 Hz, *J* = 2.2 Hz, 1H, H-6b), 3.97 (br s, 1H, H-4), 3.95 (t, *J* = 1.3 Hz, 1H, H-2), 2.32 (s, 3H, C*H*$_{3STol}$), 2.19 (s, 3H, C*H*$_{3Ac}$), 0.83 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.10 (s, 3H, C*H*$_{3TBS}$), 0.09 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H}c NMR (150 MHz, $CDCl_3$): δ (ppm) 169.4 (*C*OOR$_{Ac}$), 137.9−126.8 (12C, 3 × *C*$_{Ar}$, 9 × *C*H$_{Ar}$), 101.5 (*C*HPh), 89.6 (C-1), 72.7 (C-4), 70.6 (C-3), 69.8 (C-6), 68.7 (C-2), 60.4 (C-5), 25.8 (3C, C(*C*H$_3$)$_{3TBS}$), 21.3, 21.2 (2C, *C*H$_{3STol}$, *C*H$_{3Ac}$), 18.1 (*C*(CH$_3$)$_{3TBS}$), −4.7 (*C*H$_{3TBS}$), −4.8 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* $[M + NH_4]^+$ calcd for $C_{28}H_{42}NO_6SSi$ 548.2497; found 548.2508.

***para*-Methylphenyl 4,6-*O*-Benzylidene-2-*O*-*tert*-butyldimethylsilyl-3-*O*-dichloroacetyl-1-thio-*α*-D-idopyranoside (7).**

To a solution of alcohol **5b** (30 mg, 0.061 mmol, 1.0 equiv) in dry DCE (0.6 mL) at 0 °C was added dry pyridine (30 μL, 0.37 mmol, 6.0 equiv) followed by a solution of dichloroacetyl chloride (18 μL, 0.18 mmol, 3.0 equiv) in dry DCE (0.25 mL). The reaction mixture was stirred at 0 °C for 1 h, then co-evaporated with toluene. The residue was purified by silica gel flash chromatography (Hex/EtOAc 95:5 to 85:15) to give compound **7** (37 mg, quant.) as a colorless oil: R_f 0.44 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ +83 (*c* 1.3, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.53−7.51 (m, 2H, 2 × C*H*$_{Ar}$), 7.39−7.37 (m, 2H, 2 × C*H*$_{Ar}$), 7.33−7.31 (m, 3H, 3 × C*H*$_{Ar}$), 7.12−7.11 (m, 2H, 2 × C*H*$_{Ar}$), 6.07 (s, 1H, C*H*Cl$_2$), 5.55 (s, 1H,

C*H*Ph), 5.51 (br s, 1H, H-1), 5.02 (t, *J* = 2.2 Hz, 1H, H-3), 4.35−4.33 (m, 2H, H-5, H-6a), 4.18 (dd, *J* = 13.0 Hz, *J* = 2.1 Hz, 1H, H-6b), 4.04 (br s, 1H, H-4), 3.98 (br s, 1H, H-2), 2.33 (s, 3H, CH_{3STol}), 0.83 (s, 9H, C(CH_3)$_{3TBS}$), 0.11 (s, 3H, CH_{3TBS}), 0.09 (s, 3H, CH_{3TBS}); $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$): δ (ppm) 163.3 (*C*OOR$_{AcCl2}$), 137.7−126.7 (12C, 3 × *C*$_{Ar}$, 9 × *C*H$_{Ar}$), 101.5 (*C*HPh), 89.3 (C-1), 73.7 (C-3), 72.0 (C-4), 69.7 (C-6), 68.3 (C-2), 64.2 (*C*HCl_2), 60.2 (C-5), 25.8 (3C, C(*C*H$_3$)$_{3TBS}$), 21.2 (*C*H$_{3STol}$), 18.1 (*C*(CH$_3$)$_{3TBS}$), −4.8 (2C, 2 x *C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* $[M+NH_4]^+$ calcd for $C_{28}H_{40}Cl_2NO_6SSi$ 616.1717; found 616.1735.

***para*-Methylphenyl 3-*O*-(2-Azidomethyl)benzoyl-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-1-thio-*α*-D-idopyranoside (8).**

To a solution of alcohol **5b** (15 mg, 0.031 mmol, 1.0 equiv) and DMAP (9 mg, 0.08 mmol, 2.5 equiv) in dry pyridine (107 μL) was added a solution of AZMB$_2$O (39 mg, 0.12 mmol, 3.8 equiv) in dry pyridine (61 μL). The mixture was heated at 50 °C with an oil bath and stirred at this temperature for 24 h under Ar, after which it was co-evaporated with toluene. The residue was purified by silica gel flash chromatography (Tol/Hex 95:5) to give ester **8** (14 mg, 70%) as a colorless oil: R_f 0.4 (Hex/EtOac 8:2); $[\alpha]_D^{20}$ +70 (*c* 0.31, $CHCl_3$); ^1H NMR (600 MHz, $CDCl_3$): δ (ppm) 8.36−8.34 (m, 1H, C*H*$_{AZMB}$), 7.63−7.61 (m, 1H, C*H*$_{AZMB}$), 7.56−7.55 (m, 3H, 3 × C*H*$_{Ar}$), 7.50−7.47 (m, 1H, C*H*$_{AZMB}$), 7.41−7.40 (m, 2H, 2 × C*H*$_{STol}$), 7.33−7.32 (m, 3H, 3 × C*H*$_{Ar}$), 7.12−7.11 (m, 2H, 2 × C*H*$_{STol}$), 5.58 (br s, 1H, H-1), 5.56 (s, 1H, C*H*Ph), 5.22 (br s, 1H, H-3), 4.93 (d, *J* = 14.7 Hz, 1H, C*H*H$_{AZMB}$), 4.90 (d, *J* = 14.7 Hz, 1H, CH*H*$_{AZMB}$), 4.44 (br d, *J* = 1.0 Hz, 1H, H-5), 4.37 (d, *J* = 12.7 Hz, 1H, H-6a), 4.19 (dd, *J* = 12.7 Hz, *J* = 1.8 Hz, 1H, H-6b), 4.10 (br s, 1H, H-4), 4.07 (m, 1H, H-2), 2.33 (s, 3H, C*H*$_{3STol}$), 0.85 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.12 (s, 6H, 2 × C*H*$_{3TBS}$); $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$): δ (ppm) 164.7 (*C*OOR$_{AZMB}$), 138.4−126.8 (18C, 5 × *C*$_{Ar}$, 13 × *C*H$_{Ar}$), 101.6 (*C*HPh), 89.5 (C-1), 72.4 (C-4), 70.9 (C-3), 69.8 (C-6), 68.9 (C-2), 60.5 (C-5), 53.3 (*C*H$_{2AZMB}$), 25.8 (3C, C(*C*H$_3$)$_{3TBS}$), 21.2 (*C*H$_{3STol}$), 18.1 (*C*(CH$_3$)$_{3TBS}$), −4.7 (*C*H$_{3TBS}$), −4.8 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* $[M+NH_4]^+$ calcd for $C_{34}H_{45}N_4O_6SSi$ 665.2824; found 665.2835.

***para*-Methylphenyl 4,6-*O*-Benzylidene-2-*O*-*tert*-butyldimethylsilyl-3-*O*-*tert*-butoxycarbonyl-1-thio-*α*-D-idopyranoside (9).**

To a solution of alcohol **5b** (44 mg, 0.089 mmol, 1.0 equiv) in dry DCE (1.3 mL) were sequentially added Boc_2O (78 mg, 0.36 mmol, 4.0 equiv), Et_3N (16 μL, 0.12 mmol, 1.3 equiv), and DMAP (1 mg, 0.009 mmol, 0.1 equiv). The mixture was stirred at rt for 40 h, after which it was diluted with EtOAc and washed with a saturated aqueous $NaHCO_3$ solution and brine. The organic layers were dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 9:1) to give compound **9** (53 mg, quant.) as a colorless oil: R_f 0.47 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ +89 (*c* 0.27, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.53−7.51 (m, 2H, 2 × CH_{Ar}), 7.40−7.39 (m, 2H, 2 × CH_{Ar}), 7.32−7.31 (m, 3H, 3 × CH_{Ar}), 7.11−7.09 (m, 2H, 2 × CH_{Ar}), 5.53 (s, 1H, C*H*Ph), 5.48 (br s, 1H, H-1), 4.76 (t, *J* = 2.8 Hz, 1H, H-3), 4.32−4.30 (m, 2H, H-5, H-6a), 4.14 (dd, *J* = 12.9 Hz, *J* = 2.3 Hz, 1H, H-6b), 4.06 (br s, 1H, H-4), 4.00 (t, *J* = 2.6 Hz, 1H, H-2), 2.32 (s, 3H, CH_{3STol}), 1.53 (s, 9H, C(CH_3)$_{3Boc}$), 0.84 (s, 9H, C(CH_3)$_{3TBS}$), 0.12 (s, 3H, CH_{3TBS}), 0.10 (s, 3H, CH_{3TBS}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 152.3 (*C*OOR$_{Boc}$), 138.0−126.7 (12C, 3 × *C*$_{Ar}$, 9 × *C*H$_{Ar}$), 101.3 (*C*HPh), 89.5 (C-1), 83.2 (*C*(CH$_3$)$_{3Boc}$), 73.8 (C-3), 73.2 (C-4), 69.7 (C-6), 68.9 (C-2), 60.7 (C-5), 27.9 (3C, C(*C*H$_3$)$_{3Boc}$), 25.9 (3C, C(*C*H$_3$)$_{3TBS}$), 21.2 (*C*H$_{3STol}$), 18.1 (*C*(CH$_3$)$_{3TBS}$), −4.6 (*C*H$_{3TBS}$), −4.7 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{31}H_{48}NO_7SSi$ 606.2915; found 606.2932.

General Procedure for the NIS/TMSOTf-promoted Glycosylation.

The donor (1.2 equiv), acceptor (1.0 equiv), and NIS (1.5 equiv) were dried together under vacuum for 1 h. Then, activated 4 Å MS (4 mg/mg of donor) and dry solvent (20 mL·mmol^{-1}) were added, and the suspension was stirred at rt under Ar atmosphere for 1 h. The suspension was cooled at –10 °C and TMSOTf (0.1 equiv) was added. The mixture was stirred under Ar while being allowed to gradually warm

to 0 °C for a period of 30 min to 1 h. The reaction was then quenched with Et_3N, filtered over Celite, and concentrated under reduced pressure. The residue was purified by silica gel flash chromatography.

(2-Adamantyl) 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*β*-D-idopyranoside (14a), **(2-Adamantyl) 3-*O*-Acetyl-(*R*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*β*-D-idopyranoside (14b) and (2-Adamantyl) 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*α*-D-idopyranoside (14c).**

Donor **6a** (14.8 mg, 0.0315 mmol, 1.2 equiv) and 2-adamantanol (4.0 mg, 0.026 mmol, 1.0 equiv) were reacted according to the general procedure for NIS/TMSOTf-promoted glycosylation. Purification by silica gel flash chromatography (Hex/EtOAc 95:5 to 85:15) gave compounds **14a** (3.6 mg, 25%, colorless oil), **14b** (6.7 mg, 46%, white amorphous solid), and **14c** (0.8 mg, 5%, colorless oil).

Data for *β*-glycoside 14a: R_f 0.3 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ −27 (*c* 0.60, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.55−7.53 (m, 2H, 2 × C*H*$_{Ar}$), 7.31−7.30 (m, 3H, 3 × C*H*$_{Ar}$), 5.46 (s, 1H, C*H*Ph), 5.05 (t, *J* = 2.5 Hz, 1H, H-3), 4.68 (d, *J* = 1.1 Hz, 1H, H-1), 4.36 (d, *J* = 12.5 Hz, 1H, H-6a), 4.06 (dd, *J* = 12.5 Hz, 2.1 Hz, 1H, H-6b), 3.96 (t, *J* = 2.9 Hz, 1H, H-2$_{ad}$), 3.81 (br s, 1H, H-4), 3.66 (d, *J* = 2.8 Hz, 1H, H-2), 3.58 (m, 1H, H-5), 2.21−1.43 (m, 14H, 4 × C*H*$_{ad}$, 5 × C*H*$_{2ad}$), 2.11 (s, 3H, C*H*$_{3Ac}$), 0.85 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.14 (s, 3H, C*H*$_{3TBS}$), 0.10 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 169.2 (*C*OOR$_{Ac}$), 138.0 (*C*$_{Ar}$), 128.9 (*C*H$_{Ar}$), 127.9 (2C, 2 × *C*H$_{Ar}$), 126.9 (2C, 2 × *C*H$_{Ar}$), 101.6 (*C*HPh), 96.8 (C-1, $^1J_{C1,H1}$ = 156 Hz), 79.7 (C-2$_{ad}$), 73.6 (C-3), 73.0 (C-4), 69.8 (C-6), 68.3 (C-2), 67.1 (C-5), 37.8−27.6 (9C, 4 × *C*H$_{ad}$, 5 × *C*H$_{2ad}$), 25.9 (3C, C(*C*H$_3$)$_{3TBS}$), 21.3 (*C*H$_{3Ac}$), 18.5 (*C*(CH$_3$)$_{3TBS}$), −4.4 (*C*H$_{3TBS}$), −5.1 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* $[M + NH_4]^+$ calcd for $C_{31}H_{50}NO_7Si$ 576.3351; found 576.3363; *m/z* $[M + Na]^+$ calcd for $C_{31}H_{46}NaO_7Si$ 581.2905; found 581.2918.

Data for *β*-glycoside 14b: R_f 0.53 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ −38 (*c* 0.28, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.45−7.44 (m, 2H, 2 × C*H*$_{Ar}$), 7.35−7.31 (m, 3H, 3 × C*H*$_{Ar}$), 6.01 (t, *J* = 10.1 Hz, 1H, H-3), 5.91 (s, 1H, C*H*Ph), 4.86 (d, *J* = 3.7 Hz, 1H, H-1), 4.59 (t, *J* = 11.3 Hz, 1H, H-6a), 4.34 (dt, *J* = 11.8

Hz, J = 5.9 Hz, 1H, H-5), 4.14−4.09 (m, 2H, H-6b, H-4), 3.78 (t, J = 3.0 Hz, 1H, H-2$_{ad}$), 3.76 (dd, J = 9.8 Hz, J = 3.7 Hz, 1H, H-2), 2.20−1.42 (m, 14H, 4 × CH_{ad}, 5 × CH_{2ad}), 2.10 (s, 3H, CH_{3Ac}), 0.89 (s, 9H, C(CH_3)$_{3TBS}$), 0.11 (s, 3H, CH_{3TBS}), 0.07 (s, 3H, CH_{3TBS}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 170.6 (COOR$_{Ac}$), 137.8 (C_{Ar}), 129.0 (CH$_{Ar}$), 128.4 (2C, 2 × CH$_{Ar}$), 126.4 (2C, 2 × CH$_{Ar}$), 97.5 (C-1, $^1J_{C1,H1}$ = 171 Hz), 96.3 (CHPh), 80.4 (C-2$_{ad}$), 75.2 (C-4), 71.4 (C-2), 68.2 (C-6), 67.4 (C-5), 66.7 (C-3), 37.5−27.4 (9C, 4 × CH$_{ad}$, 5 × CH$_{2ad}$), 25.8 (3C, C(CH$_3$)$_{3TBS}$), 21.4 (CH$_{3Ac}$), 18.2 (C(CH$_3$)$_{3TBS}$), −4.0 (CH$_{3TBS}$), −4.8 (CH$_{3TBS}$); HRMS (ESI-TOF) m/z [M + NH$_4$]$^+$ calcd for $C_{31}H_{50}NO_7Si$ 576.3351; found 576.3365; m/z [M + Na]$^+$ calcd for $C_{31}H_{46}NaO_7Si$ 581.2905; found 581.2923.

Data for *α*-glycoside 14c (contaminated with traces of *β*-glycoside **14b**)**:** R_f 0.47 (Hex/EtOAc 8:2); [α]$_D^{20}$ +28 (c 0.22, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.54−7.52 (m, 2H, 2 × CH_{Ar}), 7.33−7.31 (m, 3H, 3 × CH_{Ar}), 5.50 (s, 1H, CHPh), 4.97 (d, J = 1.7 Hz, 1H, H-1), 4.94 (t, J = 3.5 Hz, 1H, H-3), 4.28 (dd, J = 12.5 Hz, J = 1.5 Hz, 1H, H-6a), 4.11 (dd, J = 12.6 Hz, 2.0 Hz, 1H, H-6b), 3.96 (t, J = 2.4 Hz, 1H, H-4), 3.92 (m, 1H, H-5), 3.78 (t, J = 2.9 Hz, 1H, H-2$_{ad}$), 3.75 (dd, J = 4.2 Hz, J = 2.1 Hz, 1H, H-2), 2.09 (s, 3H, CH_{3Ac}), 2.06−1.49 (m, 14H, 4 × CH_{ad}, 5 × CH_{2ad}), 0.85 (s, 9H, C(CH_3)$_{3TBS}$), 0.095 (s, 3H, CH_{3TBS}), 0.091 (s, 3H, CH_{3TBS}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 169.8 (COOR$_{Ac}$), 138.1 (C_{Ar}), 129.0 (CH$_{Ar}$), 128.1 (2C, 2 × CH$_{Ar}$), 126.8 (2C, 2 × CH$_{Ar}$), 101.3 (CHPh), 100.3 (C-1, $^1J_{C1,H1}$ = 171 Hz), 80.1 (C-2$_{ad}$), 73.9 (C-4), 72.2 (C-3), 69.7 (C-6), 68.1 (C-2), 60.1 (C-5), 37.7−27.3 (9C, 4 × CH$_{ad}$, 5 × CH$_{2ad}$), 25.8 (3C, C(CH$_3$)$_{3TBS}$), 21.3 (CH$_{3Ac}$), 18.1 (C(CH$_3$)$_{3TBS}$), −4.7 (CH$_{3TBS}$), −4.8 (CH$_{3TBS}$); HRMS (ESI-TOF) m/z [M + NH$_4$]$^+$ calcd for $C_{31}H_{50}NO_7Si$ 576.3351; found 576.3362; m/z [M + Na]$^+$ calcd for $C_{31}H_{46}NaO_7Si$ 581.2905; found 581.2925.

(1-Adamantyl) 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*β*-D-idopyranoside (15a), **(1-Adamantyl) 3-*O*-Acetyl-(*R*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*β*-D-idopyranoside (15b) and (1-Adamantyl) 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*α*-D-idopyranoside (15c)**

Donor **6a** (11.1 mg, 0.0236 mmol, 1.2 equiv) and 1-adamantanol (3.0 mg, 0.020 mmol, 1.0 equiv) were reacted according to the general procedure for NIS/TMSOTf-promoted glycosylation. Purification by silica gel flash chromatography (Hex/EtOAc 95:5 to 9:1) gave compounds **15a** (4.3 mg, 39%, colorless oil), **15b** (2.2 mg, 20%, colorless oil), and **15c** (1.3 mg, 12%, colorless oil).

Data for *β*-glycoside 15a: R_f 0.38 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ −20 (*c* 0.45, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.55−7.54 (m, 2H, 2 × C*H*$_{Ar}$), 7.30−7.29 (m, 3H, 3 × C*H*$_{Ar}$), 5.45 (s, 1H, C*H*Ph), 5.02 (t, *J* = 2.4 Hz, 1H, H-3), 4.82 (br s, 1H, H-1), 4.33 (d, *J* = 12.4 Hz, 1H, H-6a), 4.05 (dd, *J* = 12.5 Hz, *J* = 2.0 Hz, 1H, H-6b), 3.77 (br s, 1H, H-4), 3.57 (br s, 1H, H-5), 3.49 (br s, 1H, H-2), 2.14 (br s, 3H, 3 × C*H*$_{ad}$), 2.13 (s, 3H, C*H*$_{3Ac}$), 1.90−1.61 (m, 12H, 6 × C*H*$_{2ad}$), 0.86 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.15 (s, 3H, C*H*$_{3TBS}$), 0.08 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 169.2 (*C*OOR$_{Ac}$), 138.1 (*C*$_{Ar}$), 128.9 (*C*H$_{Ar}$), 127.9 (2C, 2 × *C*H$_{Ar}$), 127.0 (2C, 2 × *C*H$_{Ar}$), 101.6 (*C*HPh), 92.4 (C-1, $^1J_{C1,H1}$ = 153 Hz), 74.8 (C-1$_{ad}$), 73.7 (C-3), 72.4 (C-4), 69.9 (C-6), 69.3 (C-2), 67.0 (C-5), 42.6 (3C, 3 × *C*H$_{2ad}$), 36.5 (3C, 3 × *C*H$_{2ad}$), 30.8 (3C, 3 × *C*H$_{ad}$), 26.0 (3C, C(*C*H$_3$)$_{3TBS}$), 21.3 (*C*H$_{3Ac}$), 18.6 (*C*(CH$_3$)$_{3TBS}$), −4.1 (*C*H$_{3TBS}$), −5.2 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{31}H_{50}NO_7Si$ 576.3351; found 576.3357.

Data for *β*-glycoside 15b: R_f 0.48 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ −39 (*c* 0.30, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.45−7.43 (m, 2H, 2 × C*H*$_{Ar}$), 7.35−7.31 (m, 3H, 3 × C*H*$_{Ar}$), 5.97 (t, *J* = 10.1 Hz, 1H, H-3), 5.90 (s, 1H, C*H*Ph), 5.07 (d, *J* = 3.8 Hz, 1H, H-1), 4.70 (t, *J* = 11.4 Hz, 1H, H-6a), 4.32 (dt, *J* = 11.8 Hz, *J* = 6.0 Hz, 1H, H-5), 4.12−4.07 (m, 2H, H-6b, H-4), 3.69 (dd, *J* = 9.8 Hz, *J* = 3.8 Hz, 1H H-2), 2.16 (br s, 3H, 3 x C*H*$_{ad}$), 2.09 (s, 3H, C*H*$_{3Ac}$), 1.85−1.60 (m, 12H, 6 × C*H*$_{2ad}$), 0.90 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.12 (s, 3H, C*H*$_{3TBS}$), 0.08 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 170.6 (*C*OOR$_{Ac}$), 137.9 (*C*$_{Ar}$), 128.9 (*C*H$_{Ar}$), 128.4 (2C, 2 × *C*H$_{Ar}$), 126.4 (2C, 2 × *C*H$_{Ar}$), 96.2 (*C*HPh), 92.9 (C-1, $^1J_{C1,H1}$ = 171 Hz), 75.2 (C-4), 75.0 (C-1$_{ad}$), 71.1 (C-2), 68.7 (C-6), 67.5 (C-5), 66.9 (C-3), 42.9 (3C, 3 × *C*H$_{2ad}$), 36.4 (3C, 3 × *C*H$_{2ad}$), 30.8 (3C, 3 × *C*H$_{ad}$), 25.8 (3C, C(*C*H$_3$)$_{3TBS}$), 21.4 (*C*H$_{3Ac}$), 18.2 (*C*(CH$_3$)$_{3TBS}$), −3.9 (*C*H$_{3TBS}$), −4.8 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + Na]$^+$ calcd for $C_{31}H_{46}NaO_7Si$ 581.2905; found 581.2898.

Data for *α*-glycoside 15c: R_f 0.34 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ +32 (*c* 0.25, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.54−7.52 (m, 2H, 2 × CH_{Ar}), 7.32−7.31 (m, 3H, 3 × CH_{Ar}), 5.49 (s, 1H, C*H*Ph), 5.24 (d, *J* = 2.9 Hz, 1H, H-1), 4.95 (dd, *J* = 4.8 Hz, *J* = 3.2 Hz, 1H, H-3), 4.27 (dd, *J* = 12.5 Hz, *J* = 0.9 Hz, 1H, H-6a), 4.11 (dd, *J* = 12.6 Hz, *J* = 2.1 Hz, 1H, H-6b), 4.00−3.99 (m, 1H, H-5), 3.97 (m, 1H, H-4), 3.65 (dd, *J* = 4.9 Hz, *J* = 3.0 Hz, 1H, H-2), 2.13 (br s, 3H, 3 × CH_{ad}), 2.08 (s, 3H, CH_{3Ac}), 1.83−1.59 (m, 12H, 6 × CH_{2ad}), 0.86 (s, 9H, C(CH_3)$_{3TBS}$), 0.11 (s, 3H, CH_{3TBS}), 0.08 (s, 3H, CH_{3TBS}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 169.8 (*C*OOR$_{Ac}$), 138.1 (*C*$_{Ar}$), 129.0 (*C*H$_{Ar}$), 128.1 (2C, 2 × *C*H$_{Ar}$), 126.7 (2C, 2 × *C*H$_{Ar}$), 101.0 (*C*HPh), 95.3 (C-1, $^1J_{C1,H1}$ = 168 Hz), 74.5 (C-4), 74.3 (C-1$_{ad}$), 73.0 (C-3), 69.8 (C-6), 69.3 (C-2), 60.3 (C-5), 42.7 (3C, 3 × *C*H$_{2ad}$), 36.5 (3C, 3 × *C*H$_{2ad}$), 30.8 (3C, 3 × *C*H$_{ad}$), 25.9 (3C, C(*C*H$_3$)$_{3TBS}$), 21.4 (*C*H$_{3Ac}$), 18.1 (*C*(CH$_3$)$_{3TBS}$), −4.4 (*C*H$_{3TBS}$), −4.7 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{31}H_{50}NO_7Si$ 576.3351; found 576.3361.

(3-Stigmastanyl) 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*β*-D-idopyranoside (16a), **(3-Stigmastanyl) 3-*O*-Acetyl-(*R*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*β*-D-idopyranoside (16b) and (3-Stigmastanyl) 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*α*-D-idopyranoside (16c).**

Donor **6a** (9.4 mg, 0.020 mmol, 1.2 equiv) and stigmastanol (7.0 mg, 0.017 mmol, 1.0 equiv) were reacted according to the general procedure for NIS/TMSOTf-promoted glycosylation. Purification by silica gel flash chromatography (Hex/EtOAc 98:2 to 92:8) gave compounds **16a** (2.0 mg, 14%, colorless oil), **16b** (1.7 mg, 12%, white amorphous solid), and **16c** (0.5 mg, 4%, colorless oil).

Data for *β*-glycoside 16a (contaminated with traces of *β*-glycoside **16b**)**:** R_f 0.37 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ −16 (*c* 0.20, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.55−7.53 (m, 2H, 2 × CH_{Ar}), 7.30−7.29 (m, 3H, 3 × CH_{Ar}), 5.46 (s, 1H, C*H*Ph), 5.02 (t, *J* = 2.5 Hz, 1H, H-3), 4.69 (br s, 1H, H-1), 4.36 (d, *J* = 12.2 Hz, 1H, H-6a), 4.06 (dd, *J* = 12.5 Hz, *J* = 1.9 Hz, 1H, H-6b), 3.79 (br s, 1H, H-4), 3.75−3.70 (m, 1H, H-3$_{stig}$), 3.59 (d, *J* = 2.6 Hz, 1H, H-2), 3.57 (br s, 1H, H-5), 2.11 (s, 3H, CH_{3Ac}), 1.97−0.59 (m, 59H,

C(CH_3)$_{3TBS}$, 12 × CH_{2stig}, 8 × CH_{stig}, 6 × CH_{3stig}), 0.13 (s, 3H, CH_{3TBS}), 0.07 (s, 3H, CH_{3TBS}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 169.1 (*C*OOR$_{Ac}$), 138.1 (*C*$_{Ar}$), 128.9 (*C*H$_{Ar}$), 128.0 (2C, 2 × *C*H$_{Ar}$), 126.9 (2C, 2 × *C*H$_{Ar}$), 101.6 (*C*HPh), 96.9 (C-1, $^1J_{C1,H1}$ = 155 Hz), 76.9 (C-3$_{stig}$), 73.5 (C-3), 72.6 (C-4), 69.8 (C-6), 68.3 (C-2), 67.0 (C-5), 56.7−12.1 (33C, C(*C*H$_3$)$_{3TBS}$, *C*(CH$_3$)$_{3TBS}$, *C*H$_{3Ac}$, 6 × *C*H$_{3stig}$, 12 × *C*H$_{2stig}$, 8 × *C*H$_{stig}$, 2 × *C*$_{stig}$), −4.2 (*C*H$_{3TBS}$), −5.2 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{50}H_{86}NO_7Si$ 840.6168; found 840.6171.

Data for *β*-glycoside 16b: R_f 0.57 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ −30 (*c* 0.23, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.44−7.43 (m, 2H, 2 × C*H*$_{Ar}$), 7.33−7.32 (m, 3H, 3 × C*H*$_{Ar}$), 5.95 (t, *J* = 10.1 Hz, 1H, H-3), 5.89 (s, 1H, C*H*Ph), 4.85 (d, *J* = 3.9 Hz, 1H, H-1), 4.60 (t, *J* = 11.4 Hz, 1H, H-6a), 4.33 (dt, *J* = 11.9 Hz, *J* = 5.9 Hz, 1H, H-5), 4.12−4.06 (m, 2H, H-6b, H-4), 3.71 (dd, *J* = 9.8 Hz, 3.8 Hz, 1H, H-2), 3.56−3.50 (m, 1H, H-3$_{stig}$), 2.09 (s, 3H, C*H*$_{3Ac}$), 1.98−0.59 (m, 59H, C(C*H*$_3$)$_{3TBS}$, 12 × C*H*$_{2stig}$, 8 × C*H*$_{stig}$, 6 × C*H*$_{3stig}$) 0.10 (s, 3H, C*H*$_{3TBS}$), 0.09 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 170.6 (*C*OOR$_{Ac}$), 137.8 (*C*$_{Ar}$), 129.0 (*C*H$_{Ar}$), 128.4 (2C, 2 × *C*H$_{Ar}$), 126.4 (2C, 2 × *C*H$_{Ar}$), 98.1 (C-1, $^1J_{C1,H1}$ = 170 Hz), 96.3 (*C*HPh), 78.2 (C-3$_{stig}$), 75.0 (C-4), 71.2 (C-2), 68.2 (C-6), 67.3 (C-5), 66.8 (C-3), 56.6−12.1 (33C, C(*C*H$_3$)$_{3TBS}$, *C*(CH$_3$)$_{3TBS}$, *C*H$_{3Ac}$, 6 × *C*H$_{3stig}$, 12 × *C*H$_{2stig}$, 8 × *C*H$_{stig}$, 2 × *C*$_{stig}$), −4.3 (*C*H$_{3TBS}$), −4.7 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{50}H_{86}NO_7Si$ 840.6168; found 840.6169.

Data for *α*-glycoside 16c (contaminated with traces of *β*-glycoside **16b**)**:** R_f 0.47 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ −49 (*c* 0.13, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.53−7.51 (m, 2H, 2 × C*H*$_{Ar}$), 7.33−7.31 (m, 3H, 3 × C*H*$_{Ar}$), 5.49 (s, 1H, C*H*Ph), 5.00 (dd, *J* = 5.7 Hz, *J* = 3.2 Hz, 1H, H-3), 4.97 (d, *J* = 3.0 Hz, 1H, H-1), 4.29 (d, *J* = 12.6 Hz, 1H, H-6a), 4.11 (dd, *J* = 12.6 Hz, *J* = 1.9 Hz, 1H, H-6b), 3.99 (m, 1H, H-4), 3.86 (br s, 1H, H-5), 3.69 (dd, *J* = 5.7 Hz, *J* = 3.1 Hz, 1H, H-2), 3.63−3.58 (m, 1H, H-3$_{stig}$), 2.08 (s, 3H, C*H*$_{3Ac}$), 1.97−0.60 (m, 59H, C(C*H*$_3$)$_{3TBS}$, 12 × C*H*$_{2stig}$, 8 × C*H*$_{stig}$, 6 × C*H*$_{3stig}$), 0.09 (s, 3H, C*H*$_{3TBS}$), 0.07 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 169.8 (*C*OOR$_{Ac}$), 138.0 (*C*$_{Ar}$), 129.0 (*C*H$_{Ar}$), 128.1 (2C, 2 × *C*H$_{Ar}$), 126.7 (2C, 2 × *C*H$_{Ar}$), 100.9 (*C*HPh), 99.7 (C-1, $^1J_{C1,H1}$ = 171 Hz), 75.9 (C-3$_{stigmastanol}$), 75.0 (C-4), 73.2 (C-3), 69.6 (C-6), 69.1 (C-2), 60.7 (C-5), 56.6−12.1 (33C, C(*C*H$_3$)$_{3TBS}$,

C(CH$_3$)$_{3TBS}$, *C*H$_{3Ac}$, 6 × *C*H$_{3stig}$, 12 × *C*H$_{2stig}$, 8 × *C*H$_{stig}$, 2 × *C*$_{stig}$), −4.5 (*C*H$_{3TBS}$), −4.7 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{50}H_{86}NO_7Si$ 840.6168; found 840.6176.

(2-Adamantyl) (S)-4,6-*O*-Benzylidene-2-*O*-*tert*-butyldimethylsilyl-3-*O*-dichloroacetyl-*β*-D-idopyranoside (17a), (2-Adamantyl) (*R*)-4,6-*O*-Benzylidene-2-*O*-*tert*-butyldimethylsilyl-3-*O*-dichloroacetyl-*β*-D-idopyranoside (17b) and (2-Adamantyl) (*S*)-4,6-*O*-Benzylidene-2-*O*-*tert*-butyldimethylsilyl-3-*O*-dichloroacetyl-*α*-D-idopyranoside (17c).

Donor **7** (8.7 mg, 0.015 mmol, 1.2 equiv) and 2-adamantanol (2.0 mg, 0.013 mmol, 1.0 equiv) were reacted according to the general procedure for NIS/TMSOTf-promoted glycosylation. Purification by silica gel flash chromatography (Hex/EtOAc 95:5) gave compounds **17a** (3.5 mg, 42%, colorless oil), and **17b** and **17c** (2.1 mg, 25%, colorless oil, inseparable mixture **17b**/**17c** 1.0:0.3).

Data for *β*-glycoside 17a: *R*$_f$ 0.37 (Hex/EtOAc 8:2); [α]$_D^{20}$ −28 (*c* 0.45, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.54−7.53 (m, 2H, 2 × C*H*$_{Ar}$), 7.32−7.31 (m, 3H, 3 × C*H*$_{Ar}$), 5.99 (s, 1H, C*H*Cl$_2$), 5.49 (s, 1H, C*H*Ph), 5.11 (t, *J* = 2.6 Hz, 1H, H-3), 4.72 (d, *J* = 0.8 Hz, 1H, H-1), 4.38 (d, *J* = 12.5 Hz, 1H, H-6a), 4.10 (dd, *J* = 12.6 Hz, *J* = 2.0 Hz, 1H, H-6b), 3.98 (t, *J* = 3.1 Hz, H-2$_{ad}$), 3.90 (br s, 1H, H-4), 3.72 (br d, *J* = 2.9 Hz, 1H, H-2), 3.64 (br d, *J* = 1.2 Hz, 1H, H-5), 2.19−1.44 (m, 14H, 5 × C*H*$_{2ad}$, 4 × C*H*$_{ad}$), 0.85 (s, 9H, C(*C*H$_3$)$_{3TBS}$), 0.15 (*C*H$_{3TBS}$), 0.11 (*C*H$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 162.9 (*C*OOR$_{AcCl2}$), 137.8 (*C*$_{Ar}$), 129.1 (*C*H$_{Ar}$), 128.0 (2C, 2 × *C*H$_{Ar}$), 126.8 (2C, 2 × *C*H$_{Ar}$), 101.7 (*C*HPh), 96.4 (C-1, $^1J_{C1,H1}$ = 155 Hz), 79.6 (C-2$_{ad}$), 76.2 (C-3), 72.4 (C-4), 69.7 (C-6), 67.6 (C-2), 67.0 (C-5), 64.2 (*C*HCl$_2$), 37.8−27.5 (9C, 5 × *C*H$_{2ad}$, 4 × *C*H$_{ad}$), 25.9 (3C, C(*C*H$_3$)$_{3TBS}$), 18.4 (*C*(CH$_3$)$_{3TBS}$), −4.4 (*C*H$_{3TBS}$), −5.2 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{31}H_{48}Cl_2NO_7Si$ 644.2572; found 644.2573.

Data for *β*-glycoside 17b: *R*$_f$ 0.5 (Hex/EtOAc 8:2); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.45−7.43 (m, 2H, 2 × C*H*$_{Ar}$), 7.35−7.31 (m, 3H, 3 × C*H*$_{Ar}$), 6.09 (t, *J* = 9.9 Hz, 1H, H-3), 5.97 (s, 1H, C*H*Cl$_2$), 5.86 (s, 1H, C*H*Ph), 4.89 (d, *J* = 3.7 Hz, 1H, H-1), 4.57 (t, *J* = 11.3 Hz, 1H, H-6a), 4.36 (dt, *J* = 11.8 Hz, *J* = 5.7 Hz, 1H, H-5), 4.23 (dd, *J* = 10.3 Hz, *J* = 6.6 Hz, 1H, H-4), 4.15−4.13 (m, 1H, H-6b), 3.83 (dd, *J* = 9.7 Hz,

J = 3.7 Hz, 1H, H-2), 3.80 (s, 1H, H-2_{ad}), 2.17−1.44 (14H, 5 × CH_{2ad}, 4 × CH_{ad}), 0.89 (s, 9H, C(CH_3)$_{3TBS}$), 0.14 (s, 3H, CH_{3TBS}), 0.08 (s, 3H, CH_{3TBS}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 164.8 (COOR$_{AcCl2}$), 137.3 (C_{Ar}), 129.0 (CH$_{Ar}$), 128.3 (2C, 2 × CH$_{Ar}$), 126.3 (2C, 2 × CH$_{Ar}$), 97.5 (C-1, $^1J_{C1,H1}$ = 170 Hz), 96.1 (CHPh), 80.6 (C-2_{ad}), 74.7 (C-4), 71.1 (C-2), 70.6 (C-3), 68.1 (C-6), 67.2 (C-5), 64.3 (CHCl$_2$), 37.6−27.3 (9C, 5 × CH$_{2ad}$, 4 × CH$_{ad}$), 25.9 (3C, C(CH$_3$)$_{3TBS}$), 18.1 (C(CH$_3$)$_{3TBS}$), −4.8 (2C, 2 × CH$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + Na]$^+$ calcd for $C_{31}H_{44}Cl_2NaO_7Si$ 649.2126; found 649.2121.

Data for *α*-glycoside 17c: R_f 0.5 (Hex/EtOAc 8:2); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.53−7.52 (m, 0.6H, 2 × CH_{Ar}), 7.39−7.37 (m, 0.3H, CH_{Ar}), 7.15−7.10 (m, 0.6H, 2 × CH_{Ar}), 5.96 (s, 0.3H, CHCl$_2$), 5.53 (s, 0.3H, CHPh), 5.00−4.99 (m, 0.6H, H-1, H-3), 4.30 (dd, J = 12.6 Hz, J = 1.1 Hz, 0.3H, H-6a), 4.15−4.12 (m, 0.3H, H-6b), 4.01 (s, 0.3H, H-4), 3.94 (d, J = 1.3 Hz, 0.3H, H-5), 3.80 (s, 0.3H, H-2_{ad}), 3.78−3.77 (m, 0.3H, H-2), 2.17−1.44 (m, 4.2H, 5 × CH_{2ad}, 4 × CH_{ad}), 0.85 (s, 3H, C(CH_3)$_{3TBS}$), 0.14 (s, 1H CH_{3TBS}), 0.10 (s, 1H, CH_{3TBS}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 164.8 (COOR$_{AcCl2}$), 136.2 (C_{Ar}), 128.7 (CH$_{Ar}$), 128.1 (2C, 2 × CH$_{Ar}$), 126.7 (2C, 2 × CH$_{Ar}$), 101.4 (CHPh), 99.5 (C-1, $^1J_{C1,H1}$ = 170 Hz), 80.0 (C-2_{ad}), 74.8 (C-3), 72.7 (C-4), 69.6 (C-6), 67.5 (C-2), 64.3 (CHCl$_2$), 59.7 (C-5), 37.6−27.3 (9C, 5 × CH$_{2ad}$, 4 × CH$_{ad}$), 25.8 (3C, C(CH$_3$)$_{3TBS}$), 18.1 (C(CH$_3$)$_{3TBS}$), −3.8 (2C, 2 × CH$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + Na]$^+$ calcd for $C_{31}H_{44}Cl_2NaO_7Si$ 649.2126; found 649.2121.

(2-Adamantyl) 3-*O*-(2-Azidomethyl)benzoyl-(*S*)-4,6-*O*-Benzylidene-2-*O*-*tert*-butyldimethylsilyl-*β*-D-idopyranoside (18a), (2-Adamantyl) 3-*O*-(2-Azidomethyl)benzoyl-(*R*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*β*-D-idopyranoside (18b) and (2-Adamantyl) 3-*O*-(2-Azidomethyl)benzoyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*α*-D-idopyranoside (18c).

Donor **8** (7.8 mg, 0.013 mmol, 1.2 equiv) and 2-adamantanol (1.7 mg, 0.011 mmol, 1.0 equiv) were reacted according to the general procedure for NIS/TMSOTf-promoted glycosylation. Purification by silica gel flash chromatography (Hex/EtOAc 95:5 to 85:15) gave compounds **18a** (4.2 mg, 55%, colorless oil), and **18b** and **18c** (1.0 mg, 13%, colorless oil, inseparable mixture **18b**/**18c** 1.0:0.7).

Data for *β*-glycoside 18a: R_f 0.3 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ −19 (*c* 0.49, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.97−7.95 (m, 1H, C*H*$_{AZMB}$), 7.62−7.59 (m, 1H, C*H*$_{AZMB}$), 7.58−7.55 (m, 2H, 2 × C*H*$_{Ar}$), 7.53-7.52 (m, 1H, C*H*$_{AZMB}$), 7.47−7.44 (m, 1H, C*H*$_{AZMB}$), 7.33−7.31 (m, 3H, 3 × C*H*$_{Ar}$), 5.51 (s, 1H, C*H*Ph), 5.31 (t, *J* = 2.6 Hz, 1H, H-3), 4.82 (d, *J* = 1.2 Hz, 1H, H-1), 4.81 (s, 2H, C*H*$_{2AZMB}$), 4.40 (dd, *J* = 12.5 Hz, *J* = 0.7 Hz, 1H, H-6a), 4.11 (dd, *J* = 12.5 Hz, *J* = 2.1 Hz, 1H, H-6b), 4.00 (br s, 1H, H-2$_{ad}$), 3.97 (br s, 1H, H-4), 3.82 (br d, *J* = 2.9 Hz, 1H, H-2), 3.70 (br d, *J* = 1.3 Hz, 1H, H-5), 2.22−1.45 (m, 14H, 5 × C*H*$_{2ad}$, 4 × C*H*$_{ad}$), 0.88 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.17 (s, 3H, C*H*$_{3TBS}$), 0.13 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 164.8 (*C*OOR$_{AZMB}$), 138.0−126.9 (12C, 3 × *C*$_{Ar}$, 9 × *C*H$_{Ar}$), 101.7 (*C*HPh), 97.0 (C-1, $^1J_{C1,H1}$ = 156 Hz), 79.8 (C-2$_{ad}$), 74.2 (C-3), 72.9 (C-4), 69.8 (C-6), 68.3 (C-2), 67.4 (C-5), 53.2 (*C*H$_{2AZMB}$), 37.8−27.6 (9C, 5 × *C*H$_{2ad}$, 4 × *C*H$_{ad}$), 26.0 (3C, C(*C*H$_3$)$_{3TBS}$), 18.5 (*C*(CH$_3$)$_{3TBS}$), −4.3 (*C*H$_{3TBS}$), −5.1 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{37}H_{53}N_4O_7Si$ 693.3678; found 693.3679.

Data for *β*-glycoside 18b: R_f 0.4 (Hex/EtOAc 8:2); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 8.01 (d, *J* = 7.8 Hz, 1H, C*H*$_{AZMB}$), 7.58−7.27 (m, 8H, 8 × C*H*$_{Ar}$), 6.30 (t, *J* = 10.0 Hz, 1H, H-3), 5.99 (s, 1H, C*H*Ph), 4.93 (d, *J* = 3.7 Hz, 1H, H-1), 4.76 (d, *J* = 14.9 Hz, 1H, C*H*H$_{AZMB}$), 4.71 (d, *J* = 14.8 Hz, 1H, CH*H*$_{AZMB}$), 4.67 (t, *J* = 11.3 Hz, 1H, H-6a), 4.41 (dt, *J* = 11.7 Hz, *J* = 5.9 Hz, 1H, H-5), 4.34−4.30 (m, 1H, H-4), 4.17−4.12 (m, 1H, H-6b), 3.91 (dd, *J* = 9.7 Hz, *J* = 3.7 Hz, 1H, H-2), 3.82 (s, 1H, H-2$_{ad}$), 2.36−1.45 (m, 14H, 5 × C*H*$_{2ad}$, 4 × C*H*$_{ad}$), 0.76 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.03 (s, 3H, C*H*$_{3TBS}$), −0.04 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 166.3 (*C*OOR$_{AZMB}$), 137.7 (*C*$_{Ar}$), 137.6 (*C*$_{Ar}$), 133.2−126.4 (10C, 1 × *C*$_{Ar}$, 9 × *C*H$_{Ar}$), 97.6 (C-1, $^1J_{C1,H1}$ = 170 Hz), 96.4 (*C*HPh), 80.5 (C-2$_{ad}$), 75.1 (C-4), 71.5 (C-2), 67.6, 67.4 (2C, C-3, C-5), 53.0 (*C*H$_{2AZMB}$), 37.6−27.4 (9C, 5 × *C*H$_{2ad}$, 4 × *C*H$_{ad}$), 25.6 (3C, C(*C*H$_3$)$_{3TBS}$), 18.0 (*C*(CH$_3$)$_{3TBS}$), −4.74 (*C*H$_{3TBS}$), −4.92 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + Na]$^+$ calcd for $C_{37}H_{49}N_3NaO_7Si$ 698.3232; found 698.3236.

Data for *α*-glycoside 18c: R_f 0.4 (Hex/EtOAc 8:2); 8.19 (d, *J* = 7.7 Hz, 0.7H, C*H*$_{AZMB}$), 7.58−7.27 (m, 5.6H, 5.6 × C*H*$_{Ar}$), 5.54 (s, 0.7H, C*H*Ph), 5.19 (t, *J* = 2.6 Hz, 0.7H, H-3), 5.08 (s, 0.7H, H-1), 4.88 (d, *J* =

15.5 Hz, 0.7H, C*H*H$_{AZMB}$), 4.86 (d, *J* = 15.2 Hz, 0.7H, CH*H*$_{AZMB}$), 4.34−4.30 (m, 0.7H, H-6a), 4.17−4.12 (m, 0.7H, H-6b), 4.06 (s, 0.7H, H-4), 4.01 (s, 0.7H, H-5), 3.87 (s, 0.7H, H-2$_{ad}$), 3.82 (s, 0.7H, H-2), 2.36−1.45 (m, 9.8H, 5 × C*H*$_{2ad}$, 4 × C*H*$_{ad}$), 0.86 (s, 6.3H, C(C*H*$_3$)$_{3TBS}$), 0.10 (s, 2.1H, C*H*$_{3TBS}$), 0.10 (s, 2.1H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 166.3 (*C*OOR$_{AZMB}$), 138.1 (*C*$_{Ar}$), 138.0 (*C*$_{Ar}$), 133.2−126.4 (10C, 1 × *C*$_{Ar}$, 9 × *C*H$_{Ar}$), 101.5 (*C*HPh), 99.2 (C-1, $^1J_{C1,H1}$ = 172 Hz), 79.3 (C-2$_{ad}$), 72.7 (C-4), 71.6 (C-3), 68.3 (C-6), 67.9 (C-2), 59.7 (C-5), 53.2 (*C*H$_{2AZMB}$), 37.6−27.4 (9C, 5 × *C*H$_{2ad}$, 4 × *C*H$_{ad}$), 25.8 (3C, C(*C*H$_3$)$_{3TBS}$), 18.0 (*C*(CH$_3$)$_{3TBS}$), −4.88 (*C*H$_{3TBS}$), −4.92 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + Na]$^+$ calcd for $C_{37}H_{49}N_3NaO_7Si$ 698.3232; found 698.3236.

(2-Adamantyl) (*S*)-4,6-*O*-Benzylidene-2-*O*-*tert*-butyldimethylsilyl-3-*O*-*tert*-butoxycarbonyl-*β*-D-idopyranoside (19a), **(2-Adamantyl) (*R*)-4,6-*O*-Benzylidene-2-*O*-*tert*-butyldimethylsilyl-3-*O*-*tert*-butoxycarbonyl-*β*-D-idopyranoside (19b) and (2-Adamantyl) (*S*)-4,6-*O*-Benzylidene-2-*O*-*tert*-butyldimethylsilyl-3-*O*-*tert*-butoxycarbonyl-*α*-D-idopyranoside (19c).**

Donor **9** (10.2 mg, 0.017 mmol, 1.2 equiv) and 2-adamantanol (2.2 mg, 0.015 mmol, 1.0 equiv) were reacted according to the general procedure for NIS/TMSOTf-promoted glycosylation. Purification by silica gel flash chromatography (Hex/EtOAc 97:3 to 9:1) gave compounds **19a** (5.4 mg, 64%, colorless oil), and **19b** and **19c** (1.6 mg, 18%, colorless oil, inseparable mixture **19b**/**19c** 1.0:0.7).

Data for *β*-glycoside 19a: R_f 0.17 (Hex/EtOAc 9:1); $[\alpha]_D^{20}$ −23 (*c* 0.61, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.55−7.53 (m, 2H, 2 × C*H*$_{Ar}$), 7.31−7.29 (m, 3H, 3 × C*H*$_{Ar}$), 5.48 (s, 1H, C*H*Ph), 4.85 (t, *J* = 2.5 Hz, 1H, H-3), 4.73 (d, *J* = 1.1 Hz, 1H, H-1), 4.35 (d, *J* = 12.5 Hz, 1H, H-6a), 4.06 (dd, *J* = 12.5 Hz, *J* = 2.1 Hz, 1H, H-6b), 3.95 (br s, 1H, H-2$_{ad}$), 3.88 (br s, 1H, H-4), 3.73 (d, *J* = 2.9 Hz, 1H, H-2), 3.62 (d, *J* = 1.4 Hz, 1H, H-5), 2.21−1.42 (m, 14H, 5 × C*H*$_{2ad}$, 4 × C*H*$_{ad}$), 1.51 (s, 9H, C(C*H*$_3$)$_{3Boc}$), 0.85 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.14 (s, 3H, C*H*$_{3TBS}$), 0.10 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 152.2 (*C*OOR$_{Boc}$), 138.1 (*C*$_{Ar}$), 128.9 (*C*H$_{Ar}$), 127.9 (2C, 2 × *C*H$_{Ar}$), 126.9 (2C, 2 × *C*H$_{Ar}$), 101.5 (*C*HPh), 96.8 (C-1, $^1J_{C1,H1}$ = 155 Hz), 83.2 (*C*(CH$_3$)$_{3Boc}$), 79.7 (C-2$_{ad}$), 76.1 (C-3), 73.1 (C-4), 69.8 (C-6), 68.4 (C-

2), 66.9 (C-5), 37.8−27.6 (9C, 5 × CH_{2ad}, 4 × CH_{ad}), 27.9 (3C, C(CH_3)$_{3Boc}$), 26.0 (3C, C(CH_3)$_{3TBS}$), 18.4 (C(CH_3)$_{3TBS}$), −4.4 (CH_{3TBS}), −5.1 (CH_{3TBS}); HRMS (ESI-TOF) *m/z* $[M + NH_4]^+$ calcd for $C_{34}H_{56}NO_8Si$ 634.3770; found 634.3794.

Data for *β*-glycoside 19b: R_f 0.31 (Hex/EtOAc 9:1); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.47−7.46 (m, 2H, 2 × CH_{Ar}), 7.32−7.29 (m, 3H, 3 × CH_{Ar}), 5.95 (s, 1H, CHPh), 5.76 (t, J = 10.1 Hz, 1H, H-3), 4.86 (d, J = 3.8 Hz, 1H, H-1), 4.59 (t, J = 11.3 Hz, 1H, H-6a), 4.36−4.32 (m, 1H, H-5), 4.17 (dd, J = 10.4 Hz, J = 6.5 Hz, 1H, H-4), 4.11 (dd, J = 9.7 Hz, J = 4.0 Hz, 1H, H-6b), 3.78 (br s, 1H, H-2$_{ad}$), 3.74 (dd, J = 9.8 Hz, J = 3.8 Hz, 1H, H-2), 2.20−1.55 (m, 14H, 5 × CH_{2ad}, 4 × CH_{ad}), 1.44 (s, 9H, C(CH_3)$_{3Boc}$), 0.89 (s, 9H, C(CH_3)$_{3TBS}$), 0.13 (s, 3H, CH_{3TBS}), 0.07 (s, 3H, CH_{3TBS}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 153.8 ($C$$OOR_{Boc}$), 137.8 ($C_{Ar}$), 128.8 ($CH_{Ar}$), 128.1 (2C, 2 × CH_{Ar}), 126.4 (2C, 2 × CH_{Ar}), 97.7 (C-1, $^1J_{C1,H1}$ = 168 Hz), 96.1 (CHPh), 82.2 (C(CH_3)$_{3Boc}$), 80.5 (C-2$_{ad}$), 75.0 (C-4), 71.4 (C-2), 69.4 (C-3), 68.3 (C-6), 67.4 (C-5), 37.7−27.3 (9C, 5 × CH_{2ad}, 4 × CH_{ad}), 27.9 (3C, C(CH_3)$_{3Boc}$), 25.9 (3C, C(CH_3)$_{3TBS}$), 18.2 (C(CH_3)$_{3TBS}$), −4.2 (CH_{3TBS}), −4.9 (CH_{3TBS}); HRMS (ESI-TOF) *m/z* $[M + NH_4]^+$ calcd for $C_{34}H_{56}NO_8Si$ 634.3770; found 634.3781.

Data for *α*-glycoside 19c: R_f 0.28 (Hex/EtOAc 9:1); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.53−7.51 (m, 1.5H, 2 × CH_{Ar}), 7.32−7.29 (m, 2.25H, 3 × CH_{Ar}), 5.50 (s, 0.75H, CHPh), 4.95 (d, J = 2.5 Hz, 0.75H, H-1), 4.75 (dd, J = 5.0 Hz, J = 3.2 Hz, 0.75H, H-3), 4.26 (dd, J = 12.6 Hz, J = 1.1 Hz, 0.75H, H-6a), 4.09 (dd, J = 12.6 Hz, J = 2.2 Hz, 0.75H, H-6b), 4.06 (t, J = 2.4 Hz, 0.75H, H-4), 3.93 (d, J = 1.6 Hz, 0.75H, H-5), 3.83 (dd, J = 5.1 Hz, J = 2.6 Hz, 0.75H, H-2), 3.78 (br s, 0.75H, H-2$_{ad}$), 2.20−1.55 (m, 10.5H, 5 × CH_{2ad}, 4 × CH_{ad}), 1.48 (s, 6.75H, C(CH_3)$_{3Boc}$), 0.86 (s, 6.75H, C(CH_3)$_{3TBS}$), 0.10 (s, 4.5H, 2 × CH_{3TBS}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 152.5 ($C$$OOR_{Boc}$), 183.1 ($C_{Ar}$), 128.9 ($CH_{Ar}$), 128.1 (2C, 2 × CH_{Ar}), 126.7 (2C, 2 × CH_{Ar}), 101.0 (CHPh), 100.7 (C-1, $^1J_{C1,H1}$ = 172 Hz), 82.4 (C(CH_3)$_{3Boc}$), 80.4 (C-2$_{ad}$), 75.1 (C-3), 74.5 (C-4), 69.5 (C-6), 68.5 (C-2), 60.5 (C-5), 37.7−27.3 (9C, 5 × CH_{2ad}, 4 × CH_{ad}), 27.9 (3C, C(CH_3)$_{3Boc}$), 25.9 (3C, C(CH_3)$_{3TBS}$), 18.1 (C(CH_3)$_{3TBS}$), −4.68 (CH_{3TBs}), −4.73 (CH_{3TBS}); HRMS (ESI-TOF) *m/z* $[M + NH_4]^+$ calcd for $C_{34}H_{56}NO_8Si$ 634.3770; found 634.3781.

(2-Adamantyl) (*S*)-4,6-*O*-Benzylidene-*β*-D-idopyranoside (20a).

To a solution of compound **14a** (3.9 mg, 0.0070 mmol, 1.0 equiv) in dry pyridine (390 μL) at 0 °C was slowly added HF.py (195 μL). The mixture was stirred at rt for 16 h, after which it was diluted in EtOAc, and quenched with a saturated aqueous $NaHCO_3$ solution. The organic layer was washed with brine, dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The resulting alcohol was solubilized in MeOH (100 μL) and THF (100 μL) and NaOMe (25% wt in MeOH, 1 μL) was added. The mixture was stirred at rt for 1 h, then neutralized by adding Dowex until pH ≈ 7, filtered over Celite, and evaporated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 8:2 to 5:5) to give diol **20a** (3.0 mg, quant.) as a white amorphous solid: R_f 0.3 (Hex/EtOAc 1:1); $[\alpha]_D^{20}$ −70 (*c* 0.37, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.49−7.47 (m, 2H, 2 × C*H*$_{Ar}$), 7.36−7.33 (m, 3H, 3 × C*H*$_{Ar}$), 5.49 (s, 1H, C*H*Ph), 4.94 (s, 1H, H-1), 4.37 (dd, *J* = 12.4 Hz, $J_{6a\text{-}5}$ = 1.1 Hz, 1H, H-6a), 4.21 (t, *J* = 2.5 Hz, 1H, H-3), 4.06 (d, *J* = 12.5 Hz, *J* = 1.9 Hz, 1H, H-6b), 3.96−3.95 (m, 1H, H-2$_{ad}$), 3.93−3.92 (m, 1H, H-4), 3.75 (d, *J* = 1.2 Hz, 1H, H-5), 3.62 (dd, *J* = 10.8 Hz, *J* = 2.4 Hz, 1H, H-2), 3.15 (d, *J* = 10.9 Hz, 1H, O*H*-2), 2.22−1.47 (m, 15H, O*H*-3, 5 × C*H*$_{2ad}$, 4 × C*H*$_{ad}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 137.6 (*C*$_{Ar}$), 129.3 (*C*H$_{Ar}$), 128.4 (2C, 2 × *C*H$_{Ar}$), 126.3 (2C, 2 × *C*H$_{Ar}$), 101.5 (*C*HPh), 95.9 (C-1), 80.1 (C-2$_{ad}$), 75.6 (C-4), 70.44 (C-2*), 70.39 (C-3*), 70.0 (C-6), 66.6 (C-5), 37.7−27.5 (9C, 5 × *C*H$_{2ad}$, 4 × *C*H$_{ad}$); HRMS (ESI-TOF) *m/z* $[M + NH_4]^+$ calcd for $C_{23}H_{34}NO_6$ 420.2381; found 420.2386.

(2-Adamantyl) (*R*)-4,6-*O*-Benzylidene-*β*-D-idopyranoside (20b).

To a solution of compound **14b** (186 mg, 0.332 mmol, 1.0 equiv) in dry pyridine (9.3 mL) at 0 °C was slowly added HF.py (3.5 mL). The mixture was stirred at rt for 16 h, after which it was diluted with EtOAc and quenched with a saturated aqueous $NaHCO_3$ solution. The organic layer was washed with brine, dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The resulting alcohol was solubilized in MeOH (1.6 mL) and THF (1.1 mL), and NaOMe (25% wt in MeOH, 0.1 mL) was added. The mixture

was stirred at rt for 1 h, then neutralized by adding Dowex resin until pH ≈ 7, filtered over Celite and the solvents were evaporated. The residue was purified by silica gel flash chromatography (Hex/EtOAc 8:2 to 5:5) to give diol **20b** (95 mg, 73% in two steps) as a white solid foam: R_f 0.17 (Hex/EtOAc 6:4); $[\alpha]_D^{20}$ −5.8 (*c* 0.24, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.51−7.48 (m, 2H, 2 × CH_{Ar}), 7.39-7.34 (m, 2H, 2 × CH_{Ar}), 5.86 (s, 1H, C*H*Ph), 4.96 (d, *J* = 5.0 Hz, 1H, H-1), 4.55 (t, *J* = 8.5 Hz, 1H, H-3), 4.30 (dd, *J* = 11.1 Hz, *J* = 9.7 Hz, 1H, H-6a), 4.20 (dt, *J* = 9.9 Hz, *J* = 5.2 Hz, 1H, H-5), 4.08−4.04 (m, 2H, H-6b, H-4), 3.87 (t, *J* = 3.4 Hz, 1H, H-2$_{ad}$), 3.57 (td, *J* = 8.7 Hz, *J* = 3.6 Hz, 1H, H-2), 2.79 (s, 1H, O*H*-3), 2.51 (d, *J* = 9.8 Hz, 1H, O*H*-2), 2.10−1.54 (m, 14H, 5 × CH_{2ad}, 4 × *C*H$_{ad}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 137.2 (*C*$_{Ar}$), 129.2 (*C*H$_{Ar}$), 128.6 (2C, 2 × *C*H$_{Ar}$), 126.5 (2C, 2 × *C*H$_{Ar}$), 96.1 (C-1), 95.6 (*C*HPh), 80.0 (C-2$_{ad}$), 74.4 (C-4), 72.4 (C-2), 67.2 (C-6), 66.9 (C-5), 65.7 (C-3), 37.5−27.3 (9C, 5 × *C*H$_{2ad}$, 4 × *C*H$_{ad}$); HRMS (ESI-TOF) *m/z* $[M + NH_4]^+$ calcd for $C_{23}H_{34}NO_6$ 420.2381; found 420.2389.

(2-Adamantyl) (*S*)-4,6-*O*-Benzylidene-*α*-D-idopyranoside (20c).

To a solution of compound **14c** (8.1 mg, 0.015 mmol, 1.0 eq) in dry pyridine (540 μL) at 0 °C was slowly added HF·py (270 μL). The mixture was stirred at rt 16 h, after which it was diluted with EtOAc and quenched with a saturated aqueous $NaHCO_3$ solution. The organic layer was washed with brine, dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The resulting alcohol was solubilized in MeOH (97 μL) and THF (70 μL), and NaOMe (25% wt in MeOH, 5 μL) was added. The mixture was stirred at rt for 1 h, then quenched by adding Dowex resin until pH ≈ 7, filtered over Celite and the solvents were evaporated. The residue was purified by silica gel flash chromatography (Hex/EtOAc 8:2 to 7:3) to give diol **20c** (4.9 mg, 84% in two steps) as a white amorphous solid: R_f 0.47 (Hex/EtOAc 6:4); $[\alpha]_D^{20}$ +47 (*c* 0.34, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.49−7.47 (m, 2H, 2 × CH_{Ar}), 7.39−7.36 (m, 3H, 3 × CH_{Ar}), 5.54 (s, 1H, C*H*Ph), 5.20 (br s, 1H, H-1), 4.36 (dd, *J* = 12.6 Hz, *J* = 1.3 Hz, 1H, H-6a), 4.15 (d, *J* = 2.7 Hz, 1H, H-4), 4.13 (dd, *J* = 12.6 Hz, *J* = 1.7 Hz, 1H, H-6b), 4.07 (d, *J* = 10.2 Hz, 1H, O*H*-3), 4.01−4.00 (m, 2H, H-3, H-5), 3.92 (t, *J* = 2.8 Hz, 1H, H-2$_{ad}$), 3.71 (br d, *J* = 11.9 Hz, 1H, H-2), 3.65

(d, J = 12.0 Hz, 1H, O*H*-2), 2.08−1.54 (m, 14H, 5 × CH_{2ad}, 4 × CH_{ad}); $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$) : δ (ppm) 137.4 (C_{Ar}), 129.4 (CH_{Ar}), 128.5 (2C, 2 × CH_{Ar}), 126.1 (2C, 2 × CH_{Ar}), 101.6 (*C*HPh), 99.2 (C-1), 80.4 (C-2_{ad}), 76.0 (C-4), 70.2 (C-6), 68.0 (C-3), 67.2 (C-2), 59.5 (C-5), 37.4−27.2 (9C, 5 × CH_{2ad}, 4 × CH_{ad}); HRMS (ESI-TOF) *m/z* $[M + Na]^+$ calcd for $C_{23}H_{30}NaO_6$ 425.1935; found 425.1917.

(2-Adamantyl) 3-*O*-Acetyl-2-*O*-*tert*-butyldimethylsilyl-*β*-D-idopyranoside (21).

Procedure from 14a: To a solution of compound **14a** (8.8 mg, 0.016 mmol 1.0 equiv) in EtOAc (0.19 mL) was added 10% Pd/C (8.8 mg). The mixture was stirred under H_2 at rt for 2 h, after which it was filtered over Celite and the solvents were evaporated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 8:2 to 6:4) to give diol **21** (6.5 mg, 88%) as a colorless oil.

Procedure from 14b: To a solution of compound **14b** (6.4 mg, 0.012 mmol, 1.0 equiv) in EtOAc (0.20 mL) was added 10% Pd/C (6.4 mg). The mixture was heated at 40 °C with an oil bath and stirred at this temperature under H_2 for 2 h, after which it was filtered over Celite and the solvents were evaporated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 8:2 to 6:4) to give diol **21** (4.5 mg, 83%) as a colorless oil: R_f 0.28 (Hex/EtOAc 1:1); $[\alpha]_D^{20}$ +33 (*c* 0.48, $CHCl_3$); ^1H NMR (600 MHz, $CDCl_3$) : δ (ppm) 5.03 (t, J = 3.4 Hz, 1H, H-3), 4.71 (br s, 1H, H-1), 3.99 (dd, J = 11.6 Hz, J = 7.6 Hz, 1H, H-6a), 3.92 (t, J = 3.0 Hz, 1H, H-2_{ad}), 3.83 (ddd, J = 7.4 Hz, J = 4.2 Hz, J = 1.1 Hz, 1H, H-5), 3.78−3.76 (m, 2H, H-2, H-6b), 3.69 (d, J = 11.8 Hz, 1H, 4-O*H*), 3.56−3.54 (m, 1H, H-4), 2.16−1.50 (m, 18H, 6-O*H*, CH_{3Ac}, 5 × CH_{2ad}, 4 × CH_{ad}), 0.94 (s, 9H, C(CH_3)$_{3TBS}$), 0.19 (s, 6H, 2 x CH_{3TBS}); $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$): δ (ppm) 169.4 ($COOR_{Ac}$), 97.1 (C-1), 81.2 (C-2_{ad}), 75.8 (C-5), 72.0 (C-3), 70.0 (C-2), 67.3 (C-4), 62.8 (C-6), 37.7−27.4 (9C, 5 × CH_{2ad}, 4 × CH_{ad}), 25.9 (3C, C(CH_3)$_{3TBS}$), 21.2 (CH_{3Ac}), 18.4 (C(CH$_3$)$_{3TBS}$), −4.5 (CH_{3TBS}), −5.2 (CH_{3TBS}); HRMS (ESI-TOF) *m/z* $[M + Na]^+$ calcd for $C_{24}H_{42}NaO_7Si$ 493.2592; found 493.2615.

General method for the post-glycosylation epimerization experiments.

The glycoside (1.0 equiv) was dried under high vacuum for 1 h. Activated 4 Å MS (4 mg·mg^{-1} of glycoside) and dry toluene (20 mL·mmol^{-1}) were then added, and the suspension was stirred at rt under Ar atmosphere for 30 min. The mixture was cooled to −10 °C and TMSOTf (0.1 equiv) was added. The mixture was stirred under Ar while being allowed to gradually warm to 0 °C for a period of 1.5 h. The reaction was then quenched with Et_3N, filtered over Celite, and concentrated under reduced pressure. The crude residue was then directly analyzed by ^{1}H NMR in $CDCl_3$.

***para*-Methylphenyl 3-*O*-Benzyl-4,6-*O*-benzylidene-1-thio-*α*-D-idopyranoside (23).**

To a solution of compound **4b** (165 mg, 0.441 mmol, 1.0 equiv) in DCM (5.3 mL) were successively added NaOH 5% (1.8 mL), TBAHS (30 mg, 0.088 mmol, 0.2 equiv) and BnBr (79 μL, 0.66 mmol, 1.0 equiv). The mixture was heated at 40 °C with an oil bath and stirred at this temperature for 18 h. The mixture was then extracted with DCM (×3), dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The residue was purified by silica gel flash chromatography to give benzylated compound **23** (154 mg, 75%) as a white foam: R_f 0.5 (Hex/EtOAc 6:4); $[\alpha]_D^{20}$ +132 (*c* 1.00, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.47−7.31 (m, 12H, 12 × CH_{Ar}), 7.11−7.10 (m, 2H, 2 × CH_{STol}), 5.60 (br s, 1H, H-1), 5.54 (s, 1H, C*H*Ph), 4.85 (d, *J* = 11.8 Hz, 1H, C*H*H$_{Bn}$), 4.60 (d, *J* = 11.8 Hz, 1H, CH*H*$_{Bn}$), 4.46 (br s, 1H, H-5), 4.33 (dd, *J* = 12.6 Hz, *J* = 1.4 Hz, 1H, H-6a), 4.14−4.10 (m, 3H, H-6b, H-2, H-4), 3.83−3.81 (m, 2H, H-3, O*H*), 2.32 (s, 3H, CH_{3STol}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 137.5 (*C*$_{Ar}$), 137.4 (*C*$_{Ar}$), 137.0 (*C*$_{Ar}$), 133.6 (*C*$_{Ar}$), 130.9 (2C, 2 × *C*H$_{Ar}$), 129.8 (2C, 2 × *C*H$_{Ar}$), 129.4 (*C*H$_{Ar}$), 128.7 (2C, 2 × *C*H$_{Ar}$), 128.5 (2C, 2 × *C*H$_{Ar}$), 128.2 (*C*H$_{Ar}$), 127.9 (2C, 2 × *C*H$_{Ar}$), 126.1 (2C, 2 × *C*H$_{Ar}$), 101.7 (*C*HPh), 89.6 (C-1), 74.6 (C-4*), 73.9 (C-3), 72.5 (*C*H$_{2Bn}$), 70.2 (C-6), 67.8 (C-2*), 60.7 (C-5), 21.2 (*C*H$_{3STol}$); HRMS (ESI-TOF) *m/z* [M + NH_4]$^+$ calcd for $C_{27}H_{32}NO_5S$ 482.1996; found 482.2004.

***para*-Methylphenyl 3-*O*-Benzyl-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-1-thio-*α*-D-idopyranoside (24).**

A solution of alcohol **23** (124 mg, 0.267 mmol, 1.0 equiv) in dry DCE (4 mL) was cooled to 0 °C, and Et_3N (67 μL, 0.48 mmol, 1.8 equiv) and TBSOTf (93 μL, 0.40 mmol, 1.5 equiv) were successively added dropwise. The mixture was stirred at 0 °C under Ar atmosphere for 10 min, then quenched with Et_3N. The solvents were co-evaporated with toluene and the residue was purified by silica gel flash chromatography (Hex/EtOAc 95:5) to give silylated compound **24** (116 mg, 75%) as a white amorphous solid: R_f 0.6 (Hex/EtOAc 7:3); $[\alpha]_D^{20}$ +89 (*c* 0.88, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.54−7.52 (m, 2H, 2 × C*H*$_{Ar}$), 7.44−7.42 (m, 4H, 4 × C*H*$_{Ar}$), 7.39−7.36 (m, 2H, 2 × C*H*$_{Ar}$), 7.33−7.30 (m, 4H, 4 × C*H*$_{Ar}$), 7.12−7.10 (m, 2H, 2 × C*H*$_{STol}$), 5.53 (s, 1H, C*H*Ph), 5.50 (d, *J* = 1.6 Hz, 1H, H-1), 4.75 (d, *J* = 12.0 Hz, 1H, C*H*H$_{Bn}$), 4.70 (d, *J* = 12.0 Hz, 1H, CH*H*$_{Bn}$), 4.33−4.31 (m, 2H, H-6a, H-5), 4.15 (dd, *J* = 13.1 Hz, *J* = 2.5 Hz, 1H, H-6b), 4.07 (br s, 1, H-4), 4.04 (dd, *J* = 3.3 Hz, *J* = 2.5 Hz, 1H, H-2), 3.66 (t, *J* = 2.9 Hz, 1H, H-3), 2.33 (s, 3H, C*H*$_{3STol}$), 0.84 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.07 (s, 3H, C*H*$_{3TBS}$), −0.01 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 138.1 (*C*$_{Ar}$), 137.9 (*C*$_{Ar}$), 136.9 (*C*$_{Ar}$), 133.1 (*C*$_{Ar}$), 130.9 (2C, 2 × *C*H$_{Ar}$), 129.8 (2C, 2 × *C*H$_{Ar}$), 129.0 (*C*H$_{Ar}$), 128.6 (2C, 2 × *C*H$_{Ar}$), 128.1 (2C, 2 × *C*H$_{Ar}$), 128.0 (*C*H$_{Ar}$), 127.9 (2C, 2 × *C*H$_{Ar}$), 126.8 (2C, 2 × *C*H$_{Ar}$), 101.3 (*C*HPh), 90.0 (C-1), 77.5 (C-3), 74.2 (C-4), 72.5 (*C*H$_{2Bn}$), 70.0 (C-6), 69.5 (C-2), 60.8 (C-5), 25.9 (3C, C(*C*H$_3$)$_{3TBS}$), 21.2 (*C*H$_{3STol}$), 18.2 (*C*(CH$_3$)$_{3TBS}$), −4.7 (2C, 2 × *C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH_4]$^+$ calcd for $C_{33}H_{46}NO_5SSi$ 596.2861; found 596.2885.

1,2,3,4,6-Penta-*O*-acetyl-*α*-D-talopyranose (26).

Peracetylated *β*-D-galactopyranoside[47] **25** (5000 mg, 12.81 mmol, 1.0 equiv) was solubilized in dry DCM (63 mL). $AlCl_3$ (1110 mg, 8.326 mmol, 0.7 equiv) was added and the mixture was stirred at rt for 2 h. Then, the solution was diluted with $CHCl_3$ and washed three times with ice-cold water. After evaporation of the solvents under reduced pressure, the crude material was solubilized in dry CCl_4 (125 mL). The solution was heated to 50 °C with an oil bath and a solution of $SbCl_5$ (1.9 mL, 15 mmol, 1.2 equiv) in dry CCl_4 (7 mL) was added dropwise. The mixture was stirred at rt for 15 min under argon, after which the

resulting solid was retrieved by filtration, yielding the corresponding *talo*-configured antimony salt. The latter was solubilized in an aqueous solution of NaOAc (78 mL, 2.4 M). The mixture was stirred for 20 min at rt, then extracted three times with DCM. The organic layers were dried over $MgSO_4$, filtered, and evaporated under reduced pressure. The resulting alcohol was solubilized in dry pyridine (29 mL). The solution was cooled to 0 °C, Ac_2O (87 mL) was slowly added, and the resulting mixture was brought back to rt and stirred at this temperature for 16 h. The solution was diluted with DCM, washed three times with a 1 N aqueous HCl solution, and washed with brine. The organic layers were dried over $MgSO_4$, filtered, evaporated under reduced pressure, and co-evaporated with toluene. The residue was purified by silica gel flash chromatography to give peracetylated D-talopyranoside **26** (581 mg, 12%). Physical and analytical data agreed with those published.[35]

Ethyl 4,6-*O*-Benzylidene-1-thio-*α*-D-talopyranoside (27).

To a solution of peracetylated taloside **26** (50 mg, 0.13 mmol, 1.0 equiv) in dry DCM (0.5 mL) was added activated 4 Å MS (50 mg) and EtSH (19 μL, 0.26 mmol, 2.0 equiv). The suspension was cooled to 0 °C and TfOH (23 μL, 0.26 mmol, 2.0 equiv) was added dropwise. The mixture was allowed to gradually reach rt over a period of 1.5 h, after which the reaction was quenched by the addition of a saturated aqueous $NaHCO_3$ solution. I_2 was then added until the coloration persisted, followed by a 10% aqueous $Na_2S_2O_3$ solution until there were no more coloration. The aqueous layer was extracted with DCM (×3) and the combined organic layers were washed with brine, dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 8:2 to 7:3) to give ethyl 2,3,4,6-tetra-*O*-acetyl-1-thio-*α*-D-talopyranoside (35 mg, 70%) as a colorless oil: R_f 0.3 (Hex/EtOAc 4:6); $[\alpha]_D^{20}$ +66 (*c* 0.39, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 5.38 (s, 1H, H-1), 5.33−5.32 (m, 1H, H-4), 5.21 (t, J = 3.7 Hz, 1H, H-3), 5.18−5.17 (m, 1H, H-2), 4.63 (td, J = 6.6 Hz, J = 1.4 Hz, 1H, H-5), 4.21 (dd, J = 9.1 Hz, J = 4.6 Hz, 1H, H-6a), 4.18 (dd, J = 9.2 Hz, J = 4.0 Hz, 1H, H-6b), 2.71−2.59 (m, 2H, CH_{2SEt}), 2.15 (s, 3H, CH_{3Ac}), 2.14 (s, 3H, CH_{3Ac}), 2.05 (s, 3H, CH_{3Ac}), 1.99 (s, 3H, CH_{3Ac}), 1.32 (t, J = 7.4 Hz, 3H, CH_{3SEt}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 170.6 (*C*OOR$_{Ac}$),

170.3 (*C*OOR$_{Ac}$), 170.1 (*C*OOR$_{Ac}$), 169.6 (*C*OOR$_{Ac}$), 82.6 (C-1), 69.1 (C-2), 67.4 (C-5), 66.31, 66.29 (2C, C-3, C-4), 62.2 (C-6), 25.3 (*C*H$_{2SEt}$), 21.1 (*C*H$_{3Ac}$), 20.8 (2C, 2 × *C*H$_{3Ac}$), 20.7 (*C*H$_{3Ac}$), 14.8 (*C*H$_{3SEt}$); HRMS (ESI-TOF) *m/z* calcd for $C_{16}H_{28}NO_9S$ 410.1473; found 410.1495. The latter compound (51 mg, 0.13 mmol, 1.0 equiv) was solubilized in dry MeOH (0.8), and NaOMe (25% wt in MeOH, 5.8 μL, 0.027 mmol, 0.2 equiv) was added. The mixture was stirred at rt for 30 min, then neutralized with Dowex resin until pH = 7. The suspension was filtered over Celite and the solvents were evaporated under reduced pressure. The resulting crude tetraol was solubilized in benzaldehyde (440 μL) and TFA (22 μL) was added to the solution. The mixture was stirred at rt for 40 min under Ar atmosphere, cooled to 0 °C, and quenched by the slow addition of Et_3N. The solvents were co-evaporated with toluene and the residue was purified by silica gel flash chromatography (Hex/EtOAc 9:1 to 7:3) to give diol **27** (23 mg, 55% in 2 steps) as a colorless oil: R_f 0.23 (Hex/EtOAc 6:4); $[\alpha]_D^{20}$ +101 (*c* 0.190, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.48−7.47 (m, 2H, 2 × C*H*$_{Ar}$), 7.39−7.38 (m, 3H, 3 × C*H*$_{Ar}$), 5.52 (s, 1H, C*H*Ph), 5.50 (br s, 1H, H-1), 4.32 (dd, *J* = 12.9 Hz, *J* = 1.9 Hz, 1H, H-6a), 4.29−4.28 (m, 1H, H-4), 4.14−4.11 (m, 2H, H-6b, H-5), 3.87−3.85 (m, 2H, H-2, H-3), 3.47 (d, *J* = 11.9 Hz, 1H, O*H*), 2.95 (d, *J* = 9.7 Hz, 1H, O*H*), 2.73−2.60 (m, 2H, C*H*$_{2SEt}$), 1.32 (t, *J* = 7.4 Hz, 3H, C*H*$_{3SEt}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 137.3 (*C*$_{Ar}$), 129.5 (*C*H$_{Ar}$), 128.6 (2C, 2 × *C*H$_{Ar}$), 126.1 (2C, 2 × *C*H$_{Ar}$), 101.9 (*C*HPh), 85.9 (C-1), 77.0 (C-4), 71.8 (C-2*), 69.9 (C-6), 66.4 (C-3*), 63.2 (C-5), 25.5 (*C*H$_{2SEt}$), 15.1 (*C*H$_{3SEt}$); HRMS (ESI-TOF) *m/z* $[M + Na]^+$ calcd for $C_{15}H_{20}NaO_5S$ 335.0924; found 335.0936.

Ethyl 3-*O*-Acetyl-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-1-thio-*α*-D-talopyranoside (28).

Diol **27** (12 mg, 0.037 mmol, 1.0 equiv) was solubilized in dry acetonitrile (300 μL), and Ac_2O (3.9 μL, 0.041 mmol, 1.1 equiv) and TBAOAc (7 mg, 0.02 mmol, 0.6 equiv) were successively added. The mixture was heated at 40 °C with an oil bath and stirred at this temperature under Ar atmosphere for 6 h. Then, the solvents were co-evaporated with toluene and the residue was purified by silica gel flash chromatography (Hex/EtOAc 9:1 to 7:3) to give ethyl 3-*O*-acetyl-4,6-*O*-benzylidene-1-thio-*α*-D-

talopyranoside (13 mg, quant.) as a colorless oil: R_f 0.47 (Hex/EtOAc 6:4); $[\alpha]_D^{20}$ +167 (*c* 0.210, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.49−7.48 (m, 2H, 2 × C*H*$_{Ar}$), 7.39−7.37 (m, 3H, 3 × C*H*$_{Ar}$), 5.50 (s, 1H, C*H*Ph), 5.49 (d, *J* = 1.3 Hz, 1H, H-1), 5.03 (t, *J* = 3.3 Hz, 1H, H-3), 4.46−4.45 (m, 1H, H-4), 4.32 (dd, *J* = 12.6 Hz, *J* = 1.5 Hz, 1H, H-6a), 4.16 (br s, 1H, H-5), 4.12 (dd, *J* = 12.6 Hz, *J* = 1.7 Hz, 1H, H-6b), 4.09 (d, *J* = 11.2 Hz, 1H, O*H*), 3.97−3.95 (m, 1H, H-2), 2.74−2.61 (m, 2H, C*H*$_{2SEt}$), 2.16 (s, 3H, C*H*$_{3Ac}$), 1.32 (t, *J* = 7.4 Hz, 3H, C*H*$_{3SEt}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 170.7 (*C*OOR$_{Ac}$), 137.2 (*C*$_{Ar}$), 129.5 (*C*H$_{Ar}$), 128.5 (2C, 2 × *C*H$_{Ar}$), 126.2 (2C, 2 × *C*H$_{Ar}$), 101.7 (*C*HPh), 86.5 (C-1), 74.8 (C-4), 70.1, 69.9 (2C, C-2, C-6), 68.8 (C-3), 63.1 (C-5), 25.6 (*C*H$_{2SEt}$), 21.3 (*C*H$_{3Ac}$), 15.1 (*C*H$_{3SEt}$); HRMS (ESI-TOF) *m/z* $[M + Na]^+$ calcd for $C_{17}H_{22}NaO_6S$ 377.1029; found 377.1041. To a solution of the latter alcohol (12 mg, 0.034 mmol, 1.0 equiv) in dry DCE (510 μL) at 0 °C were successively slowly added Et_3N (8.5 μL, 0.061 mmol, 1.8 equiv) and TBSOTf (14 μL, 0.061 mmol, 1.8 equiv). The mixture was stirred at 0 °C under an Ar atmosphere for 15 min, quenched with Et_3N, and co-evaporated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 9:1 to 85:15) to give compound **28** (13 mg, 79%) as a colorless oil: R_f 0.36 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ +109 (*c* 0.420, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.56−7.54 (m, 2H, 2 × C*H*$_{Ar}$), 7.32−7.31 (m, 3H, 3 × C*H*$_{Ar}$), 5.44 (s, 1H, C*H*Ph), 5.40 (br s, 1H, H-1), 4.96 (t, *J* = 3.7 Hz, 1H, H-3), 4.31−4.28 (m, 2H, H-4, H-6a), 4.09 (dd, *J* = 12.5 Hz, *J* = 1.9 Hz, 1H, H-6b), 4.07 (br s, 1H, H-5), 3.99 (br d, *J* = 3.6 Hz, 1H, H-2), 2.71−2.56 (m, 2H, C*H*$_{2SEt}$), 2.10 (s, 3H, C*H*$_{3Ac}$), 1.31 (t, *J* = 7.4 Hz, 3H, C*H*$_{3SEt}$), 0.86 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.06 (s, 3H, C*H*$_{3TBS}$), 0.02 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 170.6 (*C*OOR$_{Ac}$), 138.3 (*C*$_{Ar}$), 128.9 (*C*H$_{Ar}$), 128.0 (2C, 2 × *C*H$_{Ar}$), 126.9 (2C, 2 × *C*H$_{Ar}$), 101.4 (*C*HPh), 86.5 (C-1), 72.5 (C-4), 70.0 (C-3), 69.8 (C-6), 69.4 (C-2), 62.8 (C-5), 25.8 (3C, C(*C*H$_3$)$_{3TBS}$), 25.2 (*C*H$_{2SEt}$), 21.3 (*C*H$_{3Ac}$), 18.4 (*C*(CH$_3$)$_{3TBS}$), 15.0 (*C*H$_{3SEt}$), −4.8 (2C, 2 × *C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* $[M + Na]^+$ calcd for $C_{23}H_{36}NaO_6SSi$ 491.1894; found 491.1895.

(2-Adamantyl) 3-*O*-Benzyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*β*-D-idopyranoside (29) and (2-Adamantyl) 3-*O*-Benzyl-(*S*)-4,6-*O*-benzylidene-*β*-D-idopyranoside (31).

Donor **24** (11.4 mg, 0.0197 mmol, 1.2 equiv), 2-adamantanol **11** (2.5 mg, 0.016 mmol, 1.0 equiv), and NIS (5.5 mg, 0.025 mg, 1.5 equiv) were dried together under high vacuum for 1 h. Then, activated 4 Å MS (46 mg) and dry DCE (330 μL) were added. The suspension was stirred at rt under Ar for 1 h, cooled to −10 °C, and AgOTf (0.8 mg, 0.003 mmol, 0.2 equiv) was added. The reaction flask was protected from light with the help of aluminum foil. The mixture was stirred for 2 h under Ar at −10 °C to 0 °C, after which it was quenched with Et_3N, filtered over Celite, and concentrated under reduced pressure. The residue was purified by silica gel flash chromatography (Tol/EtOAc 995:5 to 9:1) to give compound **29** (4.4 mg, 41%) as a colorless oil along with desilylated analogue **31** (3.5 mg, 40%) as a white amorphous solid.

Data for compound 29: R_f 0.40 (Tol/EtOAc 96:4); $[\alpha]_D^{20}$ −14 (*c* 0.55, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.55−7.53 (m, 2H, 2 × C*H*$_{Ar}$), 7.37−7.29 (m, 8H, 8 × C*H*$_{Ar}$), 5.46 (s, 1H, C*H*Ph), 4.78 (d, *J* = 1.2 Hz, 1H, H-1), 4.68 (d, *J* = 12.0 Hz, 1H, C*H*H$_{Bn}$), 4.61 (d, *J* = 12.0 Hz, 1H, CH*H*$_{Bn}$), 4.34 (d, *J* = 12.4 Hz, 1H, H-6a), 4.05 (dd, *J* = 12.5 Hz, *J* = 2.1 Hz, 1H, H-6b), 3.96 (br s, 1H, H-2$_{ad}$), 3.90 (br s, 1H, H-4), 3.75−3.74 (m, 1H, H-2), 3.72−3.71 (m, 1H, H-3), 3.63 (m, 1H, H-5), 2.22−1.42 (m, 14H, 5 × C*H*$_{2ad}$, 4 × C*H*$_{ad}$), 0.82 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.10 (s, 3H, C*H*$_{3TBS}$), 0.01 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 138.3 (*C*$_{Ar}$), 138.1 (*C*$_{Ar}$), 128.9 (*C*H$_{Ar}$), 128.7 (2C, 2 × *C*H$_{Ar}$), 128.1 (*C*H$_{Ar}$), 128.0 (2, 2 × *C*H$_{Ar}$), 127.8 (2C, 2 × *C*H$_{Ar}$), 127.0 (2C, 2 × *C*H$_{Ar}$), 101.6 (*C*HPh), 96.7 (C-1, $^1J_{C1,H1}$ = 157 Hz), 79.6, (C-3), 79.4 (C-2$_{ad}$), 73.7 (C-4), 72.6 (*C*H$_{2Bn}$), 70.1 (C-6), 69.0 (C-2), 66.9 (C-5), 37.9−27.6 (9C, 5 × *C*H$_{2ad}$, 4 × *C*H$_{ad}$), 26.0 (3C, C(*C*H$_3$)$_{3TBS}$), 18.5 (*C*(CH$_3$)$_{3TBS}$), −4.3 (*C*H$_{3TBS}$), −5.1 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* $[M + NH_4]^+$ calcd for $C_{36}H_{54}NO_6Si$ 624.3715; found 624.3733.

Data for desilylated glycoside 31: R_f 0.26 (Tol/EtOAc 96:4); $[\alpha]_D^{20}$ −36 (*c* 0.26, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.48−7.47 (m, 2H, 2 × C*H*$_{Ar}$), 7.38−7.32 (m, 8H, 8 × C*H*$_{Ar}$), 5.48 (s, 1H, C*H*Ph), 4.91 (br s, 1H, H-1), 4.67 (d, *J* = 12.5 Hz, 1H, C*H*H$_{Bn}$), 4.65 (d, *J* = 12.6 Hz, 1H, CH*H*$_{Bn}$), 4.36 (dd, *J* =

12.4 Hz, *J* = 1.0 Hz, 1H, H-6a), 4.06 (dd, *J* = 12.5 Hz, *J* = 1.8 Hz, 1H, H-6b), 3.99 (t, *J* = 1.3 Hz, 1H, H-4*), 3.94 (br s, 1H, H-2_{ad}), 3.90 (t, *J* = 2.8 Hz, 1H, H-3*), 3.75−3.73 (m, 2H, H-5, H-2), 3.14 (d, *J* = 11.2 Hz, 1H, O*H*-2), 2.22−1.47 (m, 14H, 5 × CH_{2ad}, 4 × CH_{ad}); $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$): δ (ppm) 137.7 (C_{Ar}), 137.6 (C_{Ar}), 129.3 (CH_{Ar}), 128.7 (2C, 2 × CH_{Ar}), 128.4 (2C, 2 x CH_{Ar}), 128.3 (CH_{Ar}), 127.8 (2C, 2 × CH_{Ar}), 126.3 (2C, 2 x CH_{Ar}), 101.6 (*C*HPh), 96.3 (C-1, $^1J_{C1,H1}$ = 155 Hz), 80.1 (C-2_{ad}), 77.2 (C-3*), 73.9 (C-4*), 72.7 (CH_{2Bn}), 70.0 (C-6), 68.1, 67.0 (2C, C-2, C-5), 37.7−27.5 (9C, 5 × CH_{2ad}, 4 × CH_{ad}); HRMS (ESI-TOF) *m/z* $[M + NH_4]^+$ calcd for $C_{30}H_{40}NO_6$ 510.2850; found 510.2842.

(2-Adamantyl) 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*α*-D-talopyranoside (30*α*), (2-Adamantyl) 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*β*-D-talopyranoside (30*β*) and (2-Adamantyl) 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-*α*-D-talopyranoside (32).

Donor **28** (12.2 mg, 0.026 mmol, 1.2 equiv) and 2-adamantanol (3.3 mg, 0.022 mmol, 1.0 equiv) were reacted according to the general procedure for NIS/TMSOTf-promoted glycosylation. Purification by silica gel flash chromatography (Hex/EtOAc 95:5 to 85:15) gave compounds **30*α*** (5.1 mg, 42%, colorless oil), and **32** and **30*β*** (2.3 mg, 23%, colorless oil, inseparable mixture **32**/**30*β*** 1.0:0.3).

Data for *α*-glycoside 30*α*: R_f 0.37 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ +28 (*c* 0.59, $CHCl_3$); ^1H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.55−7.54 (m, 2H, 2 × CH_{Ar}), 7.32−7.31 (m, 3H, 3 × CH_{Ar}), 5.42 (s, 1H, C*H*Ph), 5.08 (t, *J* = 3.6 Hz, 1H, H-3), 5.05 (br s, 1H, H-1), 4.31−4.29 (m, 2H, H-6a, H-4), 4.04 (dd, *J* = 12.5 Hz, *J* = 1.6 Hz, 1H, H-6b), 3.89 (br d, *J* = 3.0 Hz, 1H, H-2), 3.80 (br s, 1H, H-2_{ad}), 3.76 (br s, 1H, H-5), 2.10 (s, 3H, CH_{3Ac}), 2.06−1.49 (m, 14H, 4 × CH_{ad}, 5 × CH_{2ad}), 0.86 (s, 9H, C(CH_3)$_{3TBS}$), 0.05 (CH_{3TBS}), 0.02 (CH_{3TBS}); $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$): δ (ppm) 170.9 ($COOR_{Ac}$), 138.4 (C_{Ar}), 128.9 (CH_{Ar}), 127.9 (2C, 2 × CH_{Ar}), 127.0 (2C, 2 × CH_{Ar}), 101.4 (*C*HPh), 99.5 (C-1, $^1J_{C1,H1}$ = 172 Hz), 78.9 (C-2_{ad}), 72.4 (C-4), 69.85, 69.83 (2C, C-3, C-6), 68.8 (C-2), 62.5 (C-5), 37.6−27.4 (9C, 4 × CH_{ad}, 5 × CH_{2ad}), 25.9 (3C,

C(CH$_3$)$_{3TBS}$), 21.4 (CH$_{3Ac}$), 18.4 (C(CH$_3$)$_{3TBS}$), −4.75 (CH$_{3TBS}$), −4.84 (CH$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{36}H_{54}NO_6Si$ 624.3715; found 624.3733.

Data for desilylated *α*-glycoside 32: R_f 0.16 (Hex/EtOAc 8:2); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.49−7.47 (m, 2H, 2 × CH_{Ar}), 7.39−7.37 (m, 3H, 3 × CH_{Ar}), 5.48 (s, 1H, CHPh), 5.21 (t, J = 3.2 Hz, 1H, H-3), 5.18 (d, J = 1.6 Hz, 1H, H-1), 4.49−4.48 (m, 1H, H-4), 4.33 (dd, J = 12.5 Hz, J = 1.5 Hz, 1H, H-6a), 4.08 (dd, J = 12.5 Hz, J = 1.6 Hz, 1H, H-6b), 3.85−3.82 (m, 3H, H-2$_{ad}$, H-2, H-5), 3.78 (d, J = 11.6 Hz, OH-2), 2.18 (s, 3H, CH_{3Ac}), 2.05−1.48 (m, 14H, 5 × CH_{2ad}, 4 × CH_{ad}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 171.0 (COOR$_{Ac}$), 137.4 (C_{Ar}), 129.4 (CH$_{Ar}$), 128.5 (2C, 2 × CH$_{Ar}$), 126.2 (2C, 2 × CH$_{Ar}$), 101.6 (CHPh), 99.4 (C-1, $^1J_{C1,H1}$ = 175 Hz), 79.7 (C-2$_{ad}$), 74.9 (C-4), 69.9 (C-6), 69.2 (C-2), 68.7 (C-3), 62.8 (C-5), 37.5−27.3 (9C, 5 × CH$_{2ad}$, 4 × CH$_{ad}$), 21.4 (CH$_{3Ac}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{25}H_{36}NO_7$ 462.2486; found 462.2482.

Data for *β*-glycoside 30*β*: R_f 0.16 (Hex/EtOAc 8:2); ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.56−7.55 (m, 0.6H, 2 × CH_{Ar}), 7.32−7.30 (m, 0.9H, 3 × CH_{Ar}), 5.42 (s, 0.3H, CHPh), 4.79 (t, J = 3.6 Hz, 0.3H, H-3), 4.49−4.48 (m, 0.3H, H-1), 4.38 (dd, J = 12.4 Hz, J = 1.0 Hz, 0.3H, H-6a), 4.20 (br d, J = 3.9 Hz, 0.3H, H-4), 4.07 (dd, J = 12.5 Hz, J = 2.1 Hz, 0.3H, H-6b), 4.00−3.99 (m, 0.6H, H-2$_{ad}$, H-2), 3.31 (br s, 0.3H, H-5), 2.12 (s, 0.9H, CH_{3Ac}), 2.05−1.48 (m, 4.2H, 5 × CH_{2ad}, 4 × CH_{ad}), 0.87 (s, 3H, C(CH_3)$_{3TBS}$), 0.13 (s, 0.9H, CH_{3TBS}), 0.06 (s, 0.9H, CH_{3TBS}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$): δ (ppm) 171.0 (COOR$_{Ac}$), 138.2 (C_{Ar}), 128.8 (CH$_{Ar}$), 127.9 (2C, 2 × CH$_{Ar}$), 127.0 (2C, 2 × CH$_{Ar}$), 101.5 (CHPh), 97.9 (C-1, $^1J_{C1,H1}$ = 155 Hz), 79.7 (C-2$_{ad}$), 72.4 (C-3), 72.2 (C-4), 69.6 (C-6), 69.3 (C-2), 67.1 (C-5), 37.7−27.6 (9C, 5 × CH$_{2ad}$, 4 × CH$_{ad}$), 26.0 (3C, C(CH$_3$)$_{3TBS}$), 21.4 (CH$_{3Ac}$), 18.7 (C(CH$_3$)$_{3TBS}$), −4.1 (CH$_{3TBS}$), −4.9 (CH$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{31}H_{50}NO_7Si$ 576.3351; found 576.3338.

Allyl 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*α*-D-idopyranosyl-(1→4)-2-*O*-acetyl-3,6-di-*O*-*para*-methoxybenzyl-*α*-D-glucopyranoside (37*α*) and Allyl 3-*O*-Acetyl-(*S*)-4,6-*O*-

benzylidene-2-*O*-*tert*-butyldimethylsilyl-*β*-D-idopyranosyl-(1→4)-2-*O*-acetyl-3,6-di-*O*-*para*-methoxybenzyl-*α*-D-glucopyranoside (37*β*).

Donor **6a** (10.1 mg, 0.0215 mmol, 1.2 equiv), acceptor **33**[58] (9.0 mg, 0.018 mmol, 1.0 equiv), and tri-*tert*-butylpyridine (13.3 mg, 0.0537 mmol, 3.0 equiv) were dried together under high vacuum for 1 h. Then, activated 4 Å MS (40 mg) and dry DCE (320 μL) were added. The suspension was stirred at rt under Ar atmosphere for 1 h, after which Me_2S_2 (4.8 μL, 0.054 mmol, 3.0 equiv) and MeOTf (5.9 μL, 0.054 mmol, 3.0 equiv) were successively added. The mixture was stirred at rt for 2 h and was then quenched by adding Et_3N, filtered over Celite, and concentrated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 9:1 to 6:4) to give *α*-glycoside **37*α*** (8.3 mg, 51%) and *β*-glycoside **37*β*** (6.3 mg, 37%) as colorless oils.

Data for *α*-glycoside 37*α*: R_f 0.36 (Hex/EtOAc 6:4); $[\alpha]_D^{20}$ +16 (*c* 0.12, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.48−7.46 (m, 2H, 2 × C*H*$_{Ar}$), 7.30−7.28 (m, 5H, 5 × C*H*$_{Ar}$), 7.18−7.17 (m, 2H, 2 × C*H*$_{Ar}$), 6.90−6.88 (m, 2H, 2 × C*H*$_{Ar}$), 6.83−6.82 (m, 2H, 2 × C*H*$_{Ar}$), 5.90 (ddd, *J* = 17.0 Hz, *J* = 10.8 Hz, *J* = 5.6 Hz, 1H, C*H*$_{Allyl}$), 5.41 (s, 1H, C*H*Ph), 5.37 (d, *J* = 3.1 Hz, 1H, H-1B), 5.31 (ddd, *J* = 17.1 Hz, *J* = 3.2 Hz, *J* = 1.6 Hz, 1H, =C*H*H$_{Allyl}$), 5.21 (ddd, *J* = 10.5 Hz, *J* = 3.2 Hz, *J* = 1.2 Hz, 1H, =CH*H*$_{Allyl}$), 5.07 (d, *J* = 3.7 Hz, 1H, H-1A), 4.95 (dd, *J* = 5.1 Hz, *J* = 2.9 Hz, 1H, H-3B), 4.84 (dd, *J* = 9.8 Hz, *J* = 3.7 Hz, 1H, H-2A), 4.71 (d, *J* = 11.0 Hz, 1H, C*H*H$_{PMB}$), 4.65 (d, *J* = 11.0 Hz, 1H, CH*H*$_{PMB}$), 4.56 (d, *J* = 11.7 Hz, 1H, C*H*H$_{PMB}$), 4.53 (d, *J* = 11.7 Hz, 1H, CH*H*$_{PMB}$), 4.21 (ddt, *J* = 13.3 Hz, *J* = 5.0 Hz, *J* = 1.5 Hz, 1H, C*H*H$_{Allyl}$), 4.10 (dd, *J* = 12.8 Hz, *J* = 0.9 Hz, 1H, H-6Ba*), 4.04−4.01 (m, 2H, CH*H*$_{Allyl}$, H-3A), 3.97 (t, *J* = 9.3 Hz, 1H, H-4A), 3.89 (t, *J* = 2.3 Hz, 1H, H-4B), 3.84 (dd, *J* = 12.8 Hz, *J* = 2.1 Hz, 1H, H-6Bb*), 3.81−3.80 (m, 4H, H-5A, C*H*$_{3PMB}$), 3.77 (s, 3H, C*H*$_{3PMB}$), 3.73−3.70 (m, 3H, H-2B, H-6Aa*, H-6Ab*), 3.69 (br d, *J* = 1.4 Hz, 1H, H-5B), 2.10 (s, 3H, C*H*$_{3Ac}$), 1.94 (s, 3H, C*H*$_{3Ac}$), 0.78 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.03 (s, 3H, C*H*$_{3TBS}$), 0.02 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) : δ (ppm) 169.5 (2C, 2 × *C*OOR$_{Ac}$), 159.4 (*C*$_{Ar}$), 159.1 (*C*$_{Ar}$), 137.9 (*C*$_{Ar}$), 133.8 (*C*H$_{Allyl}$), 130.7−126.7 (11C, 9 × *C*H$_{Ar}$, 2 × *C*$_{Ar}$), 117.7 (=*C*H$_{2Allyl}$), 113.9 (4C, 4 x *C*H$_{Ar}$), 101.4 (C-1B, $^1J_{C1,H1}$ = 175 Hz), 101.1 (*C*HPh), 95.0 (C-1A, $^1J_{C1,H1}$

= 176 Hz), 80.3 (C-3A), 74.5 (C-4B), 74.0 (CH$_{2PMB}$), 73.8 (C-2A), 73.3 (CH$_{2PMB}$), 73.2 (C-4A), 72.6 (C-3B), 70.8 (C-5A), 69.4 (C-6B*), 68.9 (C-6A*), 68.5, 68.4 (2C, CH$_{2Allyl}$, C-2B), 60.8 (C-5B), 55.4 (2C, 2 x CH$_{3PMB}$), 25.8 (3C, C(CH$_3$)$_{3TBS}$), 21.4 (CH$_{3Ac}$), 21.0 (CH$_{3Ac}$), 18.0 (C(CH$_3$)$_{3TBS}$), −4.3 (CH$_{3TBS}$), −4.7 (CH$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{48}H_{68}NO_{15}Si$ 926.4353; found 926.4367.

Data for *β*-glycoside 37*β*: R_f 0.20 (Hex/EtOAc 6:4); $[\alpha]_D^{20}$ +16 (*c* 0.66, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.56−7.54 (m, 2H, 2 × C$H$$_{Ar}$), 7.43−7.42 (m, 2H, 2 × C$H$$_{Ar}$), 7.30−7.29 (m, 3H, 3 × C$H$$_{Ar}$), 7.24−7.23 (m, 2H, 2 × C$H$$_{Ar}$), 6.87−6.84 (m, 2H, 2 × C$H$$_{Ar}$), 6.72−6.70 (m, 2H, 2 × C$H$$_{Ar}$), 5.92−5.86 (m, 1H, C$H$$_{Allyl}$), 5.47 (s, 1H, C$H$Ph), 5.32−5.29 (m, 1H, =CHH$_{Allyl}$), 5.26 (d, *J* = 9.7 Hz, 1H, CHH$_{PMB}$), 5.21 (dd, *J* = 10.4 Hz, *J* = 1.4 Hz, 1H, CHH_{Allyl}), 5.10 (d, *J* = 3.9 Hz, 1H, H-1A), 5.01 (t, *J* = 2.4 Hz, 1H, H-3B), 4.82 (dd, *J* = 10.1 Hz, *J* = 3.9 Hz, 1H, H-2A), 4.76 (d, *J* = 0.9 Hz, 1H, H-1B), 4.53−4.48 (m, 3H, CHH_{PMB}, CH_{2PMB}), 4.30 (br d, *J* = 12.2 Hz, 1H, H-6Ba), 4.19 (ddt, *J* = 13.2 Hz, *J* = 5.1 Hz, *J* = 1.5 Hz, 1H, CHH$_{Allyl}$), 4.08 (t, *J* = 9.3 Hz, 1H, H-4A), 4.03 (ddt, *J* = 13.3 Hz, *J* = 6.2 Hz, *J* = 1.2 Hz, 1H, CHH_{Allyl}), 3.98−3.93 (m, 2H, H-3A, H-6Bb), 3.82−3.80 (m, 4H, CH_{3PMB}, H-5A), 3.77 (br s, 1H, H-4B), 3.72 (dd, *J* = 11.2 Hz, *J* = 1.7 Hz, 1H, H-6Aa), 3.65−3.62 (m, 5H, CH_{3PMB}, H-2B, H-6Ab), 3.48 (br d, *J* = 1.0 Hz, 1H, H-5B), 2.12 (s, 3H, CH_{3Ac}), 1.96 (s, 3H, CH_{3Ac}), 0.81 (s, 9H, C(CH_3)$_{3TBS}$), 0.10 (s, 3H, CH_{3TBS}), 0.05 (s, 3H, CH_{3TBS}); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) : δ (ppm) 170.4 (COOR$_{Ac}$), 169.0 (COOR$_{Ac}$), 159.3 (C_{Ar}), 159.2 (C_{Ar}), 138.3 (C_{Ar}), 133.7 (CH$_{Allyl}$), 131.4−127.0 (11C, 2 × C_{Ar}, 9 × CH$_{Ar}$), 117.9 (=CH$_{2Allyl}$), 113.9 (2C, 2 × CH$_{Ar}$), 113.8 (2C, 2 × CH$_{Ar}$), 101.7 (CHPh), 99.8 (C-1B, $^1J_{C1,H1}$ = 160.0 Hz), 95.1 (C-1A, $^1J_{C1,H1}$ = 174.4 Hz), 78.2, 78.1 (2C, C-4A, C-3A), 75.9 (CH$_{2PMB}$), 73.2, 73.1, 73.0 (3C, CH$_{2PMB}$, C-2A, C-3B), 72.2 (C-4B), 70.7 (C-5A), 69.3 (C-6B), 68.6 (C-6A), 68.4 (CH$_{2Allyl}$), 67.8, 67.4 (2C, C-2B, C-5B), 55.4 (CH$_{3PMB}$), 55.3 (CH$_{3PMB}$), 25.8 (3C, C(CH$_3$)$_{3TBS}$), 21.1 (CH$_{3Ac}$), 21.0 (CH$_{3Ac}$), 18.3 (C(CH$_3$)$_{3TBS}$), −4.3 (CH$_{3TBS}$), −5.0 (CH$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{48}H_{68}NO_{15}Si$ 926.4353; found 926.4359.

Allyl 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*α*-D-idopyranosyl-(1→2)-3-*O*-*para*-methoxybenzyl-4,6-*O*-*para*-methoxybenzylidene-*α*-D-glucopyranoside (38).

Donor **6a** (10.6 mg, 0.0227 mmol, 1.2 equiv), acceptor **34**[58] (8.0 mg, 0.017 mmol, 1.0 equiv), and tri-*tert*-butylpyridine (13.0 mg, 0.0523 mmol, 3.0 equiv) were dried together under high vacuum for 1 h. Then, activated 4 Å MS (43 mg) and dry DCE (310 μL) were added. The suspension was stirred at rt under Ar atmosphere for 1 h, after which Me_2S_2 (4.7 μL, 0.052 mmol, 3.0 equiv) and MeOTf (5.7 μL, 0.052 mmol, 3.0 equiv) were successively added. The mixture was stirred at rt for 2 h and was then quenched by adding Et_3N, filtered over Celite, and concentrated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 9:1 to 6:4) to give *α*-glycoside **38** (8.6 mg, 57%) as a colorless oil: R_f 0.48 (Hex/EtOAc 6:4); $[\alpha]_D^{20}$ +49 (*c* 0.87, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.51−7.50 (m, 2H, 2 × C*H*$_{Ar}$), 7.40−7.39 (m, 2H, 2 × C*H*$_{Ar}$), 7.31−7.30 (m, 3H, 3 × C*H*$_{Ar}$), 7.27−7.26 (m, 2H, 2 × C*H*$_{Ar}$), 6.90−6.89 (m, 2H, 2 × C*H*$_{Ar}$), 6.87−6.85 (m, 2H, 2 × C*H*$_{Ar}$), 5.91 (dddd, *J* = 17.0 Hz, *J* = 10.4 Hz, *J* = 6.5 Hz, *J* = 5.2 Hz, 1H, C*H*$_{Allyl}$), 5.53 (s, 1H, C*H*Ph$_{OMe}$*), 5.43 (s, 1H, C*H*Ph*), 5.32 (dq, *J* = 17.2 Hz, *J* = 1.5 Hz, 1H, =C*H*H$_{Allyl}$), 5.23 (dq, *J* = 10.4 Hz, *J* = 1.2 Hz, =CH*H*$_{Allyl}$), 5.05 (d, *J* = 2.6 Hz, 1H, H-1A), 4.96 (t, *J* = 2.7 Hz, 1H, H-3B), 4.93 (br s, 1H, H-1B), 4.83 (d, *J* = 10.4 Hz, 1H, C*H*H$_{PMB}$), 4.69 (d, *J* = 10.4 Hz, 1H, CH*H*$_{PMB}$), 4.26 (dd, *J* = 10.2 Hz, *J* = 4.9 Hz, 1H, H-6Aa), 4.22 (ddt, *J* = 12.9 Hz, *J* = 5.2 Hz, *J* = 1.3 Hz, 1H, C*H*H$_{Allyl}$), 4.14 (dd, *J* = 12.7 Hz, *J* = 1.1 Hz, 1H, H-6Ba), 4.09 (br d, *J* = 1.3 Hz, 1H, H-5B), 4.01 (ddt, *J* = 13.0 Hz, *J* = 6.6 Hz, *J* = 1.2 Hz, 1H, CH*H*$_{Allyl}$), 3.96−3.95 (m, 2H, H-2A, H-3A), 3.89−3.85 (m, 2H, H-5A, H-4B), 3.81 (s, 6H, C*H*$_{3PMB}$, C*H*$_{3PhOMe}$), 3.75−3.76 (m, 2H, H-6Ab, H-2B), 3.69 (dd, *J* = 12.7 Hz, *J* = 1.7 Hz, 1H, H-6Bb), 3.65−3.62 (m, 1H, H-4A), 2.08 (s, 3H, C*H*$_{3Ac}$), 0.86 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.11 (s, 3H, C*H*$_{3TBS}$), 0.11 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) : δ (ppm) 169.6 (*C*OOR$_{Ac}$), 160.1 (*C*$_{Ar}$), 159.5 (*C*$_{Ar}$), 138.0 (*C*$_{Ar}$), 133.5−126.7 (11C, 2 × *C*$_{Ar}$, 9 × *C*H$_{Ar}$), 118.5 (=*C*H$_{2Allyl}$), 113.9 (2C, 2 x *C*H$_{Ar}$), 113.7 (2C, 2 × *C*H$_{Ar}$), 101.4 (*C*HPh$_{OMe}$*), 101.3 (*C*HPh*), 98.2 (C-1B, $^1J_{C1,H1}$ = 171 Hz), 95.2 (C-1A, $^1J_{C1,H1}$ = 172 Hz), 82.3 (C-4A), 77.4 (C-3A*), 75.1 (*C*H$_{2PMB}$), 73.6 (C-2A*), 73.0 (C-4B), 71.7 (C-3B), 69.4 (C-6B), 69.1 (C-6A), 68.6 (*C*H$_{2Allyl}$), 67.2 (C-2B), 62.6 (C-5A), 59.4 (C-5B), 55.5 (*C*H$_{3OMe}$),

55.4 (CH$_{3OMe}$), 25.8 (3C, C(CH$_3$)$_{3TBS}$), 21.4 (CH$_{3Ac}$), 18.1 (C(CH$_3$)$_{3TBS}$), −4.7 (CH$_{3TBS}$), −4.9 (CH$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{46}H_{64}NO_{14}Si$ 882.4093; found 882.4091.

Allyl 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*α*-D-idopyranosyl-(1→4)-3-*O*-*tert*-butyldimethylsilyl-2-deoxy-2-trichloroacetamido-*β*-D-glucopyranoside (39a) and Allyl 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*α*-D-idopyranosyl-(1→3)-3-*O*-*tert*-butyldimethylsilyl-2-deoxy-2-trichloroacetamido-*β*-D-glucopyranoside (39b).

Donor **6a** (10.2 mg, 0.0217 mmol, 1.2 equiv), acceptor **35**[56] (8.0 mg, 0.017 mmol, 1.0 equiv), and tri-*tert*-butylpyridine (12.4 mg, 0.0501 mmol, 3.0 equiv) were dried together under high vacuum for 1 h. Then, activated 4 Å MS (41 mg) and dry DCE (300 μL) were added. The suspension was stirred at rt under Ar atmosphere for 1 h, after which Me_2S_2 (4.5 μL, 0.050 mmol, 3.0 equiv) and MeOTf (5.5 μL, 0.050 mmol, 3.0 equiv) were successively added. The mixture was stirred at rt for 2 h and was then quenched by adding Et_3N, filtered over Celite, and concentrated under reduced pressure. The residue was purified by silica gel flash chromatography (Tol/EtOAc 95:5 to 8:2) to give (1→4)-linked *α*-glycoside **39a** (1.2 mg, 8%) and (1→3)-linked *α*-glycoside **39b** (4.4 mg, 30%) as colorless oils.

Data for (1→4)-linked *α*-glycoside 39a: R_f 0.57 (Tol/EtOAc 8:2); $[\alpha]_D^{20}$ −5.6 (*c* 0.25, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.52−7.51 (m, 2H, 2 × CH_{Ar}), 7.33−7.32 (m, 3H, 3 × CH_{Ar}), 6.96 (d, *J* = 6.1 Hz, 1H, N*H*), 5.87 (ddd, *J* = 22.3 Hz, *J* = 11.0 Hz, *J* = 5.8 Hz, 1H, CH_{Allyl}), 5.49 (s, 1H, C*H*Ph), 5.43 (d, *J* = 2.8 Hz, 1H, H-1B), 5.28 (dd, *J* = 17.3 Hz, *J* = 1.6 Hz, 1H, =C*H*H$_{Allyl}$), 5.22 (dd, *J* = 10.4 Hz, *J* = 1.3 Hz, 1H, =CH*H*$_{Allyl}$), 4.97 (t, *J* = 3.6 Hz, 1H, H-3B), 4.72 (d, *J* = 7.9 Hz, 1H, H-1A), 4.36−4.31 (m, 2H, H-6Ba, C*H*H$_{Allyl}$), 4.17 (td, *J* = 9.7 Hz, *J* = 4.2 Hz, 1H, H-3A), 4.11−4.08 (m, 2H, H-6Bb, CH*H*$_{Allyl}$), 3.98−3.95 (m, 2H, H-4B, H-6Aa), 3.89 (br d, *J* = 1.4 Hz, 1H, H-5B), 3.84 (dd, *J* = 11.3 Hz, *J* = 5.5 Hz, 1H, H-6Ab), 3.79 (dd, *J* = 4.3 Hz, *J* = 2.9 Hz, 1H, H-2B), 3.72 (t, *J* = 8.7 Hz, 1H, H-4A), 3.44 (ddd, *J* = 9.9 Hz, *J* = 7.9 Hz, *J* = 6.2 Hz, 1H, H-2A), 3.40 (ddd, *J* = 8.0 Hz, *J* = 4.8 Hz, *J* = 2.0 Hz, 1H, H-5A), 3.20 (d, *J* = 4.6 Hz, 1H, O*H*-3), 2.09 (s, 3H, CH_{3Ac}), 0.91 (s, 9H, C(CH_3)$_{3TBS}$), 0.84 (s, 9H, C(CH_3)$_{3TBS}$), 0.11

(s, 3H, CH_{3TBS}), 0.09 (s, 6H, 2 × CH_{3TBS}), 0.08 (s, 3H, CH_{3TBS}); $^{13}C\{^{1}H\}$ NMR (150 MHz, $CDCl_3$) : δ (ppm) 169.5 (COOR$_{Ac}$), 162.6 (CONH), 137.8 (C_{Ar}), 133.4 (CH$_{Allyl}$), 129.1 (CH$_{Ar}$), 128.2 (2C, 2 x CH$_{Ar}$), 126.7 (2C, 2 × CH$_{Ar}$), 118.5 (=CH$_{2Allyl}$), 101.8 (C-1B, $^{1}J_{C1,H1}$ = 175 Hz), 101.2 (CHPh), 98.1 (C-1A, $^{1}J_{C1,H1}$ = 164 Hz), 76.1 (C-5A), 75.1 (C-4A), 73.9 (C-4B), 73.3 (C-3A), 72.3 (C-3B), 70.0, 69.7 (2C, CH$_{2Allyl}$, C-6B), 68.0 (C-2B), 62.9 (C-6A), 61.0 (C-5B), 59.6 (C-2A), 26.1 (3C, C(CH$_3$)$_{3TBS}$), 25.8 (3C, C(CH$_3$)$_{3TBS}$), 21.3 (CH$_{3Ac}$), 18.6 (C(CH$_3$)$_{3TBS}$), 18.1 (C(CH$_3$)$_{3TBS}$), -4.6 (CH$_{3TBS}$), −4.7 (CH$_{3TBS}$), −4.9 (CH$_{3TBS}$), −5.0 (CH$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{38}H_{64}Cl_2[^{37}Cl]N_2O_{12}Si_2$ 903.3039; found 903.3040.

Data for (1→3)-linked *α*-glycoside 39b: R_f 0.48 (Tol/EtOAc 8:2); $[\alpha]_D^{20}$ +8.2 (*c* 0.44, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.51−7.50 (m, 2H, 2 × CH_{Ar}), 7.32−7.31 (m, 3H, 3 × CH_{Ar}), 6.69 (d, J = 8.9 Hz, 1H, NH), 5.83 (ddd, J = 16.9 Hz, J = 10.8 Hz, J = 5.6 Hz, 1H, CH_{Allyl}), 5.53 (d, J = 2.7 Hz, 1H, H-1B), 5.47 (s, 1H, CHPh), 5.27 (dd, J = 17.2 Hz, J = 1.5 Hz, 1H, =CHH$_{Allyl}$), 5.17 (dd, J = 10.4 Hz, J = 1.3 Hz, 1H, =CHH_{Allyl}), 4.90 (t, J = 3.4 Hz, 1H, H-3B), 4.57 (d, J = 8.3 Hz, 1H, H-1A), 4.32 (dd, J = 12.9 Hz, J = 5.0 Hz, 1H, CHH$_{Allyl}$), 4.29 (d, J = 12.8 Hz, 1H, H-6Ba), 4.05−3.98 (m, 3H, CHH_{Allyl}, H-6Bb, H-6Aa), 3.92−3.91 (m, 3H, H-4A, H-4B, H-5B), 3.83 (t, J = 3.4 Hz, 1H, H-2B), 3.82−3.75 (m, 3H, H-2A, H-3A, H-6Ab), 3.59 (d, J = 1.2 Hz, 1H, OH-4), 3.40 (ddd, J = 9.1 Hz, J = 7.7 Hz, J = 4.8 Hz, 1H, H-5A), 2.10 (s, 3H, CH_{3Ac}), 0.90 (s, 9H, C(CH_3)$_{3TBS}$), 0.84 (s, 9H, C(CH_3)$_{3TBS}$), 0.12 (s, 3H, CH_{3TBS}), 0.11 (s, 3H, CH_{3TBS}), 0.11 (s, 3H, CH_{3TBS}), 0.08 (s, 3H, CH_{3TBS}); $^{13}C\{^{1}H\}$ NMR (150 MHz, $CDCl_3$) : δ (ppm) 170.0 (COOR$_{Ac}$), 161.8 (CONH), 137.9 (C_{Ar}), 133.5 (CH$_{Allyl}$), 129.1 (CH$_{Ar}$), 128.1 (2C, 2 × CH$_{Ar}$), 126.7 (2C, 2 × CH$_{Ar}$), 118.0 (=CH$_{2Allyl}$), 101.8 (C-1B, $^{1}J_{C1,H1}$ = 175 Hz), 101.3 (CHPh), 99.9 (C-1A, $^{1}J_{C1,H1}$ = 164 Hz), 77.9 (C-4A*), 76.4 (C-3A), 73.7 (C-4B*), 72.9 (C-5A), 72.0 (C-3B), 70.12, 70.08 (2C, CH$_{2Allyl}$, C-6B), 67.9 (C-2B), 65.6 (C-6A), 60.6 (C-5B), 56.1 (C-2A), 25.9 (3C, C(CH$_3$)$_{3TBS}$), 25.8 (3C, C(CH$_3$)$_{3TBS}$), 21.3 (CH$_{3Ac}$), 18.2 (C(CH$_3$)$_{3TBS}$), 18.1 (C(CH$_3$)$_{3TBS}$), −4.7 (CH$_{3TBS}$), −4.8 (CH$_{3TBS}$), −5.47 (CH$_{3TBS}$), −5.51 (CH$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{38}H_{64}Cl_2[^{37}Cl]N_2O_{12}Si_2$ 903.3039; found 903.3067.

***tert*-Butyldimethylsilyl 3-*O*-Acetyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*α*-D-idopyranosyl-(1→4)-3,6-di-*O*-benzyl-2-deoxy-2-trichloroacetamido-*β*-D-glucopyranoside (40).**

Donor **6b** (14.6 mg, 0.0275 mmol, 1.2 equiv), acceptor **36**[57] (14.2 mg, 0.0229 mmol, 1.0 equiv), and tri-*tert*-butylpyridine (17.1 mg, 0.0688 mmol, 3.0 equiv) were dried together under high vacuum for 1 h. Then, activated 4 Å MS (58 mg) and dry DCE (410 μL) were added. The suspension was stirred at rt under Ar atmosphere for 1 h, after which Me_2S_2 (6.1 μL, 0.069 mmol, 3.0 equiv) and MeOTf (7.5 μL, 0.069 mmol, 3.0 equiv) were successively added. The mixture was stirred at rt for 2 h and was then quenched by adding Et_3N, filtered over Celite, and concentrated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 95:5 to 8:2) to give α-glycoside **40** (6.9 mg, 29%) as a colorless oil: R_f 0.52 (Hex/EtOAc 7:3); $[\alpha]_D^{20}$ +29 (*c* 0.68, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.48−7.47 (m, 2H, 2 × C*H*$_{Ar}$), 7.37−7.33 (m, 5H, 5 × C*H*$_{Ar}$), 7.30−7.28 (m, 7H, 7 × C*H*$_{Ar}$), 7.24−7.23 (m, 1H, C*H*$_{Ar}$), 7.03 (d, *J* = 7.8 Hz, 1H, N*H*), 5.43 (s, 1H, C*H*Ph), 5.34 (d, *J* = 2.4 Hz, 1H, H-1B), 5.12 (d, *J* = 7.0 Hz, 1H, H-1A), 4.94 (t, *J* = 3.7 Hz, 1H, H-3B), 4.73 (d, *J* = 10.9 Hz, 1H, C*H*H$_{Bn}$), 4.63 (d, *J* = 11.0 Hz, 1H, CH*H*$_{Bn}$), 4.60 (s, 2H, C*H*$_{2Bn}$), 4.18 (t, *J* = 8.4 Hz, 1H, H-3A), 4.13−4.10 (m, 2H, H-6Aa, H-4A), 3.91 (br s, 1H, H-4B), 3.87 (br d, *J* = 12.3 Hz, 1H, H-6Ab), 3.83 (dd, *J* = 10.8 Hz, *J* = 2.7 Hz, 1H, H-6Ba), 3.77−3.75 (m, 2H, H-6Bb, H-5B), 3.69 (t, *J* = 3.5 Hz, 1H, H-2B), 3.63−3.58 (m, 2H, H-2A, H-5A), 2.09 (s, 3H, C*H*$_{3Ac}$), 0.89 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.74 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.15 (s, 3H, C*H*$_{3TBS}$), 0.12 (s, 3H, C*H*$_{3TBS}$), 0.02 (s, 3H, C*H*$_{3TBS}$), −0.02 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) : δ (ppm) 169.5 (*C*OOR$_{Ac}$), 161.9 (*C*ONH), 138.3 (*C*$_{Ar}$), 137.8 (*C*$_{Ar}$), 137.6 (*C*$_{Ar}$), 129.9−126.6 (15C, 15 × *C*H$_{Ar}$), 101.2 (*C*HPh), 100.7 (C-1B, $^1J_{C1,H1}$ = 175 Hz), 94.1 (C-1A, $^1J_{C1,H1}$ = 163 Hz), 79.4 (C-3A), 75.2 (C-5A), 74.1 (C-4B), 73.9 (*C*H$_{2Bn}$), 72.5 (*C*H$_{2Bn}$), 72.2 (C-3B), 71.6 (C-4A), 69.6 (C-6B), 69.3 (C-6A), 68.2 (C-2B), 60.7 (C-5B), 59.5 (C-2A), 25.8 (3C, C(*C*H$_3$)$_{3TBS}$), 25.7 (3C, *C*(CH$_3$)$_{3TBS}$), 21.4 (*C*H$_{3Ac}$), 18.0 (*C*(CH$_3$)$_{3TBS}$), 17.9 (*C*(CH$_3$)$_{3TBS}$), −4.1 (*C*H$_{3TBS}$), −4.5 (*C*H$_{3TBS}$), −4.7 (*C*H$_{3TBS}$), −5.0 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* $[M + NH_4]^+$ calcd for $C_{49}H_{72}Cl_3N_2O_{12}Si_2$ 1041.3684; found 1041.3683.

***tert*-Butyldimethylsilyl 3-*O*-Benzyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*α*-D-idopyranosyl-(1→4)-3,6-di-*O*-benzyl-2-deoxy-2-trichloroacetamido-*β*-D-glucopyranoside (41*α*) and *tert*-Butyldimethylsilyl 3-*O*-Benzyl-(*S*)-4,6-*O*-benzylidene-2-*O*-*tert*-butyldimethylsilyl-*β*-D-idopyranosyl-(1→4)-3,6-di-*O*-benzyl-2-deoxy-2-trichloroacetamido-*β*-D-glucopyranoside (41*β*).**

Donor **24** (11.2 mg, 0.0194 mmol, 1.2 equiv), acceptor **36**[57] (10.0 mg, 0.0162 mmol, 1.0 equiv), and tri-*tert*-butylpyridine (12.0 mg, 0.0485 mmol, 3.0 equiv) were dried together under high vacuum for 1 h. Then, activated 4 Å MS (45 mg) and dry DCE (290 μL) were added. The suspension was stirred at rt under Ar atmosphere for 1 h, after which Me_2S_2 (4.3 μL, 0.049 mmol, 3.0 equiv) and MeOTf (5.3 μL, 0.049 mmol, 3.0 equiv) were successively added. The mixture was stirred at rt for 2 h and was then quenched by adding Et_3N, filtered over Celite, and concentrated under reduced pressure. The residue was purified by silica gel flash chromatography (Hex/EtOAc 95:5 to 75:25) to give *α*-glycoside **41*α*** (10.1 mg, 58%) as a colorless oil along with *β*-glycoside **41*β*** (1.4 mg, 8%) as a white amorphous solid.

Data for *α*-glycoside 41*α*: R_f 0.41 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ +27 (*c* 0.84, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.45−7.44 (m, 2H, 2 × C*H*$_{Ar}$), 7.35−7.25 (m, 18H, 18 × C*H*$_{Ar}$), 6.97 (d, *J* = 7.8 Hz, 1H, N*H*), 5.43 (s, 1H, C*H*Ph), 5.30 (d, *J* = 4.6 Hz, 1H, H-1B), 5.13 (d, *J* = 7.4 Hz, 1H, H-1A), 4.82 (d, *J* = 10.8 Hz, 1H, C*H*H$_{Bn}$), 4.71 (d, *J* = 11.8 Hz, 1H, C*H*H$_{Bn}$), 4.63 (d, *J* = 11.8 Hz, 1H, CH*H*$_{Bn}$), 4.61−4.59 (m, 2H, C*H*H$_{Bn}$, CH*H*$_{Bn}$), 4.55 (d, *J* = 12.2 Hz, 1H, CH*H*$_{Bn}$), 4.21 (dd, *J* = 9.7 Hz, *J* = 8.2 Hz, 1H, H-3A), 4.09−4.06 (m, 2H, H-4A, H-6Aa*), 4.04 (t, *J* = 2.5 Hz, 1H, H-4B), 3.87 (dd, *J* = 12.8 Hz, *J* = 2.2 Hz, 1H, H-6Ab*), 3.74−3.70 (m, 2H, H-2B, H-6Ba*), 3.67−3.59 (m, 4H, H-6Bb*, H-5B, H-5A, H-3B), 3.54 (dt, *J* = 10.4 Hz, *J* = 7.6 Hz, 1H, H-2A), 0.89 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.80 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.15 (s, 3H, C*H*$_{3TBS}$), 0.12 (s, 3H, C*H*$_{3TBS}$), 0.05 (s, 3H, C*H*$_{3TBS}$), −0.01 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) : δ (ppm) 161.8 (*C*ONH), 138.5 (*C*$_{Ar}$), 138.3 (*C*$_{Ar}$), 138.0 (*C*$_{Ar}$), 137.9 (*C*$_{Ar}$), 129.0−126.5 (20C, 20 × *C*H$_{Ar}$), 101.1 (C-1B, $^1J_{C1,H1}$ = 175 Hz), 100.5 (*C*HPh), 94.2 (C-1A, $^1J_{C1,H1}$ = 162 Hz), 80.4 (C-5A*), 80.0 (C-3A), 77.7 (C-4B), 75.0 (C-3B*), 73.6 (*C*H$_{2Bn}$), 72.8 (*C*H$_{2Bn}$), 72.6 (*C*H$_{2Bn}$), 71.6 (C-4A), 71.1 (C-

2B), 69.5 (C-6B*), 69.3 (C-6A*), 61.9 (C-5B), 60.2 (C-2A), 26.0 (3C, C(CH$_3$)$_{3TBS}$), 25.8 (3C, C(CH$_3$)$_{3TBS}$), 18.2 (C(CH$_3$)$_{3TBS}$), 18.0 (C(CH$_3$)$_{3TBS}$), −3.8 (CH$_{3TBS}$), −4.0 (CH$_{3TBS}$), −4.4 (CH$_{3TBS}$), −5.1 (CH$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{54}H_{76}Cl_2[^{37}Cl]N_2O_{11}Si_2$ 1091.4035; found 1091.3980.

Data for *β*-glycoside 41*β*: R_f 0.31 (Hex/EtOAc 8:2); $[\alpha]_D^{20}$ −7.5 (*c* 0.20, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) : δ (ppm) 7.53−7.51 (m, 4H, 4 × CH_{Ar}), 7.33−7.28 (m, 11H, 11 × CH_{Ar}), 7.26−7.23 (m, 3H, 3 × CH_{Ar}), 7.13−7.12 (m, 2H, 2 × CH_{Ar}), 6.98 (d, *J* = 7.4 Hz, 1H, N*H*), 5.46 (s, 1H, C*H*Ph), 5.39 (d, *J* = 9.5 Hz, 1H, C*H*H$_{Bn}$), 5.20 (d, *J* = 7.8 Hz, 1H, H-1A), 4.88 (br s, 1H, H-1B), 4.66 (d, *J* = 11.9 Hz, 1H, C*H*H$_{Bn}$), 4.58 (d, *J* = 11.8 Hz, CH*H*$_{Bn}$), 4.54 (d, *J* = 12.3 Hz, 1H, C*H*H$_{Bn}$), 4.45 (d, *J* = 12.3 Hz, 1H, CH*H*$_{Bn}$), 4.43 (d, *J* = 9.5 Hz, 1H, CH*H*$_{Bn}$), 4.24 (d, *J* = 12.6 Hz, 1H, H-6Ba), 4.14−4.07 (m, 2H, H-3A, H-4A), 3.97 (dd, *J* = 12.6 Hz, *J* = 2.1 Hz, 1H, H-6Bb), 3.89 (br s, 1H, H-4B*), 3.76−3.74 (m, 2H, H-6Aa, H-2B), 3.69 (t, *J* = 2.4 Hz, 1H, H-3B*), 3.63 (dd, *J* = 11.0 Hz, *J* = 3.6 Hz, 1H, H-6Ab), 3.54 (s, 1H, H-5B), 3.52−3.51 (m, 1H, H-5A), 3.36 (td, *J* = 9.9 Hz, *J* = 7.6 Hz, 1H, H-2A), 0.89 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.76 (s, 9H, C(C*H*$_3$)$_{3TBS}$), 0.13 (s, 3H, C*H*$_{3TBS}$), 0.10 (s, 3H, C*H*$_{3TBS}$), 0.05 (s, 3H, C*H*$_{3TBS}$), −0.05 (s, 3H, C*H*$_{3TBS}$); ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) : δ (ppm) 161.7 (*C*ONH), 138.4 (2C, 2 × C_{Ar}), 138.3 (C_{Ar}), 137.9 (C_{Ar}), 129.6−127.1 (20C, 20 × *C*H$_{Ar}$), 101.8 (*C*HPh), 99.7 (C-1B, $^1J_{C1,H1}$ = 158 Hz), 94.5 (C-1A, $^1J_{C1,H1}$ = 162 Hz), 79.2 (C-3B*), 78.2, 77.8 (2C, C-3A, C-4A), 75.9 (*C*H$_{2Bn}$), 75.3 (C-5A), 73.1 (*C*H$_{2Bn}$), 72.7, 72.6 (2C, *C*H$_{2Bn}$, C-4B*), 69.7 (C-6B), 68.8 (C-6A), 68.5 (C-2B), 67.5 (C-5B), 60.9 (C-2A), 25.8 (18C, 2 × C(*C*H$_3$)$_{3TBS}$), 18.3 (*C*(CH$_3$)$_{3TBS}$), 18.1 (*C*(CH$_3$)$_{3TBS}$), −4.0 (*C*H$_{3TBS}$), −4.1 (*C*H$_{3TBS}$), −4.9 (*C*H$_{3TBS}$), −5.1 (*C*H$_{3TBS}$); HRMS (ESI-TOF) *m/z* [M + NH$_4$]$^+$ calcd for $C_{54}H_{76}Cl_2[^{37}Cl]N_2O_{11}Si_2$ 1091.4035; found 1091.4047.

DFT Calculations.

3D models of simplified compounds **22a**−**22c** were generated on Spartan Student v8 and a conformer search was done with these models using MMFF force field. The conformers were then subjected to a

geometrical optimization with the help of Gaussian[61] using the functional and basis set B3LYP/6-31G+(d,p). All DFT calculation were done using an ultrafine grid. Interaction with the solvent (dichloroethane) was taken into account with the polarizable continuum model (IEF-PCM). The thermochemical parameters were derived from the calculation of the frequencies, which was also used to confirm that true minima were obtained. The values of free energies were extracted to compute the Boltzmann distribution, which was used to select the conformers that would be used for further calculations (>1%). Thermochemical parameters of the selected conformers were again determined using the level of theory B3LYP/6-311++G(2d,2p) and the Boltzmann distribution was computed with the extracted values. ^{1}H and ^{13}C chemical shifts of the selected conformers were predicted in chloroform through the calculation of the shielding tensors at the level of theory mPW1PW91/6-311+G(2d,p). The shielding tensors were averaged based on the respective Boltzmann weight of each conformer determined for both levels of theory (B3LYP/6-31G+(d,p) and B3LYP/6-311G++(2d,2p), and the chemical shifts were derived by scaling the shielding tensors against the experimental values. Theoretical ^{1}H-^{1}H coupling constants were determined by NMR single-point calculation and were again averaged based on the respective Boltzmann weight of each conformer determined for both levels of theory. Interproton distances were extracted from the optimized geometries on Spartan.

ASSOCIATED CONTENT

Supporting Information

1D and 2D NMR spectra for all new compounds; X-ray crystallographic data for **20a** (Tables S1-S5, Fig. S1); 3D coordinates, energy, abundance, theoretical NMR data, and theoretical interproton distances calculated for *in silico* compounds (Table S6-S27); and CIF file.

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Notes

The authors declare no competing financial interest.

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