CONTROLLING THE SIDE CHAIN CONFORMATION AND THE ANOMERIC SELECTIVITY OF *GLUCO*- AND *GALACTO*-HEXOPYRANOSYL DONORS WITH THE AID OF A DUMMY LIGAND

by

NICOLAS OSORIO-MORALES

(Under the Direction of DAVID CRICH)

ABSTRACT

The use of a dummy ligand to control the conformation of the side chain of hexopyranosyl donors is described. The effect of the dummy ligand in the anomeric selectivity is evaluated with in glycosylation reactions with different glycosyl acceptors. The results of the glycosylations showed excellent equatorial selectivities in the case of *galacto* donors. For *gluco* donors with side chain with *gg* conformation preferred equatorial substitution whereas the *gt* conformation gave no selectivity. Deprotection of glycosides was carried in one single step with Raney-nickel hydrogenolysis.

INDEX WORDS: glycosylation, side chain conformation, desulfurization.

CONTROLLING THE SIDE CHAIN CONFORMATION AND THE ANOMERIC SELECTIVITY OF *GLUCO*- AND *GALACTO*-HEXOPYRANOSYL DONORS WITH THE AID OF A DUMMY LIGAND

by

NICOLAS OSORIO-MORALES

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2022

CONTROLLING THE SIDE CHAIN CONFORMATION AND THE ANOMERIC SELECTIVITY OF *GLUCO*- AND *GALACTO*-HEXOPYRANOSYL DONORS WITH THE AID OF A DUMMY LIGAND

by

NICOLAS OSORIO-MORALES

Major Professor: David Crich
Committee: Christopher Newton
Vladimir Popik

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
December 2022

DEDICATION

To my Mom and Dad and, my sisters Diana and Mafe.

ACKNOWLEDGEMENTS

I am very thankful with Fulbright Colombia and Colombia Cientifica for awarding me with the scholarship Fulbright Pasaporte a la Ciencia. This award made me realize that I have the capabilities to face the toughest challenges for those who study abroad, away from home, especially when the world was paralized in one of the hardest times of human kind history.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SCHEMES

ABBREVIATION LIST

Å	Anstrong
Ac	Acetyl
AWMS	Acid Washed Molecular Sieves
ax	Axial
Boc	*tert*-Butyloxicarbonyl
COSY	Correlation Spectroscopy
DMP	Dess-Martin Periodinane
eq	equatorial
Equiv.	Equivalents
HBD	Hydrogen Bond Donors
HMBC	Heteronuclear Multiple Bond Correlation
HSQC	Heteronuclear Single Quantum Coherence Spectroscopy
LG	Leaving group
NGP	Neighboring group participation
NOESY	Nuclear Overhauser Effect Spectroscopy
PO or OP	Protecting group
PTSA	*p*-toluensulfonic acid
Trt	trityl

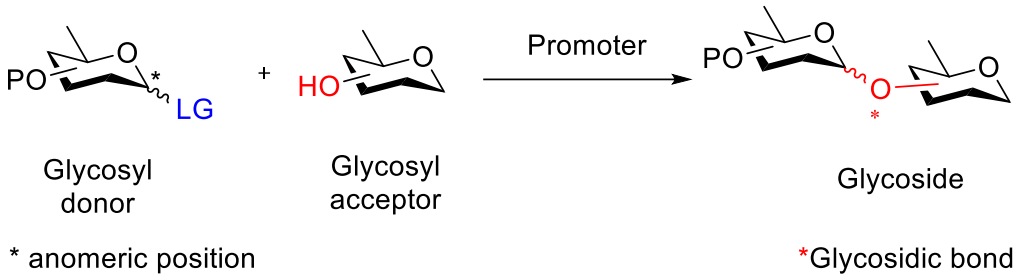
CHAPTER 1

INTRODUCTION

Proteins, nucleic acids and carbohydrates are the constituents of life. Proteins are involved mostly in structural and signaling processes, and nucleic acids are responsible for carrying the genetical information of living beings. Carbohydrates on the other hand, have multiple functions within the animal bodies ranging from acting as energy providers to formation of structural scaffolds.[1] Therefore, chemists have been intrigued to find methods that allow them to obtain complex carbohydrates that can be applied in benefit to the human race. Such methods can be chemical synthesis or biological synthesis. Both have their advantages and disadvantages. For example, syntheses of carbohydrates using bacteria to produce highly selective and complex carbohydrates have been developed.[1] However, the principal disadvantage is that bacteria are limited just to produce small quantities in the range of μg's. To the contrary, chemical methods can give good quantities (ranging from mg to g) but with low selectivity usually leading to complex mixtures affecting the construction of more complex carbohydrates.[2] Nevertheless, chemists have invested huge effort in developing new methods to overcome this problem.

To have an accurate approach to develop methods and strategies to synthesize selectively carbohydrates, it is necessary to look at the glycosylation reaction. This reaction can be defined in several ways, one of which is as a reaction that forms a glycosidic bond between two glycosyl moieties (monomers) a glycosyl donor and a glycosyl acceptor (Figure 1). A glycosyl donor is that carbohydrate unit where the anomeric position is attached to a leaving group, and a glycosyl

acceptor is that carbohydrate with a hydroxyl group that works as a nucleophile substituting the leaving group at the anomeric position producing a glycoside (Scheme 1). This reaction is one of the most important reactions in organic chemistry and it has been widely studied by many scientists, especially its mechanism that is crucial to design methodologies that lead to stereo and regioselective control of the glycosides.[3]



Scheme 1. General scheme for the glycosylation reaction.

Before getting into details of the reaction mechanism of glycosylation, it is necessary to mention the possible products of this reaction. First, regioselectivity of glycosylation indicates the hydroxyl group at a certain position at which the glycosyl acceptor will make the substitution to form a glycosidic bond. For example, when a fully deprotected glycosyl acceptor is part of a reaction, without considering the difference in reactivity of each hydroxyl group, the substitution can take place with any of the free hydroxyl groups giving 1→2, 1→3, 1→4, 1→6, and 1→1 linkages. Moreover, two glucose units with a 1→4 glycosidic linkage can form maltose or cellobiose, just as the same units but 1→6 linked form isomaltose and gentiobiose (Figure 1).[1]

The orientation of the glycosidic bond in these pairs of molecules are different. Maltose has a 1→4 linkage with an axial (generally α) orientation in the anomeric carbon while cellobiose has an equatorial orientation (generally β) (Figure 1).

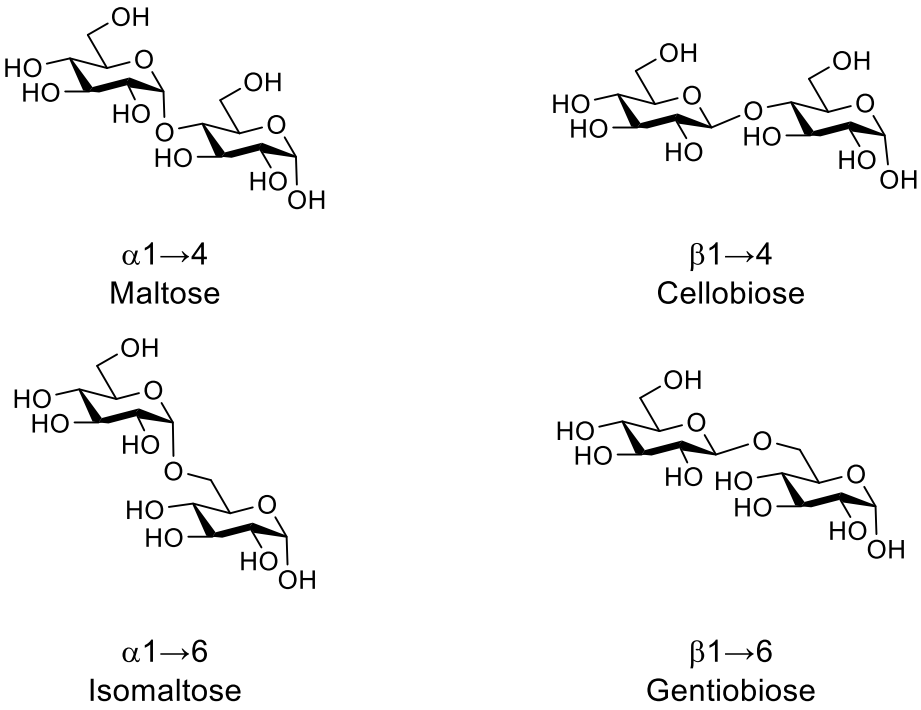


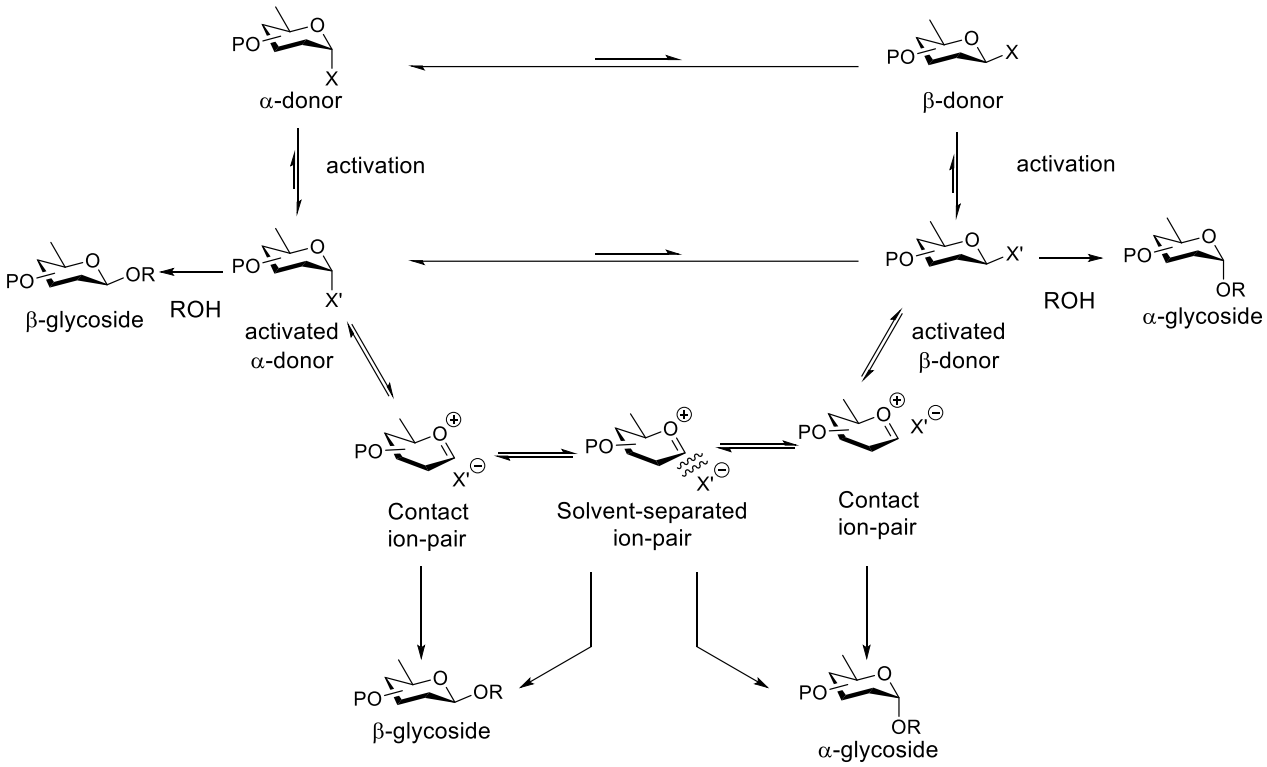
Figure 1. Some of the regio and stereoisomers of maltose.

With these possibilities in mind, a glycosylation reaction can give multiple products in an often unpredictable manner.[1] To minimize these difficulties chemists rely upon protecting groups to achieve regioselective substitution. In the literature there are plenty of examples of strategies to get regioselective glycosylations within few steps. However, to date diastereoselective glycosylations that lead to a single α- or β-substitutions are still challenging and usually α,β-mixtures (mixture of anomers), are obtained. Faced with these problems, many authors have come up with interesting methods to control the stereoselectivity of glycosylations.

Mechanism of glycosylation

To give a better insight of the strategies for stereoselective glycosylations it is necessary to describe the importance of the reaction mechanism. Understanding how the substitution by a glycosyl acceptor works can assist chemists in designing strategies to obtain one single anomer. Due to the vast diversity in carbohydrate moieties, currently there is not just one single

mechanism widely accepted by scientists. There are many mechanisms that apply in different cases, for instance a Fischer glycosylation is carried out by a different pathway than a Koenigs-Knorr reaction, thus, every different strategy may have its own pathway towards the final glycoside. However, through the years, the mechanism of glycosylation has been widely studied leading to generalities that can be applied to every glycosylation reaction.



Scheme 2. Reaction mechanism map of glycosylation reaction.

Since in essence a glycosylation is a substitution reaction, the mechanism can be narrowed down to an S_N1 and an S_N2 type reaction. Depending on the conditions a reaction can go by either pathway; the problem arises when both mechanisms come into play, leading to unpredictable selectivity. In Scheme 2 an entire map of the equilibrium of a glycosylation reaction is presented. Starting from an α-donor, the glycosyl donor is activated by the promoter in a covalent manner forming an activated glycosyl donor allowing the glycosyl acceptor to do the substitution following an S_N2 mechanism and therefore provoking an inversion of the

orientation in the anomeric position. On the other hand, a β-donor will take place in an analogous manner to give α-glycoside. However, the covalent activated donor is in equilibrium with the corresponding ion pair (Scheme 2) forming an oxocarbenium ion that undergoes an S_N1 type substitution resulting in a mixture of anomers. Therefore, the reaction mechanism of a glycosylation reaction is best described as a continuum equilibrium between the S_N1 and S_N2 pathways (Scheme 2).[3] Finding a strategy to favor the S_N2 mechanism over the S_N1 is one key to obtaining stereoselective glycosylations. In the literature there are many methods that follow the general pathway while blocking either the α- or β-face with the corresponding inversion in the anomeric position. These methods include the use of an ester group at C2, which is known as neighboring group participation; the use of transition metals, chiral catalysts and other strategies that favor α- or β-selectivity will be described next.

Stereodirecting participation

Before going into detail of stereodirecting participation, it is necessary to describe the orientation of the glycosidic bond in geometrical terms. In Figure 2, the orientation of the anomeric bond is explained in relation with the orientation of the hydroxyl group at C2. For instance, glucose with the anomeric bond in β-position can also be described as having 1,2-*trans* equatorial geometry. Correspondingly, the α-anomer has the 1,2-*cis* axial geometry; for mannose, the C2 hydroxyl is in the axial orientation making the α-anomer have a 1,2-*trans* axial geometry and the β-anomer for mannose has the 1,2-*cis* equatorial geometry.[4]

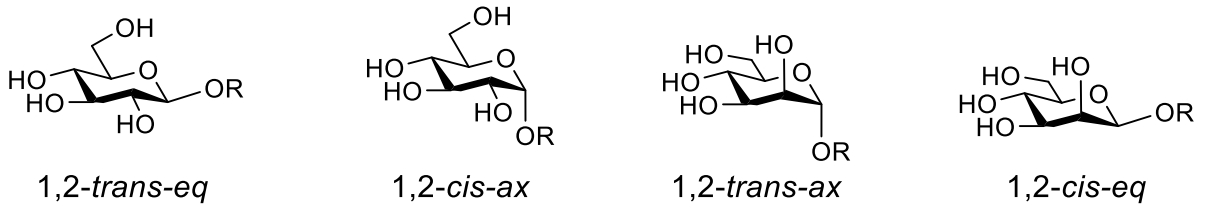
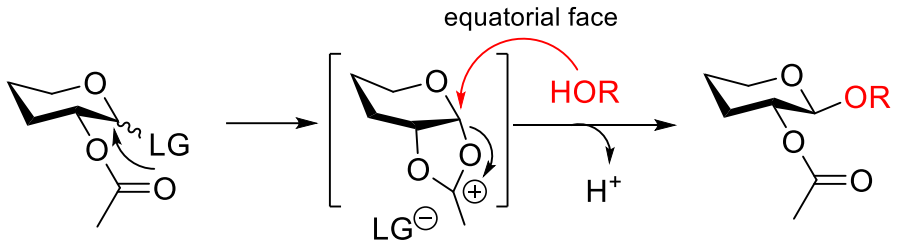


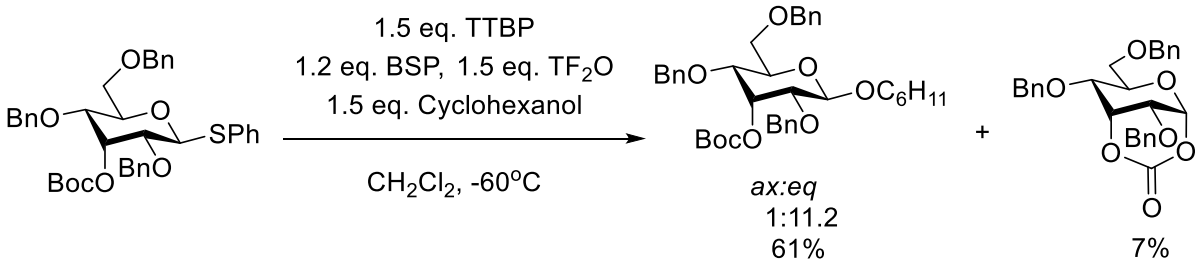
Figure 2. Correlation of C2 group orientation with the glycosidic bond.

Nowadays, the use of stereodirecting esters has become one of the most effective strategies to obtain selectively 1,2-*trans* glycosides. This strategy involves an ester type moiety at C2 that stabilizes the developing positive charge in the anomeric position forming an acyloxonium ion as an intermediate in the glycosylation, blocking the *cis*-face and leaving the opposite face available for the glycosyl acceptor to do the nucleophilic attack forming the 1,2-*trans* glycoside (Scheme 3). [5]



Scheme 3. Neighboring group participation via acyloxonium ion intermediate.

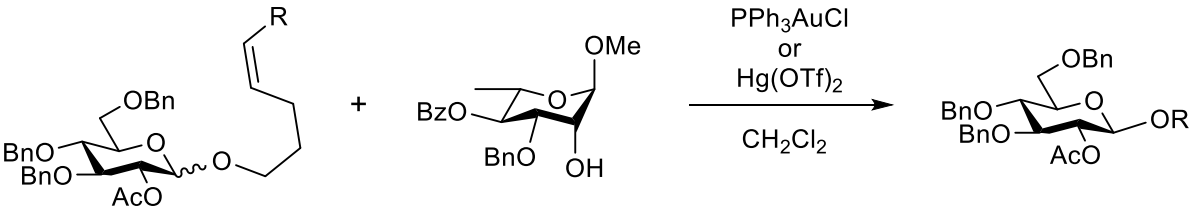
Crich and coworkers studied the participation of esters at C3, C4 and C6 finding that distal group participation (Participation by ester groups different to C2) is not a main reaction pathway in glycosylation reactions with the exception of axial esters at the 3-position. This puts the participating group near the anomeric position forming 1,3-carbonates as a byproduct as well as the glycoside with excellent equatorial selectivity (Scheme 4)[6]. A paper from 2021 by the same lab further showed that distal group participation is not the main intermediate in glycosylations, employing donors with axial esters at the 4-position. [7]



Scheme 4. Non-Vicinal group participation by C-3 carbonate intermediate.

Transition metals promoted glycosylations

The best-known example of transition metal-promoted glycosylation by a glycosyl halide is the Koenigs-Knorr reaction.[8] This reaction employs a glycosyl halide as donor with activation by silver carbonate in the presence of the alcohol acceptor to give the corresponding glycoside. After the Koenigs-Knorr strategy, few advances were made until the burst of organometallic catalysts. Transition metals are the center of catalytic cycles and they can also act as Lewis acids to promote glycosylations, however to be considered as a metal-catalyzed glycosylation the reaction has to go through a catalytic cycle.[9] A recent example using a gold or mercury catalyst with *O*-pentenyl donors shows good β-selectivity (Scheme 5). The metal atom coordinates to the alkene moiety prompting a 5-*exo*-*trig* cyclization-derived intermediate that later works as a leaving group to form the glycoside in the presence of a hydroxyl moiety. In this case, the transition metal catalyst is part of a catalytic cycle, however, these reactions were conducted with the presence of neighboring ester groups at C2 which makes them β-selective.[10]

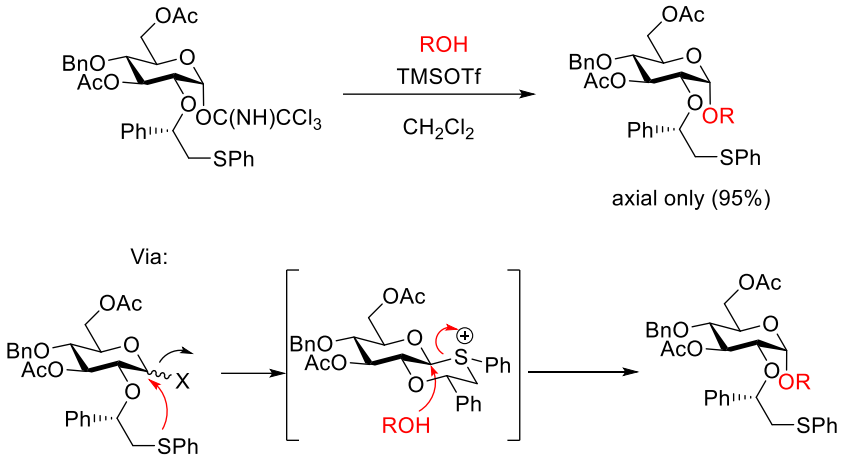


Scheme 5. Gold catalyzed glycosylation with directing group participation.

Glycosylation promoted by chiral catalysts or auxiliaries

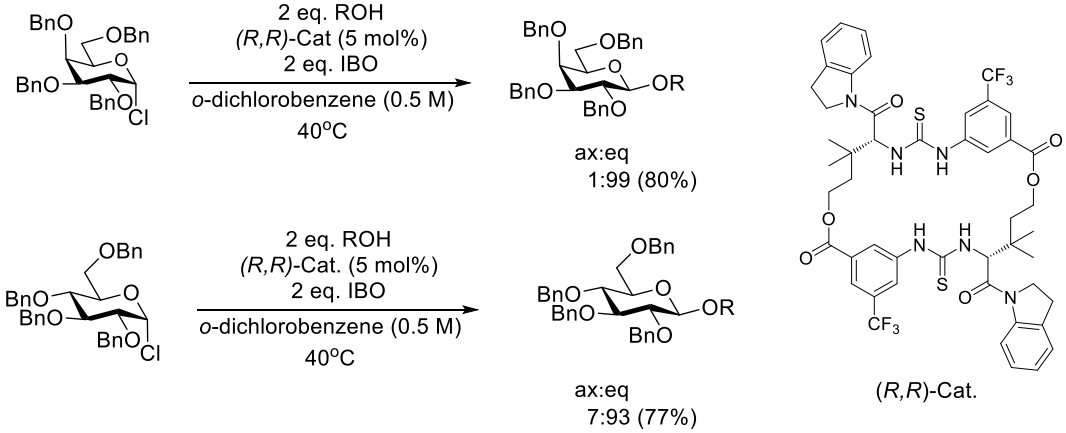
Employing any kind of chiral catalyst, auxiliary or stereodirecting group can favor one or the other anomer in a glycosylation. An interesting example to obtain 1,2-*cis* glycosides is described by Boons and coworkers where they use a chiral auxiliary with a pendant (1*S*)-phenyl-2-(phenylsulfanyl)ethyl chiral moiety at C2, which undergo neighboring group participation through a fused *trans*-decalin sulfonium ion intermediate that blocks the equatorial face of the

donor allowing the nucleophilic attack to take place only on the α-face giving exclusively the α-anomer with good yields (Scheme 6).[11]



Scheme 6 Chiral neighboring group participation by a (*1S*)-phenyl-2-(phenylsulfanyl)ethyl chiral moiety.

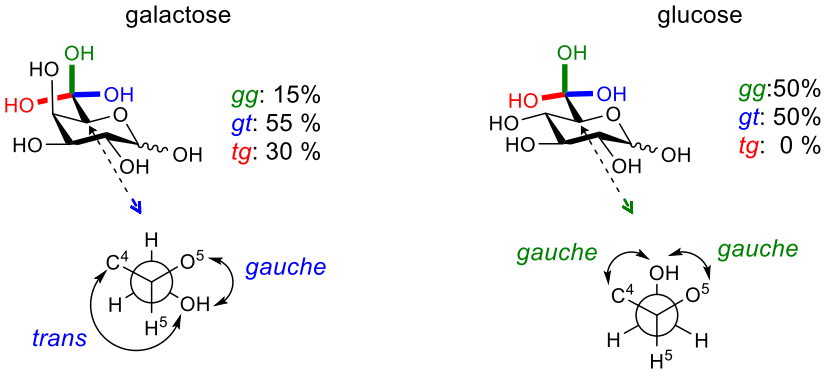
The use of chiral catalysts has been employed effectively for stereoselective glycosylation. Jacobsen and coworkers reported the use of a high β-selective chiral hydrogen-bond-donor HBD catalyst. This type of catalyst has been studied by the same group in multiple asymmetric reactions. A macrocyclic HBD catalyst is employed in conjunction with a glycosyl halide donor giving α:β selectivities up to 1:99. The catalyst interacts with the α-glycosyl halide blocking the axial face as well as guiding the glycosyl acceptor via hydrogen bond towards the equatorial face (Scheme 7).[12]



Scheme 7. Hydrogen bond donor chiral catalyst for stereoselective glycosylations.

Side chain conformation and its influence in glycosylation reactions.

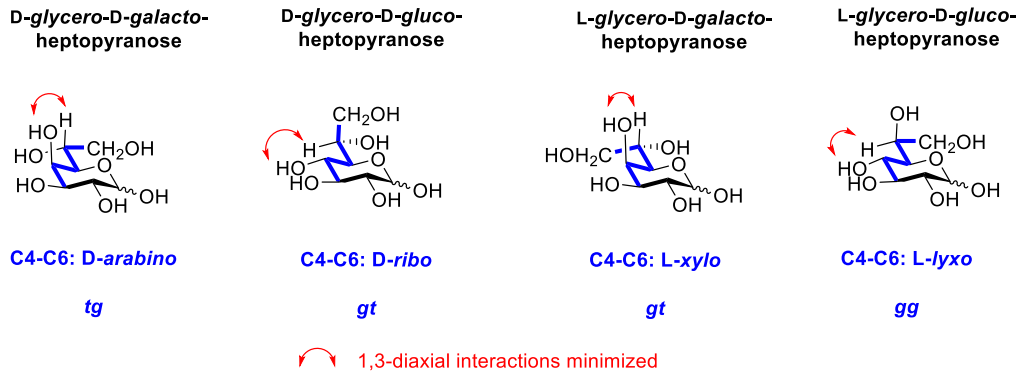
To understand the role of the side chain it is important to explain how the possible conformations of the C-C exoclyclic bond (side chain) in the hepto and hexopyranosides are described. First, since C5-C6 bond rotates freely the conformations are in equilibrium. As seen from a Newman projection, the exocyclic C5-C6 bond can potentially adopt any of three staggered conformations. To describe unambiguously the position of the hydroxyl group a pair of letters is used to indicate the corresponding correlations, the first letter describes the O5-O6 correlation and the second letter describes the C4-O6 correlation.[13] As described in Scheme 8, *gt* is the side chain conformation where O6 has a *gauche* correlation with O5 and a *trans* correlation with C4. For glucose, *gg* and *gt* side chain conformation are typically equally populated, and the *tg* conformation is nearly unpopulated.[14]



Scheme 8. Side chain conformations of galactose and glucose.

In the heptopyranose series, the relative equilibrium is determined by the C4-C6 stereotriad having that major conformation with a 1,3-diaxial interaction minimized. This determines the orientation of H6, generally in the same plane with O4. Analogously, H4 is orientated in such a way that it minimizes the 1,3-diaxial interactions (Scheme 9). The D-*glycero*-D-*galacto* configuration adopts the *tg* side chain conformation; the L-*glycero*-D-*galacto* configuration adopts the *gt* side chain conformation; and the D-*glycero*-D-*gluco* configuration

adopts the *gt* side chain conformation and the L-*glycero*-D-*gluco* configuration adopts the *gg* side chain conformation.[15]



Scheme 9. Possible side chain conformations for heptopyranoses.

With the corresponding conformations in mind, Bols and coworkers evaluated the spontaneous hydrolysis of three different diastereoisomers with the three possible side chain conformations *gg*, *gt* and *tg*. The results showed that reactivity decreases following the sequence *gg*> *gt*>*tg*.[16] Crich and coworkers similarly evaluated the effect of the side chain conformations in three diastereoisomers of galactose finding the same correlation in the relative reaction rates. (*gg*> *gt*>*tg*) (Figure 3).[17]

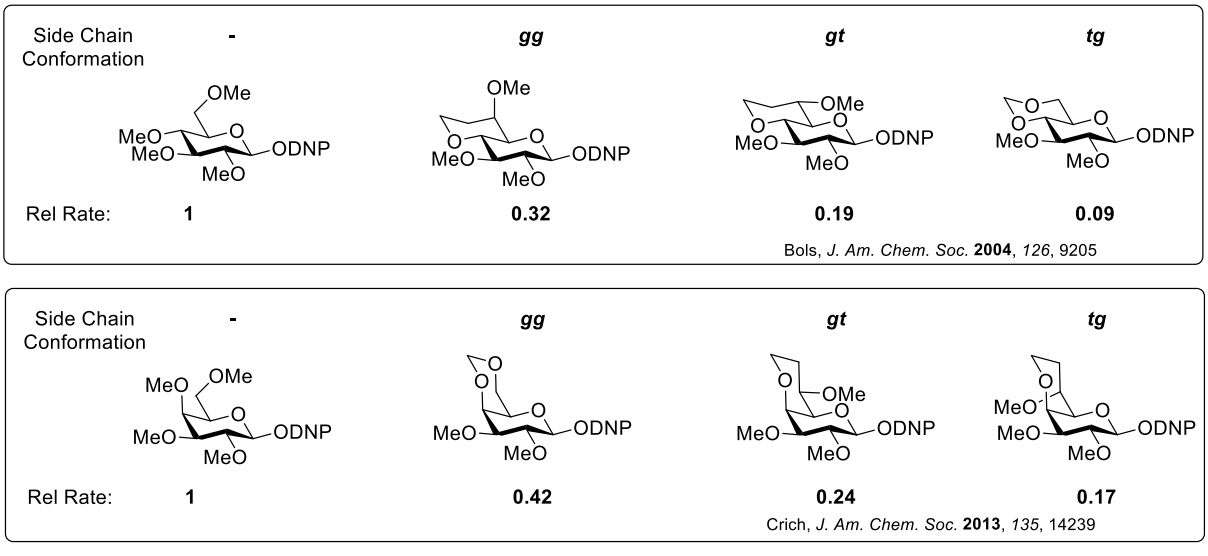


Figure 3. Relative reaction rate of spontaneous hydrolysis of glucose and galactose with fixed side chain conformation.[16-17]

The influence of side chain on reactivity arises from its relative ability to stabilize the developing partial charge on the anomeric center and ring oxygen. A priori, the side chain with the *gg* conformation stabilizes the partial positive charge by electrostatic interactions making the oxocarbenium intermediate have a longer life time and therefore the reaction follows an S_N1 mechanism losing selectivity. The *tg* side chain conformation destabilizes the forming positive charge making the glycosyl donor less reactive thus favoring a covalent activated glycosyl donor following an S_N2 pathway and albeit more selective.

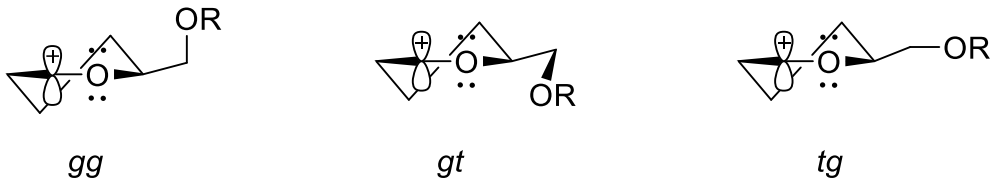


Figure 4. Side chain influence on the anomeric position.

These electronic effects on the partial charge at the anomeric center are comparable to the influence of the C4-O4 bond in the pair galactose and glucose. The hydroxyl group at C4 in glucose is pointing away from the ring oxygen disfavoring the positive charge formed making glucose less reactive. The galactose C4-O4 is axially orientated stabilizing the positive charge by electrostatic interactions making the life time of the oxocarbenium ion longer (Figure 5).

Figure 5. Relative influence of O4 orientation in galactose and glucose.

These experiments gave the first insights into the effect of the side chain conformation on reactivity, stablishing that anomeric selectivity can be influenced if the side chain conformation is restricted.

A common way to fix the side chain conformation is the use of benzylidene acetals, which in the case of glucose can only afford the *tg* conformation and in galactose only the *gg* conformation, therefore the options are limited. Crich and coworkers evaluated the effect of the side chain conformation in heptopyranosyl donors by the addition of a methyl group to the 6-position of hexopyranosides via the Grignard reaction. The methyl group addition in galactose resulted in two diastereoisomers that preferentially adopted the *tg* and the *gt* side chain conformations. In glucose the corresponding addition gave two diastereoisomers with the predominant *gg* and *gt* conformations. The anomeric selectivity of these methylated donors was evaluated with different alcohols and glycosyl acceptors. The findings showed that controlling the side chain conformation is an effective strategy to achieve stereoselective glycosylations. The heptopyranosyl donor with the *gluco* configuration and the *gg* side chain conformation was found to be the most selective additionally for a hydrogen bond with the acceptor and directing it to equatorial substitution. Galactose configuration for the heptopyranosyl donor with the *tg* conformation proved to be more selective than the donor with the *gt* conformation as expected (Figure 6).[18]

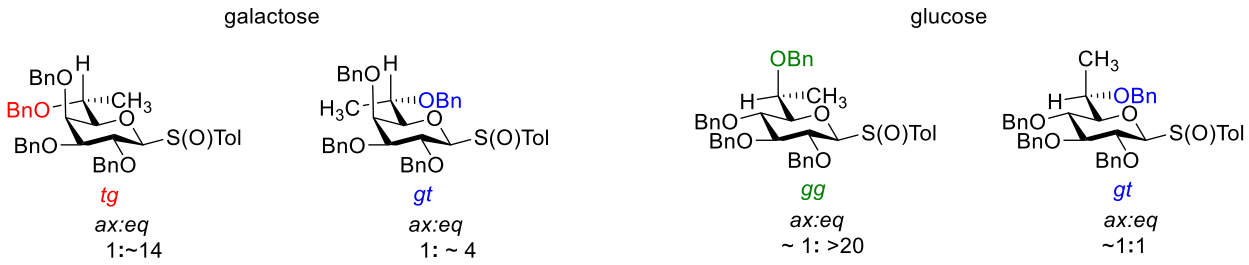


Figure 6. Heptopyranosyl donors and the anomeric selectivity.

Research problem

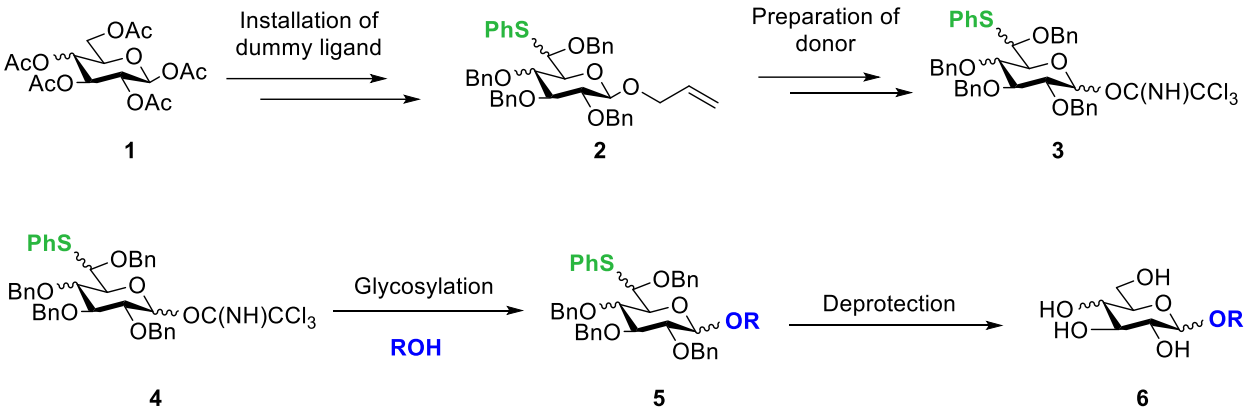
The goal of the research outlined in the thesis was to develop a strategy to mimic the effect of the methyl group at 6-position to control the side chain conformation and consequently the anomeric selectivity in hexopyranosyl donors. This could be achieved by the installation of a group with similar electronegativity and steric properties, that could be easily installed and removed (a dummy ligand) in further steps after glycosylations to obtain the free hexopyranoside form. Additionally, this dummy ligand must be stable under typical glycosylation conditions. These requirements were considered to be met by a thioether moiety, specifically by a thiophenyl group, resulting in the overall goal of the synthesis of such derivatives, the analysis of their conformations, the study of selectivity in glycosylation reactions employing them, and finally their removal.

CHAPTER 2

RESULTS AND DISCUSSION

Strategy for the installation of the dummy ligand

Following the considerations described above, the synthesis of the corresponding monothioacetal **2** started with both β-D-glucose and β-D-galactose O-pentaacetate. First it was found that allyl glycosides were suitable to protect the anomeric position mainly because removing this moiety can be done without removing the dummy ligand with strong conditions (Scheme 10).



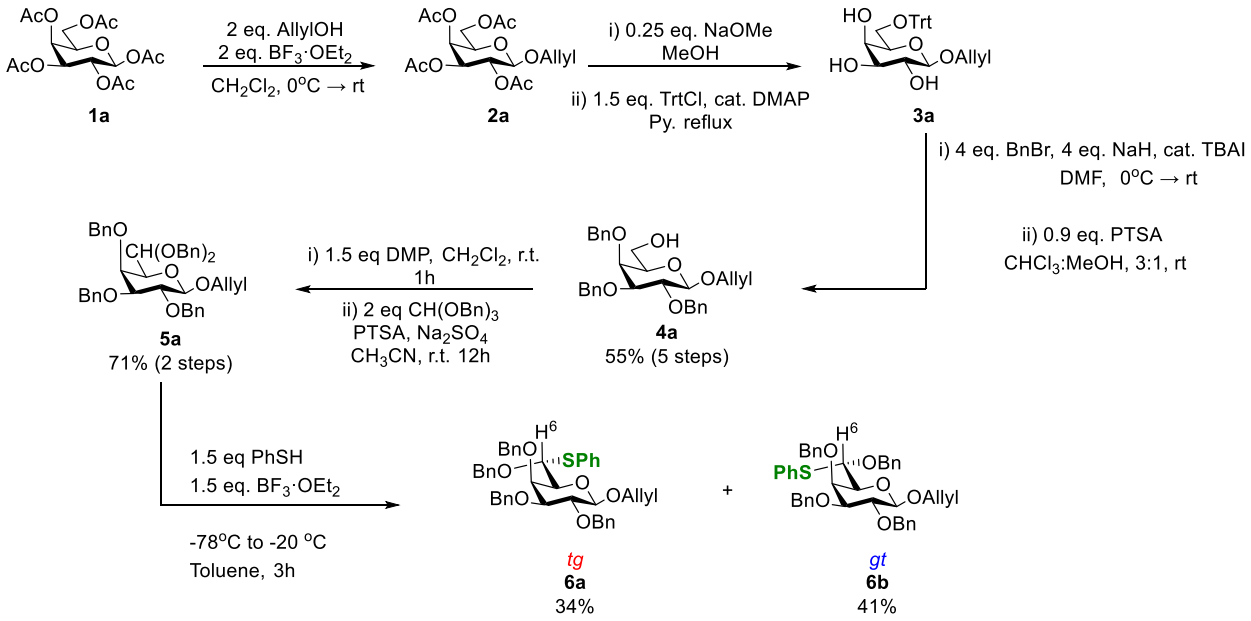
Scheme 10. General strategy for the installation of the dummy ligand.

The allyl glycoside can be easily synthesized from the hexopyranose pentaacetate using the C2 ester as NGP to give the allyl β-glycoside. The next steps consist of protecting the hydroxyl groups followed by the installation of the dummy ligand. Later, the removal of the allyl group and preparation of the trichloroacetimidate donors. Glycosylations were done with a series of glycosyl acceptors, and after purification, desulfurization and debenzylation with Raney-nickel was done to give the deprotected glycosides (Scheme 10).

Dummy Ligand installation: Synthetic Route

Galactose series

The following synthetic route (Scheme 11) shows the steps in detail towards the two diastereoisomers of the monothioacetal **6a** and **6b**. The synthesis starts with formation of the allyl glycoside from β-D-galactose pentaacetate, followed by deacetylation under Zemplen conditions,[19] then selective trityl protection of the primary hydroxyl group was done with a catalytic amount of DMAP and under reflux in pyridine. Later, benzylation took place following typical conditions with NaH. Subsequently, the trityl group was removed with 0.9 equiv. of PTSA to give the alcohol **4a** which was purified by silica-gel column chromatography in 55% yield after 5 steps.



Scheme 11. Synthetic route for the monothioacetal installation at the 6-position in galactose.

Dess-Martin periodinane oxidation of the alcohol **4a** was done to form the corresponding aldehyde which without further purification after work-up was used in the next step. The dibenzyl acetal was formed using 0.1 equiv. of PTSA and 2 equiv. of tribenzyl orthoformate

giving 71% yield after two steps. The installation of the dummy ligand was carried out with 1.5 equiv. of thiophenol, to which addition of 1.5 equiv of $BF_3 \cdot OEt_2$ was done at – 78 °C. the temperature was increased to – 20 °C and after 3 hours the reaction was quenched with triethylamine. The stirred mixture was allowed to reach room temperature and then the mixture was diluted with dichloromethane and washed with aqueous saturated $NaHCO_3$. Silica-gel column chromatography was performed to isolate diastereoisomers **6a** and **6b**. Careful control of this last step is vital to avoid over reaction, which gives dithioacetals.

For the diastereoisomer **6a**, ^{1}H and ^{13}C NMR peaks were assigned starting with the anomeric proton. 1,2-*trans* galactosides show a characteristic coupling constant for the anomeric proton around 7-8 Hz. In this case the chemical shift for the anomeric proton is 4.26 ppm a doublet with a $J_{1,2}$ of 7.7 Hz.

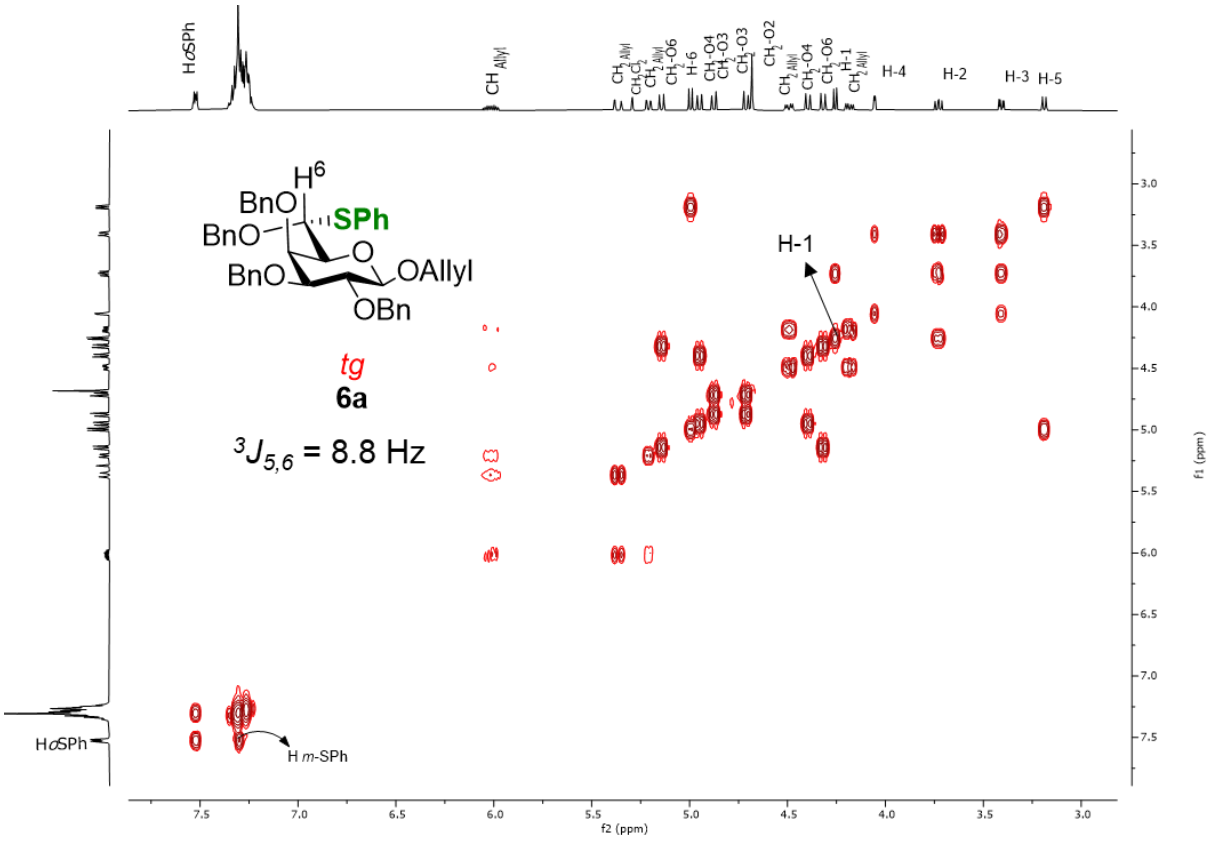


Figure 7. COSY spectrum of compound **6a** in CD_2Cl_2. Chemical shifts are shown in ppm.

From this point with the COSY spectrum (Figure 7) along with the coupling constants led to the assignation of the ring protons and allyl protons. The respective carbon peaks were assigned with the HSQC spectrum (Figure 8). Now, the corresponding signals for methylene carbon and protons of 6-OCH_2Ph were indicated with the HMBC spectrum (Figure 9) a correlation between H6 and carbon 6-O$\underline{C}H_2$Ph was observed. In this figure, the corresponding structure for **6a** is shown from a different angle so that the side chain is observed from the back to facilitate the analysis. Similarly, the *ipso* carbon from the thiophenyl moiety (C*i*-SPh) was assigned with an observable 3-bond correlation between H6 and C*i*-SPh as shown in Figure 13. With the *ipso* carbon from thiophenyl moiety defined, a 3-bond correlation is observed with the HMBC spectrum allowing the *meta* protons from the SPh group to be assigned. Consequently, the *ortho* protons were also assigned with the COSY spectrum (Figure 7).

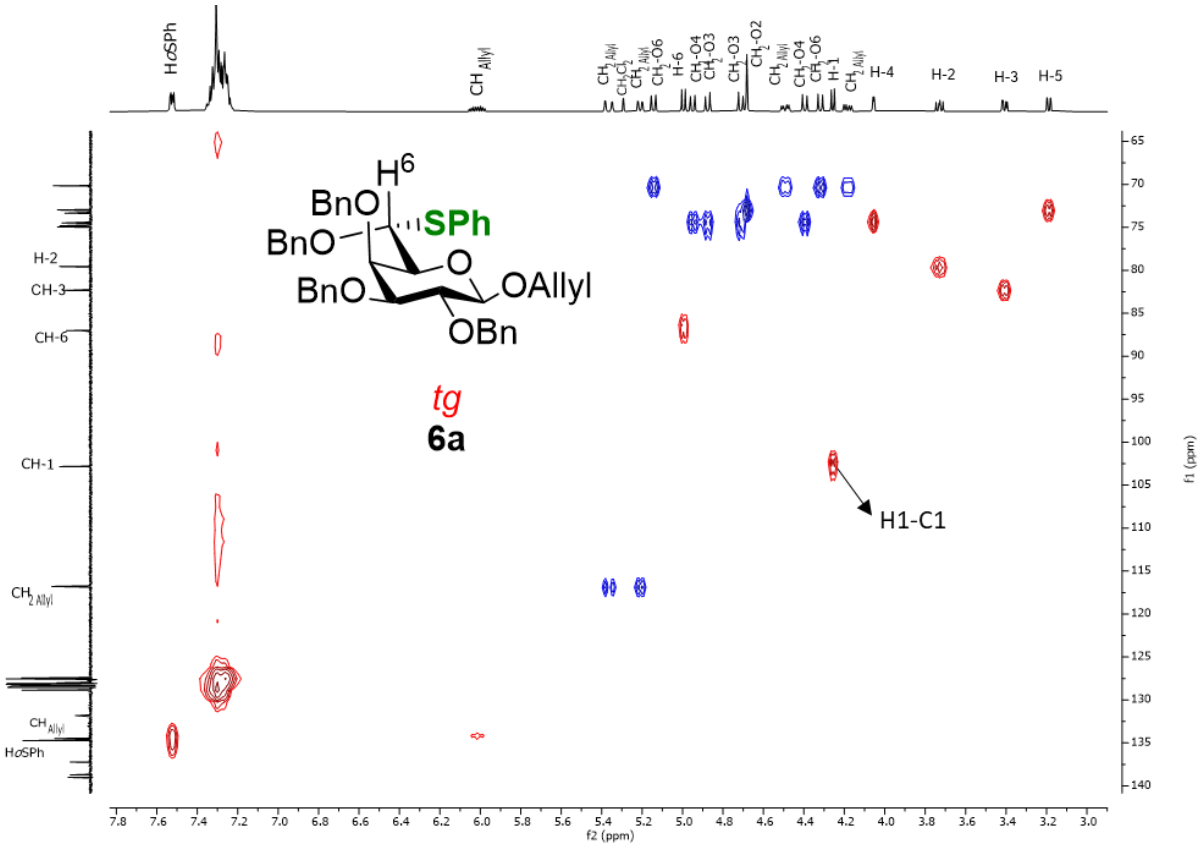


Figure 8. HSQC spectrum of compound **6a**.

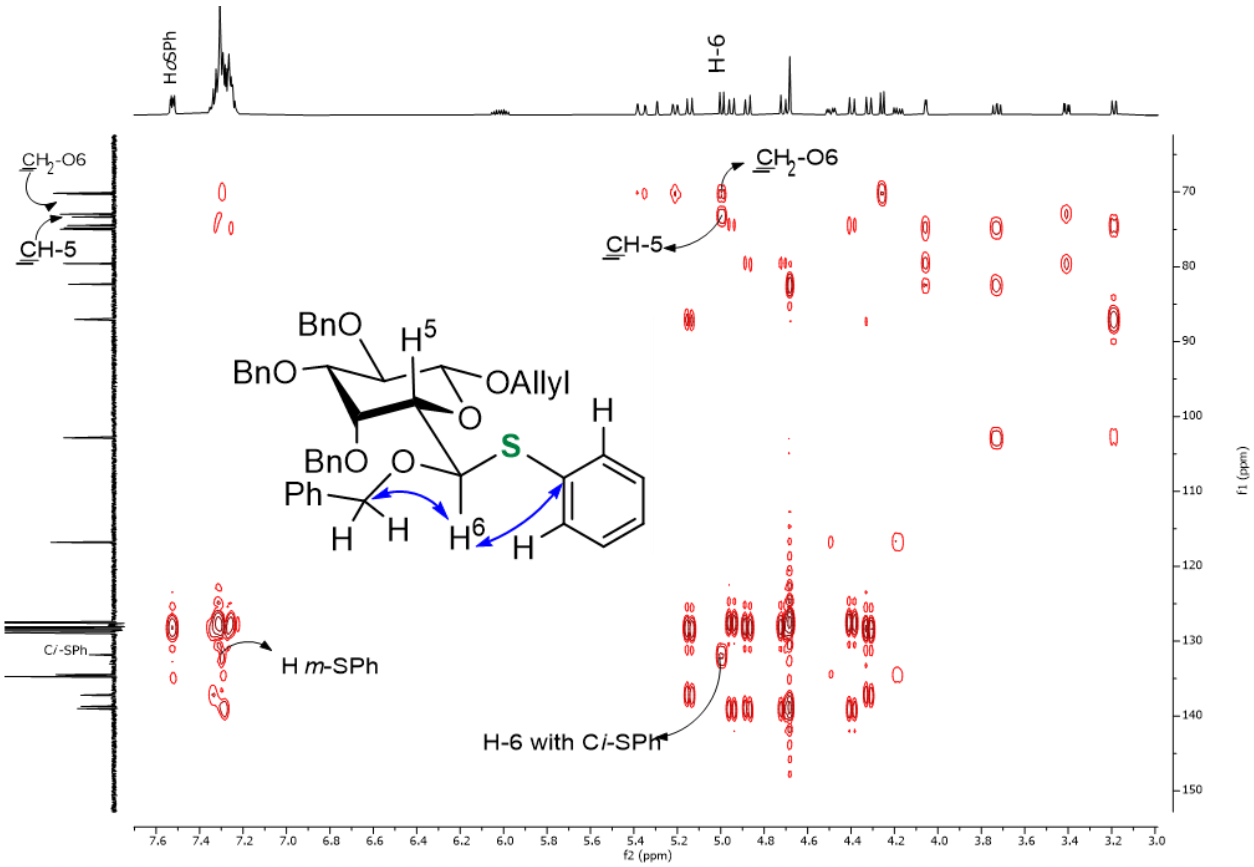


Figure 9. HMBC spectrum in CD_2Cl_2 of compound **6a**.

It is now time to look for the spatial correlation within the structure in order to find the configuration at 6-position. 2D NOESY shows the spatial proximity within 5 Å. For compound **6a** two key NOE interactions revealed the spatial proximity between 6-OCH_2Ph and H6 as well as NOE correlation of the methylene from the allyl group and the *ortho* protons of the thiophenyl group (Figure 10). This indicates that the thiophenyl group is pointing towards the ring oxygen which is in concordance with the diastereoisomers with the *tg* side chain conformation, along with the $^3J_{5,6}$ of 8.8 Hz indicating an antiperiplanar relationship of H5-H6.

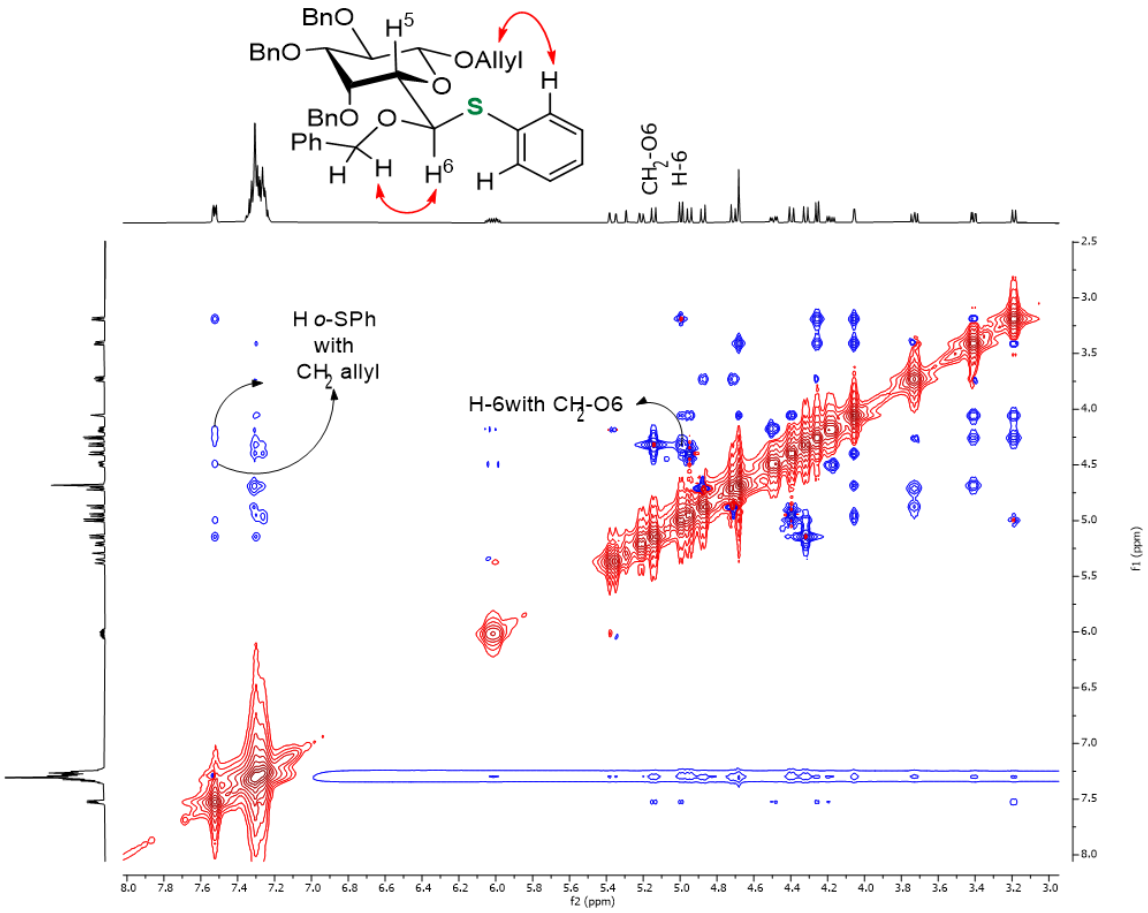


Figure 10. *NOESY spectrum in CD_2Cl_2 for compound* ***6a****.*

For the diastereoisomer **6b** the anomeric proton was found at 4.17 ppm with a coupling constant of 7.7 Hz. With the COSY NMR spectrum (Figure 11) ring protons were assigned starting from H1. The protons from allyl group were assigned with COSY NMR spectrum having the =CH that shows a characteristic multiplicity at 5.87 – 5.70 ppm as reference.

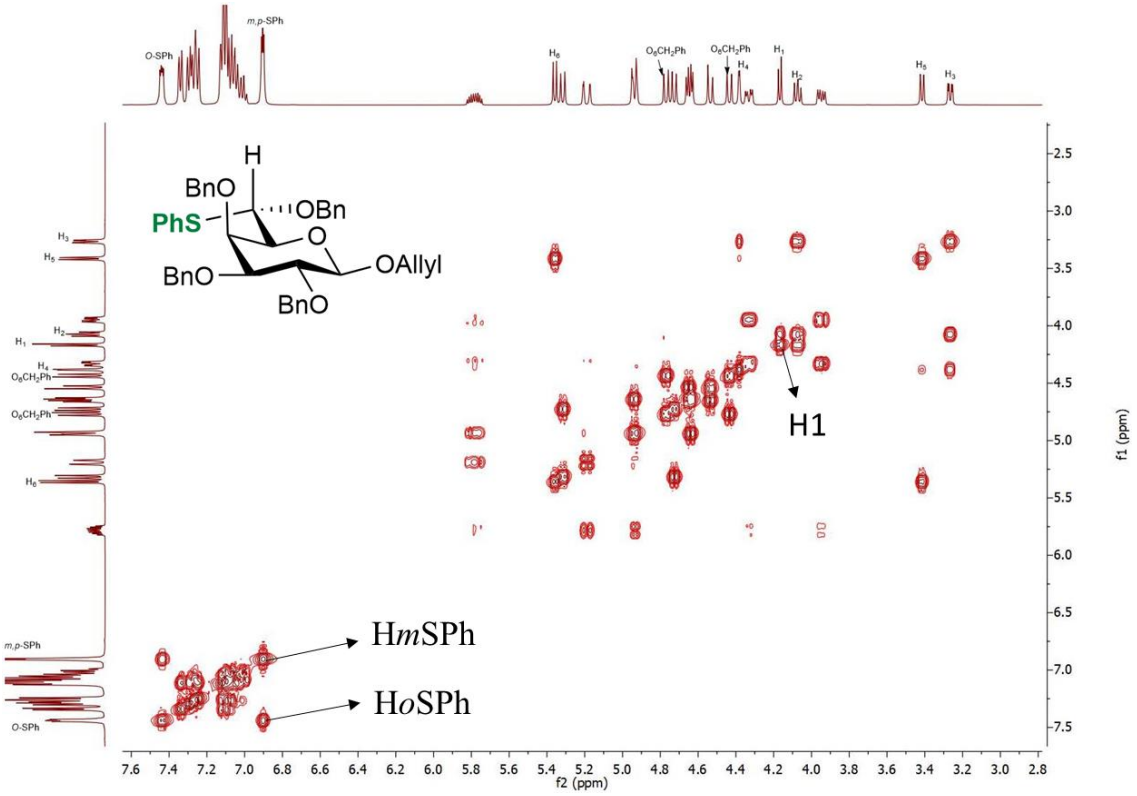


Figure 11. COSY spectrum of compound **6b** in C_6D_6.

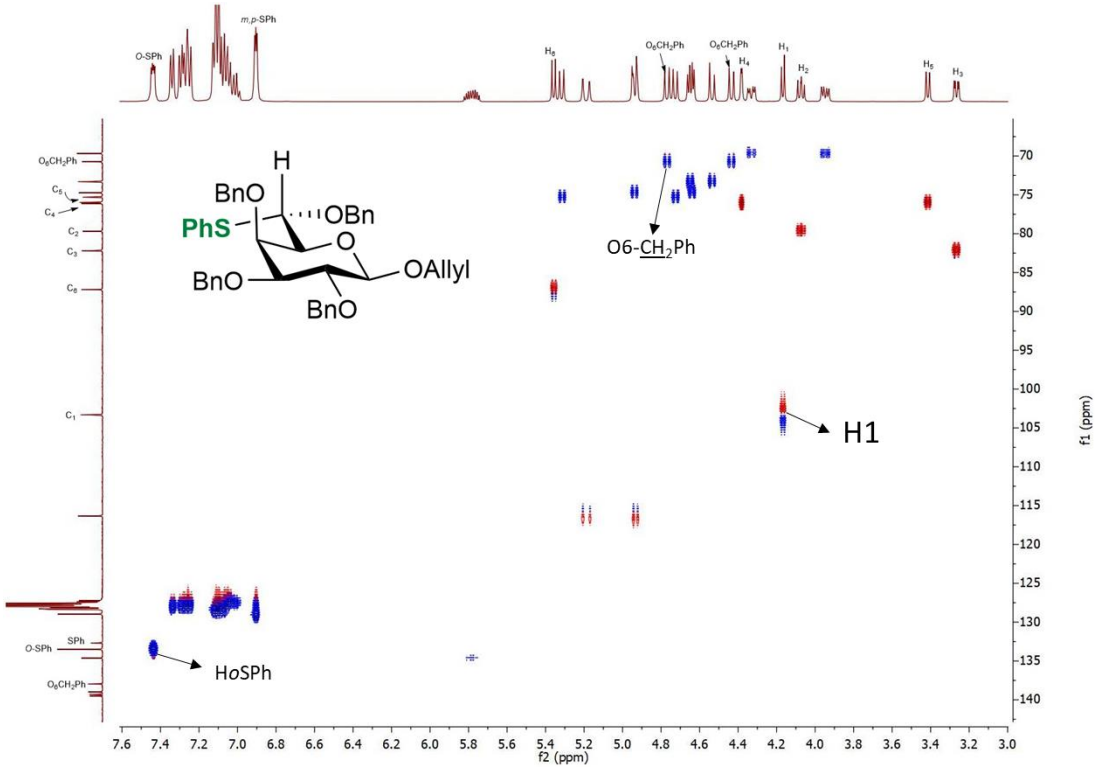


Figure 12. HSQC spectrum of compound **6b** in C_6D_6.

Also, coupling constants provide important information to determine the orientation of the corresponding ring protons, for instance, the $^{3}J_{5,6}$ coupling constant of 8.8 Hz indicates an antiperiplanar correlation between H5 and H6. Now with the orientation of H6 defined, it is necessary to corroborate the orientation of the benzyl and thiophenyl groups at 6-position. To do this, an analogous analysis was done as described previously where the signals for the methylene protons in the benzyl group at 6-position were located with HMBC correlations.

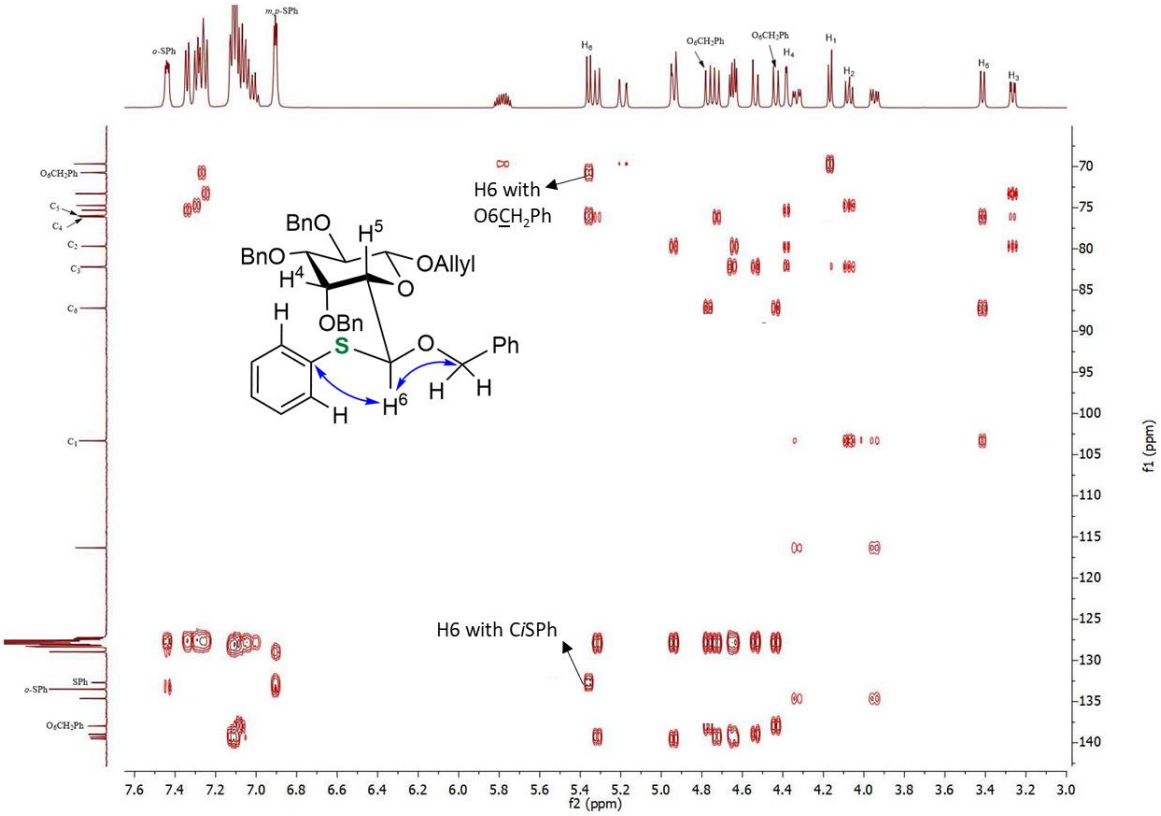


Figure 13. HMBC spectrum of compound **6b** in C_6D_6.

Carbon signals were assigned with the HSQC spectrum (Figure 12). The carbon peak for the methylene in O6-$\underline{C}H_2$Ph was found with the HMBC spectrum (Figure 13) which allows the respective protons to be assigned with C-H direct correlation in the HSQC. A 3-bond C-H interaction was observed between H6 the methylene of the benzyl group at 6-position. Also, HMBC interaction was found between H6 and the *ipso* carbon of the thiophenyl group,

subsequently a 3-bond heteronuclear interaction allowed the *meta* protons in the SPh moiety to be found. Then, the COSY spectrum showed the interaction that located the *ortho* protons.

The *ortho* protons from the thiophenyl moiety showed a NOE interaction with H4 suggesting that the SPh group is pointing away from the ring oxygen. Additionally, taking into account the $^{3}J_{5,6}$ of 8.8 Hz matching with an antiperiplanar H5-H6 relationship, NMR data suggests that the diastereoisomer **6b** adopts the *gt* side chain conformation (Figure 11).

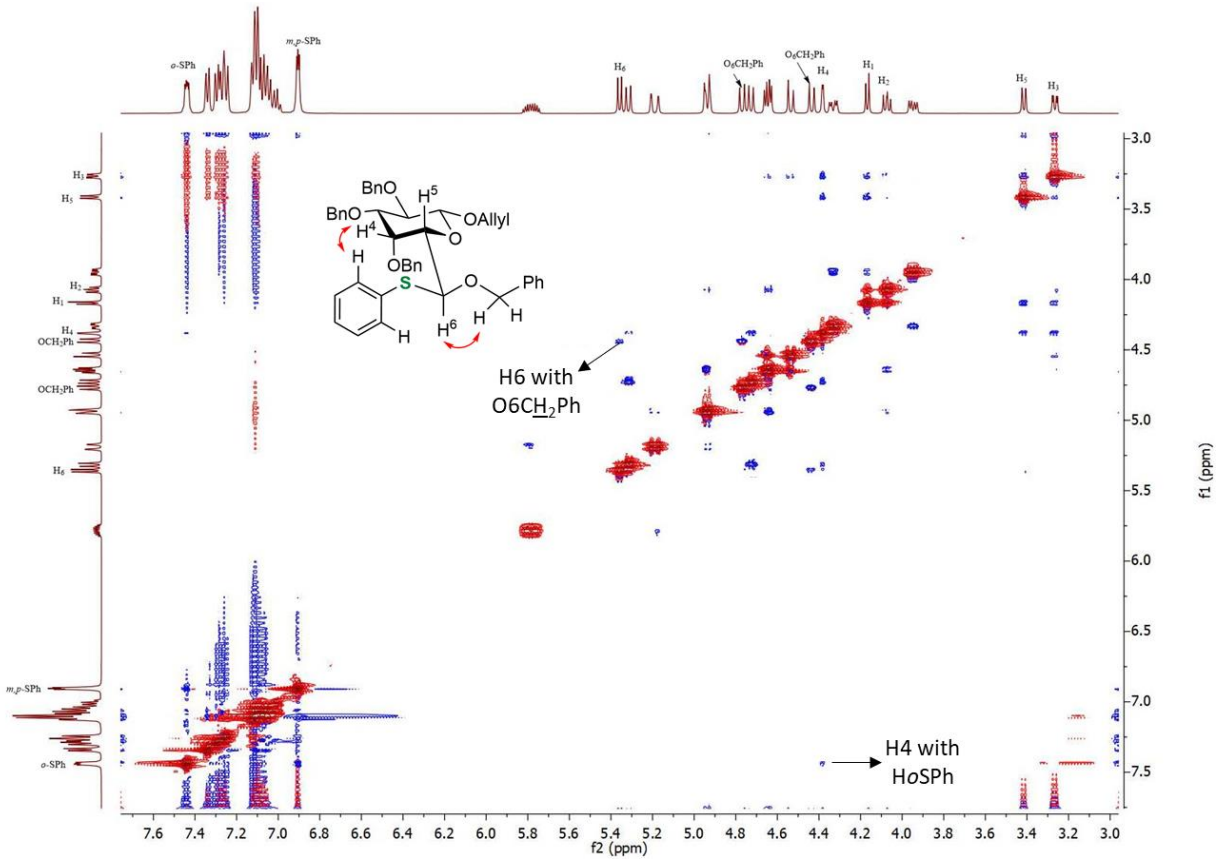


Figure 14. NOESY spectrum of compound **6b** in C_6D_6.

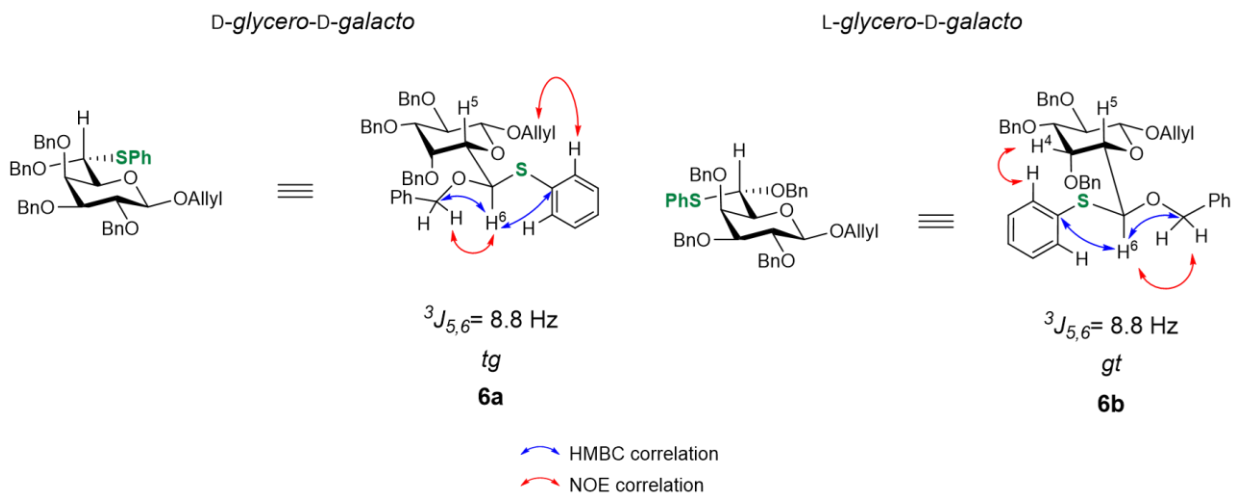


Figure 15. *Key NOE and HMBC interactions for compounds* ***6a*** *and* ***6b****.*

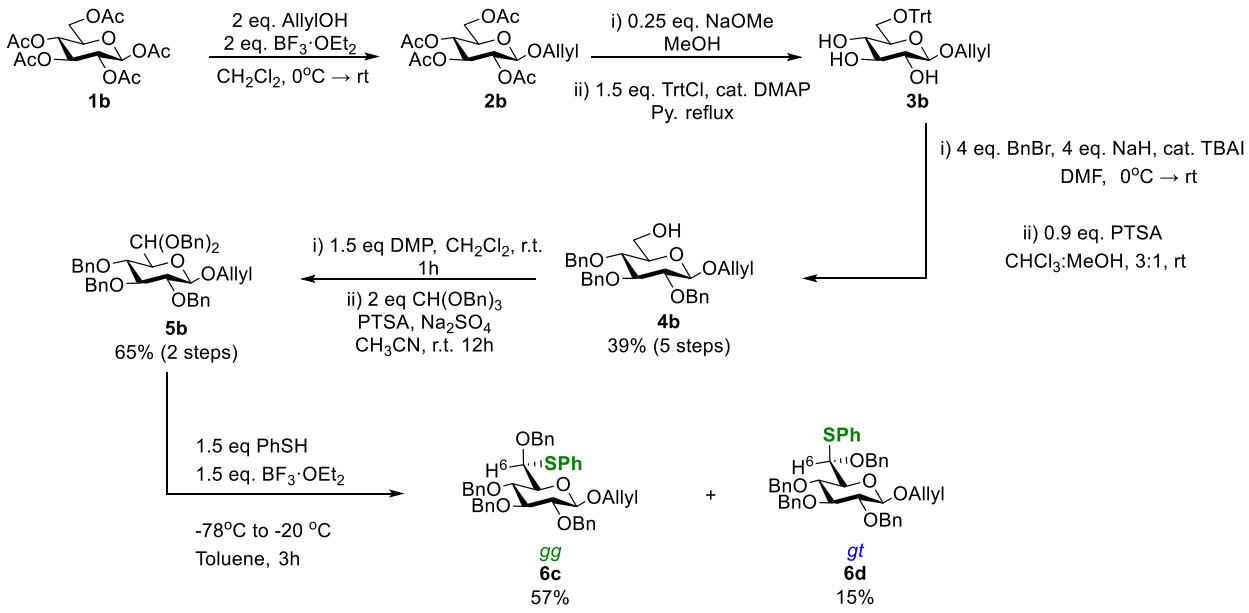
The configurations of these two diastereoisomers were assigned with 2D NMR spectra along with the $^{3}J_{5,6}$ coupling constants analysis. Proton and carbon peaks were assigned with ^{1}H, ^{13}C 1D NMR, with the coupling constants correlation as well as 2D NMR experiments like COSY, HSQC and HMBC. Once all the peaks where defined, NOESY correlations were found for the monothioacetal isolated in 34% yield (**6a**) showing the (*R*) configuration that adopts the *tg* conformation. For the second diastereoisomer isolated in 41% yield (**6b**) NOE interactions showed the (*S*) configuration at 6-position adopting a *gt* side chain conformation.

Glucose series

The synthetic route to access the monothioacetal diastereoisomers **6c** and **6d** in the glucose series followed the same steps as in the galactose series with few minor differences in yields and selectivity in the dummy ligand installation. The synthesis started from β-D-glucose pentaacetate to form the respective allyl glycoside (Scheme 12). Later, deacetylation was done following Zemplen conditions. Protection of the primary alcohol was done using trityl chloride followed by protection of the remaining hydroxyl groups with benzyl bromide and NaH in DMF.

Then the trityl group was removed with PTSA to yield in 39% over 5 steps the alcohol **4b** after silica-gel column chromatography.

The corresponding aldehyde was obtained by treatment of **4b** with Dess-Martin periodinane in dichloromethane. Subsequently, the dibenzyl acetal **5b** was synthesized in 65% yield in two steps after column chromatographic purification. The dummy ligand was installed by cooling down the dibenzyl acetal **5b** in toluene. Next 1.5 equiv. of thiophenol were added, then addition of 1.5 equiv. of $BF_3{\cdot}OEt_2$ was done in a dropwise manner. The temperature was switched to – 20 ^oC with continuous stirring. After 3 hours Et_3N was added to stop the reaction and the mixture was allowed to reach room temperature. Compounds **6c** and **6d** were extracted with dichloromethane and washed with aqueous saturated $NaHCO_3$ and purified using silica-gel column chromatography to yield diastereoisomers **6c** in 57% yield and **6d** in 15% yield. As in the galactose series, control of the temperature is crucial to avoid over reaction, which gives dithioacetals.



Scheme 12. Synthetic route for the monothioacetal *installation* at 6-position in g*luc*ose.

With both diasteroisomers isolated, their side chain configuration and corresponding conformations were assigned. Structural elucidation began with the assignation of the ring protons starting from the anomeric proton that gives a characteristic $^{3}J_{1,2}$ around 7-8 Hz. For diastereoisomer **6c**, chemical shift for the anomeric proton is 4.42 ppm, a doublet with a $^{3}J_{1,2}$ of 7.2 Hz, the remaining ring protons were assigned with the COSY spectrum. Allyl protons were assigned with coupling constant analysis and COSY spectrum having the =CH with a ddt multiplicity at 5.81 ppm as reference (Figure 16). The corresponding carbon signals were assigned with the HSQC spectrum (Figure 17).

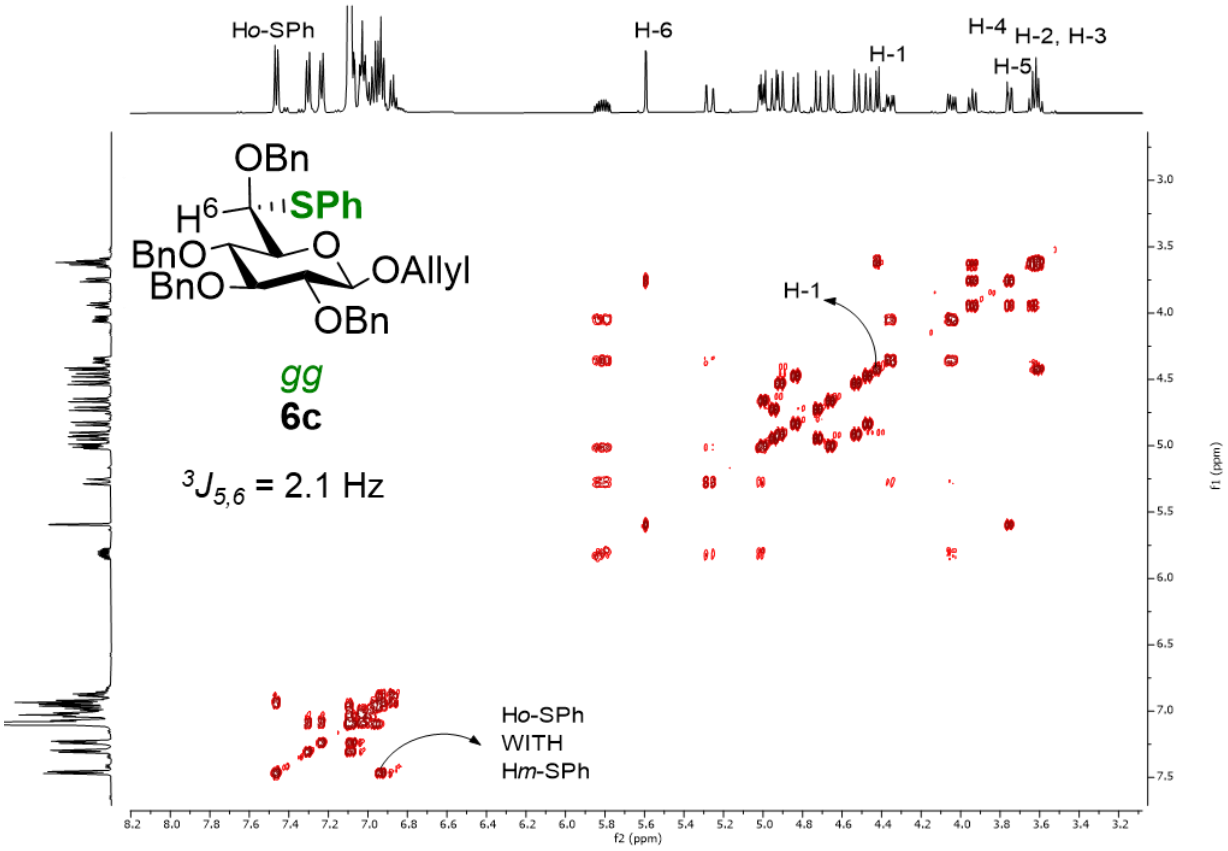


Figure 16. *COSY spectrum for compound* ***6c*** *in* C_6D_6.

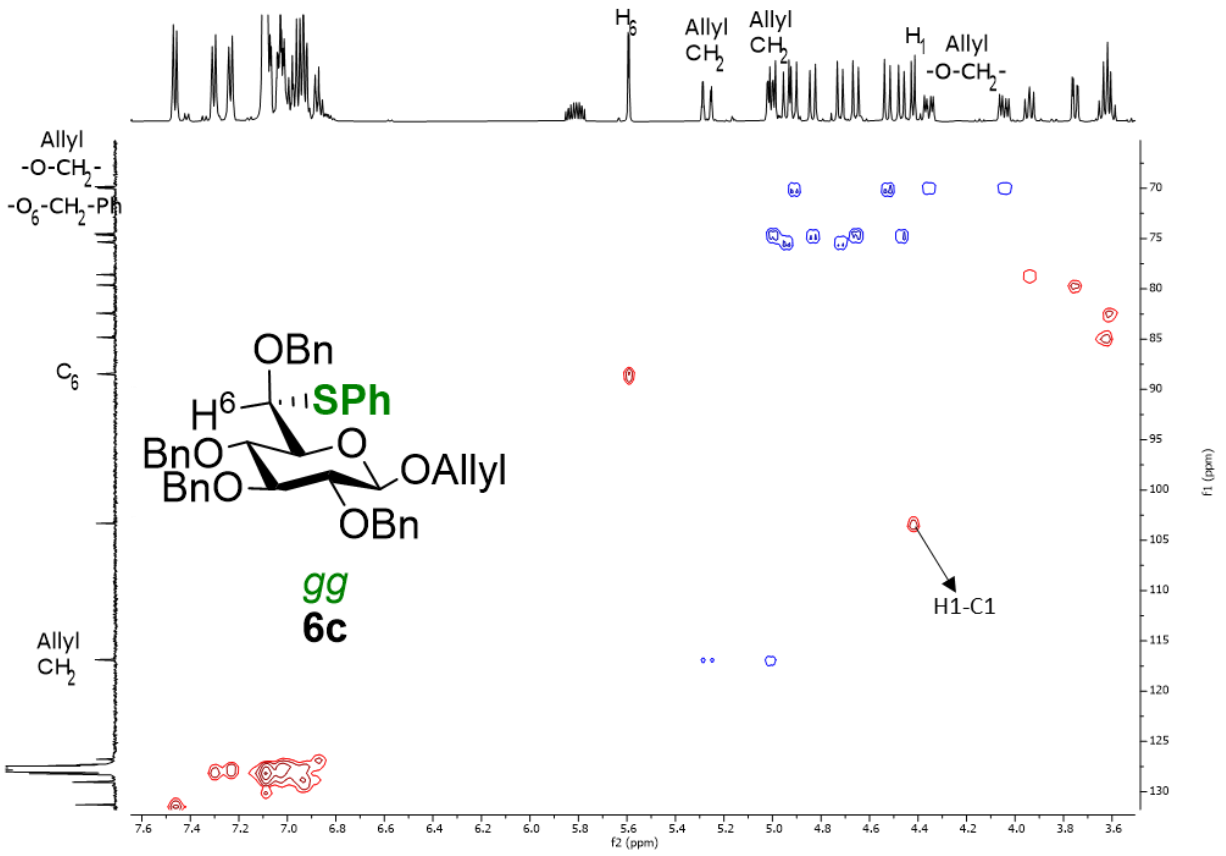


Figure 17. HSQC spectrum of **6c** in C_6D_6.

In the HMBC spectrum, H6 showed a 3-bond correlation with the carbon from the methylene 6-O<u>C</u>H_2Ph. A 3-bond correlation between H6 and C*i*-SPh is observed, this allows the remaining protons of the thiophenyl moiety to be found with a 3-bond correlation with the *meta* protons in the SPh group (Figure 18). In this figure, the corresponding structure for **6c** is shown from a different angle, where the side chain is observed from the back to provide a better explanation of the correlations. Going back to the COSY spectrum, H*m*SPh protons showed correlation with the respective *ortho* protons in the same ring indicating the corresponding chemical shift at 7.46 ppm (Figure 16).

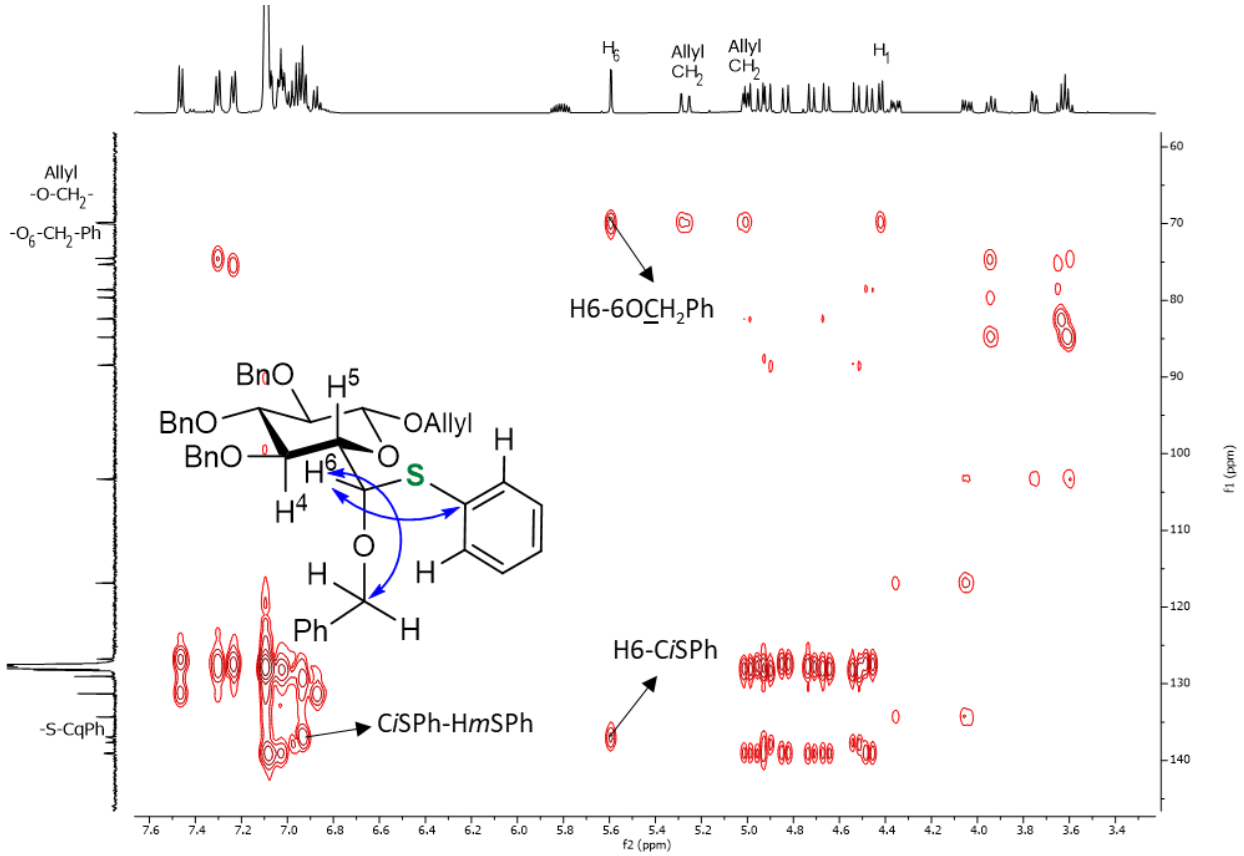


Figure 18. *HMBC spectrum of compound* ***6c*** *in* C_6D_6.

With the necessary proton and carbon peaks assigned, 2D NOESY shows the spatial proximity of protons within 5 Å, allowing to confirm the configuration and the corresponding side chain conformation for compound **6c** (Figure 18). Several NOE interactions are observed in the spectrum. Two key interactions between H6-H4 and H4-6OC$\underline{H}_2$Ph along with $^3J_{5,6}$ of 2.1 Hz suggest unequivocally the (*S*) configuration in carbon 6 with the corresponding *gg* side chain conformation. No observable interactions were found between the thiophenyl protons and H4 or 4OCH_2Ph.

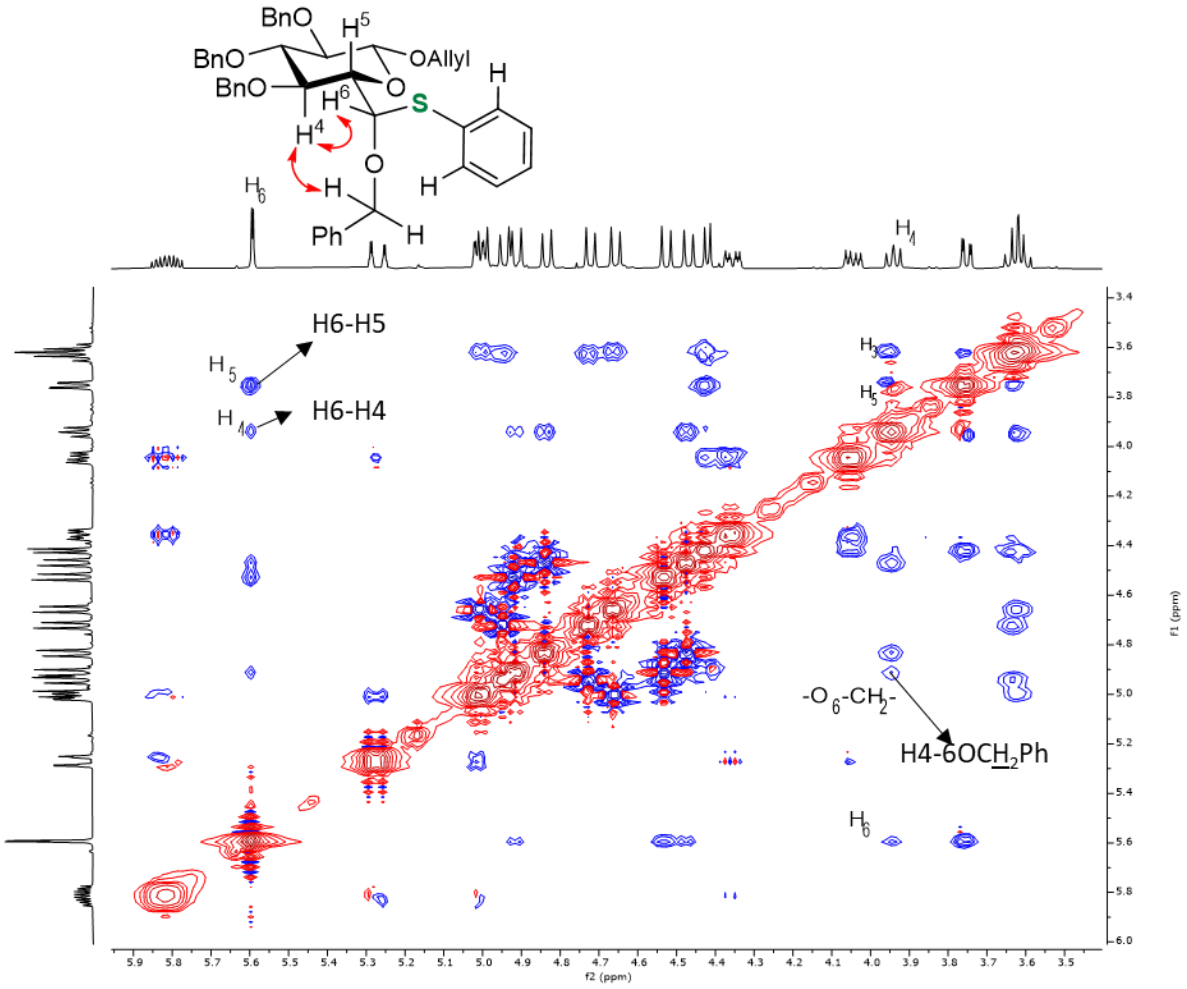


Figure 19. *2D NOESY spectrum of compound* ***6c****.*

For the second diastereoisomers of the glucose series **6d** the NMR spectra are shown next. The analysis follows a similar process as in the previous compound. Starting from the ^{1}H NMR and COSY spectra (Figure 20), the anomeric proton showed a chemical shift of 4.38 ppm and a coupling constant $^{3}J_{1,2}$ = 7.5 Hz characteristic for a β-substitution. Having the anomeric proton as a reference, the remaining ring protons were assigned with the COSY spectrum (Figure 20). The coupling constant $^{3}J_{5,6}$ of 1.5 Hz matches with a *gauche* relationship between H5 and H6. Allyl protons were assigned with the COSY spectrum starting from the =CH with a ddt multiplicity at 5.74 ppm along with the characteristic coupling constants for this group (J = 16.4, 10.7, 5.4 Hz).

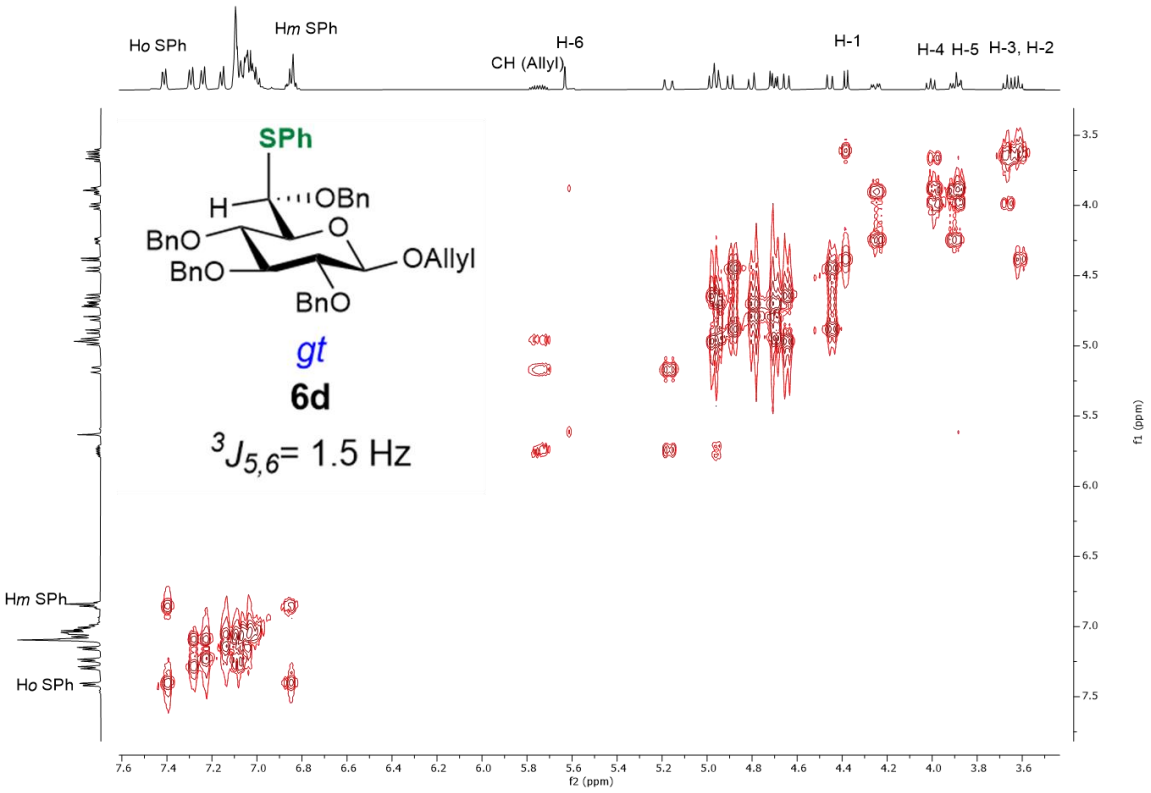


Figure 20. COSY spectrum of compound **6d** in C_6D_6.

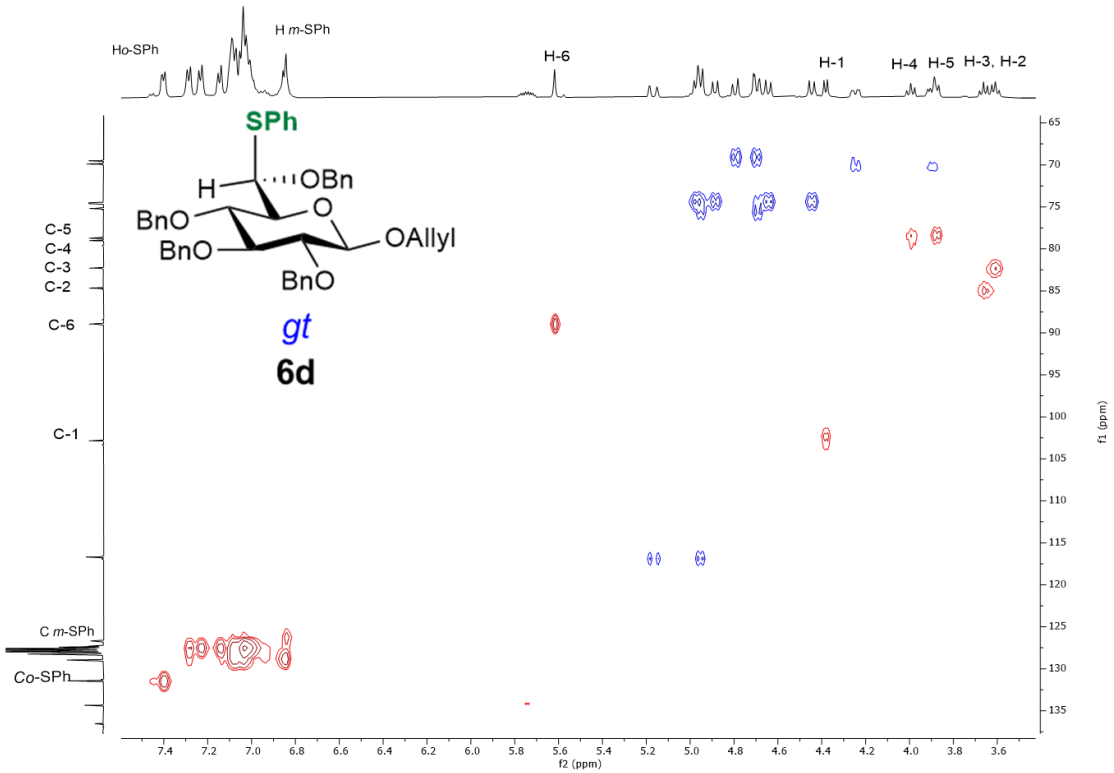


Figure 21. HSQC spectrum of compound **6d** in C_6D_6.

With the ring and allyl protons assigned, the HSQC spectrum (Figure 21) showed direct C-H interactions to find the corresponding carbon peaks. The anomeric carbon was observed at a 102.8 ppm, this chemical shift is characteristic for β-substituted glucose. C6 showed an 88.9 ppm chemical shift; this peak is useful to find the respective signals of the side chain groups.

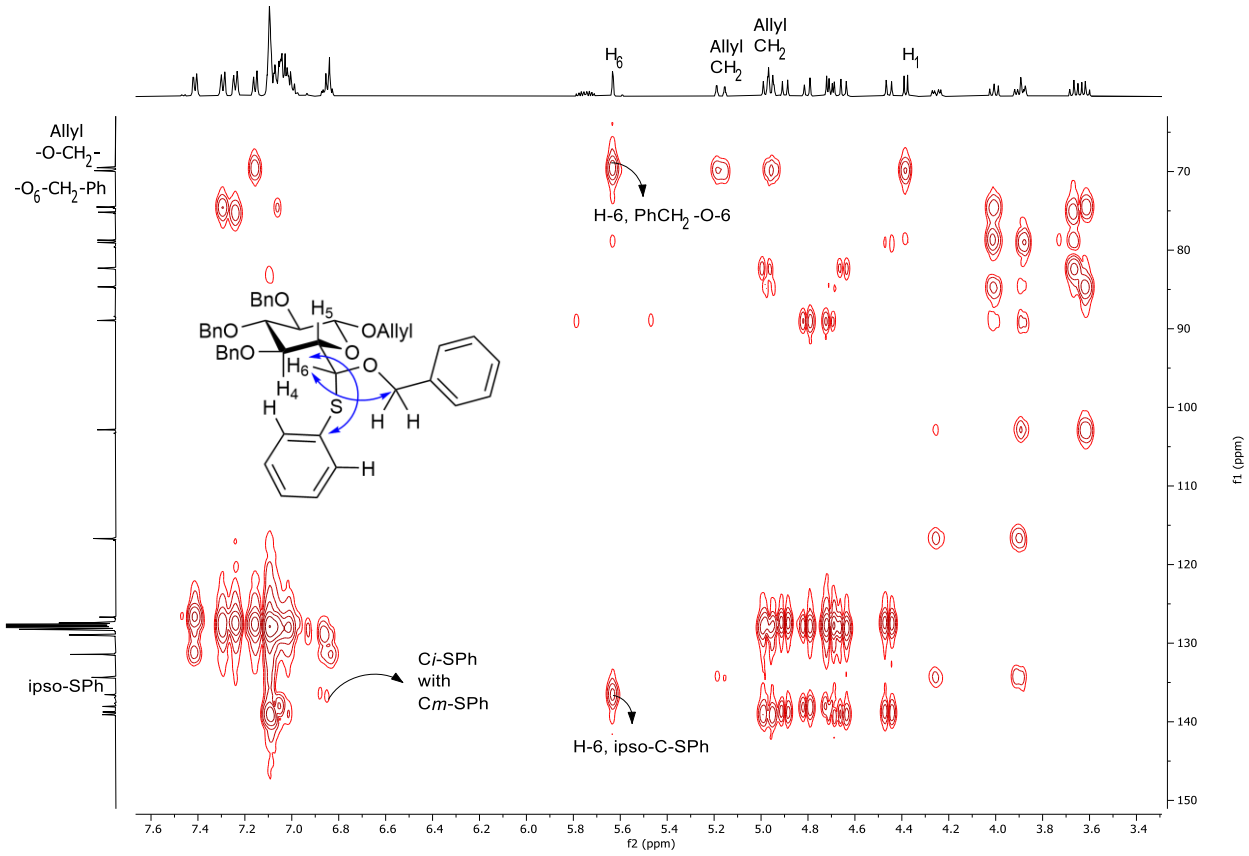


Figure 22. HMBC spectrum of compound **6d** in C_6D_6.

With the ring proton and carbon peaks defined, the HMBC spectrum (Figure 22) showed the correlations to find the chemical shifts of the side chain groups. Two key interactions were observed, beginning with a 3-bond interaction between H6 and the carbon at 6-O<u>C</u>H_2Ph which subsequently allowed the corresponding methylene protons to be found in the HSQC spectrum. The second key interaction showed a 3-bond correlation between H6 and the *ipso* carbon of the SPh group which helped to find the remaining protons in the SPh group. A 3-bond interaction in

the HMBC spectrum between C*i*SPh carbon and the *meta* protons from the thiophenyl group was observed and then with the COSY spectrum the *ortho* protons were assigned.

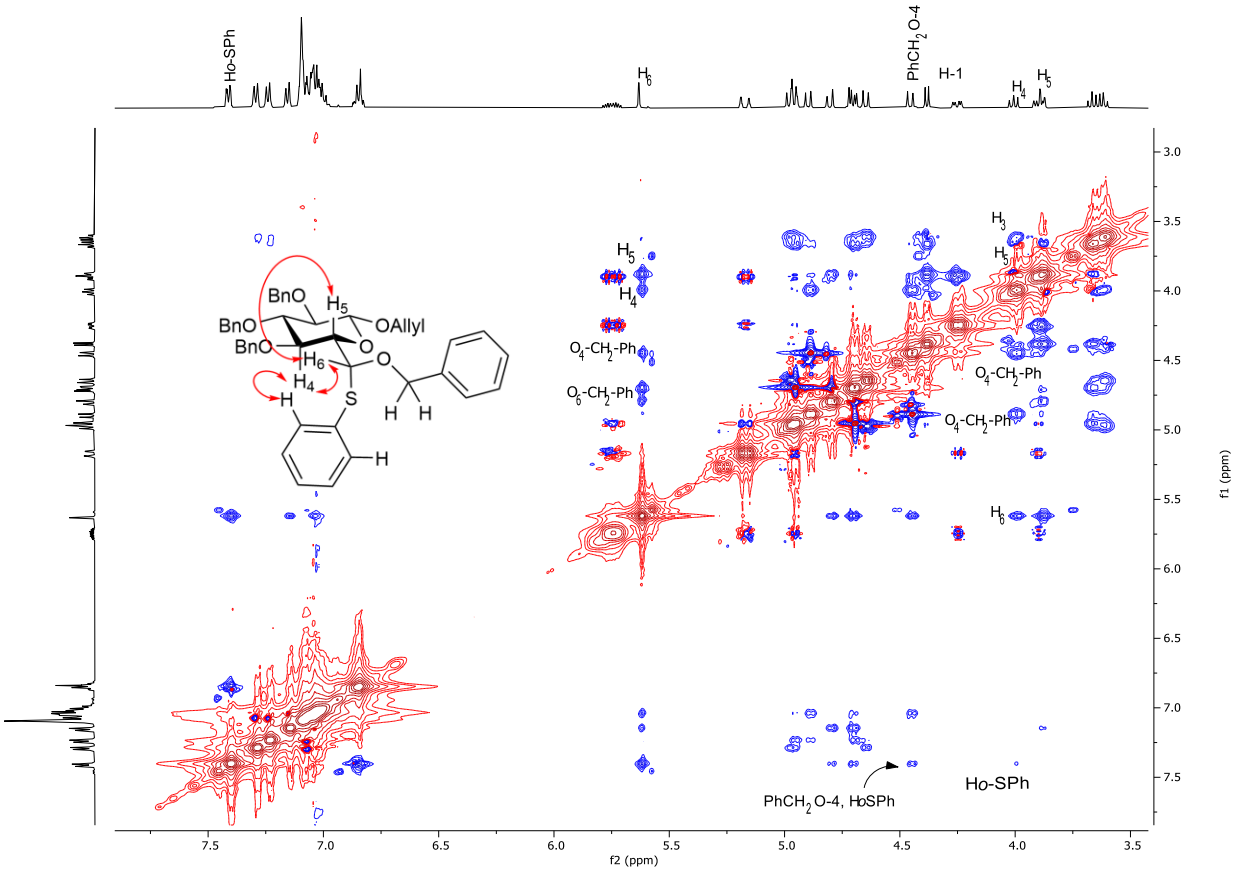


Figure 23. NOESY spectrum of compound **6d** in C_6D_6.

In the NOESY spectrum (Figure 23), the methylene protons from the 6-OCH_2Ph group showed a NOE interaction with H4 suggesting that the benzyl group at 6-position is pointing towards the ring oxygen with *gauche* correlation. Additionally, taking into account the $^3J_{5,6}$ of 1.5 Hz matching with a *gauche* H5-H6 relationship, data put together suggests for diastereoisomer **6d** the *gt* side chain conformation (Figure 24). In the next figure the key interactions are summarized, providing the configuration on the side chain of both diastereoisomers in the glucose series.

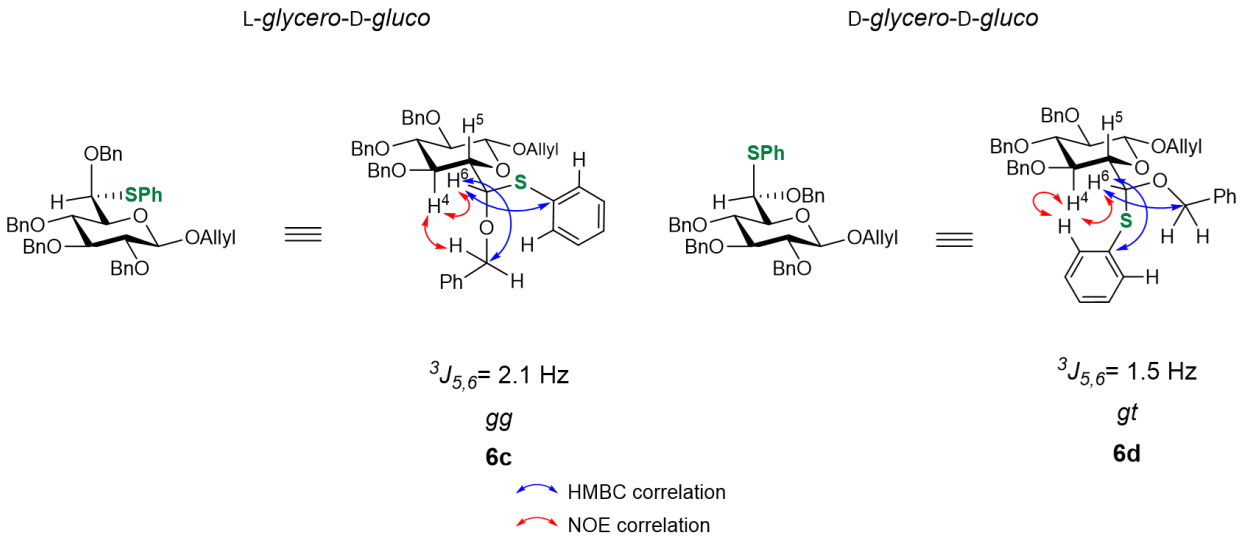
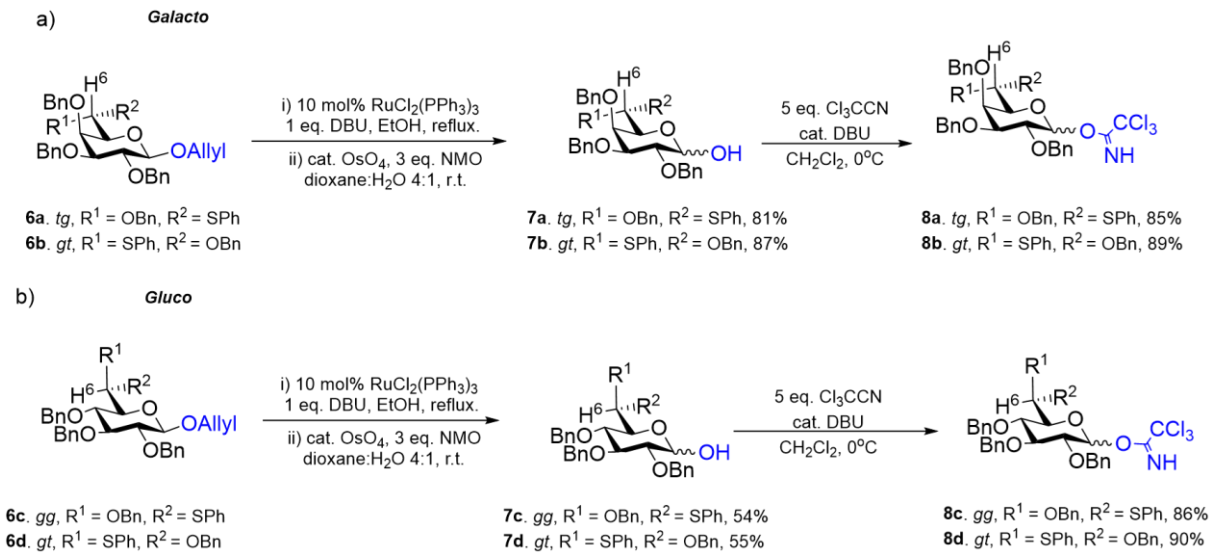


Figure 24. *Key NOE and HMBC interactions for compounds* ***6c*** *and* ***6d****.*

With the structure of compounds **6a-d** with the respective side chain conformation confirmed, the next step consisted of the synthesis of the glycosyl donors. As mentioned before, trichloroacetimidate donors were used for the glycosylation reaction promoted by trimethylsilyl triflate.[20]

Synthesis of trichloroacetimidate donors

The synthesis of the trichloroacetimidate donors consisted of three steps, starting with a 2 step deallylation of monothioacetals **6a-d**. First, isomerization of the alkene in the allyl group was done with 10 mol% of $RuCl_2(PPh_3)_3$ locating the double bond in the internal position that after column purification was treated with OsO_4 and NMO to form the corresponding anomeric hemiacetal. After column purification, the hemiacetal **7a-d** was treated with 5 equiv. of Cl_3CCN and a catalytic amount of DBU in dichloromethane at 0 ^oC. Trichloroacetimidates tend to undergo rearrangement, therefore column chromatography was done rapidly before continuing directly with the next step (Scheme 13).



Scheme 13. *Synthesis of trichloroacetimidate donors a)* ***8a-b*** *b)* ***8c-d****.*

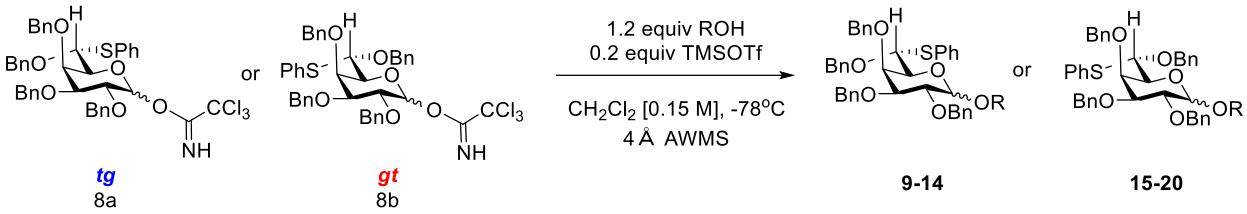
Glycosylations: Evaluation of the influence of the side chain on the anomeric selectivity

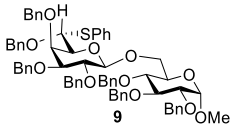
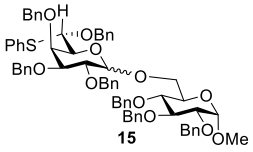
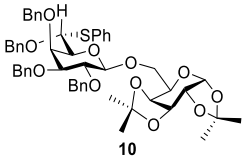
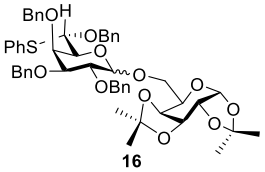
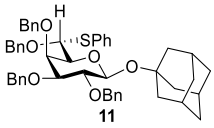
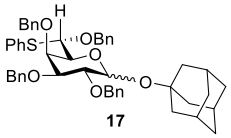
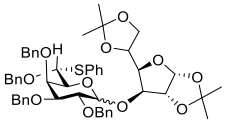
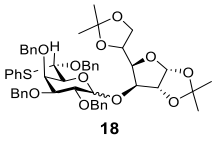
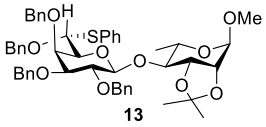
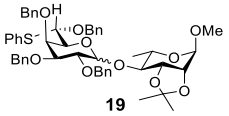
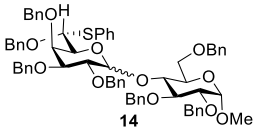
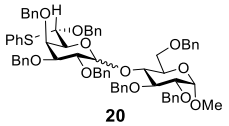
For the glycosylations, each diastereoisomer **8a-d** individually with the respective acceptor was coevaporated with toluene. The mixture was then dissolved in dichloromethane and it was stirred for 1 h with activated 4 Å acid washed molecular sieves (4 Å AWMS). Then, the stirred mixture was cooled down to – 78 °C and 0.2 equiv. of trimethylsilyl triflate were added and this mixture was stirred for 4 hours at the same temperature as before. [20][21] The reaction was quenched with 0.1 mL of triethylamine and after the proper work-up a crude product was obtained. This crude product was analyzed by proton NMR to determine the anomeric *ax*:*eq* ratio. Consecutive silica-gel column chromatography afforded the isolated glycosides for full characterization.

In Table 1, the results of the glycosylation reactions are shown with the galactose donors **8a** with the configuration D-*glycero*-D-*galacto* with the *tg* side chain conformation and **8b** with the configuration L-*glycero*-D-*galacto* with the *gt* side chain conformation. Starting with donor **8a**, more reactive acceptors[22] showed excellent selectivity giving only equatorial substitution as

shown in compounds **9** to **11** and **13**, which is in concordance with the results in the heptopyranosyl donors [18] showing that the *tg* side chain conformation controls the anomeric reactivity giving excellent selectivity and high yields up to 85%.

Table 1. *Glycosylation reactions* D-glycero-D-galacto *donor* ***8a*** *and* L-glycero-D-galacto *donor* ***8b.***



Product D-*gly*-D-*gal*, *tg*	Yield (%)	ax:eq	Product L-*gly*-D-*gal*, *gt*	Yield (%)	ax:eq
 **9**	75	eq only	 **15**	81	1:11.9
 **10**	68	eq only	 **16**	69	1:11.5
 **11**	61	eq only	 **17**	72	1:4.1
 **12**	85	1:4.3	 **18**	85	1:6.3
 **13**	77	eq only	 **19**	84	1:1
 **14**	76	1:1.1	 **20**	56	4.2:1

Less reactive acceptors like in compound **12** showed an equatorial preference to less degree and, in compound **14** there is no selectivity. In case of donor with the *gt* side chain conformation, products **15** and **16** showed excellent equatorial substitution. Glycosides **17** and **18** were synthesized with good equatorial selectivity and product **19** did not show any preference for either α- or β-substitution. An inversion in selectivity occurs when 4-OH glucosyl acceptor reacts in the reaction with donor **8b** (*gt*) to give product **20**, this can be explained in essence by the relative reactivity of the acceptor which allows the nascent positive charge to be present for longer time and therefore the substitution follows a S_N1 mechanism[3] as well as invoking other effects to come into play like the anomeric effect.[23]

The second set of donors with the *gluco*-configuration gave the corresponding products in good yields from 59 to 89% (Table 2). The effect of the side chain conformation on the selectivity behaves in a similar way with the heptopyranosyl donor series with *gluco* configuration. The products of the hexopyranosyl donors with more reactive acceptors (Table 2) were synthesized with good selectivity up to 1:8.7 *ax*:*eq* (glycosides **21** to **23**) which is in concordance with the hypothesis of the hydrogen bond directing effect in the heptopyranosyl series (Figure 25 a). [18] However, in comparison with the effect of the methyl group in the heptosides, it is clear that the electronegativity of the thiophenyl group changes the selectivity in the *gluco* series (Figure 20). This can be explained in terms of the overall electronwithdrawing effect of the side chain.

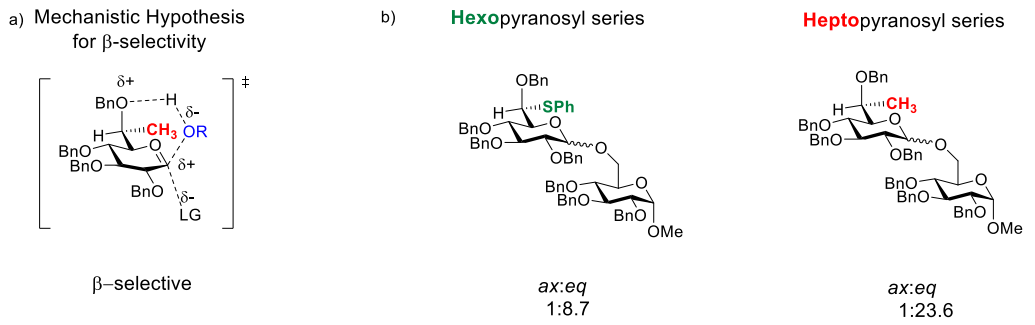
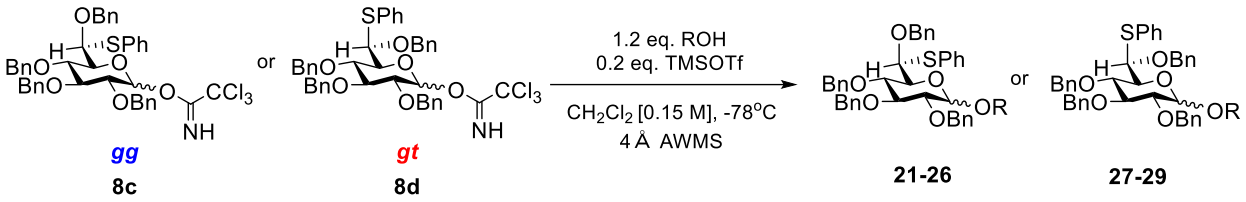
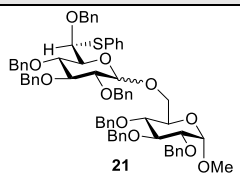
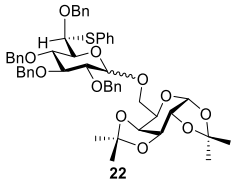
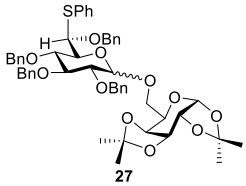
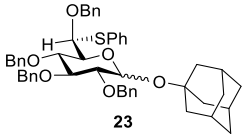
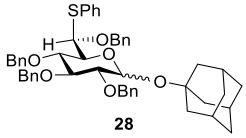


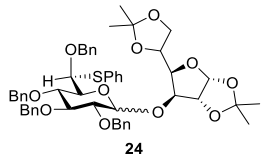
Figure 25. *Comparison of the selectivity between hexo and heptopyranosyl donors.*

Donor with the *gt* side chain conformation showed a mixed selectivity as expected, where the effect of the *gt* conformation has an intermediate behavior at stabilizing the nascent positive charge at the anomeric position.[17]

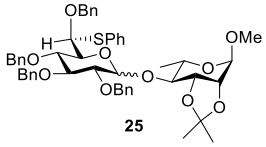
Table 2. *Glycosylation Reactions with* L-glycero-D-gluco *Donor* ***8c*** *and* D-glycero-D-gluco *Donor* ***8d.***



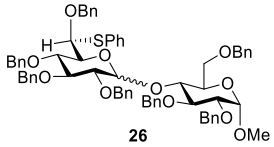
Product L-*gly*-D-*glu*, *gg*	Yield (%)	ax:eq	Product D-*gly*-D-*glu*, *gt*	Yield (%)	ax:eq
 **21**	80	1:8.7			
 **22**	89	1:5.5	 **27**	73	1:1.3
 **23**	59	1:7.5	 **28**	88	4.8:1



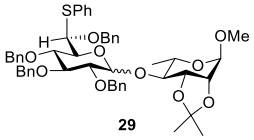
24 75 1:2.9



25 70 1:1.1



26 80 1.3:1

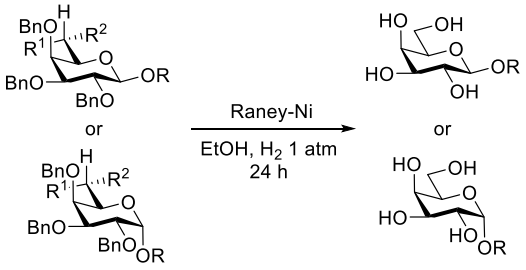


29 68 2:1

Desulfurization of glycosides

Along with the idea of the dummy ligand to control the side chain conformation and anomeric selectivity, the final step was the removal of the thiophenyl group. Raney-nickel hydrogenolysis provided a good strategy to perform concomitantly debenzylation and desulfurization[24] to give the desired products with excellent yields (Tables 3 and 4). To carry out these reactions, a suspension in ethanol of the isolated glycosides was treated with Raney-nickel under 1 atm hydrogen atmosphere. The thiophenyl moiety is cleaved easily and the benzyl groups are removed slowly, after 24 h the reactions got to completion. It is evident that the Raney-nickel deprotection of *galacto* and *gluco* glycosides with either side chain conformation is lost, resulting in the same compound when the only difference is the configuration at 6-position.

Table 3. *Desulfurization with Raney-Nickel for the* D-glycero-D-galacto *and* L-glycero-D-galacto *series.*



D-*glycero*-D-*galacto* = R^1 = OBn, R^2 = SPh
L-*glycero*-D-*galacto* = R^1 = SPh, R^2 = OBn

D-*gly*-D-*gal* isomers	L-*gly*-D-*gal* isomers

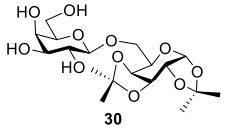
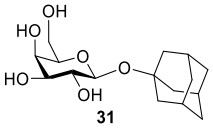
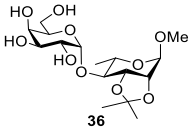
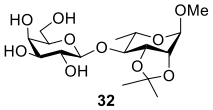
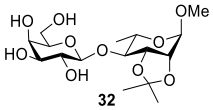
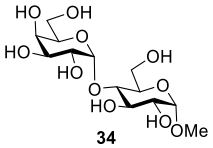
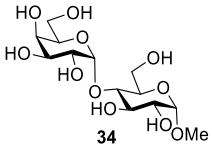
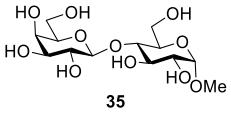
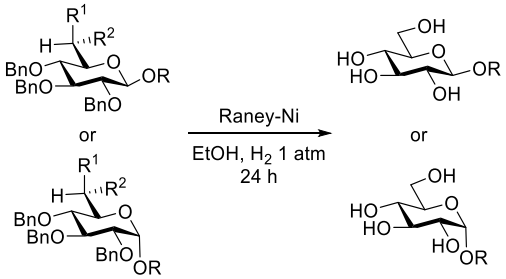
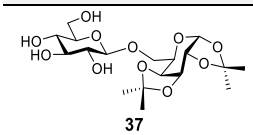
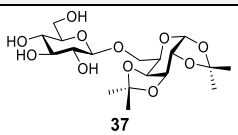
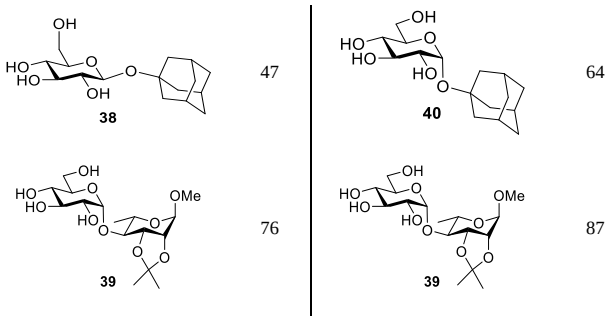
Product[a]	% Yield[b]	Product[a]	% Yield[b]
 **30**	75		
 **31**	76	 **36**	94
 **32**	93	 **32**	95
D-*gly*-D-*gal* isomers		**L-*gly*-D-*gal* isomers**	
Product	% Yield	Product	% Yield
 **34**	94	 **34**	96
 **35**	89		

Table 4. *Desulfurization with Raney Nickel for the* L-glycero-D-gluco *and* D-glycero-D-gluco *series.*



L-*glycero*-D-*gluco* = R^1 = SPh, R^2 = OBn
D-*glycero*-D-*gluco* = R^1 = OBn, R^2 = SPh

L-*gly*-D-*glc* isomers		D-*gly*-D-*glc* isomers	
Product	% Yield	Product	% Yield
 **37**	67	 **37**	83



Future Directions

The strategy describing the use of a dummy ligand to control side chain conformation and anomeric selectivity in glycosylation reactions can be applied effectively for stereoselective synthesis of glycosides. The dummy ligand can be modified in order to i) obtain better yields of one single diastereoisomer in the installation of the dummy ligand and ii) in order to improve the selectivity in glycosylation reactions. In the example below, a cyclic monothioacetal is proposed as a dummy ligand to obtain selectively one single diastereoisomer with the respective side chain conformation (Figure 21). Starting from enantiomerically pure 3-chloro-1-phenylpropan-1-ol is transformed into the corresponding 3-mercaptopropanol in 2 simple steps. Reaction between this thiol moiety and the aldehyde at 6-position of the hexopyranoside forms selectively the cyclic monothioacetal, which can be easily characterize with 2D NOESY and coupling constant analysis. This example will also provide a different electronic effect on the side chain and a similar evaluation of the anomeric selectivity can be done.

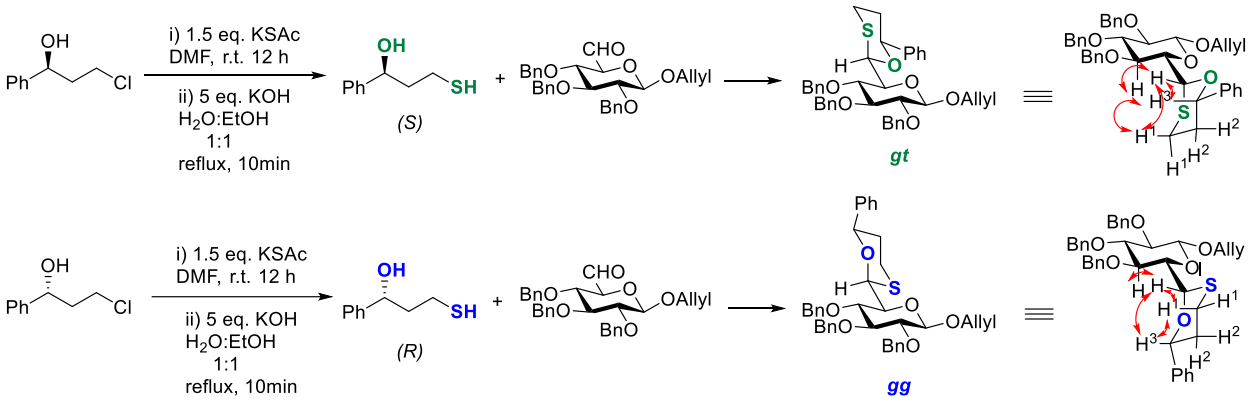


Figure 26. *Stereoselective synthesis of monothioacetal derivatives.* ↔ *NOE interactions.*

CHAPTER 3

CONCLUSIONS

- The installation of the dummy ligand is the key step of the syntheses. Methods to improve the yield and stereoselectivity for a single isomer are under development.
- The *Galacto* series showed excellent equatorial selectivity with high yields in both configurations. The side chain with more electron-withdrawing effect destabilizes the oxocarbenium ion leading the glycosylation to a S_N2 pathway.
- In the *gluco* series, the dummy S-phenyl ligand provides stronger electron-withdrawing effect to the side chain thus decreasing H-bond interactions between O6 and glycosyl acceptor which leads to stereoselectivity decrease contrary to the findings reported earlier for the similar heptopyranosyl series.
- Desulfurization gave the deprotected sugars in one single step removing benzyl and thiophenyl groups simultaneously.

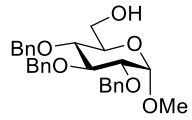
CHAPTER 4

EXPERIMENTAL

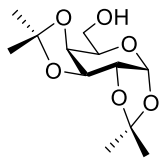
General Experimental details

All reactions were carried out under argon unless otherwise stated. 1-Adamantanol and 1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose were purchased from commercial suppliers. Solvents used for column chromatography were of analytical grade and were purchased from commercial suppliers. Thin-layer chromatography was carried out with 250 μm glass-backed silica (XHL) plates. Detection of compounds was achieved by UV absorption (254 nm) and by staining with 10% sulfuric acid in ethanol. Purification of crude residues was performed by silica gel chromatography using 230−400 mesh grade 60 silica. Specific rotations were measured in chloroform on an automatic polarimeter with a path length of 10 cm. NMR spectra were recorded in C_6D_6, CD_2Cl_2 or $CDCl_3$ at either 500, 600, or 900 MHz as indicated. High-resolution (HRMS) mass spectra were recorded in the electrospray mode using an orbitrap mass analyzer (Thermo Fisher ESI-Orbitrap). Chemical shifts (δ) are recorded in ppm, and multiplicities are abbreviated as follows: s (singlet), m (multiplet), br (broad), d (doublet), t (triplet), and q (quartet).

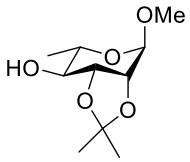
Preparation of acceptors and starting materials



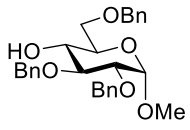
Methyl 2,3,4-tri-*O*-benzyl-α-D-glucopyranoside. This colorless oil was prepared according to the literature method and had spectral data consistent with the literature [25](1.4 g, 98%).



1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose. This colorless syrup was prepared according to the literature method and had spectral data consistent with the literature [26] (0.80 g, 74%).



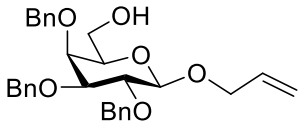
Methyl 2,3-*O*-isopropylidene-α-L-rhamnopyranoside. This colorless oil was prepared according to the literature method and had spectral data consistent with the literature[27] (1.1g, 87%).



Methyl 2,3,6-tri-*O*-benzyl-α-D-glucopyranoside. This colorless syrup was prepared according to the literature method and had spectral data consistent with the literature [25] (2.95 g, 98%) as a colorless syrup.

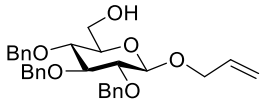
Allyl 2,3,4-tri-*O*-benzyl-galactopyranoside (4a) and Allyl 2,3,4-tri-*O*-benzyl-*β*-D-glucopyranoside (4b).

Allyl 2,3,4-tri-*O*-benzyl-β-D-galactopyranoside (4a)



This compound, a colorless oil, was prepared from β-D-galactose pentaacetate, starting with the synthesis of the allyl glycoside and deacetylation[28], followed by trityl group protection of O6, benzylation and final trityl group removal (3.67 g, 51%).[29] Spectral data is consistent with the literature.[30] **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.40 – 7.26 (m, 15H, Ar-H), 6.04 – 5.90 (m, 1H, =CH), 5.33 (dq, *J* = 17.4, 1.7 Hz, 1H, $=CH_2$), 5.19 (dq, *J* = 10.4, 1.5 Hz, 1H, $=CH_2$), 5.02 – 4.92 (m, 2H, Ph-CH_2-), 4.82 (d, *J* = 11.8 Hz, 1H, Ph-CH_2-), 4.79 (d, *J* = 10.9 Hz, 1H, Ph-CH_2-), 4.75 (d, *J* = 11.8 Hz, 1H, Ph-CH_2-), 4.67 (d, *J* = 11.8 Hz, 1H, Ph-CH_2-), 4.47 – 4.35 (m, 2H, CH), 4.14 (ddt, *J* = 13.0, 5.9, 1.5 Hz, 1H, -OCH_{2a}-), 3.88 (dd, *J* = 9.8, 7.7 Hz, 1H, H2), 3.80 – 3.73 (m, 2H, CH), 3.57 – 3.47 (m, 2H, CH), 3.37 (dd, *J* = 6.8, 5.6 Hz, 1H, H5), 1.64 (s, 1H, OH). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.7 (C), 138.5 (C), 138.35 (C), 134.33 (CH), 128.7 (Ar), 128.5 (Ar), 128.4 (Ar), 128.3 (Ar), 128.0 (Ar), 127.8 (Ar), 127.7 (Ar), 127.6 (Ar), 117.2 ($=CH_2$), 103.2 (CH1), 82.3 (CH3), 79.7 (CH2), 75.3 (CH5), 74.6 (CH6), 74.2 (CH4), 73.5 (CH_2), 73.0 (CH_2), 70.4 (OCH_2), 62.1 (CH_2). **HRMS (**ESI): m/z calcd for $C_{30}H_{34}O_6Na$ $[M+Na]^+$, 513.2247 found 513.2242.

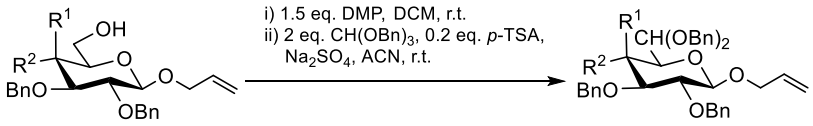
Allyl 2,3,4-tri-*O*-benzyl-β-D-glucopyranoside (4b)



This compound, an amorphous withe solid, was prepared from β-D-glucose pentaacetate, starting with the synthesis of the allyl glycoside and deacetylation[28], followed by trityl group protection of O6, benzylation and final trityl group removal (3.52 g, 31%).[29] Spectral data is consistent with the literature.[31] **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.36 – 7.24 (m, 15H; Ar-H), 5.95 (ddt, *J* = 17.2, 10.5, 5.6 Hz, 1H; =CH), 5.34 (dq, *J* = 17.2, 1.6 Hz, 1H; $=CH_{2a}$), 5.21 (dq, *J* = 10.5, 1.4 Hz, 1H; $=CH_{2b}$), 4.98 – 4.89 (m, 2H; Ph-CH_2-), 4.86 (d, *J* = 10.9 Hz, 1H; Ph-CH_2-), 4.80 (d, *J* = 10.9 Hz, 1H; Ph-CH_2-), 4.72 (d, *J* = 10.9 Hz, 1H; Ph-CH_2-), 4.63 (d, *J* = 10.9 Hz, 1H; Ph-CH_2-), 4.49 (d, *J* = 7.8 Hz; 1H, H-1), 4.39 (ddt, *J* = 12.9, 5.6, 1.6 Hz, 1H; -OCH_{2a}-), 4.15 (ddt, *J* = 12.9, 5.6, 1.4 Hz, 1H; -OCH_{2b}-), 3.86 (d, *J* = 12.0 Hz, 1H; H-6a), 3.70 (d, *J* = 12.0 Hz, 1H; H-6b), 3.66 (t, *J* =

9.1 Hz, 1H; H-3), 3.56 (t, *J* = 9.1 Hz, 1H; H-4), 3.44 (dd, *J* = 9.1, 7.8 Hz, 1H; H-2), 3.35 (ddd, *J* = 9.1, 4.7, 2.8 Hz, 1H; H-5), 1.87 (s, 1H; OH). **$^{13}C\{^{1}H\}$ NMR** (126 MHz, $CDCl_3$) δ 138.6 (Ar-H), 138.4 (Ar-H), 138.1 (Ar-H), 134.0 (=CH), 128.6 (Ar-H), 128.5 (Ar-H), 128.3 (Ar-H), 128.2 (Ar-H), 128.0 (Ar-H), 127.97 (Ar-H), 127.8 (Ar-H), 127.7 (Ar-H), 117.6 (CH_2), 102.9 (CH-1), 84.6 (CH-4), 82.4 (CH-3), 77.7 (CH-2), 75.8 (CH-5), 75.2 (CH_2-6), 75.12 (CH_2), 75.07 (CH_2), 70.8 (CH_2), 62.2 (CH_2). **HRMS (**ESI): m/z calcd for $C_{30}H_{34}O_6Na$ $[M+Na]^+$, 513.2247 found 513.2240.

General Procedure for the Syntheses of Dibenzylacetals. (GP1)



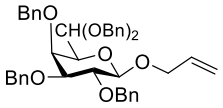
4a. Gal, R^1 = OBn, R^2 = H
4b. Glc, R^1 = H, R^2 = OBn

5a. Gal, R^1 = OBn, R^2 = H
5b. Glc, R^1 = H, R^2 = OBn

To a stirred solution of alcohol (**4a** or **4b**, 1 equiv., 0.5 M) in anhydrous CH_2Cl_2 was added of Dess-Martin periodinane (1.5 equiv.) Stirring was continued for 1 h at room temperature. After the completion of the reaction as observed by TLC, saturated aqueous $Na_2S_2O_3$ (50 mL) and saturated aqueous $NaHCO_3$ (50 mL) were added to the reaction mixture, which was stirred for another 0.25 h. The organic layer was separated, and the aqueous layer was extracted with CH_2Cl_2 (3x50 mL). The combined organic layers were collected, dried over anhydrous Na_2SO_4 and concentrated under reduced pressure to afford a crude residue which was used immediately without further purification.

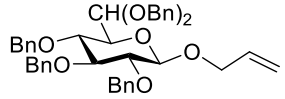
An 0.5 M solution of crude aldehyde (1 equiv.) in anhydrous acetonitrile was stirred with Na_2SO_4 (0.2 g/mmol) for 5 minutes before addition of *p*TSA (0.2 equiv.) and subsequently addition of $CH(OBn)_3$ (2 equiv.) in a dropwise manner. After complete addition the reaction mixture was stirred at room temperature overnight, then it was quenched with Et_3N (2.0 mL), filtered and concentrated under reduced pressure to afford a crude residue. Purification of this crude product by silica gel chromatography using 100% hexane to 5% ethyl acetate in hexane gave the dibenzylacetals.

Allyl 2,3,4,6,6-penta-*O*-benzyl-*β*-D-galactopyranoside (5a)



Prepared from compound **4a** (3.67 g, 7.34 mmol) following general procedure **GP1** as a white amorphous solid (3.6 g, 71%) $[\alpha]^{21}_D$ = +27.7 (*c* = 1.0, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.41 – 7.19 (m, 25H, ArH), 5.94 (ddt, *J* = 16.4, 10.9, 5.6 Hz, 1H, =CH), 5.29 (dq, *J* = 17.2, 1.8 Hz, 1H, $=CH_{2a}$), 5.17 (dq, *J* = 10.5, 1.5 Hz, 1H, $=CH_{2b}$), 5.02 (d, *J* = 7.4 Hz, 1H, H6), 5.00 – 4.92 (m, 2H, CH_2), 4.82 – 4.73 (m, 3H, CH_2), 4.74 – 4.63 (m, 3H, CH_2), 4.48 (d, *J* = 11.5 Hz, 1H, CH_2), 4.44 – 4.36 (m, 2H, H1, -OCH_{2a}-), 4.26 (d, *J* = 11.3 Hz, 1H, CH_2), 4.11 (dd, *J* = 13.0, 6.0 Hz, 1H, -OCH_{2b}-), 4.03 (d, *J* = 2.9 Hz, 1H, H4), 3.88 (dd, *J* = 9.7, 7.7 Hz, 1H, H2), 3.52 (dd, *J* = 9.7, 2.9 Hz, 1H, H3), 3.49 (d, *J* = 7.3 Hz, 1H, H5); **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.9 (C), 138.8 (C), 138.6 (C), 138.3 (C), 137.6 (C), 134.2 (=CH), 128.5 (Ar), 128.44 (Ar), 128.4 (Ar), 128.2 (Ar), 128.1 (Ar), 128.0 (Ar), 127.9 (Ar), 127.83 (Ar), 127.8 (Ar), 127.65 (Ar), 127.6 (Ar), 127.5 (Ar), 117.3 ($=CH_2$), 103.2 (C1), 100.5 (C6), 82.4 (C3), 79.5 (C2), 75.7 (CH_2), 75.3 (C5), 74.7 (CH_2), 74.5 (C4), 73.3 (CH_2), 70.3 (CH_2), 69.7 (OCH_2), 69.4 (CH_2). **HRMS** (ESI): *m*/*z* calcd for $C_{44}H_{50}O_7Na$ [M + Na], 709.3135; found, 709.3118.

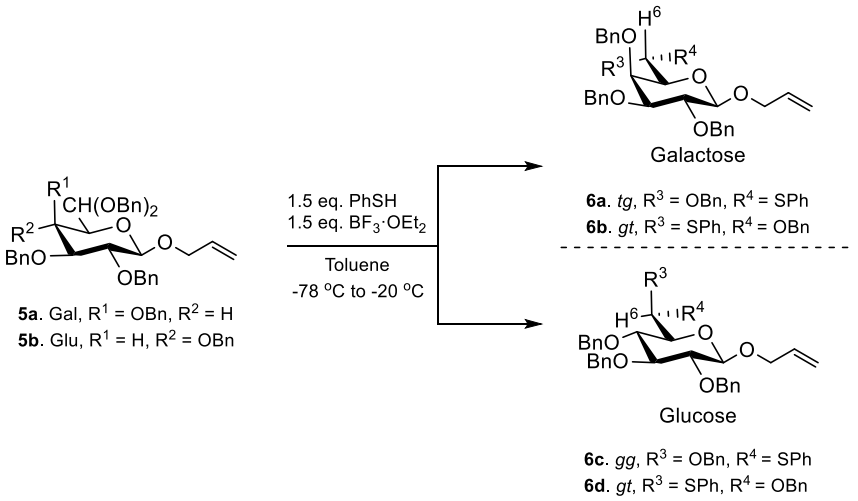
Allyl 2,3,4,6,6-penta-*O*-benzyl-β-D-glucopyranoside (5b)



Prepared from compound **4b** (3.52 g, 7.18 mmol) following general procedure **GP1** as a white amorphous solid (3.2 g, 65%) $[\alpha]^{21}_D$ = +3.9 (*c* = 0.1, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.43 – 7.16 (m, 23H; Ar-H), 7.09 (dd, *J* = 7.0, 2.7 Hz, 2H; Ar-H), 5.96 (ddt, *J* = 17.3, 10.2, 5.5 Hz, 1H; =CH), 5.34 (dq, *J* = 17.3, 1.7 Hz, 1H; $=CH_{2a}$), 5.20 (dq, *J* = 10.2, 1.7 Hz, 1H; $=CH_{2b}$), 5.04 (d, *J* = 1.9 Hz, 1H; H-6), 5.00 (d, *J* = 11.0 Hz, 1H; Ph-CH_2-), 4.94 (d, *J* = 11.0 Hz, 1H; Ph-CH_2-), 4.87 – 4.71 (m, 6H; Ph-CH_2-), 4.59 (d, *J* = 12.0 Hz, 1H; Ph-CH_2-), 4.47 (d, *J* = 7.7 Hz, 1H; H-1), 4.43 (ddt, *J* = 13.1, 5.5, 1.7 Hz, 1H; -OCH_{2a}-), 4.34 (d, *J* = 10.8 Hz, 1H; Ph-CH_2-), 4.12 (ddt, *J* = 13.1, 5.5, 1.7 Hz, 1H; -OCH_{2b}-), 3.73 (t, *J* = 8.9 Hz, 1H; H-4), 3.68 (t, *J* = 8.9 Hz, 1H; H-3), 3.63 (dd, *J* = 8.9, 1.9 Hz, 1H; H-5), 3.57 (t, *J* = 8.9, 7.7 Hz, 1H; H-2). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.46 (C), 138.4 (C), 138.22 (C), 138.2 (C), 137.5 (C), 134.0 (=CH), 128.34 (Ar), 128.30 (Ar), 128.24 (Ar), 128.2 (Ar), 128.10 (Ar), 128.07 (Ar), 127.77 (Ar), 127.7 (Ar), 127.59 (Ar), 127.56 (Ar), 127.54 (Ar), 127.5 (Ar), 127.4 (Ar), 117.2 (CH_2), 102.7 (CH-1), 98.3 (CH-6), 84.6 (CH-3), 81.9 (CH-2), 78.1 (CH-4), 76.0 (CH-5), 75.6 (CH_2), 74.6 (CH_2), 74.4 (CH_2), 70.1 (CH_2), 68.8

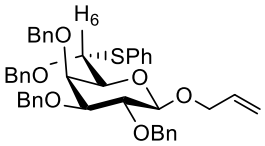
(CH_2), 68.4 (CH_2). **HRMS (**ESI): m/z calcd for $C_{44}H_{46}O_7Na$ $[M+Na]^+$, 709.3136 found 709.3137.

General Procedure for the Syntheses of Monothioacetals 6a-d. (GP2)



Dibenzylacetal (**5a** or **5b**, 1 equivalent) was co-evaporated with toluene and dried overnight under high vacuum. The residue was dissolved in anhydrous toluene to give a 0.2 M solution and cooled down to –78 °C. Thiophenol (1.5 equiv.) was added at the same temperature before. $BF_3{\cdot}OEt_2$ (1.5 equiv.) was added in a dropwise manner. After complete addition the reaction mixture was stirred for 10 mins at the same temperature and then gradually brought to –20 °C over a period of 3 h. The reaction mixture was stirred at – 20 °C for 0.5 h and then quenched with saturated aqueous $NaHCO_3$ (20 mL) and extracted with EtOAc (3x 20 mL). The combined organic layers were collected, dried over anhydrous sodium sulfate and concentrated under reduced pressure to afford a crude residue, which was purified by silica gel chromatography using 5% to 10% ethyl acetate and hexane as eluent to afford the corresponding mixture of monothioacetals.

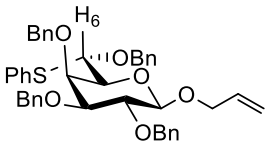
Allyl (6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*β*-D-galactopyranoside 6a



Prepared from compound **5a** (2.0 g, 2.91 mmol) following general procedure **GP2** as a colorless syrup (0.68 g, 34%) $[\alpha]^{23}_D$ = – 32.1 (*c* = 1.0, $CHCl_3$). **^{1}H NMR** (500 MHz, CD_2Cl_2) δ 7.57 – 7.48 (m, 2H, H*o*-SPh), 7.39 – 7.19 (m, 24H, Ar-H), 6.02 (dddd, *J* = 17.1, 10.7, 6.0, 5.0 Hz, 1H, =CH), 5.37 (dq, *J* = 17.1, 1.7 Hz, 1H, $=CH_{2a\ (trans)}$), 5.21 (dq, *J* = 10.7, 1.5 Hz, 1H, $=CH_{2a\ (cis)}$), 5.14 (d, *J* = 11.0 Hz, 1H, CH_2-O^6), 5.00 (d, *J* = 8.9 Hz, 1H, H-6), 4.95 (d, *J* = 11.0 Hz, 1H, CH_2-O^4), 4.88 (d, *J* = 11.0

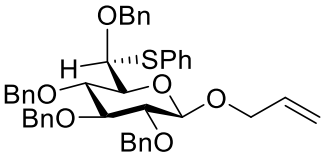
Hz, 1H, CH_2-O^3), 4.71 (d, *J* = 11.0 Hz, 1H, CH_2-O^3), 4.68 (s, 2H, CH_2-O^2), 4.49 (ddt, *J* = 13.0, 5.0, 1.7 Hz, 1H, -O-CH_{2a}-), 4.40 (d, *J* = 11.0 Hz, 1H, CH_2-O^4), 4.32 (d, *J* = 11.0 Hz, 1H, CH_2-O^6), 4.26 (d, *J* = 7.7 Hz, 1H, H-1), 4.18 (ddt, *J* = 13.0, 6.0, 1.5 Hz, 1H, -O-CH_{2b}-), 4.06 (dd, *J* = 3.0, 1.0 Hz, 1H, H-4), 3.73 (dd, *J* = 9.7, 7.7 Hz, 1H, H-2), 3.41 (dd, *J* = 9.7, 2.9 Hz, 1H, H-3), 3.19 (dd, *J* = 8.9, 1.1 Hz, 1H, H-5). **^{13}C {^{1}H}c NMR (126 MHz, CD_2Cl_2)** δ 139.1 (C), 139.0 (C), 138.7 (C), 137.2 (C), 134.7 ($CH_{o\text{-}SPh}$), 134.5 (=CH), 131.8 (C), 128.9 (Ar), 128.5 (Ar), 128.4 (Ar), 128.28 (Ar), 128.26 (Ar), 128.19 (Ar), 128.18 (Ar), 128.08 (Ar), 128.01 (Ar), 127.6 (Ar), 127.54 (Ar), 127.50 (Ar), 127.4 (Ar), 116.8 (=CH_2), 102.8 (CH-1), 87.0 (CH-6), 82.3 (CH-3), 80.0 (CH-2), 75.0 (CH_2-O^3), 74.8 (CH_2-O^4), 74.5 (CH-4), 73.4 (CH_2-O^2), 73.0 (CH-5), 70.3 (CH_2-O^6), 70.2 (OCH_2). **HRMS** (ESI): *m*/*z* calcd for $C_{43}H_{48}O_6SNa$ [M + Na], 711.2750; found, 711.2734.

Allyl (6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*β*-D-galactopyranoside 6b



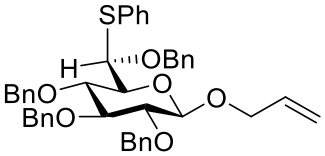
Prepared from compound **5a** (2.0 g, 2.91 mmol) following general procedure **GP2** as a colorless syrup (0.82 g, 41%). $[\alpha]^{23}_D$ = +22.8 (*c* = 2.0, $CHCl_3$) **^{1}H NMR** (500 MHz, C_6D_6) δ 7.47 – 7.41 (m, 2H, *o*-SPh), 7.37 – 7.31 (m, 2H, ArH), 7.32 – 7.21 (m, 6H, ArH), 7.15 – 6.97 (m, 12H, ArH), 6.96 – 6.85 (m, 3H, *m*,*p*-SPh), 5.87 – 5.70 (m, 1H, =CH), 5.37 – 5.27 (m, 2H, H6, CH2), 5.19 (dq, *J* = 17.4, 1.8 Hz, 1H, =CH_{2a}), 4.98 – 4.89 (m, 2H, CH_2, =CH_{2b}), 4.77 (d, *J* = 11.7 Hz, 1H, CH_2), 4.73 (d, *J* = 10.9 Hz, 1H, CH_2), 4.65 (dd, *J* = 11.8, 5.3 Hz, 2H,), 4.54 (d, *J* = 12.2 Hz, 1H, CH_2), 4.43 (d, *J* = 11.7 Hz, 1H, CH_2), 4.38 (d, *J* = 3.0 Hz, 1H, H4), 4.36 – 4.30 (m, 1H, -OCH_{2a}-), 4.17 (d, *J* = 7.7 Hz, 1H, H1), 4.07 (dd, *J* = 9.7, 7.6 Hz, 1H, H2), 3.95 (ddt, *J* = 13.2, 5.9, 1.7 Hz, 1H, -OCH_{2b}-), 3.41 (d, *J* = 8.8 Hz, 1H, H5), 3.27 (dd, *J* = 9.7, 2.9 Hz, 1H, H3). **^{13}C{^{1}H} NMR** (126 MHz, C_6D_6) δ 139.5 (C), 139.3 (C), 139.0 (C), 138.0 (C), 134.6 (=CH), 133.5 (Ar), 132.7 (Ar), 128.9 (Ar), 128.4 (Ar), 128.29 (Ar), 128.2 (Ar), 128.1 (Ar), 128.0 (Ar), 127.97 (Ar), 127.91 (Ar), 127.86 (Ar), 127.78 (Ar), 127.73 (Ar), 127.68 (Ar), 127.6 (Ar), 127.5 (Ar), 127.4 (Ar), 127.2 (Ar), 116.3 (=CH_2), 103.3 (C1), 87.2 (C6), 82.2 (C3), 79.7 (C2), 76.1 (C4), 76.0 (C5), 75.3 (CH_2), 74.7 (CH_2), 73.3 (CH_2), 70.7 (CH_2), 69.7 (OCH_2). **HRMS** (ESI): *m*/*z* calcd for $C_{43}H_{44}O_6SNa$ [M + Na], 711.2750; found, 711.2750.

Allyl (6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*β*-D-glucopyranoside 6c



Prepared from compound **5b** (1.6 g, 2.33 mmol) following general procedure **GP2** as a colorless syrup (0.923 g, 57%). $[\alpha]^{20}_D$ = +6.3 (*c* = 2.0, $CHCl_3$). **^{1}H NMR** (500 MHz, C_6D_6) δ 7.48 – 7.44 (m, 2H, H*o*-SPh), 7.37 – 7.27 (m, 2H, Ar-H), 7.26 – 7.20 (m, 2H, Ar-H), 7.09 – 6.84 (m, 19H, Ar-H), 5.81 (ddt, *J* = 17.1, 10.7, 6.1, 5.0 Hz, 1H, =CH), 5.59 (d, *J* = 2.1 Hz, 1H, H-6), 5.27 (dd, *J* = 17.1, 1.5 Hz, 1H, $=CH_{2a}$), 5.03 – 4.98 (m, 2H, $=CH_{2b}$, CH_2), 4.93 (m, 2H, CH_2), 4.83 (d, *J* = 11.3 Hz, 1H, CH_2), 4.72 (d, *J* = 11.3 Hz, 1H, CH_2), 4.66 (d, *J* = 11.3 Hz, 1H, CH_2), 4.53 (d, *J* = 11.6 Hz, 1H, CH_2), 4.47 (d, *J* = 11.6 Hz, 1H, CH_2), 4.42 (d, *J* = 7.2 Hz, 1H, H-1), 4.36 (ddt, *J* = 13.2, 5.0, 1.5 Hz, 1H, -OCH_{2a}-), 4.04 (ddt, *J* = 13.2, 6.1, 1.5 Hz, 1H, -OCH_{2b}-), 3.94 (dd, *J* = 9.7, 8.4 Hz, 1H, H-4), 3.75 (dd, *J* = 9.7, 2.1 Hz, 1H, H-5), 3.62 (m, 2H, H-2, H-3). **^{13}C{^{1}H} NMR** (126 MHz, C_6D_6) δ 139.17 (C), 139.10 (C), 139.0 (C), 137.6 (C), 136.9 (C), 134.3 (=CH), 131.3 (SPh-*C*H*o*), 129.0 (Ar), 128.26 (Ar), 128.21 (Ar), 128.18 (Ar), 128.0 (Ar), 127.9 (Ar), 127.7 (Ar), 127.5 (Ar), 127.4 (Ar), 127.3 (Ar), 126.7 (Ar), 116.8 ($=CH_2$), 103.3 (CH-1), 88.4 (CH-6), 84.8 (CH-3), 82.4 (CH-2), 79.6 (CH-5), 78.5 (CH-4), 75.3 (CH_2), 74.6 (CH_2), 74.5 (CH_2), 69.9 (CH_2), 69.8 (-OCH_2-). **HRMS (**ESI): m/z calcd for $C_{43}H_{44}O_6NaS$ $[M+Na]^+$, 711.2751 found 711.2741

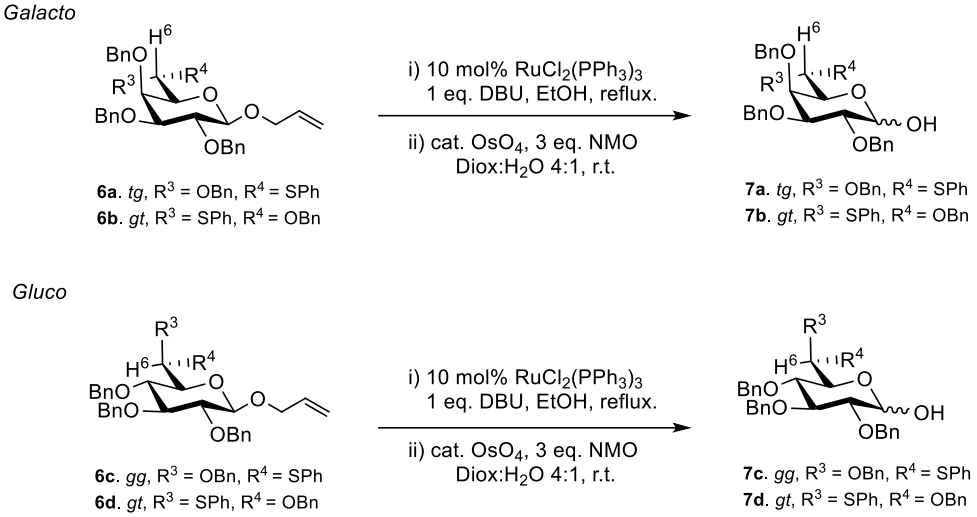
Allyl (6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*β*-D-glucopyranoside 6d



Prepared from compound **5b** (1.6 g, 2.33 mmol) following general procedure **GP2** as a white amorphous solid (0.192 g, 12%). $[\alpha]^{20}_D$ = +6.6 (*c* = 0.2, $CHCl_3$). **^{1}H NMR** (500 MHz, C_6D_6) δ 7.43 – 7.37 (m, 2H, H*o*-SPh), 7.31 - 7.28 (m, 2H, Ar-H), 7.26 – 7.21 (m, 2H, Ar-H), 7.18 – 7.12 (m, 2H, Ar-H), 7.12 – 6.91 (m, 14H, Ar-H), 6.90 – 6.81 (m, 3H, Ar-H), 5.74 (ddt, *J* = 16.4, 10.7, 5.4 Hz, 1H, =C-H), 5.62 (d, *J* = 1.5 Hz, 1H, H-6), 5.17 (dq, *J* = 16.4, 1.8 Hz, 1H, $=CH_{2a}$), 5.00 – 4.93 (m, 3H, $=CH_{2b}$, CH_2), 4.89 (d, *J* = 11.4 Hz, 1H, CH_2), 4.79 (d, *J* = 11.9 Hz, 1H, CH_2), 4.71 – 4.68 (m, 2H, CH_2), 4.64 (d, *J* = 11.4 Hz, 1H, CH_2), 4.45 (d, *J* = 11.4 Hz, 1H, CH_2), 4.38 (d, *J* = 7.5 Hz, 1H, H-1), 4.25 (ddt, *J* = 13.0, 5.4, 1.8 Hz, 1H, -OCH_{2a}-), 4.01 (dd, *J* = 9.6, 8.5 Hz, 1H, H-4), 3.94 – 3.85 (m, 2H, H-5, -OCH_{2b}-), 3.67 (dd, *J* = 9.1, 8.5 Hz, 1H, H-3), 3.62 (d, *J* = 9.1, 7.5 Hz, 1H, H-2). **^{13}C{^{1}H} NMR** (126 MHz, C_6D_6) δ 139.09 (C), 139.03 (C), 138.7 (C), 138.0 (C), 136.5 (C_i-SPh), 134.3 (=CH-), 131.4 (C_oH-SPh), 128.9 (Ar-H), 128.3 (Ar), 128.24 (Ar), 128.21 (Ar), 128.0 (Ar), 127.8 (Ar), 127.6 (Ar), 127.5 (Ar), 127.45 (Ar), 127.42(Ar), 127.37 (Ar), 127.31 (Ar), 126.6 (Ar), 116.6 ($=CH_2$), 102.8 (CH-1), 88.9 (CH-6),

84.6 (CH-3), 82.2 (CH-2), 79.0 (CH-4), 78.7 (CH-5), 75.1 (CH_2), 74.6 (CH_2), 74.5 (CH_2), 69.8 (CH_2), 69.5 (CH_2). **HRMS (**ESI): m/z calcd for $C_{43}H_{44}O_6NaS$ $[M+Na]^+$, 711.2751 found 711.2741

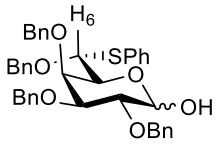
General procedure for Deallylation. GP3



To a stirred solution of allyl glycoside (1.0 equiv.) and $RuCl_2(PPh_3)_3$ (0.1 equiv.) in ethyl alcohol (0.1 M) was added DBU (1.0 equiv.). The resulting mixture was heated to reflux for 5 h before the solvent was evaporated under reduced pressure to afford a crude residue that was taken up in CH_2Cl_2 (50 mL) and washed with water (50 mL). The organic layer was separated and the aqueous layer was extracted with CH_2Cl_2 (2 x 50 mL). The organic layers were combined were dried over Na_2SO_4 addition, filtered and concentrated under reduced pressure to give a crude mixture, which was purified with silica gel column chromatography using 10% ethyl acetate in hexane as eluent to afford colorless syrup.

A stirred 0.1 M solution of the prepared compound in previous step in 1,4-dioxane/water (4:1) was treated with NMO (3.0 equiv.) and OsO_4 (2% in *t*-butanol, 2 drops) and stirred until completion (monitored by TLC) at room temperature. The reaction was quenched with saturated aqueous $Na_2S_2O_3$, diluted with ethyl acetate, washed with brine, and dried over Na_2SO_4. The organic layer was filtered and concentrated under reduced pressure to afford a crude residue that was purified by silica gel column chromatography using 15% to 25% ethyl acetate in hexane as eluent to afford a colorless syrup as a mixture of anomers.

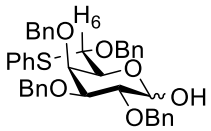
(6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-galactopyranose (7a)



Prepared using general protocol **GP3** from **6a** (0.7 g, 1.02 mmol) to afford mixture of 2.4:1, *ax:eq* anomers (0.53 g, 81%).

Mixture of anomers: **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.67 – 7.58 (m, 7H), 7.40 – 7.26 (m, 35H), 5.39 (d, *J* = 3.7 Hz, 2.4H), 5.19 – 5.12 (m, 3.5H), 5.09 – 4.99 (m, 7.1H), 4.93 (d, *J* = 11.0 Hz, 1H), 4.85 – 4.76 (m, 6.1H), 4.75 – 4.68 (m, 7.1H), 4.56 (dd, *J* = 7.4, 4.1 Hz, 1H), 4.48 – 4.40 (m, 3.5H), 4.32 – 4.26 (m, 3.5H), 4.17 (d, *J* = 2.7 Hz, 2.4H), 4.10 – 4.05 (m, 3.5H), 3.91 (d, *J* = 9.0 Hz, 2.4H), 3.88 (dd, *J* = 9.9, 2.7 Hz, 2.4H), 3.74 (d, *J* = 6.2 Hz, 1H), 3.45 (dd, *J* = 9.6, 2.8 Hz, 1H), 3.20 (d, *J* = 8.8 Hz, 1H), 2.77 (d, *J* = 2.5 Hz, 2.2H). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.10, 138.9, 138.8, 138.7, 138.5, 138.4, 137.3, 137.1, 135.4, 135.0, 131.9, 131.2, 129.0, 128.8, 128.68, 128.65, 128.5, 128.48, 128.47, 128.40, 128.38, 128.37, 128.35, 128.30, 128.16, 128.13, 128.10, 127.88, 127.8, 127.68, 127.66, 127.64, 127.61, 127.57, 127.55, 127.53, 127.51, 127.49, 97.9, 92.0, 87.1, 86.8, 82.6, 81.0, 79.2, 76.6, 75.4, 75.2, 74.8, 74.7, 74.3, 73.8, 73.5, 73.0, 70.4, 70.3, 70.1. HRMS (ESI): *m*/*z* calcd for $C_{40}H_{40}O_6SNa$ [M + Na], 671.2438; found, 671.2427.

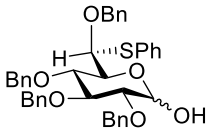
(6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-galactopyranose. (7b)



Prepared using general protocol **GP3** from **6b** (0.9 g, 1.31 mmol) to afford mixture of 2.4:1, *ax:eq* anomers (0.74 g, 87%).

Mixture of anomers: **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.73 – 6.65 (m, 85H), 5.33 (t, *J* = 3.1 Hz, 2H), 5.18 – 5.09 (m, 6.5H), 4.99 (d, *J* = 11.6 Hz, 1H), 4.96 – 4.91 (m, 3.2H), 4.87 (d, *J* = 11.9 Hz, 2.3H), 4.85 – 4.59 (m, 16.9H), 4.48 – 4.42 (m, 3H), 4.35 (d, *J* = 2.8 Hz, 1H), 4.21 (d, *J* = 5.5 Hz, 1H), 4.14 – 4.03 (m, 4.2H), 3.88 (dd, *J* = 10.0, 2.7 Hz, 2H), 3.80 (dd, *J* = 9.7, 7.5 Hz, 1H), 3.65 (d, *J* = 2.8 Hz, 2H), 3.38 (d, *J* = 9.0 Hz, 1H), 3.33 (dd, *J* = 9.7, 2.8 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 138.99, 138.91, 138.90, 138.8, 138.6, 138.5, 137.2, 137.1, 133.6, 133.0, 132.7, 131.8, 129.17, 129.16, 128.58, 128.57, 128.56, 128.50, 128.49, 128.47, 128.46, 128.38, 128.33, 128.31, 128.2, 128.1, 128.04, 128.00, 127.9, 127.88, 127.86, 127.81, 127.79, 127.75, 127.74, 127.6, 127.53, 127.51, 127.0, 98.0, 91.9, 86.7, 86.1, 82.2, 80.42, 79.2, 76.3, 76.1, 75.6, 75.0, 74.97, 74.95, 74.8, 73.35, 73.33, 73.2, 71.5, 70.4, 69.9. HRMS (ESI): *m*/*z* calcd for $C_{40}H_{40}O_6SNa$ [M + Na], 671.2438; found, 671.2430.

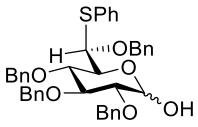
(6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-glucopyranose. 7c



Prepared using general protocol **GP3** from **6c** (0.9 g, 1.30 mmol) to afford mixture of 1.5:1, *ax:eq* anomers (0.46 g, 54%).

Mixture of anomers: **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.55 – 7.49 (m, 5H), 7.39 – 7.33 (m, 7H), 7.32 – 7.08 (m, 40H), 7.06 – 7.01 (m, 5H), 5.35 – 5.31 (m, 3H), 5.30 (t, *J* = 2.9 Hz, 1.5H, H-1 α anomer), 5.00 – 4.87 (m, 5H), 4.86 – 4.67 (m, 12.5H), 4.54 (d, *J* = 11.8 Hz, 1H, CH_2), 4.43 (d, *J* = 11.8 Hz, 1.5H, CH_2), 4.39 (d, *J* = 9.9 Hz, 1.5H, CH), 4.21 (d, *J* = 11.0 Hz, 1H, CH_2), 4.17 (d, *J* = 11.3 Hz, 1.5H, CH_2), 4.13 (t, *J* = 7.1 Hz, 1H, H-1 β anomer), 4.02 (t, *J* = 9.3 Hz, 1.5H, CH), 3.83 (dd, *J* = 9.7, 1.7 Hz, 1H, CH), 3.75 (t, *J* = 9.2 Hz, 1H, CH), 3.70 (d, *J* = 9.5 Hz, 1H, CH), 3.66 (t, *J* = 9.2 Hz, 1.5H, CH), 3.61 (dd, *J* = 9.6, 3.5 Hz, 1.5H, CH), 3.45 (t, *J* = 8.6 Hz, 1.5H, CH), 3.37 (d, *J* = 5.2 Hz, 1.5H, CH), 3.12 (d, *J* = 2.9 Hz, 1.5H, CH). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.6 (C), 138.5 (C), 138.4 (C), 138.3 (C), 138.0 (C), 137.0 (C), 136.9 (C), 136.1 (C), 135.7 (C), 132.5 (Ar), 132.4 (Ar), 129.22 (Ar), 129.18 (Ar), 128.7 (Ar), 128.65 (Ar), 128.61 (Ar), 128.55 (Ar), 128.50 (Ar), 128.46 (Ar), 128.4 (Ar), 128.3 (Ar), 128.2 (Ar), 128.1 (Ar), 128.0 (Ar), 127.8 (Ar), 127.68 (Ar), 127.6 (Ar), 127.5 (Ar), 98.1 (CH-1 β anomer), 91.5 (CH-1 α anomer), 88.2 (CH), 87.2 (CH), 84.7 (CH), 83.2 (CH), 81.9 (CH), 80.0 (CH), 79.5 (CH), 78.4 (CH), 78.2 (CH), 76.0 (CH_2), 75.8 (CH_2), 75.3 (CH_2), 74.8 (CH_2), 74.7 (CH_2), 73.4 (CH), 70.6 (CH_2), 70.2 (CH_2). **HRMS (**ESI): m/z calcd for $C_{40}H_{40}O_6NaS$ $[M+Na]^+$, 671.2438 found 671.2432.

(6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-glucopyranose. 7d

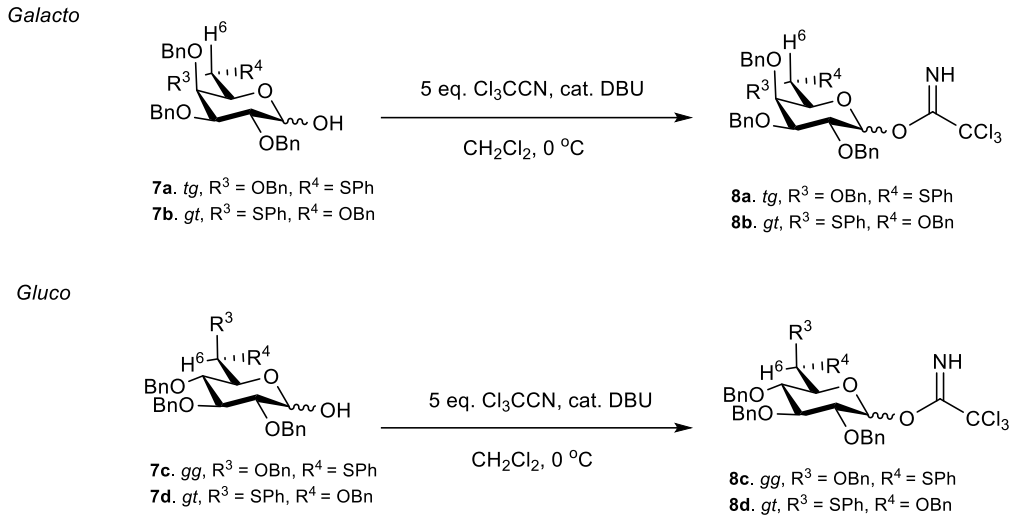


Prepared using general protocol **GP3** from **6d** (0.192 g, 0.28 mmol) to afford mixture of 9.8:1, *ax:eq* anomers (0.099 g, 55%).

Mixture of anomers **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.41 – 7.13 (m, 23H, Ar-H), 7.01 – 6.98 (m, 2H, Ar-H), 5.38 (d, *J* = 1.4 Hz, 1H, H-6), 5.24 (t, *J* = 3.2 Hz, 1H, H-1), 4.97 (d, *J* = 11.0 Hz, 1H, CH_2), 4.86 (d, *J* = 11.0 Hz, 1H, CH_2), 4.83 – 4.74 (m, 3H, CH_2), 4.71 (d, *J* = 12.0 Hz, 1H), 4.63 (d, *J* = 12.0 Hz, 1H, CH_2), 4.43 – 4.36 (m, 2H, CH_2, H-5), 4.03 (t, *J* = 9.2 Hz, 1H, H-4), 3.79 (t, *J* = 9.2 Hz, 1H, H-3), 3.60 (dd, *J* = 9.2, 3.2 Hz, 1H, H-2), 2.91 (d, *J* = 3.2 Hz, 1H, OH). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.6 (C), 138.2 (C), 137.9 (C), 137.5 (C), 135.6 (C), 131.9 (Ar), 129.1 (Ar), 128.6 (Ar), 128.5 (Ar), 128.4 (Ar), 128.4 (Ar), 128.11 (Ar), 128.10 (Ar), 128.08 (Ar), 128.0 (Ar), 127.8 (Ar), 127.6 (Ar), 127.5 (Ar), 127.2 (Ar), 91.3 (CH-1), 89.0

(CH-6), 81.6 (CH-4), 80.2 (CH-2), 79.1 (CH-3), 75.7 (CH_2), 74.9 (CH_2), 74.1 (CH_2), 73.3 (CH-5), 70.0 (CH_2). **HRMS (**ESI): m/z calcd for $C_{40}H_{40}O_6NaS$ $[M+Na]^+$, 671.2438 found 671.2424

General procedure for trichloroacetimidate preparation. GP4



The hemiacetal (1.0 equiv.) was dissolved in CH_2Cl_2 (0.2 M) and cooled down to 0 °C before trichloroacetonitrile (5.0 equiv.) and then DBU (1 drop) were added and the reaction mixture stirred for 0.5 h at the same temperature. After completion the reaction mixture was diluted with dichloromethane and washed with water. The aqueous layer was extracted with CH_2Cl_2 (2x20 mL). The organic layers combined were dried over Na_2SO_4 and concentrated under reduced pressure. The crude product was passed through a silica gel column, eluting with 10 to 20% ethyl acetate in hexane to give the trichloroacetamidate, which was used in the next step without further purification.

(6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-galactopyranosyl trichloroacetimidate (8a)

Prepared (0.55 g, 85%) by following the general protocol **GP4** from hemiacetal **7a** (0.53 g, 0.82 mmol) as colorless syrup. **HRMS (**ESI): m/z calcd for $C_{42}H_{40}O_6NCl_3NaS$ $[M+Na]^+$, 814.1534 found 814.1517.

(6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-galactopyranosyl trichloroacetimidate (8b)

Prepared (0.80 g, 89%) by following the general protocol **GP4** from hemiacetal **7b** (0.74 g, 1.14 mmol) as colorless syrup. **HRMS (**ESI): m/z calcd for $C_{42}H_{40}O_6NCl_3NaS$ $[M+Na]^+$, 814.1534 found 814.1506.

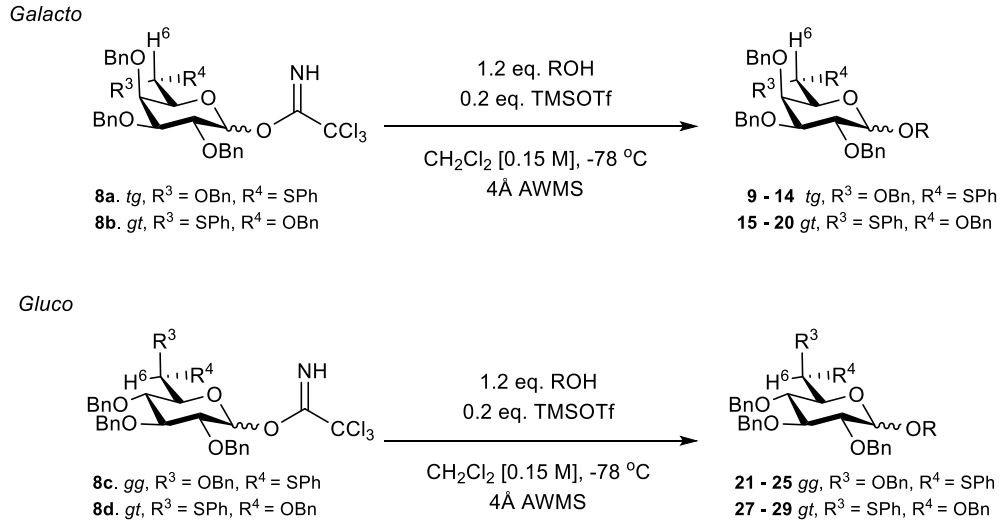
(6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-glucopyranosyl trichloroacetimidate (8c)

Prepared (0.48 g, 86%) by following the general protocol **GP4** from hemiacetal **7c** (0.46 g, 0.71 mmol) as colorless syrup. **HRMS (**ESI): m/z calcd for $C_{42}H_{40}O_6NCl_3NaS$ $[M+Na]^+$, 814.1534 found 814.1529.

(6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-glucopyranosyl trichloroacetimidate (8d)

Prepared (0.108 g, 90%) by following the general protocol **GP4** from hemiacetal **7d** (0.099g, 0.15 mmol) as colorless syrup. **HRMS (**ESI): m/z calcd for $C_{42}H_{40}O_6NCl_3NaS$ $[M+Na]^+$, 814.1534 found 814.1511.

General procedure for glycosylation reaction. GP5

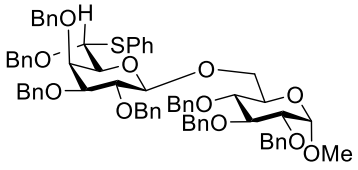


A mixture of the donor (1.0 equiv.), and acceptor (1.2 equiv.) was co-evaporated with toluene twice, then taken up in anhydrous CH_2Cl_2 (0.15 M) and stirred for 1 h with activated 4 Å AWMS (2 g/mmol of the donor) at room temperature under argon before cooling to −78 °C. The reaction mixture was treated with TMSOTf (0.2 equiv.) and stirred for 4−5 h at −78 °C before it was quenched with triethylamine (0.2 mL). The reaction mixture was diluted with dichloromethane (10 mL), filtered through a pad of Celite, and washed with saturated aqueous $NaHCO_3$. The organic layer was separated, dried over Na_2SO_4, filtered, and concentrated under reduced pressure. Purification by flash column chromatography on silica gel (hexane/ethyl

acetate) afforded the corresponding α/β-glycopyranosides. The anomeric ratio of the products was determined by integration of the ^{1}H NMR spectra of the crude product mixtures.

Methyl (6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*β*-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside (9)

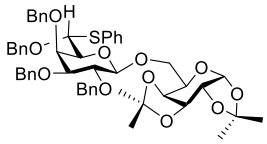
Compound **9β** was obtained (31.1 mg, 75%) as a single isomer from the reaction of donor **8a** (30.0 mg, 37.8 μmol) and acceptor (21.1 mg, 45.4 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9).



$[\alpha]^{20}_{D}$ = –14.0 (*c* = 1.9, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.50 (d, *J* = 7.5 Hz, 2H, ArH), 7.39 – 7.21 (m, 31H, ArH), 7.21 – 7.14 (m, 7H, ArH), 5.12 (d, *J* = 11.1 Hz, 1H, -CH_2), 5.03 – 4.94 (m, 3H, H6', -CH_2), 4.91 (d, *J* = 10.9 Hz, 1H, CH_2), 4.80 (m, 2H, CH_2), 4.77 – 4.70 (m, 2H, CH_2), 4.70 – 4.66 (m, 2H, CH_2), 4.63 (d, *J* = 3.6 Hz, 1H, H1), 4.54 (d, *J* = 11.0 Hz, 1H, CH_2), 4.40 (d, *J* = 11.4 Hz, 1H, CH_2), 4.34 (dd, *J* = 10.9, 2.2 Hz, 1H, H6b), 4.25 (d, *J* = 11.0 Hz, 1H, CH_2), 4.18 (d, *J* = 7.7 Hz, 1H, H1'), 4.05 – 3.99 (m, 2H, CH), 3.97 – 3.91 (m, 1H, CH), 3.87 (dd, *J* = 9.7, 7.7 Hz, 1H, H2'), 3.73 (dd, *J* = 10.9, 5.2 Hz, 1H, H6a), 3.58 – 3.50 (m, 2H, H2, CH), 3.38 (dd, *J* = 9.7, 2.8 Hz, 1H, H3'), 3.32 (s, 3H, OCH_3), 3.13 (d, *J* = 8.8 Hz, 1H, H5'). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.04 (C), 139.02 (C), 138.8 (C), 138.7 (C), 138.5 (C), 138.4 (C), 138.3 (C), 137.1 (C), 134.8 (Ar), 132.5 (Ar), 131.9 (Ar), 128.8 (Ar), 128.6 (Ar), 128.5 (Ar), 128.45 (Ar), 128.43 (Ar), 128.40 (Ar), 128.3 (Ar), 128.28 (Ar), 128.24 (Ar), 128.13 (Ar), 128.11 (Ar), 128.08 (Ar), 128.04 (Ar), 128.00 (Ar), 127.9 (Ar), 127.65 (Ar), 127.60 (Ar), 127.58 (Ar), 127.53 (Ar), 127.51 (Ar), 127.46 (Ar), 127.40 (Ar), 104.3 (C1'), 98.1 (C1), 87.0 (C6'), 82.7 (CH), 82.2 (CH), 80.0 (CH), 79.4 (CH), 78.4 (CH), 75.8 (CH_2), 75.3 (CH_2), 75.1 (CH_2), 74.7 (CH_2), 74.3 (CH), 73.5 (CH), 73.4 (CH_2), 73.0 (CH_2), 70.3 (CH_2), 70.0 (CH), 68.9 (C6), 55.3 (OCH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{68}H_{70}O_{11}SNa$ [M + Na], 1117.4531; found, 1117.4495.

(6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*β*-D-galactopyranosyl-(1→6)-1,2:3,4-*O*-diisopropylidene-*α*-D-galactopyranose (10)

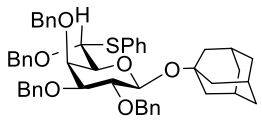
Compound **10β** was obtained (34.4 mg, 68%) as a single isomer from the reaction of donor **8a** (45.0 mg, 56.7 μmol) and acceptor (17.7 mg, 68.0 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9).



$[\alpha]^{21}_D$ = – 45.9 (*c* = 0.5, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.56 – 7.51 (m, 2H, ArH), 7.42 – 7.36 (m, 2H, ArH), 7.35 – 7.16 (m, 21H, ArH), 5.57 (d, *J* = 5.0 Hz, 1H, H1), 5.12 (d, *J* = 11.0 Hz, 1H, -CH_2), 5.02 – 4.97 (m, 2H, -CH_2, H6'), 4.94 (d, *J* = 11.4 Hz, 1H, -CH_2), 4.74 – 4.66 (m, 2H, CH_2), 4.65 – 4.57 (m, 2H, H3, -CH_2), 4.40 (d, *J* = 11.4 Hz, 1H, CH_2), 4.31 (dd, *J* = 5.0, 2.4 Hz, 1H, H2), 4.29 – 4.21 (m, 3H, CH_2, CH), 4.19 (d, *J* = 7.4 Hz, 1H, H1'), 4.11 (dt, *J* = 7.4, 2.8 Hz, 1H, CH), 4.01 (d, *J* = 2.8 Hz, 1H, H4'), 3.79 (dd, *J* = 9.7, 7.4 Hz, 1H, H2'), 3.73 (dd, *J* = 10.9, 7.7 Hz, 1H, CH), 3.35 (dd, *J* = 9.7, 2.8 Hz, 1H, H3'), 3.08 (d, *J* = 8.8 Hz, 1H, H5), 1.50 – 1.46 (m, 6H, 2xCH_3), 1.34 (s, 3H, CH_3), 1.30 (s, 3H, CH_3); **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.06 (C), 139.0 (C), 138.7 (C), 137.1 (C), 135.2 (Ar), 131.4 (Ar), 128.8 (Ar), 128.66 (Ar), 128.60 (Ar), 128.4 (Ar), 128.3 (Ar), 128.26 (Ar), 128.20 (Ar), 128.1 (Ar), 128.0 (Ar), 127.8 (Ar), 127.46 (Ar), 127.40 (Ar), 127.38 (Ar), 109.4 (CMe_2), 108.7 (CMe_2), 104.7 (C1'), 96.5 (C1), 86.7 (C6'), 82.3 (C3'), 79.1 (C2'), 74.71 (CH_2), 74.68 (CH_2), 74.4 (C4'), 73.2 (C5), 71.6 (CH), 70.9 (CH), 70.6 (CH), 70.2 (C6), 70.1 (CH_2), 67.8 (CH), 26.16 (CH_3), 26.12 (CH_3), 25.2 (CH_3), 24.6 (CH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{52}H_{58}O_{11}SNa$ [M + Na], 913.3592; found, 913.3571.

Adamantyl (6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*β*-D-galactopyranoside (11)

Compounds **11β** was obtained (24.1 mg, 61%) as a single isomer from the reaction of donor **8a** (40.0 mg, 50.4 μmol) and acceptor (9.2 mg, 60.5 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9).

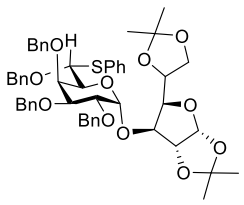


$[\alpha]^{21}_D$ = – 6.0 (*c* = 0.7, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.55 – 7.48 (m, 2H, ArH), 7.35 – 7.17 (m, 23H, ArH), 5.08 – 5.02 (m, 2H, H6, -CH_2), 4.98 (d, *J* = 11.4 Hz, 1H, -CH_2), 4.94 (d, *J* = 11.0 Hz, 1H, -CH_2), 4.74 – 4.69 (m, 2H, CH_2), 4.66 (d, *J* = 11.8 Hz, 1H, -CH_2), 4.56 (d, *J* = 7.7 Hz, 1H, H1), 4.44 (d, *J* = 11.4 Hz, 1H, -CH_2), 4.19 (d, *J* = 10.9 Hz, 1H, -CH_2), 4.07 (dd, *J* = 2.8, 1.1 Hz, 1H, H4), 3.79 (dd, *J* = 9.7, 7.7 Hz, 1H, H2), 3.47 – 3.31 (m, 2H, H3, H5), 2.13 (dq, *J* = 6.4, 3.5, 3.0 Hz, 3H, Ada), 1.95 – 1.88 (m, 3H, Ada), 1.88 – 1.79 (m, 3H, Ada), 1.67 – 1.55 (m, 6H, Ada). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.1 (C), 138.9 (C), 138.7 (C), 137.1 (C), 134.0 (Ar), 132.7 (Ar), 128.7 (Ar), 128.5 (Ar), 128.35 (Ar), 128.30 (Ar), 128.27 (Ar), 128.21 (Ar), 128.1 (Ar), 127.9 (Ar), 127.6 (Ar), 127.5 (Ar), 127.48 (Ar), 127.45 (Ar), 127.29 (Ar), 127.23 (Ar), 96.67 (C1), 87.87 (C6), 82.93 (C3), 79.63 (C2), 75.27 (CH_2), 75.23 (CH_2), 74.73 (C4), 74.69 (CH_2), 74.09 (C5),

73.20 (CH_2), 70.37 (CH_2), 42.79 (Ada), 42.36 (Ada), 36.43 (Ada), 30.82 (Ada), 30.74 (Ada). **HRMS** (ESI): *m*/*z* calcd for $C_{50}H_{54}O_6SNa$ [M + Na], 805.3533; found, 805.3537.

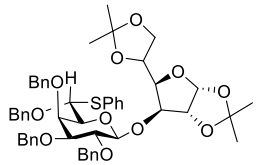
(6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α*-D-galactopyranosyl-(1→3)-1,2:5,6-di-*O*-isopropylidene-*α*-D-glucofuranose (12)

Compounds **12*α*** and **12*β*** were obtained as a mixture of anomers (38.2 mg, 85%, α/β = 1:4.3) from the reaction of donor **8a** (40.0 mg, 50.4 μmol) and acceptor (15.7 mg, 60.5 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated column chromatography gave pure samples of α- and β-isomer for full characterization.



$[\alpha]^{20}_D$ = +12.5 (*c* = 0.5, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.57 – 7.52 (m, 2H. ArH), 7.99 – 7.06 (m, 23H, ArH), 5.86 (d, *J* = 3.3 Hz, 1H, H1), 5.25 (d, *J* = 3.7 Hz, 1H, H1'), 5.03 (d, *J* = 9.11H, H6'), 4.99 (d, *J* = 11.0 Hz, 2H, -CH_2), 4.94 (d, *J* = 3.6 Hz, 1H, H2), 4.83 – 4.74 (m, 2H, CH_2), 4.73 – 4.66 (m, 2H, CH_2), 4.50 – 4.42 (m, 1H, CH), 4.38 (d, *J* = 11.3 Hz, 1H, -CH_2), 4.24 (d, *J* = 2.4 Hz, 1H, H4'), 4.20 – 4.14 (m, 4H, CH, CH_2), 4.13 – 4.05 (m, 1H, H2'), 4.02 – 3.94 (m, 3H, CH, CH_2), 3.89 – 3.83 (m, 1H, H3'), 1.47 (s, 3H, CH3), 1.40 (s, 3H, CH3), 1.24 (s, 3H, CH3), 1.22 (s, 3H, CH3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.0 (C), 138.7 (C), 138.6 (C), 137.0 (C), 135.1 (C), 132.5 (Ar), 129.1 (Ar), 128.5 (Ar), 128.4 (Ar), 128.38 (Ar), 128.28 (Ar), 128.22 (Ar), 128.1 (Ar), 127.6 (Ar), 127.59 (Ar), 127.57 (Ar), 127.46 (Ar), 127.4 (Ar), 127.3 (Ar), 111.8 (CMe_2), 108.9(CMe_2), 105.3 (C1), 99.3 (C1'), 90.1 (C6'), 83.3 (C2), 82.1 (C4), 81.3 (CH), 78.7 (CH), 76.5 (CH), 75.6 (CH), 74.7 (CH_2), 73.5 (CH_2), 73.14 (CH_2), 73.1 (CH), 72.6 (CH), 70.7 (CH_2), 66.9 (CH_2), 26.94 (CH3), 26.9 (CH3), 26.4 (CH3), 25.4 (CH3). **HRMS** (ESI): *m*/*z* calcd for $C_{52}H_{58}O_{11}SNa$ [M + Na], 913.3592; found, 913.3566.

***β* isomer:**

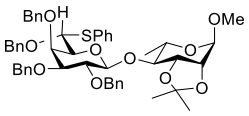


$[\alpha]^{21}_D$ = -22.9 (*c* = 0.4, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.54 – 7.49 (m, 2H, ArH), 7.35 – 7.21 (m, 23H, ArH), 5.79 (d, *J* = 3.8 Hz, 1H, H1), 5.12 (d, *J* = 11.0 Hz, 1H, -CH_2), 5.01 (d, *J* = 8.8 Hz, 1H, H6'), 4.96 (d, *J* = 11.5 Hz, 1H, -CH_2), 4.73 (d, *J* = 11.0 Hz, 1H, -CH_2), 4.67 – 4.62 (m, 3H, CH_2), 4.51 – 4.45 (m, 3H, H2, -CH_2), 4.42 – 4.38 (m, 2H, CH, CH_2), 4.25 (d, *J* = 11.0 Hz, 1H, -CH_2), 4.19 (d, *J* = 7.7 Hz, 1H, H1'), 4.11 – 4.05 (m, 2H, CH_2), 4.03 (dd, *J* = 3.0, 1.1 Hz, 1H, H4'), 3.69 (dd, *J* = 9.7, 7.7 Hz, 1H, H2'), 3.37 (dd, *J* = 9.7, 2.9 Hz, 1H, H3'), 3.11 (dd, *J* =

8.9, 1.1 Hz, 1H, H5'), 1.51 (s, 3H, CH_3), 1.45 (s, 3H, CH_3), 1.37 (s, 3H, CH_3), 1.25 (s, 3H, CH_3). **$^{13}C\{^1H\}$ NMR** (126 MHz, $CDCl_3$) δ 138.9 (C), 138.39 (C), 138.3 (C), 137.0 (C), 134.5 (Ar), 132.1 (Ar), 129.0 (Ar), 128.6 (Ar), 128.51 (Ar), 128.50 (Ar), 128.48 (Ar), 128.45 (Ar), 128.3 (Ar), 128.18 (Ar), 128.17 (Ar), 127.84 (Ar), 127.8 (Ar), 127.7 (Ar), 127.5 (Ar), 127.3 (Ar), 111.8 (CMe_2), 108.3(CMe_2), 105.2 (C1), 101.4 (C1'), 86.9 (C6'), 82.6 (C3'), 82.3 (CH), 80.4 (CH), 80.2 (CH), 79.4 (C2'), 75.4 (CH_2), 74.7 (CH_2), 74.3 (C4'), 74.0 (CH), 73.9 (C5'), 73.0 (CH_2), 70.4 (CH_2), 65.4 (CH_2), 26.9 (CH_3), 26.6 (CH_3), 26.3 (CH_3), 25.5 (CH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{52}H_{58}O_{11}SNa$ [M + Na], 913.3592; found, 913.3564.

Methyl (6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*β*-D-galactopyranosyl-(1→4)-2,3-*O*-isopropylidene-*α*-L-rhamnopyranoside (13*β*)

Compound **13*β*** was obtained (31.3 mg, 77%) as a single isomer from the reaction of donor **8a** (38.0 mg, 47.9 μmol) and acceptor (12.5 mg, 57.5 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9).

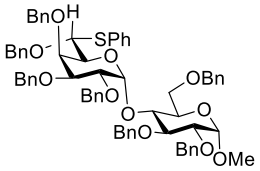


$[\alpha]^{21}_D$ = – 26.6 (*c* = 1.0, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$)) δ 7.56 – 7.49 (m, 2H, ArH), 7.39 (dd, *J* = 7.9, 1.7 Hz, 2H, ArH), 7.34 – 7.17 (m, 21H, ArH), 5.09 – 5.03 (m, 2H, -CH_2, H6'), 4.99 (d, *J* = 11.5 Hz, 1H, -CH_2), 4.92 (d, *J* = 10.9 Hz, 1H, -CH_2), 4.86 (s, 1H, H1), 4.78 (d, *J* = 7.7 Hz, 1H, H1'), 4.74 – 4.69 (m, 2H, -CH_2), 4.66 (d, *J* = 11.8 Hz, 1H, -CH_2), 4.42 (d, *J* = 11.5 Hz, 1H, -CH_2), 4.26 (t, *J* = 6.0 Hz, 1H, CH), 4.20 (d, *J* = 11.0 Hz, 1H, CH_2), 4.11 (dd, *J* = 5.9, 0.8 Hz, 1H, CH), 4.04 (dd, *J* = 3.1, 1.1 Hz, 1H, H4'), 3.77 (dd, *J* = 9.7, 7.7 Hz, 1H, H2'), 3.67 (m, 2H, H5), 3.49 (dd, *J* = 9.7, 2.9 Hz, 1H, H3'), 3.39 (s, 3H, OMe), 3.38 – 3.31 (m, 1H, CH), 1.54 (s, 3H, CH_3), 1.40 (d, *J* = 5.7 Hz, 3H, CH_3), 1.34 (s, 3H, CH_3). **$^{13}C\{^1H\}$ NMR** (126 MHz, $CDCl_3$) δ 139.2 (C), 138.9 (C), 138.7 (C), 137.1 (C), 133.6 (Ar), 133.5 (Ar), 133.2 (Ar), 128.9 (Ar), 128.5 (Ar), 128.3 (Ar), 128.29 (Ar), 128.25 (Ar), 128.0 (Ar), 127.6 (Ar), 127.57 (Ar), 127.53 (Ar), 127.52 (Ar), 127.47 (Ar), 127.42 (Ar), 127.37 (Ar), 127.34 (Ar), 109.3 (CMe2), 102.9 (C1'), 98.2 (C1), 88.0 (C6'), 82.6 (C3'), 82.4 (CH), 80.2 (CH), 79.8 (CH), 78.4 (CH), 75.9 (CH), 75.2 (CH_2), 74.8 (C4'), 74.6 (CH_2), 74.0 (CH), 73.2 (CH_2), 70.3 (CH_2), 64.5 (CH_2), 54.9 (OCH_3), 28.2 (CH_3), 26.2 (CH_3), 18.1 (CH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{50}H_{56}O_{10}SNa$ [M + Na], 871.3486; found, 871.3470.

Methyl (6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α/β*-D-galactopyranosyl-(1→4)-2,3,4-tri-*O*-benzyl-*α*-D-glucopyranoside (14)

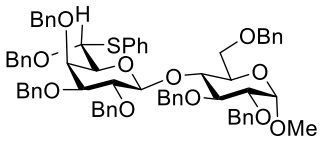
Compounds **14*α*** and **14*β*** were obtained as a mixture of anomers (47.9 mg, 76%, α/β = 1:1.1) from the reaction of donor **8a** (50.0 mg, 63.0 μmol) and acceptor (35.1 mg, 76.6 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated column chromatography gave pure samples of α- and β-isomer for full characterization.

α isomer:



$[\alpha]^{21}_D$ = +18.0 (*c* = 1.0, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.59 – 7.53 (m, 2H, ArH), 7.35 – 7.15 (m, 38H, ArH), 5.68 (d, *J* = 3.7 Hz, 1H, H1'), 5.07 – 4.99 (m, 2H, H6', CH_2), 4.96 – 4.89 (m, 2H, CH_2), 4.82 (d, *J* = 11.4 Hz, 1H, CH_2), 4.67 (d, *J* = 12.1 Hz, 1H, CH_2), 4.65 – 4.61 (m, 2H, CH_2), 4.61 – 4.55 (m, 3H, H1, CH_2), 4.55 – 4.49 (m, 2H, CH_2), 4.45 (d, *J* = 12.1 Hz, 1H, CH_2), 4.37 (d, *J* = 11.2 Hz, 1H, CH_2), 4.17 (d, *J* = 10.9 Hz, 1H, CH_2), 4.07 (dd, *J* = 2.8, 1.4 Hz, 1H, H4'), 4.04 – 3.94 (m, 3H, H2',CH), 3.90 – 3.81 (m, 2H, H5, CH), 3.76 – 3.68 (m, 2H, CH, H6b), 3.66 (dd, *J* = 10.4, 2.7 Hz, 1H, H6a), 3.55 (dd, *J* = 9.2, 3.6 Hz, 1H, CH), 3.38 (s, 3H, OCH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.2 (C), 139.0 (C), 138.8 (C), 138.4 (C), 138.2 (C), 138.2 (C), 137.4 (C), 135.6 (C), 132.7 (Ar), 129.0 (Ar), 128.5 (Ar), 128.4 (Ar), 128.37 (Ar), 128.35 (Ar), 128.32 (Ar), 128.31 (Ar), 128.29 (Ar), 128.27 (Ar), 127.99 (Ar), 127.96 (Ar), 127.94 (Ar), 127.7 (Ar), 127.59 (Ar), 127.53 (Ar), 127.4 (Ar), 127.3 (Ar), 127.2 (Ar), 127.1 (Ar), 127.0 (Ar), 97.8 (C1), 97.1 (C1'), 90.4 (C6'), 82.0 (CH), 79.9 (CH), 79.1 (CH), 76.0 (CH), 75.7 (C4'), 74.9 (CH_2), 74.3 (CH_2), 73.9 (CH), 73.5 (CH_2), 73.4 (CH_2), 73.1 (CH_2), 72.6 (CH), 70.6 (CH_2), 70.1 (C6), 69.6 (CH), 55.2 (OCH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{68}H_{70}O_{11}SNa$ [M + Na], 1117.4531; found, 1117.4503.

β isomer:



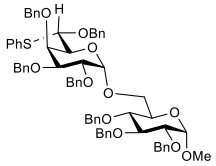
$[\alpha]^{21}_D$ = – 22.0 (*c* = 1.0, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$)) δ 7.59 – 7.55 (m, 2H, ArH), 7.47 – 7.41 (m, 2H, ArH), 7.34 – 7.16 (m, 30H, ArH), 7.16 – 7.06 (m, 4H, ArH), 7.05 – 6.98 (m, 2H, ArH), 5.17 (d, *J* = 11.0 Hz, 1H, -CH_2), 5.03 (d, *J* = 11.0 Hz, 1H, -CH_2), 4.99 (d, *J* = 11.3 Hz, 1H, -CH_2), 4.84 (d, *J* = 12.2 Hz, 1H, -CH_2), 4.80 (d, *J* = 8.8 Hz, 1H, H6'), 4.79 – 4.70 (m, 3H, -CH_2), 4.69 – 4.64 (m,

3H, CH_2), 4.57 (m, 2H, H1, -CH_2), 4.38 (d, *J* = 11.3 Hz, 1H, -CH_2), 4.33 (d, *J* = 12.2 Hz, 1H, -CH_2), 4.21 – 4.14 (m, 2H, CH_2), 4.07 (dd, *J* = 10.1, 9.0 Hz, 1H, CH), 4.04 (dd, *J* = 2.9, 1.1 Hz, 1H, H4'), 3.87 (t, *J* = 9.4 Hz, 1H, CH), 3.80 – 3.72 (m, 2H, H2'), 3.61 (dt, *J* = 10.0, 2.7 Hz, 1H, CH), 3.49 (dd, *J* = 9.7, 3.7 Hz, 1H, CH), 3.44 (dd, *J* = 10.8, 2.1 Hz, 1H, CH), 3.37 (s, 3H, OCH_3), 3.26 – 3.14 (m, 2H, H3', H5'). **$^{13}C\{^1H\}$ NMR** (126 MHz, $CDCl_3$) δ 139.8 (C), 139.3 (C), 139.0 (C), 138.7 (C), 138.6 (C), 138.0 (C), 137.3 (C), 134.5 (Ar), 133.6 (Ar), 128.78 (Ar), 128.7 (Ar), 128.6 (Ar), 128.48, (Ar) 128.41 (Ar), 128.38 (Ar), 128.30 (Ar), 128.27 (Ar), 128.24 (Ar), 128.2 (Ar), 127.97 (Ar), 127.94 (Ar), 127.93 (Ar), 127.74 (Ar), 127.7 (Ar), 127.6 (Ar), 127.5 (Ar), 127.4 (Ar), 127.34 (Ar), 127.30 (Ar), 127.2 (Ar), 127.0 (Ar), 102.3 (C1'), 98.8 (C1), 88.8 (C6'), 82.6 (C3'), 80.6 (CH), 80.2 (CH), 78.5 (CH), 75.9 (CH), 75.7 (CH_2), 75.2 (CH_2), 74.7 (CH_2), 74.5 (C4'), 74.4 (C5'), 73.8 (CH_2), 73.5 (CH_2), 72.8 (CH_2), 70.26 (CH_2), 70.2 (CH), 67.9 (CH_2), 55.4 (OCH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{68}H_{70}O_{11}SNa$ [M + Na], 1117.4531; found, 1117.4529.

Methyl (6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α*/*β*-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzyl-*α*-D-glucopyranoside (15)

Compounds **15α** and **15β** were obtained as a mixture of anomers (78.3 mg, 81%, α/β = 1:11.9) from the reaction of donor **8b** (70.0 mg, 88.2 μmol) and acceptor (49.2 mg, 105.9 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated column chromatography gave pure samples of α- and β-isomer for full characterization.

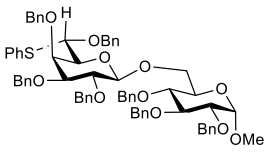
α isomer:



$[\alpha]^{20}_D$ = +23.2 (*c* = 2.0, $CHCl_3$). **^1H NMR** (900 MHz, $CDCl_3$) δ 7.42 – 7.12 (m, 40H, ArH), 5.14 (m, 2H, -CH_2, H6'), 5.05 (d, *J* = 3.7 Hz, 1H, H1'), 4.95 (d, *J* = 11.0 Hz, 1H, -CH_2), 4.85 (t, *J* = 11.2 Hz, 2H, -CH_2), 4.82 – 4.67 (m, 6H, -CH_2, -CH), 4.64 – 4.54 (m, 3H, -CH_2), 4.49 (d, *J* = 11.1 Hz, 1H, -CH_2), 4.45 (d, *J* = 3.5 Hz, 1H, H1'), 4.36 (s, 1H, H4'), 4.07 (d, *J* = 9.9 Hz, 1H, -CH), 3.94 (t, *J* = 9.5 Hz, 1H, -CH), 3.91 (d, *J* = 8.9 Hz, 1H, -CH), 3.84 – 3.81 (m, 1H, -CH), 3.71 (s, 3H), 3.50 (s, 1H, -CH), 3.38 (dd, *J* = 9.2, 4.0 Hz, 1H, -CH), 3.23 (s, 3H, -OCH_3). **$^{13}C\{^1H\}$ NMR** (226 MHz, $CDCl_3$) δ 138.9 (C), 138.8 (C), 138.4 (C), 138.2 (C), 137.9 (C), 132.9 (Ar), 128.9 (Ar), 128.4 (Ar), 128.36 (Ar), 128.34 (Ar), 128.3 (Ar), 128.19 (Ar), 128.13 (Ar), 128.0 (Ar), 127.97 (Ar),

127.94 (Ar), 127.9 (Ar), 127.8 (Ar), 127.6 (Ar), 127.58 (Ar), 127.53 (Ar), 127.50 (Ar), 127.37 (Ar), 127.34 (Ar), 97.7 (C1'), 97.6 (C1), 87.5 (C6'), 82.0 (CH), 80.1 (CH), 78.6 (CH), 78.1 (CH), 77.2 (CH), 76.36 (CH), 76.34 (CH), 75.7, 75.0, 74.9, 73.4 (CH_2), 73.0 (CH_2), 72.5 (CH_2), 71.8 (CH_2), 70.4 (CH_2), 70.1 (CH_2), 66.0 (CH_2), 54.9 (OCH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{68}H_{70}O_{11}SNa$ [M + Na], 1117.4531; found, 1117.4532.

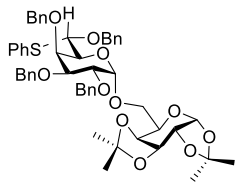
***β* isomer:**



$[\alpha]^{21}_D$ = +27.4 (*c* = 1.0, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.39 – 7.15 (m, 38H, ArH), 7.11 – 7.06 (m, 2H, ArH), 5.14 – 5.06 (m, 2H, -CH_2, H6'), 4.96 – 4.89 (m, 2H, -CH_2), 4.84 (d, *J* = 11.6 Hz, 1H, -CH_2), 4.80 – 4.69 (m, 5H, -CH_2, -CH_2), 4.68 – 4.55 (m, 5H, -CH_2, H1), 4.45 (d, *J* = 11.1 Hz, 1H, -CH_2), 4.29 (d, *J* = 2.8 Hz, 1H, H4'), 4.21 – 4.12 (m, 2H, H1', H6b), 3.94 (t, *J* = 9.3 Hz, 1H, -CH), 3.86 (dd, *J* = 9.7, 7.7 Hz, 1H, H2'), 3.77 (ddd, *J* = 10.1, 4.5, 2.1 Hz, 1H, H5), 3.61 (dd, *J* = 11.0, 4.5 Hz, 1H, H6a), 3.54 – 3.44 (m, 2H, -CH, H2), 3.35 (dd, *J* = 9.7, 2.8 Hz, 1H, H3'), 3.33 – 3.27 (m, 4H, H5',OCH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.0 (C), 138.9 (C), 138.8 (C), 138.52 (C), 138.5 (C), 138.3 (C), 137.5 (C), 133.7 (Ar), 131.9 (Ar), 129.0 (Ar), 128.53 (Ar), 128.50 (Ar), 128.41 (Ar), 128.39 (Ar), 128.34 (Ar), 128.31 (Ar), 128.23 (Ar), 128.19 (Ar), 128.03 (Ar), 128.01 (Ar), 127.99 (Ar), 127.97 (Ar), 127.96 (Ar), 127.8 (Ar), 127.78 (Ar), 127.74 (Ar), 127.71 (Ar), 127.57 (Ar), 127.52 (Ar), 127.44 (Ar), 127.41 (Ar), 104.2 (C1'), 98.1 (C1), 86.6 (C6'), 82.5 (C3'), 82.1 (-CH), 79.9 (CH), 79.2 (C2'), 77.9 (CH), 75.9 (C5'), 75.7 (CH_2), 75.2 (C4'), 75.1 (CH_2), 74.9 (CH_2), 74.8 (-CH_2), 73.4 (CH_2), 73.3 (CH_2), 71.0 (CH_2), 69.9 (C5), 68.5 (C6), 55.2 (OCH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{68}H_{70}O_{11}SNa$ [M + Na], 1117.4531; found, 1117.4541.

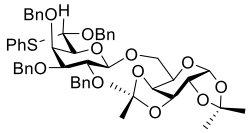
(6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α*/*β*-D-galactopyranosyl-(1→6)-1,2:3,4-*O*-diisopropylidene-*α*-D-galactopyranose (16)

Compounds **16α** and **16β** were obtained as a mixture of anomers (48.1 mg, 69%, α/β = 1:11.5) from the reaction of donor **8b** (62.0 mg, 78.2 μmol) and acceptor (24.4 mg, 93.8 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). The α isomer was not obtained pure and was characterized in the mixture of anomers by the following diagnostic signals.



α isomer: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.42 – 7.39 (m, 2H, ArH), 7.38 – 7.31 (m, 6H, ArH), 7.30 – 7.19 (m, 17H, ArH), 5.48 (d, *J* = 5.0 Hz, 1H, H1), 5.15 – 5.10 (m, 2H, H6', -CH_2), 5.07 (d, *J* = 10.8 Hz, 1H, -CH_2), 4.88 – 4.82 (m, 2H, -CH_2), 4.78 – 4.67 (m, 3H, -CH_2), 4.63 – 4.57 (m, 2H, -CH_2), 4.51 (dd, *J* = 7.9, 2.4 Hz, 1H, -CH), 4.39 – 4.35 (m, 1H, -CH), 4.27 (dd, *J* = 5.0, 2.4 Hz, 1H, H2), 4.14 (dd, *J* = 7.9, 1.9 Hz, 1H, -CH), 4.07 (dd, *J* = 10.0, 3.7 Hz, 1H, H6b), 3.99 (td, *J* = 6.9, 1.9 Hz, 1H, H5), 3.94 – 3.90 (m, 1H, -CH), 3.85 (dd, *J* = 10.1, 2.8 Hz, 1H, H2'), 3.77 (dd, *J* = 10.8, 7.1 Hz, 1H, H6a), 3.67 (dd, *J* = 10.8, 6.6 Hz, 1H, -CH), 1.51 (s, 3H, CH_3), 1.37 (s, 3H, CH_3), 1.31 (s, 3H, CH_3), 1.25 (s, 3H, CH_3).

Repeated column chromatography gave a pure sample of β-isomer for full characterization.

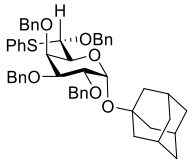


β isomer: $[\alpha]^{21}_{D}$ = +23.5 (*c* = 0.9, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.48 – 7.43 (m, 2H, ArH), 7.41 – 7.18 (m, 23H, ArH), 5.56 (d, *J* = 5.0 Hz, 1H, H1), 5.15 – 5.10 (m, 2H, -CH_2, H6'), 5.05 (d, *J* = 11.2 Hz, 1H, -CH_2), 4.91 (d, *J* = 11.4 Hz, 1H, -CH_2), 4.86 (d, *J* = 12.1 Hz, 1H, -CH_2), 4.75 (m, 2H, -CH_2), 4.65 (m, 2H, -CH_2), 4.51 (dd, *J* = 7.9, 2.4 Hz, 1H, H3), 4.34 (d, *J* = 7.7 Hz, 1H, H1'), 4.32 (d, *J* = 2.9 Hz, 1H, H4'), 4.29 (dd, *J* = 5.0, 2.4 Hz, 1H, H2), 4.18 (dd, *J* = 7.9, 1.9 Hz, 1H, -CH), 4.14 (dd, *J* = 10.8, 3.6 Hz, 1H, H6b), 4.09 (ddd, *J* = 7.4, 3.5, 1.8 Hz, 1H, H5), 3.86 (dd, *J* = 9.8, 7.6 Hz, 1H, H2'), 3.73 (dd, *J* = 10.8, 7.4 Hz, 1H, H6a), 3.40 – 3.34 (m, 2H, H3', H5'), 1.50 (s, 3H, CH_3), 1.41 (s, 3H, CH_3), 1.32 (s, 3H, CH_3), 1.29 (s, 3H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.1 (C), 138.9 (C), 138.8 (C), 137.6 (C), 133.8 (Ar), 131.9 (Ar), 129.1 (Ar), 128.7 (Ar), 128.49 (Ar), 128.46 (Ar), 128.3 (Ar), 128.23 (Ar), 128.21 (Ar), 128.1 (Ar), 128.0 (Ar), 127.8 (Ar), 127.7 (Ar), 127.48 (Ar), 127.44 (Ar), 109.3 (CMe_2), 108.7 (CMe_2), 104.9 (C1'), 96.5 (C1), 86.9 (C6'), 82.0 (C3'), 78.9 (C2'), 75.8 (C5'), 75.3 (C4'), 75.0 (CH_2), 74.6 (CH_2), 73.5 (CH_2), 71.5 (CH_2), 71.1 (CH_2), 70.8 (CH_2), 70.6 (C2), 69.9 (C6), 67.7 (C5), 26.2 (CH_3), 26.1 (CH_3), 25.2 (CH_3), 24.5 (CH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{52}H_{58}O_{11}SNa$ [M + Na], 913.3592; found, 913.3575.

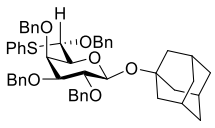
Adamantyl (6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α*-D-galactopyranoside (17)

Compounds **17α** and **17β** were obtained as a mixture of anomers (48.3 mg, 72%, α/β = 1:4.1) from the reaction of donor **8b** (68.0 mg, 85.7 μmol) and adamantanol (15.6 mg, 102.9 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl

acetate/hexane, 1:9). Repeated column chromatography gave pure samples of α- and β-isomer for full characterization.



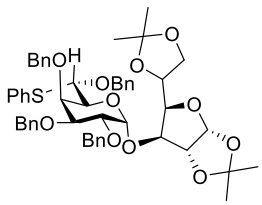
$[\alpha]^{20}_D$ = – 6.6 (*c* = 0.6, $CHCl_3$). **α isomer:** ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.46 – 7.42 (m, 2H, ArH), 7.41 – 7.38 (m, 2H, ArH), 7.38 – 7.33 (m, 4H, ArH), 7.32 – 7.19 (m, 17H, ArH), 5.33 (d, *J* = 3.8 Hz, 1H, H1), 5.13 (d, *J* = 10.9 Hz, 1H, CH_2), 5.06 (d, *J* = 9.1 Hz, 1H, H6), 4.95 (d, *J* = 11.2 Hz, 1H, CH_2), 4.86 (d, *J* = 11.7 Hz, 1H, CH_2), 4.76 (d, *J* = 11.7 Hz, 1H, CH_2), 4.72 (d, *J* = 12.0 Hz, 1H, CH_2), 4.68 (d, *J* = 12.0 Hz, 1H, CH_2), 4.61 (d, *J* = 10.9 Hz, 1H, CH_2), 4.48 (d, *J* = 11.2 Hz, 1H, CH_2), 4.42 (d, *J* = 2.8 Hz, 1H, H4), 4.08 – 4.00 (m, 2H, H2, H5), 3.85 (dd, *J* = 10.1, 2.8 Hz, 1H, H3), 2.00 (p, *J* = 3.3 Hz, 3H, Ada), 1.81 – 1.74 (m, 3H, Ada), 1.66 (dq, *J* = 11.7, 2.6 Hz, 3H, Ada), 1.59 – 1.52 (m, 3H, Ada), 1.51 – 1.45 (m, 3H, Ada). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.18 (C), 139.14 (C), 138.9 (C), 137.9 (C), 133.5 (Ar), 132.7 (Ar), 128.9 (Ar), 128.4 (Ar), 128.3 (Ar), 128.23 (Ar), 128.18 (Ar), 128.07 (Ar), 128.04 (Ar), 127.7 (Ar), 127.6 (Ar), 127.58 (Ar), 127.55 (Ar), 127.50 (Ar), 127.42 (Ar), 127.39 (Ar), 90.6 (C1), 87.9 (C6), 79.7 (C3), 77.3 (-CH_2), 76.4 (C2), 76.3 (C4), 74.9 (CH_2), 74.5 (CH_2), 73.2 (CH_2), 72.9 (CH_2), 71.5 (CH_2), 71.3 (C5), 42.4 (Ada), 36.3 (Ada), 30.7 (Ada). **HRMS** (ESI): *m*/*z* calcd for $C_{50}H_{54}O_6SNa$ [M + Na], 805.3533; found, 805.3520.



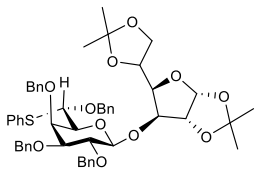
β isomer: $[\alpha]^{21}_D$ = +21.6 (*c* = 1.0, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40 – 7.18 (m, 25H, ArH), 5.15 – 5.08 (m, 2H, H6, CH_2), 4.95 (d, *J* = 11.1 Hz, 1H, CH_2), 4.87 (d, *J* = 11.0 Hz, 1H, CH_2), 4.78 (d, *J* = 12.0 Hz, 1H, CH_2), 4.74 – 4.68 (m, 2H, -CH_2), 4.60 (d, *J* = 10.9 Hz, 1H, -CH_2), 4.56 (d, *J* = 11.0 Hz, 1H, -CH_2), 4.51 (d, *J* = 7.7 Hz, 1H, H1), 4.29 (dd, *J* = 2.9, 1.0 Hz, 1H, H4), 3.78 (dd, *J* = 9.8, 7.7 Hz, 1H, H2), 3.37 (dd, *J* = 9.8, 2.9 Hz, 1H, H3), 3.33 (dd, *J* = 8.8, 1.0 Hz, 1H, H5), 2.02 (t, *J* = 3.2 Hz, 3H, Ada), 1.85 (dq, *J* = 11.5, 2.4 Hz, 3H, Ada), 1.75 (dq, *J* = 11.6, 2.7 Hz, 3H, Ada), 1.61 – 1.47 (m, 6H, Ada). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.04 (C), 139.0 (C), 138.8 (C), 137.6 (C), 133.5 (Ar), 132.3 (Ar), 129.0 (Ar), 128.44 (Ar), 128.39 (Ar), 128.34 (Ar), 128.30 (Ar), 128.27 (Ar), 128.1 (Ar), 128.0 (Ar), 127.8 (Ar), 127.7 (Ar), 127.65 (Ar), 127.60 (Ar), 127.54 (Ar), 127.51 (Ar), 127.4 (Ar), 96.7 (C1), 87.3 (C6), 82.8 (C3), 79.4 (CH_2), 75.9 (C5), 75.5 (C4), 75.16 (CH_2), 75.1 (CH_2), 74.9 (CH_2), 73.5 (CH_2), 71.5 (CH_2), 42.8 (Ada), 36.3 (Ada), 30.7 (Ada). **HRMS** (ESI): *m*/*z* calcd for $C_{50}H_{54}O_6SNa$ [M + Na], 805.3533; found, 805.3525.

6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α*-D-galactopyranosyl-(1→3)-1,2:5,6-di-*O*-isopropylidene-*α*-D-glucofuranose (18)

Compounds **18α** and **18β** were obtained as a mixture of anomers (57.2 mg, 85%, α/β = 1:6.3) from the reaction of donor **8b** (60.0 mg, 75.6 μmol) and acceptor (23.7 mg, 90.8 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated column chromatography gave pure samples of α- and β-isomer for full characterization.



α isomer: $[\alpha]^{23}_D$ = +36.3 (*c* = 1.0, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.43 – 7.20 (m, 26H, ArH), 5.20 (d, *J* = 3.5 Hz, 1H, H1), 5.13 (d, *J* = 10.9 Hz, 1H, -CH_2), 5.08 (d, *J* = 3.8 Hz, 1H, H1), 5.01 (d, *J* = 11.6 Hz, 1H, -CH_2), 4.96 (d, *J* = 9.3 Hz, 1H, H6'), 4.87 (d, *J* = 12.0 Hz, 1H, -CH_2), 4.76 – 4.64 (m, 4H, -CH_2), 4.62 (d, *J* = 11.6 Hz, 1H, -CH_2), 4.53 (d, *J* = 3.5 Hz, 1H, H2), 4.44 (dd, *J* = 2.8, 1.1 Hz, 1H, H4'), 4.36 (td, *J* = 6.5, 5.2 Hz, 1H, -CH), 4.12 (dd, *J* = 6.5, 2.8 Hz, 1H), 4.05 – 3.97 (m, 3H, -CH_2, CH), 3.89 (dd, *J* = 8.5, 5.3 Hz, 1H, -CH_2), 3.63 (dd, *J* = 10.2, 2.8 Hz, 1H, CH), 3.57 (dd, *J* = 9.3, 1.1 Hz, 1H, CH), 1.39 (s, 3H, CH_3), 1.38 (s, 3H, CH_3), 1.19 (s, 3H, CH_3), 0.86 (s, 3H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.85 (C), 138.79 (C), 138.75 (C), 137.3 (C), 134.5 (C), 130.9 (Ar), 129.0 (Ar), 128.57 (Ar), 128.54 (Ar), 128.43 (Ar), 128.40 (Ar), 128.3 (Ar), 128.1 (Ar), 128.0 (Ar), 127.80 (Ar), 127.78 (Ar), 127.66 (Ar), 127.63 (Ar), 127.61 (Ar), 127.5 (Ar), 111.5 (CMe2), 108.8 (CMe_2), 105.0 (C1), 99.7 (C1'), 86.2 (C6'), 82.8 (CH), 82.4 (CH), 80.9 (CH), 78.8 (CH), 76.6 (CH), 76.1 (CH), 75.1 (CH_2), 73.5 (CH_2), 73.2 (CH_2), 72.8 (CH), 71.9 (CH_2), 71.3 (CH_2), 66.5 (C6), 26.9 (CH_3), 26.8 (CH_3), 25.8 (CH_3), 25.3 (CH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{52}H_{58}O_{11}SNa$ [M + Na], 913.3592; found, 913.3596.

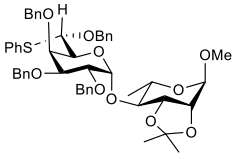


β isomer: $[\alpha]^{21}_D$ = +26.1 (*c* = 1.0, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.38 – 7.23 (m, 23H, ArH), 7.23 – 7.18 (m, 2H, ArH), 5.72 (d, *J* = 3.8 Hz, 1H, H1), 5.10 (d, *J* = 11.1 Hz, 1H, CH_2), 5.05 (d, *J* = 8.81H, H6'), 4.85 (d, *J* = 11.5 Hz, 1H, -CH_2), 4.79 – 4.72 (m, 3H, -CH_2), 4.71 – 4.64 (m, 2H, -CH_2), 4.61 (d, *J* = 11.2 Hz, 1H, -CH_2), 4.45 – 4.37 (m, 2H, CH, H2), 4.33 (t, *J* = 3.7 Hz, 1H, CH), 4.31 – 4.25 (m, 3H, -CH, H1'), 4.04 – 3.97 (m, 2H, H6), 3.70 (dd, *J* = 9.7, 7.7 Hz, 1H, H2'), 3.35 (dd, *J* = 9.7, 2.8 Hz, 1H, H3'), 3.29 (dd, *J* = 8.8, 1.2 Hz, 1H, H5'), 1.44 (s, 3H, CH_3), 1.36 (s, 3H, CH_3), 1.26 (s, 3H, CH_3), 1.18 (s, 3H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.9 (C), 138.5 (C), 138.3 (C), 137.3 (C), 133.8 (Ar), 131.6 (Ar), 129.1 (Ar), 128.5 (Ar), 128.4

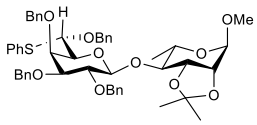
(Ar), 128.3 (Ar), 128.27 (Ar), 128.1 (Ar), 127.88 (Ar), 127.83 (Ar), 127.77 (Ar), 127.72 (Ar), 127.6 (Ar), 127.4 (Ar), 111.7 (CMe_2), 108.4 (CMe2), 105.2 (C1), 101.7 (C1'), 86.2 (C6'), 82.8 (CH), 82.3 (C3'), 80.40 (CH), 80.3 (CH), 79.3 (C2'), 76.3 (C5'), 75.2(CH_2), 75.1 (CH_2), 74.8 (CH), 73.7 (CH), 73.3 (CH_2), 71.3 (CH_2), 65.7 (C6), 26.8 (CH_3), 26.6 (CH_3), 26.2 (CH_3), 25.4 (CH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{52}H_{58}O_{11}SNa$ [M + Na], 913.3592; found, 913.3589.

Methyl (6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α/β*-D-galactopyranosyl-(1→4)-2,3-*O*-isopropylidene-*α*-L-rhamnopyranoside (19)

Compounds **19α** and **19β** were obtained as a mixture of anomers (54.0 mg, 84%, α/β = 1:1.02) from the reaction of donor **8b** (60.0 mg, 75.6 μmol) and acceptor (19.8 mg, 90.8 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated column chromatography gave pure samples of α- and β-isomer for full characterization.



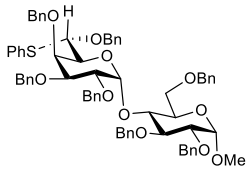
α isomer: $[\alpha]^{21}_D$ = +31.0 (*c* = 1.0, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.48 – 7.44 (m, 2H, ArH), 7.38 – 7.18 (m, 23H, ArH), 5.23 (d, *J* = 3.7 Hz, 1H, $H_{1'}$), 5.15 (d, *J* = 7.4 Hz, 1H, $H_{6'}$), 5.03 (d, *J* = 10.8 Hz, 1H, CH_2), 4.84 (d, *J* = 11.5 Hz, 1H, CH_2), 4.81 – 4.77 (m, 3H, CH_2, H_1), 4.74 (d, *J* = 11.8 Hz, 1H, CH_2), 4.67 (m, 2H), 4.50 (d, *J* = 11.5 Hz, 1H, CH_2), 4.37 (dd, *J* = 2.8, 1.3 Hz, 1H, H4'), 4.22 – 4.16 (m, 2H, H5', H3), 4.13 (dd, *J* = 10.2, 3.6 Hz, 1H, H2'), 3.95 (d, *J* = 5.8 Hz, 1H, H2), 3.86 (dd, *J* = 10.2, 2.7 Hz, 1H, H3'), 3.62 (dq, *J* = 9.7, 6.3 Hz, 1H, H5), 3.37 (dd, *J* = 9.8, 7.1 Hz, 1H, H4), 3.33 (s, 3H, OCH_3), 1.33 (s, 3H, CH_3), 1.29 (d, *J* = 6.3 Hz, 3H, CH_3), 1.13 (s, 3H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.1 (C), 138.8 (C), 138.7 (C), 137.8 (C), 132.8 (Ar), 128.9 (Ar), 128.4 (Ar), 128.39 (Ar), 128.33 (Ar), 128.09 (Ar), 128.07 (Ar), 128.01 (Ar), 127.7 (Ar), 127.6 (Ar), 127.5 (Ar), 127.4 (Ar), 127.3 (Ar), 127.2 (Ar), 109.0 (CMe_2), 98.3 (C1'), 98.1 (C1), 89.7 (C6'), 81.4 (C4), 79.3 (C3'), 77.0 (C3), 76.5 (C2'), 75.7 (C2), 75.4 (C4'), 74.6 (CH_2), 73.8 (CH_2), 72.9 (CH_2), 71.5 (C5'), 71.2, 64.6 (C5), 54.8 (OCH_3), 28.2 (CH_3), 26.3 (CH_3), 17.9 (CH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{50}H_{56}O_{10}SNa$ [M + Na], 871.3486; found, 871.3478.



β isomer: $[\alpha]^{21}_D$ = +18.6 (*c* = 1.0, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.39 – 7.21 (m, 23H, ArH), 7.20 – 7.15 (m, 2H, ArH), 5.13 – 5.08 (m, 2H, H6', CH_2), 4.93 – 4.83 (m, 3H, H1, CH_2), 4.80 (d, *J* = 12.1 Hz, 1H, CH_2), 4.75 (dd, *J* = 7.8, 1.1 Hz, 1H, H1'), 4.73 – 4.67 (m, 3H, CH_2), 4.61 (d, *J* = 11.1 Hz, 1H, CH_2), 4.25 (d, *J* = 3.0 Hz, 1H, H4'), 4.17 (t, *J* = 6.4 Hz, 1H, H3), 4.04 (d, *J* = 5.7 Hz, 1H, H2), 3.78 – 3.70 (m, 2H, H2', H4), 3.62 (m, 1H, H5), 3.42 – 3.36 (m, 4H, H3', OCH_3), 3.31 – 3.26 (m, 1H, H5'), 1.33 (d, *J* = 6.1 Hz, 3H, CH_3), 1.29 – 1.22 (m, 6H, 2xCH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.2 (C), 138.8 (C), 137.4 (C), 133.6 (Ar), 132.1 (Ar), 128.9 (Ar), 128.5 (Ar), 128.26 (Ar), 128.24 (Ar), 128.21 (Ar), 128.1 (Ar), 127.9 (Ar), 127.86 (Ar), 127.80 (Ar), 127.73 (Ar), 127.69 (Ar), 127.46 (Ar), 127.41 (Ar), 109.3 (CMe_2), 102.2 (C1'), 98.2 (C1), 86.3 (C6'), 82.5 (C3'), 79.7 (C4), 78.5 (C3), 78.1 (C2'), 76.0 (C2), 75.8 (C5'), 75.6 (C4'), 75.0 (CH_2), 74.9 (CH_2), 73.6 (CH_2), 70.7 (CH_2), 64.5 (C5), 54.9 (OCH_3), 27.7 (CH_3), 26.4 (CH_3), 18.0 (CH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{50}H_{56}O_{10}SNa$ [M + Na], 871.3486; found, 871.3484.

Methyl (6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α/β*-D-galactopyranosyl-(1→4)-2,3,4-tri-*O*-benzyl-*α*-D-glucopyranoside (20)

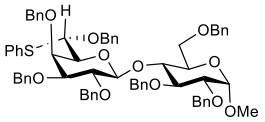
Compounds **20α** and 20**β** were obtained as a mixture of anomers (47.9 mg, 56%, α/β = 4.2:1) from the reaction of donor **8b** (62.0 mg, 78.2 μmol) and acceptor (43.6 mg, 93.8 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated chromatography gave a pure sample of the α-isomer for full characterization.



α isomer: $[\alpha]^{21}_D$ = +35.8 (*c* = 0.8, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.44 – 7.40 (m, 2H, ArH), 7.25 (d, *J* = 2.1 Hz, 11H, ArH), 5.60 (d, *J* = 3.8 Hz, 1H, H1'), 5.10 – 5.03 (m, 2H, CH_2, H6'), 4.90 – 4.84 (m, 2H, CH_2), 4.82 (d, *J* = 11.4 Hz, 1H, CH_2), 4.72 (d, *J* = 11.7 Hz, 1H, CH_2), 4.68 – 4.61 (m, 3H, CH_2), 4.59 – 4.54 (m, 2H, CH_2), 4.53 – 4.49 (m, 2H, H1, CH), 4.47 (d, *J* = 11.3 Hz, 1H, CH_2), 4.37 – 4.32 (m, 2H, CH, CH_2), 4.22 (d, *J* = 12.0 Hz, 1H, CH_2), 4.00 (dd, *J* = 10.3, 3.8 Hz, 1H, H2'), 3.94 (dd, *J* = 9.6, 8.1 Hz, 1H, CH), 3.82 (dd, *J* = 8.7, 1.3 Hz, 1H, H5'), 3.80 – 3.75 (m, 1H, CH), 3.76 – 3.70 (m, 2H, CH), 3.53 (dd, *J* = 10.9, 5.9 Hz, 1H, H6b), 3.43 (dd, *J* = 9.6, 3.5 Hz, 1H, CH), 3.37 (dd, *J* = 10.8, 2.1 Hz, 1H, H6a), 3.32 (s, 3H, OCH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.2 (C), 138.8 (C), 138.7 (C), 138.6 (C), 138.4 (C), 138.2 (C), 137.8 (C), 133.09 (Ar), 133.06 (C), 129.1 (Ar), 128.48 (Ar), 128.47 (Ar), 128.45 (Ar), 128.33 (Ar), 128.29

(Ar), 128.25 (Ar), 128.23 (Ar), 127.96 (Ar), 127.93 (Ar), 127.89 (Ar), 127.81 (Ar), 127.66 (Ar), 127.61 (Ar), 127.58 (Ar), 127.54 (Ar), 127.50 (Ar), 127.4 (Ar), 127.1 (Ar), 127.0 (Ar), 97.6 (C1'), 97.4 (C1), 88.3 (C6'), 81.9 (CH_2), 80.0 (CH_2), 79.2 (CH_2), 76.2 (CH), 75.8 (CH_2), 75.0 (CH_2), 74.6 (CH_2), 74.5 (CH_2), 73.4 (CH_2), 73.3 (CH_2), 73.2 (CH_2), 73.1 (CH_2), 72.9 (C5'), 71.4 (CH), 70.2 (CH), 69.5 (C6), 55.0 (OCH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{68}H_{70}O_{11}SNa$ [M + Na], 1117.4531; found, 1117.4504.

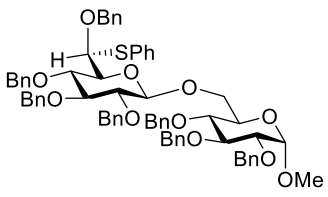
The β isomer was not obtained pure and was characterized in the mixture of anomers by the following diagnostic signals**:** ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.94 (d, *J* = 8.7 Hz, 1H, $H_{6'}$),



4.56 (d, *J* = 3.8 Hz, 1H, H1'), 3.25 (d, *J* = 8.7 Hz, 1H, H5'); ^{13}C NMR (126 MHz, $CDCl_3$) δ 139.4 (C), 139.1 (C), 139.0 (C), 138.69 (C), 138.67 (C), 138.2 (C), 137.9 (C), 133.1 (Ar), 132.8 (Ar), 129.0 (Ar), 128.97 (Ar), 128.91 (Ar), 128.49 (Ar), 128.48 (Ar), 128.45 (Ar), 128.43 (Ar), 128.33 (Ar), 128.30 (Ar), 128.26 (Ar), 128.23 (Ar), 128.1 (Ar), 128.09 (Ar), 128.06 (Ar), 127.97 (Ar), 127.94 (Ar), 127.91 (Ar), 127.90 (Ar), 127.7 (Ar), 127.69 (Ar), 127.67 (Ar), 127.64 (Ar), 127.63 (Ar), 127.59 (Ar), 127.56 (Ar), 127.55 (Ar), 127.51 (Ar), 127.4 (Ar), 127.2 (Ar), 127.1 (Ar), 127.07 (Ar), 127.01 (Ar), 102.4 (C1'), 98.7 (C1), 87.3 (C6'), 82.7 (CH), 80.2 (CH), 80.0 (CH), 79.1 (CH), 76.5 (CH_2), 75.9 (CH), 75.7 (CH), 75.6 (CH_2), 75.2 (CH_2), 75.1 (CH_2), 73.9 (CH_2), 73.3 (CH_2), 73.1 (CH_2), 72.3 (CH_2), 70.2 (CH_2), 67.9 (C6), 55.3 (OCH_3).

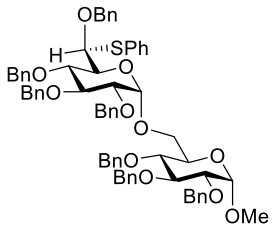
Methyl (6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-glucopyranosyl-(1→6)-2,3,4-tri-*O*-benzyl-*α*-D-glucopyranoside (21)

Compounds **21α** and **21β** were obtained as a mixture of anomers (66.2 mg, 80%, α/β = 8.7:1) from the reaction of donor **8c** (60.0 mg, 75.0 μmol) and acceptor (42.2 mg, 90.0 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated column chromatography gave a pure sample of β-isomer for full characterization.



β isomer: $[\alpha]^{20}_D$ = +7.1 (*c* 0.3, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.48 – 7.45 (m, 2H, Ar-H), 7.34 – 7.14 (m, 36H, Ar-H), 7.06 (dd, *J* = 6.7, 2.9 Hz, 2H, CH_2), 5.39 (d, *J* = 2.0 Hz, 1H, H6'), 4.97 (m, 2H, CH_2), 4.89 (d, *J* = 11.0 Hz, 1H, CH_2), 4.83 (d, *J* = 12.0 Hz, 1H, CH_2), 4.78 (d, *J* = 11.0 Hz, 1H, CH_2), 4.76 – 4.69 (m, 5H, CH_2, CH), 4.64 (d, *J* = 12.0

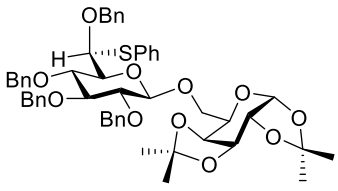
Hz, 1H, CH_2), 4.60 (d, *J* = 3.6 Hz, 1H, H1), 4.55 - 4.51 (m, 2H, CH_2), 4.38 – 4.30 (m, 2H, H1', CH_2), 4.23 (dd, *J* = 10.9, 2.0 Hz, 1H, H5'), 4.00 (t, *J* = 9.2 Hz, 1H, CH), 3.86 (dd, *J* = 10.2, 5.0 Hz, 1H, H5), 3.75 (t, *J* = 9.4 Hz, 1H, CH), 3.71 – 3.64 (m, 2H, CH), 3.61 (t, *J* = 8.9 Hz, 1H, H3'), 3.54 – 3.45 (m, 3H, CH), 3.32 (s, 3H, OCH_3). **$^{13}C\{^1H\}$ NMR** (126 MHz, $CDCl_3$) δ 139.0 (C), 138.5 (C), 138.46 (C), 138.43 (C), 138.3 (C), 138.2 (C), 137.3 (C), 136.3 (C), 131.6 (Ar), 129.2 (Ar), 128.57 (Ar), 128.51 (Ar), 128.49 (Ar), 128.44 (Ar), 128.40 (Ar), 128.3 (Ar), 128.2 (Ar), 128.08 (Ar), 128.05 (Ar), 128.02 (Ar), 127.9 (Ar), 127.8 (Ar), 127.79 (Ar), 127.75 (Ar), 127.73 (Ar), 127.72 (Ar), 127.69 (Ar), 127.64 (Ar), 127.1 (Ar), 104.6 (CH1'), 98.1 (CH1), 88.0 (CH6'), 84.8 (CH), 82.1 (CH), 82.0 (CH), 80.0 (CH), 79.4 (CH), 78.3 (CH), 78.2 (CH), 77.4 (CH_2), 77.1 (CH_2), 76.9 (CH_2), 75.9 (CH_2), 75.7 (CH), 75.0 (CH_2), 74.9 (CH_2), 74.9 (CH_2), 73.4 (CH_2), 70.0 (CH), 69.8 (CH_2), 68.9, 55.3 (CH_3). **HRMS (**ESI): m/z calcd for $C_{68}H_{70}O_{11}NaS$ $[M+Na]^+$, 1117.45310 found 1117.4521.



The α isomer was identified in the mixture by the following diagnostic signals: **^1H NMR** (500 MHz, $CDCl_3$) δ 5.31 (d, *J* = 1.7 Hz, 1H, H6'), 5.15 (d, *J* = 3.5 Hz, 1H, H1'), 3.48 – 3.42 (m, 1H), 3.38 (s, 3H, OCH_3).

(6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-glucopyranosyl-(1→6)-1,2:3,4-*O*-diisopropylidene-*α*-D-galactopyranose (22)

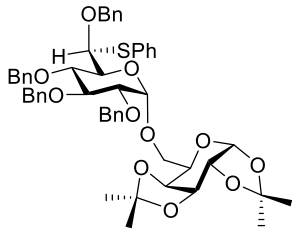
Compounds **22α** and **22β** were obtained as a mixture of anomers (57.0 mg, 89%, α/β = 5.5:1) from the reaction of donor **8c** (57.0 mg, 71.8 μmol) and acceptor (22.4 mg, 86.0 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated column chromatography gave a pure sample of β-isomer for full characterization.



β isomer: $[\alpha]^{20}_D$ = –16.8 (*c* 0.6, $CHCl_3$). **^1H NMR** (500 MHz, $CDCl_3$) δ 7.55 – 7.49 (m, 2H, Ar-H), 7.46 – 7.40 (m, 3H, Ar-H), 7.39 – 7.07 (m, 26H, Ar-H), 7.04 – 6.99 (m, 2H, Ar-H), 5.57 (d, *J* = 5.0 Hz, 1H, H1), 5.36 (d, *J* = 1.5 Hz, 1H, H6' donor), 5.07 (d, *J* = 11.2 Hz, 1H, CH_2), 4.95 (d, *J* = 10.8 Hz, 1H, CH_2), 4.86 (d, *J* = 11.9 Hz, 1H, CH_2), 4.77 – 4.67 (m, 3H, CH_2), 4.60 (dd, *J* = 7.9, 2.4 Hz, 1H, H3), 4.52 (d, *J* = 11.8 Hz, 1H, CH_2), 4.47 (d, *J* = 7.8 Hz, 1H, H1'), 4.31 (dd, *J* = 5.0, 2.4 Hz, 1H, H2), 4.25 (dd, *J* = 7.9, 1.5 Hz, 1H, H4), 4.22 (d, *J* =

10.9 Hz, 1H, CH_2), 4.15 – 4.04 (m, 2H, H5, H6a'), 3.74 (m, 3H, H4', H5', H6'b'), 3.63 (t, *J* = 8.5 Hz, 1H, H3'), 3.49 (dd, *J* = 9.1, 7.8 Hz, 1H, H2'), 1.50 (s, 3H, CH_3), 1.47 (s, 3H, CH_3), 1.33 (s, 3H, CH_3), 1.30 (s, 3H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.8 (C), 138.6 (C), 138.3 (C), 137.1 (C), 136.3 (C), 131.9 (Ar), 129.2 (Ar), 128.78 (Ar), 128.74 (Ar), 128.5 (Ar), 128.4 (Ar), 128.39 (Ar), 128.36 (Ar), 128.30 (Ar), 128.0 (Ar), 127.9 (Ar), 127.8 (Ar), 127.68 (Ar), 127.66 (Ar), 127.5 (Ar), 127.2 (Ar), 109.4 (CMe_2), 108.6 (CMe_2), 105.0 (CH1'), 96.5 (CH1), 88.0 (CH6), 84.7 (CH3'), 81.5 (CH2'), 79.3 (CH4'), 78.2 (CH5'), 75.8 (CH_2), 74.7 (CH_2), 74.3 (CH_2), 71.5 (CH4), 70.9 (CH_2), 70.6 (CH3), 70.1 (CH_2), 69.9 (CH_2), 67.6 (CH_3), 26.17 (CH_3), 26.14 (CH_3), 24.5 (CH_3). **HRMS (**ESI): m/z calcd for $C_{52}H_{58}O_{11}NaS$ $[M+Na]^+$, 913.3592 found 913.3573

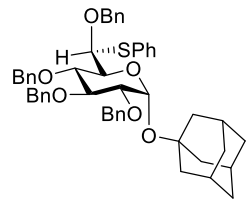
The α isomer was not obtained pure and was characterized in the mixture of anomers by the following diagnostic signals:



α isomer: ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.56 (d, *J* = 5.1 Hz, 1H, H6' acceptor), 5.15 (d, *J* = 3.6 Hz, 1H, H1'), 4.42 – 4.36 (m, 2H), 4.06 – 3.99 (m, 2H), 3.82 (dd, *J* = 10.4, 7.6 Hz, 1H), 1.55 (s, 3H, CH_3), 1.46 (s, 3H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 96.5 (C1'), 96.4 (C-6), 26.3 (CH_3), 25.0 (CH_3), 24.8 (CH_3).

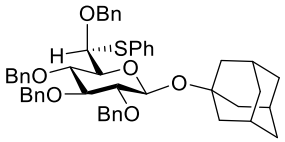
Adamantyl (6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-glucopyranoside (23)

Compounds **23α** and **23β** were obtained as a mixture of anomers (31.0 mg, 59%, α/β = 7.5:1) from the reaction of donor **8c** (53.0 mg, 66.8 μmol) and acceptor (12.2 mg, 80.0 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated column chromatography gave pure samples of α- and β-isomer for full characterization.



α isomer: $[\alpha]^{20}_D$ = +46.5 (*c* 0.1, $CHCl_3$). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.55 – 7.50 (m, 2H, Ar-H), 7.41 – 7.15 (m, 18H, Ar-H), 7.11 – 7.07 (m, 2H, Ar-H), 7.05 – 7.01 (m, 2H, Ar-H), 5.42 (d, *J* = 3.5 Hz, 1H, H1'), 5.39 (d, *J* = 1.6 Hz, 1H, H6'), 5.00 (d, *J* = 10.7 Hz, 1H, CH_2), 4.82 – 4.75 (m, 3H, CH_2), 4.71 (m, 2H, CH_2), 4.41 (d, *J* = 11.9 Hz, 1H, CH_2), 4.37 (dd, *J* = 9.8, 1.6 Hz, 1H, H5'), 4.13 (d, *J* = 10.9 Hz, 1H, CH_2), 4.06 (t, *J* = 9.8 Hz, 1H, H4'), 3.69 (t, *J* = 9.8 Hz, 1H, H3'), 3.58 (dd, *J* = 9.8, 3.5 Hz, 1H, H2'), 2.20 – 2.17 (m, 3H, CH), 2.02 – 1.98 (m, 3H, CH_2), 1.88 (dd, *J* = 11.5, 3.0 Hz, 3H, CH_2), 1.65 (d, *J* = 3.0 Hz, 6H, CH_2). **^{13}C{^{1}H} NMR** (156 MHz, $CDCl_3$) δ 138.8

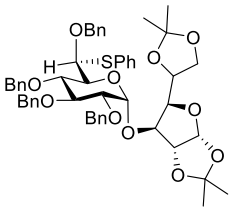
(C), 138.3 (C), 138.2 (C), 136.9 (C), 136.8 (C), 131.8 (Ar), 129.1 (Ar), 128.6 (Ar), 128.4 (Ar), 128.3 (Ar), 128.2 (Ar), 128.1 (Ar), 128.0 (Ar), 127.9 (Ar), 127.8 (Ar), 127.7 (Ar), 127.6 (Ar), 127.5 (Ar), 127.0 (Ar), 90.0 (CH1'), 88.6 (CH6'), 81.8 (CH4'), 80.0 (CH2'), 78.7 (CH3'), 75.6 (CH_2), 75.1 (CH5'), 74.9 (CH_2), 74.7 (CH_2), 73.0 (CH_2), 70.3 (CH_2), 42.5 (CH_2), 36.3 (CH_2), 30.7 (CH). **HRMS (**ESI): m/z calcd for $C_{50}H_{54}O_6NaS$ $[M+Na]^+$, 805.3533 found 805.3537.



β isomer: $[\alpha]^{20}_D$ = +5.7 (*c* 1.0, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.49 (dt, *J* = 8.1, 1.2 Hz, 2H, Ar-H), 7.37 – 7.33 (m, 2H, Ar-H), 7.32 – 7.11 (m, 19H, Ar-H), 7.05 (m, 2H, Ar-H), 5.43 (d, *J* = 1.3 Hz, 1H, H6'), 5.02 (d, *J* = 11.0 Hz, 1H, CH_2), 4.90 (d, *J* = 11.0 Hz, 1H, CH_2), 4.83 (d, *J* = 11.9 Hz, 1H, CH_2), 4.77 – 4.66 (m, 4H, H1', CH_2), 4.56 (d, *J* = 11.9 Hz, 1H, CH_2), 4.32 (d, *J* = 10.9 Hz, 1H, CH_2), 3.78 – 3.69 (m, 2H, H4', H5'), 3.63 (t, *J* = 8.6 Hz, 1H, H3'), 3.48 (dd, *J* = 8.6, 7.8, 1H, H2'), 2.22 – 2.16 (m, 3H, CH), 1.99 (dt, *J* = 11.6, 3.1 Hz, 3H, CH_2), 1.91 (dt, *J* = 11.6, 3.1 Hz, 3H, CH_2), 1.66 (d, *J* = 3.1 Hz, 6H, CH_2). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.7 (C), 138.6 (C), 138.4 (C), 137.5 (C), 136.9 (C), 131.4 (Ar), 129.1 (Ar), 128.45 (Ar), 128.44 (Ar), 128.36 (Ar), 128.34 (Ar), 128.31 (Ar), 128.0 (Ar), 127.76 (Ar), 127.70 (Ar), 127.68 (Ar), 127.63 (Ar), 127.0 (Ar), 97.2 (CH1'), 88.2 (CH6'), 85.1 (CH3'), 82.3 (CH2'), 79.3 (CH5'), 78.4 (CH4'), 75.8 (CH_2), 75.6 (C), 75.0 (CH_2), 74.8 (CH_2), 69.6 (CH_2), 42.9 (CH_2), 36.4 (CH_2), 30.8 (CH). **HRMS (**ESI): m/z calcd for $C_{50}H_{54}O_6NaS$ $[M+Na]^+$, 805.3533 found 805.3537.

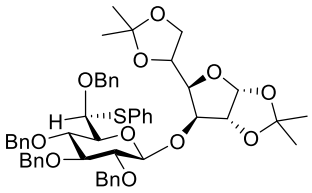
(6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-glucopyranosyl-(1→3)-1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose (24)

Compounds **24α** and **24β** were obtained as a mixture of anomers (125.0 mg, 75%, α/β = 2.9:1) from the reaction of donor **8c** (148.0 mg, 186.0 μmol) and acceptor (58.3 mg, 223.0 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated column chromatography gave pure samples of α- and β-isomer for full characterization.



α isomer: $[\alpha]^{20}_D$ = +34.9 (*c* 0.9, $CHCl_3$).**^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.53 – 7.46 (m, 2H, Ar-H), 7.37 – 7.11 (m, 21H, Ar-H), 7.02 – 6.97 (m, 2H, Ar-H), 5.87 (d, *J* = 3.5 Hz, 1H, H1), 5.34 – 5.30 (m, 2H, H6', H1'), 4.97 – 4.91 (m, 2H, CH_2), 4.86 (d, *J* = 11.7 Hz, 1H, CH_2), 4.76 – 4.72 (m, 3H, CH, CH_2), 4.68 (d, *J* = 11.7 Hz, 1H, CH_2), 4.47 (td, *J* = 8.4, 6.1, 5.1 Hz, 1H, H5), 4.42 (d, *J* = 11.7 Hz, 2H, CH_2), 4.31 (d, *J* = 2.7 Hz, 1H, H3), 4.17 (dd, *J* = 8.4, 2.7 Hz, 1H, H4), 4.15 – 4.10 (m, 2H, CH),

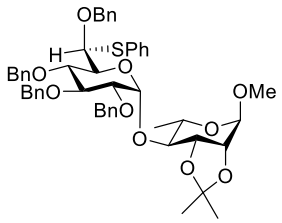
4.06 – 4.04 (m, 2H, CH), 3.92 (t, *J* = 9.4 Hz, 1H, H4'), 3.68 (t, *J* = 9.4 Hz, 1H, H3'), 3.58 (dd, *J* = 9.4, 3.5 Hz, 1H, H2'), 1.49 (s, 3H, CH_3), 1.41 (s, 3H, CH_3), 1.25 (s, 6H, CH_3).. **$^{13}C\{^1H\}$ NMR** (126 MHz, $CDCl_3$) δ 138.5 (C), 138.2 (C), 138.1 (C), 138.0 (C), 136.7 (C), 136.2 (C), 131.8 (Ar), 129.3 (Ar), 128.9 (Ar), 128.7 (Ar), 128.68 (Ar), 128.65 (Ar), 128.5 (Ar), 128.49 (Ar), 128.47 (Ar), 128.2 (Ar), 128.1 (Ar), 127.86 (Ar), 127.8 (Ar), 127.7 (Ar), 127.6 (Ar), 111.9 (CMe_2), 109.1 (CMe_2), 105.4 (CH1), 98.4 (CH1'), 88.5 (CH6'), 83.7 (CH), 81.6 (CH), 81.4 (CH), 81.3 (CH), 80.0 (CH), 78.2 (CH), 76.3 (CH), 75.9 (CH_2), 75.1 (CH_2), 73.2 (CH_2), 72.5 (CH), 70.7 (CH_2), 67.2 (CH_2), 27.1 (CH_3), 26.9 (CH_3), 26.3 (CH_3), 25.6 (CH_3). **HRMS (**ESI): m/z calcd for $C_{52}H_{58}O_{11}NaS$ $[M+Na]^+$, 913.3592 found 913.3596.



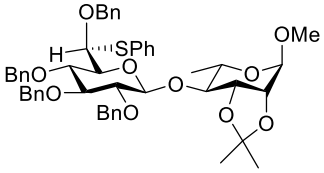
β isomer: $[\alpha]^{20}_D$ = +6.2 (*c* 0.7, $CHCl_3$).**^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.50 – 7.44 (m, 2H, Ar-H), 7.35 – 7.18 (m, 21H, Ar-H), 7.13 – 7.06 (m, 2H, Ar-H), 5.78 (d, *J* = 3.7 Hz, 1H, H1), 5.40 (d, *J* = 1.7 Hz, 1H, H6'), 4.89 (d, 11.0 Hz, 1H, CH_2), 4.84 (d, *J* = 11.7 Hz, 1H, CH_2), 4.79 – 4.72 (m, 4H, CH_2), 4.59 (d, *J* = 11.7 Hz, 1H, CH_2), 4.48 – 4.45 (m, 3H, CH), 4.44 – 4.40 (m, 2H, CH), 4.27 (d, *J* = 3.2 Hz, 1H, H3), 4.06 (d, *J* = 6.3 Hz, 2H, CH), 3.80 – 3.70 (m, 2H, H4', H5'), 3.63 (t, *J* = 8.6 Hz, 1H, H3'), 3.38 (dd, *J* = 8.6, 7.8 Hz, 1H, H2'), 1.50 (s, 3H, CH_3), 1.45 (s, 3H, CH_3), 1.28 (s, 3H, CH_3), 1.25 (s, 3H, CH_3).**$^{13}C\{^1H\}$ NMR** (126 MHz, $CDCl_3$) δ 138.4 (C), 138.2 (C), 138.1 (C), 137.5 (C), 136.2 (C), 131.3 (Ar), 129.2 (Ar), 128.59 (Ar), 128.51 (Ar), 128.47 (Ar), 128.42 (Ar), 128.2 (Ar), 127.89 (Ar), 127.84 (Ar), 127.80 (Ar), 127.7 (Ar), 127.1 (Ar), 112.0 (CMe_2), 108.4 (CMe_2), 105.2 (CH1), 102.0 (CH1'), 87.5 (CH), 84.6 (CH), 82.8 (CH), 82.1 (CH), 80.8 (CH), 80.2 (CH), 79.6 (CH), 78.2 (CH), 77.3 (CH), 77.1 (CH), 76.8 (CH), 75.8 (CH_2), 75.0 (CH_2), 73.8 (CH), 69.4 (CH_2), 65.6 (CH_2), 26.6 (CH_3), 26.2 (CH_3), 25.2 (CH_3). **HRMS (**ESI): m/z calcd for $C_{52}H_{58}O_{11}NaS$ $[M+Na]^+$, 913.3592 found 913.3596.

Methyl (6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-glucopyranosyl-(1→4)-2,3-O-isopropylidene-α-L-rhamnopyranoside. (25)

Compound **25α** and **25β** were obtained as a mixture of anomers (53.7 mg, 79%, α/β = 1.1:1) from the reaction of donor **8c** (63.0 mg, 79.4 μmol) and acceptor (20.8 mg, 95.3 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated column chromatography gave pure samples of α- and β-isomer for full characterization.



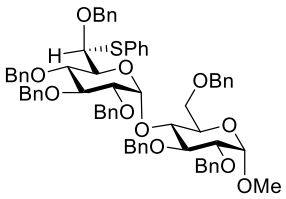
α isomer: $[\alpha]^{20}_D$ = +20.6 (*c* 1.5, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.54 – 7.48 (m, 2H, Ar-H), 7.35 – 7.12 (m, 19H, Ar-H), 7.11 – 7.06 (m, 2H, Ar-H), 7.05 – 6.98 (m, 2H, Ar-H), 5.31 (d, *J* = 1.8 Hz, 1H, H6'), 5.28 (d, *J* = 3.4 Hz, 1H, H1'), 4.92 (d, *J* = 10.8 Hz, 1H, CH_2), 4.83 – 4.70 (m, 5H, H1, CH_2), 4.65 (d, *J* = 11.8 Hz, 1H, CH_2), 4.48 (t, *J* = 6.4 Hz, 1H, H4), 4.38 (d, *J* = 11.8 Hz, 1H, CH_2), 4.32 (dd, *J* = 9.8, 1.8 Hz, 1H, H5'), 4.19 (d, *J* = 10.8 Hz, 1H, CH_2), 4.10 (dd, *J* = 6.3, 0.8 Hz, 1H, H2), 3.97 (t, *J* = 9.5 Hz, 1H, H3'), 3.72 (m, 2H, H4', H5), 3.57 (dd, *J* = 9.5, 3.4 Hz, 1H, H2'), 3.42 (dd, *J* = 9.7, 6.3 Hz, 1H, H3), 3.34 (s, 3H, CH_3), 1.48 (s, 3H, CH_3), 1.35 (d, *J* = 6.3 Hz, 3H, CH_3), 1.28 (s, 3H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.7 (C), 138.4 (C), 138.3 (C), 137.0 (C), 136.9 (C), 132.1 (Ar), 129.1 (Ar), 128.6 (Ar), 128.54 (Ar), 128.50 (Ar), 128.3 (Ar), 128.1 (Ar), 127.94 (Ar), 127.90 (Ar), 127.7 (Ar), 127.6 (Ar), 127.1 (Ar), 109.1 (CMe_2), 98.4 (CH1), 97.5 (CH1'), 89.5 (CH6'), 82.8 (CH3), 81.7 (CH3'), 80.5 (CH2'), 78.7 (CH), 77.0 (CH), 75.7 (CH_2), 75.6 (CH), 75.5 (CH), 74.8 (CH_2), 73.5 (CH_2), 70.5 (CH_2), 64.4 (CH), 54.8 (OCH_3), 28.1 (CH_3), 26.1 (CH_3), 18.1 (CH_3). **HRMS (**ESI): m/z calcd for $C_{50}H_{56}O_{10}NaS$ $[M+Na]^+$, 871.3486 found 871.3477.



β isomer: $[\alpha]^{20}_D$ = –27.6 (*c* 1.3, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.47 – 7.43 (m, 2H, Ar-H), 7.40 – 7.36 (m, 2H), 7.35 – 7.15 (m, 19H, Ar-H), 7.13 – 7.09 (m, 2H), 5.48 (d, *J* = 2.0 Hz, 1H, H6'), 5.01 – 4.86 (m, 4H, CH, CH_2), 4.85 – 4.65 (m, 6H, CH_2), 4.48 (d, *J* = 10.9 Hz, 1H, CH_2), 4.24 (dd, *J* = 7.3, 5.6 Hz, 1H, H3), 4.11 (d, *J* = 5.6 Hz, 1H, H2), 3.82 – 3.62 (m, 5H, CH), 3.44 (t, *J* = 8.5 Hz, 1H), 3.40 (s, 3H, OCH_3), 1.59 (s, 3H, CH_3), 1.42 (d, *J* = 6.2 Hz, 3H, CH_3), 1.35 (s, 3H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.7 (C), 138.6 (C), 138.4 (C), 137.8 (C), 136.7 (C), 130.9 (Ar), 129.1 (Ar), 128.44 (Ar), 128.41 (Ar), 128.3 (Ar), 128.1 (Ar), 127.9 (Ar), 127.8 (Ar), 127.7 (Ar), 127.6 (Ar), 126.8 (Ar), 109.6 (CMe_2), 102.9 (CH1'), 98.1 (CH1), 87.8 (CH), 84.8 (CH), 82.4 (CH), 79.3 (CH), 79.2 (CH), 78.5 (CH), 78.4 (CH), 76.0 (CH), 75.8 (CH_2), 74.9 (CH_2), 74.8 (CH_2), 68.9 (CH_2), 64.4 (CH), 54.9 (CH_3), 28.2 (CH_3), 26.5 (CH_3), 17.8 (CH_3). **HRMS (**ESI): m/z calcd for $C_{50}H_{56}O_{10}NaS$ $[M+Na]^+$, 871.3486 found 871.3477

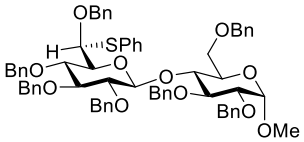
Methyl (6*S*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-glucopyranosyl-(1→4)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside. (26)

Compounds **26α** and **26β** were obtained as a mixture of anomers (34.0 mg, 80%, α/β = 1.1:1) from the reaction of donor **8c** (30.5 mg, 38.4 μmol) and acceptor (21.4 mg, 46.1 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated column chromatography gave a pure sample of α-isomer for full characterization.



α isomer: $[\alpha]^{20}_{D}$ = +29.5 (*c* 0.6, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.46 – 7.41 (m, 2H, Ar-H), 7.32 – 7.12 (m, 40H, Ar-H), 7.11 – 7.07 (m, 2H, Ar-H), 7.04 – 7.00 (m, 2H, Ar-H), 5.65 (d, *J* = 3.3 Hz, 1H, H1'), 5.34 (d, *J* = 1.7 Hz, 1H, H6'), 4.97 (d, *J* = 11.5 Hz, 1H, CH_2), 4.86 (d, *J* = 11.5 Hz, 1H, CH_2), 4.82 (d, *J* = 10.7 Hz, 1H, CH_2), 4.78 (d, *J* = 11.8 Hz, 1H, CH_2), 4.74 (d, *J* = 11.0 Hz, 1H, CH_2), 4.70 – 4.65 (m, 2H, CH_2), 4.60 – 4.57 (m, 2H, CH), 4.59 – 4.51 (m, 3H, CH), 4.45 – 4.41 (m, 2H, CH_2), 4.17 (d, *J* = 11.05 Hz, 1H, CH_2) 4.13 (dd, *J* = 9.50, 2.0 Hz, 1H, CH), 4.06 (t, *J* = 8.7 Hz, 1H, CH), 3.96 – 3.82 (m, 5H, CH, CH_2), 3.63 (t, *J* = 9.4 Hz, 1H, H3'), 3.58 (dd, *J* = 9.4, 3.3 Hz, 1H, H2'), 3.45 (dd, *J* = 9.4, 3.2 Hz, 1H, H2), 3.37 (s, 3H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 139.2 (C), 138.6 (C), 138.5 (C), 138.3 (C), 138.2 (C), 138.0 (C), 136.9 (C), 136.7 (C), 131.2 (Ar), 129.2 (Ar), 128.7 (Ar), 128.5 (Ar), 128.46 (Ar), 128.42 (Ar), 128.40 (Ar), 128.33 (Ar), 128.29 (Ar), 128.24 (Ar), 128.0 (Ar), 127.9 (Ar), 127.7 (Ar), 127.6 (Ar), 127.4 (Ar), 127.09 (Ar), 127.05 (Ar), 126.9 (Ar), 97.7 (CH1), 96.9 (CH1'), 88.0 (CH6'), 81.9 (CH), 81.8 (CH), 79.9 (CH), 79.5 (CH), 78.4 (CH), 76.5 (CH), 75.7 (CH_2), 74.9 (CH_2), 74.8 (CH_2), 74.5 (CH), 73.4 (CH_2), 73.3 (CH_2), 73.1 (CH_2), 70.1 (CH_2), 69.7 (CH), 55.1 (CH_3). **HRMS (**ESI): m/z calcd for $C_{68}H_{70}O_{11}NaS$ $[M+Na]^+$, 1117.4531 found 1117.4506.

The β isomer was not obtained pure and was characterized in the mixture of anomers by the following diagnostic signals:

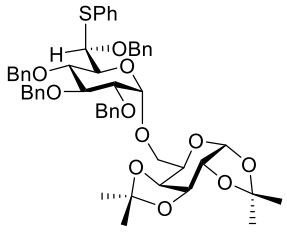


β isomer: ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.35 (d, *J* = 1.7 Hz, 1H; H6'), 4.46 (d, *J* = 7.3 Hz, 1H; H1'), 3.38 (s, 3H; OCH_3).

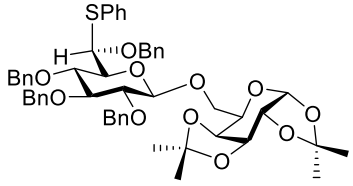
(6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-glucopyranosyl-(1→6)-1,2:3,4-*O*-diisopropylidene-α-D-galactopyranose. (27)

Compounds **27α** and **27β** were obtained as a mixture of anomers (32.0 mg, 73%, α/β = 1.3:1) from the reaction of donor **8d** (38.5 mg, 48.0 μmol) and acceptor (15.2 mg, 58.0 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9).

Repeated column chromatography gave pure samples of α- and β-isomer for full characterization.



α isomer: $[\alpha]^{20}_D$ = +3.2 (*c* 0.6, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.39 – 7.11 (m, 23H), 7.01 (m, 2H), 5.52 (d, *J* = 5.1 Hz, 1H, H1), 5.36 (d, *J* = 1.5 Hz, 1H, H6'), 5.08 (d, *J* = 3.5 Hz, 1H, H1'), 5.00 (d, *J* = 10.9 Hz, 1H, CH_2), 4.86 (d, *J* = 11.0 Hz, 1H, CH_2), 4.76 (m, 2H, CH_2, CH), 4.68 – 4.62 (m, 2H, CH), 4.57 (dd, *J* = 8.0, 2.4 Hz, 1H, H5), 4.39 (d, *J* = 11.2 Hz, 1H, CH_2), 4.34 (dd, *J* = 8.0, 2.0 Hz, 1H, H4), 4.31 – 4.27 (m, 2H), 4.07 (m, 2H, H3,), 3.90 (dd, *J* = 10.4, 6.4 Hz, 1H), 3.82 (d, *J* = 9.3 Hz, 1H, H3'), 3.78 (dd, *J* = 7.4, 3.0 Hz, 1H, H2), 3.61 (dd, *J* = 9.6, 3.5 Hz, 1H, H2'), 1.54 (s, 3H, CH_3), 1.42 (s, 3H, CH_3), 1.32 (s, 3H, CH_3), 1.29 (s, 3H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.8 (C), 138.4 (C), 138.3 (C), 137.4 (C), 135.9 (C), 131.8 (Ar), 129.1 (Ar), 128.5 (Ar), 128.47 (Ar), 128.41 (Ar), 128.39 (Ar), 128.03 (Ar), 128.00 (Ar), 127.83 (Ar), 127.79 (Ar), 127.6 (Ar), 127.1 (Ar), 109.3 (CMe_2), 108.7 (CMe_2), 96.8 (CH1'), 96.4 (CH1), 89.3 (CH), 81.8 (CH), 80.0 (CH), 79.1 (CH), 75.6 (CH_2), 74.8 (CH), 74.0 (CH_2), 72.4 (CH_2), 70.9 (CH), 70.8 (CH), 70.7 (CH), 70.1 (CH), 66.3 (CH), 65.6 (CH_2), 26.3 (CH_3), 26.2 (CH_3), 25.0 (CH_3), 24.8 (CH_3). **HRMS (**ESI): m/z calcd for $C_{52}H_{58}O_{11}NaS$ $[M+Na]^+$, 913.3592 found 913.3573.

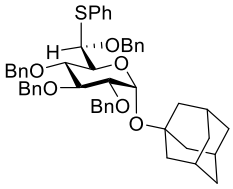


β isomer: $[\alpha]^{20}_D$ = –17.5 (*c* 0.3, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.44 – 7.39 (m, 4H, Ar-H), 7.32 – 7.15 (m, 19H, Ar-H), 7.02 – 6.98 (m, 2H, Ar-H), 5.56 (d, *J* = 5.0 Hz, 1H, H1), 5.40 (d, *J* = 1.3 Hz, 1H, H6'), 5.05 (d, *J* = 11.2 Hz, 1H, CH_2), 4.96 (d, *J* = 11.0 Hz, 1H, CH_2), 4.84 – 4.77 (m, 3H, CH_2), 4.75 – 4.69 (m, 2H, CH_2), 4.57 (dd, *J* = 7.9, 2.4 Hz, 1H, H4), 4.51 (d, *J* = 7.7 Hz, 1H, H1'), 4.41 (d, *J* = 10.9 Hz, 1H, CH_2), 4.30 (dd, *J* = 5.0, 2.4 Hz, 1H, H2), 4.24 (dd, *J* = 7.9, 1.9 Hz, 1H, H5), 4.13 (dd, *J* = 10.7, 3.5 Hz, 1H, H6a), 4.08 (dt, *J* = 9.2, 2.5 Hz, 1H, H3), 3.87 – 3.79 (m, 2H, H4', H5'), 3.73 (dd, *J* = 10.7, 7.5 Hz, 1H, H6b), 3.68 (t, *J* = 9.1 Hz, 1H, H3'), 3.49 (dd, *J* = 9.1, 7.7 Hz, 1H, H2'), 1.51 (s, 3H, CH_3), 1.42 (s, 3H, CH_3), 1.30 (m, 6H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.76 (C), 138.7 (C), 138.1 (C), 137.7 (C), 136.0 (C), 131.5 (Ar), 129.1 (Ar), 128.7 (Ar), 128.44 (Ar), 128.41 (Ar), 128.38 (Ar), 128.3 (Ar), 128.0 (Ar), 127.89 (Ar), 127.8 (Ar), 127.65 (Ar), 127.6 (Ar), 127.0 (Ar), 109.4 (C), 108.7 (C), 104.2 (CH1'), 96.5 (CH1), 88.7 (CH6'), 84.5 (CH), 81.7 (CH), 78.8 (CH), 78.4 (CH), 77.35 (CH), 77.30 (CH), 77.1 (CH), 76.8 (CH), 75.6 (CH_2), 75.0 (CH_2), 74.4 (CH), 71.5 (CH),

70.9 (CH), 70.6 (CH_2), 69.8 (CH_2), 69.6 (CH_2), 67.6 (CH), 26.2 (CH_3), 26.1 (CH_3), 25.1 (CH_3), 24.5 (CH_3). **HRMS (**ESI): m/z calcd for $C_{52}H_{58}O_{11}NaS$ $[M+Na]^+$, 913.3592 found 913.3573.

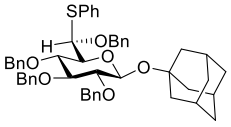
Adamantyl (6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-glucopyranoside. (28)

Compounds **28α** and **28β** were obtained as a mixture of anomers (63.0 mg, 88%, α/β = 1:4.8) from the reaction of donor **8d** (72.0 mg, 90.7 μmol) and acceptor (16.6 mg, 109.0 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated column chromatography gave a pure sample of α-isomer for full characterization.



α isomer: $[\alpha]^{20}_D$ = +46.2 (*c* 1.1, $CHCl_3$). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.46 – 7.14 (m, 24H, Ar-H), 7.08 (m, 2H, Ar-H), 5.33 (m, 2H, CH, H1', H6'), 5.02 (d, *J* = 10.8 Hz, 1H, CH_2), 4.90 (d, *J* = 11.0 Hz, 1H, CH_2), 4.84 – 4.75 (m, 2H, CH_2), 4.71 – 4.67 (m, 2H, CH_2), 4.55 – 4.45 (m, 2H, H5', CH_2), 4.39 (d, *J* = 10.8 Hz, 1H, CH_2), 4.10 (t, *J* = 9.5 Hz, 1H, H3'), 3.83 (dd, *J* = 9.5, 8.7 Hz, 1H, H4'), 3.58 (dd, *J* = 9.5, 3.6 Hz, 1H, H2'), 2.08 (t, J = 3.2 Hz, 3H, CH), 1.89 (m, 3H, CH_2), 1.83 (m, 3H, CH_2), 1.64 – 1.54 (m, 6H, CH_2). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.9 (C), 138.4 (C), 138.3 (C), 137.6 (C), 136.1 (C), 131.8 (Ar), 129.1 (Ar), 128.5 (Ar), 128.4 (Ar), 128.3 (Ar), 128.2 (Ar), 128.0 (Ar), 127.9 (Ar), 127.8 (Ar), 127.7 (Ar), 127.68 (Ar), 127.62 (Ar), 127.5 (Ar), 90.4 (CH1'), 89.9 (CH6'), 82.0 (CH3'), 80.4 (CH2'), 79.5 (CH4'), 75.5 (CH_2), 75.0 (CH_2), 74.9 (CH_2), 73.3 (CH_2), 73.0 (CH5'), 71.0 (CH_2), 42.5 (CH_2), 36.3 (CH_2), 30.7 (CH). **HRMS (**ESI): m/z calcd for $C_{50}H_{54}O_6NaS$ $[M+Na]^+$, 805.3533 found 805.3519.

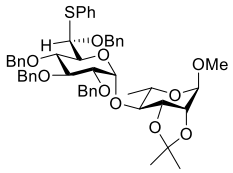
The β isomer was not obtained pure and was characterized in the mixture of anomers by the following diagnostic signals:



β isomer: ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.40 (d, *J* = 1.9 Hz, 1H; H6'), 3.71 (m, 1H, H3'), 3.50 (dd, *J* = 9.23, 7.61 Hz, 1H, H2').

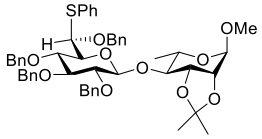
Methyl (6*R*)-6-phenylthio-2,3,4,6-tetra-*O*-benzyl-*α,β*-D-glucopyranosyl-(1→4)-2,3-*O*-isopropylidene-α-L-rhamnopyranoside. (29)

Compounds **29α** and **29β** were obtained as a mixture of anomers (27.3 mg, 68%, α/β = 1:2) from the reaction of donor **8d** (37.0 mg, 46.7 μmol) and acceptor (12.2 mg, 56.0 μmol) by following the general procedure **GP5** for glycosylation (eluting with ethyl acetate/hexane, 1:9). Repeated column chromatography gave a pure sample of α-isomer for full characterization.



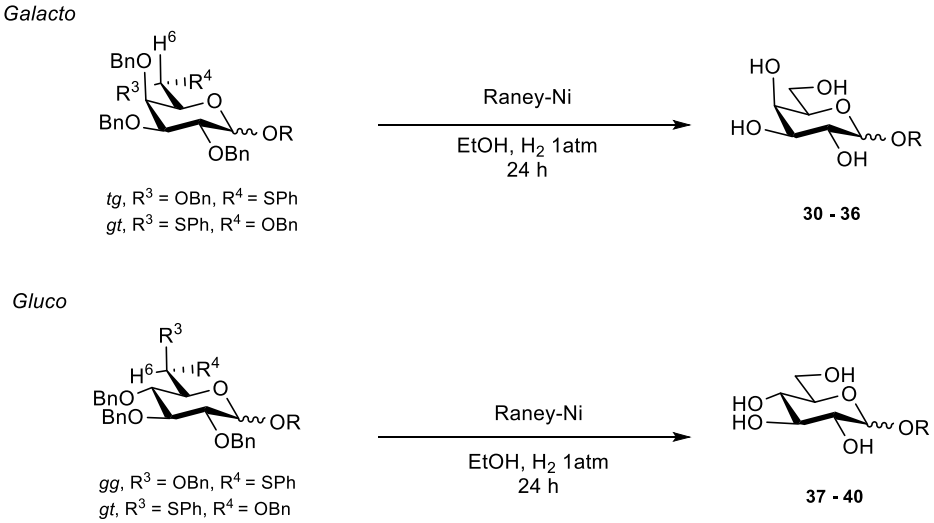
α isomer: $[\alpha]^{20}_D$ = +7.2 (*c* 0.6, $CHCl_3$) **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.44 – 7.38 (m, 2H, Ar-H), 7.37 – 7.11 (m, 23H, Ar-H), 5.32 (d, *J* = 1.4 Hz, 1H, H6'), 5.12 (d, *J* = 3.4 Hz, 1H, H1'), 4.95 (d, *J* = 10.8 Hz, 1H, CH_2), 4.85 (d, *J* = 10.8 Hz, 1H, CH_2), 4.83 – 4.79 (m, 3H, H1, CH_2), 4.77 (d, *J* = 11.6 Hz, 1H, CH_2), 4.69 (d, *J* = 11.6 Hz, 1H, CH_2), 4.64 (d, *J* = 12.1 Hz, 1H, CH_2), 4.58 (d, *J* = 10.8 Hz, 1H, CH_2), 4.51 (dd, *J* = 9.9, 1.4 Hz, 1H, H5'), 4.21 (dd, *J* = 7.0, 5.7 Hz, 1H, H3), 4.06 (t, *J* = 9.5 Hz, 1H, H3'), 3.99 (d, *J* = 5.7 Hz, 1H, H2), 3.89 (dd, *J* = 9.9, 9.5 Hz, 1H, H4'), 3.75 – 3.68 (m, 1H, H5), 3.57 (dd, *J* = 9.5, 3.4 Hz, 1H, H2'), 3.38 (dd, *J* = 9.9, 7.0 Hz, 1H, H4), 3.34 (s, 3H, OCH_3), 1.41 (s, 3H, CH_3), 1.33 (d, *J* = 6.3 Hz, 3H, CH_3), 1.16 (s, 3H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ 138.7 (C), 138.3 (C), 138.1 (C), 137.8 (C), 136.8 (C), 131.5 (Ar), 129.0 (Ar), 128.53 (Ar), 128.50 (Ar), 128.3 (Ar), 128.0 (Ar), 127.95 (Ar), 127.93 (Ar), 127.8 (Ar), 127.7 (Ar), 127.6 (Ar), 127.56 (Ar), 126.9 (Ar), 109.2 (C), 98.1 (CH1'), 98.0 (CH1), 89.8 (CH6'), 82.3 (CH4), 81.8 (CH3'), 80.6 (CH2'), 78.9 (CH4'), 77.2 (CH3), 75.80 (CH_2), 75.6 (CH_2), 75.0 (CH_2), 74.9 (CH), 73.9 (CH_2), 70.6 (CH_2), 64.6 (CH5), 54.7 (CH_3), 28.0 (CH_3), 26.2 (CH_3), 17.8 (CH_3). **HRMS (**ESI): m/z calcd for $C_{50}H_{56}O_{10}NaS$ $[M+Na]^+$, 871.3486 found 871.3455

The β isomer was not obtained pure and was characterized in the mixture of anomers by the following diagnostic signals:



β isomer: ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.35 (s, 1H, H6'), 4.99 (d, *J* = 8.3 Hz, 1H, H1'), 3.38 (s, 3H, CH_3).

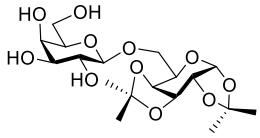
General procedure for desulfurization



A suspension of glycoside (1.0 equiv.) in ethanol (0.1 M) was treated with Raney nickel (1 g/mmol) that had been previously washed with ethanol. The reaction mixture was stirred overnight under 1 atm of hydrogen at room temperature. The reaction mixture was diluted with ethanol and filtered through Celite. The filter cake was washed with additional ethanol and the combined filtrate was dried over Na_2SO_4, filtered through cotton, and concentrated under vacuum to afford a crude residue, which was purified by silica gel chromatography (0→10 % CH_3OH in CH_2Cl_2) to give the desired deprotected glycoside.

6-*O*-(β-D-Galactopyranosyl)-1,2:3,4-*O*-diisopropylidene-α-D-galactopyranose (30)

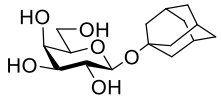
Obtained from the deprotection of compound **10*β*** (15 mg) using general procedure for desulfurization (MeOH/CH_2Cl_2, 1:9); yield (5.3 mg, 75%). Spectral data is consistent with the literature.[32]



$[\alpha]^{23}_D$ = -36.5 (*c* = 0.3, MeOH) **^{1}H NMR** (500 MHz, CD_3OD) δ 5.49 (d, *J* = 5.0 Hz, 1H), 4.60 (dd, *J* = 7.9, 2.4 Hz, 1H), 4.35 (dd, *J* = 5.0, 2.4 Hz, 1H), 4.28 (dd, *J* = 7.9, 1.6 Hz, 1H), 4.21 (d, *J* = 7.6 Hz, 1H), 4.07 – 3.98 (m, 2H), 3.80 (dd, *J* = 3.3, 1.1 Hz, 1H), 3.75 – 3.59 (m, 3H), 3.54 – 3.47 (m, 2H), 3.44 (dd, *J* = 9.7, 3.4 Hz, 1H), 1.49 (s, 3H), 1.37 (s, 3H), 1.32 (s, 3H), 1.30 (s, 3H). **^{13}C {^{1}H} NMR** (126 MHz, CD_3OD) δ 109.1 (C), 108.7 (C), 104.0 (CH), 96.4 (CH), 75.4 (CH), 73.4 (CH), 71.1 (CH), 70.65 (CH), 70.61 (CH), 68.9 (CH), 68.4 (CH), 67.6 (CH), 61.1 (CH_2), 24.9 (CH_2), 23.7 (CH_3), 23.1 (CH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{18}H_{30}O_{11}Na$ [M + Na], 445.1680; found, 445.1674.

Adamantyl β-D-galactopyranoside (31)

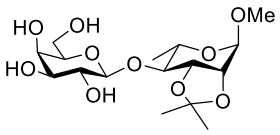
Obtained from the deprotection of compound **11*β*** (9.0 mg) using general procedure for desulfurization (MeOH/CH_2Cl_2, 1:9); yield (2.7 mg, 76%).



$[\alpha]^{23}_D$ = +1.4 (*c* = 0.3, MeOH). **^{1}H NMR** (500 MHz, MeOD-d_4) δ 4.52 – 4.43 (m, 1H, H1), 3.82 – 3.77 (m, 1H, H4), 3.72 – 3.61 (m, 2H, H6), 3.49 – 3.39 (m, 3H, H2, H3, H5), 2.10 (p, *J* = 3.2 Hz, 3H, Ada), 1.93 – 1.87 (m, 3H, Ada), 1.83 – 1.74 (m, 3H, Ada), 1.70 – 1.59 (m, 6H, Ada). **^{13}C {^{1}H} NMR** (126 MHz, MeOD-d_4) δ 96.41 (C1), 74.91 (CH), 74.55 (CH), 73.76 (CH), 71.24 (CH), 68.84 (C4), 61.02 (C6), 42.31 (Ada), 36.07 (Ada), 30.87 (Ada). **HRMS** (ESI): *m*/*z* calcd for $C_{16}H_{26}O_6Na$ [M + Na], 337.1621; found, 337.1613.

Methyl 4-*O*-(β-D-galactopyranosyl)-2,3-*O*-isopropylidene-α-L-rhamnopyranoside (32)

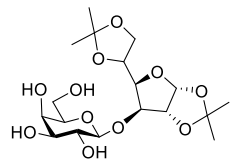
Obtained from the deprotection of compound **13*β*** (12 mg) using general procedure for desulfurization (MeOH/CH_2Cl_2, 1:9); yield (5.0 mg, 93%).



$[\alpha]^{23}_{D}$ = -27.6 (*c* = 0.7, MeOH). **^{1}H NMR** (500 MHz, MeOD-d_4) δ 4.77 (s, 1H, H1), 4.73 – 4.65 (m, 1H, H1'), 4.23 (dd, *J* = 7.0, 5.7 Hz, 1H, CH), 4.07 (dd, *J* = 5.6, 0.8 Hz, 1H, CH), 3.84 – 3.80 (m, 1H, H4'), 3.75 – 3.57 (m, 4H, CH_2, CH), 3.45 – 3.39 (m, 3H, H2'), 3.33 (s, 3H, OCH_3), 1.47 (s, 3H, CH_3), 1.30 (s, 3H, CH_3), 1.24 (d, *J* = 6.0 Hz, 3H, CH_3). **^{13}C {^{1}H} NMR** (126 MHz, MeOD-d_4) δ 109.0 (CMe2), 101.6 (C1'), 98.0 (C1), 78.1 (CH), 77.9 (CH), 75.9 (CH), 75.3 (CH), 73.7 (CH), 71.5 (CH), 68.8 (CH), 64.0 (CH), 60.8 (C6'), 53.8 (OCH_3), 27.0 (CH_3), 26.9 (CH_3), 25.25 (CH_3), 16.7 (CH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{16}H_{28}O_{10}Na$ [M + Na], 403.1574; found, 403.1567.

3-*O*-(β-D-Galactopyranosyl)-1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose (33)

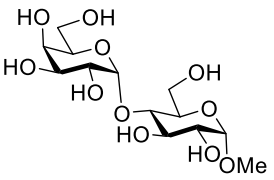
Obtained from the deprotection of compound **12*β*** (15 mg) using general procedure for desulfurization (MeOH/CH_2Cl_2, 1:9); yield (6.5 mg, 91%).



$[\alpha]^{23}_{D}$ = -1.8 (*c* = 0.8, MeOH). **^{1}H NMR** (500 MHz, MeOD-d_4) δ 5.91 (d, *J* = 3.7 Hz, 1H, H1), 4.68 (d, *J* = 3.7 Hz, 1H, H2), 4.46 (td, *J* = 6.3, 4.7 Hz, 1H, CH), 4.36 (d, *J* = 3.2 Hz, 1H, CH), 4.34 – 4.29 (m, 2H, H1'), 4.09 (dd, *J* = 8.5, 6.6 Hz, 1H, CH2), 4.02 (dd, *J* = 8.6, 6.1 Hz, 1H, CH2), 3.84 – 3.75 (m, 2H, H4', H6b), 3.70 (dd, *J* = 11.4, 4.9 Hz, 1H, H6a), 3.56 – 3.49 (m, 1H, CH), 3.49 – 3.44 (m, 2H, CH), 1.46 (s, 3H, CH_3), 1.40 (s, 3H, CH_3), 1.33 (s, 3H, CH_3), 1.31 (s, 3H, CH_3); **^{13}C {^{1}H} NMR** (126 MHz, CD_3OD) δ 111.68 (CMe2), 108.31 (CMe2), 105.24 (C1), 102.32 (C1'), 83.13 (CH), 80.36 (CH), 80.12 (CH), 75.66 (CH), 73.71 (CH), 73.59 (CH), 70.67 (CH), 68.93 (CH), 65.45 (CH_2), 61.25 (CH_2), 25.77 (CH_3), 25.41 (CH_3), 25.11 (CH_3), 24.08 (CH_3). **HRMS** (ESI): *m*/*z* calcd for $C_{18}H_{30}O_{11}Na$ [M + Na], 445.1680; found, 445.1673.

Methyl α-D-galactopyranosyl-(l-4)-α-D-glucopyranoside (34)

Obtained from the deprotection of compound **14*α*** (15 mg) using general procedure for desulfurization. The crude residue obtained was triturated with $CHCl_3$ (3x2 ml), filtered and concentrated to afford pure product; yield (4.6 mg, 94%). Spectral data is consistent with the reported literature.[33]

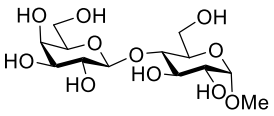


$[\alpha]^{23}_{D}$ = +30.7 (*c* = 0.4, MeOH). **^{1}H NMR** (600 MHz, D_2O) δ 5.33 (s, 1H, H1), 4.74 (d, *J* = 3.9 Hz, 1H, H1'), 3.95 – 3.73 (m, 7H, CH, CH2), 3.70-3.66 (m, 3H, CH, CH_2), 3.59 – 3.49 (m, 2H, CH), 3.35 (s, 3H, OCH_3). **^{13}C{^{1}H} NMR** (151 MHz, D_2O) δ 99.9 (C1), 99.0 (C1'), 77.0 (CH), 73.5 (CH), 71.7 (CH), 71.0 (CH), 70.1 (CH), 69.3 (CH), 69.1 (CH), 68.6 (CH), 61.1 (CH2), 60.5

(CH2), 55.0 (OCH_3). HRMS (ESI): *m*/*z* calcd for $C_{13}H_{24}O_{11}Na$ [M + Na], 379.1210; found, 379.1206.

Methyl β-D-galactopyranosyl-(l-4)-α-D-glucopyranoside (35)

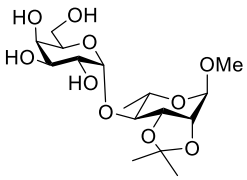
Obtained from the deprotection of compound **14*β*** (16 mg) using general procedure for desulfurization. The crude residue obtained was triturated with $CHCl_3$ (3x2 mL), filtered and concentrated to afford pure product; yield (4.6 mg, 89%).[34]



$[\alpha]^{23}_D$ = +31.6 (*c* = 0.3, MeOH). ^{1}H NMR (500 MHz, D_2O) δ 4.84 (d, *J* = 3.8 Hz, 1H, H1), 4.47 (d, *J* = 7.8 Hz, 1H, H1'), 3.99 – 3.93 (m, 2H, CH), 3.90 – 3.73 (m, 6H, CH), 3.69 (dd, *J* = 9.8, 3.5 Hz, 2H, CH, CH2), 3.66 – 3.62 (m, 1H, CH), 3.57 (dd, *J* = 10.0, 7.8 Hz, 1H, CH2), 3.45 (s, 3H, OCH_3). **^{13}C{^{1}H} NMR** (126 MHz, D_2O) δ 102.9 (C1'), 99.1 (C1), 78.46 (CH), 75.44 (CH), 72.63 (CH), 71.82 (CH), 71.05 (CH), 70.99 (CH), 70.34 (CH), 68.65 (CH), 61.12 (CH2), 59.99 (CH2), 55.18 (OMe). HRMS (ESI): *m*/*z* calcd for $C_{13}H_{24}O_{11}Na$ [M + Na], 379.1210; found, 379.1201.

Methyl 4-*O*-(α-D-galactopyranosyl)-2,3-*O*-isopropylidene-α-L-rhamnopyranoside (36)

Obtained (14 mg) from the deprotection of compound **19*α*** using general procedure for desulfurization (MeOH/CH_2Cl_2, 1:9); yield (5.9 mg, 94%).

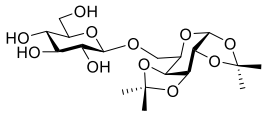


$[\alpha]^{23}_D$ = +46.6 (*c* = 0.6, MeOH). **^{1}H NMR** (500 MHz, CD_3OD) δ 4.91 (d, *J* = 3.8 Hz, 1H, H1'), 4.77 (s, 1H, H1), 4.12 – 4.06 (m, 2H, CH), 4.06 – 4.01 (m, 1H, CH), 3.96 (dd, *J* = 3.3, 1.3 Hz, 1H, H4'), 3.77 (dd, *J* = 10.2, 3.8 Hz, 1H, H2'), 3.72 (s, 2H, H5', CH2), 3.34 (s, 3H, OCH_3), 1.48 (s, 3H, CH_3), 1.36 – 1.25 (m, 6H, 2xCH_3). **^{13}C{^{1}H} NMR** (126 MHz, CD_3OD) δ 109.00 (CMe2), 100.46 (C1'), 97.95 (C1), 81.24 (CH), 77.11 (CH), 75.97 (CH), 70.21 (CH), 69.99 (CH), 69.76 (C4'), 69.06 (CH), 64.80 (CH), 61.03 (CH_2), 53.81 (OMe), 27.02 (CH3), 25.15 (CH_3), 16.67 (CH3). **HRMS** (ESI): *m*/*z* calcd for $C_{16}H_{28}O_{10}Na$ [M + Na], 403.1574; found, 403.1567.

6-*O*-β-D-*gluco*pyranosyl-1,2:3,4-*O*-diisopropylidene-α-D-galactopyranose. (37)

Obtained (6.4 mg, 67%) from the deprotection of compound **22β** (20 mg, 10 μmol) using general procedure for desulfurization (MeOH/CH_2Cl_2, 1:9)

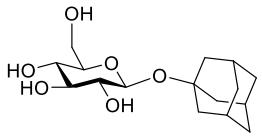
Obtained (5.1 mg, 83%) from the deprotection of compound **27β** (12 mg, 13 μmol) using general procedure for desulfurization (MeOH/CH_2Cl_2, 1:9). Spectral data is consistent with the reported. [35]



$[\alpha]^{20}_{D}$ = – 41.8 (*c* 0.3, CH_3CN) **^{1}H NMR** (500 MHz, CD_3CN) δ 5.44 (d, *J* = 5.1 Hz, 1H, H1), 4.58 (dd, *J* = 8.0, 2.5 Hz, 1H, H3), 4.31 (dd, *J* = 5.1, 2.4 Hz, 1H, H2), 4.28 – 4.22 (m, 2H, H5, H1'), 3.97 – 3.88 (m, 2H, $CH_2$6a, $CH_2$6'a), 3.71 (d, *J* = 9.9 Hz 1H, $CH_2$6b), 3.63 – 3.51 (m, 3H, H4', H5', $CH_2$6'), 3.43 (br, 1H, $CH_2$6'b), 3.35 (s, 1H, OH), 3.30 (s, 1H, OH), 3.27 – 3.23 (m, 1H, H3'), 3.20 (s, 1H, OH), 3.07 (t, *J* = 8.4 Hz, 1H, H2'), 2.80 (s, 1H, OH), 1.47 (s, 3H, CH_3), 1.35 (s, 3H, CH_3), 1.28 (s, 6H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, CD_3CN) δ 108.9 (CMe_2), 108.4 (CMe_2), 103.4 (CH), 96.3 (CH), 76.7 (CH), 76.3 (CH), 73.7 (CH), 71.0 (CH), 70.6 (CH), 70.5 (CH), 68.4 (CH_2), 67.2 (CH), 61.9 (CH_2), 25.4 (CH_3), 25.3 (CH_3), 24.2 (CH_3), 23.7 (CH_3). **HRMS (**ESI): m/z calcd for $C_{18}H_{30}O_{11}Na$ $[M+Na]^+$, 445.1680 found 445.1680.

Adamantyl *β*-D-*gluco*pyranoside. (38)

Obtained (4.7 mg, 46%) from the deprotection of compound **23β** (25 mg, 31 μmol) using general procedure for desulfurization ($MeOH/CH_2Cl_2$, 1:9). Spectral data is consistent with the literature.[36]

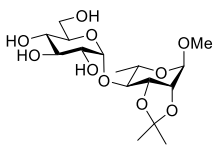


$[\alpha]^{20}_{D}$ = –12.4 (*c* 0.3, CH_3OH) **^{1}H NMR** (500 MHz, CD_3OD) δ 4.53 (d, *J* = 7.8 Hz, 1H, H1), 3.79 (dd, *J* = 11.9, 2.3 Hz, 1H, H6a), 3.61 (dd, *J* = 11.9, 5.3 Hz, 1H, H6b), 3.33 (t, *J* = 8.7 Hz, 1H, H3), 3.24 (d, *J* = 8.2 Hz, 1H, H4), 3.26 – 3.19 (m, 1H), 3.09 (dd, *J* = 9.2, 7.8 Hz, 1H, H2), 2.11 (q, *J* = 3.3 Hz, 3H, Ada), 1.93 – 1.87 (m, 3H, Ada), 1.81 – 1.76 (m, 3H, Ada), 1.69 – 1.60 (m, 6H, Ada). **^{13}C{^{1}H} NMR** (126 MHz, CD_3OD) δ 95.8 (CH1), 76.8 (CH), 76.2 (CH), 74.7 (CH), 73.7 (CH), 70.4 (CH), 61.5 (CH_2), 42.2 (Ada), 36.0 (Ada), 30.8 (Ada). **HRMS (**ESI): m/z calcd for $C_{16}H_{26}O_6Na$ $[M+Na]^+$, 337.1622 found 337.1612.

Methyl 4-*O*-α-D-*gluco*pyranosyl-2,3-*O*-isopropylidene-α-L-rhamnopyranoside. (39)

Obtained (8.6 mg, 76%) from the deprotection of compound **25α** (23.5 mg, 27 μmol) using general procedure for desulfurization ($MeOH/CH_2Cl_2$, 1:9).

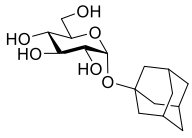
Obtained (3.8 mg, 87%) from the deprotection of compound **27α** (9.7 mg, 11 μmol) using general procedure for desulfurization ($MeOH/CH_2Cl_2$, 1:9) Spectral data is consistent with the reported in literature.[37]



$[\alpha]^{20}_{D}$ = +41.7 (*c* 0.6, CH_3OH) **^{1}H NMR** (500 MHz, CD_3OD) δ 4.92 (d, *J* = 3.8 Hz, 1H, H1), 4.80 (s, 1H, H1'), 4.15 – 4.06 (m, 2H, H2, H3'), 3.84 (dt, *J* = 10.0, 3.1 Hz, 1H, H6'), 3.77 (m, 2H, CH), 3.70 (dq, *J* = 9.9, 6.3 Hz, 1H, H5), 3.65 – 3.60 (m, 1H, H4), 3.47 – 3.35 (m, 2H, H3, H4'), 3.36 (s, 3H, OCH_3), 3.35 - 3.32 (m, 1H, CH) 1.51 (s, 3H, CH_3), 1.33 (d, *J* = 6.4 Hz, 3H, CH_3), 1.31 (s, 3H, CH_3). **^{13}C{^{1}H} NMR** (126 MHz, CD_3OD) δ 110.3 (CMe_2), 101.5 (CH1'), 99.3 (CH1), 82.54 (CH), 78.5 (CH), 77.3 (CH), 74.9 (CH), 73.7 (CH), 73.3 (CH), 71.3 (CH), 66.2 (CH), 62.1 (CH_3), 55.1 (CH_2), 28.4 (CH_3), 26.5 (CH_3), 17.9 (CH_3). **HRMS (**ESI): m/z calcd for $C_{16}H_{28}O_{10}Na$ $[M+Na]^+$, 403.1575 found 403.1572.

Adamantyl *α*-D-*gluco*pyranoside. (40)

Obtained (4.3 mg, 64%) from the deprotection of compound **28*α*** (16.7 mg, 21 μmol) using general procedure for desulfurization (MeOH/CH_2Cl_2, 1:9).



$[\alpha]^{20}_{D}$ = +19.1 (*c* 0.5, CH_3CN) **^{1}H NMR** (500 MHz, CD_3OD) δ 5.17 (d, *J* = 3.9 Hz, 1H, H1), 3.75 – 3.70 (m, 2H, H4, $CH_2$6), 3.65 (dd, *J* = 12.3, 5.6 Hz, 1H, $CH_2$6), 3.62 – 3.58 (m, 1H, H5), 3.30 (d, *J* = 3.9 Hz, 1H, H2), 3.26 (br, 1H, H3), 2.15 – 2.08 (m, 3H, CHada), 1.94 – 1.84 (m, 3H, Ada), 1.85 – 1.78 (m, 3H, Ada), 1.65 (dd, *J* = 3.8 Hz, 6H, Ada). **^{13}C{^{1}H} NMR** (126 MHz, CD_3OD) δ 91.6 (CH1), 74.0 (CH), 73.9 (CH), 72.1 (CH), 71.8 (CH), 70.7 (CH), 61.4 (CH_2), 42.2 (Ada), 36.1 (Ada), 30.8 (Ada). **HRMS (**ESI): m/z calcd for $C_{16}H_{26}O_6Na$ $[M+Na]^+$, 337.1622 found 337.1608.

References

[1] H. Rüdiger, H.-J. Gabius, in *The sugar Code: Fundamentals of Glycosciences* (Ed.: H.-J. Gabius), Wiley-Blackwell, **2009**.

[2] D. Crich, *Acc. Chem. Res.* **2010**, *43*, 1144-1153.

[3] P. O. Adero, H. Amarasekara, P. Wen, L. Bohé, D. Crich, *Chem. Rev.* **2018**, *118*, 8242-8284.

[4] A. V. Demchenko, *Handbook of Chemical Glycosylation: Advances in Stereoselectivity and Therapeutic Relevance*, Wiley-VCH, Weinheim, **2008**.

[5] K. B. Gash, G. U. Yuen, *J. Org. Chem.* **1966**, *31*, 4234-4235.

[6] D. Crich, T. Hu, F. Cai, *J. Org. Chem.* **2008**, *73*, 8942-8953.

[7] K. Upadhyaya, Y. P. Subedi, D. Crich, *Angew. Chem. Int. Ed.* **2021**, *60*, 25397-25403.

[8] a) W. Koenigs, E. Knorr, *Ber. Dtsch. Chem. Ges.* **1901**, *34*, 957-981; b) Y. Singh, S. A. Geringer, A. V. Demchenko, *Chem. Rev.* **2022**, *122*, 11701-11758.

[9] E. B. Bauer, *Org. Biomol. Chem.* **2020**, *18*, 9160-9180.

[10] Y. Zu, C. Cai, J. Sheng, L. Cheng, Y. Feng, S. Zhang, Q. Zhang, Y. Chai, *Org. Lett.* **2019**, *21*, 8270-8274.

[11] J.-H. Kim, H. Yang, J. Park, G.-J. Boons, *J. Am. Chem. Soc.* **2005**, *127*, 12090-12097.

[12] Y. Park, K. C. Harper, N. Kuhl, Eugene E. Kwan, R. Y. Liu, E. N. Jacobsen, *Science* **2017**, *355*, 162-166.

[13] K. Bock, J. Ø. Duus, *J. Carbohydr. Chem.* **1994**, *13*, 513-543.

[14] T. B. Grindley, in *Glycoscience: Chemistry and Chemical Biology I-III, Vol. 1* (Eds.: B. O. Fraser-Reid, K. Tatsuta, J. Thiem), Springer, Berlin, **2001**, pp. 3-51.

[15] nomenclature based on multiple configuration groups in carbohydrates.

[16] H. H. Jensen, L. U. Nordstrøm, M. Bols, J. *Am. Chem. Soc. 2***004,** 1*26,* 9205-9213.

[17] M. Moumé-Pymbock, T. Furukawa, S. Mondal, D. Crich, J. *Am. Chem. Soc. 2***013,** 1*35,* 14249-14255.

[18] K. Upadhyaya, R. Bagul, D. Crich, J. *Org. Chem. 2***021,** 8*6,* 12199-12225.

[19] G. Zemplén, A. Kunz, B*erichte der deutschen chemischen Gesellschaft (A and B series) 1***923,** 5*6,* 1705-1710.

[20] a) R. R. Schmidt, J. Michel, M. Roos, L*iebigs Ann. Chem. 1***984,** 1343-1357; b) R. R. Schmidt, K. W, A*dv. Carbohydr. Chem. Biochem. 1***994,** 5*0,* 21-123.

[21] P. R. Andreana, D. Crich, A*CS Cent. Sci. 2***021,** 7, 1454-1462.

[22] a) S. Van der Vorm, T. Hansen, H. S. Overkleeft, G. A. Van der Marel, J. D. C. Codée, C*hem. Sci. 2***017,** 8, 1867-1875; b) C.-W. Chang, M.-H. Lin, C.-K. Chan, K.-Y. Su, C.-H. Wu, W.-C. Lo, S. Lam, Y.-T. Cheng, P.-H. Liao, C.-H. Wong, C.-C. Wang, A*ngew. Chem. Int. Ed. 2***021,** 6*0,* 12413-12423.

[23] C. M. Filloux, A*ngew. Chem. Int. Ed. 2***015,** 5*4,* 8880-8894.

[24] a) T. F. McMillan, D. Crich, E*ur. J. Org. Chem. 2***022,** 2*022,* 128-135; b) L. Somogyi, C*arbohydr. Res. 1***987,** 1*66,* 166-169.

[25] a) M. Matwiejuk, J. Thiem, E*ur. J. Org. Chem. 2***011,** 2*011,* 5860-5878; b) P. J. Garegg, H. Hultberg, S. Wallin, C*arbohydrates Research 1***982,** 1*08,* 97-101; c) P. J. Garegg, in

P*reparative Carbohydrate Chemistry* (Ed.: S. Hannessian), Marcel Dekker, New York, 1**996,** pp. 53-67.
[26] J. Chan, A. Lu, A. J. Bennet, J. *Am. Chem. Soc. 2***011,** 1*33,* 2989-2997.
[27] a) T. G. Frihed, M. Heuckendorff, C. M. Pedersen, M. Bols, A*ngew. Chem. Int. Ed. 2***012,** 5*1,* 12285-12288; b) A. Lipták, J. Imre, P. Nánási, C*arbohydr. Res. 1***981,** 9*2,* 154-156.
[28] Y. A. Lin, J. M. Chalker, B. G. Davis, J. *Am. Chem. Soc. 2***010,** 1*32,* 16805-16811.
[29] a) G. Bellucci, C. Chiappe, F. D'Andrea, T*etrahedron: Asymmetry 1***995,** 6, 221-230; b) A. Ali, R. A. Vishwakarma, T*etrahedron 2***010,** 6*6,* 4357-4369.
[30] Y. Nakahara, T. Ogawa, C*arbohydr. Res. 1***989,** 1*94,* 95-114.
[31] T. Yamazaki, F. Sugawara, K. Ohta, K. Masaki, K. Nakayama, K. Sakaguchi, N. Sato, H. Sahara, T. Fujita, *Vol. US 2002/0052327 A1,* TOYO SUISAN KAISHA, LTD, 2**002.**
[32] a) C. P. J. Glaudemans, E. Zissis, M. E. Jolley, C*arbohydr. Res. 1***975,** 4*0,* 129-135; b) A. Borbás, L. Jánossy, A. Lipták, C*arbohydr. Res. 1***999,** 3*18,* 98-109.
[33] J. Dahmén, T. Frejd, T. Lave, F. Lindh, G. Magnusson, G. Noori, K. P»lsson, C*arbohydr. Res. 1***983,** 1*13,* 219-224.
[34] a) K. i. Takeo, K. Okushio, K. Fukuyama, T. Kuge, C*arbohydr. Res. 1***983,** 1*21,* 163-173; b) E. Farkas, U. Schmidt, J. Thiem, J. Kowalczyk, M. Kunz, M. Vogel, S*ynth. 2***003,** 5, 699-706.
[35] a) M. C. Parlato, M. N. Kamat, H. Wang, K. J. Stine, A. Demchenko, J. *Org. Chem. 2***007,** 7*3,* 1716-1725; b) S. Hanessian, C. Bacquet, N. Lehong, C*arbohydr. Res. 1***980,** 8*0,* C17-C22.
[36] D. Crich, F. Cai, O*rg. Lett. 2***007,** 9, 1613-1615.
[37] S. Salamone, C. Guerreiro, E. Cambon, J. M. Hargreaves, N. Tarrat, M. Remaud-Simeon, I. Andre, L. A. Mulard, J. *Org. Chem. 2***015,** 8*0,* 11237-11257.