Supporting Information

Zirconium-Catalysed Direct Substitution of Alcohols: Enhancing the Selectivity by Kinetic Analysis

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1. General Information

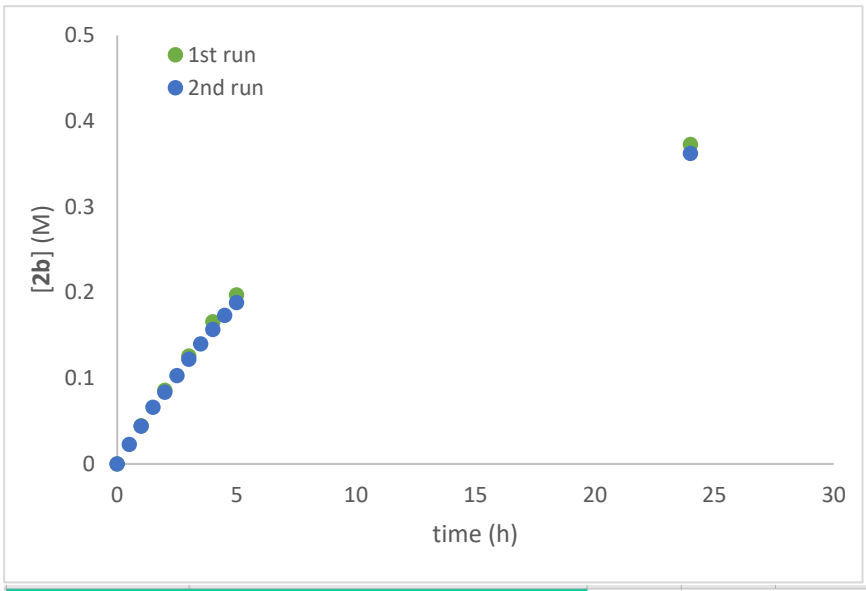
All reactions were carried out in glassware that was not pre-dried unless otherwise stated. THF was dried using a solvent dispensing system, where solvent is passed through activated alumina columns, stored under N_2 and over activated 4Å molecular sieves when needed. BTF denoted as *dry* was distilled under N_2 and stored over activated 4Å molecular sieves. Water used for reactions and HPLC analysis was obtained from Milli-Q® system. Trifluoromethanesulfonic acid (triflic acid, TfOH) was stored and handled under N_2 atmosphere, using Hamilton syringes. Molecular sieves (3Å, powder) were heat gun-dried under vacuum for 20 minutes and cooled under N_2 prior to use. All other solvents and reagents were purchased from commercial suppliers and used without further purification unless otherwise noted. TLC analyses were performed on pre-coated silica gel 60 F254 plates, and visualized using UV light, $KMNO_4$ (solution in mixture of $KMNO_4$/K_2CO_3/NaOH in H_2O), phosphomolybdic acid stain (solution in EtOH) or vanillin (solution in 1% H_2SO_4 in EtOH). Flash column chromatography was conducted using 40-60 µm, 230-400 mesh, 60Å silica gel as stationary phase. NMR spectra were recorded using either a Bruker Avance II 400 MHz or a Bruker Avance 500 MHz spectrometer at 298 K (unless otherwise stated, see Section 3) using $CDCl_3$, acetone-d_6 or toluene-d_8 as solvents. Chemical shifts are given in ppm relative to the residual solvent peak (^{1}H NMR: $CDCl_3$ δ 7.26; acetone-d_6 δ 2.05; toluene-d_8 δ 2.09; ^{13}C NMR: $CDCl_3$ δ 77.16; acetone-d_6 δ 29.84; toluene-d_8 δ 20.40) with multiplicity (br = broad, s = singlet, d = doublet, t = triplet, q = quartet, quin = quintuplet, sext = sextet, m = multiplet), coupling constants (in Hz) and integration. Kinetic data was analysed by Agilent 1260 Infinity Quaternary LC (Eclipse Plus 18C column) with a gradient of acetonitrile and 0.1% formic acid in Milli-Q water at a flow rate of 1.0 mL/min, using 4,4'-di-*tert*-butylbiphenyl (DTBB) as internal standard. HPLC with a chiral stationary phase was performed using a Chiralcel OJ-RH column with eluent compositions specified for the products (Section 4.4). High-resolution mass spectrometry analyses were performed using a Thermo Scientific Q Exactive HF Hybrid Quadrupole-Orbitrap HESI. Full analytical data is given if the compound is novel.

2. Kinetic evaluation of reaction parameters

The kinetic experiments were carried out in accordance with general procedure A (Section 4.1). Comprehensive tutorials of "different excess" and "same excess" experiment are found in the Reaction Progress Kinetic Analysis literature,[1] whereas detailed information about retrieval of orders in catalyst and reagents are found in the Visual Time Normalization Analysis literature.[2]

2.1. Reproducibility

A.



B.

std conditions = 0.02M Zr, 0.5M BnOH, 1M 2-PhEtOH, 100°C	
exp n.	yield at 24h (%)
Repetition 1	68.6
Repetition 2	73.1
Repetition 3	71.9
Repetition 4	65.7
Repetition 5	69.2
average	**69.7**
std deviation	**2.6**
std error	**1.2**

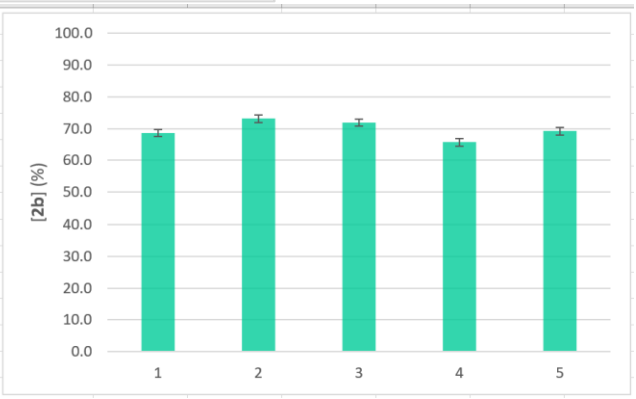


Figure S1. A. Reproducibility of standard conditions (0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF). **B.** Standard deviation (2.6) and error (1.2 %) for five repetitions of identical experiments under standard conditions.

2.2. Control experiments

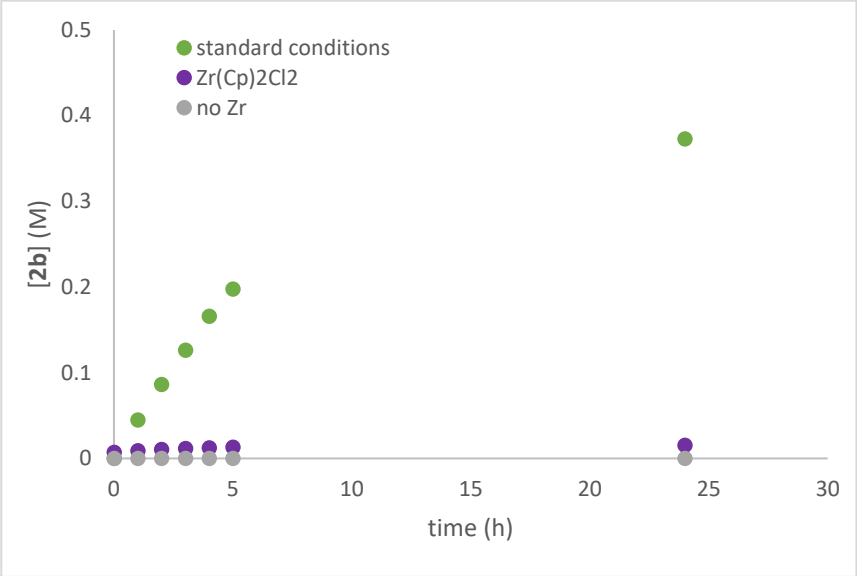


Figure S2. Control experiments. Standard conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **1a**, 1 M **1b**, 100 ^oC, BTF.

2.3. Different excess experiments

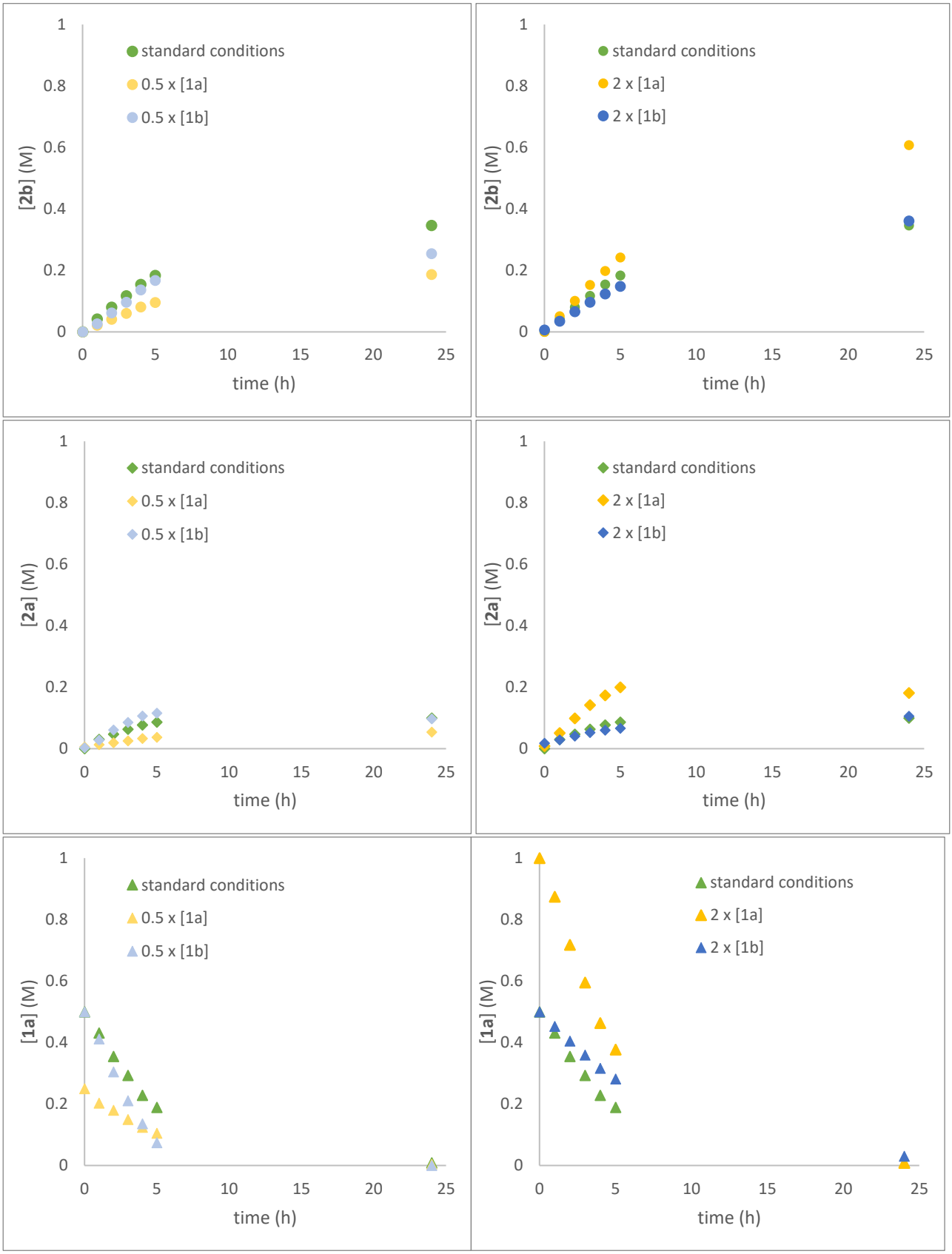
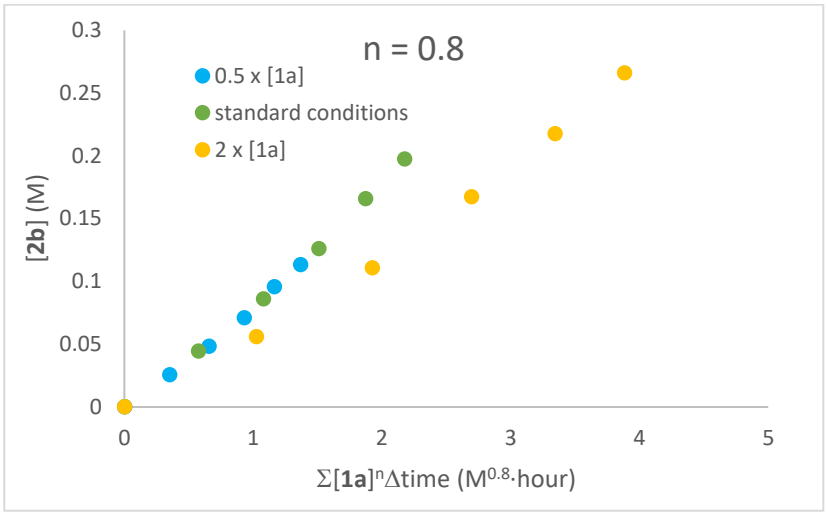
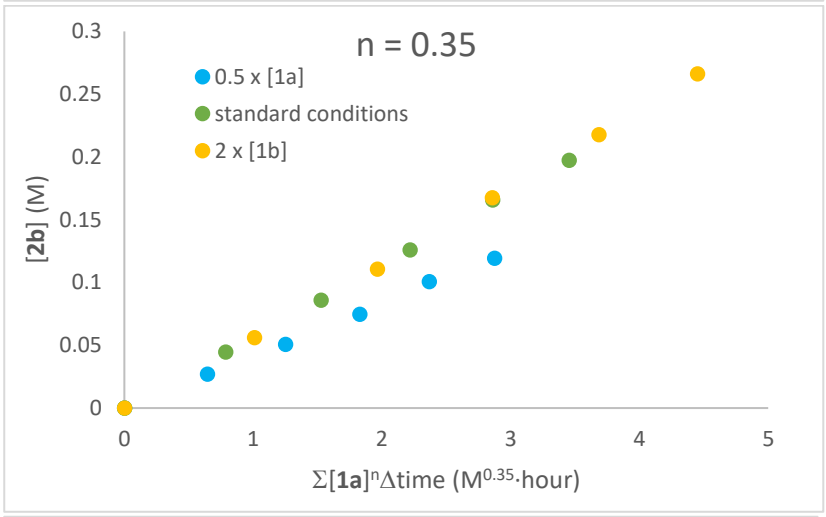


Figure S3. Different excess experiments. Standard conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF. Values are normalized to $[\mathbf{1a}]_0$.

2.4. Determination of order in [reactants]





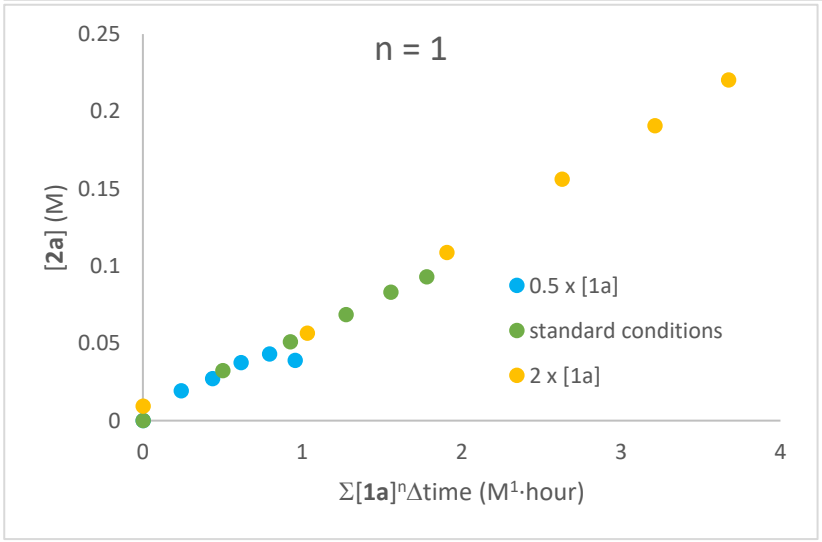


Figure S4. Different [BnOH] experiments plotted using Variable Time Normalization Analysis.[2b] Standard conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF.

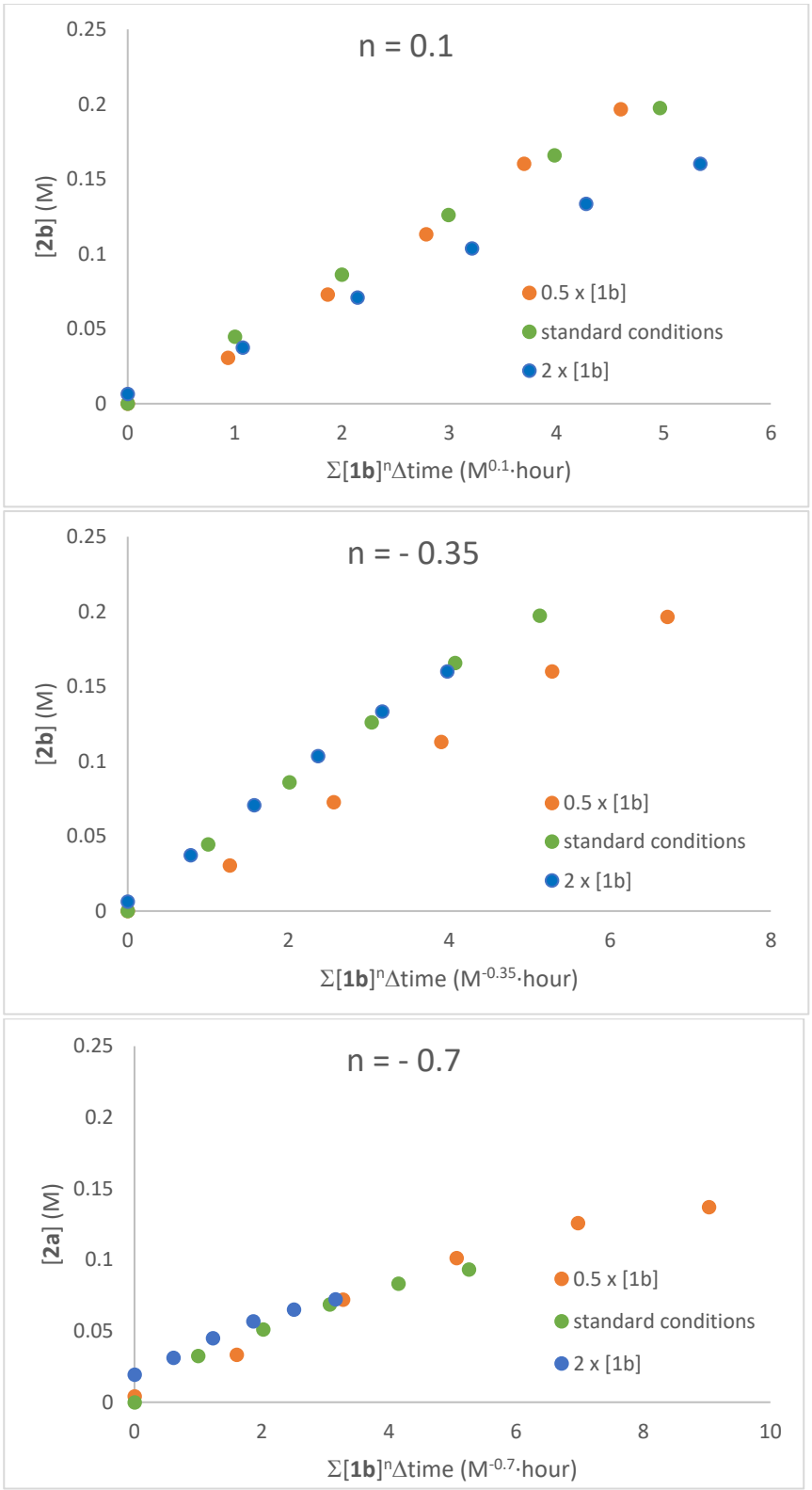


Figure S5. Different [2-PhEtOH] experiments plotted using Variable Time Normalization Analysis at 0.5 M concentration of **1a**.[2b] Standard conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF.

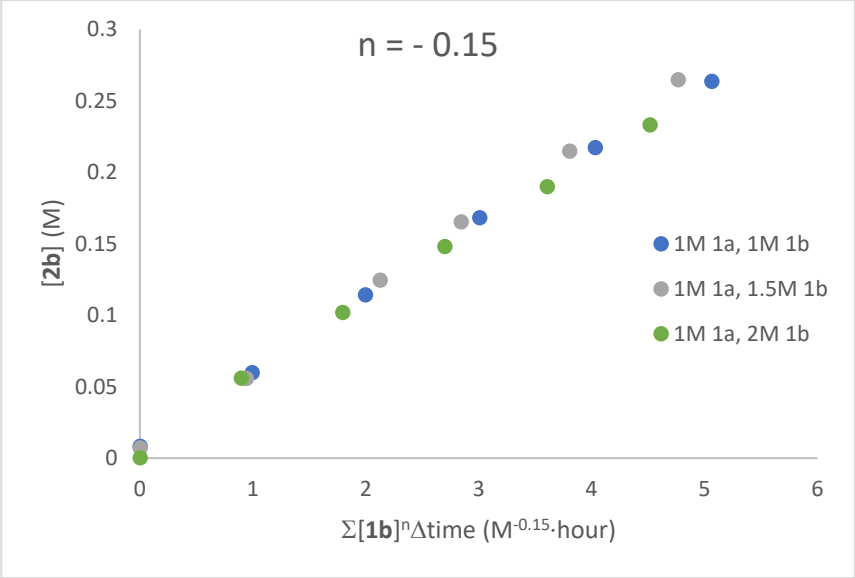


Figure S6. Different [2-PhEtOH] experiments plotted using Variable Time Normalization Analysis at 1 M concentration of **1a**.[2b] Conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 1 M **1a**, 1-2 M **1b**, 100 °C, BTF.

2.5. Different [catalyst] experiments

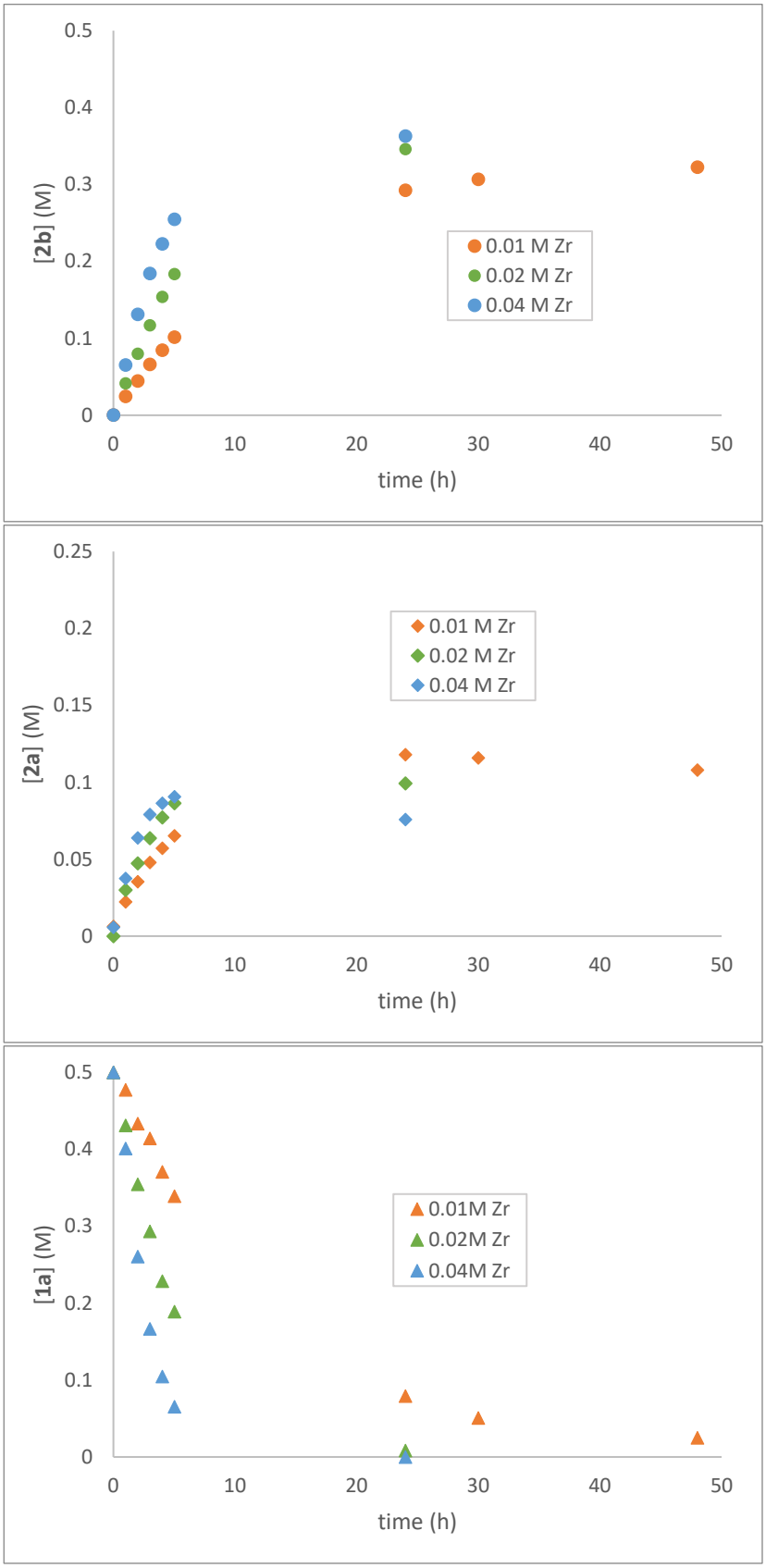


Figure S7. Different catalyst concentrations. Conditions: x M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF. Values are normalized to $[\mathbf{1a}]_0$.

2.6. Determination of catalyst order

The order in catalyst was determined using Variable Time Normalization Analysis.[2a]

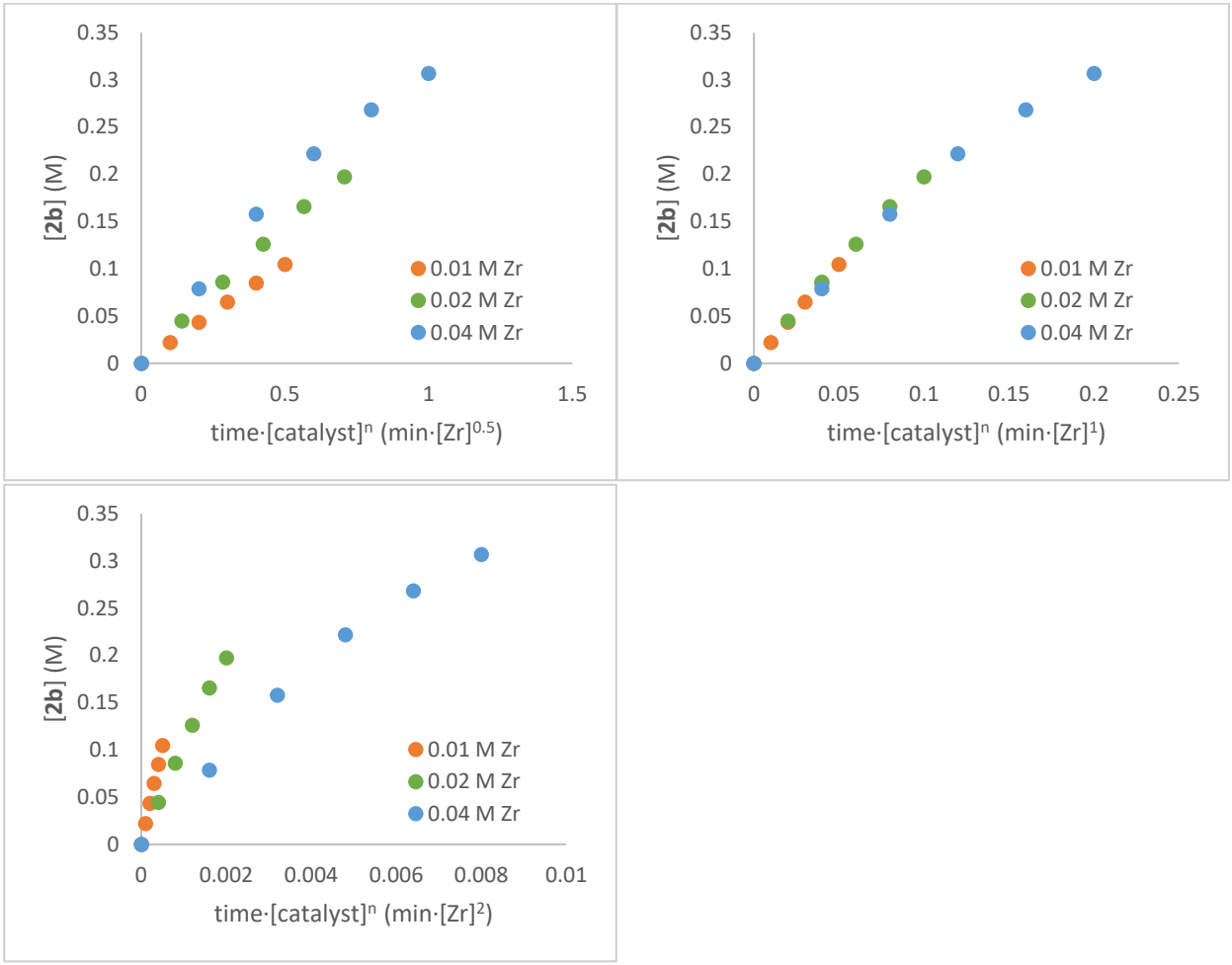


Figure S8. Order in [catalyst] for the formation of product **2b** for reaction time 0-5 hours. Conditions: x M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M BnOH, 1 M 2-PhEtOH, 100 °C, BTF.

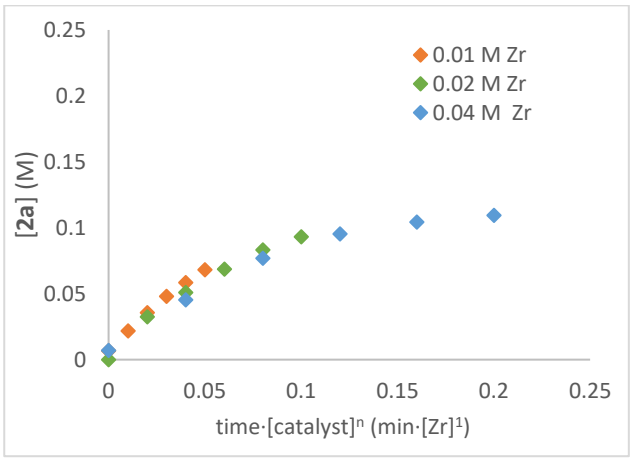


Figure S9. Order in [catalyst] for formation of **2a**. Conditions: x M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF.

2.7. Same excess experiments

Same excess experiments[1] followed the general etherification procedure A (Section 4.1), with conditions mimicking 25% conversion of benzyl alcohol: 0.375 M benzyl alcohol **1a**, 0.875 M 2-phenylethanol **1b**, 0.02 M $Zr(Cp)_2(CF_3SO_3)2{\cdot}THF$, 0.01 M DTBB as internal standard, BTF, 100°C; and same excess conditions mimicking 25% conversion of benzyl alcohol with addition of the corresponding amount of H_2O at the outset of the reaction: 0.125 M Milli-Q H_2O, 0.375 M benzyl alcohol **1a**, 0.875 M 2-phenylethanol **1b**, 0.02 M $Zr(Cp)_2(CF_3SO_3)2{\cdot}THF$, 0.01 M DTBB as internal standard, BTF, 100°C. Values for **1a** are normalized to $[\mathbf{1a}]_0$.

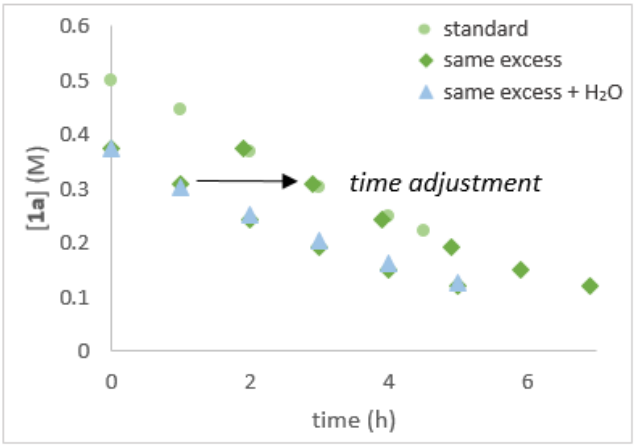


Figure S10. Same excess experiments. Standard conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2{\cdot}THF$, 0.5 M **1a**, 1 M **1b**, 0.01 M DTBB as internal standard, 100 °C, BTF (0.5 mmol BnOH scale).

2.8. Catalyst comparisons

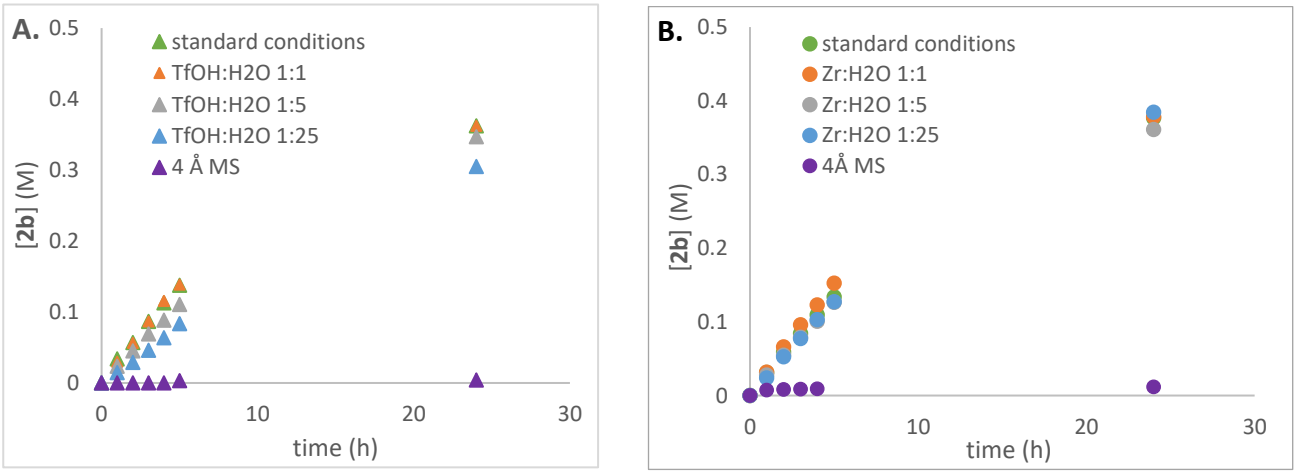


Figure S11. A. Reaction behavior in presence of trifluoromethanesulfonic acid in catalytic amounts. **B.** Reaction behavior in presence of zirconocene triflate in catalytic amounts. Standard conditions: 0.02 M CF_3SO_3H or $Zr(Cp)_2(CF_3SO_3)_2{\cdot}THF$, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF (1.5 mmol BnOH scale, 4Å MS 45 mg, except 4Å MS addition to Zr-catalyzed reaction: 0.5 mmol **1a** scale, 4Å MS 15 mg).

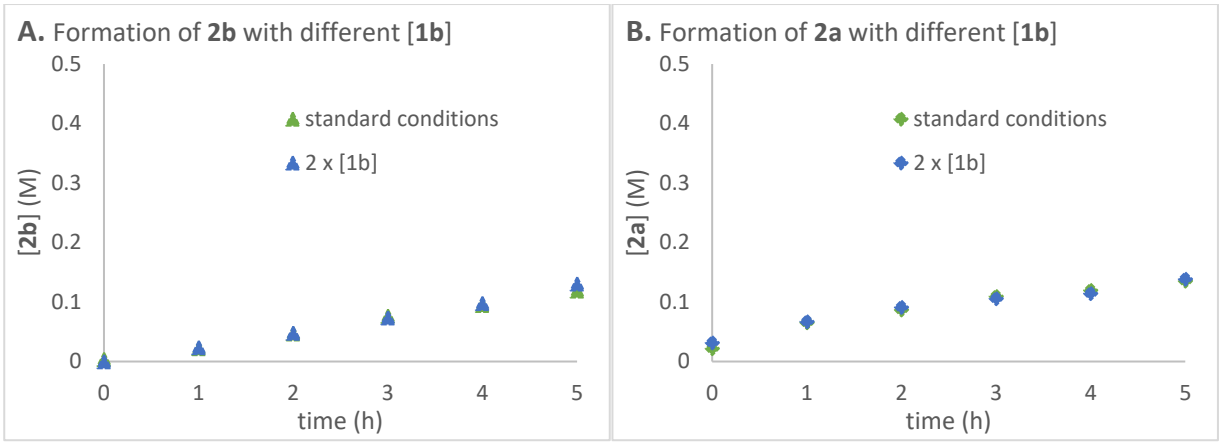


Figure S12. A. Formation of **2b** in presence of trifluoromethanesulfonic acid in catalytic amounts with different excess **1b**. **B.** Formation of **2a** in presence of trifluoromethanesulfonic acid in catalytic amounts. Standard conditions: 0.02 M CF_3SO_3H, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF (0.5 mmol **1a** scale).

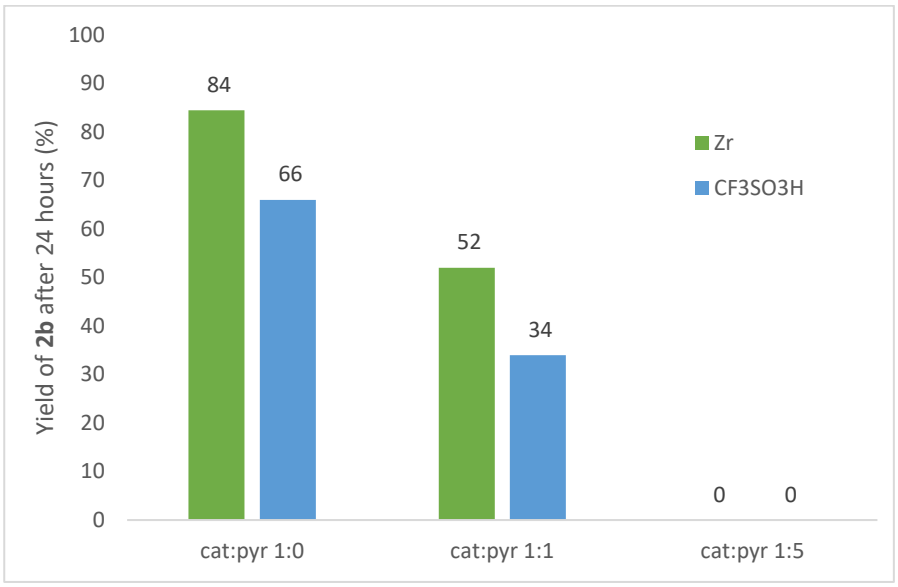


Figure S13. Reaction outcome after 24 hours in presence of either zirconocene triflate or trifluoromethylsulfonic (triflic) acid in catalytic amounts with varying concentrations of 2,6-di-*tert*-butyl-4-methylpyridine (pyr). Standard conditions (Zr): 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.25 M **1a**, 1 M **1b**, 100 °C, BTF. The pyridine was added along with the reagents and present from time = 0 in the reaction mixture. Standard conditions (CF_3SO_3H): 0.02 M CF_3SO_3H, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF. The pyridine was added along with the reagents and present from time = 0 in the reaction mixture.

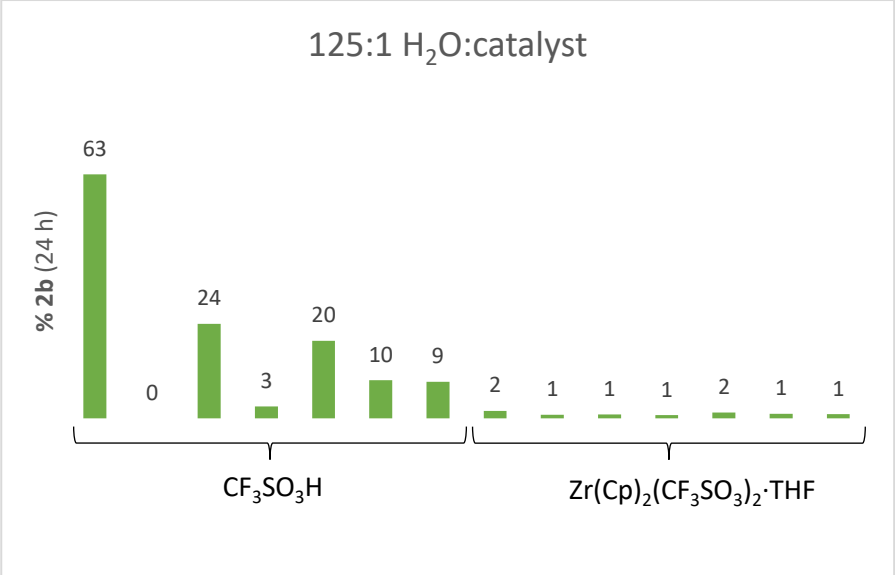


Figure S14. Reaction behavior in presence of 125:1 water:catalyst. Conditions: 0.02 M catalyst, 0.5 M **1a**, 1 M **1b**, 2.5 M H_2O, 100 °C, BTF (1.5 mmol **1a** scale). The reaction was repeated seven times for each catalyst. Values are normalized to $[\mathbf{1a}]_0$.

The yield of **2b** in the 125:1 H_2O:catalyst experiment repeatedly did not exceed 2% in the presence of the Zr catalyst, whereas triflic acid catalysis resulted in 10% median yield over seven runs (Figure S14). For the latter, a variation in the yield between 0 and 63% after 24 hours was observed where high yielding reactions correlated with observation of water droplets in the vial cap and/or leaking caps.

In a set of experiments 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF was let to react with 1 eq. of H_2O in BTF at 100 °C for 0.5 h, then dried under reduced pressure and high vacuum. The dark solid residue was then used as catalyst in a standard etherification procedure without further manipulation (0.5 mmol **1a**, 1.0 mmol **1b** scale, Figure S15A). The same rate of ether formation corresponding to the use of Zr catalyst that was not pre-treated with 1 eq H_2O was observed in absence of molecular sieves (Figure S15B and S15C), and inhibition of catalysis was confirmed in presence of 4Å molecular sieves (Figure S15D).

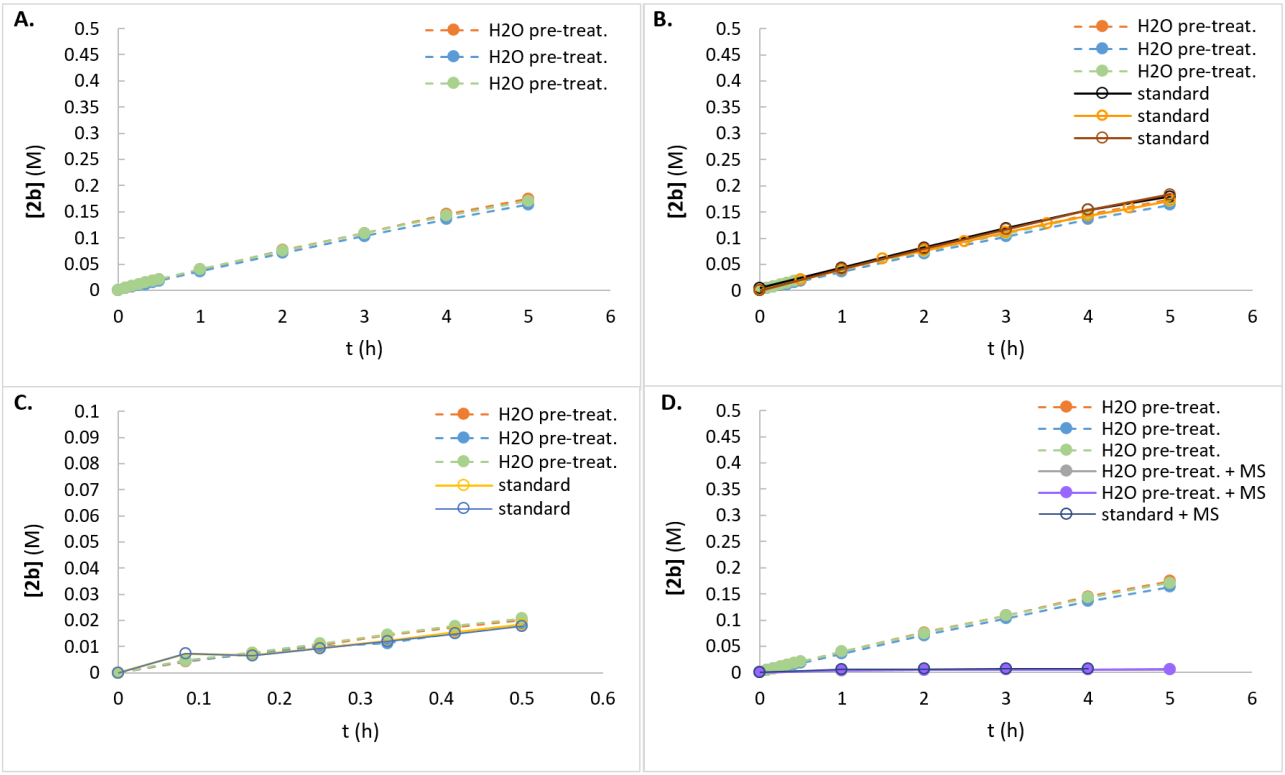


Figure S15. A. Formation of **2b** when $Zr(Cp)_2(CF_3SO_3)_2$·THF is pre-treated with 1 eq H_2O **B.** Comparison with standard conditions (0-5 h monitoring) **C.** Comparison with standard conditions (0-0.5 h monitoring) **D.** Reaction behavior in presence of 4Å MS (15 mg, 0.5 mmol **1a** scale). Conditions: 0.02 M catalyst, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF (0.5 mmol **1a** scale). Values are normalized to $[\mathbf{1a}]_0$.

2.9. Substitution effects

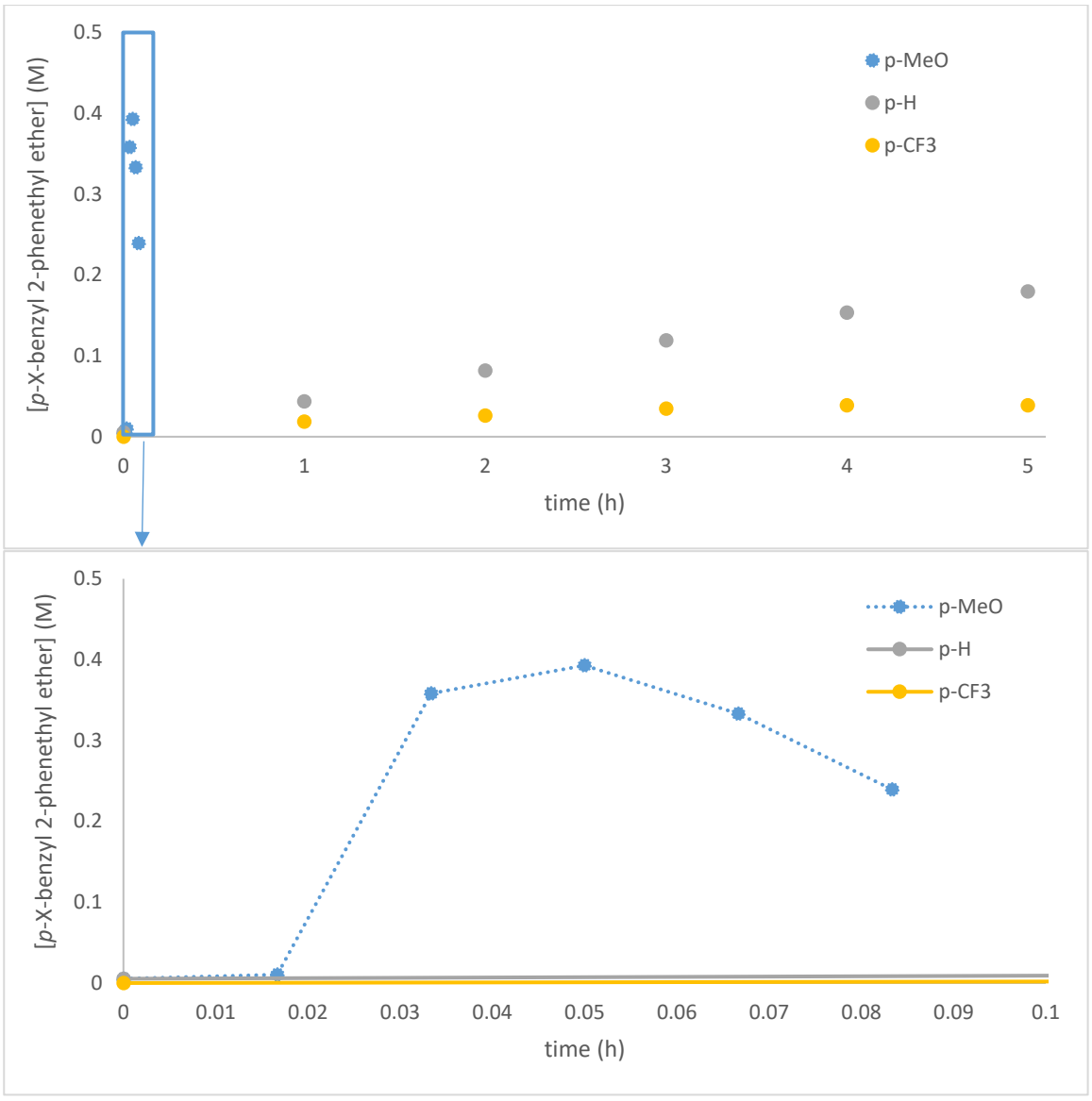


Figure S16. Rate comparison for the etherification of different p-substituted benzyl alcohols. Conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M *p*-X-BnOH, 1 M **1b**, 100 °C, BTF (0.5 mmol *p*-X-BnOH scale). Values are normalized to $[benzylic\ alcohol]_0$.

2.10. Transetherification

Formation of **2b** can take place via direct etherification of **1a** and **1b** or via transetherification by **2a** and **1b**. The rate of the latter occurs at a slower rate as shown in Figure S17.

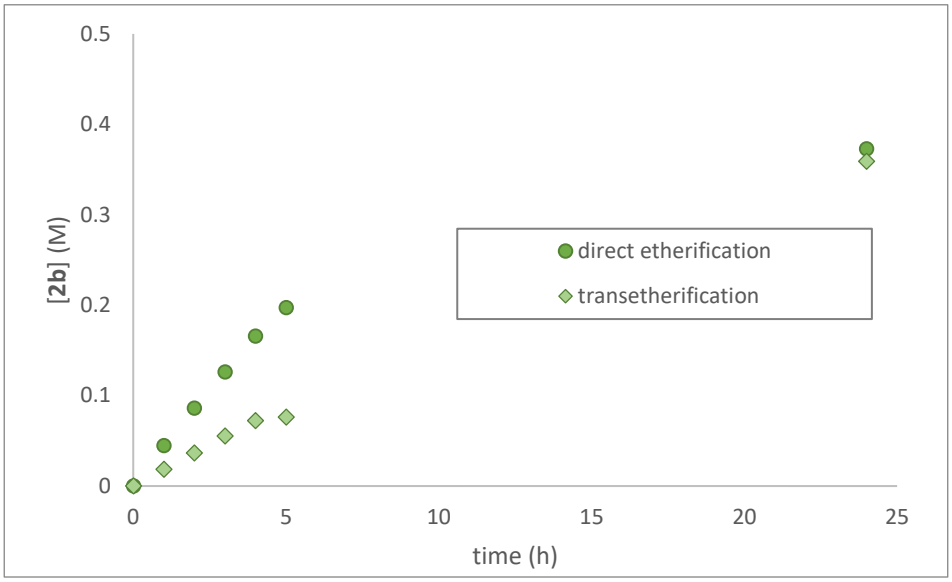


Figure S17. Rate comparison for direct etherification and transetherification Conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **1a** or **2a**, 1 M **1b**, 100 °C, BTF (0.5 mmol scale).

A set of experiments with different concentrations of reactants and catalyst was carried out under transetherification conditions, indicating that the transformation has a positive rate dependence on [Zr] and [**2a**] and negative rate dependence on [**1b**] (Figure S18).

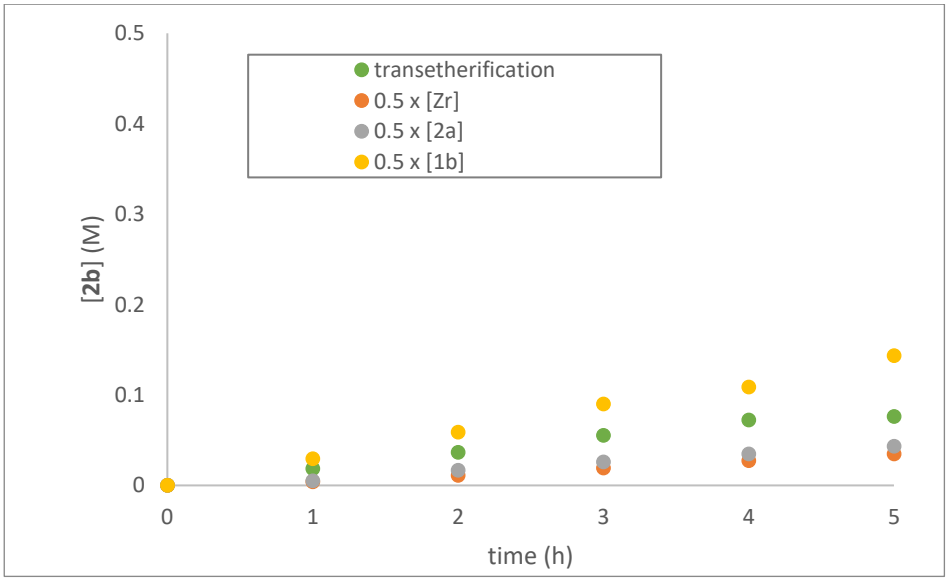


Figure S18. The effect on transetherification rate by concentration of reaction components. Standard transetherification conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **2a**, 1 M **1b**, 100 °C, BTF (0.5 mmol scale).

The efficiency by which the transetherification process occurs under different set of synthetically relevant conditions can be seen in Figure S19-S21 where the concentration of **2a** is plotted against the concentration of **2b**. As evident in Figure S19, the profiles have two main regimes where the slope of the curves are different. In the first regime of both plots **2a** and **2b** are growing simultaneously. The second regime has a negative slope for the reaction with higher [Zr], indicating that the rate of transetherification is positively correlated with [Zr].

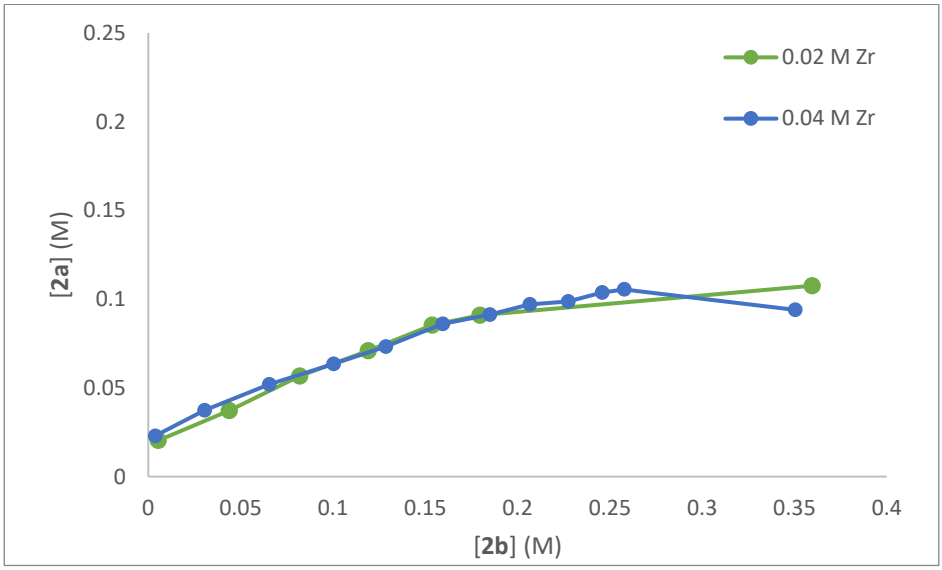


Figure S19. Transformation of **2a** into **2b** in reactions with different [Zr]. Conditions: 0.02 or 0.04 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 **1a**, 1 M **1b**, 100 °C, BTF (0.5 mmol scale). Concentrations are normalized to $[\mathbf{2a}]_0$.

In Figure S20 the first regime shows that both **2a** and **2b** are growing simultaneously in both plots. In the second regime, the slope is negative for the reaction where higher [**2a**] has formed (2 x [**1a**]). This growth of **2b** at the expense of **2a** indicates that the rate of transetherification is positively correlated with [**2a**].

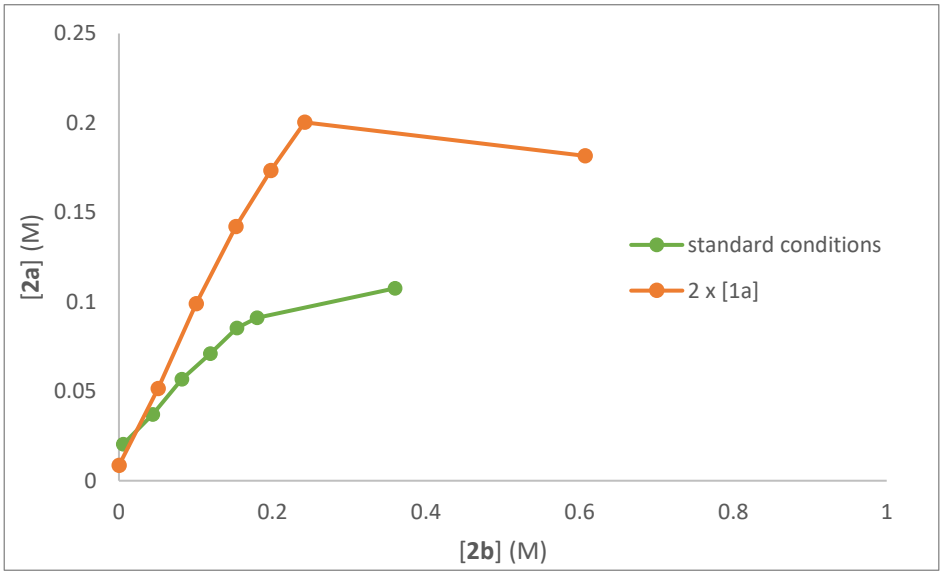


Figure S20. Transformation of **2a** into **2b** in reactions with different [**1a**]. Conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 or 1M **1a**, 1 M **1b**, 100 °C, BTF (0.5 mmol scale). Concentrations are normalized to $[\mathbf{2a}]_0$.

Figure S21 shows the result of standard conditions and those of the reaction using 2 x [**1b**]. In this case both the first and second regime has a positive slope, indicating that [**2a**] and [**2b**] are growing simultaneously. This behavior suggests that [**1b**] is not a driving force for the transetherification process.

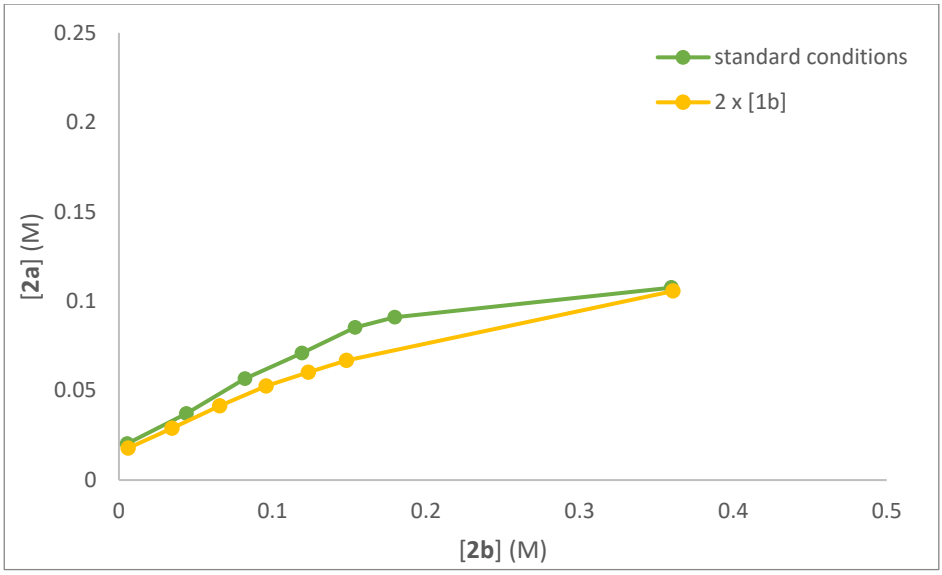


Figure S21. Transformation of **2a** into **2b** in reactions with different [**1b**]. Conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **1a**, 1 or 2 M **1b**, 100 °C, BTF (0.5 mmol scale). Concentrations are normalized to $[\mathbf{2a}]_0$.

Figure S22 shows the time course data for the formation of **2b** for the reactions in Figures S19-21.

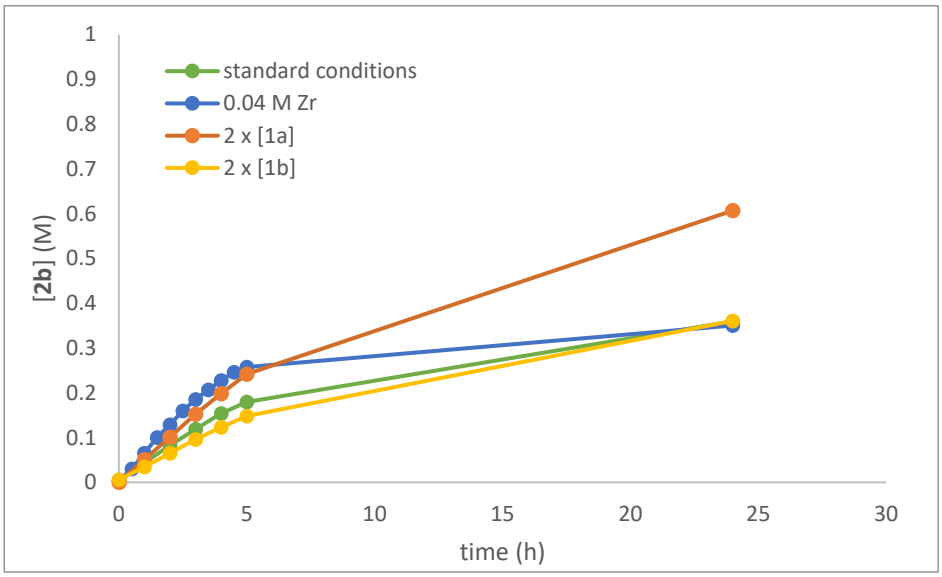


Figure S22. Formation of **2b** over time. Standard conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF (0.5 mmol scale). Concentrations are normalized to $[\mathbf{2a}]_0$.

Figure S23 shows the time course data for the formation of **2a** for the reactions in Figures S19-21.

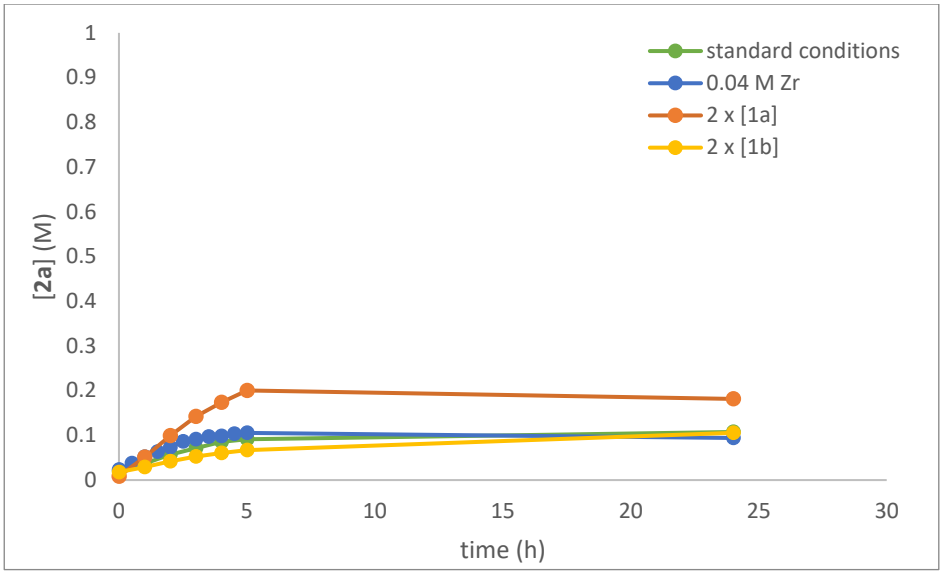


Figure S23. Formation of **2a** over time. Standard conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF (0.5 mmol scale). Concentrations are normalized to $[\mathbf{2a}]_0$.

Figure S24 shows the time course data for the consumption of **1a** for the reactions in Figures S19-21.

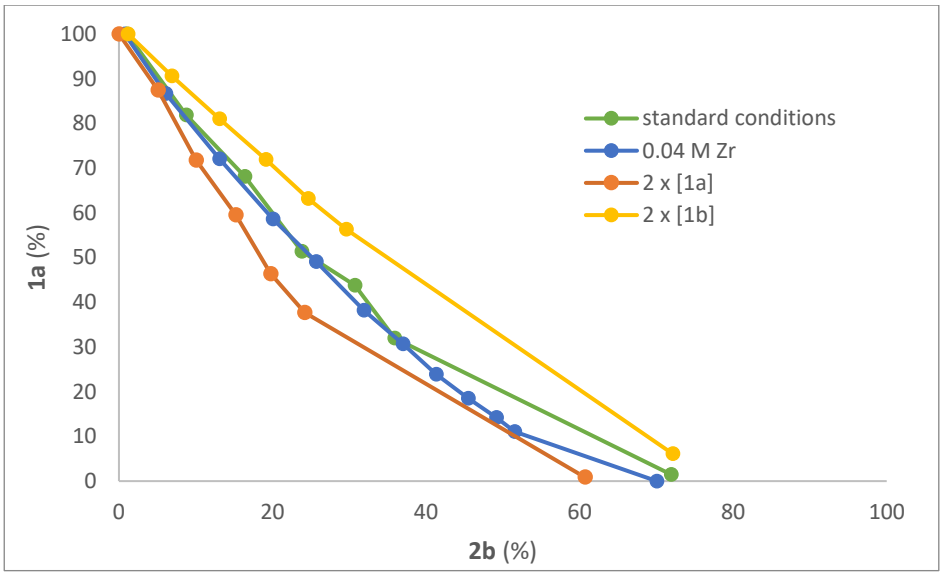


Figure S24. Conversion of **1a** into **2b**. Standard conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF (0.5 mmol scale).

Figure S25 shows the incorporation of **1a** into **2b** for the reactions in Figures S19-21.

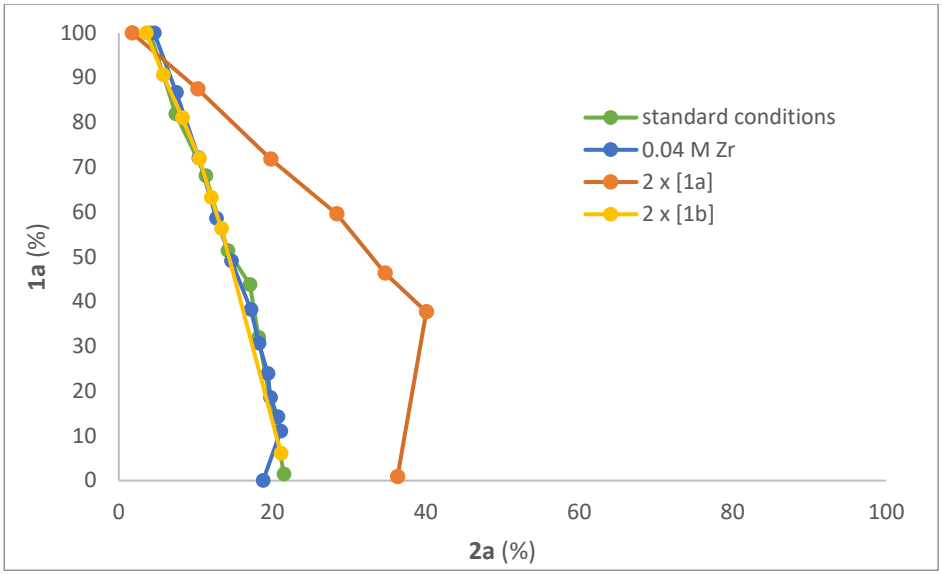


Figure S25. Conversion of **1a** into **2a**. Standard conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M **1a**, 1 M **1b**, 100 °C, BTF (0.5 mmol scale).

Figure S26 shows the two zirconium-catalyzed processes that lead to formation of product **2b**.

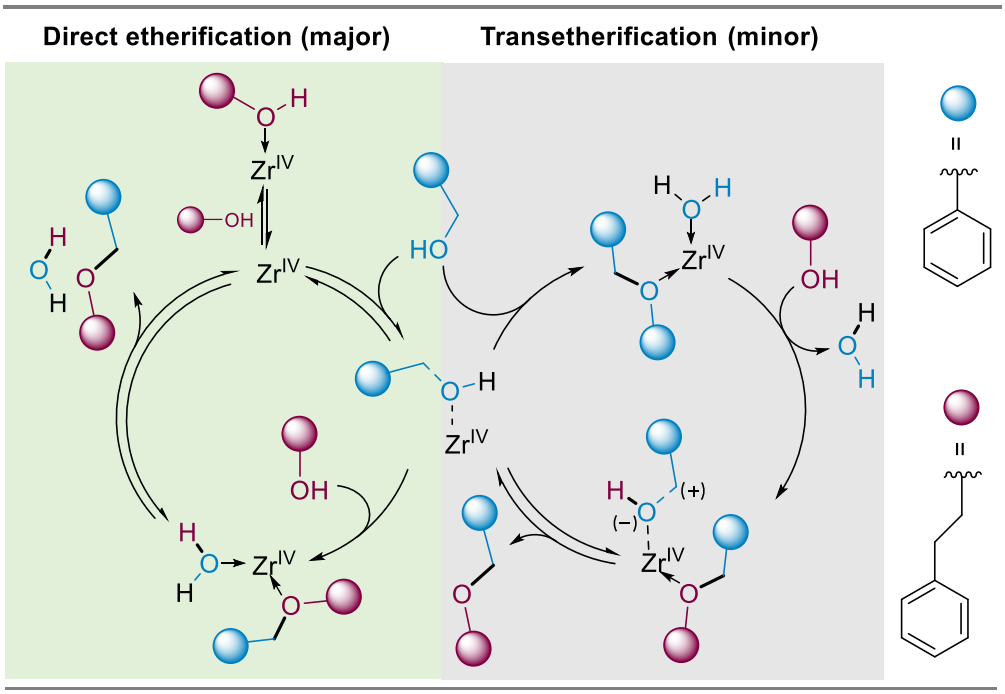


Figure S26. Major and minor catalytic pathways for **2b** formation

2.11. COPASI kinetic modeling

Global kinetic modeling was performed using COPASI as modeling software (http://www.copasi.org).[3] A model with the chemical steps shown in Figures S27 and S28 was constructed to fit the proposed mechanism. Since the experiments in Figure S11 and S14 indicated that water is not inhibiting the catalyst in the synthetically relevant concentration range, interaction between water and the catalyst was not explicitly included in the model. Similarly, transetherification was not integrated in the model as the rate of this process is considerably lower compared to direct etherification and hence assumed to contribute only marginally to formation of **2b** during the first hours of the reaction (Section 2.10).

#	Name	Reaction	Rate Law
1	Reaction 1	Zr + 1a = Act	Mass action (reversible)
2	Reaction 2	1b + Zr = Off	Mass action (reversible)
3	Reaction 3	Act + 1b -> 2b + Zr + H2O	Mass action (irreversible)
4	Reaction 4	Act + 1a -> 2a + Zr + H2O	Mass action (irreversible)

Figure S27. Kinetic model built in COPASI software

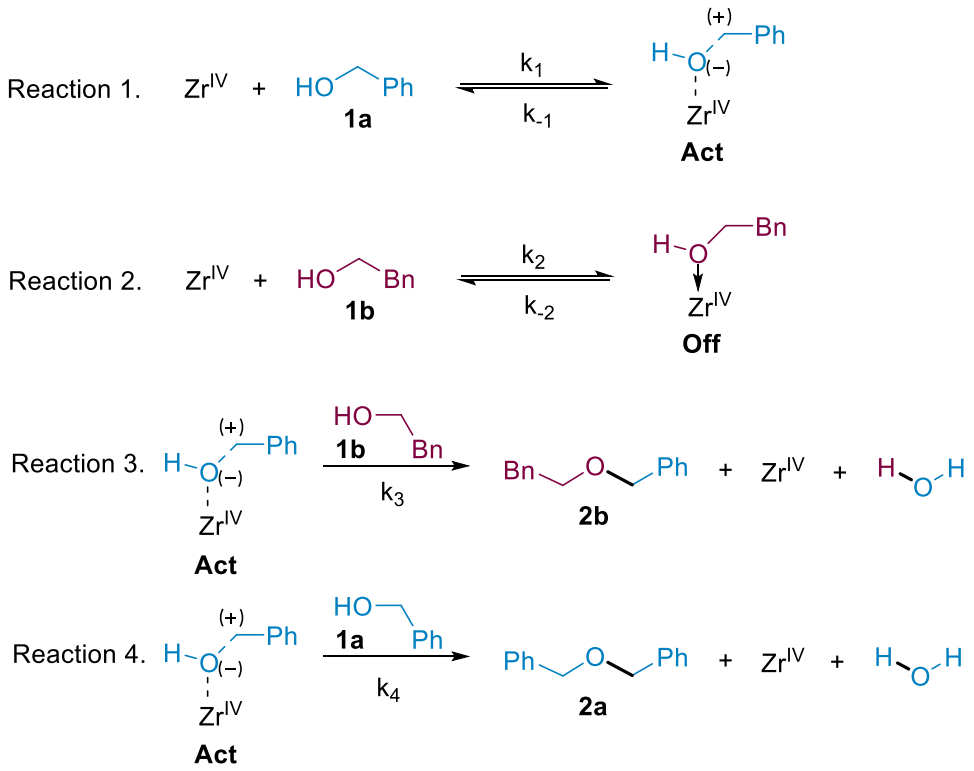


Figure S28. Schematic diagram of the reactions in the COPASI model

The kinetic model was optimized using the function Parameter Estimation with Hooke & Jeeves method and resulted in the kinetic constants shown in Table S1. As the model is underdetermined, these constants are not necessarily representing the true values for each individual step. However, as the simulated data generated from these constants fit well with the experimental data the model provides support for the

proposed catalytic cycle. Fits of the model to the experimental data used to optimize it are shown in Figure S29-S35 for 0-5 hours.

Table S1. Kinetic constants obtained via COPASI modeling

Kinetic Constant	*Value*	*Std. Deviation*
k_1	8.05364	0.404429
k_{-1}	1.27728e-8	5.75836e-6
k_2	38.3334	543.565
k_{-2}	266.206	3812.68
k_3	1259.68	13555.3
k_4	447.308	16084

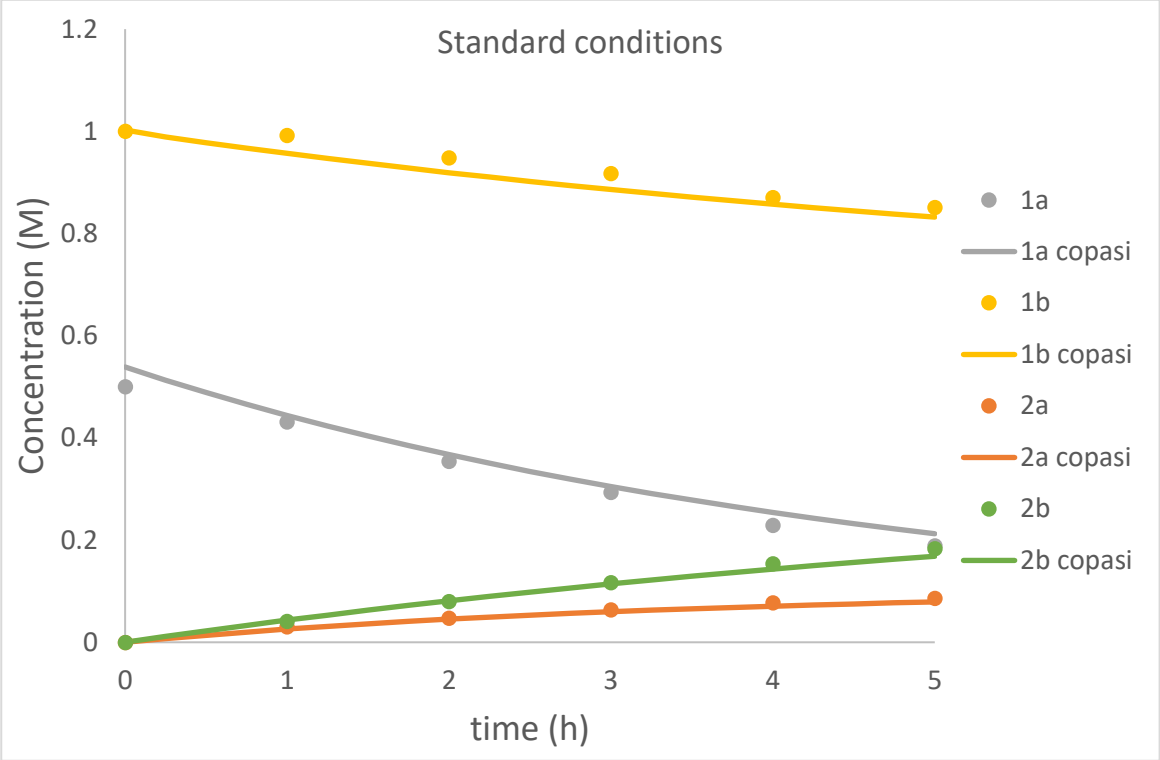


Figure S29. Model fit to standard conditions

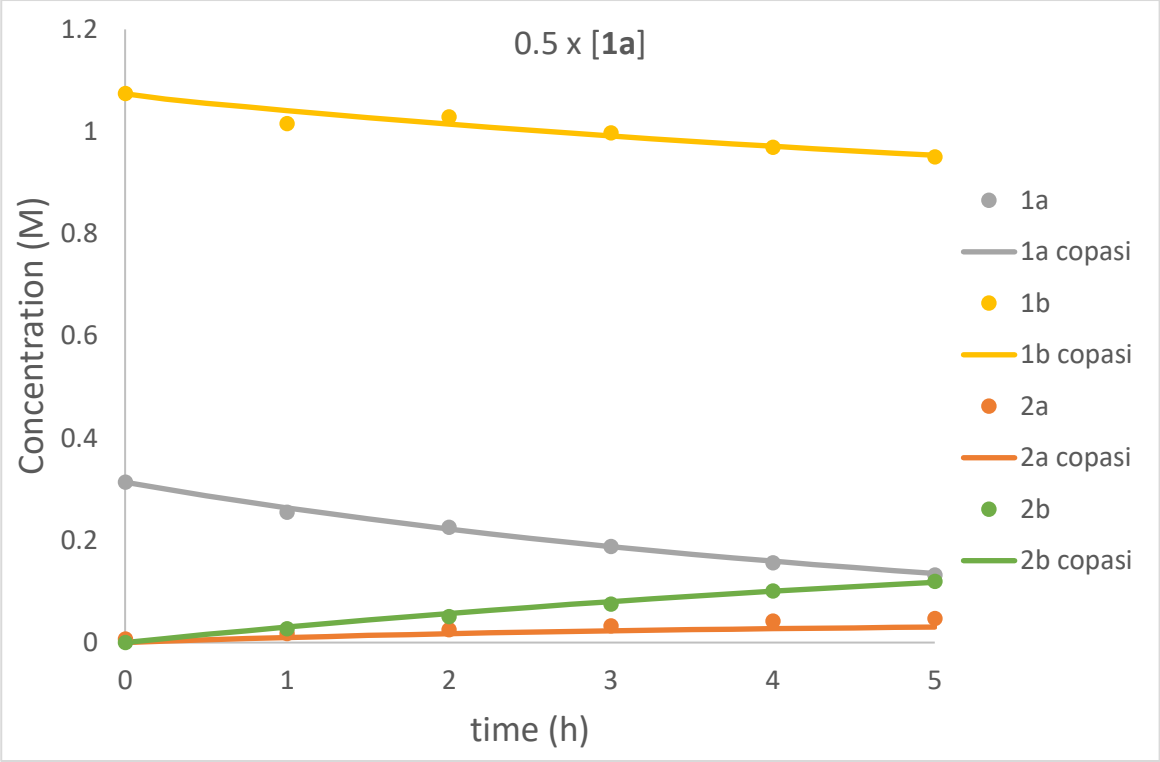


Figure S30. Model fit to 0.5 x [**1a**] conditions

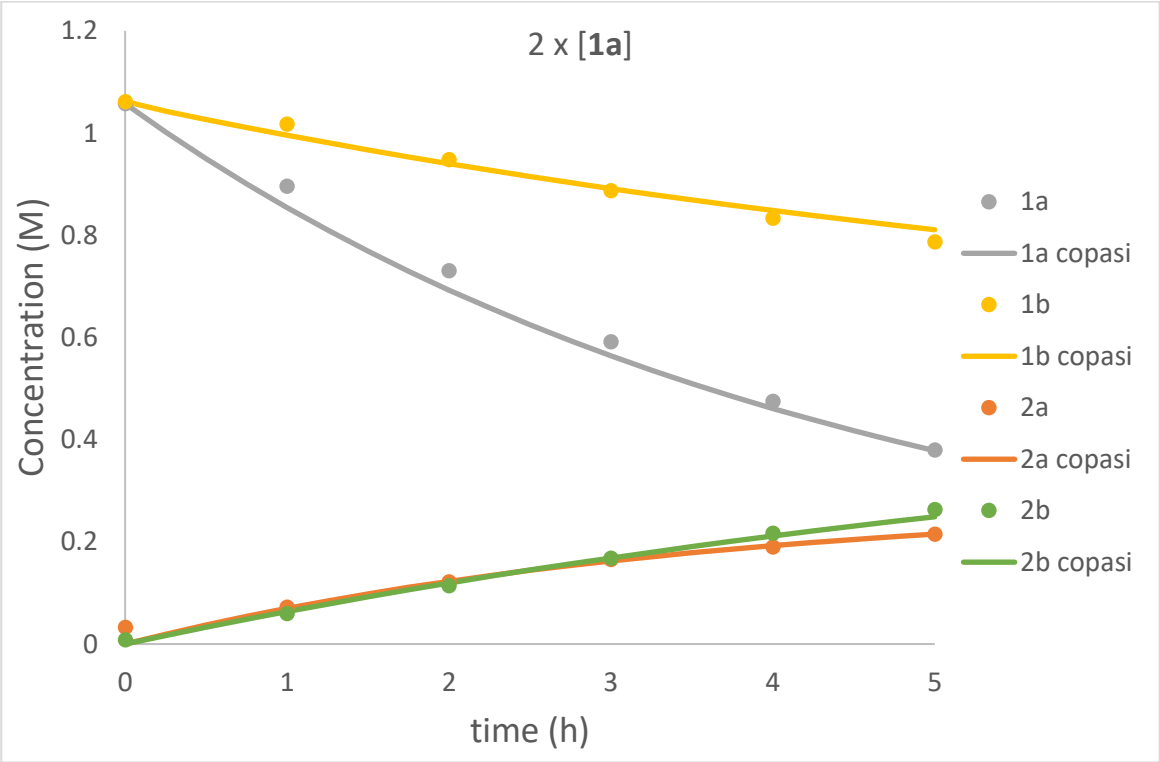


Figure S31. Model fit to 2 x [**1a**] conditions

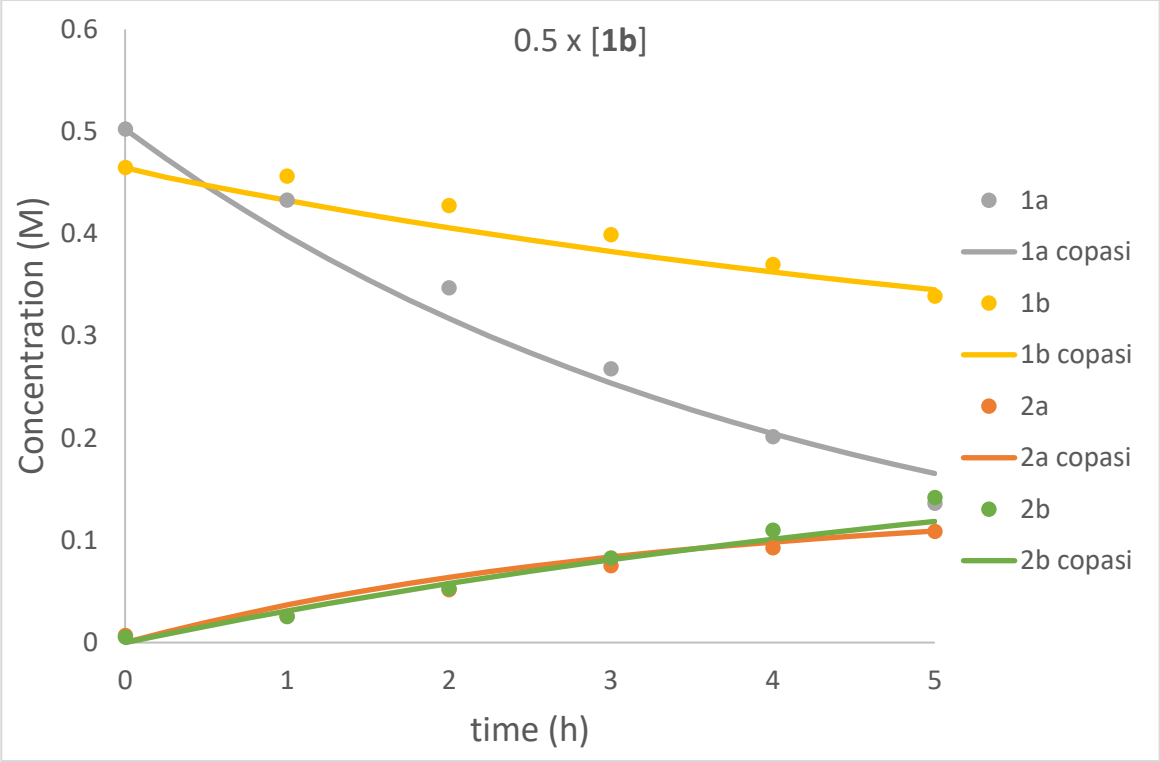


Figure S32. Model fit to 0.5 x [**1b**] conditions

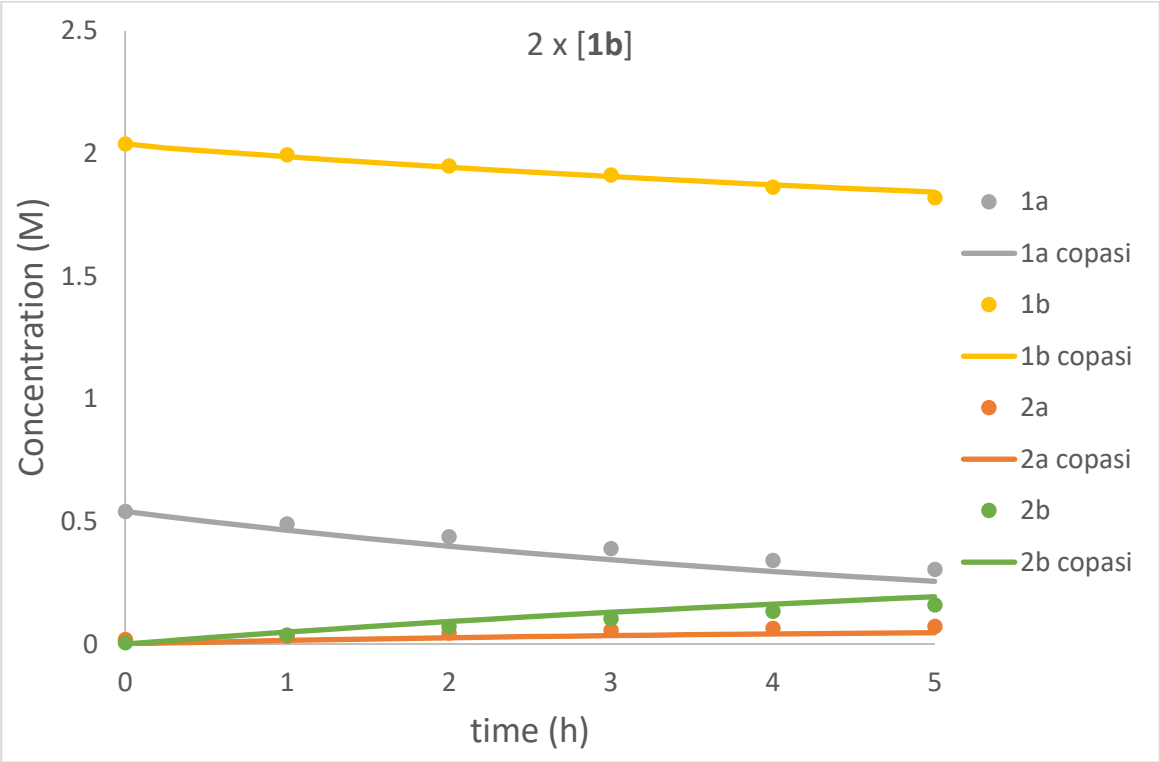


Figure S33. Model fit to 2 x [**1b**] conditions

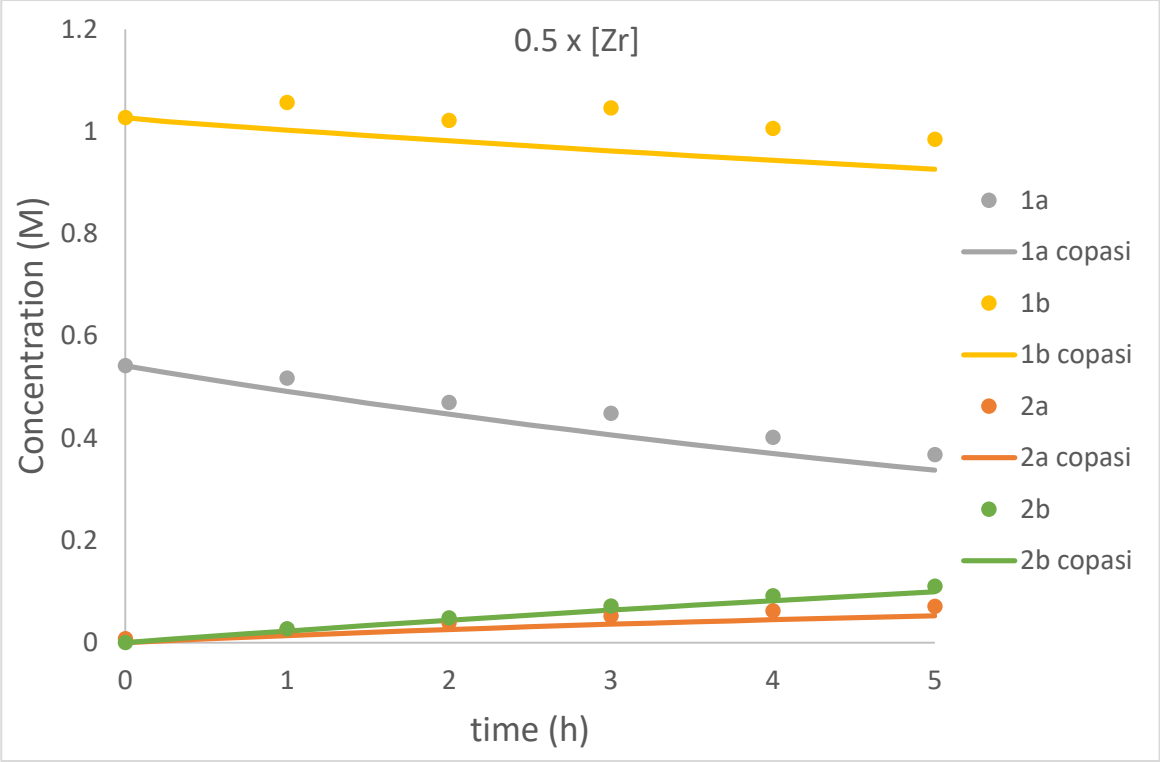


Figure S34. Model fit to 0.5 x [**Zr**] conditions

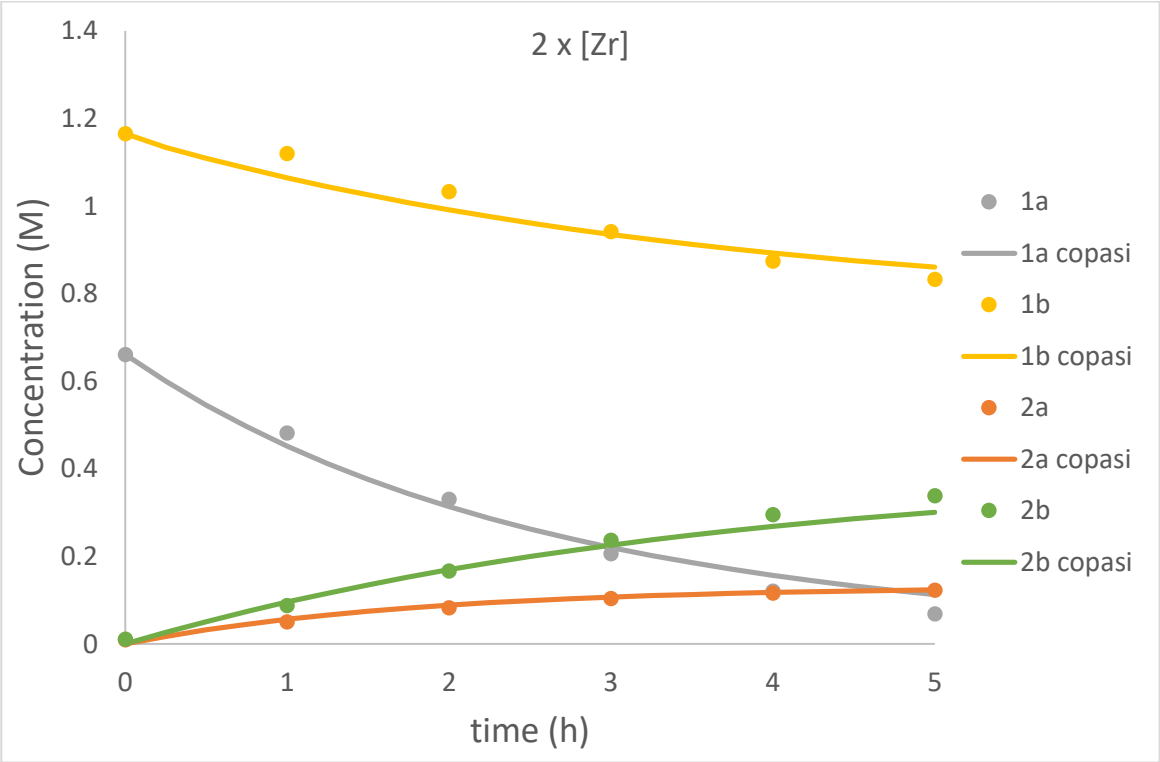


Figure S35. Model fit to 2 x [**Zr**] conditions

3. NMR study of catalyst

To a standard NMR tube were added ^{13}C(1)-benzyl alcohol (0.25 mmol, 26 µL) and 0.5 mL toluene-d_8, and a ^{13}C-NMR spectrum was recorded at 104 °C (Figure S36, S37 top and S38C). Another tube was prepared in the same manner with the addition of $Zr(Cp)_2(CF_3SO_3)_2$·THF (0.01 mmol, 5.9 mg), and ^{13}C-NMR spectra were recorded at 104 °C after 1 min (Figure S37, bottom) and after 10 min (Figure S38D). A sample of dibenzyl ether **2a** in 0.5 mL toluene-d_8 was also prepared and a ^{13}C-NMR spectrum recorded at 104 °C for comparison (Figure S38B). Signals appearing around 40 ppm were found to correspond to *ortho* and *para*-benzylated toluene. The reference compounds were prepared by stirring benzyl alcohol (0.25 mmol, 26 µL) and $Zr(Cp)_2(CF_3SO_3)_2$·THF (0.01 mmol, 5.9 mg) in 0.5 mL toluene at 100 °C for 22 h. The solvent was removed by rotary evaporation and the resulting mixture filtered with pentane through a short plug of silica, affording a mixture of the benzylated toluene isomers as a colorless oil (*ca.* 25 mg). ^{1}H-NMR and ^{13}C-NMR spectra of this mixture were recorded in toluene-d_8 at 25 °C (Figure S38A). All the ^{13}C-NMR spectra for this study were recorded at 125 MHz on a Bruker Avance 500 MHz spectrometer.

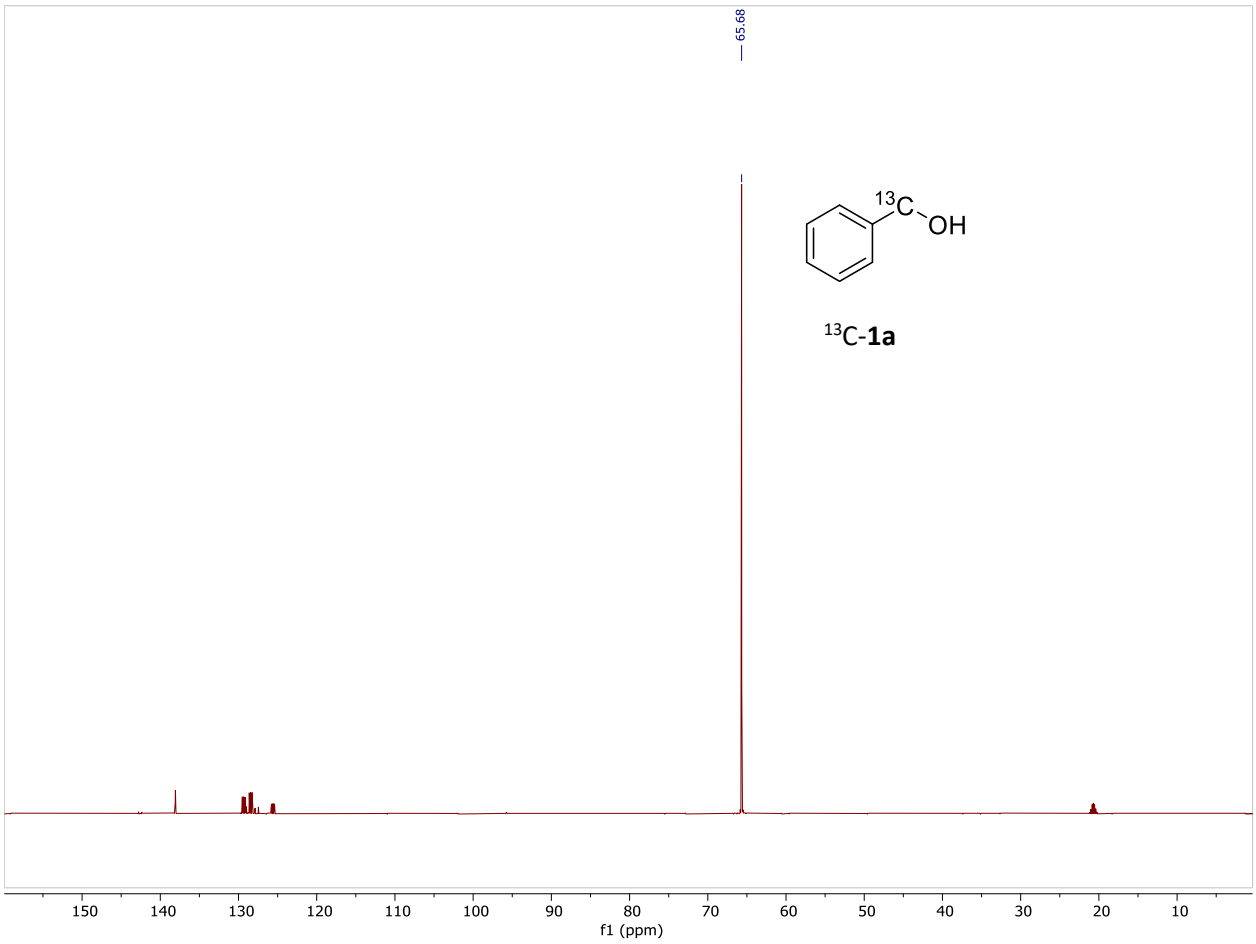


Figure S36. ^{13}C-NMR of ^{13}C(1)-benzyl alcohol in the absence of zirconocene triflate. Conditions: 0.5 M ^{13}C(1)-**1b**, 104 °C, toluene-d_8.

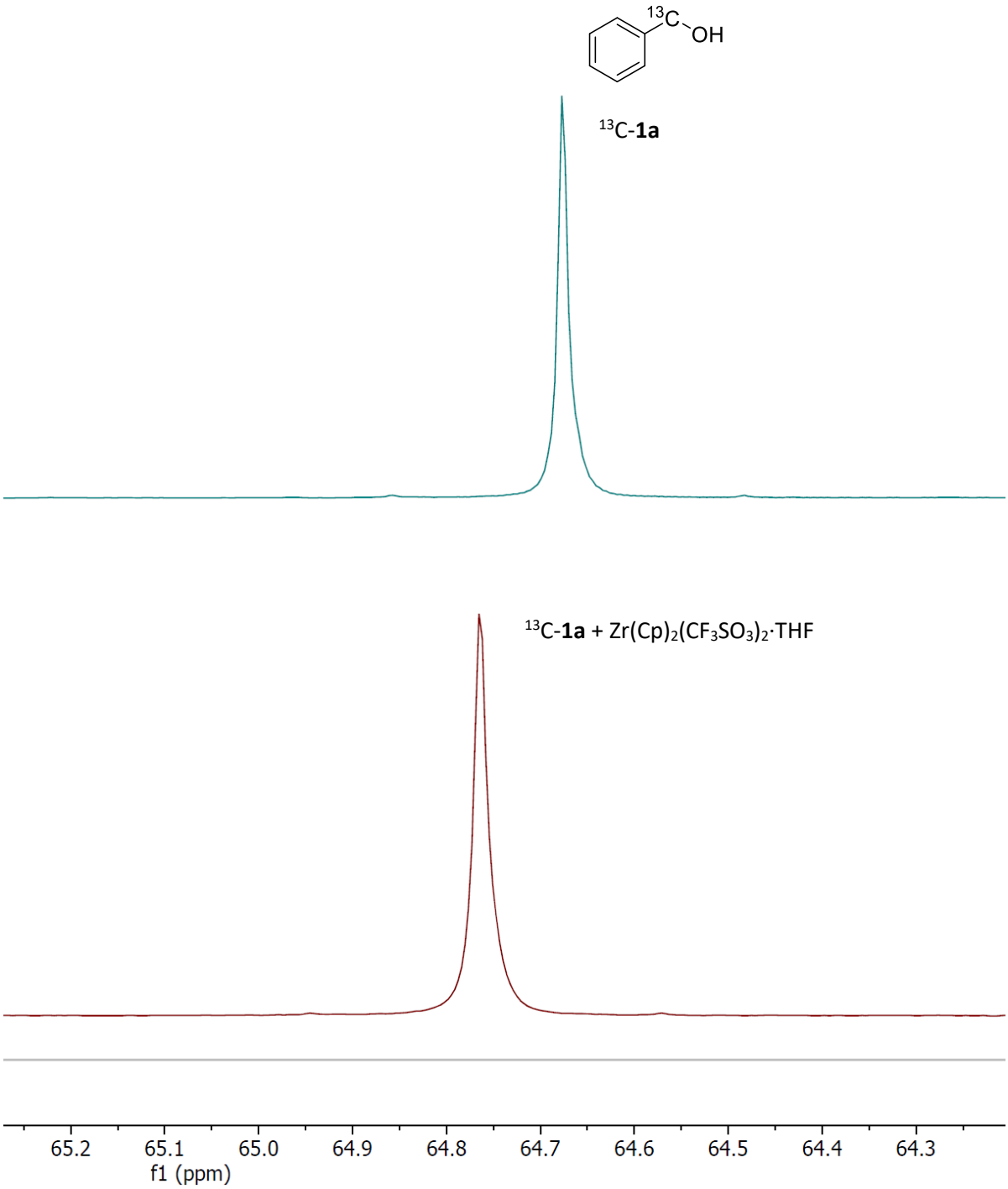


Figure S37. ^{13}C-NMR of ^{13}C(1)-benzyl alcohol in the absence (top) and presence (bottom) of zirconocene triflate (1 minute). Conditions: 0 or 0.02 M Zr(Cp)$_2$(CF$_3$SO$_3$)$_2$·THF, 0.5 M ^{13}C(1)-**1b**, 104 °C, toluene-d$_8$.

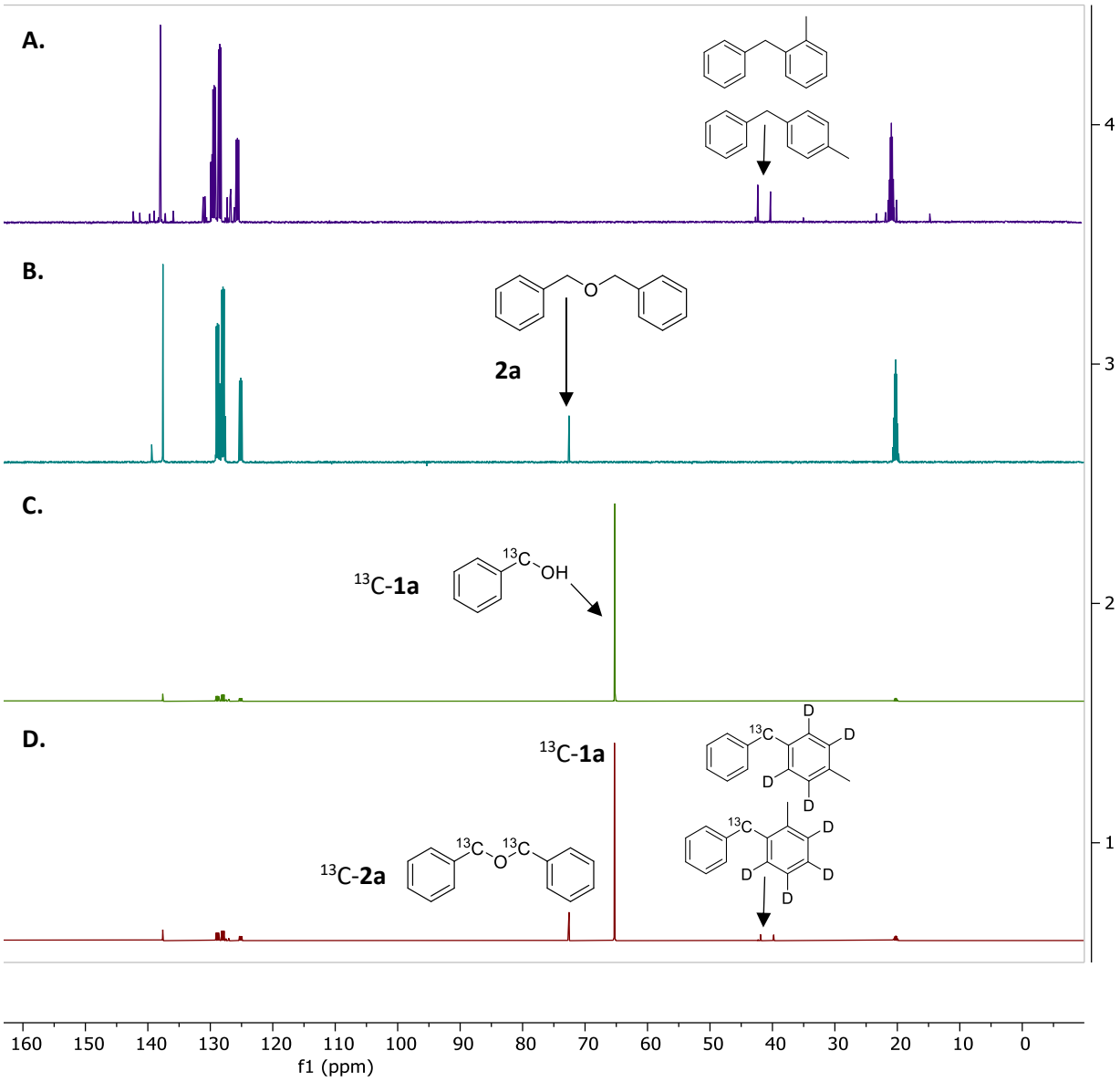


Figure S38. ^{13}C-NMR spectra of *in situ* formed products from ^{13}C(1)-**1a** and reference spectra. ***A.*** Mixture of *o*- and *p*-benzyltoluene in toluene- d_8. ***B.*** Dibenzyl ether in toluene-d_8 at 104 °C. ***C.*** ^{13}C(1)-**1a** at 104 °C in toluene-d_8. ***D.*** Compound distribution in a mixture of ^{13}C(1)-**1a** and zirconocene triflate after 10 minutes in toluene-d_8 (Conditions: 0.02 M $Zr(Cp)_2(CF_3SO_3)_2$·THF, 0.5 M ^{13}C(1)-**1b**, 104 °C, toluene-d_8).

4. General procedures

Reactions were carried out in 4 mL screw neck glass vials with screw caps with PTFE/rubber septa under ambient atmosphere unless otherwise noted. Reaction mixtures were furnished with stir bars and agitated at *ca* 800 rpm. Analysis for kinetics was carried out by removing aliquots of 20 µL starting from 0-point (at the time of inserting the reaction vessel in an oil bath at the indicated temperature) and every hour after that unless otherwise noted. The aliquots were then analyzed by HPLC, and integrated against an internal standard (4,4'-di-*tert*-butylbiphenyl, DTBB). NMR yields were determined by quantitative ^{1}H-NMR analysis in $CDCl_3$ using 1,3,5-trimethoxybenzene as internal standard (added to the crude reaction mixture after evaporation of the solvent), and recording the spectra with D1 = 5 s or 10 s.

4.1. General etherification procedure for kinetic analysis (A)

$Zr(Cp)_2(CF_3SO_3)_2$·THF (0.02 mmol, 11.8 mg), benzyl alcohol (0.5 mmol, 52 µL), 2-phenylethanol (1.0 mmol, 120 µL), internal standard 4,4'-di-*tert*-butylbiphenyl (0.01 mmol, 0.25 mL of a 0.04 M stock solution in benzotrifluoride) and benzotrifluoride (up to 1 mL of total reaction volume) were added into the reaction vessel under air atmosphere. The screw cap was tightened and the vial immersed in an oil bath at 100 °C. At indicated times, 20 µL reaction mixture was removed with a microliter syringe and mixed with 0.5 mL of 10% v/v aqueous acetonitrile (HPLC gradient grade), filtered in a filter vial (polypropylene housing, PTFE membrane) and subjected to HPLC analysis.

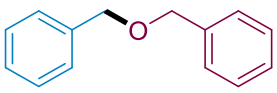
4.2. General substitution procedure for product isolation (B)

$Zr(Cp)_2(CF_3SO_3)_2$·THF (0.02 mmol, 11.8 mg), alcohol (0.25 mmol), nucleophile (1.0 mmol) and benzotrifluoride (up to 1 mL of total reaction volume) were added into the reaction vessel under air atmosphere. The screw cap was tightened and the vial immersed in an oil bath at the indicated temperature. After 24 h (unless otherwise stated) the reaction mixture was brought to room temperature and purified by column chromatography on silica gel using mixtures of EtOAc or Et_2O in petroleum ether or EtOAc in pentane as eluent (see individual compounds for eluent composition).

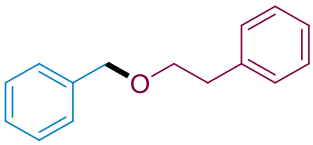
4.3. General substitution procedure for product isolation with sequential addition of alcohol (C)

$Zr(Cp)_2(CF_3SO_3)_2$·THF (0.02 mmol, 11.8 mg), nucleophile (1.0 mmol) and benzotrifluoride (up to 1 mL of total reaction volume) were added into the reaction vessel under air atmosphere. The screw cap was tightened and the vial immersed in an oil bath at the indicated temperature. The alcohol (0.5 mmol) was added via syringe in portions (5 x 0.1 mmol) with 1 h interval (from 0 to 4 h, unless otherwise indicated). After 24 h (unless otherwise stated) the reaction mixture was brought to room temperature and purified by column chromatography on silica gel using mixtures of EtOAc in petroleum ether or EtOAc in pentane as eluent (see individual compounds for eluent composition).

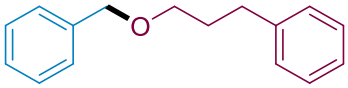
4.4. Synthetic details and analytical data for products 2a-2y', 3a-3f, 4a-4c



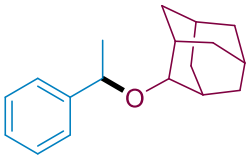
Compound **2a** was synthesized according to a reported procedure[4] and used as reference for kinetic analysis. Analytical data matches with the literature.[5] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 – 7.18 (m, 10H), 4.58 (s, 4H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.35, 128.49, 127.87, 127.72, 72.18.



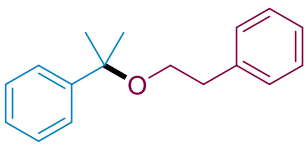
Compound **2b** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanol at 100 °C for 24 h. Under these conditions, the selectivity towards the unsymmetrical ether was 12:1 (determined by crude ^{1}H-NMR). The product was isolated as yellow oil in 84% yield (49 mg, 0.21 mmol **2b**, isolated with 0.02 mmol of **2a**, calculated by ^{1}H-NMR). Flash column chromatography eluent: 4% EtOAc in petroleum ether. R_f=0.74 (10% EtOAc in pentane). Alternatively, compound **2b** was synthesized according to the general procedure C in 0.5 mmol scale, using 1.0 mmol of 2-phenylethanol at 100 °C for 24 h. The product was isolated as yellow oil in 84% yield (99 mg, 0.42 mmol **2b**, isolated with 0.05 mmol of **2a**, calculated by ^{1}H-NMR). Analytical data matches with reported literature.[6] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54 – 7.06 (m, 10H), 4.52 (s, 2H), 3.69 (t, *J* = 7.2 Hz, 2H), 2.93 (t, *J* = 7.2 Hz, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 139.10, 138.54, 129.07, 128.50, 128.48, 127.75, 127.67, 126.33, 73.10, 71.39, 36.52.



Compound **2c** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 3-phenylpropanol at 100 °C for 24 h. The product was isolated as colorless oil in 82% yield (50 mg, 0.204 mmol **2c**, isolated with 0.019 mmol of **2a**, calculated by ^{1}H-NMR). Flash column chromatography eluent: 5% EtOAc in petroleum ether. R_f=0.70 (10% EtOAc in pentane). Alternatively, compound **2c** was synthesized according to the general procedure C in 0.5 mmol scale, using 1.0 mmol of 3-phenylpropanol at 100 °C for 24 h. NMR yield: 67% yield (0.333 mmol **2b**). Analytical data matches with reported literature.[7] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 – 7.32 (m, 4H), 7.32 – 7.24 (m, 3H), 7.22 – 7.15 (m, 3H), 4.51 (s, 2H), 3.50 (t, *J* = 6.4 Hz, 2H), 2.77 – 2.66 (m, 2H), 2.01 – 1.86 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.11, 138.71, 128.61, 128.53, 128.50, 128.43, 127.80, 127.66, 125.87, 73.04, 69.62, 32.51, 31.50.

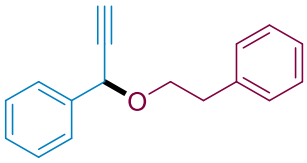


Compound **2d** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-adamantanol at 80 °C for 18 h. The product was isolated as colorless oil in 56% yield (36 mg, 0.14 mmol **2d**). Flash column chromatography eluent: 4% EtOAc in petroleum ether. R_f=0.92 (10% EtOAc in pentane). Alternatively, compound **2d** was synthesized according to the general procedure C in 0.5 mmol scale, using 1.0 mmol of 2-adamantanol at 80 °C for 18 h. NMR yield: 61% (0.303 mmol **2d**). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 – 7.18 (m, 5H), 4.58 (q, *J* = 6.5 Hz, 1H), 3.43 – 3.34 (m, 1H), 2.22 – 2.11 (m, 2H), 2.11 – 2.05 (m, 1H), 1.89 – 1.72 (m, 5H), 1.71 – 1.69 (m, 2H), 1.58 – 1.45 (m, 4H), 1.43 (d, *J* = 6.5 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.35, 128.34, 127.06, 126.18, 78.76, 73.71, 37.81, 36.85, 36.53, 33.26, 31.94, 31.76, 31.09, 27.71, 27.62, 24.96. HRMS (HESI) m/z: $[M+NH_4]^+$ calcd for $C_{18}H_{28}ON$ 274.2171; found 274.2164.

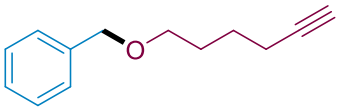


Compound **2e** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanol at 60 °C for 0.75 h. The product was isolated as colorless oil in 60% yield (36 mg, 0.15 mmol **2e**). Flash column chromatography eluent: 4% EtOAc in petroleum ether. R_f=0.74 (10% EtOAc in pentane). Alternatively, compound **2e** was synthesized according to the general procedure C in 0.5 mmol scale, using 1.0 mmol of 2-phenylethanol at 60 °C for 0.75 h (addition of 5 x 0.1 mmol portions every 5 min, from 0 to 20 min of reaction time). NMR yield: 71% (0.353 mmol **2e**). Analytical data matches with reported literature.[8] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 – 7.08 (m, 10H), 3.35 (t, *J* = 7.4 Hz, 2H), 2.83 (t, *J* =

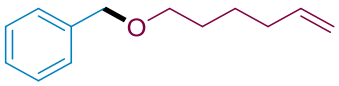
7.4 Hz, 2H), 1.50 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 146.54, 139.35, 129.19, 128.31, 128.24, 126.86, 126.19, 125.80, 76.79, 64.22, 37.26, 28.49.



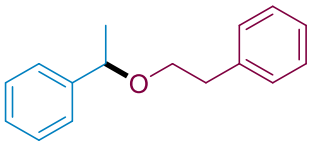
Compound **2f** was synthesized according to the general procedure B in 0.5 mmol scale, using 2.0 mmol of 2-phenylethanol at 80 °C for 1.5 h. The product was isolated as yellow oil in 91% yield (108 mg, 0.457 mmol **2f**). Flash column chromatography eluent: 5% EtOAc in pentane. R_f=0.62 (5% EtOAc in pentane). Alternatively, compound **2f** was synthesized according to the general procedure C in 0.5 mmol scale, using 1.0 mmol of 2-phenylethanol at 80 °C for 1.5 h (addition of 5 x 0.1 mmol portions every 10 min, from 0 to 40 min of reaction time). The product was isolated as yellow oil in 85% yield (101 mg, 0.427 mmol **2f**). Analytical data matches with reported literature.[9] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 – 7.45 (m, 2H), 7.41 – 7.19 (m, 8H), 5.19 (d, *J* = 2.2 Hz, 1H), 3.90 (dt, *J* = 9.1, 7.3 Hz, 1H), 3.73 (dt, *J* = 9.1, 7.3 Hz, 1H), 2.96 (t, *J* = 7.3 Hz, 2H), 2.64 (d, *J* = 2.2 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.83, 138.29, 129.10, 128.63, 128.57, 128.48, 127.40, 126.38, 81.75, 75.74, 71.53, 69.39, 36.33.



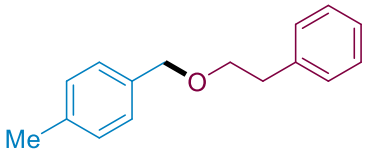
Compound **2g** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 5-hexyn-1-ol at 100 °C for 24 h. Under these conditions, the selectivity towards the unsymmetrical ether was 5.9:1 (determined by crude ^{1}H-NMR). The product was isolated as colorless oil in 45% yield (26 mg, 0.113 mmol **2g**, isolated with 0.023 mmol **2a**, calculated by ^{1}H-NMR). Flash column chromatography eluent: 4% EtOAc in petroleum ether. R_f=0.70 (10% EtOAc in pentane). Alternatively, compound **2g** was synthesized according to the general procedure C in 0.5 mmol scale, using 1.0 mmol of 5-hexyn-1-ol at 100 °C for 24 h. Under these conditions, the selectivity towards the unsymmetrical ether was 2.8:1 (determined by crude ^{1}H-NMR). NMR yield: 41% (0.21 mmol **2g**). Analytical data matches with reported literature.[10] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 – 7.25 (m, 5H), 4.51 (s, 2H), 3.51 (t, *J* = 6.2 Hz, 2H), 2.23 (td, *J* = 7.0, 2.6 Hz, 2H), 1.95 (t, *J* = 2.6 Hz, 1H), 1.80 – 1.71 (m, 2H), 1.69 – 1.59 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.70, 128.49, 127.74, 127.65, 84.47, 73.01, 69.86, 68.53, 28.90, 25.37, 18.34.



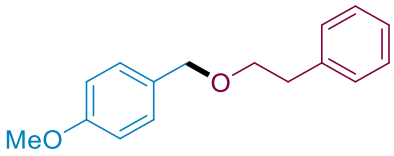
Compound **2h** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 5-hexen-1-ol at 100 °C for 24 h. Under these conditions, the selectivity towards the unsymmetrical ether was 6.3:1 (determined by crude ^{1}H-NMR). The product was isolated as colorless oil in 54% yield (30 mg, 0.134 mmol **2h**, isolated with 0.023 mmol **2a**, calculated by ^{1}H-NMR). Flash column chromatography eluent: 4% EtOAc in petroleum ether. R_f=0.76 (10% EtOAc in pentane). Alternatively, compound **2h** was synthesized according to the general procedure C in 0.5 mmol scale, using 1.0 mmol of 5-hexen-1-ol at 100 °C for 24 h. Under these conditions, the selectivity towards the unsymmetrical ether was 3.5:1 (determined by crude ^{1}H-NMR). NMR yield: 60% (0.30 mmol **2h**). Analytical data matches with reported literature.[11] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 – 7.25 (m, 5H), 5.88 – 5.77 (m, 1H), 5.04 – 5.00 (m, 2H), 4.52 (s, 2H), 3.49 (t, *J* = 6.5 Hz, 2H), 2.09 (tdt, *J* = 7.9, 6.6, 1.4 Hz, 2H), 1.71 – 1.58 (m, 2H), 1.56 – 1.44 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.88, 128.47, 127.91, 127.73, 127.60, 114.63, 72.99, 70.37, 33.68, 29.35, 25.63.



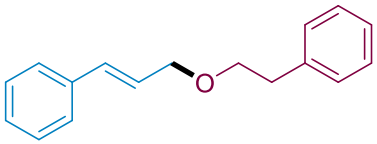
Compound **2i** was synthesized according to the general procedure B in 0.5 mmol scale, using 1.0 mmol of 2-phenylethanol at 80 °C for 20 h, starting from (S)-1-phenylethanol. The product was isolated as yellow oil in 73% yield (83 mg, 0.37 mmol **2i**). Flash column chromatography eluent: 3% EtOAc in petroleum ether. R_f=0.81 (10% EtOAc in pentane). Alternatively, compound **2i** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanol at 80 °C for 20 h. NMR yield: 80% yield (0.201 mmol **2i**). Alternatively, compound **2i** was synthesized according to the general procedure C in 0.5 mmol scale, using 1.0 mmol of 2-phenylethanol at 80 °C for 20 h. NMR yield: 72% yield (0.358 mmol **2i**). Analytical data matches with reported literature.[12] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 – 7.11 (m, 10H), 4.41 (q, *J* = 6.5 Hz, 1H), 3.52 (t, *J* = 7.3 Hz, 2H), 2.95 – 2.82 (m, 2H), 1.43 (d, *J* = 6.4 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 144.08, 139.18, 129.08, 128.51, 128.38, 127.47, 126.26, 126.23, 78.23, 69.74, 36.70, 24.26. HPLC: Chiralcel OJ-RH column, 60:40 ACN:H_2O (0.1% formic acid), 1.0 mL/min; t_R= 8.5 min / 9.5 min, 0% *ee*. A racemate prepared from (±)-1-phenylethanol was used for comparison.



Compound **2j** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanol at 100 °C for 1.5 h. The product was isolated as yellow oil in 92% yield (52 mg, 0.23 mmol **2j**). Flash column chromatography eluent: 4% EtOAc in petroleum ether. R_f=0.88 (10% EtOAc in pentane). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31 – 7.01 (m, 10H), 4.41 (s, 2H), 3.60 (t, *J* = 7.2 Hz, 2H), 2.85 (t, *J* = 7.2 Hz, 2H), 2.26 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 139.13, 137.32, 135.47, 129.16, 129.06, 128.44, 127.85, 126.28, 72.96, 71.20, 36.51, 21.28. HRMS (HESI) m/z: $[M+NH_4]^+$ calcd for $C_{16}H_{22}ON$ 244.1701; found 244.1693.

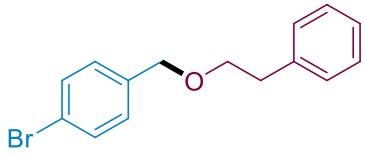


Compound **2k** was synthesized according to the general procedure B in 0.5 mmol scale, using 1.0 mmol of 2-phenylethanol at 60 °C for 1 h. The product was isolated as colorless oil in 78% yield (95 mg, 0.39 mmol **2k**). Flash column chromatography eluent: 4% EtOAc in petroleum ether. R_f=0.63 (10% EtOAc in pentane). Alternatively, compound **2k** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanol at 60 °C for 1 h. The product was isolated as colorless oil in 97% yield (59 mg, 0.243 mmol **2k**). Alternatively, compound **2k** was synthesized according to the general procedure C in 0.5 mmol scale, using 1.0 mmol of 2-phenylethanol at 60 °C for 1 h (addition of 5 x 0.1 mmol portions every 10 min, from 0 to 40 min of reaction time). The product was isolated as colorless oil in 86% yield (104 mg, 0.429 mmol **2k**). Analytical data matches with reported literature.[6] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 – 7.18 (m, 7H), 6.90 (d, *J* = 8.7 Hz, 2H), 4.49 (s, 2H), 3.83 (s, 3H), 3.70 (t, *J* = 7.2 Hz, 2H), 2.95 (t, *J* = 7.2 Hz, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.28, 139.14, 130.63, 129.38, 129.07, 128.47, 126.31, 113.90, 72.77, 71.11, 55.42, 36.52.

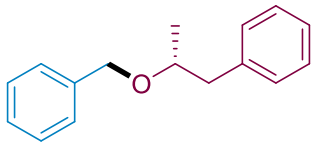


Compound **2l** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanol at 60 °C for 3h. The product was isolated as colorless oil in

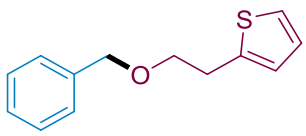
71% yield (42 mg, 0.176 mmol **2l**). Flash column chromatography eluent: 2%-6% Et_2O in petroleum ether. R_f=0.67 (10% EtOAc in pentane). Analytical data matches with reported literature.[13] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 – 7.15 (m, 10H), 6.58 (d, *J* = 16.0 Hz, 1H), 6.28 (dt, *J* = 15.9, 6.0 Hz, 1H), 4.17 (dd, *J* = 6.0, 1.5 Hz, 2H), 3.72 (t, *J* = 7.2 Hz, 2H), 2.95 (t, *J* = 7.2 Hz, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 139.08, 136.88, 132.38, 129.08, 128.68, 128.52, 127.77, 126.62, 126.37, 126.30, 71.63, 71.41, 36.57.



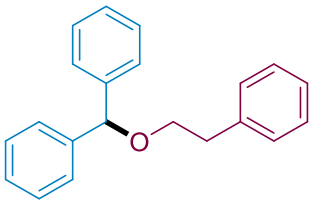
Compound **2m** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanol at 100 °C for 24 h. Under these conditions, the selectivity towards the unsymmetrical ether was 6.7:1 (determined by crude ^{1}H-NMR). The product was isolated as yellow oil in 54% yield (45 mg, 0.134 mmol **2m**, isolated with 0.017 mmol of bis-(4-bromobenzyl ether)[14], calculated by ^{1}H-NMR). Flash column chromatography eluent: 4% EtOAc in petroleum ether. R_f=0.70 (10% EtOAc in pentane). Alternatively, compound **2m** was synthesized according to the general procedure C in 0.5 mmol scale, using 1.0 mmol of 2-phenylethanol at 100 °C for 24 h. NMR yield: 53% yield (0.267 mmol **2m**). Analytical data matches with reported literature.[15] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 (d, *J* = 8.4 Hz, 2H), 7.33 – 7.19 (m, 6H), 7.16 (d, *J* = 8.3 Hz, 2H), 4.47 (s, 2H), 3.69 (t, *J* = 7.1 Hz, 2H), 2.93 (t, *J* = 7.1 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.99, 137.60, 131.71, 131.58, 129.50, 129.31, 129.10, 129.06, 128.50, 126.40, 121.48, 72.30, 71.48, 36.49.



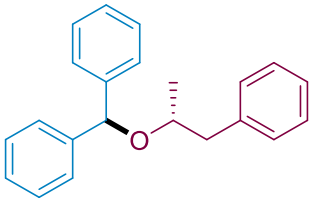
Compound **2n** was synthesized according to the general procedure B in 0.5 mmol scale, using 1.0 mmol of (R)-3-phenyl-2-propanol at 100 °C for 24 h. Under these conditions, the selectivity towards the unsymmetrical ether was 3:1 (determined by crude ^{1}H-NMR). The product was isolated as yellow oil in 55% yield (79 mg, 0.27 mmol **2n**, isolated with 0.08 mmol of **2a**, calculated by ^{1}H-NMR). Flash column chromatography eluent: 3% EtOAc in petroleum ether. R_f=0.81 (10% EtOAc in pentane). Alternatively, compound **2n** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanol at 100 °C for 24 h. NMR yield: 65% yield (0.162 mmol **2n**). Alternatively, compound **2n** was synthesized according to the general procedure C in 0.5 mmol scale, using 1.0 mmol of 2-phenylethanol at 100 °C for 24 h. NMR yield: 53% yield (0.264 mmol **2n**). Analytical data matches with reported literature.[16] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 – 7.11 (m, 10H), 4.56 – 4.41 (m, 2H), 3.76 – 3.71 (m, 1H), 2.96 (dd, *J* = 13.5, 6.4 Hz, 1H), 2.70 (dd, *J* = 13.5, 6.4 Hz, 1H), 1.19 (d, *J* = 6.1 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 139.22, 139.00, 129.67, 128.43, 128.35, 127.69, 127.51, 126.22, 76.31, 70.75, 43.36, 19.70. HPLC: Chiralcel OJ-RH column, 90:10 ACN:H_2O (0.1% formic acid), 1.0 mL/min; t_R= 2.6 min (minor) / 2.7 min (major), 84% *ee*. A racemate prepared starting from (±)-3-phenyl-2-propanol was used for comparison.



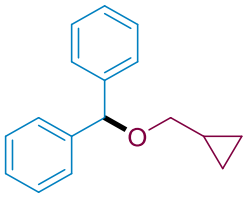
Compound **2o** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-thiophenethanol at 100 °C for 24 h. NMR yield: 37%. The product was isolated as waxy colorless solid by prep TLC (5% EtOAc in petroleum ether). R_f = 0.40 (20% EtOAc in petroleum ether). Analytical data matches with reported literature.[17] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.38 – 7.27 (m, 5H), 7.15 (dd, *J* = 5.1, 1.0 Hz, 1H), 6.94 (dd, *J* = 5.1, 3.4 Hz, 1H), 6.86 (m, 1H), 4.56 (s, 2H), 3.72 (t, *J* = 6.8 Hz, 2H), 3.15 (t, *J* = 6.8 Hz, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 141.45, 138.39, 128.54, 127.82, 127.75, 126.82, 125.29, 123.78, 73.22, 71.08, 30.67.



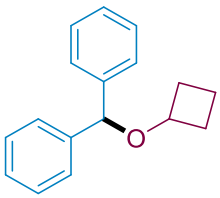
Compound **2p** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanol at 60 °C for 0.75 h. The product was isolated as colorless oil in 96% yield (69 mg, 0.24 mmol **2p**). Flash column chromatography eluent: 4% EtOAc in petroleum ether. R_f=0.77 (10% EtOAc in pentane). Analytical data matches with reported literature.[8] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 – 7.16 (m, 15H), 5.35 (s, 1H), 3.67 (t, *J* = 7.1 Hz, 2H), 2.97 (t, *J* = 7.1 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.50, 139.26, 129.19, 128.48, 128.40, 127.49, 127.06, 126.28, 83.90, 70.16, 36.68.



Compound **2q** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of (R)-3-phenyl-2-propanol at 60 °C for 0.75 h. Under these conditions, the selectivity towards the unsymmetrical ether was 8.2:1 (determined by crude ^{1}H-NMR). The product was isolated as colorless oil in 67% yield (59 mg, 0.167 mmol **2q**, isolated with 0.02 mmol of bis(diphenyl)methyl ether[5], calculated by ^{1}H-NMR). Flash column chromatography eluent: 4%-8% EtOAc in petroleum ether. R_f=0.84 (10% EtOAc in pentane). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 – 7.11 (m, 15H), 5.47 (s, 1H), 3.73 (sext, *J* = 6.2 Hz, 1H), 2.99 (dd, *J* = 13.4, 6.6 Hz, 1H), 2.74 (dd, *J* = 13.4, 6.3 Hz, 1H), 1.20 (d, *J* = 6.1 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 143.27, 142.57, 139.26, 129.80, 128.44, 128.36, 128.29, 127.37, 127.34, 127.25, 127.07, 126.18, 80.98, 74.07, 43.70, 19.74. HPLC: Chiralcel OJ-RH column, 70:30 ACN:H_2O (0.1% formic acid), 1.0 mL/min; t_R= 6.9 min (minor) / 7.4 min (major) , 96% *ee*. A racemate prepared starting from (±)-3-phenyl-2-propanol was used for comparison. HRMS (HESI) m/z: $[M+NH_4]^+$ calcd for $C_{22}H_{26}ON$ 320.2014; found 320.2008.

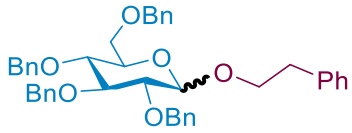


Compound **2r** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of cyclopropanemethanol at 60 °C for 1 h. The product was isolated as colorless oil in 77% yield (46 mg, 0.193 mmol **2r**). Flash column chromatography eluent: 4% EtOAc in petroleum ether. R_f=0.82 (10% EtOAc in pentane). Analytical data matches with reported literature.[18] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48 – 7.21 (m, 10H), 5.46 (s, 1H), 3.37 (d, *J* = 6.8 Hz, 2H), 1.25 – 1.10 (m, 1H), 0.62 – 0.53 (m, 2H), 0.24 (dt, *J* = 6.1, 4.5 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.60, 128.48, 127.47, 127.17, 83.23, 73.76, 10.88, 3.22.

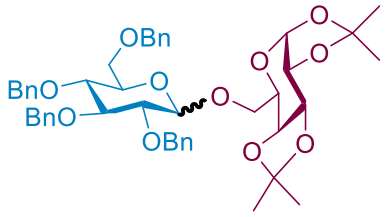


Compound **2s** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of cyclobutanol at 60 °C for 1 h. Under these conditions, the selectivity towards the unsymmetrical ether was 10.2:1 (determined by crude ^{1}H-NMR). The product was isolated as colorless oil in 81% yield (52 mg, 0.203 mmol **2s**, isolated with 0.01 mmol of bis(diphenyl)methyl ether[5], calculated by ^{1}H-NMR). Flash column chromatography eluent: 4% EtOAc in petroleum ether. R_f=0.85 (10% EtOAc in pentane).

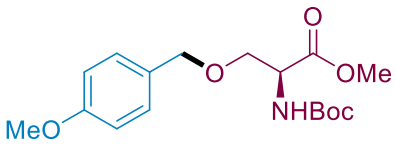
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 – 7.22 (m, 10H), 5.39 (s, 1H), 4.03 (quin, *J* = 7.4 Hz, 1H), 2.22 – 2.14 (m, 2H), 2.12 – 2.02 (m, 2H), 1.75 – 1.68 (m, 1H), 1.51 – 1.39 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.64, 128.41, 127.45, 127.24, 80.82, 71.56, 30.83, 12.74. HRMS (HESI) m/z: $[M+NH_4]^+$ calcd for $C_{17}H_{22}ON$ 256.1701; found 256.1699.



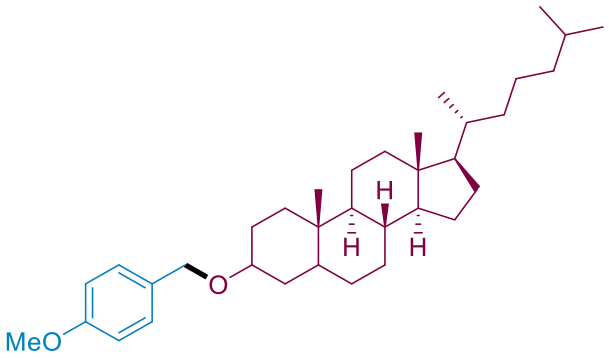
Compound **2t** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanol at 60 °C for 18 h. The product was isolated as pale yellow oil in 74% yield (119 mg, 0.185 mmol **2t**, 50:50 mixture of α and β anomers, determined by ^{1}H-NMR). Flash column chromatography eluent: 10%-20% EtOAc in petroleum ether. R_f=0.37 (10% EtOAc in pentane). Analytical data matches with reported literature.[19] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 – 7.13 (m, 25H), 4.99 (d, *J* = 10.8 Hz, 1H, β), 4.92 (d, *J* = 10.9 Hz, 1H, α), 4.84 – 4.74 (m, 3H), 4.65 – 4.46 (m, 3H), 4.46 – 4.33 (m, 2H), 4.22 (dt, *J* = 9.5, 6.7 Hz, 1H, β), 4.01 – 3.96 (m, 1H, α), 3.89 – 3.38 (m, 7H), 3.05 – 2.88 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 139.02 (α/β), 138.83 (α/β), 138.78 (α/β), 138.63 (β), 138.52 (α), 138.48 (α), 138.32 (β), 138.25 (β), 138.09 (α), 129.14 (α), 129.07 (β), 128.55 (α/β), 128.52 (α/β), 128.50 (α/β), 128.48 (α/β), 128.43 (α/β), 128.28 (α/β), 128.16 (α/β), 128.12 (α/β), 128.00 (α/β), 127.96 (α/β), 127.92 (α/β), 127.89 (α/β), 127.78 (α/β), 127.75 (α/β), 127.71 (α), 126.43 (α/β), 103.79 (β), 97.00 (α), 84.82 (β), 82.38 (β), 82.14 (α), 80.17 (α), 78.03 (β), 77.82 (α), 75.82 (α/β), 75.14 (β), 75.04 (α), 75.01 (β), 74.85 (β), 73.64 (β), 73.58 (α), 73.32 (α), 70.78 (β), 70.33 (α), 69.11 (β), 68.92 (α), 68.62 (α), 36.44 (β), 36.16 (α).



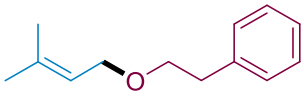
Compound **2u** was synthesized according to the general procedure B in 0.25 mmol scale, using 0.5 mmol of 1,2:3,4-Di-*O*-isopropylidene-α-D-galactopyranose at 60 °C for 18 h. The product was isolated as colorless oil in 50% yield (98 mg, 0.125 mmol **2u**, 60:40 mixture of α and β anomers, determined by ^{1}H-NMR). Flash column chromatography eluent: 10%-20% EtOAc in petroleum ether. R_f=0.30 (10% EtOAc in pentane). Analytical data matches with reported literature.[20] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.37 – 7.33 (m, 2H, β), 7.31 – 7.16 (m, 18H), 7.08 – 7.05 (m, 2H), 5.50 (d, *J* = 5.0 Hz, 1H, β), 5.45 (d, *J* = 5.0 Hz, 1H, α), 4.99 (d, *J* = 11.1 Hz, 1H, β), 4.94 – 4.92 (m, 2H, α), 4.88 (d, *J* = 10.9 Hz, 1H, β), 4.75 (d, *J* = 10.3 Hz, 1H, α), 4.73 – 4.68 (m, 3H), 4.67 – 4.59 (m, 3H), 4.57 – 4.48 (m, 5H), 4.46 – 4.34 (m, 4H), 4.29 (dd, *J* = 7.9, 2.0 Hz, 1H, α), 4.26 – 4.23 (m, 2H), 4.18 (dd, *J* = 7.9, 1.9 Hz, 1H, β), 4.09 (dd, *J* = 10.7, 3.7 Hz, 1H, β), 4.03 – 4.01 (m, 1H, β), 3.98 – 3.95 (m, 1H), 3.91 (t, *J* = 9.2 Hz, 1H, α), 3.78 – 3.49 (m, 12H), 3.42 – 3.34 (m, 2H, β), 1.46 (s, 3H, α), 1.43 (s, 3H, β), 1.38 (s, 3H), 1.25 (s, 6H), 1.24 (s, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 139.06 (α), 138.82 (β), 138.47 (α), 138.46 (α), 138.28 (β), 138.26 (β), 138.09 (α), 128.74 (β), 128.45 (α/β), 128.31 (α/β), 128.08 (β), 128.03 (α), 128.01 (α), 127.98 (β), 127.92 (α/β), 127.80 (α/β), 127.75 (α/β), 127.73 (α/β), 127.70 (α/β), 127.64 (α/β), 127.62 (α/β), 127.58 (β), 109.47 (β), 109.30 (α), 108.69 (α), 108.67 (β), 104.50 (β), 97.16 (α), 96.50 (β), 96.42 (α), 84.66 (β), 82.07 (α), 81.74 (β), 79.92 (α), 77.84 (β), 77.69 (α), 75.76 (β), 75.73 (α), 75.09 (α/β), 74.86 (β), 74.45 (β), 73.60 (β), 73.57 (α), 72.46 (α), 71.55 (β), 70.92 (α), 70.89 (α), 70.77 (β), 70.75 (α), 70.59 (β), 70.33 (α), 69.81 (β), 68.88 (β), 68.48 (α), 67.47 (β), 66.32 (α), 65.81 (α), 26.28 (α), 26.19 (α), 26.15 (β), 26.11 (β), 25.14 (β), 25.04 (α), 24.76 (α), 24.56 (β).



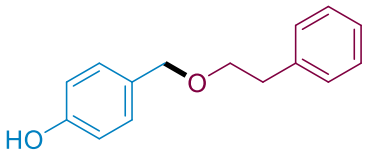
Compound **2v** was synthesized according to the general procedure B in 0.5 mmol scale, using 0.5 mmol of N-Boc-L-serine methyl ester at 60 °C for 48 h. The product was isolated as colorless oil in 23% yield (40 mg, 0.117 mmol **2v**). Flash column chromatography eluent: 12% EtOAc in petroleum ether. R_f = 0.60 (20% EtOAc in petroleum ether). Analytical data matches with reported literature.[21] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.23 – 7.16 (m, 2H), 6.90 – 6.84 (m, 2H), 5.36 (br d, *J* = 8.3 Hz, 1H), 4.50 – 4.38 (m, 3H), 3.82 (m, 1H), 3.80 (s, 3H), 3.73 (s, 3H), 3.65 (dd, *J* = 9.4, 3.2 Hz, 1H), 1.45 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 171.37, 159.48, 155.64, 129.77, 129.40, 113.95, 80.20, 77.41, 77.16, 76.90, 73.05, 69.73, 55.42, 54.14, 52.55, 28.46.



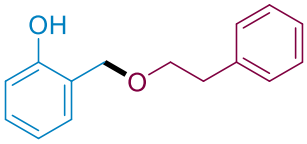
Compound **2w** was synthesized according to the general procedure B in 0.237 mmol scale, using 0.5 mmol of β-cholestanol at 60 °C for 18 h. Under these conditions, the selectivity towards the unsymmetrical ether was 4:1 (determined by crude ^{1}H-NMR). The product was isolated as white solid in 62% yield (75 mg, 0.147 mmol **2w**, isolated with 0.004 mmol of 4,4'-dimethoxydibenzyl ether[22], calculated by ^{1}H-NMR). Flash column chromatography eluent: 5%-10% EtOAc in petroleum ether. R_f=0.65 (10% EtOAc in pentane). Analytical data matches with reported literature.[23] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.27 – 7.25 (m, 2H), 6.88 – 6.86 (m, 2H), 4.51 – 4.45 (m, 2H), 3.80 (s, 3H), 3.35 – 3.27 (m, 1H), 1.96 (dt, *J* = 12.5, 3.4 Hz, 1H), 1.92 – 1.62 (m, 6H), 1.60 – 0.93 (m, 24H), 0.90 (d, *J* = 6.5 Hz, 3H), 0.87 – 0.85 (m, 6H), 0.80 (s, 3H), 0.65 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.14, 131.49, 129.24, 113.89, 77.88, 69.55, 56.68, 56.45, 55.42, 54.60, 45.04, 42.76, 40.22, 39.67, 37.20, 36.33, 35.95, 35.66, 35.02, 32.29, 29.04, 28.46, 28.40, 28.16, 24.37, 23.98, 22.96, 22.71, 21.38, 18.82, 12.44, 12.22.



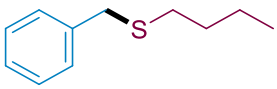
Compound **2x** was synthesized from 2-methyl-3-buten-2-ol according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanol at 60 °C for 1.5 h. The linear:branched ether selectivity was 9:1 (determined by crude ^{1}H-NMR). The product was isolated as colorless oil in 53% yield (25 mg, 0.132 mmol **2x**). Alternatively, compound **2x** was synthesized from prenol according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanol at 60 °C for 1.5 h. The linear:branched ether selectivity was 7:1 (determined by crude ^{1}H-NMR). The product was isolated as colorless oil in 34% yield (16 mg, 0.084 mmol **2x**). Flash column chromatography eluent: 2%-4% Et_2O in petroleum ether. R_f=0.63 (10% EtOAc in pentane). Analytical data matches with reported literature.[24] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 – 7.12 (m, 5H), 5.44 – 5.29 (m, 1H), 3.99 (d, *J* = 6.9 Hz, 2H), 3.64 (t, *J* = 7.4 Hz, 2H), 2.91 (t, *J* = 7.4 Hz, 2H), 1.76 (s, 3H), 1.67 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 139.17, 137.04, 129.04, 128.49, 126.29, 121.29, 71.27, 67.49, 36.59, 25.96, 18.16.



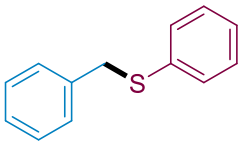
Compound **2y** was synthesized according to the general procedure B in THF in 0.25 mmol scale, using 1.0 mmol of 1-phenylethanol at 40 °C for 4 h. NMR yield: 81%. The product was isolated as white solid by preparative TLC (20% EtOAc in petroleum ether). R_f = 0.50 (20% EtOAc in petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 – 7.30 (m, 2H), 7.30 – 7.20 (m, 5H), 6.85 – 6.79 (m, 2H), 5.12 (s, 1H), 4.51 (s, 2H), 3.74 (t, *J* = 7.3 Hz, 2H), 2.98 (t, *J* = 7.3 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.31, 139.03, 130.54, 129.66, 129.06, 128.48, 126.34, 115.37, 72.78, 71.14, 36.45. HRMS (HESI) m/z: $[M-H]^-$ calcd for $C_{15}H_{15}O_2$ 227.1072; found 227.1073.



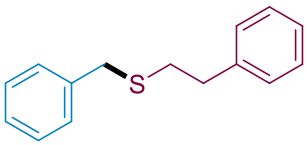
Compound **2y'** was synthesized according to the general procedure B in THF and in 0.25 mmol scale, using 1.0 mmol of 1-phenylethanol at 40 °C for 8 h. The product was isolated as colorless waxy solid in 34% yield (20 mg, 0.086 mmol **2y'**). Flash column chromatography eluent: 5-10% EtOAc in petroleum ether. R_f = 0.70 (20% EtOAc in petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 – 7.29 (m, 2H), 7.27 – 7.16 (m, 4H), 6.98 (dd, *J* = 7.4, 1.8 Hz, 1H), 6.89 – 6.79 (m, 2H), 4.69 (s, 2H), 3.78 (t, *J* = 6.8 Hz, 2H), 2.95 (t, *J* = 6.8 Hz, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 156.37, 138.34, 129.59, 128.94, 128.72, 128.13, 126.71, 122.25, 119.92, 116.71, 72.76, 71.68, 36.26. HRMS (HESI) m/z: $[M-H]^-$ calcd for $C_{15}H_{15}O_2$ 227.1072; found 227.1074.



Compound **3a** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 1-butanethiol at 100 °C for 24 h. NMR yield: 72%. Alternatively, compound **3a** was synthesized according to the general procedure B in 0.5 mmol scale, using 1.0 mmol of 1-butanethiol at 100 °C for 24 h. The product was isolated as colorless oil in 59% yield (53 mg, 0.29 mmol **3a**) by preparative TLC (100% petroleum ether). R_f = 0.65 (20% EtOAc in petroleum ether). Analytical data matches with reported literature.[25] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.25 (m, 5H), 3.69 (s, 2H), 2.41 (m, 2H), 1.52 (quint, *J* = 7.3 Hz, 2H), 1.35 (sext, *J* = 7.3 Hz, 2H), 0.86 (t, *J* = 7.3 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.83, 128.93, 128.53, 126.95, 77.48, 77.36, 77.16, 76.84, 36.36, 31.46, 31.13, 22.10, 13.78.

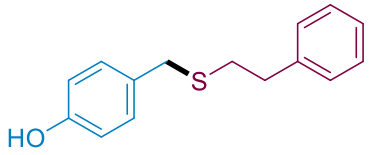


Compound **3b** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of thiophenol at 100 °C for 24 h. The product was isolated as colorless oil in 32% yield (16 mg, 0.08 mmol **3b**). Flash column chromatography eluent: 1-2% EtOAc in petroleum ether. R_f = 0.70 (10% EtOAc in petroleum ether). Alternatively, compound **3b** was synthesized according to the general procedure B in 0.5 mmol scale, using 1.0 mmol of thiophenol at 100 °C for 24 h. The product was isolated in *ca* 20% yield by preparative TLC (100% petroleum ether). Analytical data matches with reported literature.[26] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 – 7.04 (m, 10H), 4.06 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.58, 136.49, 129.95, 128.96, 128.95, 128.62, 127.30, 126.47, 39.17.

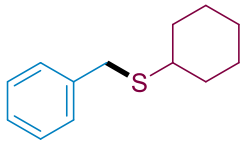


Compound **3c** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanethiol at 100 °C for 24 h. NMR yield: 85%. Alternatively, compound **3c**

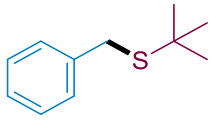
was synthesized according to the general procedure B in 0.5 mmol scale, using 0.5 mmol of 2-phenylethanethiol at 100 °C for 24 h. The product was isolated with minor impurities in 83% yield as beige oil (95 mg, 0.415 mmol). Flash column chromatography eluent: 2% EtOAc in petroleum ether. R_f = 0.74 (10% EtOAc in petroleum ether). Analytical data matches with reported literature.[27] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34 – 7.14 (m, 8H), 7.13 (m, 2H), 3.69 (s, 2H), 2.81 (m, 2H), 2.64 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 140.62, 138.51, 128.97, 128.59, 128.53, 127.07, 126.40, 36.53, 36.12, 32.86.



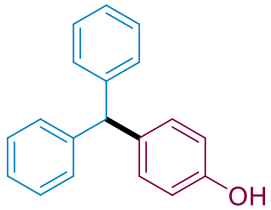
Compound **3d** was synthesized according to the general procedure B in THF in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanethiol at 40 °C for 4 h. The product was isolated with minor impurities in 81% yield as colorless oil (49 mg, 0.202 mmol). Flash column chromatography eluent: 8% EtOAc in petroleum ether. Finer purification was performed by preparative TLC (5% EtOAc in petroleum ether). R_f = 0.42 (20% EtOAc in petroleum ether). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 – 7.37 (m, 2H), 7.36 – 7.25 (m, 5H), 6.92 – 6.86 (m, 2H), 5.06 (s, 1H), 3.79 (s, 2H), 2.96 (m, 2H), 2.78 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.62, 140.68, 130.63, 130.27, 128.62, 128.58, 126.45, 115.49, 36.15, 35.93, 32.82. HRMS (HESI) m/z: $[M-H]^-$ calcd for $C_{15}H_{15}OS$ 243.0844; found 243.0847.



Compound **3e** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-cyclohexanethiol at 100 °C for 24 h. NMR yield: 90%. The product was purified by preparative TLC (100% petroleum ether) as colorless waxy solid. R_f = 0.74 (10% EtOAc in petroleum ether). Analytical data matches with reported literature.[28] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.34 – 7.28 (m, 4H), 7.23 (m, 1H), 3.74 (s, 2H), 2.56 (tt, *J* = 10.5, 3.6 Hz, 1H), 1.99 – 1.90 (m, 2H), 1.75 (m, 2H), 1.63 – 1.51 (m, 2H), 1.39 – 1.20 (m, 4H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 139.10, 128.90, 128.58, 126.91, 43.06, 34.74, 33.52, 26.14, 26.01.

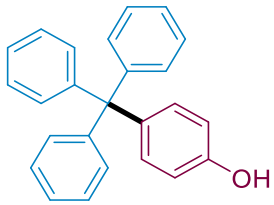


Compound **3f** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-methyl-2-propanethiol at 100 °C for 24 h. NMR yield: 46%. The product was purified by preparative TLC (100% petroleum ether) as colorless oil. R_f = 0.74 (10% EtOAc in petroleum ether). Analytical data matches with reported literature.[29] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 – 7.33 (m, 2H), 7.29 (ddd, *J* = 7.8, 6.7, 1.3 Hz, 2H), 7.24 – 7.19 (m, 1H), 3.77 (s, 2H), 1.36 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.74, 129.10, 128.60, 126.91, 77.48, 77.16, 76.84, 43.02, 33.58, 31.06.

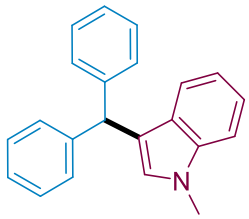


Compound **4a** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of phenol at 60 °C for 18 h. NMR yield: 65%. Alternatively, compound **4a** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of phenol at 60 °C for 0.75 h. The product was isolated as white solid in 46% yield (30 mg, 0.115 mmol **4a**). Flash column chromatography eluent: 10%-15% EtOAc in petroleum ether. R_f=0.36 (10% EtOAc in pentane). Analytical data matches with reported literature.[30] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.27 – 7.24 (m, 4H), 7.22 – 7.15 (m, 2H), 7.13

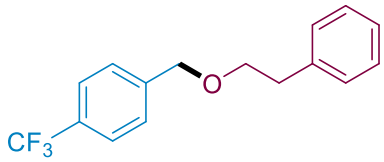
– 7.06 (m, 4H), 7.00 – 6.87 (m, 2H), 6.76 – 6.67 (m, 2H), 5.47 (s, 1H), 4.98 (s, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 154.00, 144.32, 136.41, 130.71, 129.50, 128.42, 126.37, 115.27, 56.12.



Compound **4b** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of phenol at 60 °C for 0.75 h. The product was isolated as white solid in 29% yield (24 mg, 0.071 mmol **4b**). Flash column chromatography eluent: 5%-20% EtOAc in petroleum ether. R_f=0.27 (10% EtOAc in pentane). Analytical data matches with reported literature.[31] ^{1}H NMR (400 MHz, acetone-d_6) δ 8.31 (s, 1H), 7.33 – 7.24 (m, 6H), 7.23 – 7.15 (m, 9H), 7.03 – 6.97 (m, 2H), 6.78 – 6.72 (m, 2H). ^{13}C NMR (125 MHz, acetone-d_6) δ 156.37, 148.17, 138.50, 132.96, 131.83, 128.28, 126.72, 115.12, 65.10.



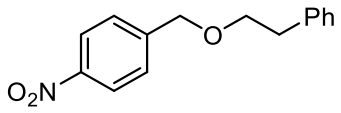
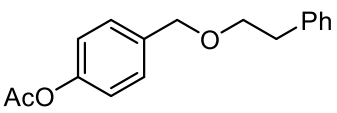
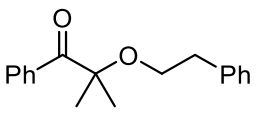
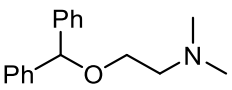
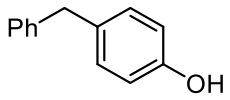
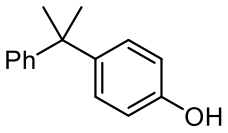
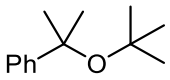
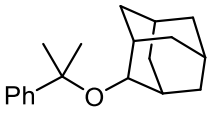
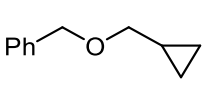
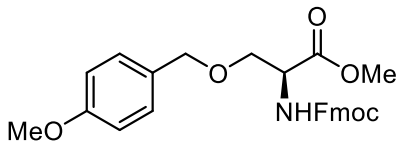
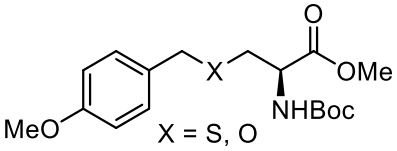
Compound **4c** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of N-methylindole at 60 °C for 18 h. NMR yield: 93% (0.232 mmol **4c**). The product was isolated as white solid by preparative TLC (2% EtOAc in petroleum ether). R_f=0.77 (10% EtOAc in pentane). Analytical data matches with reported literature.[32] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 – 7.10 (m, 13H), 6.97 (t, *J* = 7.5 Hz, 1H), 6.41 (s, 1H), 5.66 (s, 1H), 3.69 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 144.30, 137.64, 129.19, 128.91, 128.44, 127.56, 126.35, 121.81, 120.17, 119.01, 118.47, 109.29, 48.98, 32.86.

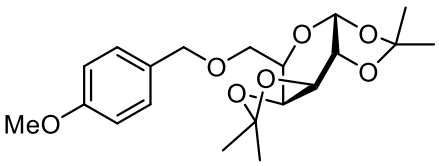
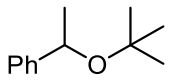
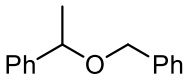


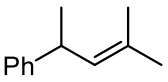
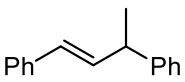
Compound **S-1** was synthesized according to the general procedure B in 0.25 mmol scale, using 1.0 mmol of 2-phenylethanol at 100 °C for 96 h. The product was isolated as colorless oil in *ca.* 5% yield by preparative TLC (3.2 mg, 0.011 mmol **S-1**, 2% EtOAc in petroleum ether). R_f=0.74 (10% EtOAc in pentane). The compound was used as reference in the kinetic analysis of the etherification of different *para*-substituted benzyl alcohols (see Section **2.8**). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.58 – 7.56 (m, 2H), 7.40 – 7.38 (m, 2H), 7.33 – 7.27 (m, 2H), 7.24 – 7.20 (m, 3H), 4.57 (s, 2H), 3.72 (t, *J* = 7.0 Hz, 2H), 2.95 (t, *J* = 7.0 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.71, 138.95, 129.08, 128.53, 127.57, 126.45, 125.45, 125.41, 72.25, 71.73, 36.50. ^{19}F NMR (376 MHz, $CDCl_3$) δ -62.48. HRMS (HESI) m/z: $[M+NH_4]^+$ calcd for $C_{16}H_{19}F_3ON$ 298.1419; found 298.1411.

5. Unsuccessful substitutions

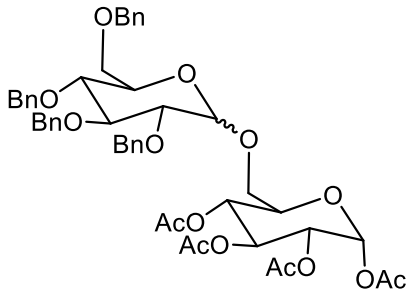
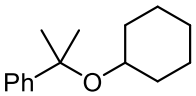
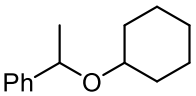
No desired product observed:

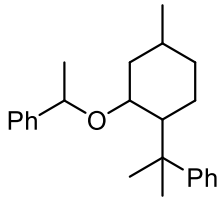
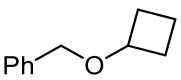
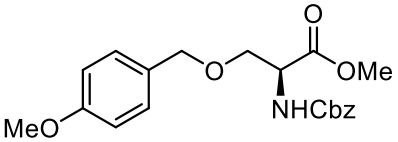












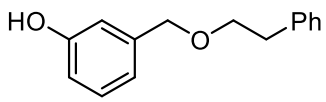
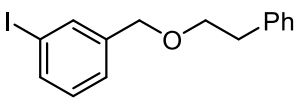




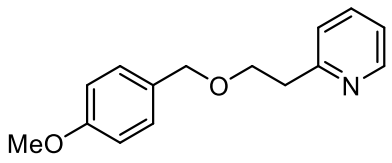
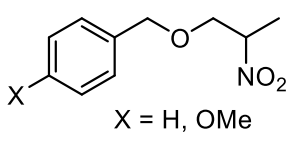
→ When reacting 1-phenylethanol with *tert*-butanol or benzyl alcohol, alkenes deriving from dehydration/addition processes[33] were observed instead of ethers, although not as the major reaction outcome:  

Traces or low amount of desired product observed:


(*ca.* 15%);  (<15%);  (<20%);


(*ca.* 15%);  (traces);  (traces);


(traces);  (<14%);


(traces); 

(traces)

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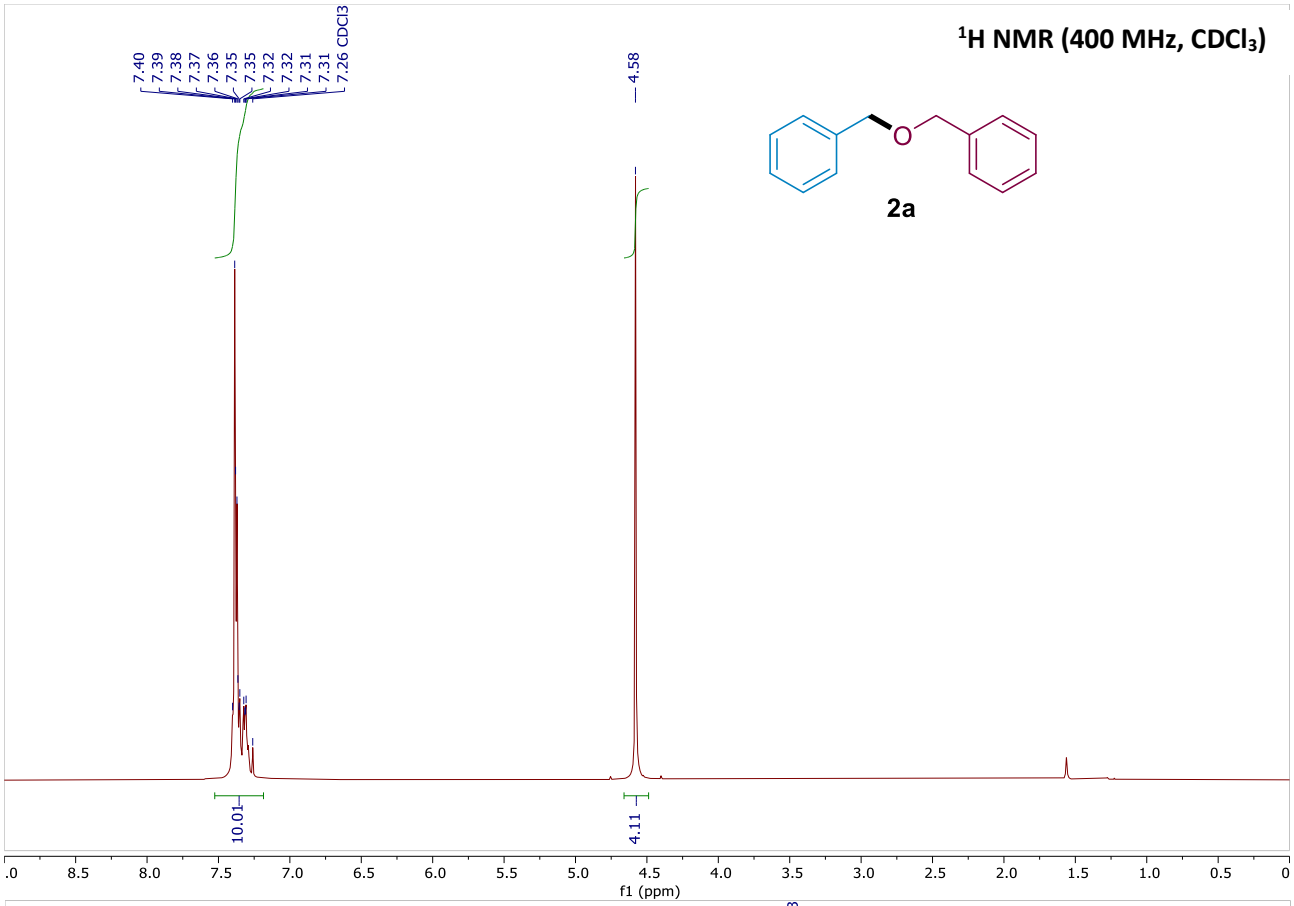
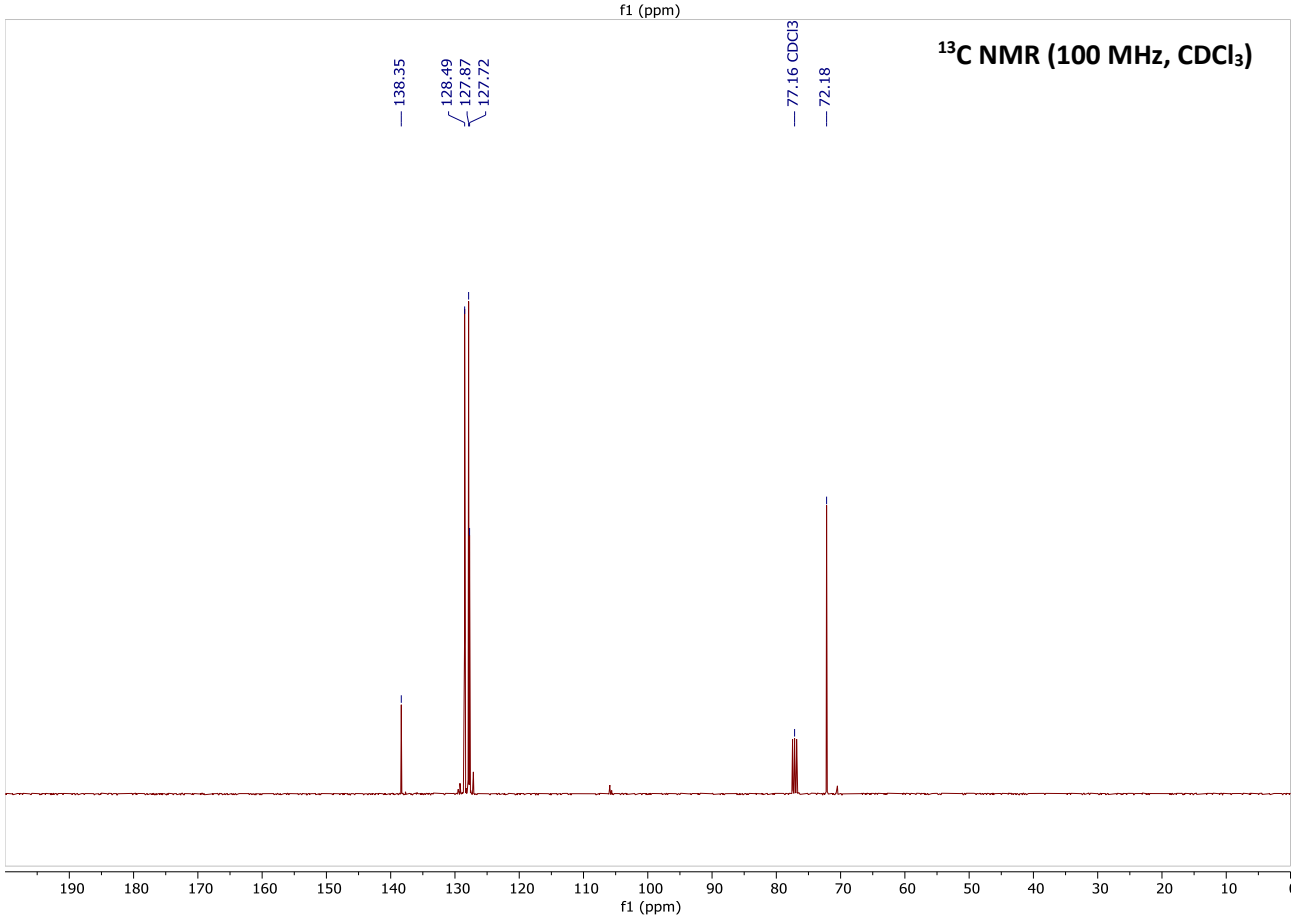
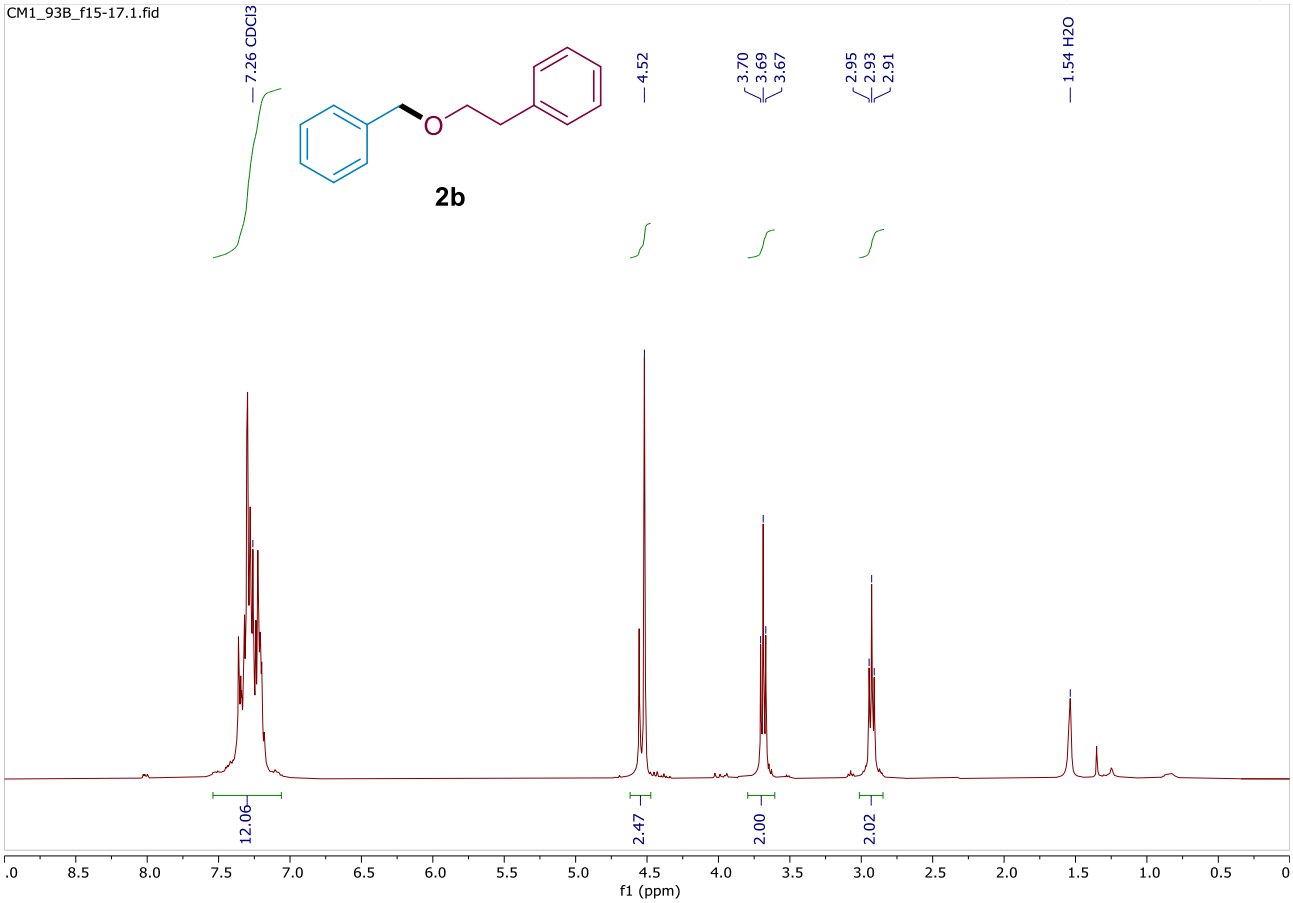
7. ^{1}H-NMR and ^{13}C-NMR spectra for compounds 2a-2y', 3a-3f, 4a-4c



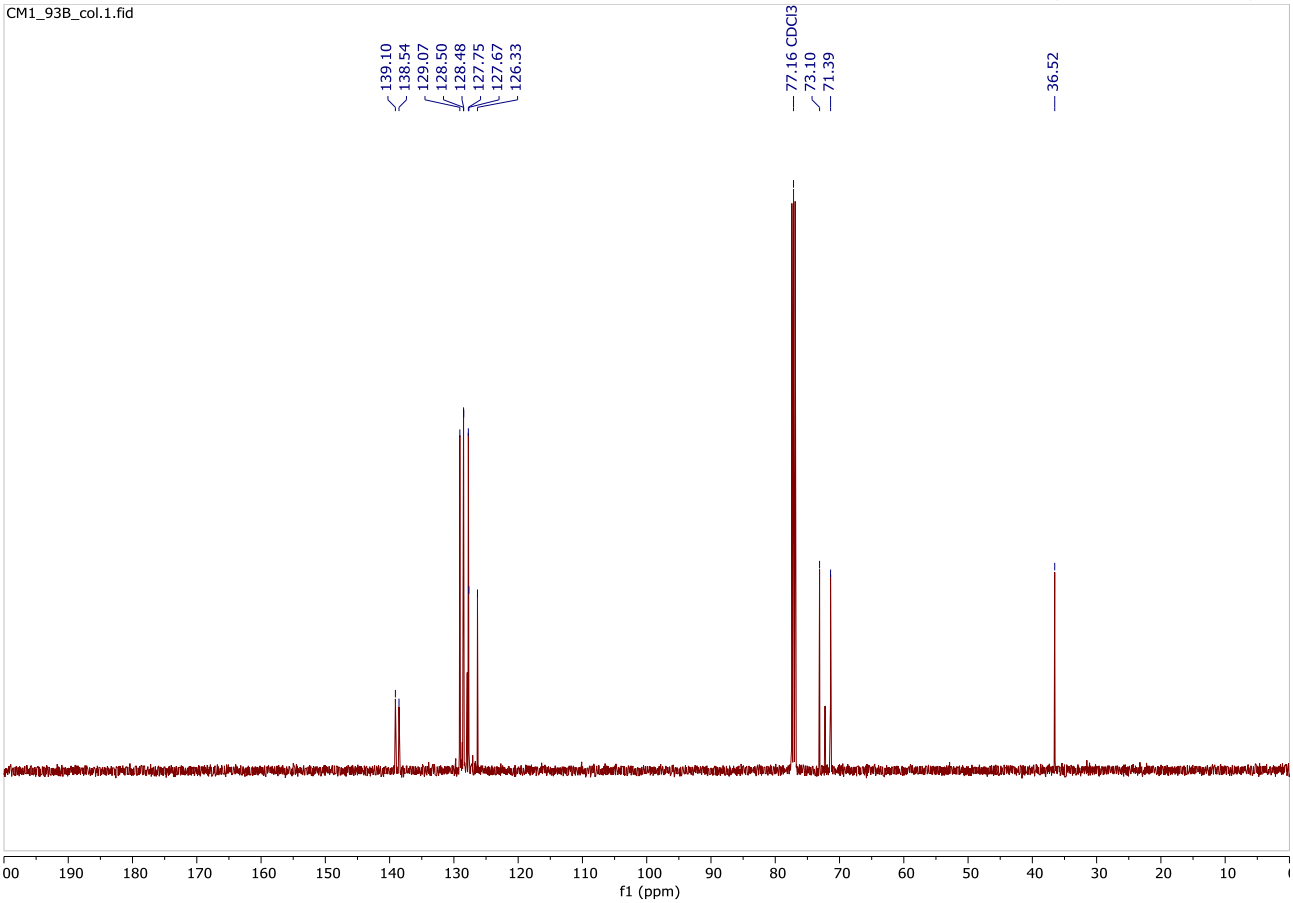


^{1}H NMR (400 MHz, $CDCl_3$)



2b

^{13}C NMR (125 MHz, $CDCl_3$)



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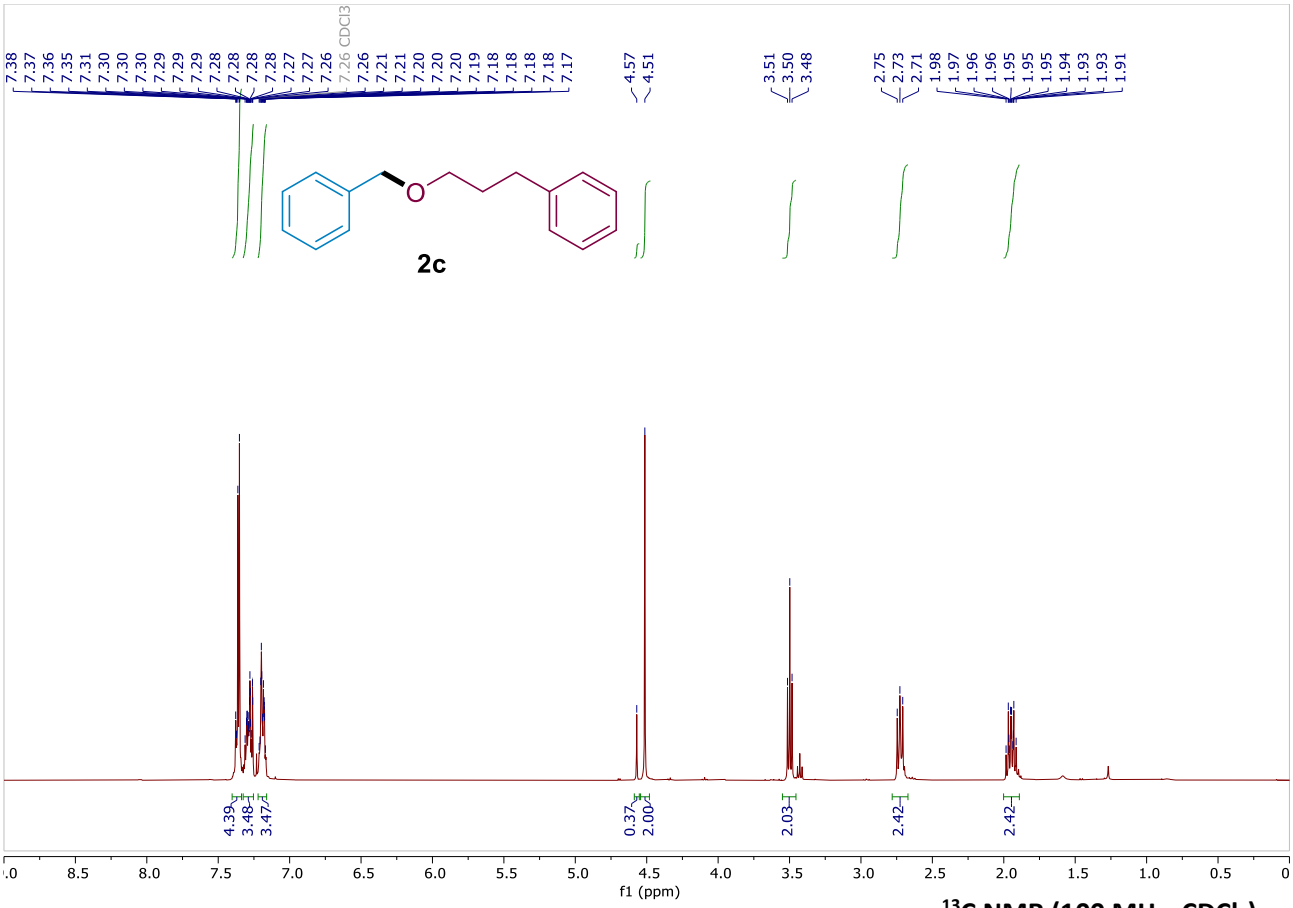

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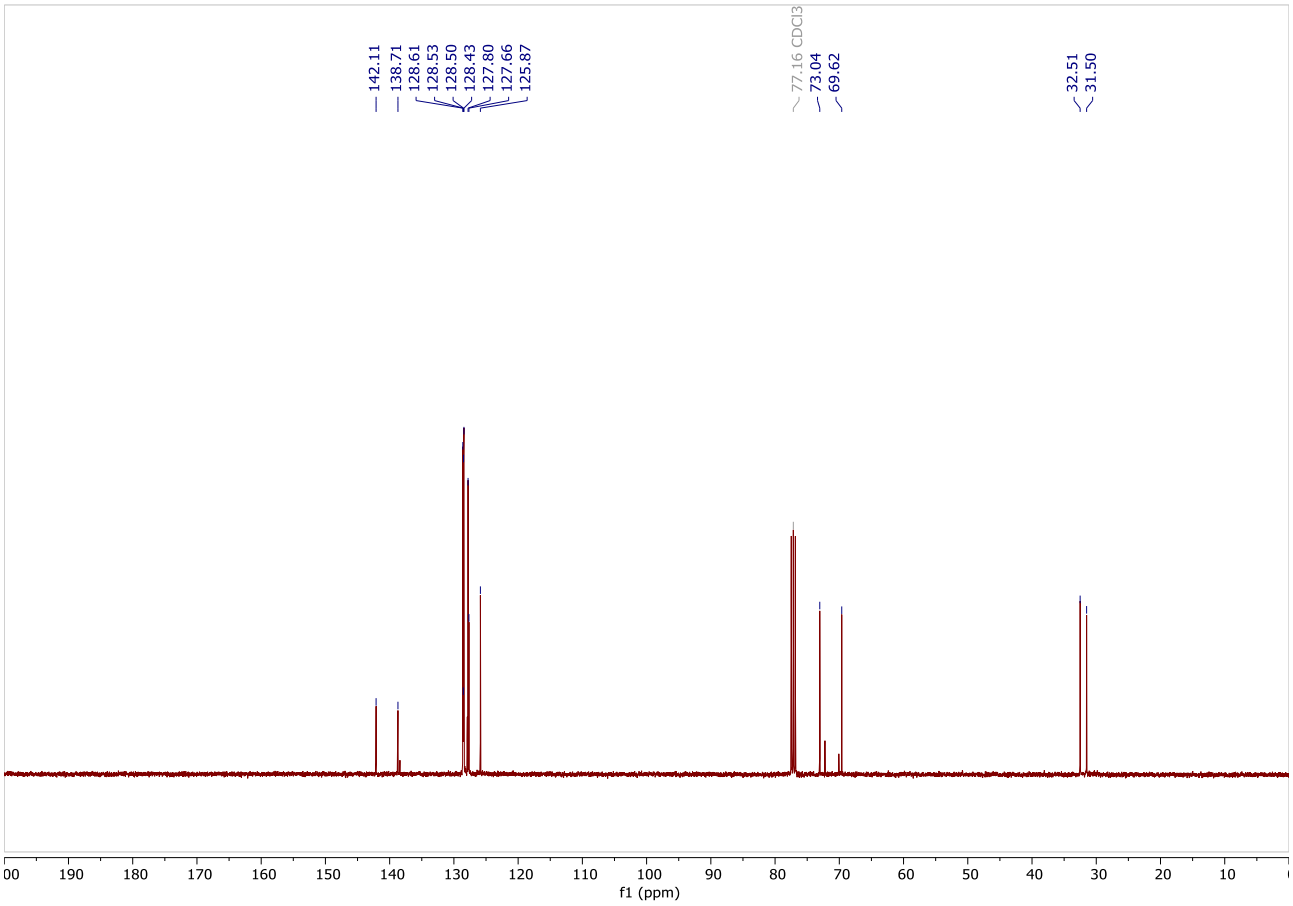

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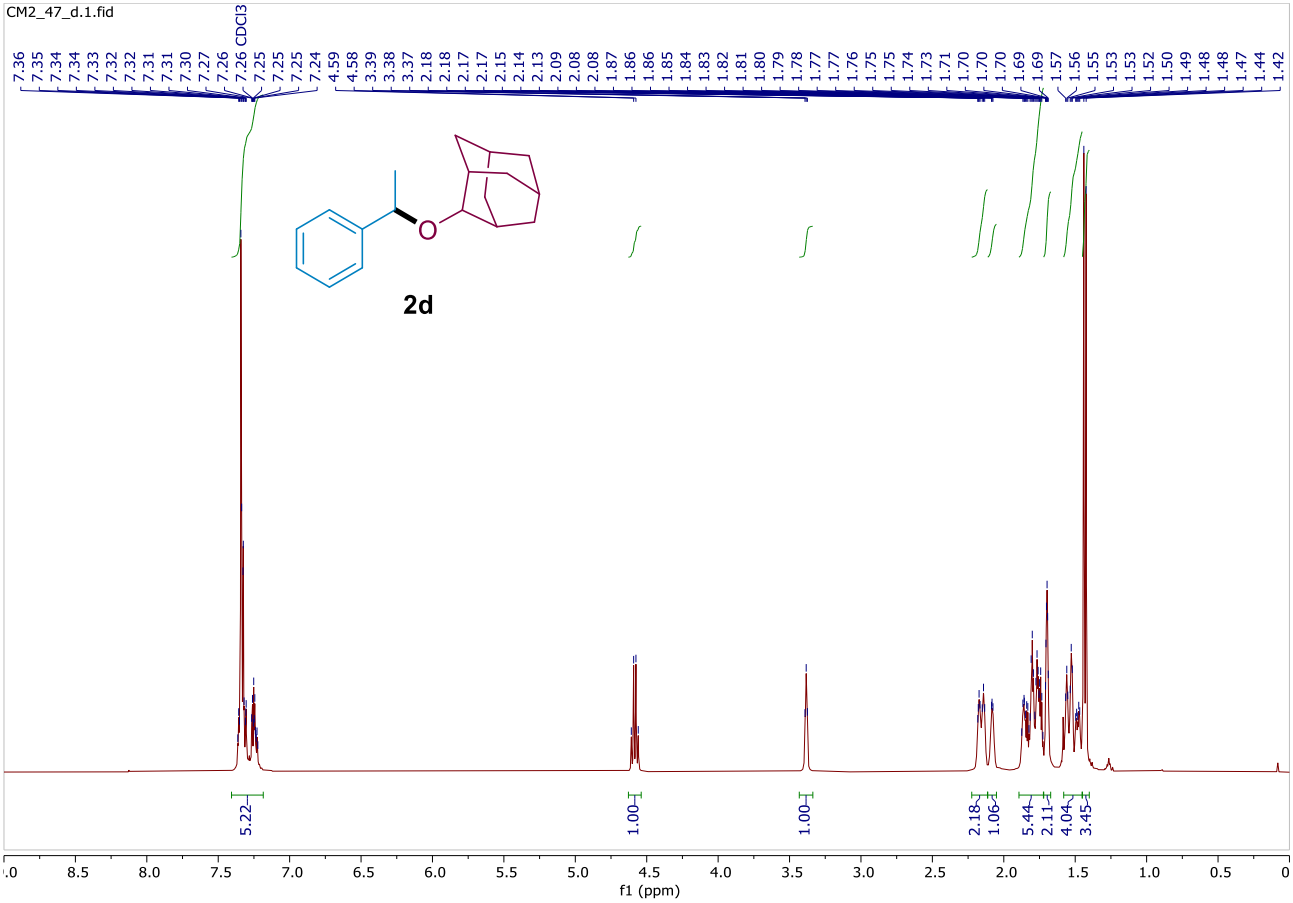

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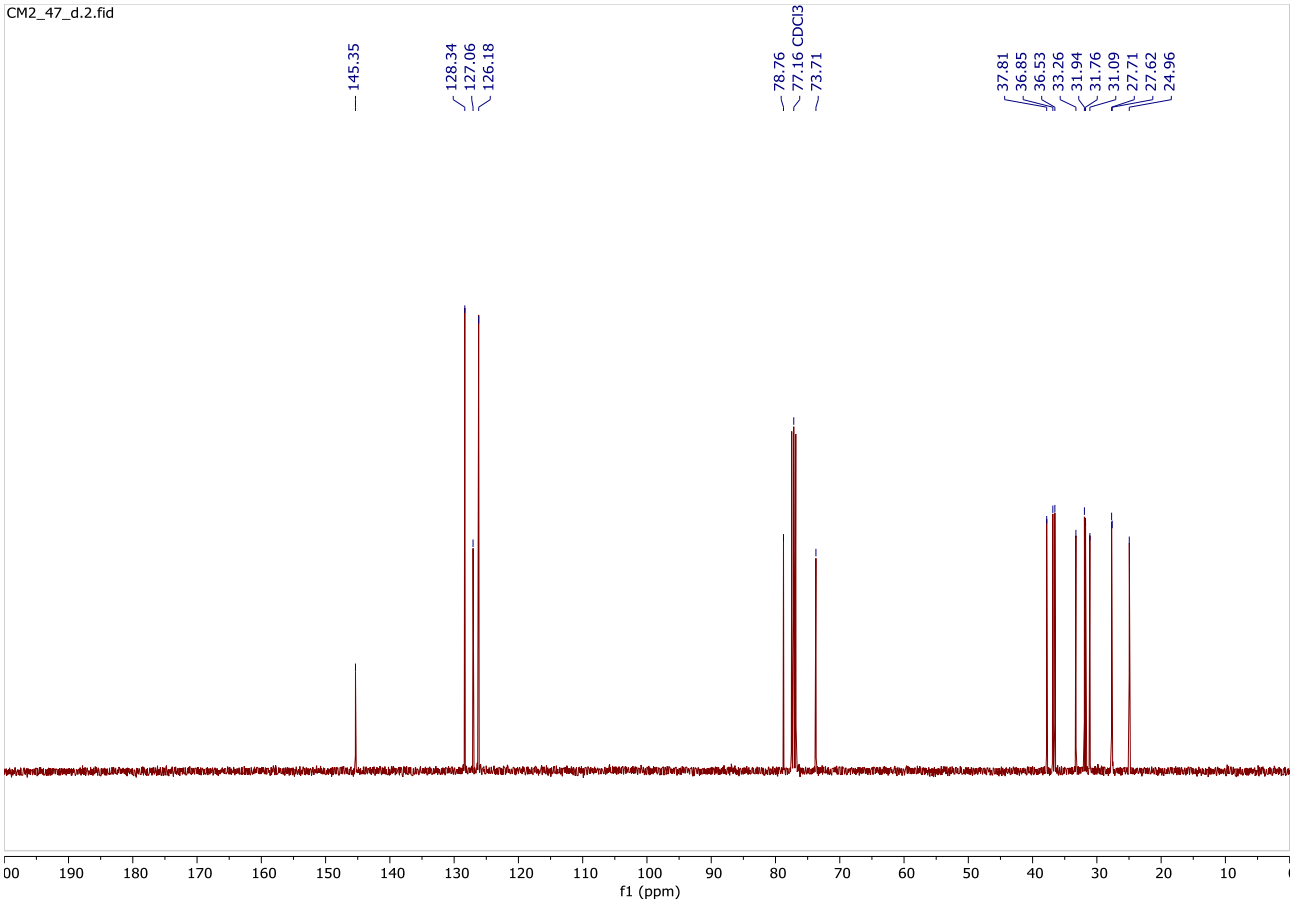

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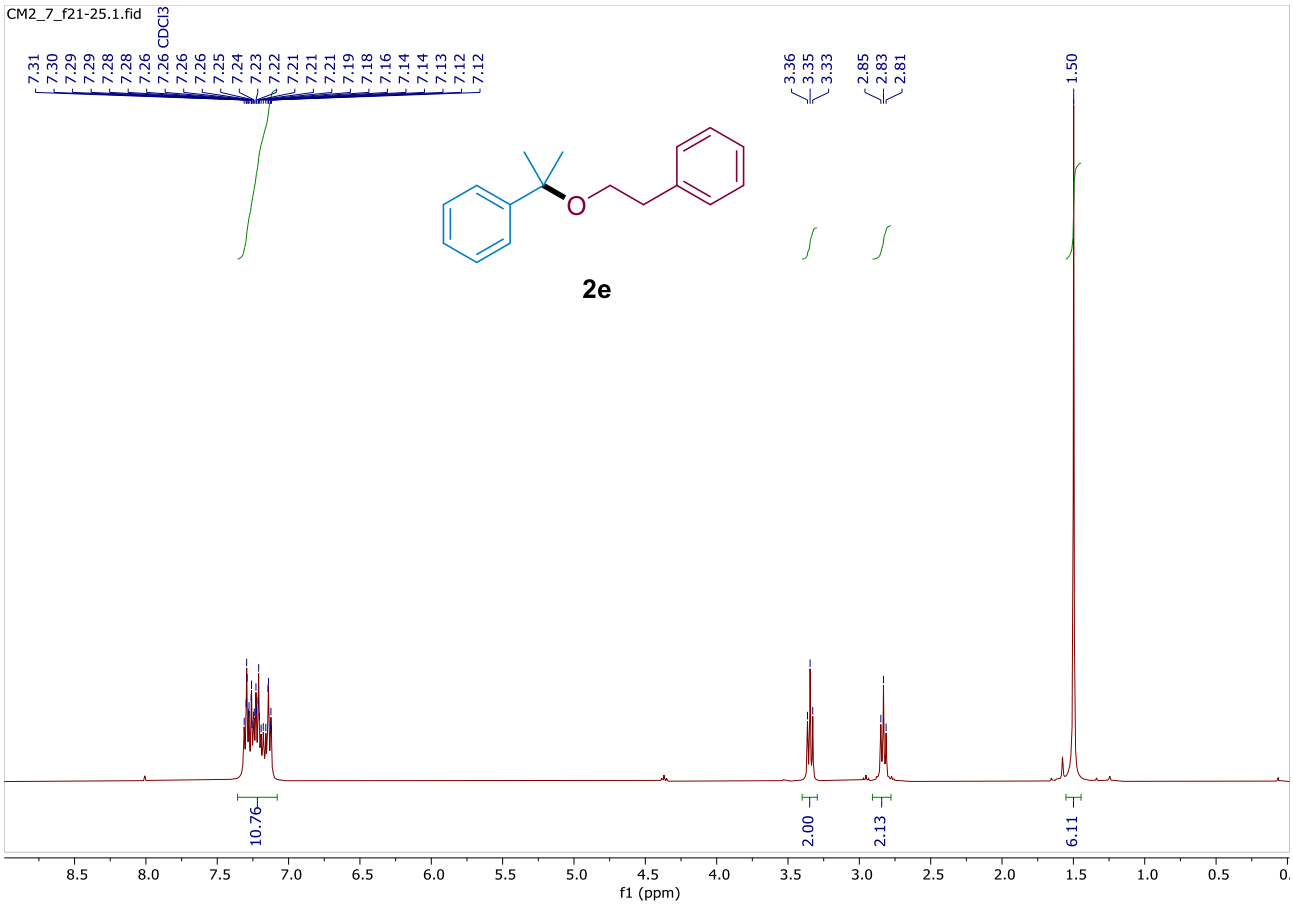
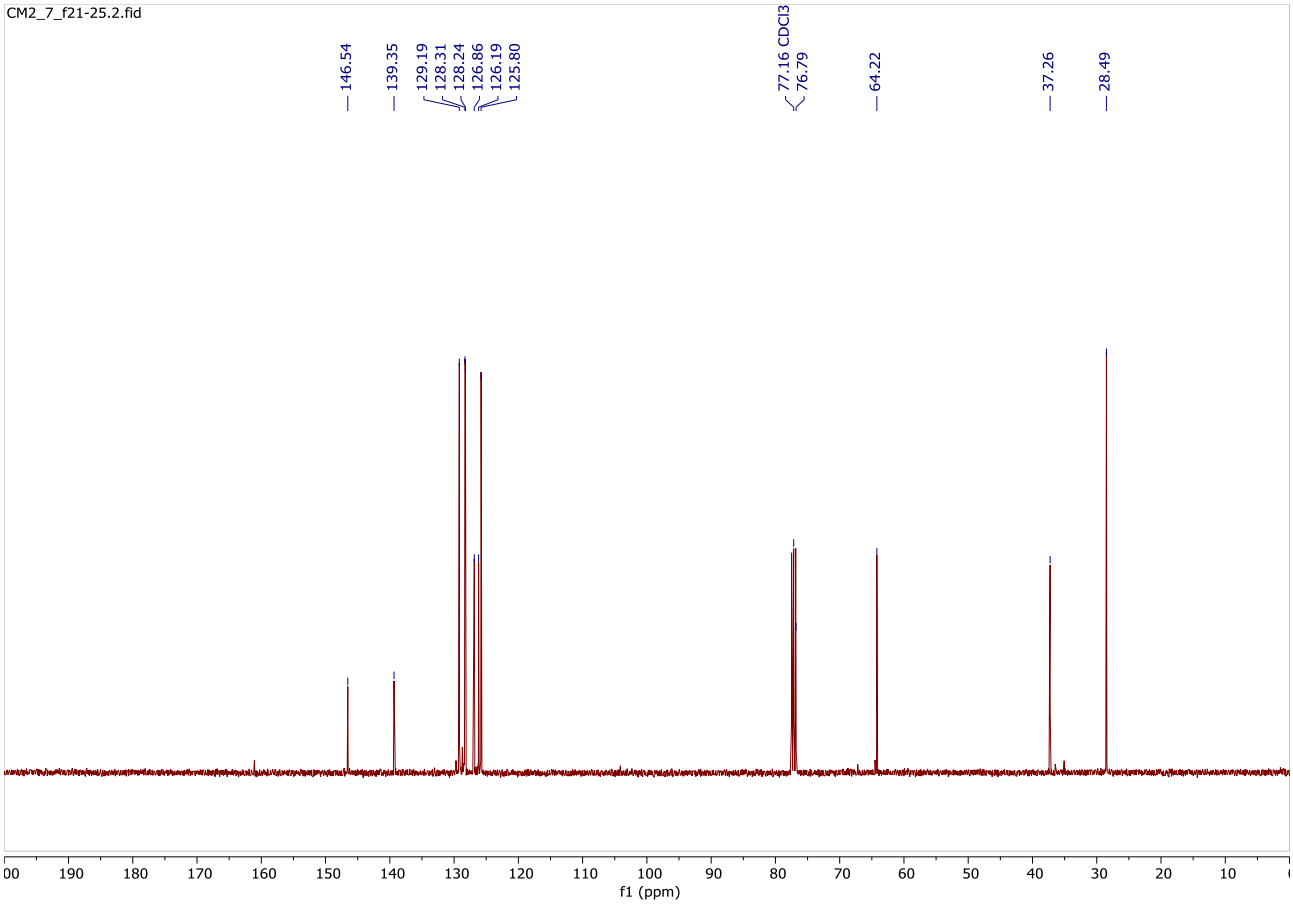


2e

^{13}C NMR (100 MHz, $CDCl_3$)



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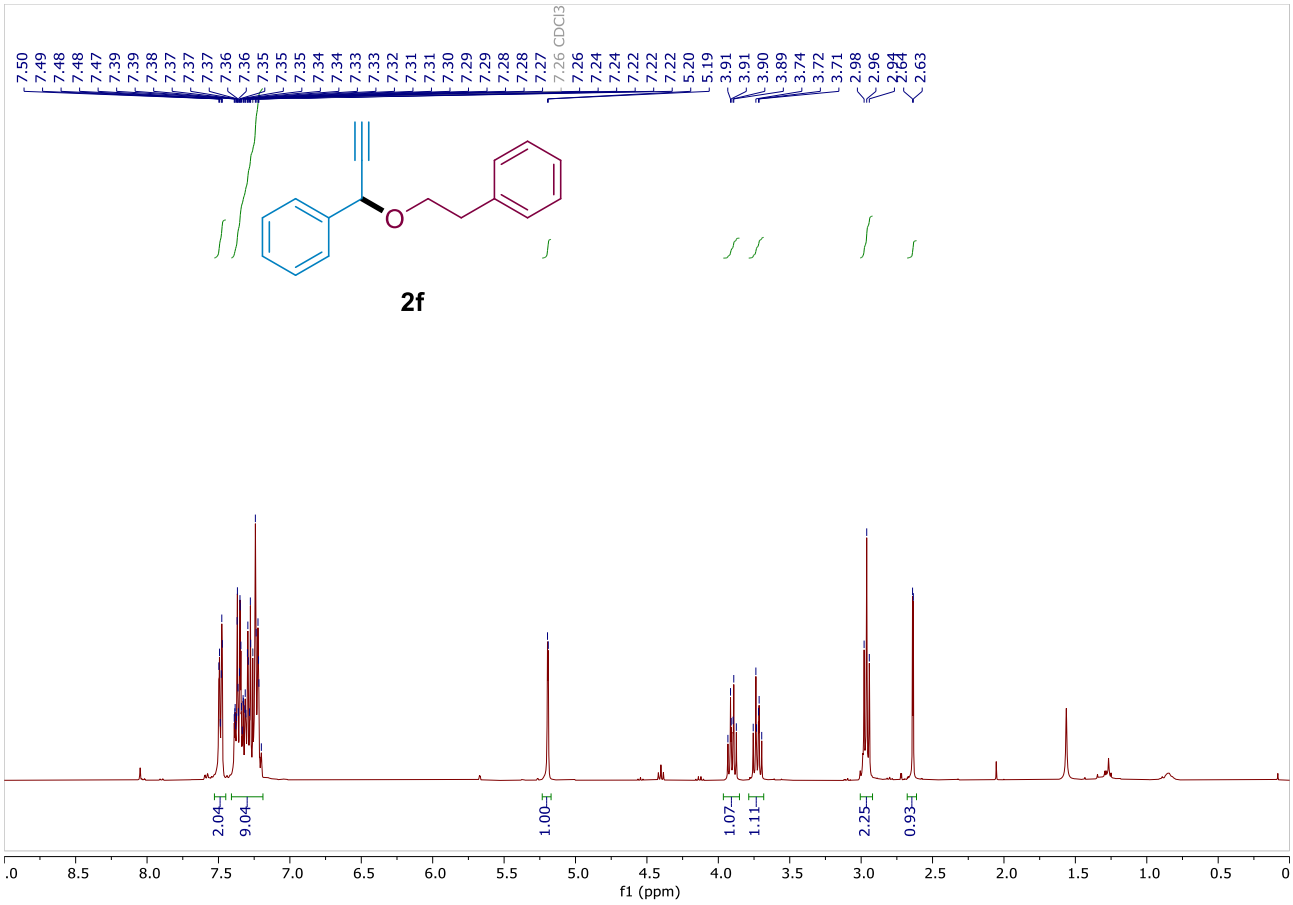

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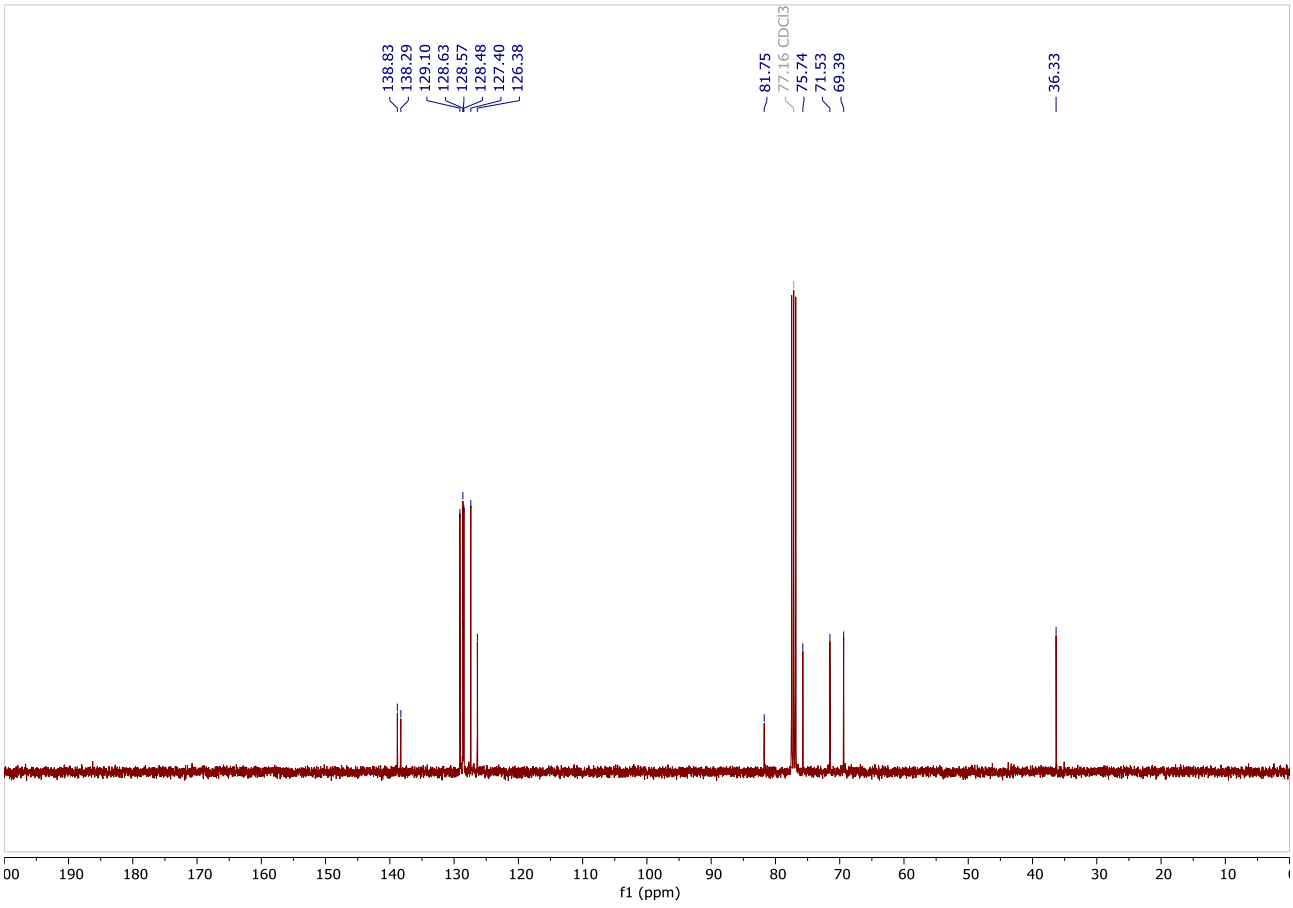

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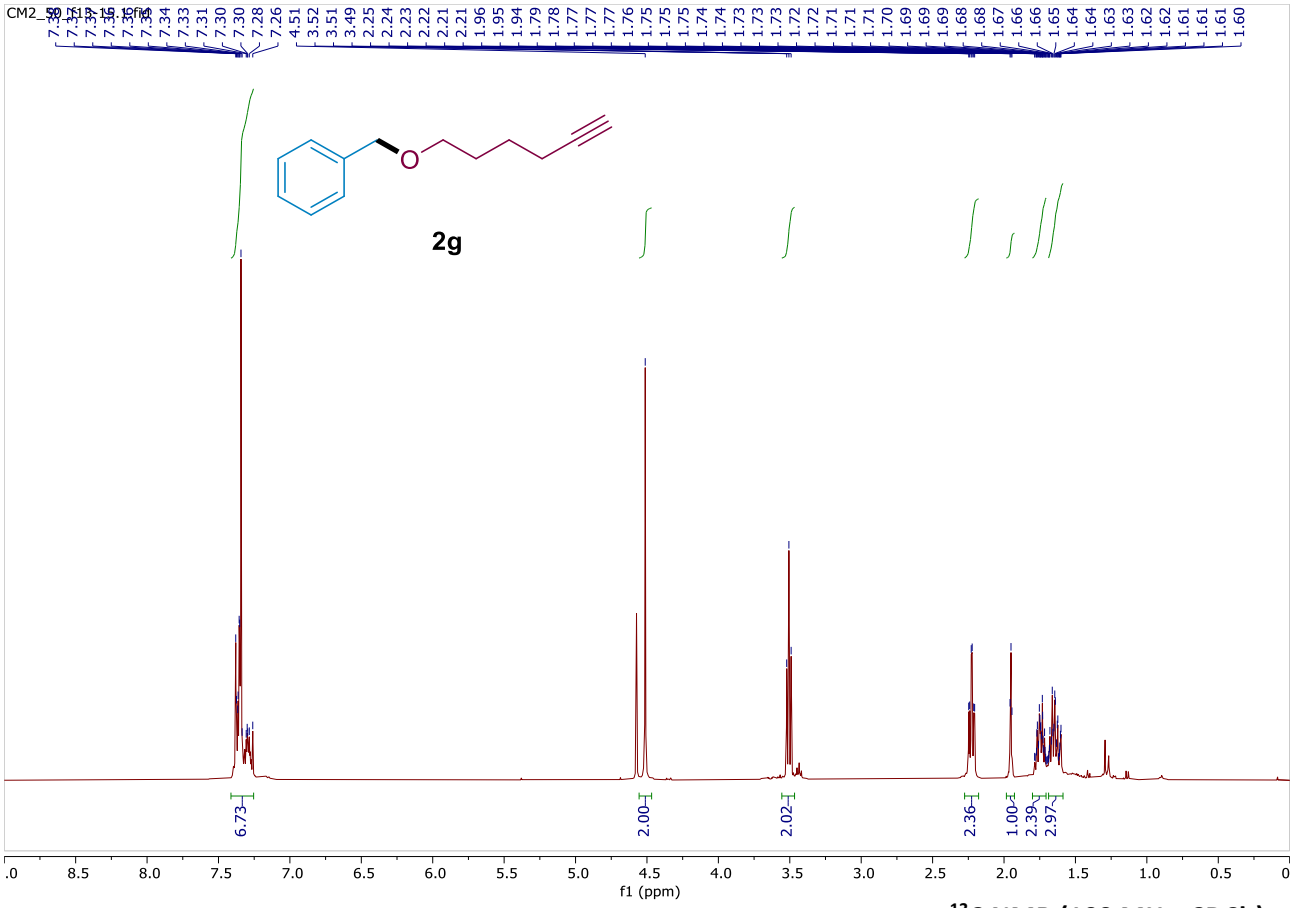

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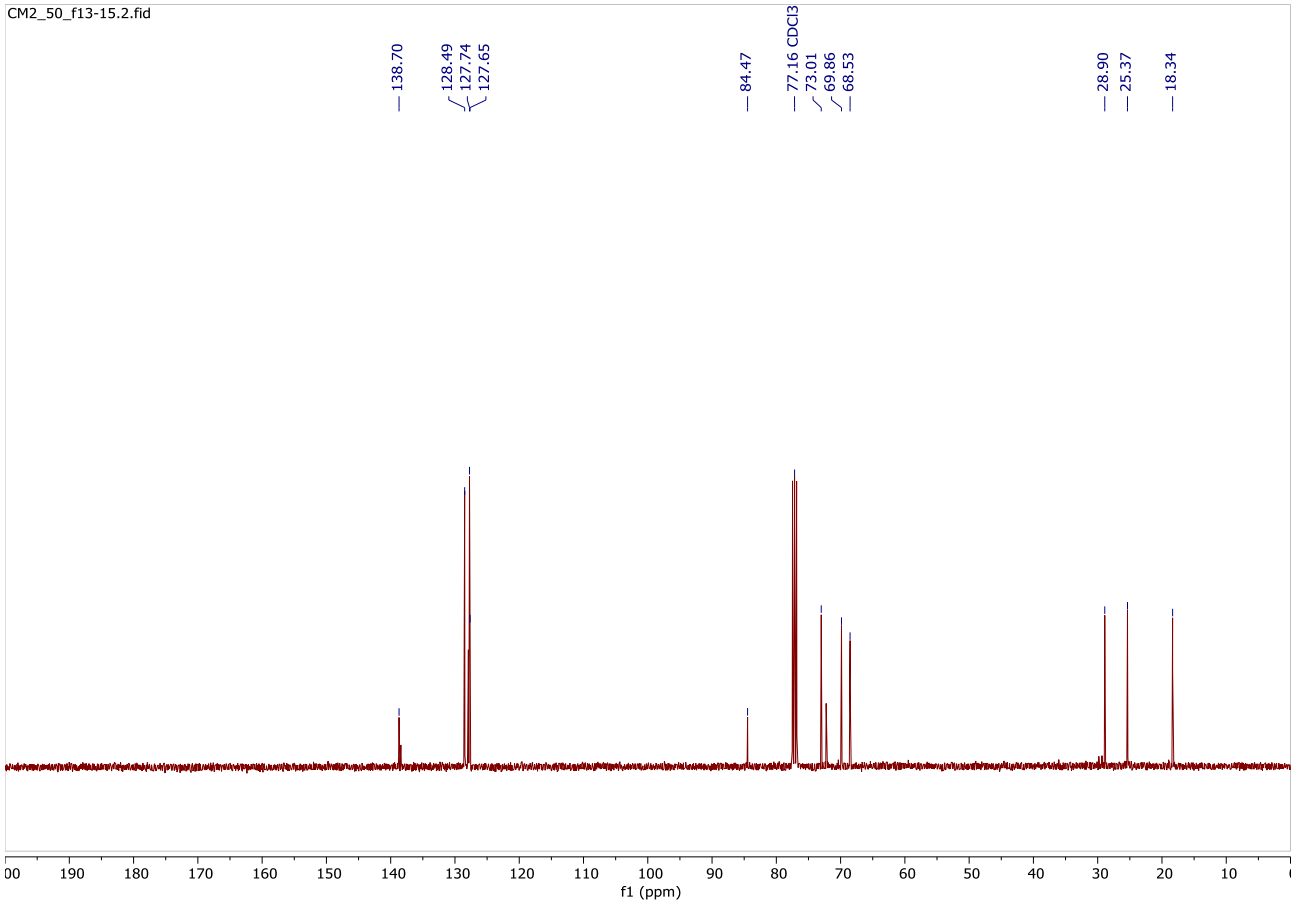

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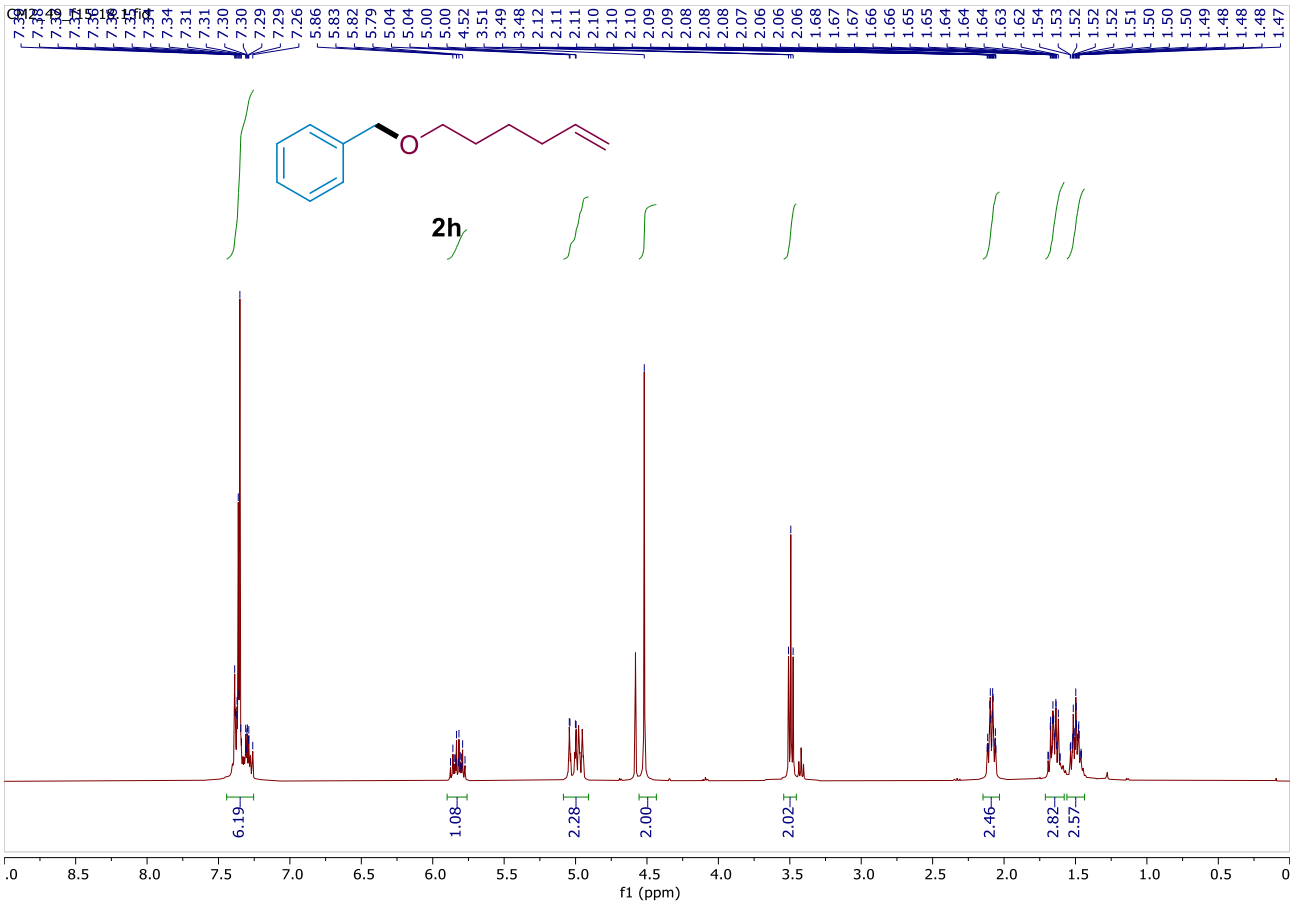
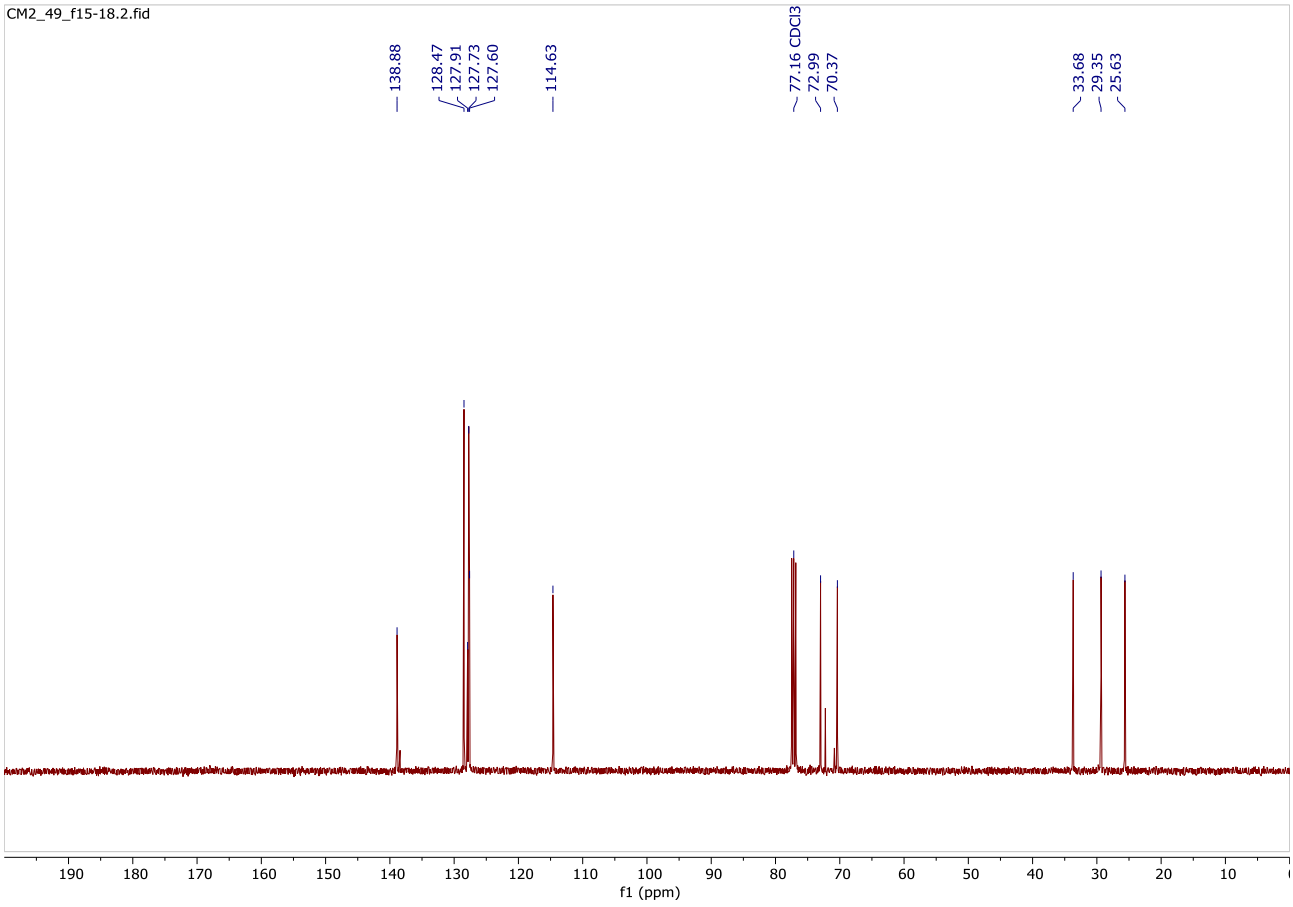
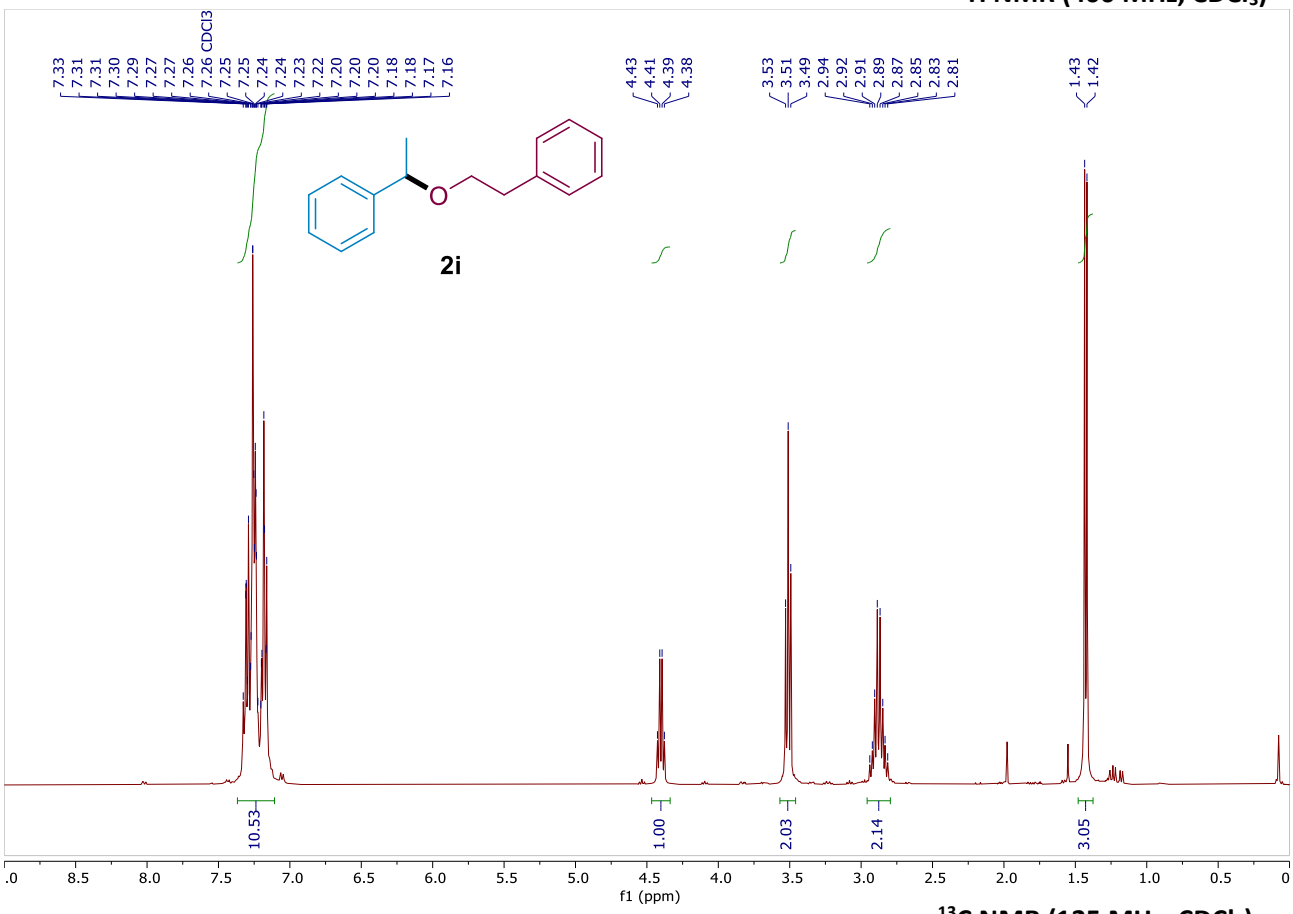


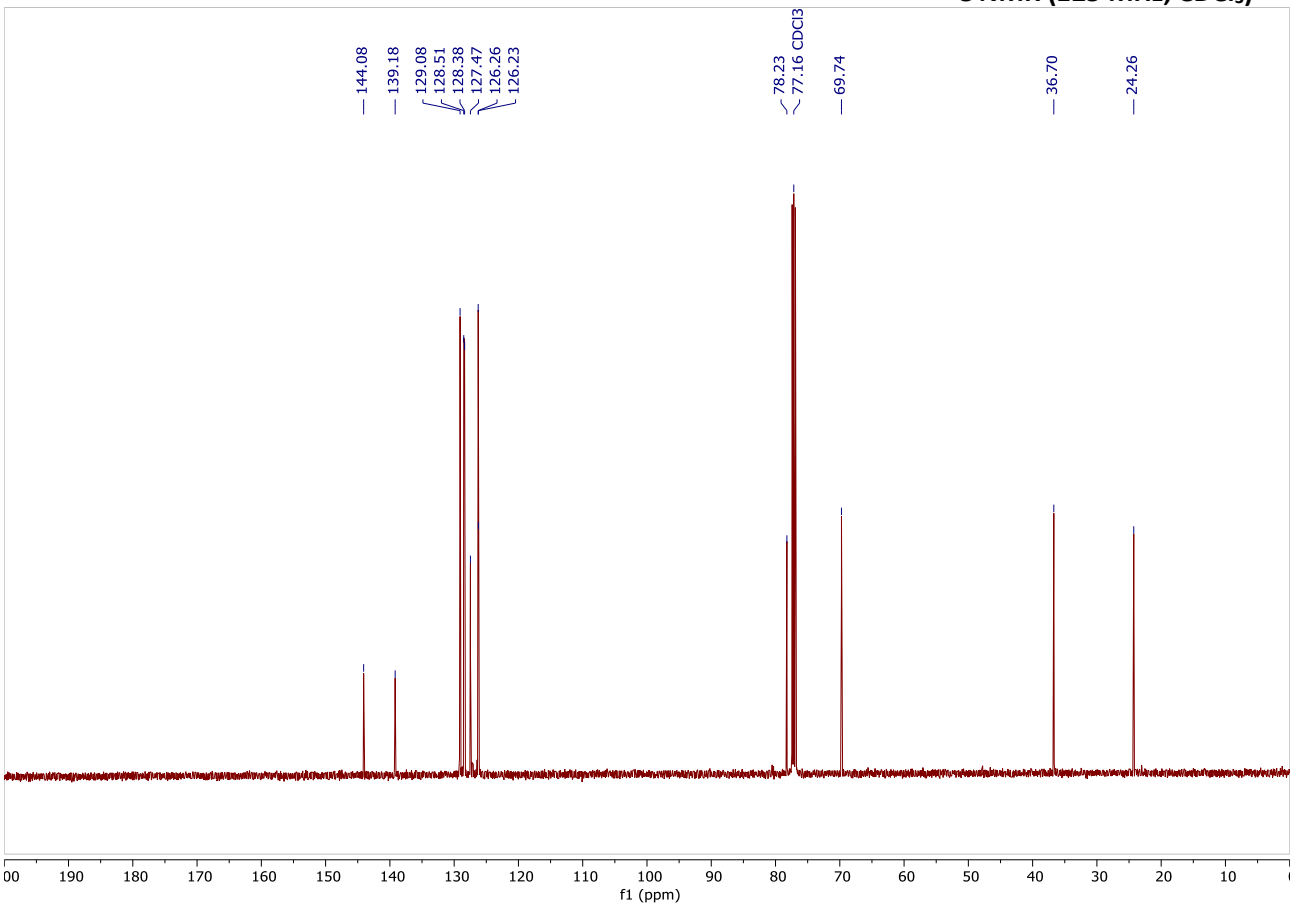
^{13}C NMR (100 MHz, $CDCl_3$)



^{1}H NMR (400 MHz, $CDCl_3$)



^{13}C NMR (125 MHz, $CDCl_3$)



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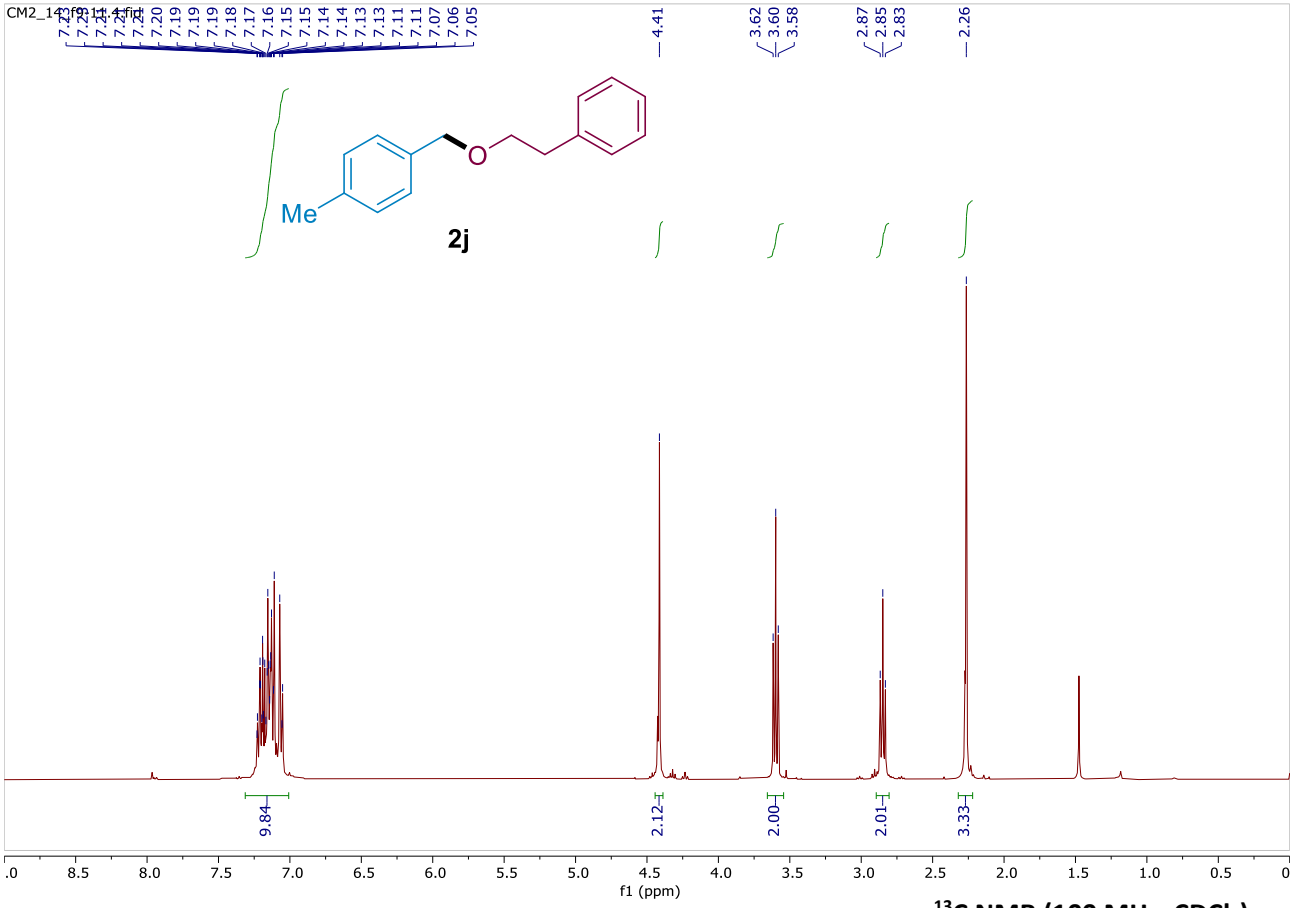

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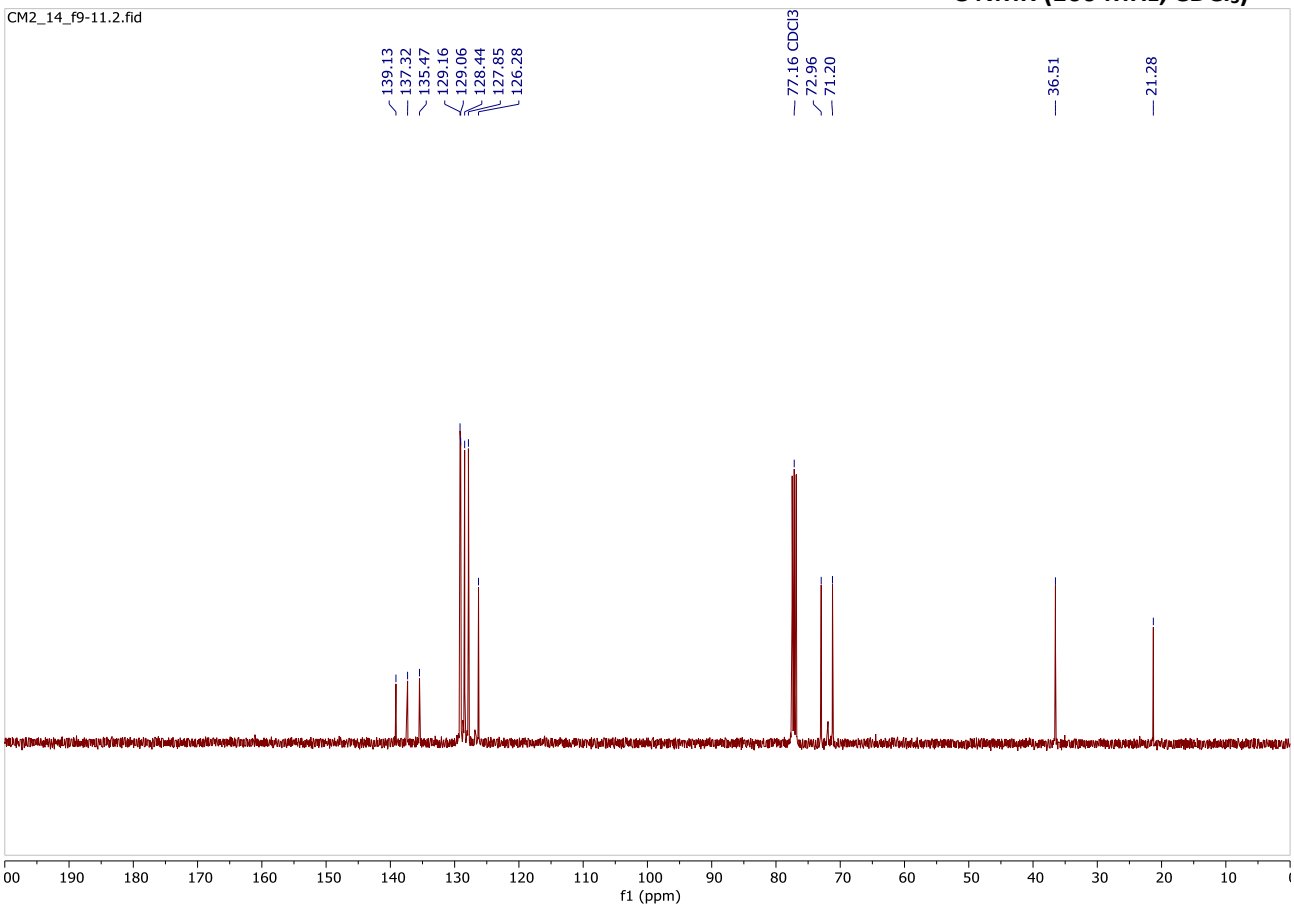

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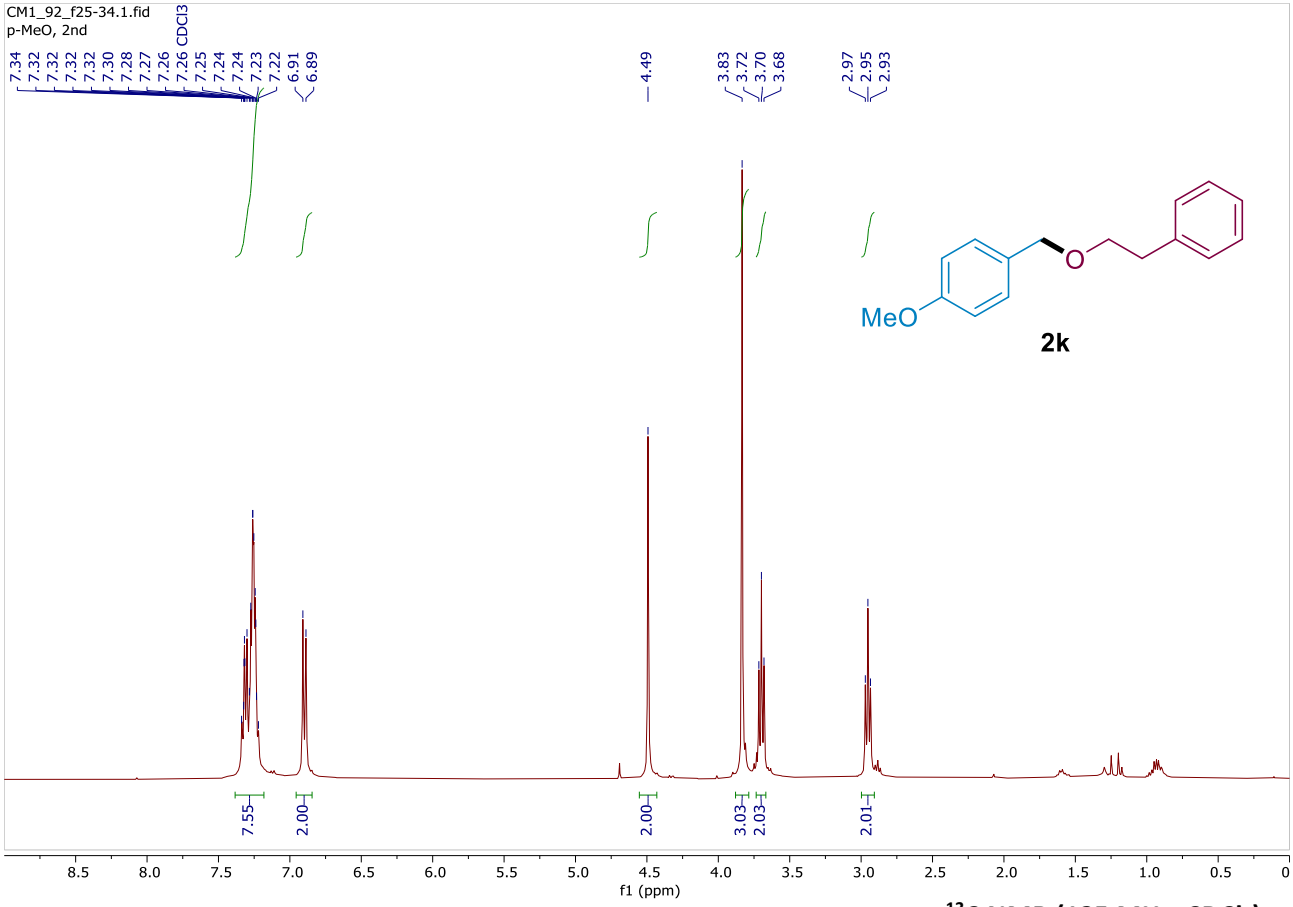
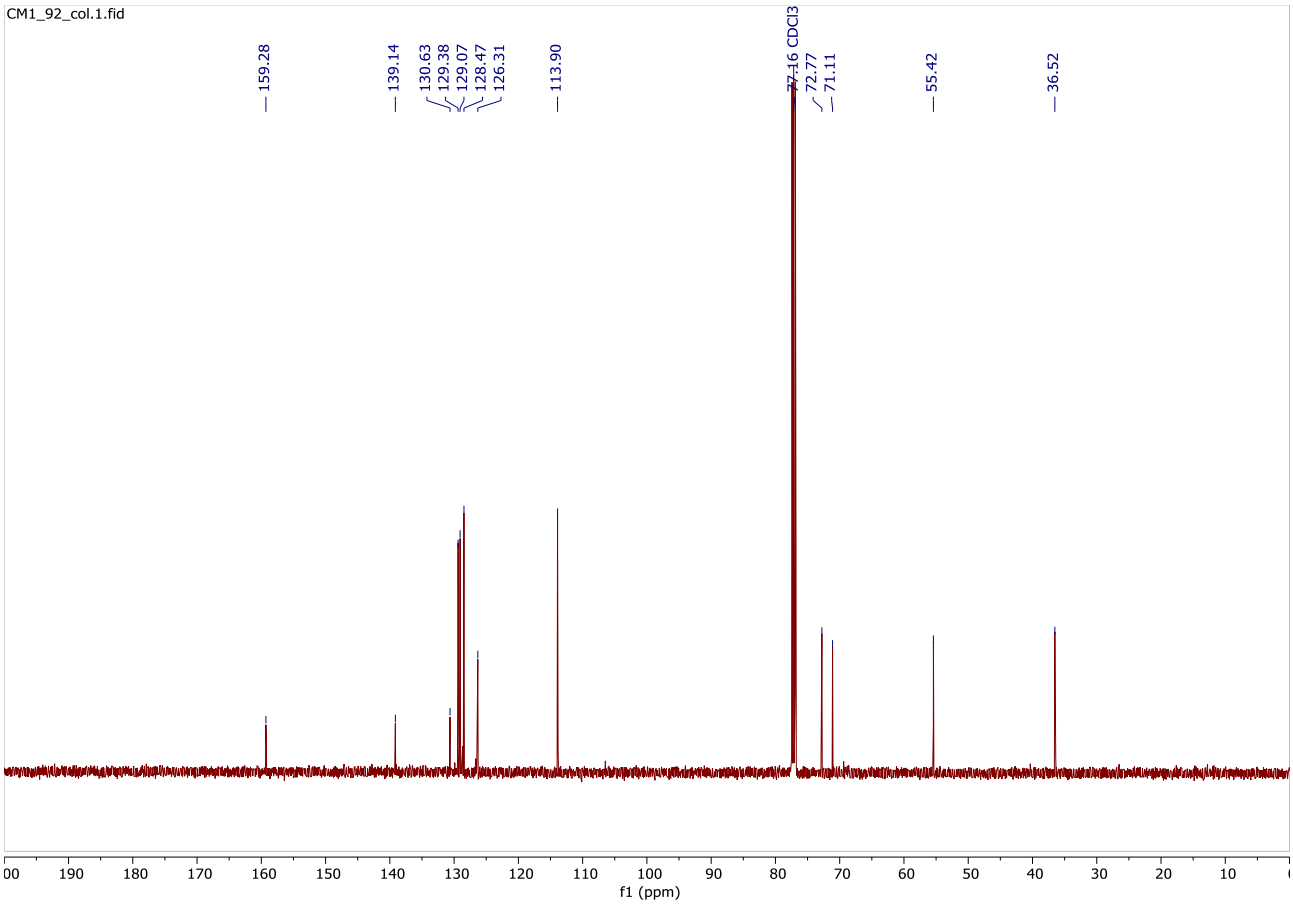
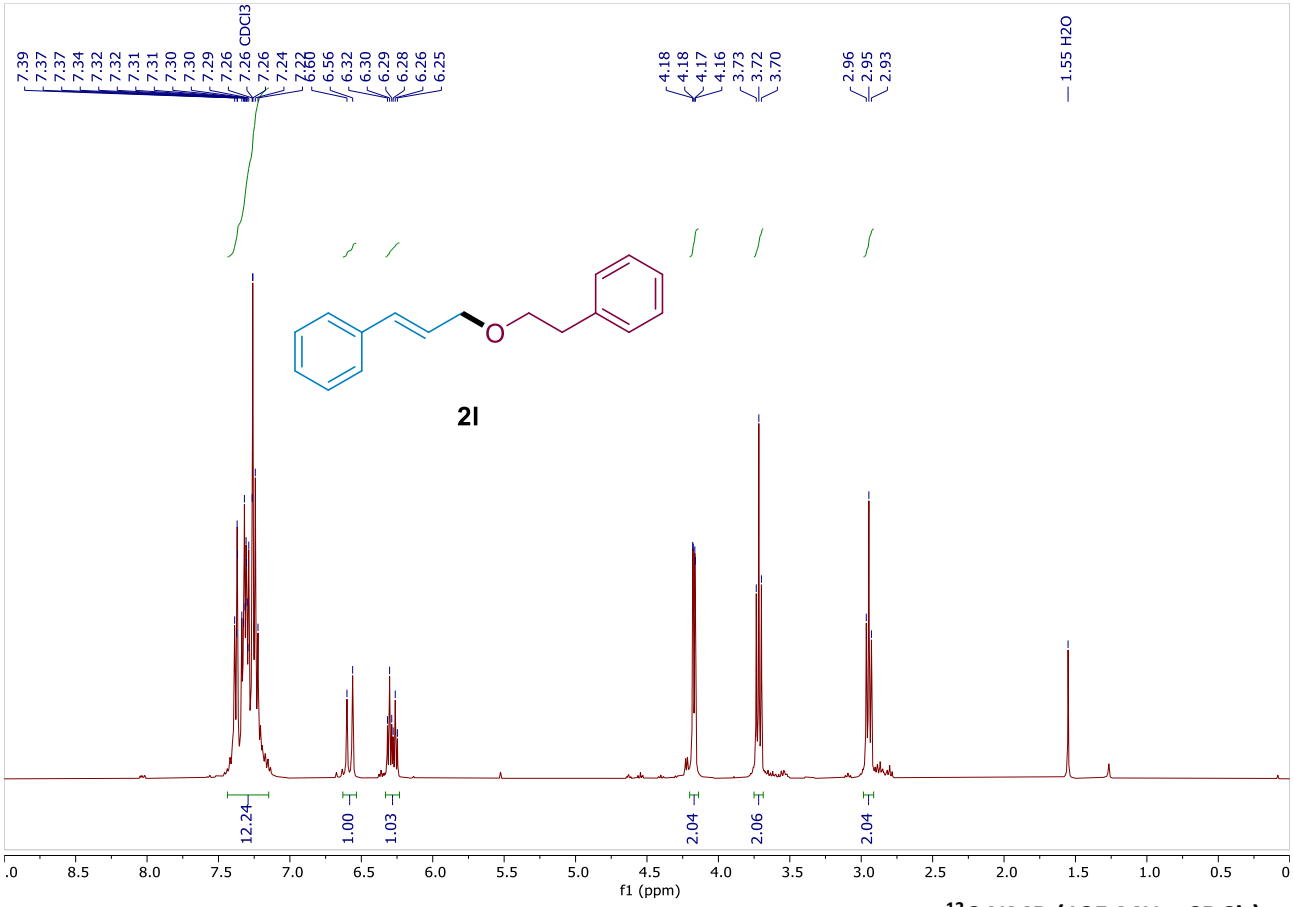


^{13}C NMR (125 MHz, $CDCl_3$)

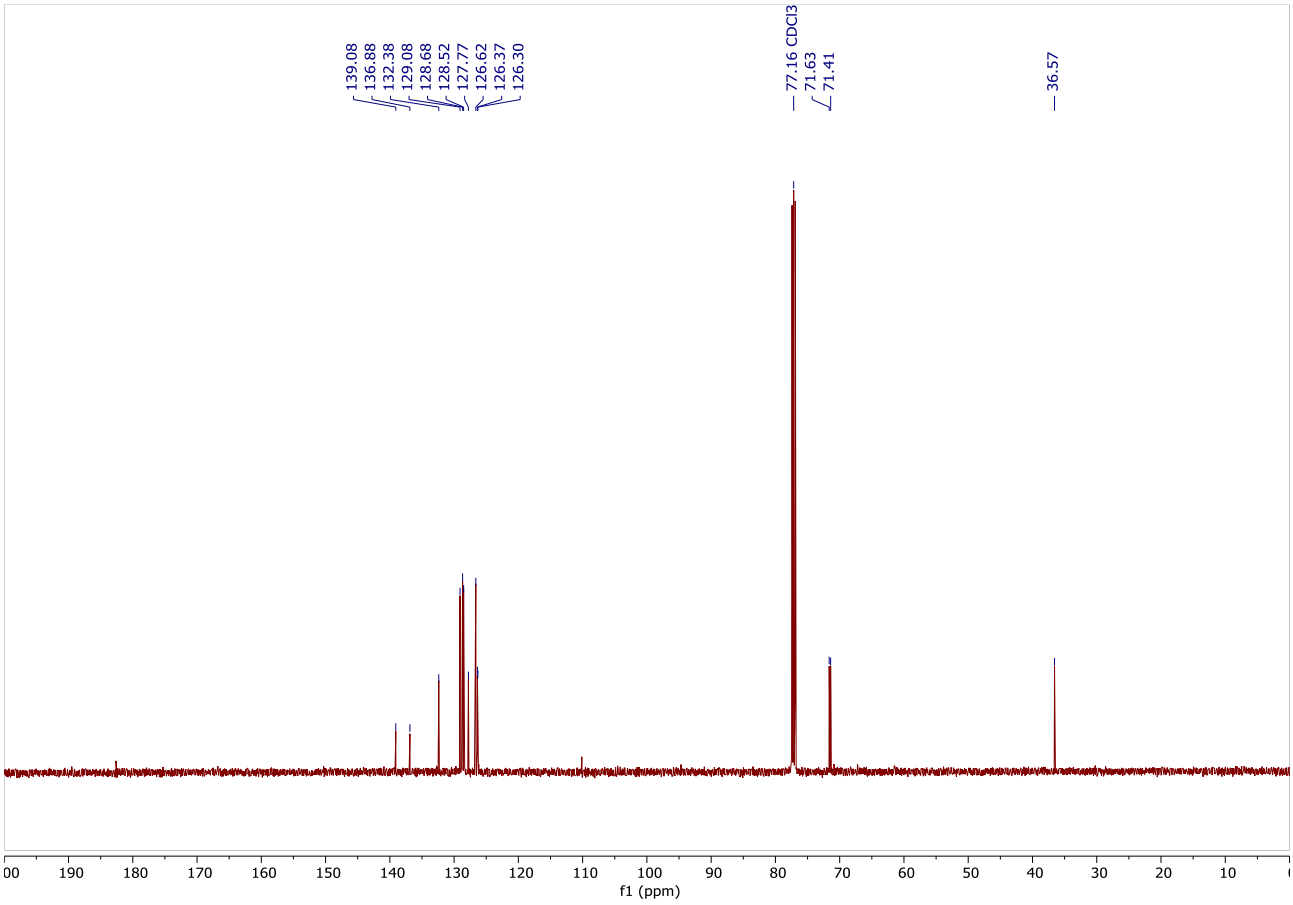


^{1}H NMR (400 MHz, $CDCl_3$)

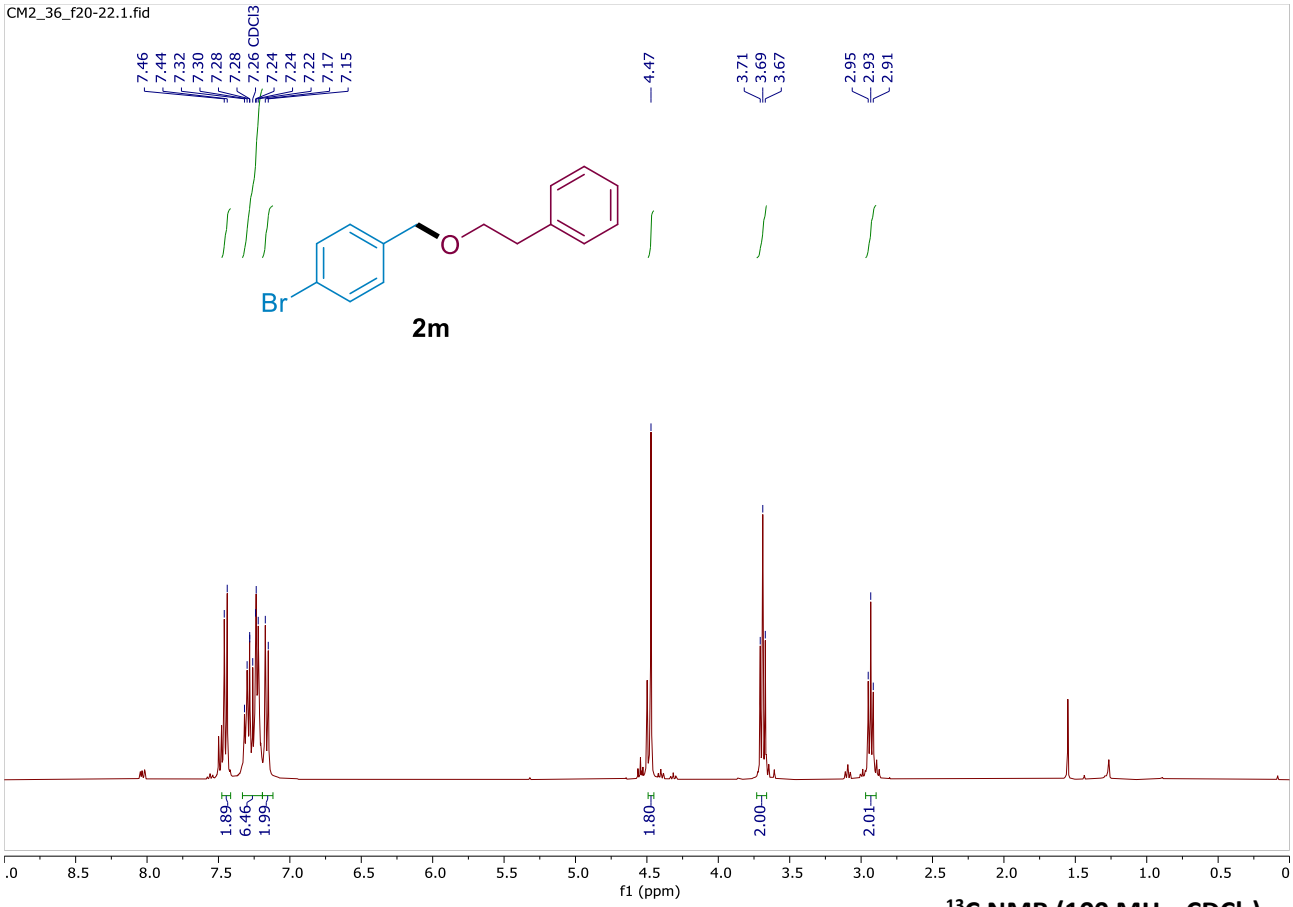


2l

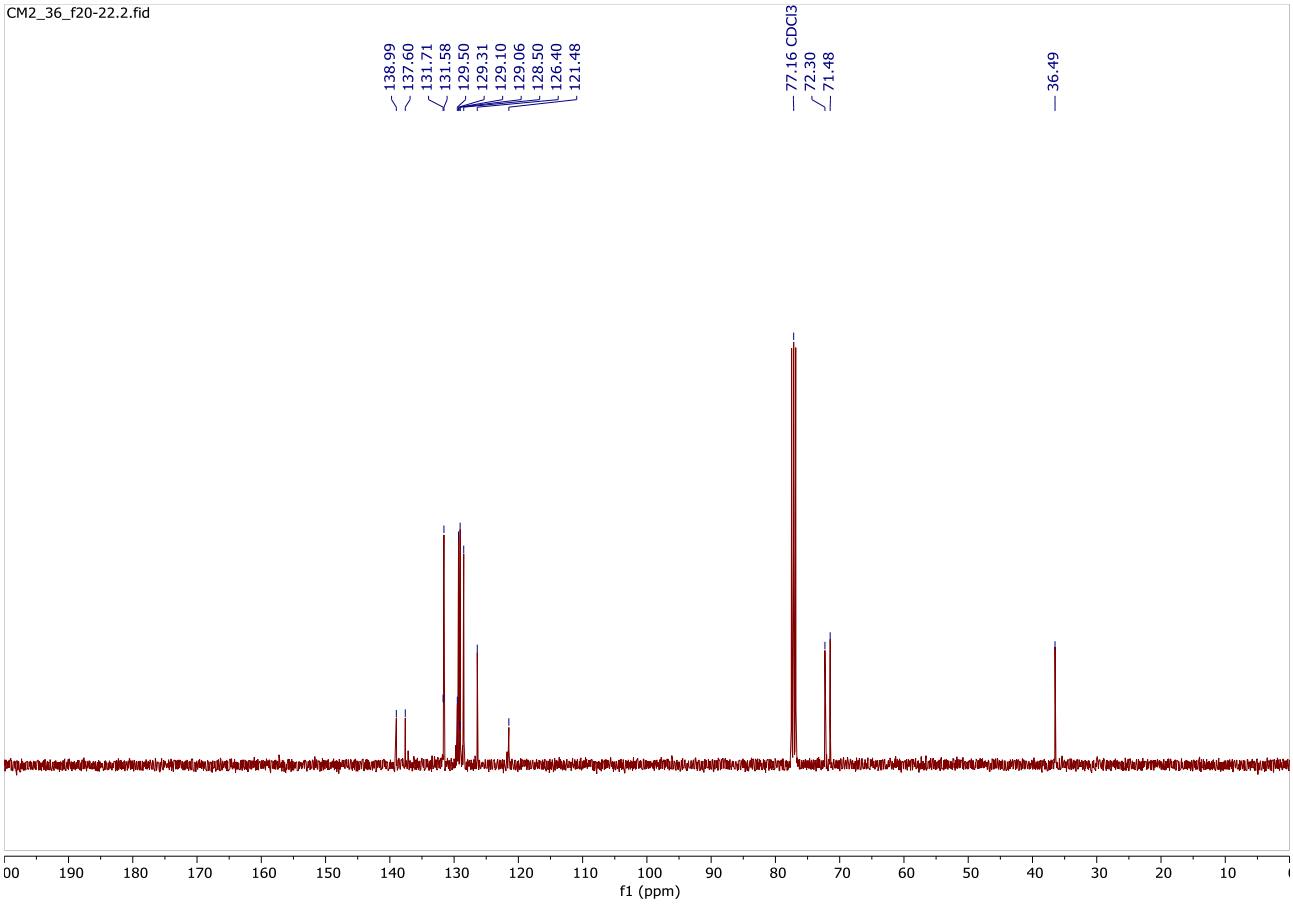
^{13}C NMR (125 MHz, $CDCl_3$)



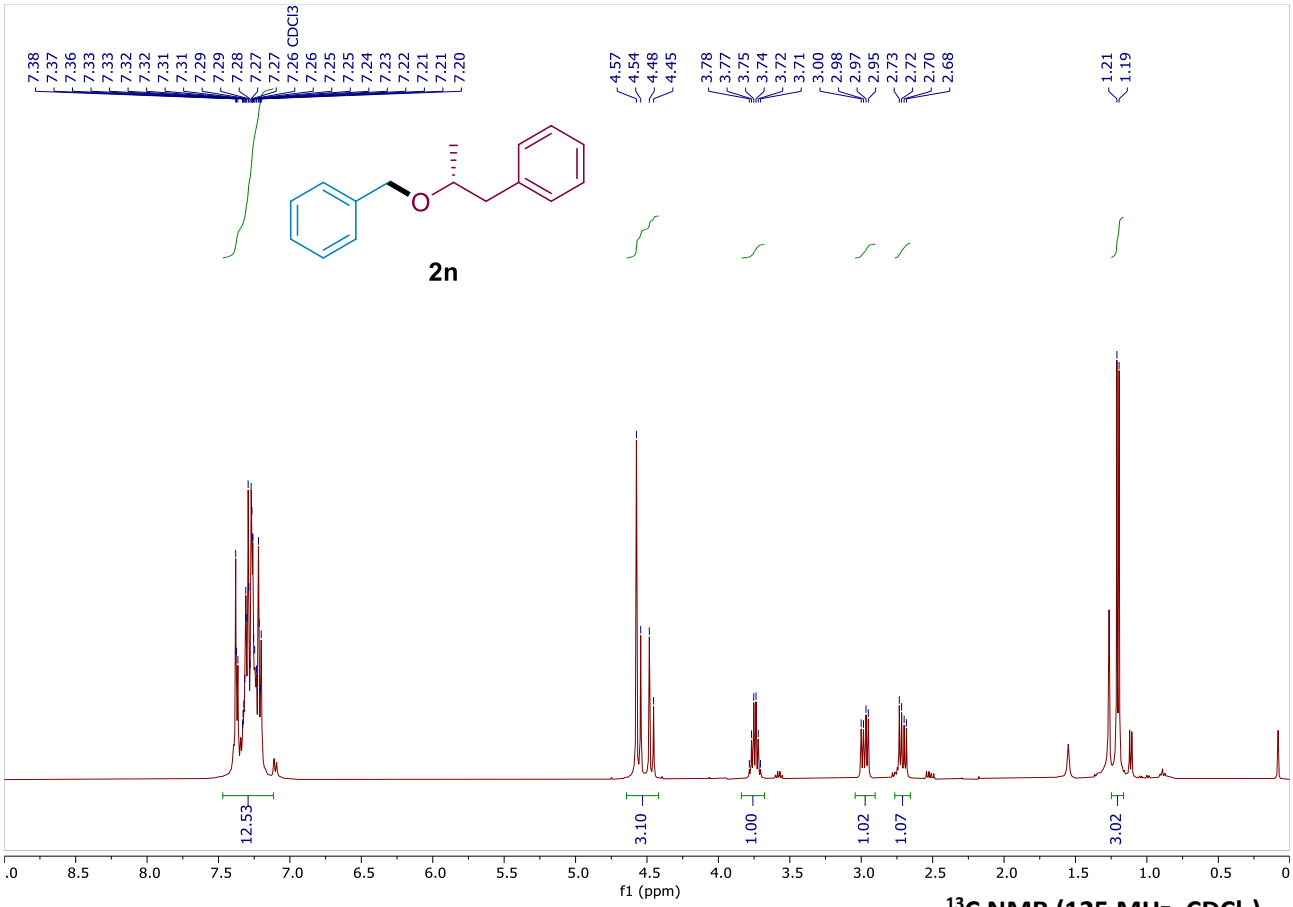
^{1}H NMR (400 MHz, $CDCl_3$)



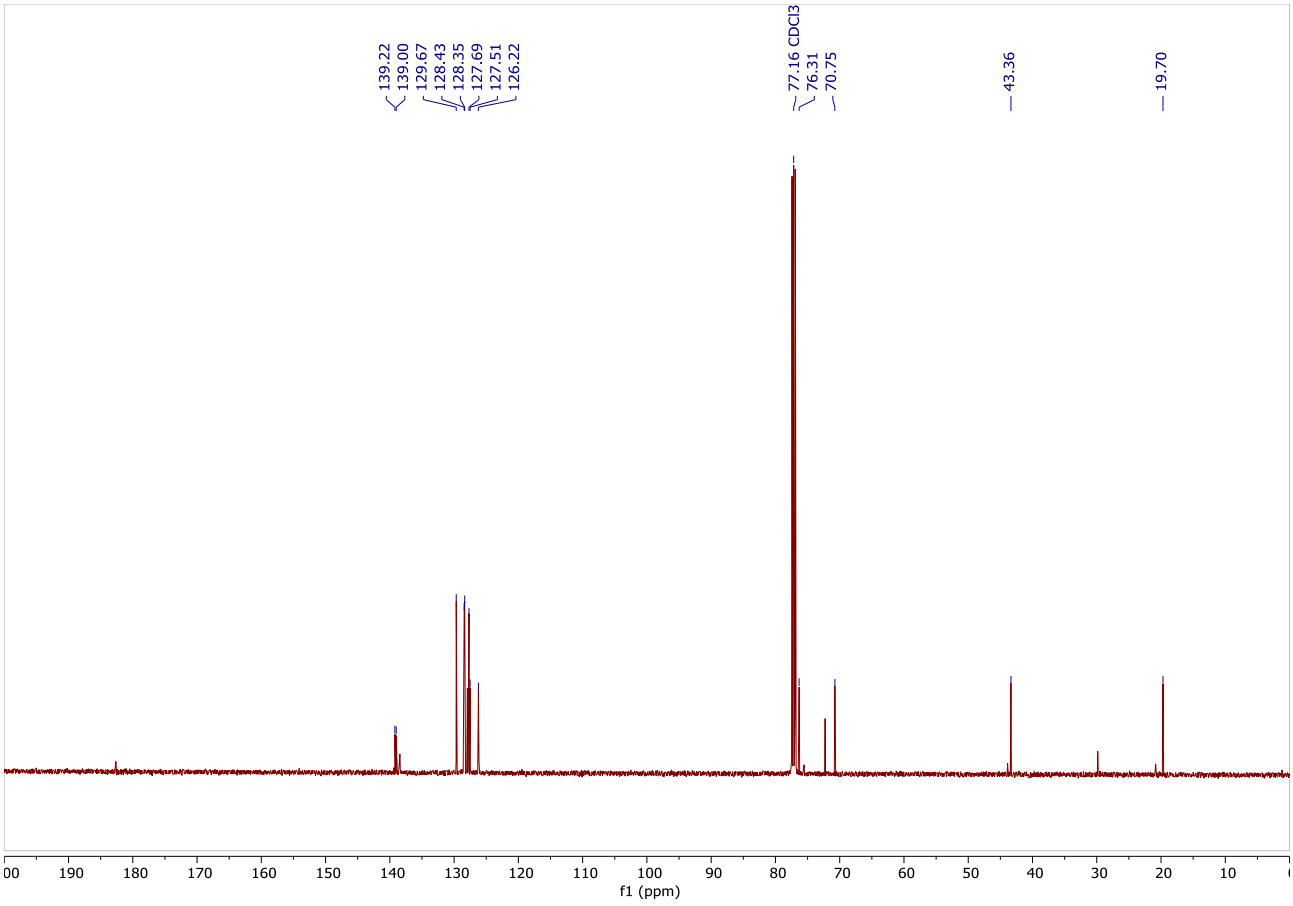
^{13}C NMR (100 MHz, $CDCl_3$)



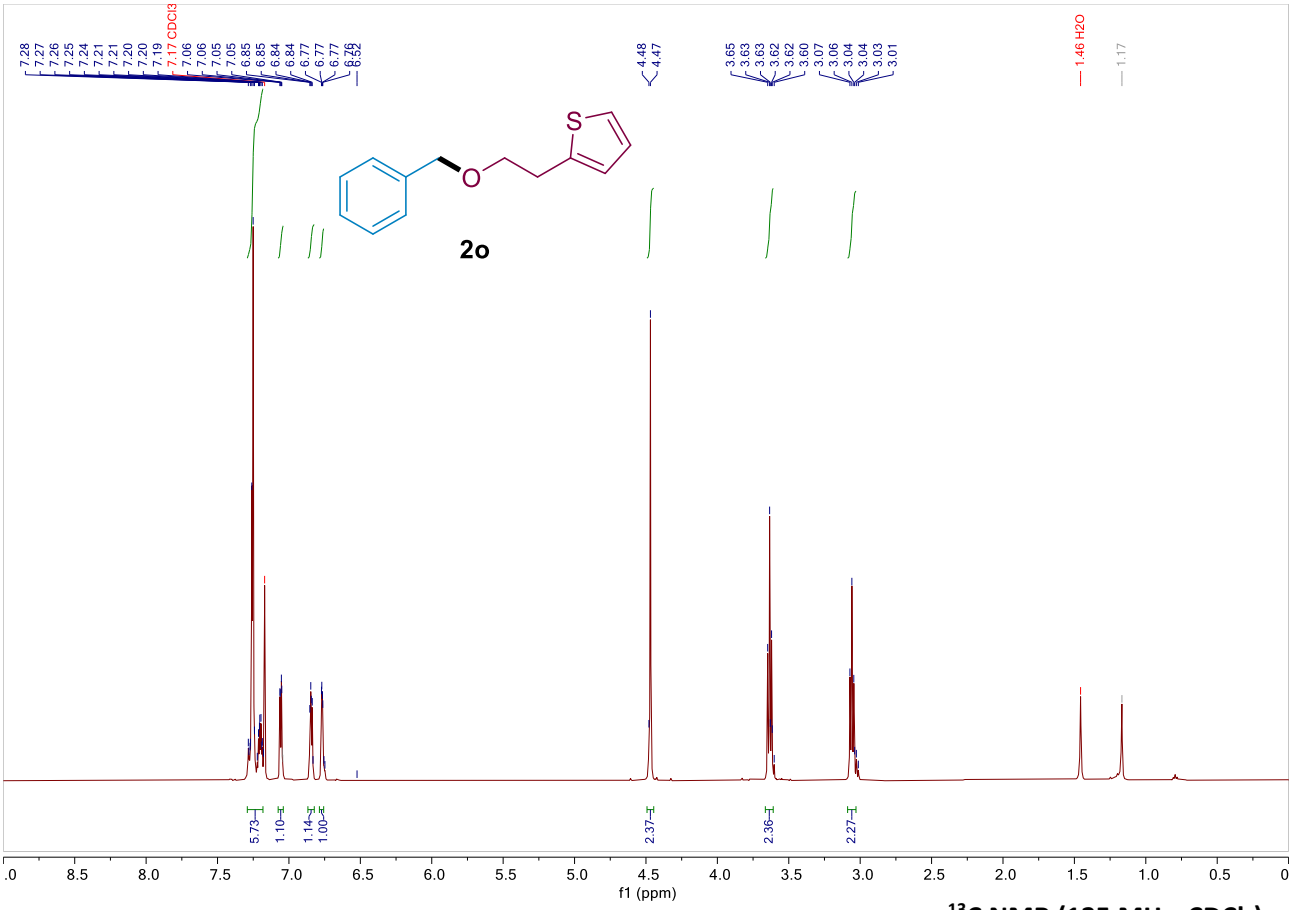
^{1}H NMR (400 MHz, $CDCl_3$)



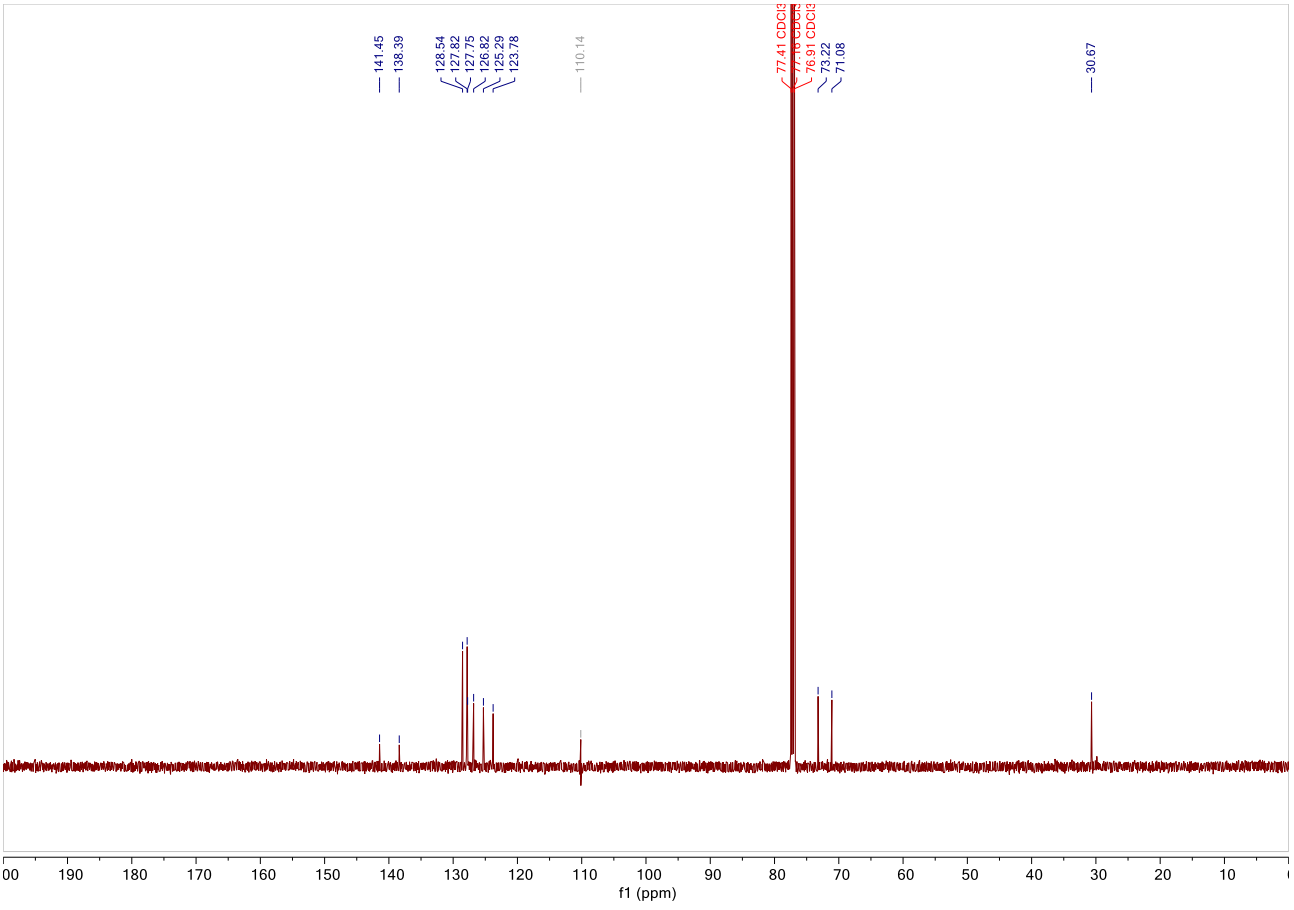
^{13}C NMR (125 MHz, $CDCl_3$)



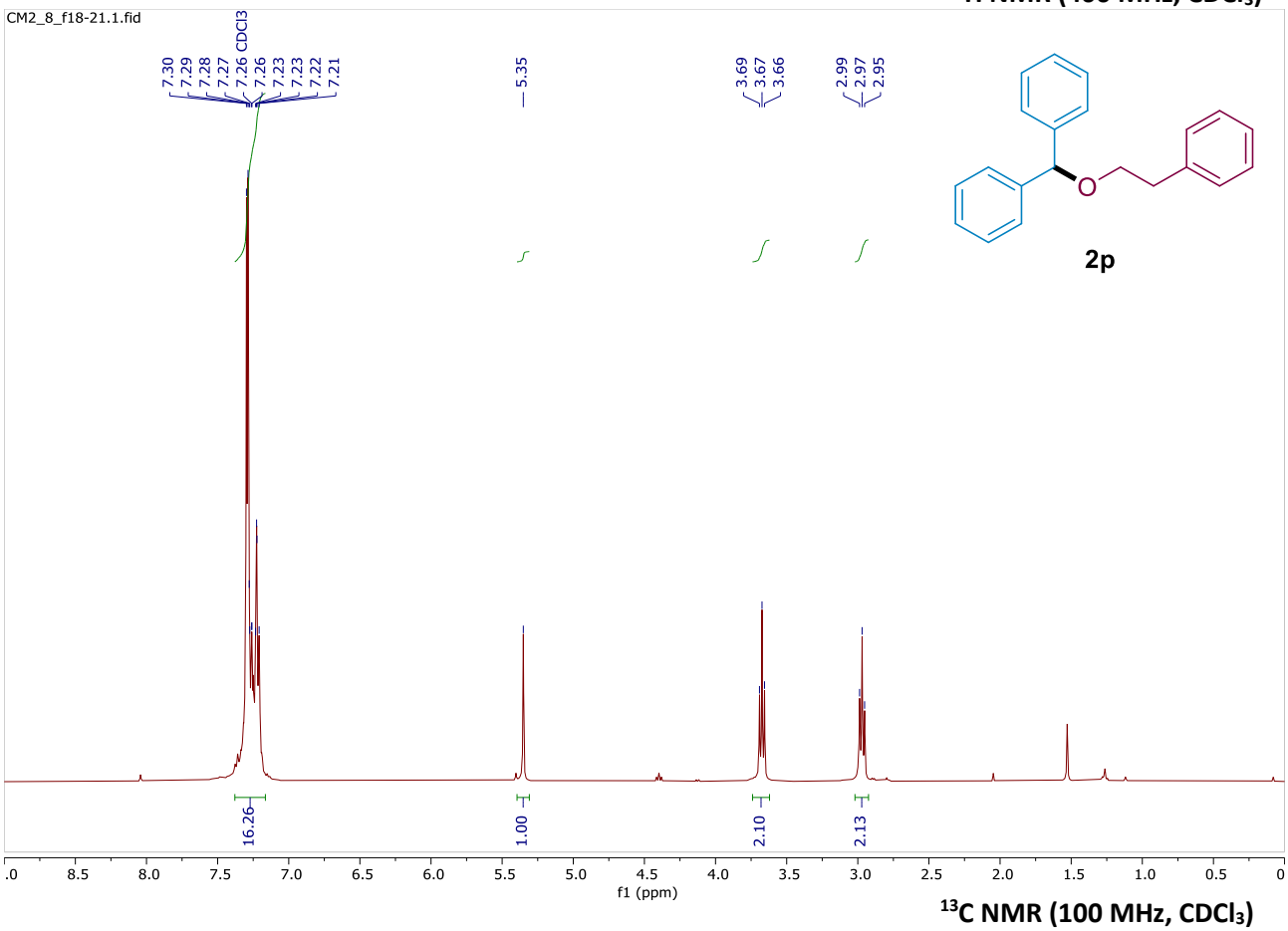
^{1}H NMR (500 MHz, $CDCl_3$)



^{13}C NMR (125 MHz, $CDCl_3$)

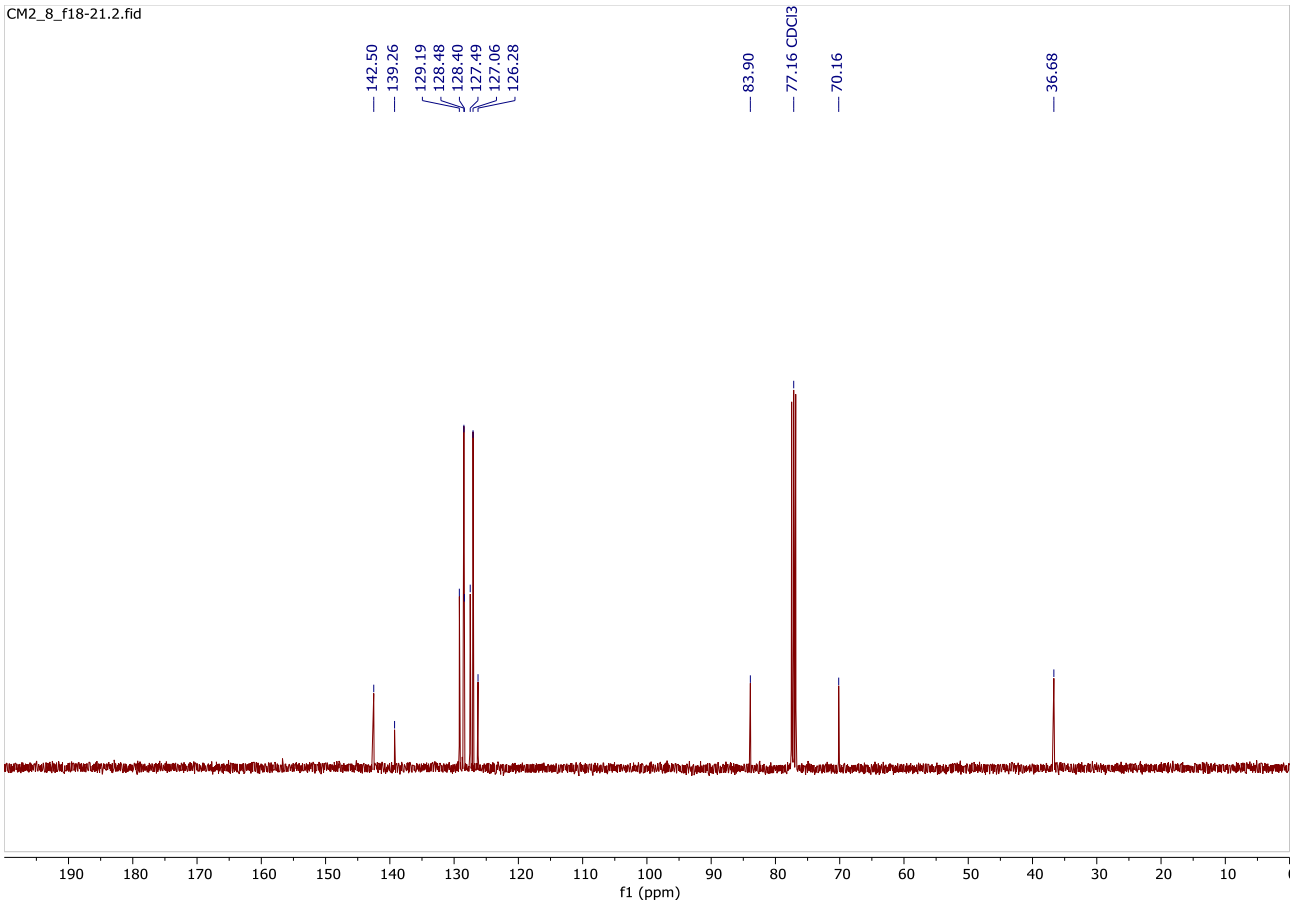


^{1}H NMR (400 MHz, $CDCl_3$)

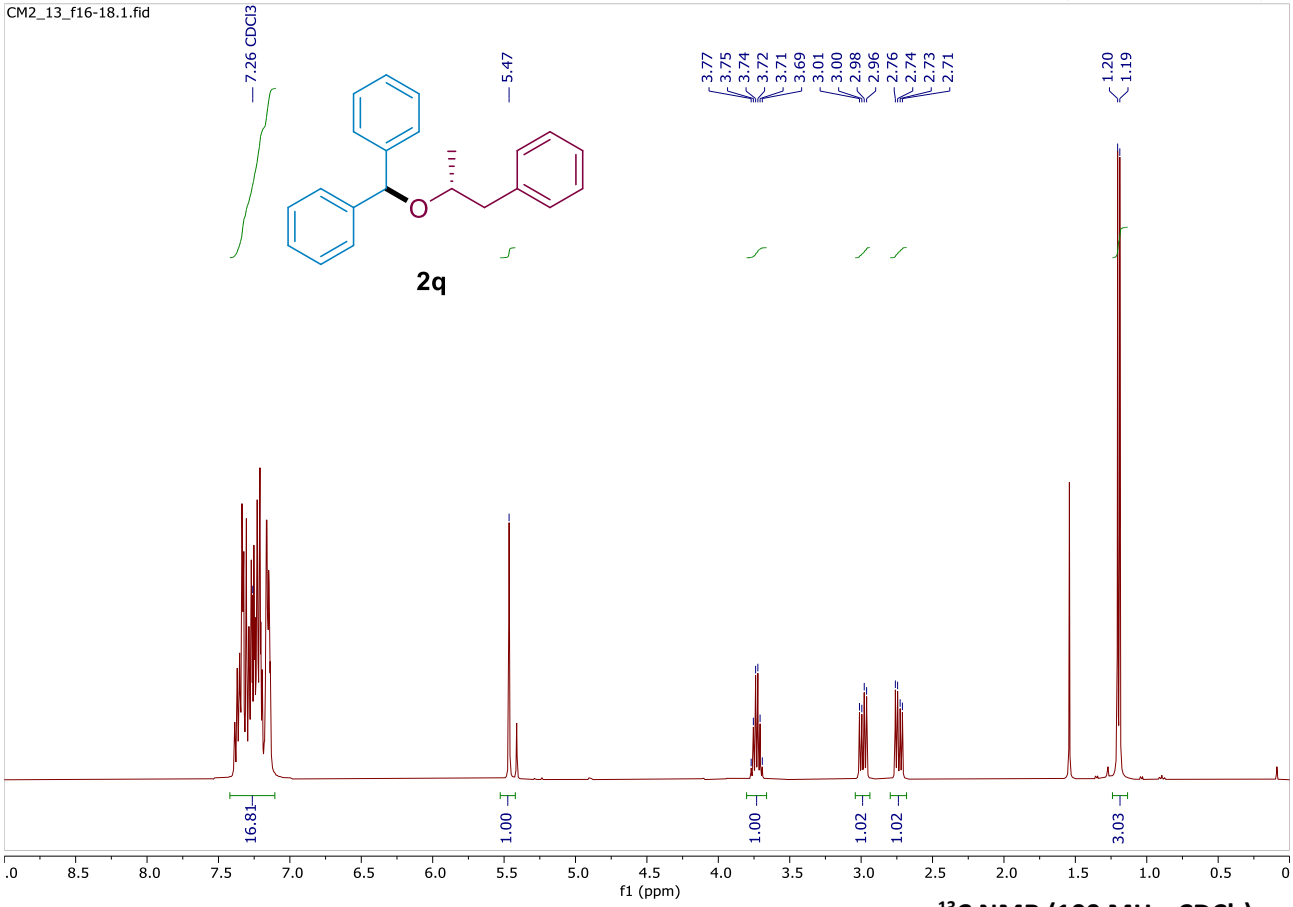


2p

^{13}C NMR (100 MHz, $CDCl_3$)

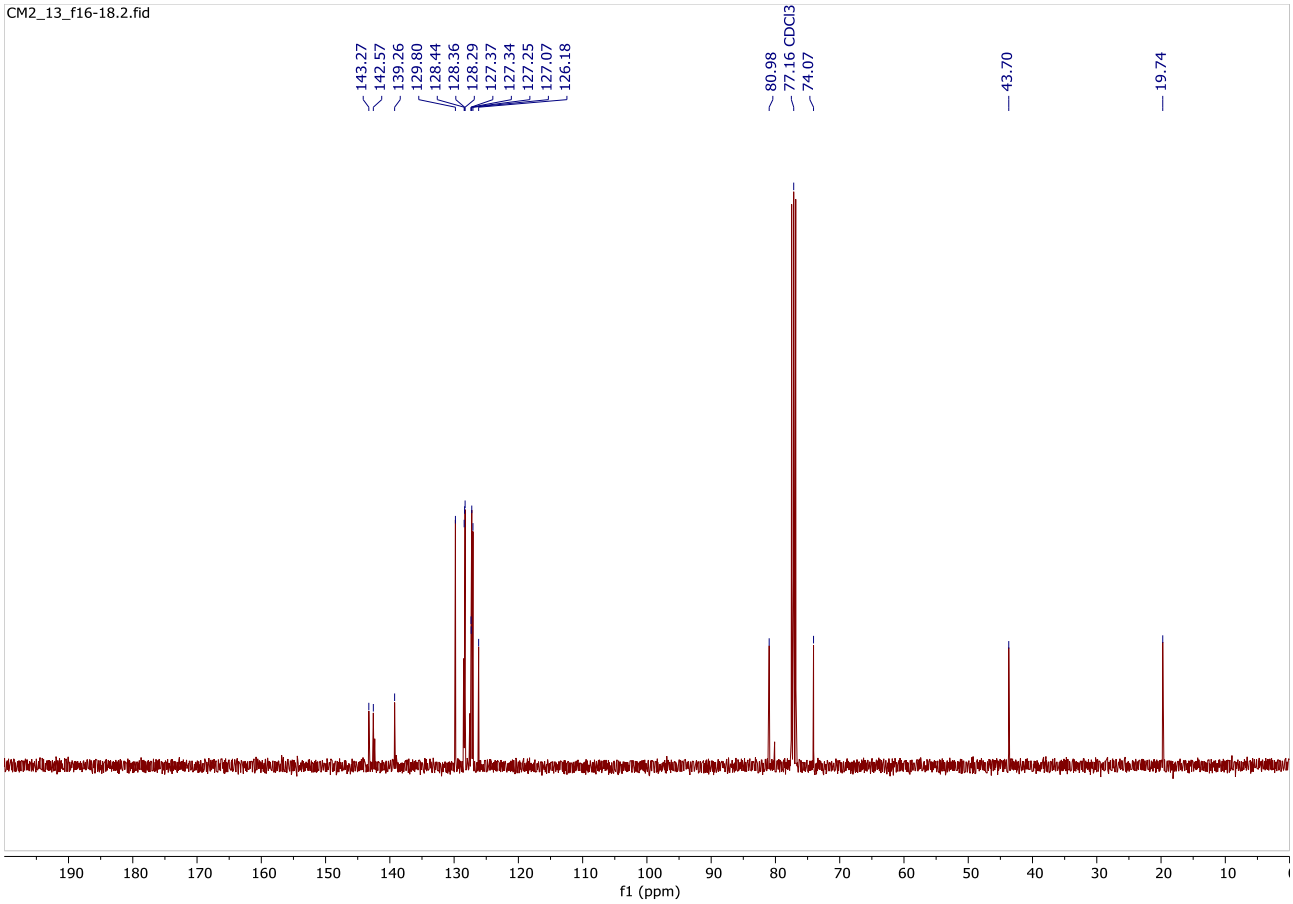


^{1}H NMR (400 MHz, $CDCl_3$)

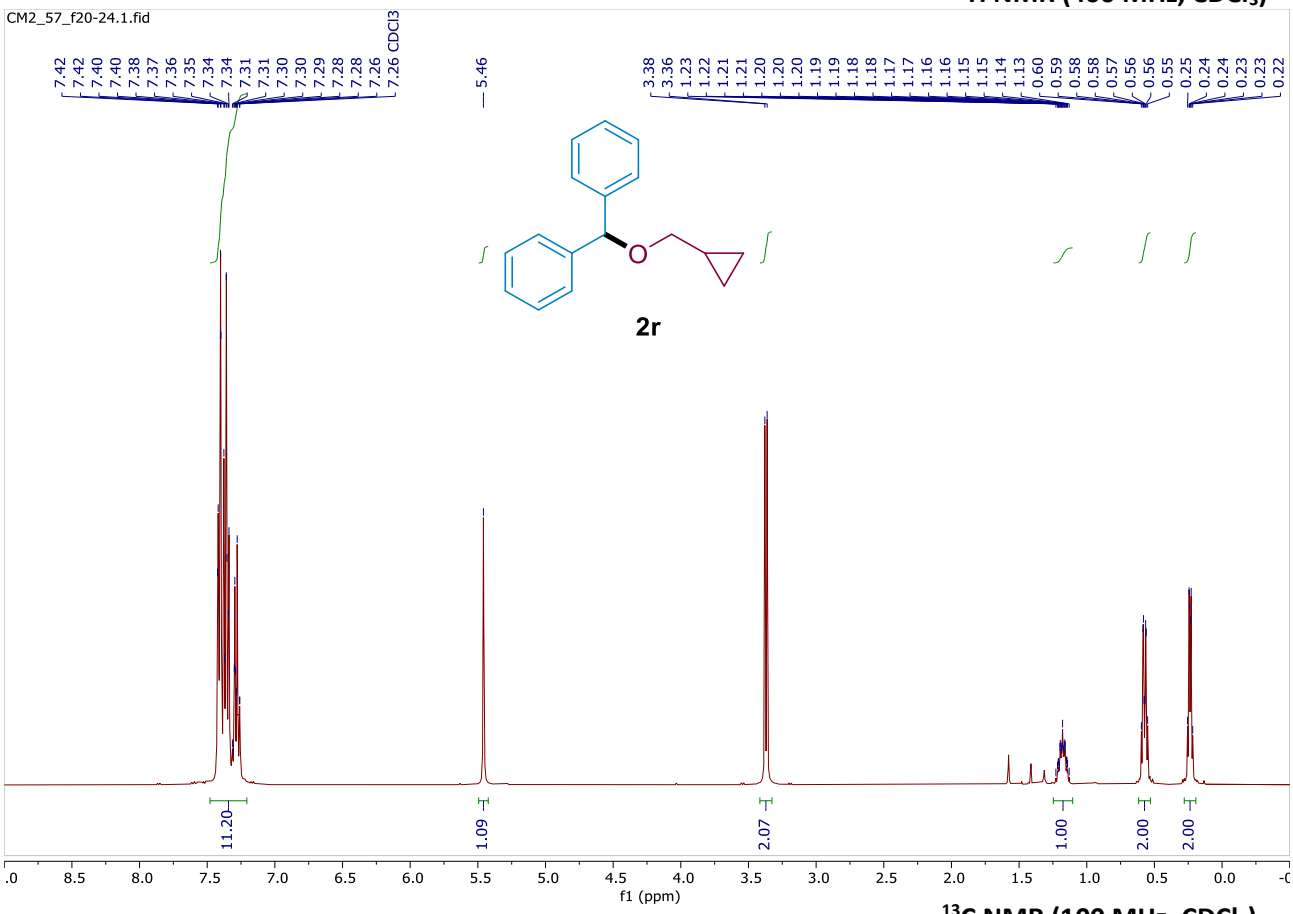


2q

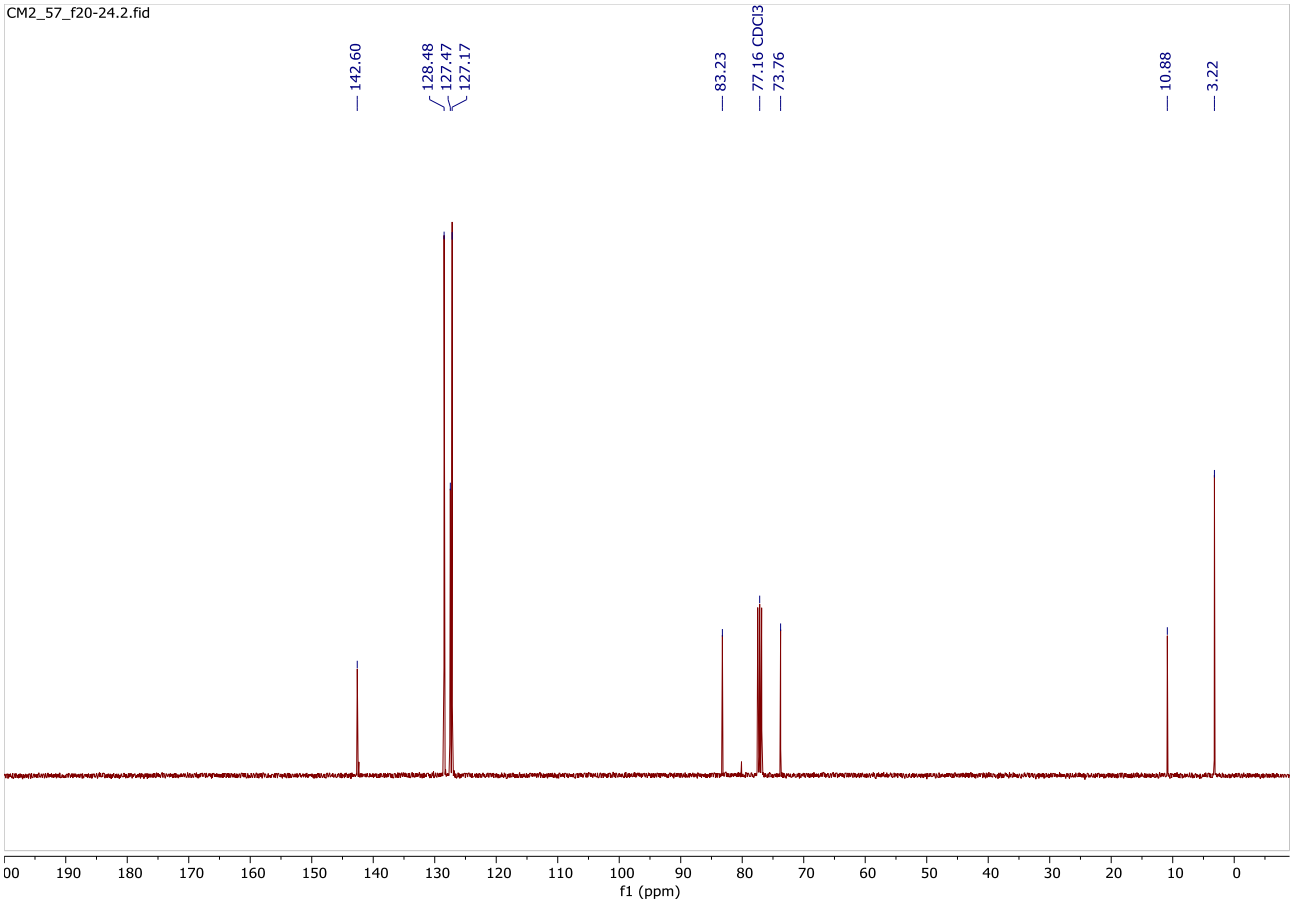
^{13}C NMR (100 MHz, $CDCl_3$)



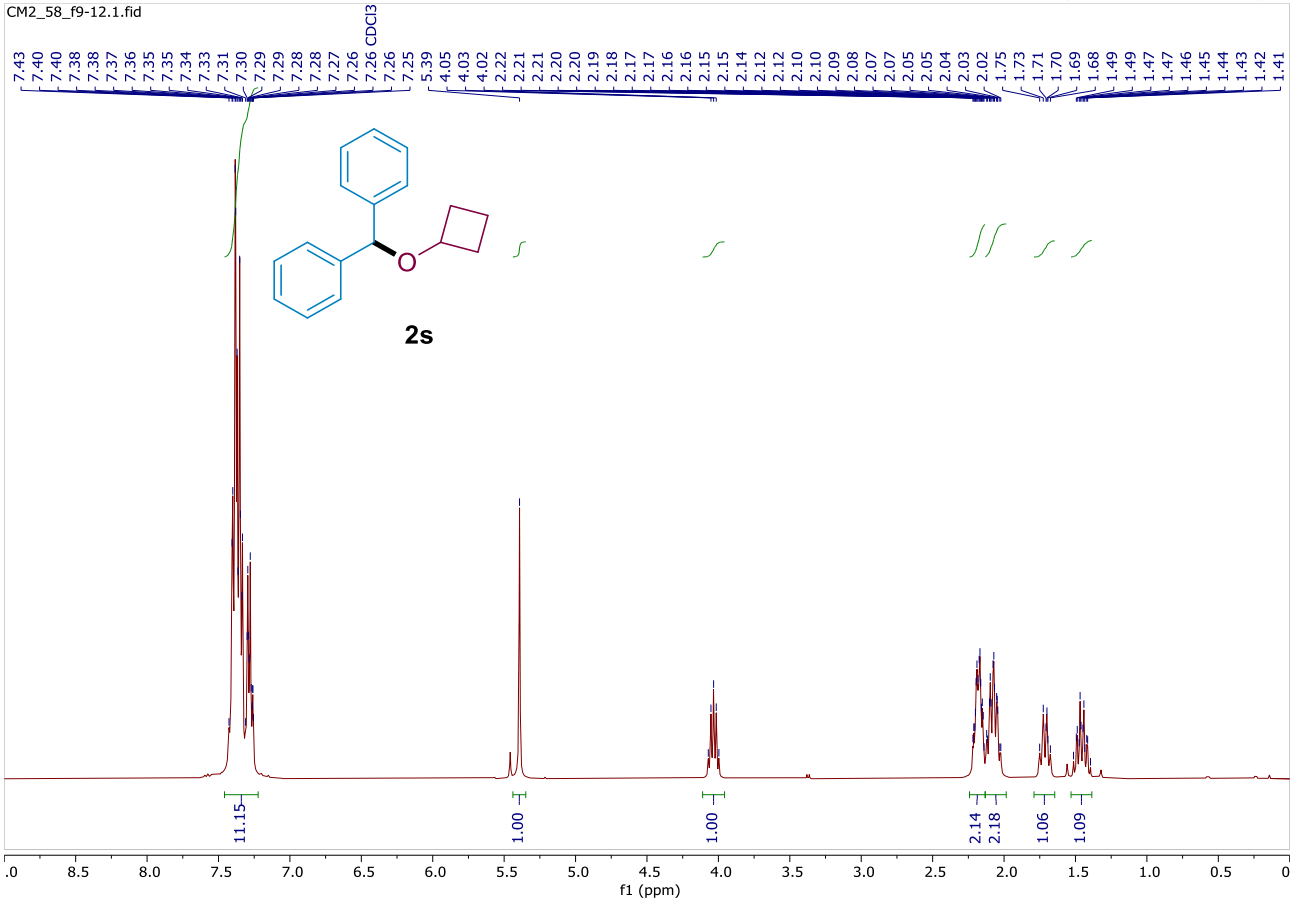
^{1}H NMR (400 MHz, $CDCl_3$)



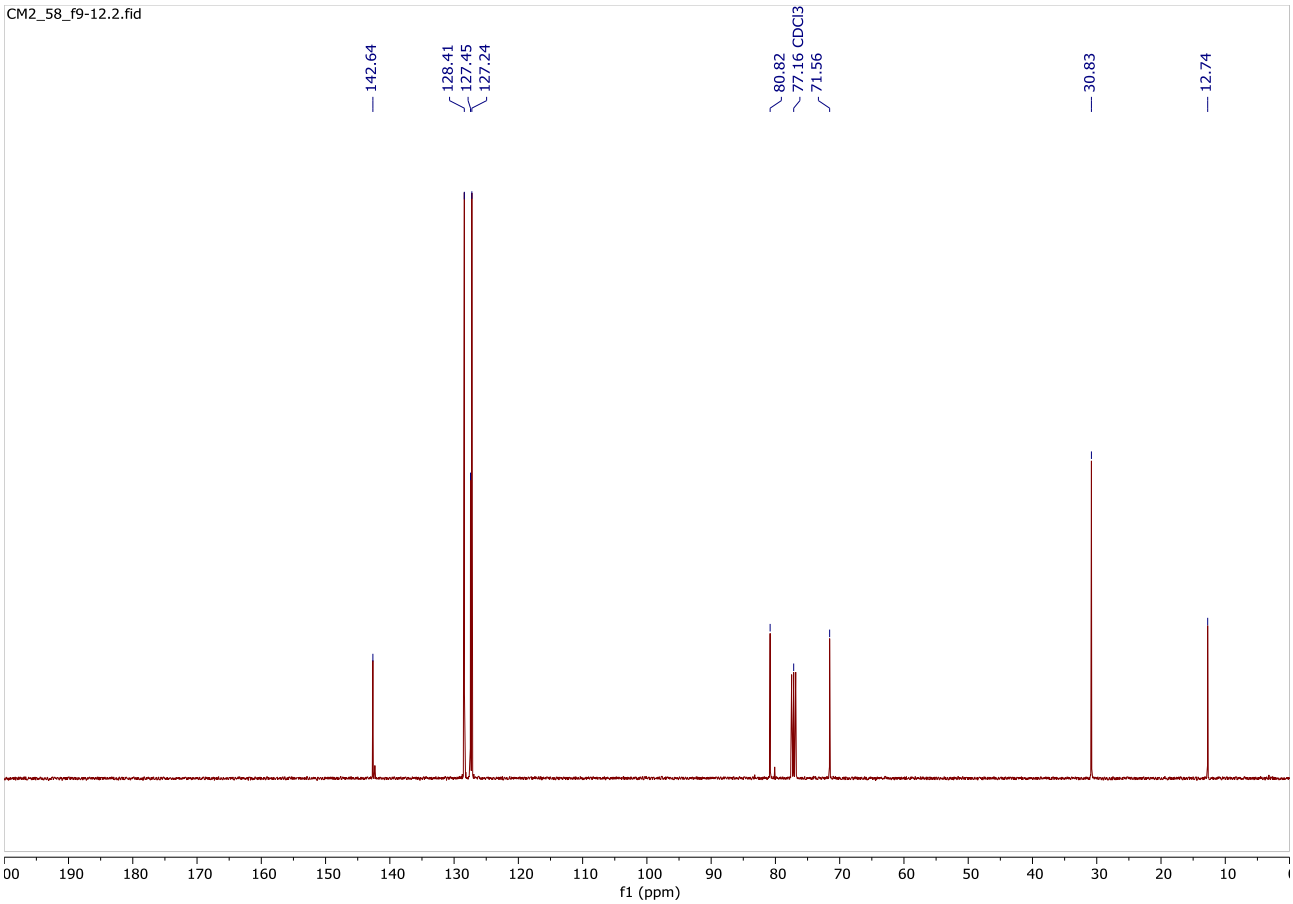
^{13}C NMR (100 MHz, $CDCl_3$)



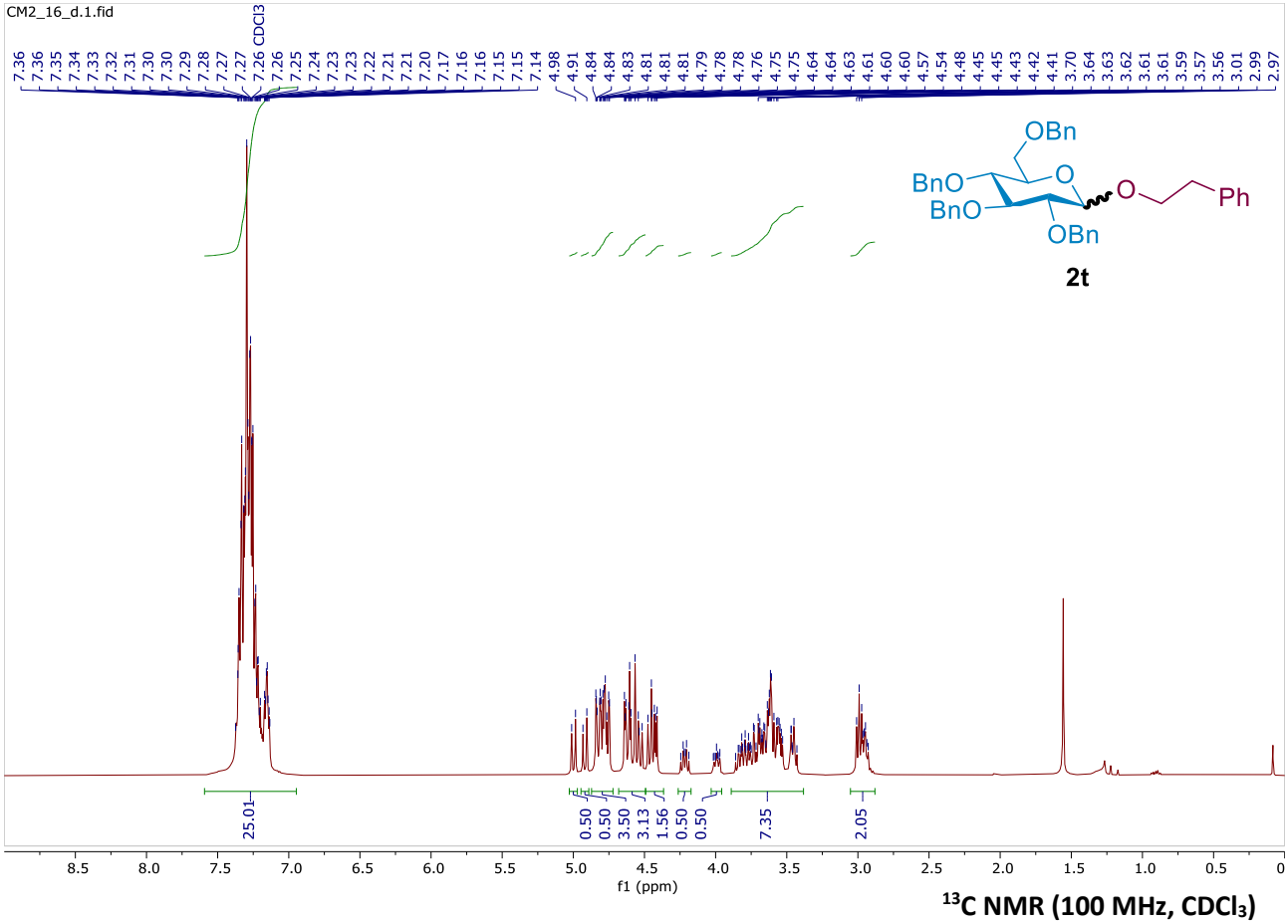
^{1}H NMR (400 MHz, $CDCl_3$)



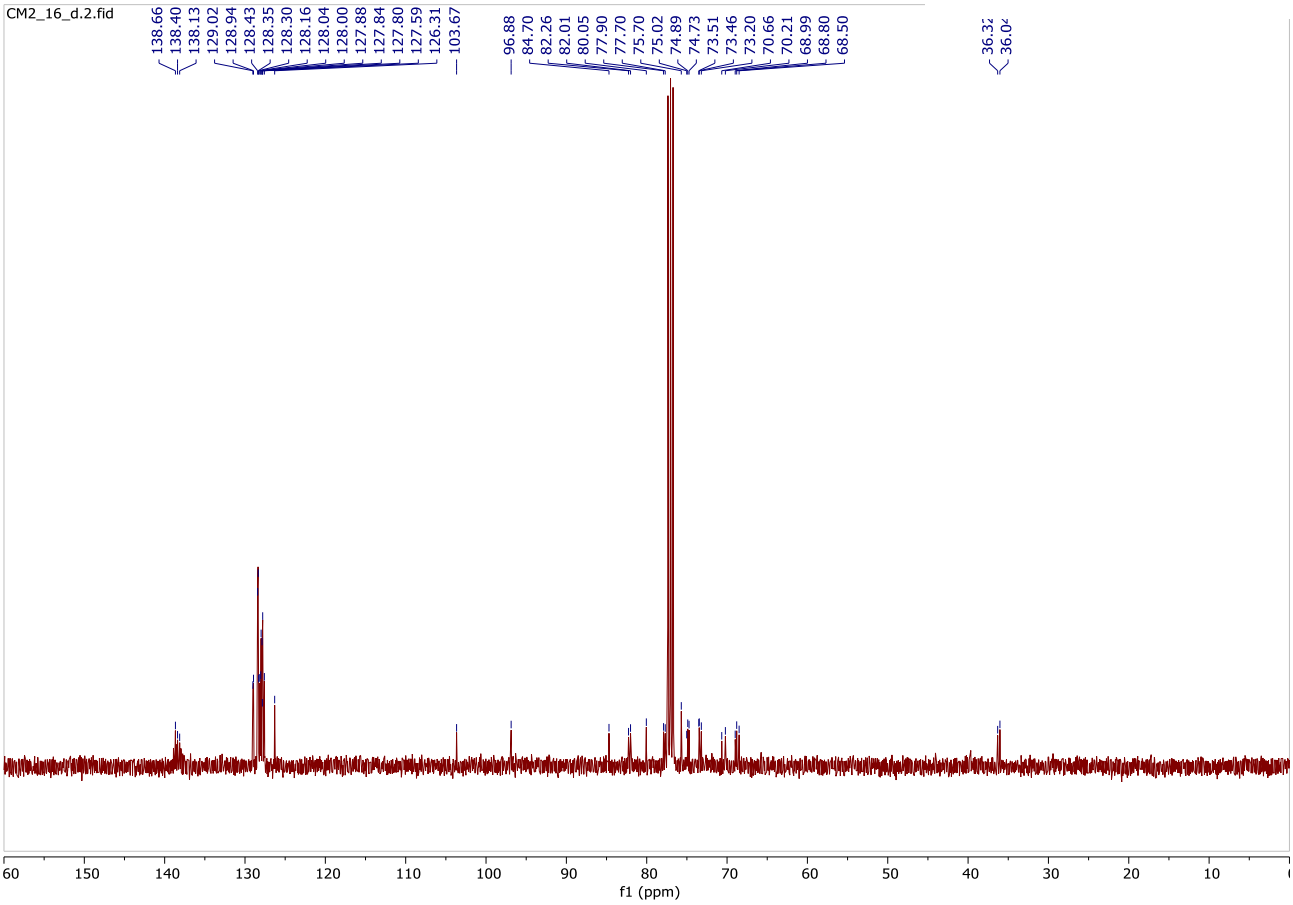
^{13}C NMR (100 MHz, $CDCl_3$)



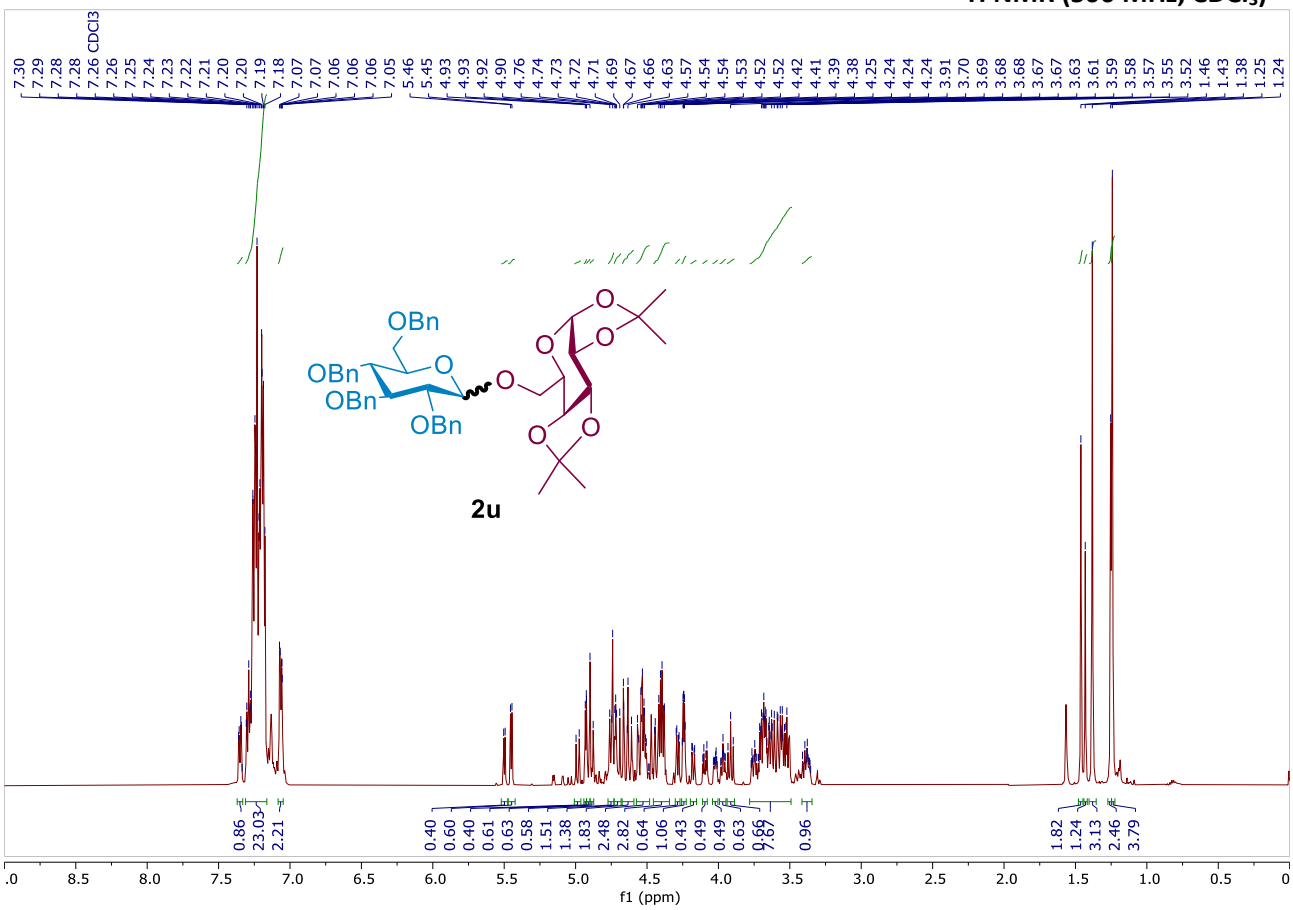
^{1}H NMR (400 MHz, $CDCl_3$)



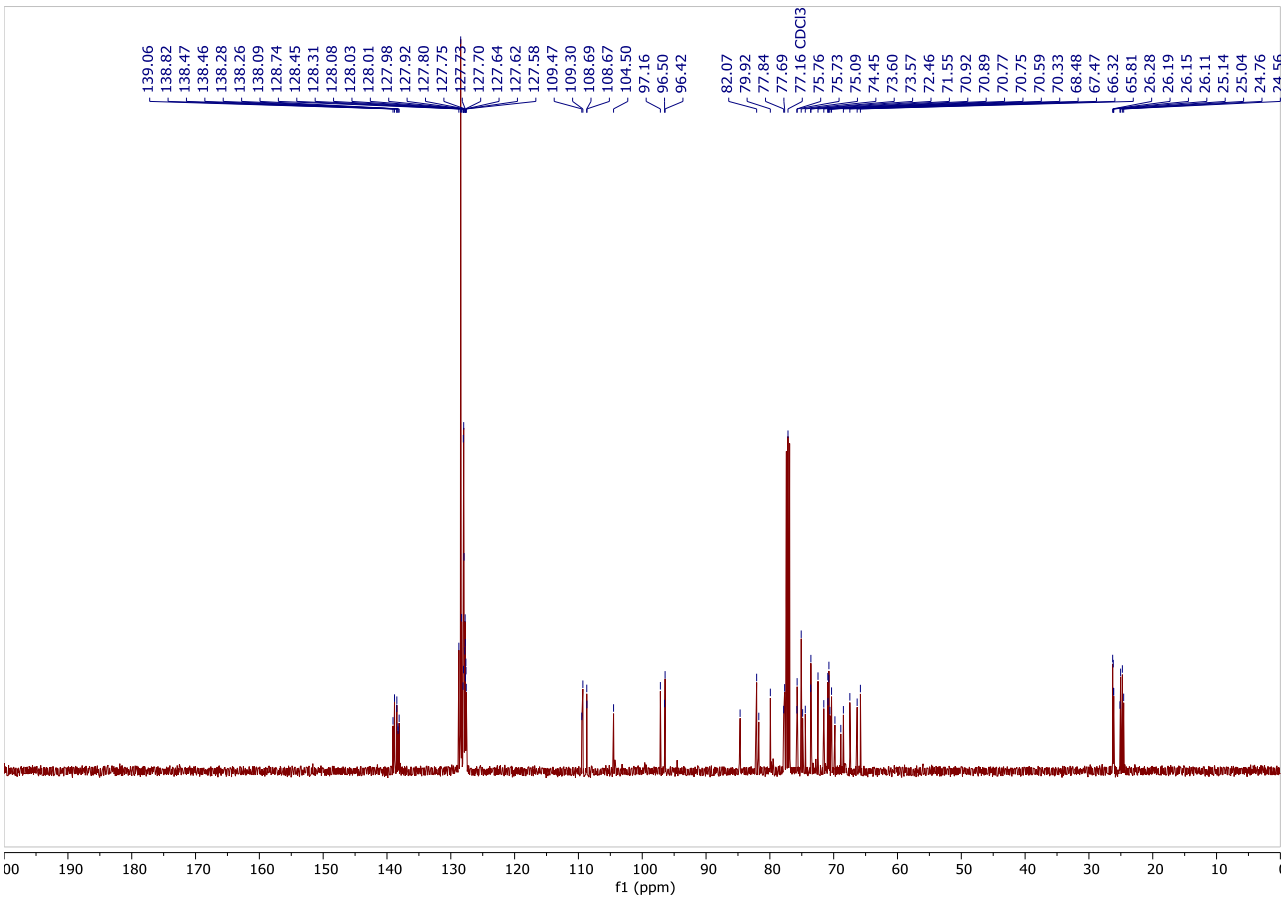
^{13}C NMR (100 MHz, $CDCl_3$)



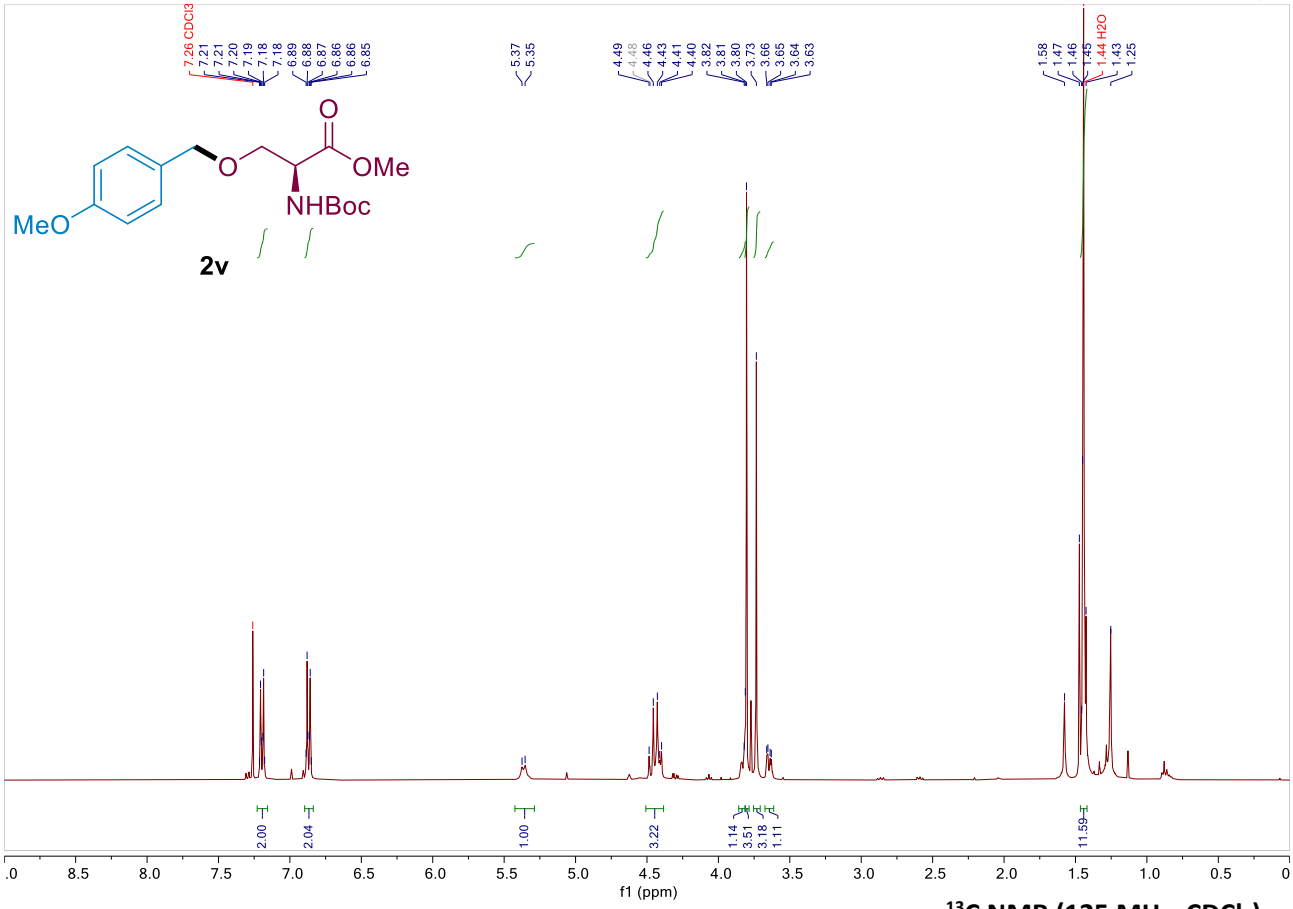
^{1}H NMR (500 MHz, $CDCl_3$)



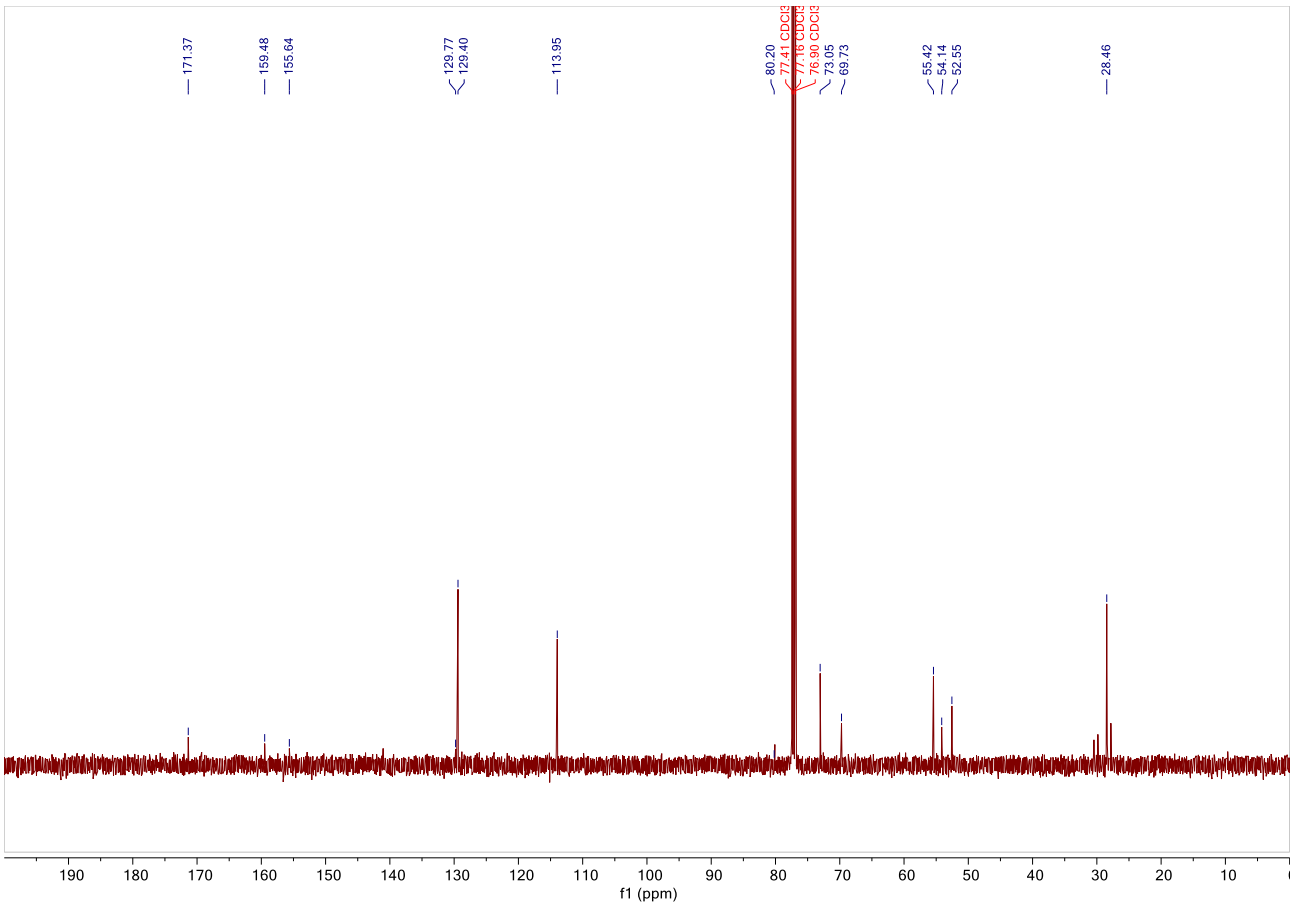
^{13}C NMR (125 MHz, $CDCl_3$)



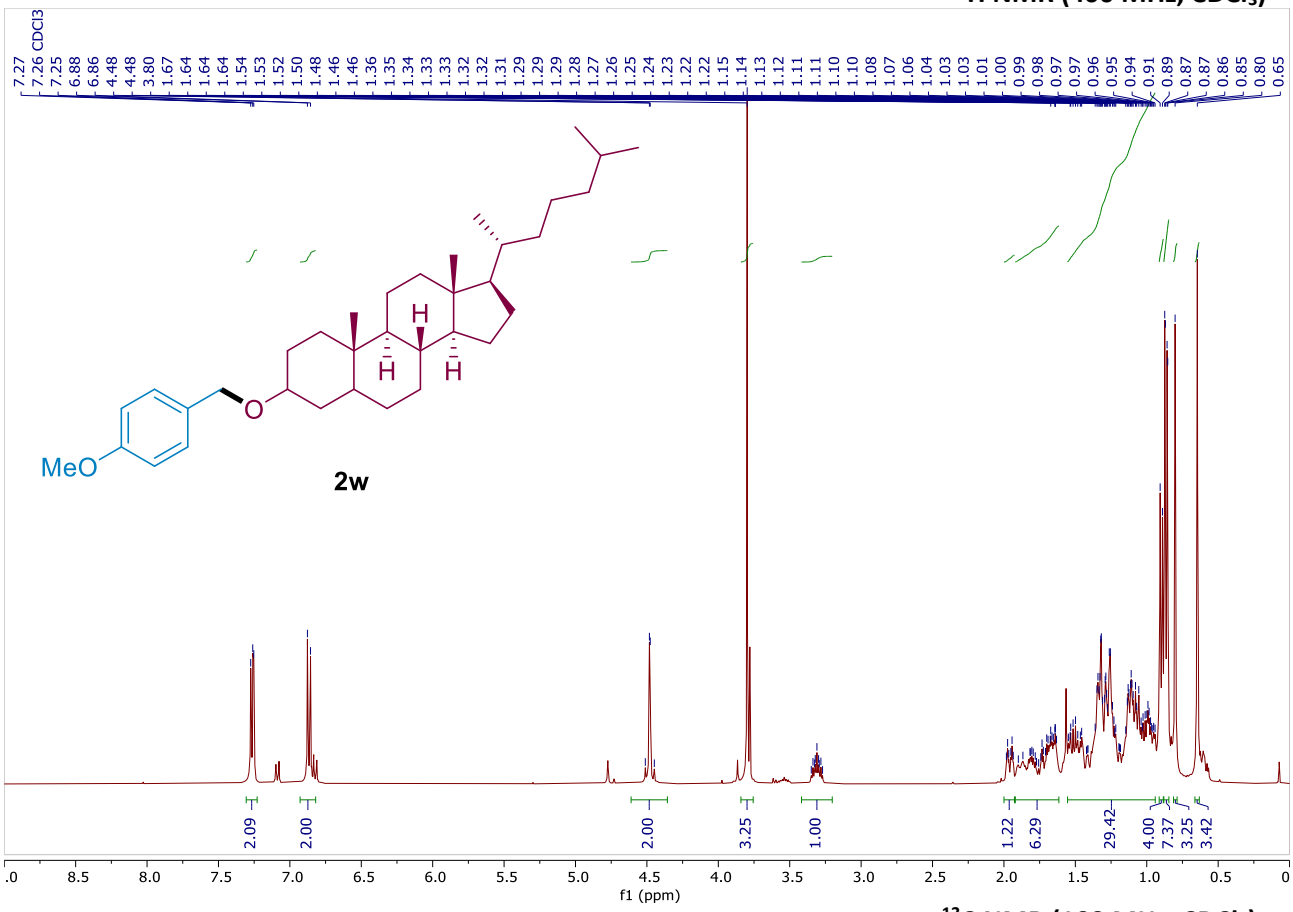
^{1}H NMR (400 MHz, $CDCl_3$)



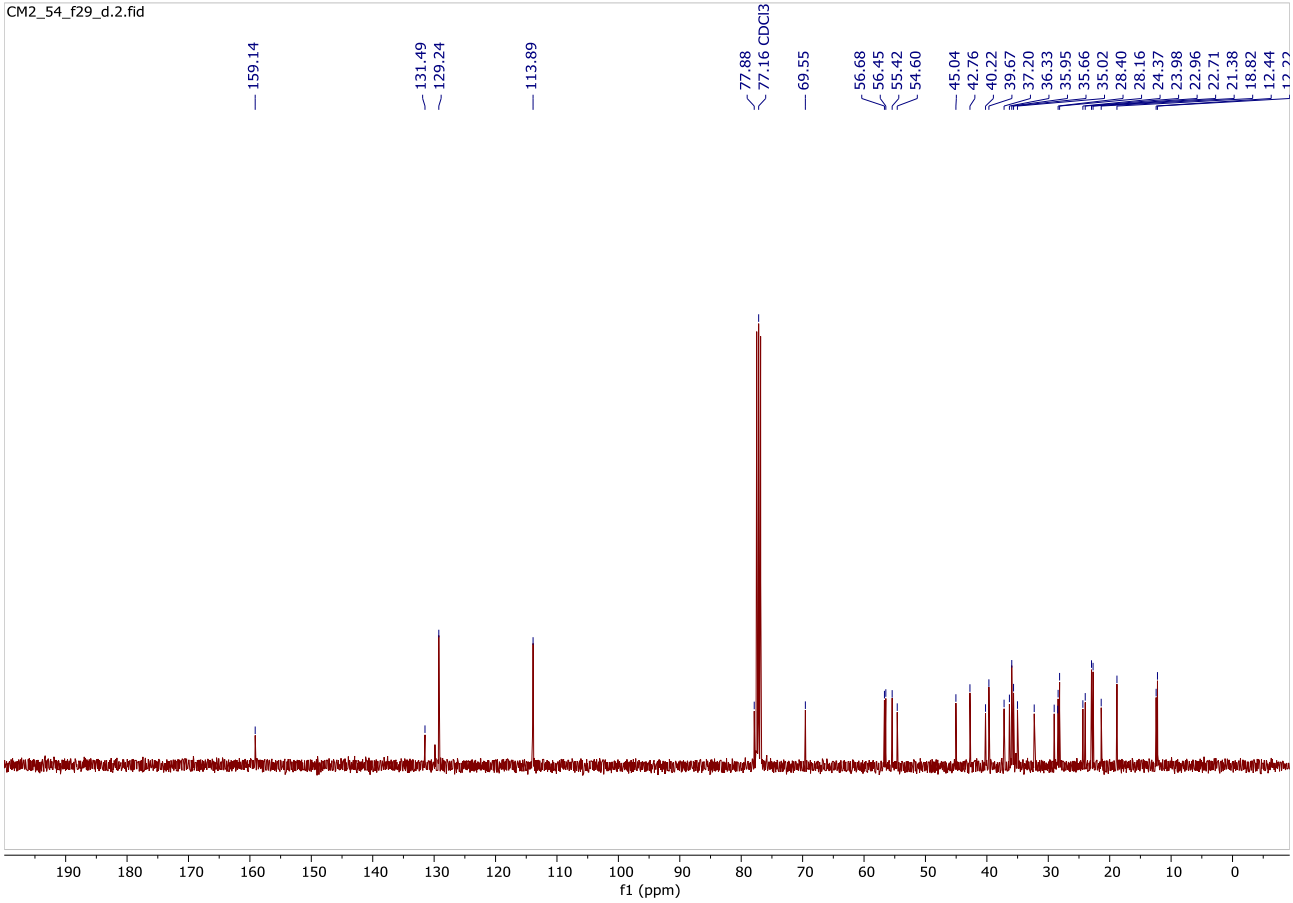
^{13}C NMR (125 MHz, $CDCl_3$)



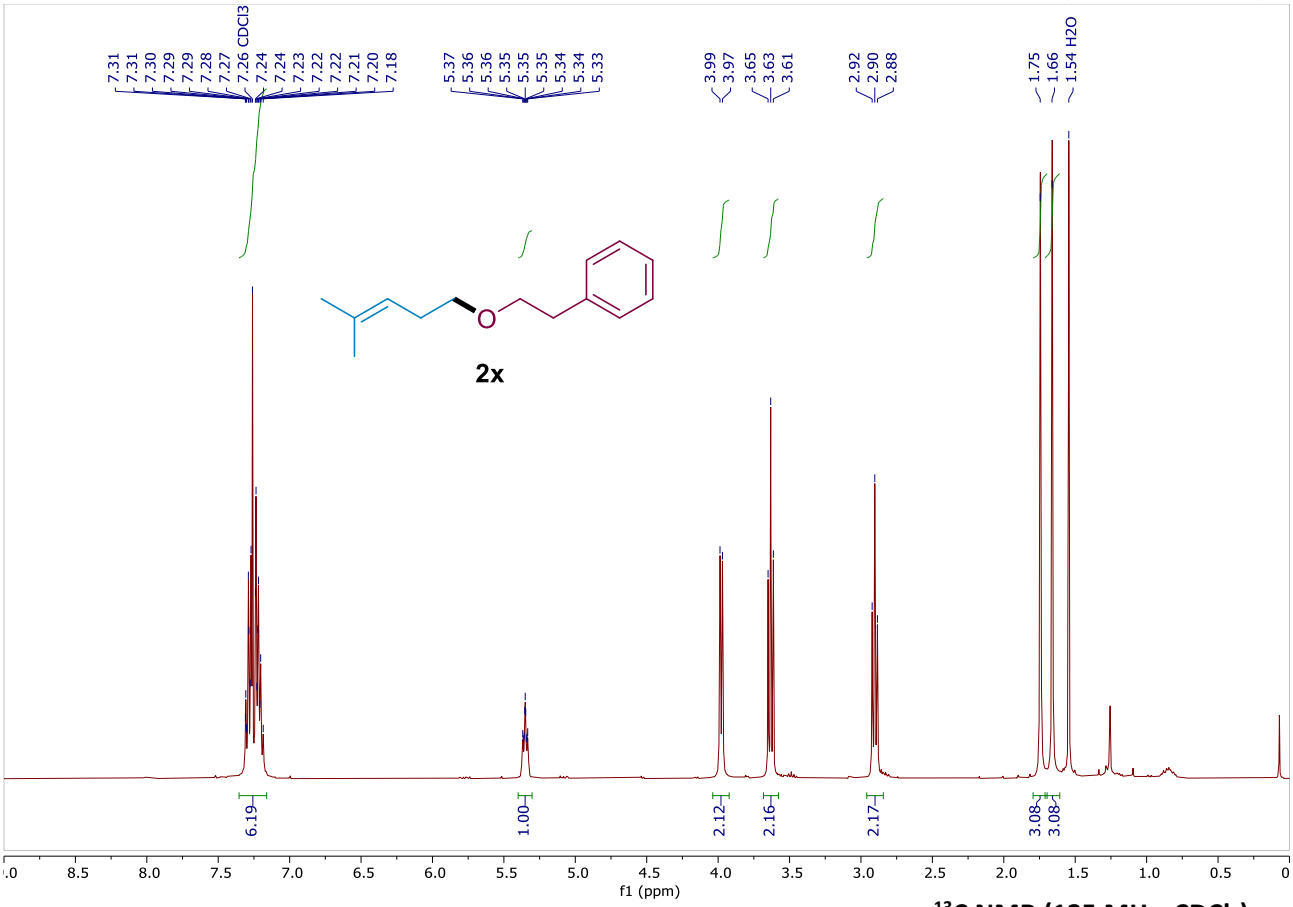
^{1}H NMR (400 MHz, $CDCl_3$)



^{13}C NMR (100 MHz, $CDCl_3$)

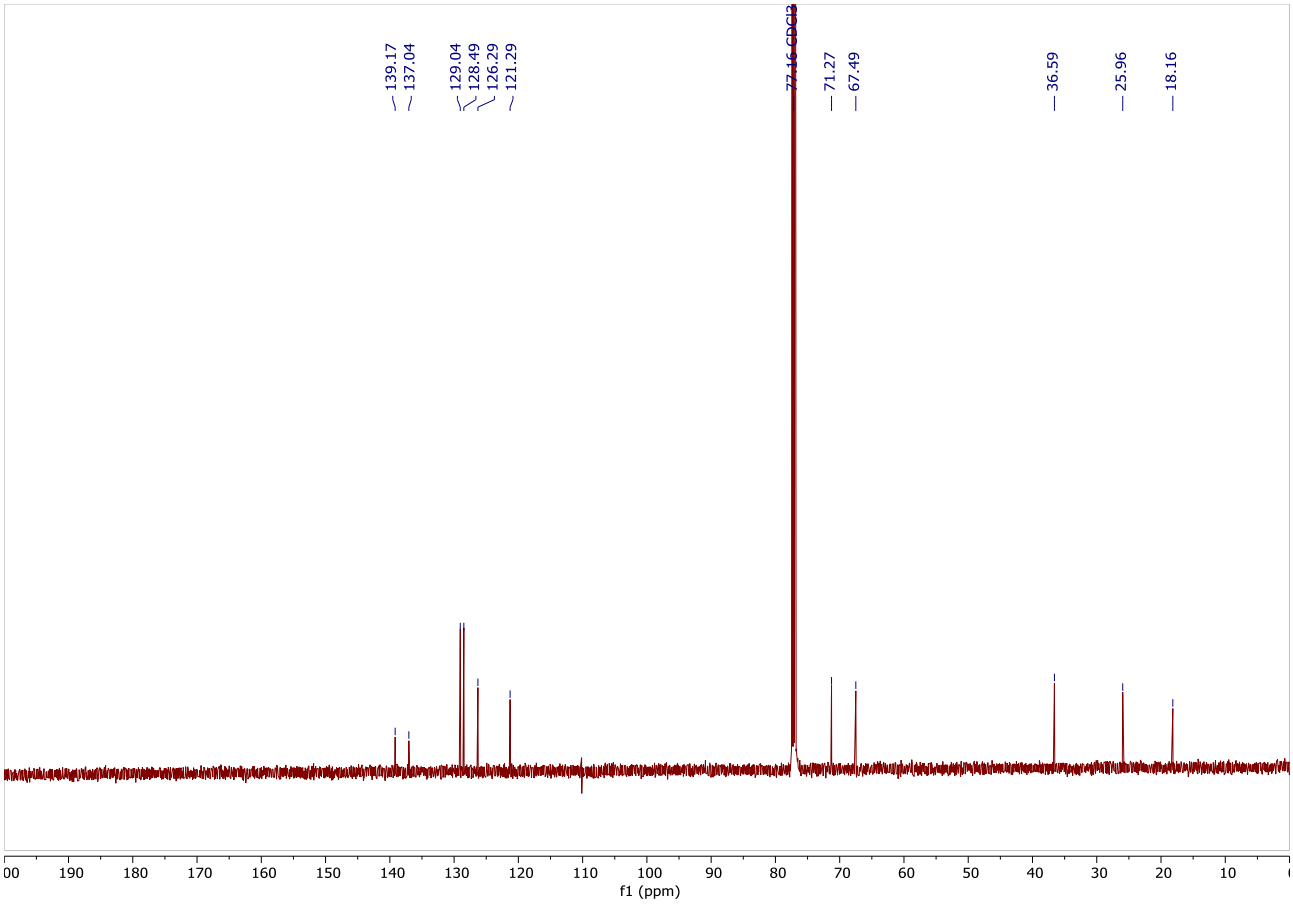


^{1}H NMR (400 MHz, $CDCl_3$)

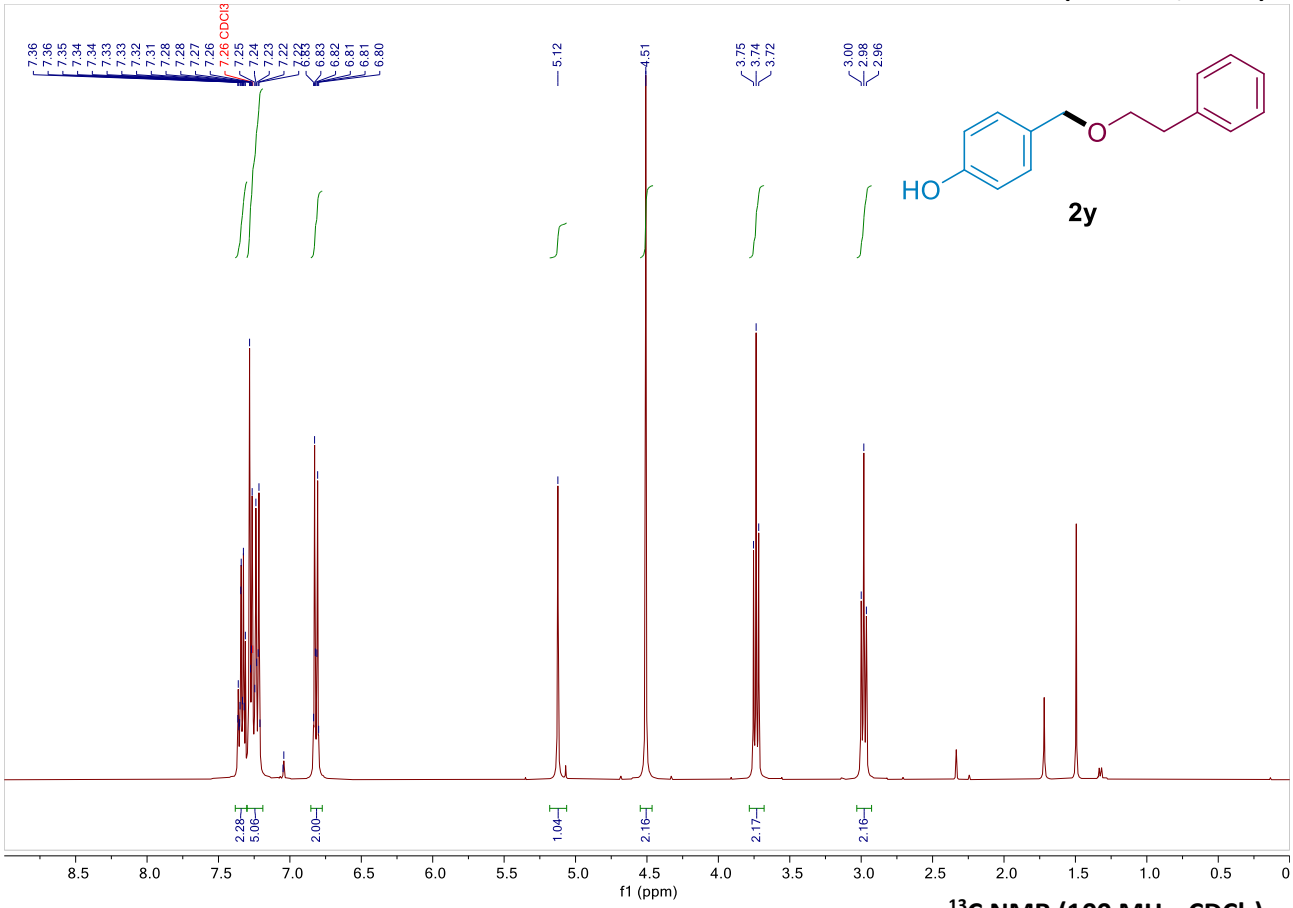


2x

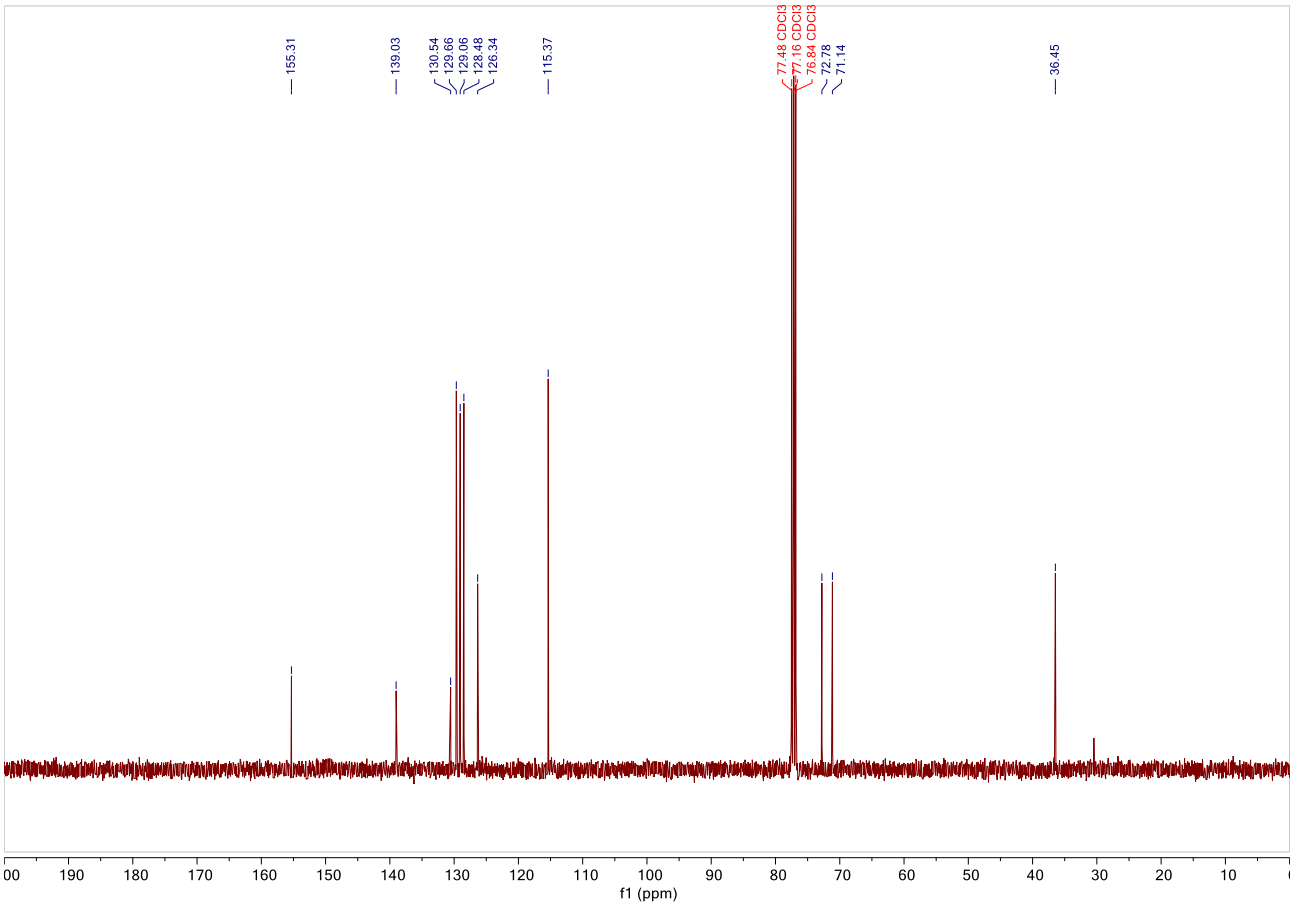
^{13}C NMR (125 MHz, $CDCl_3$)



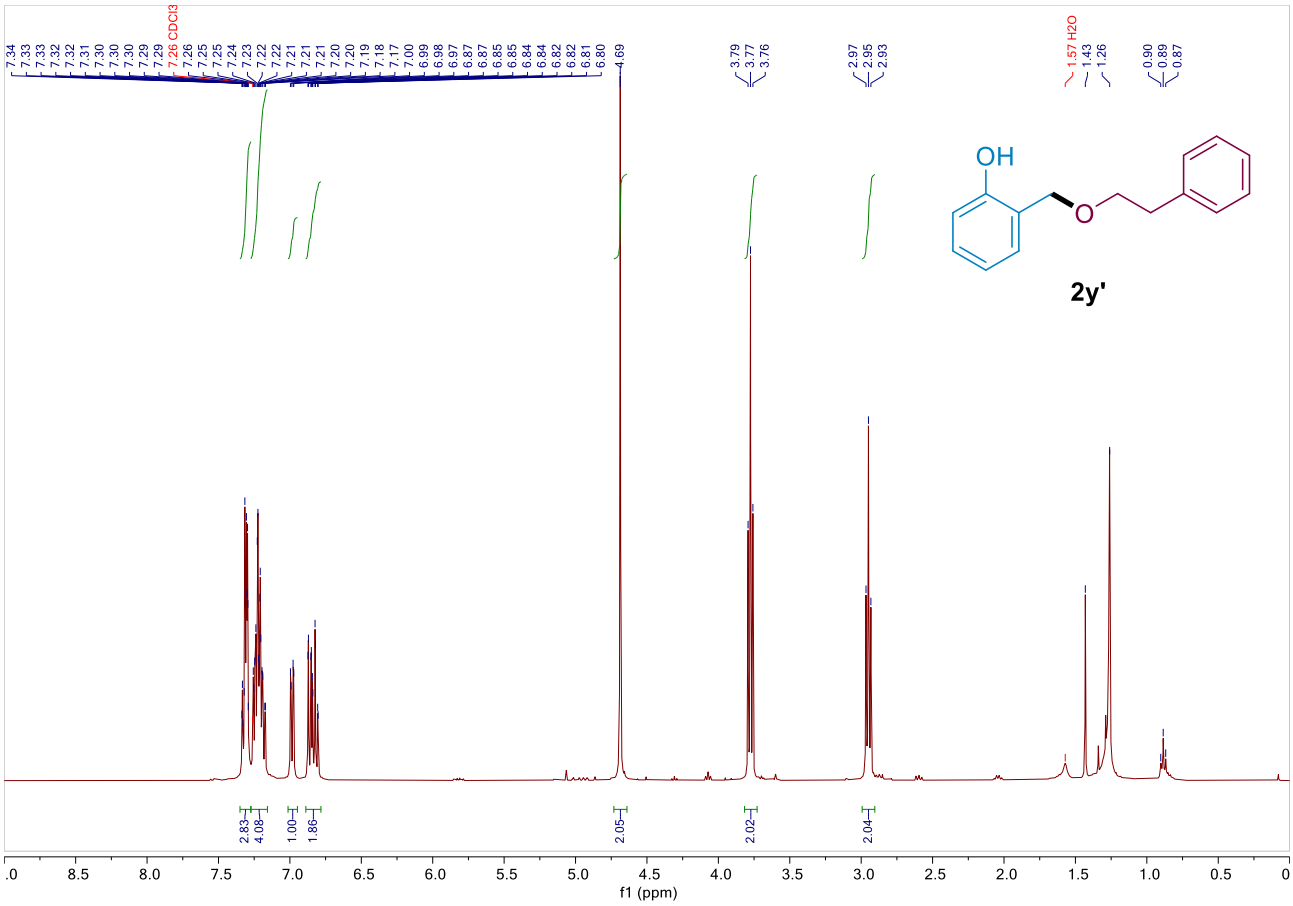
^{1}H NMR (400 MHz, $CDCl_3$)



^{13}C NMR (100 MHz, $CDCl_3$)

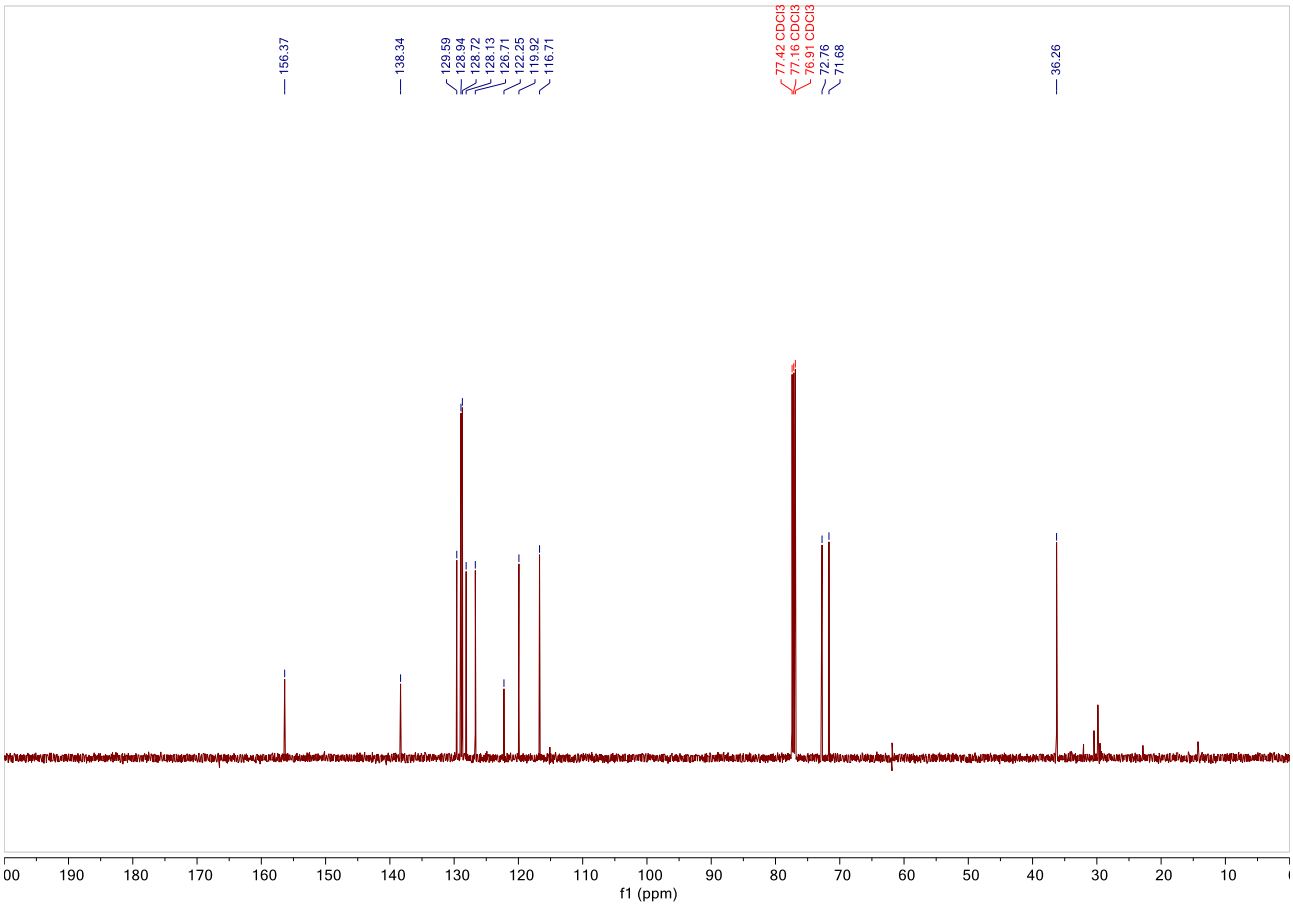


^{1}H NMR (400 MHz, $CDCl_3$)

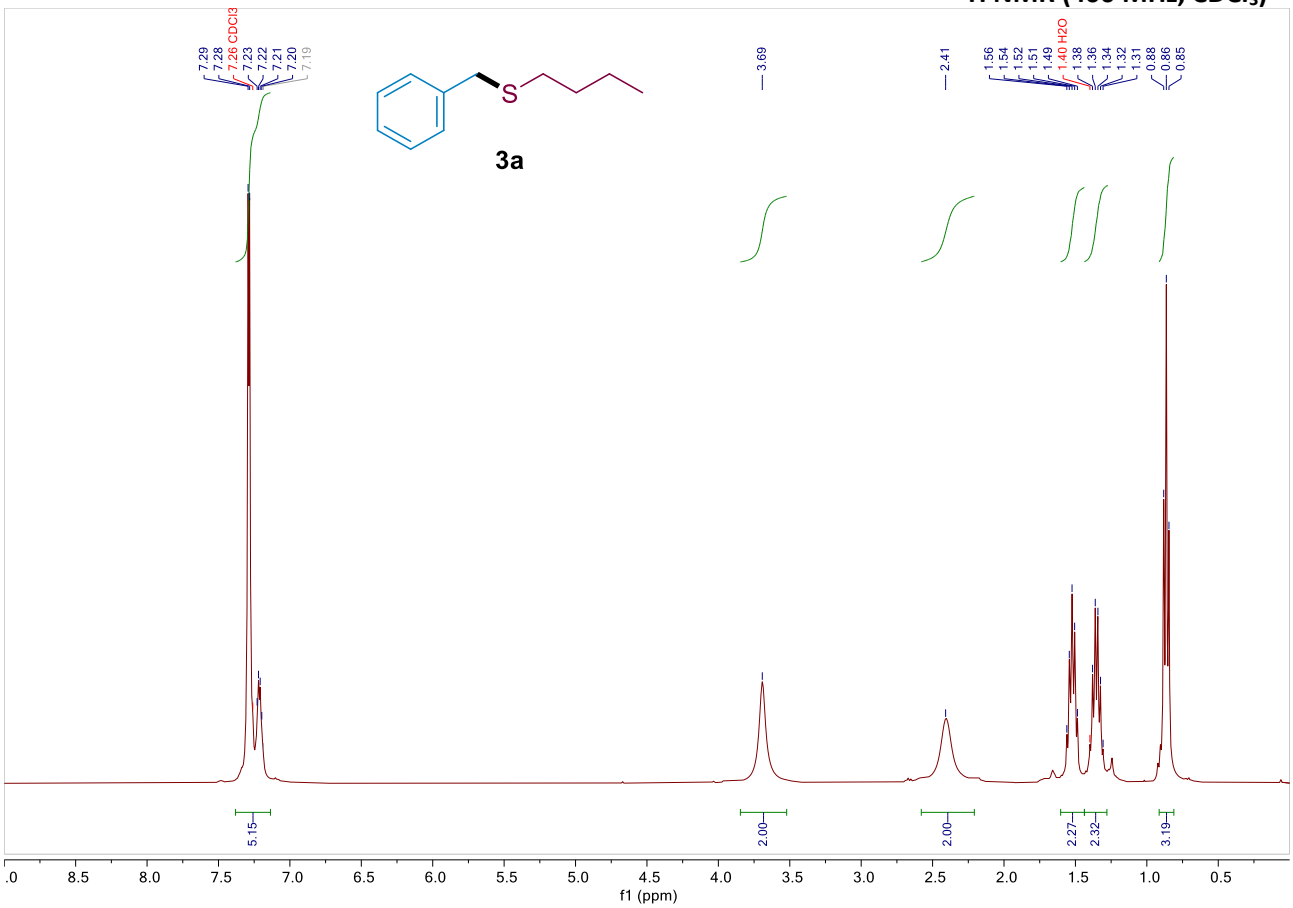


2y'

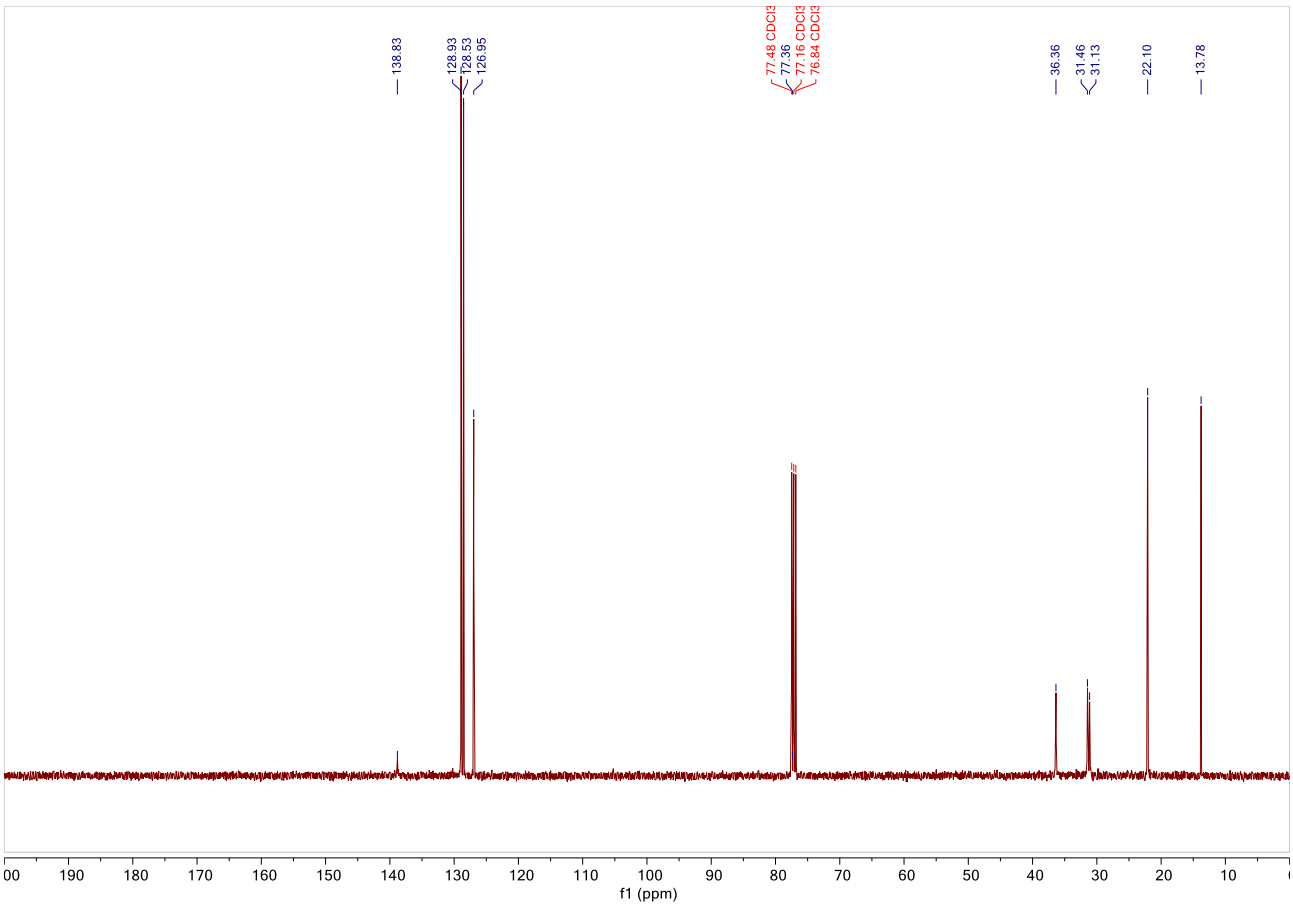
^{13}C NMR (125 MHz, $CDCl_3$)



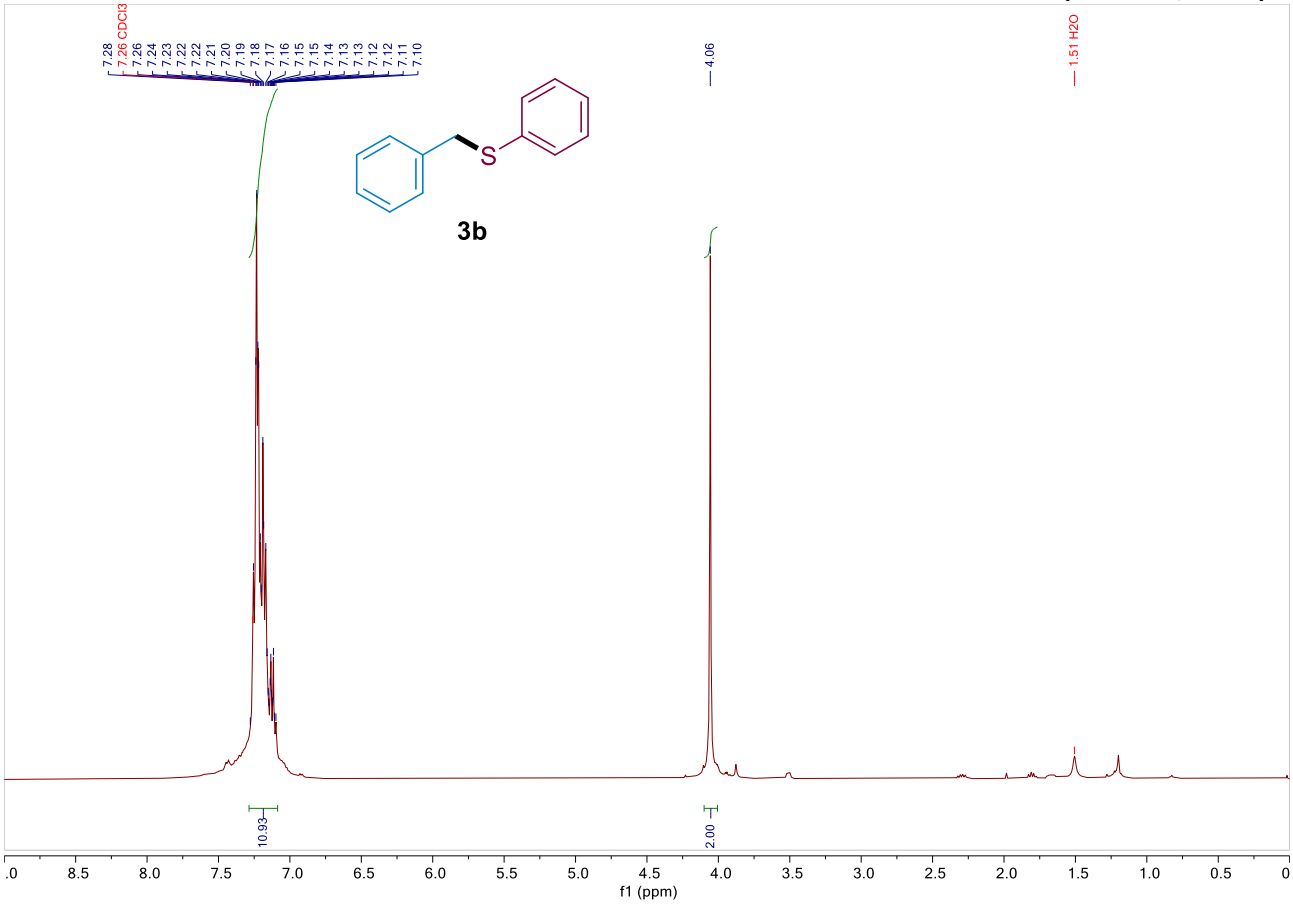
^{1}H NMR (400 MHz, $CDCl_3$)



^{13}C NMR (100 MHz, $CDCl_3$)

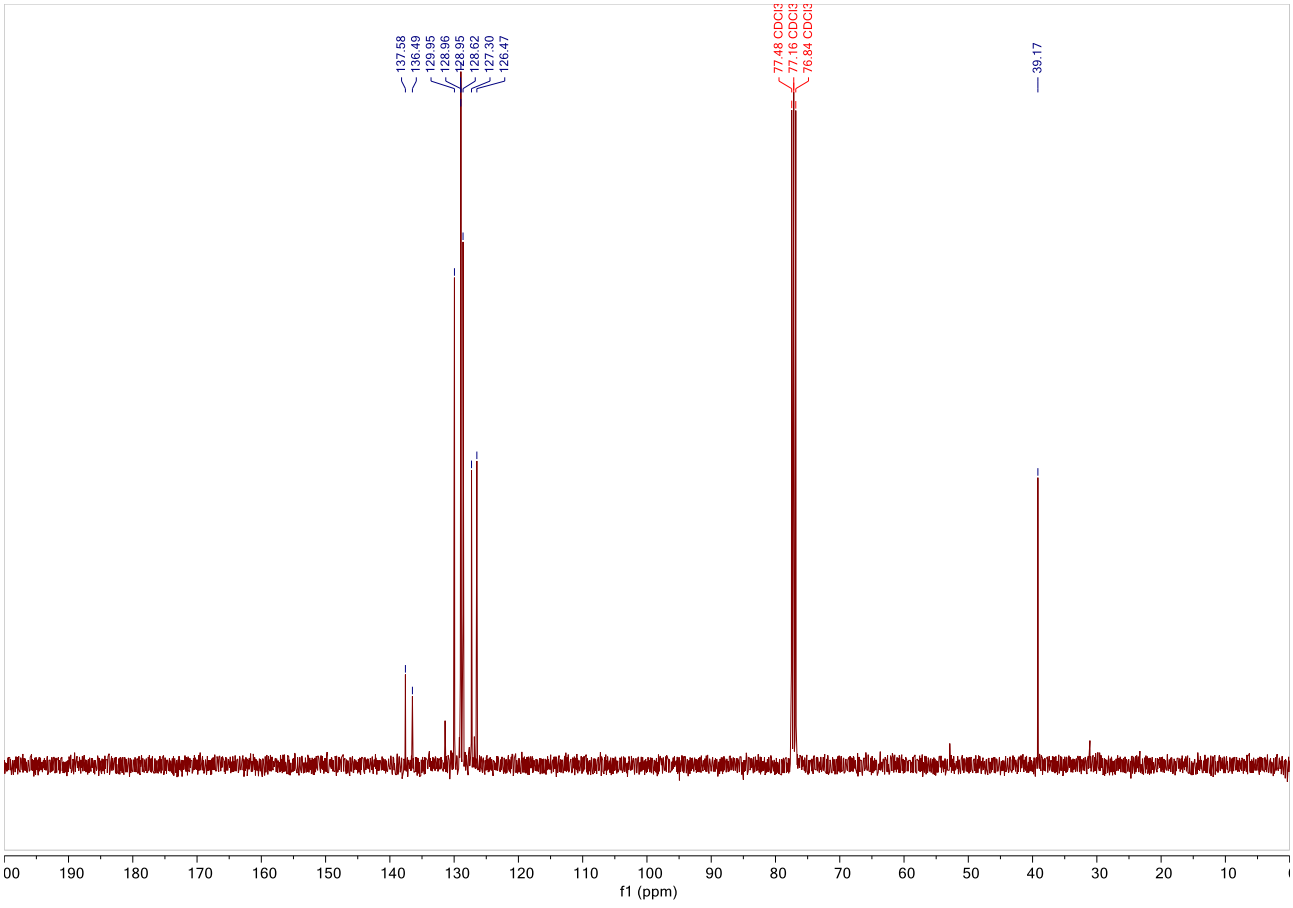


^{1}H NMR (400 MHz, $CDCl_3$)

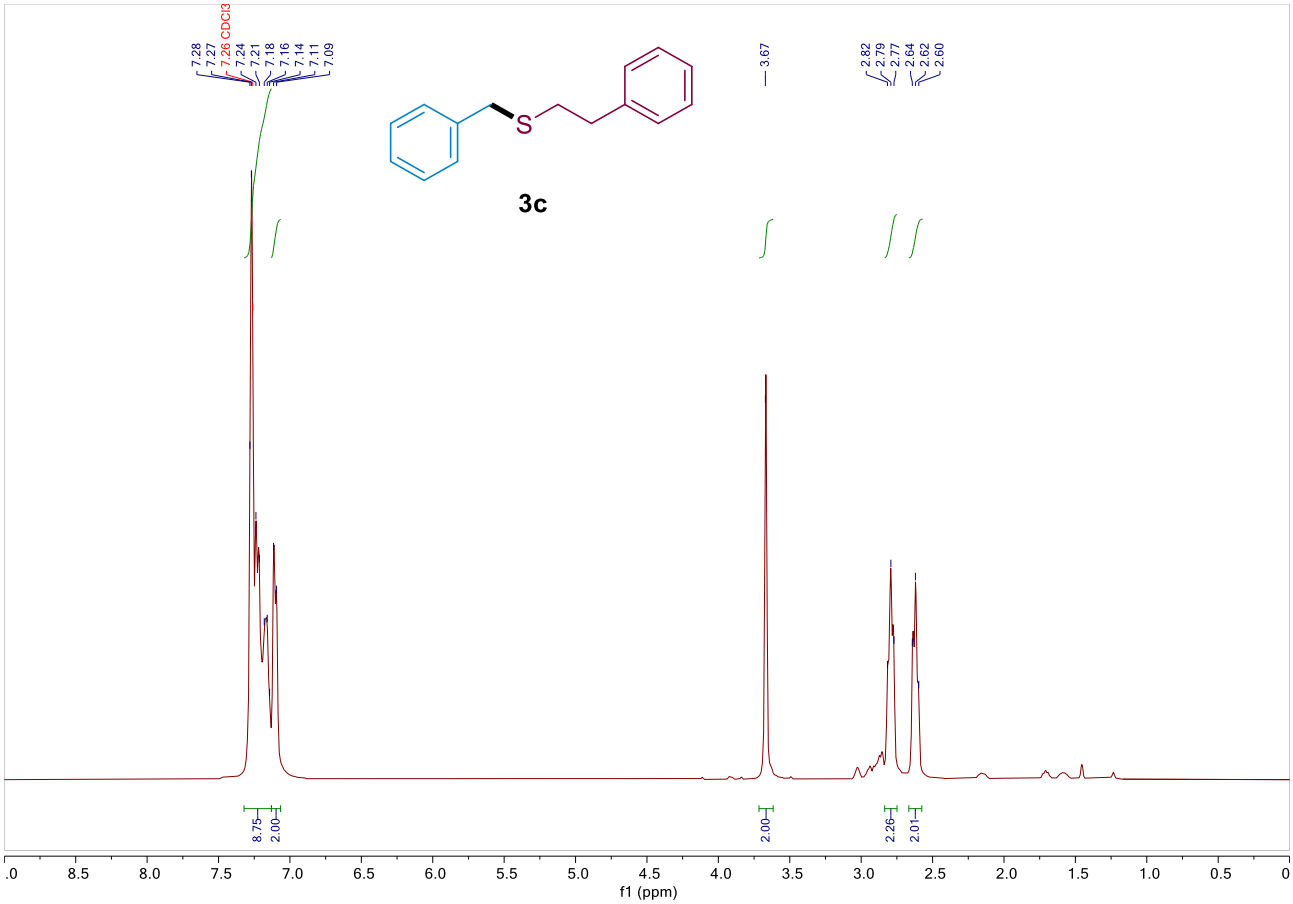


3b

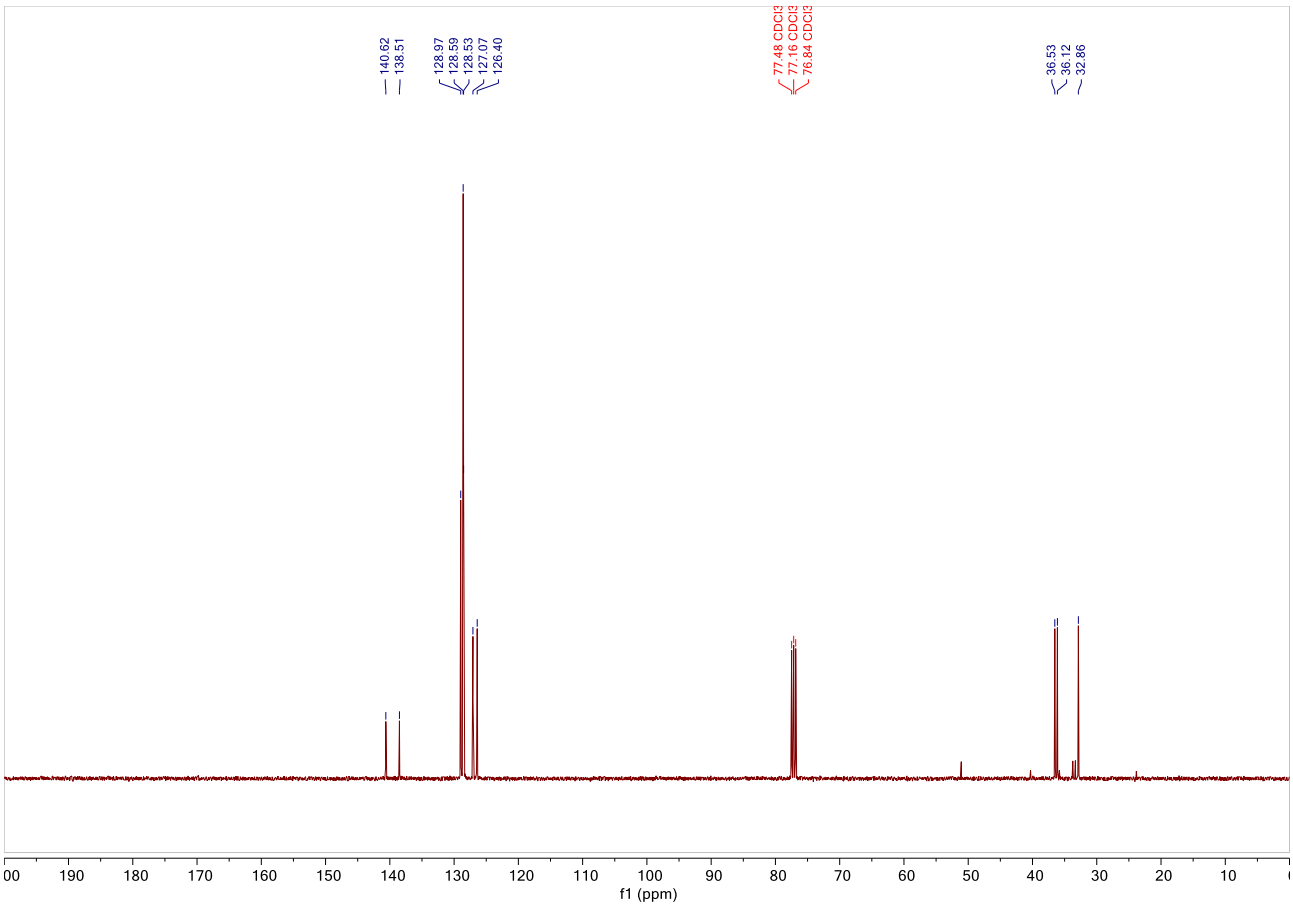
^{13}C NMR (100 MHz, $CDCl_3$)



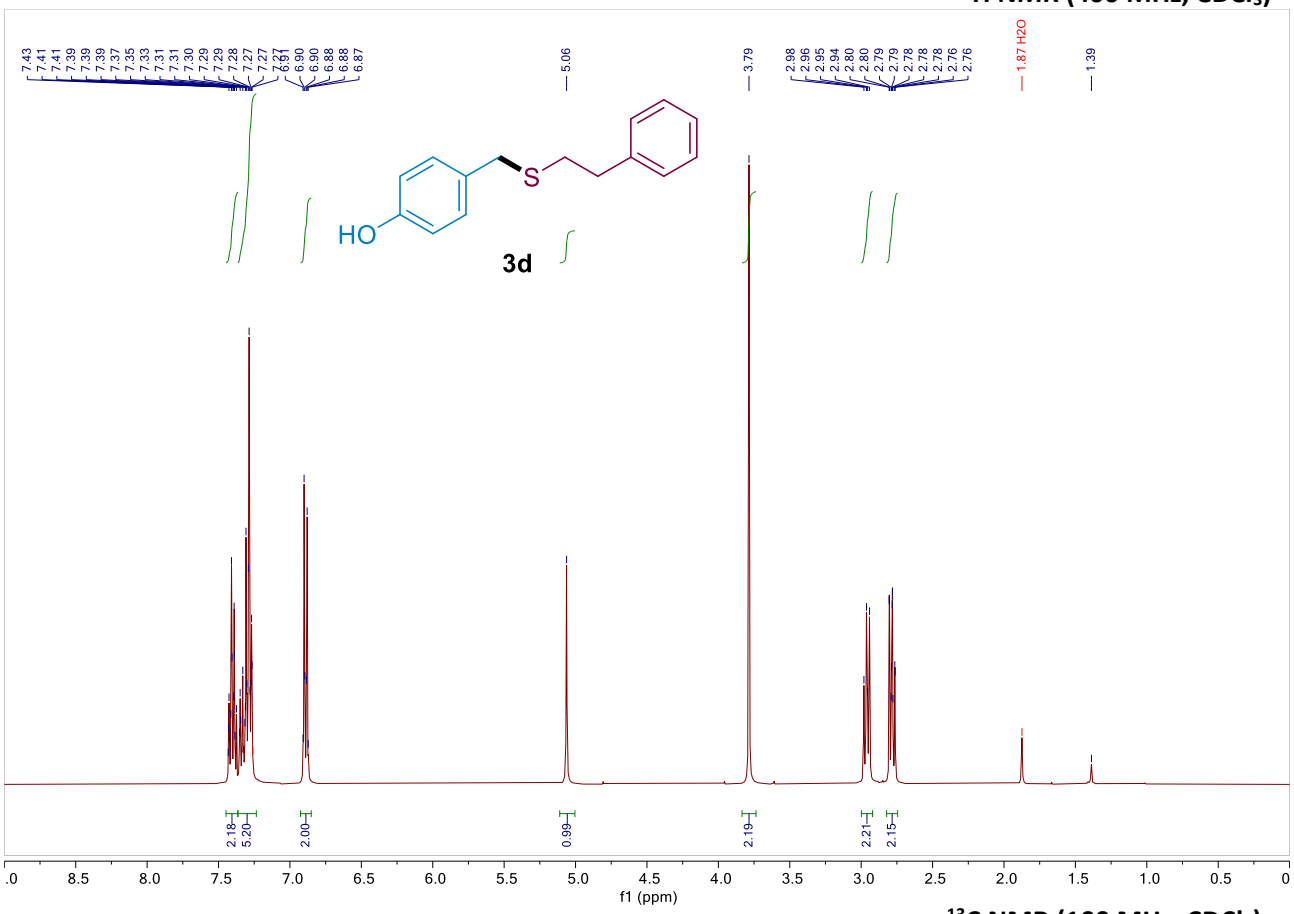
^{1}H NMR (400 MHz, $CDCl_3$)



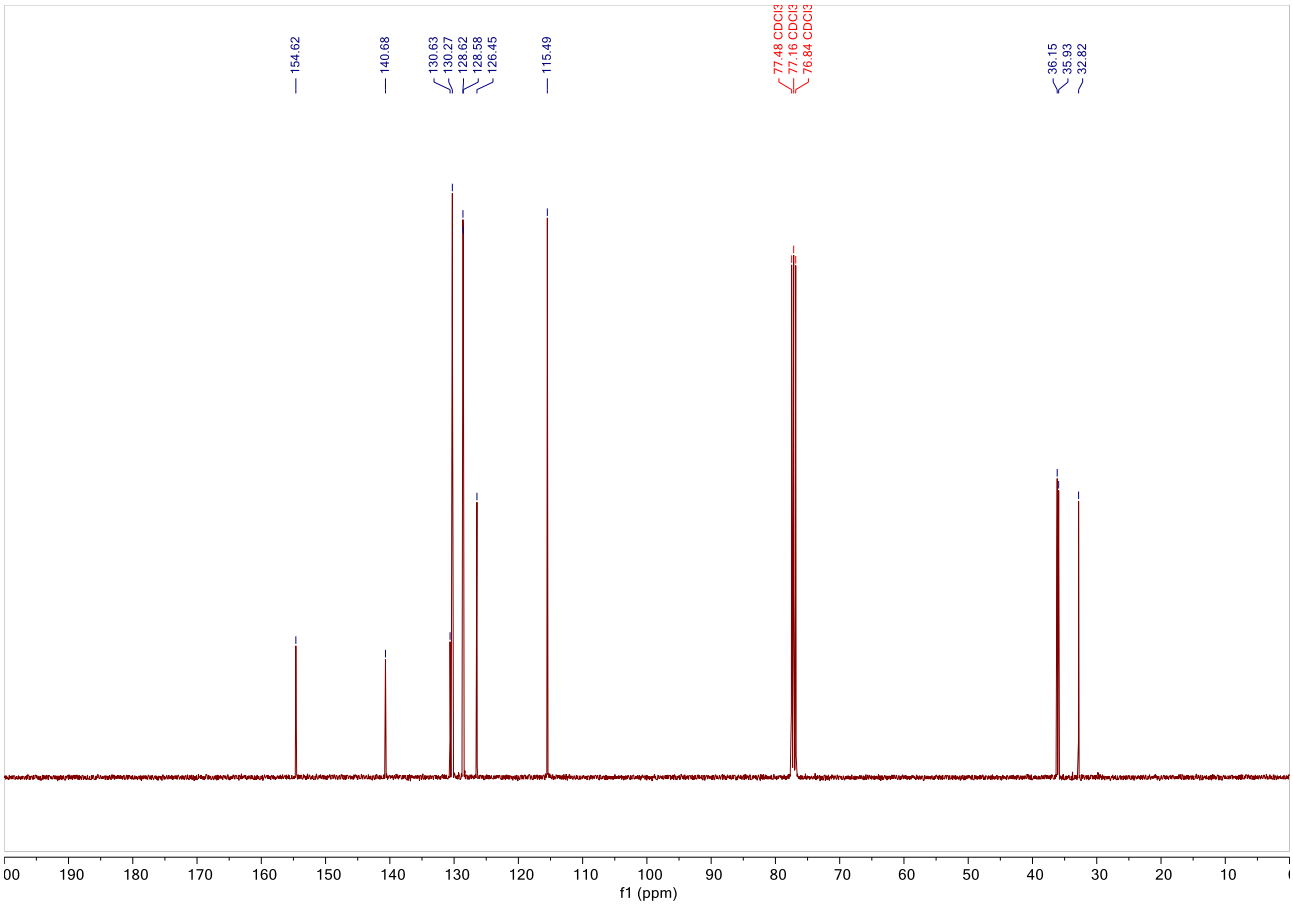
^{13}C NMR (100 MHz, $CDCl_3$)



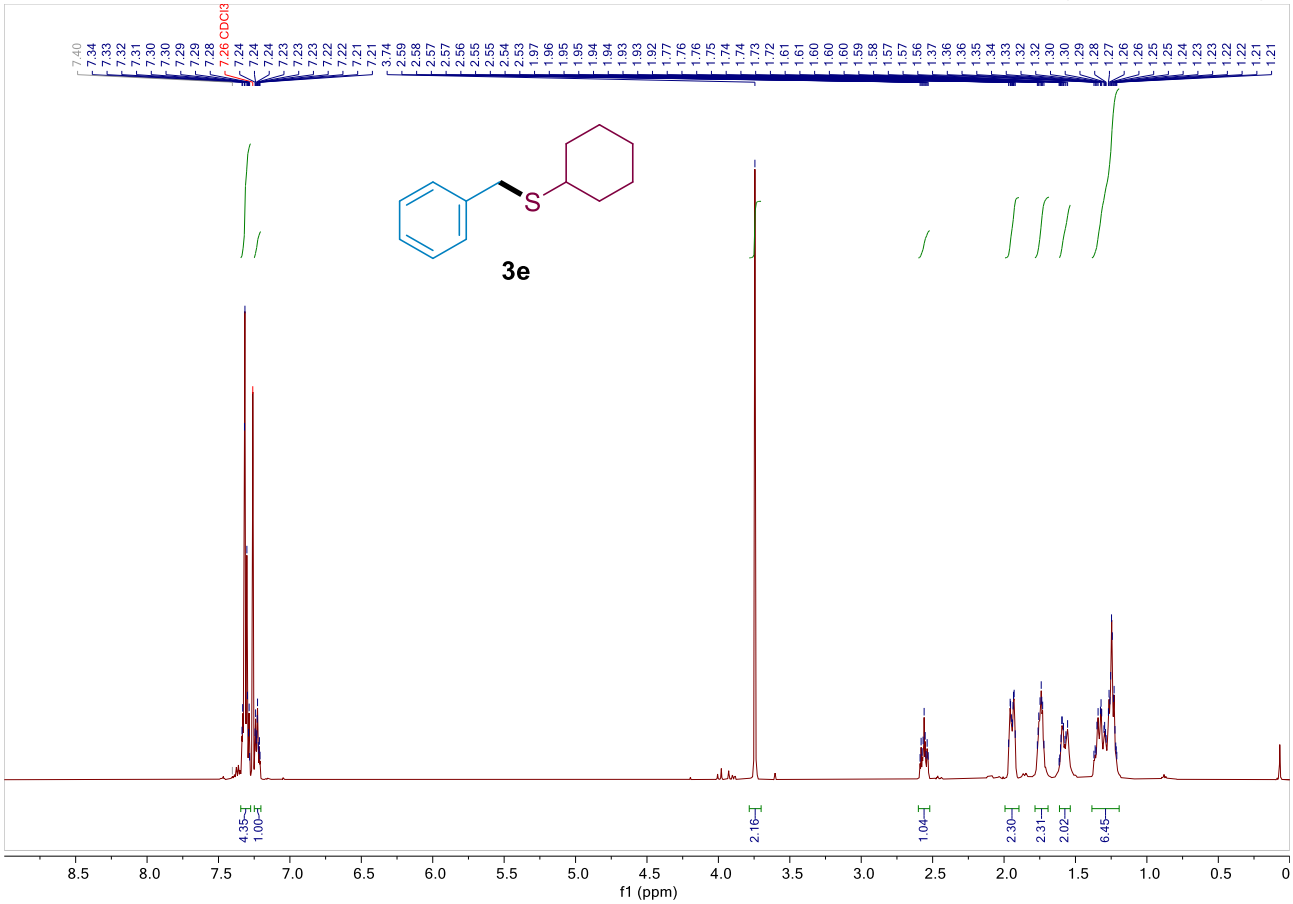
^{1}H NMR (400 MHz, $CDCl_3$)



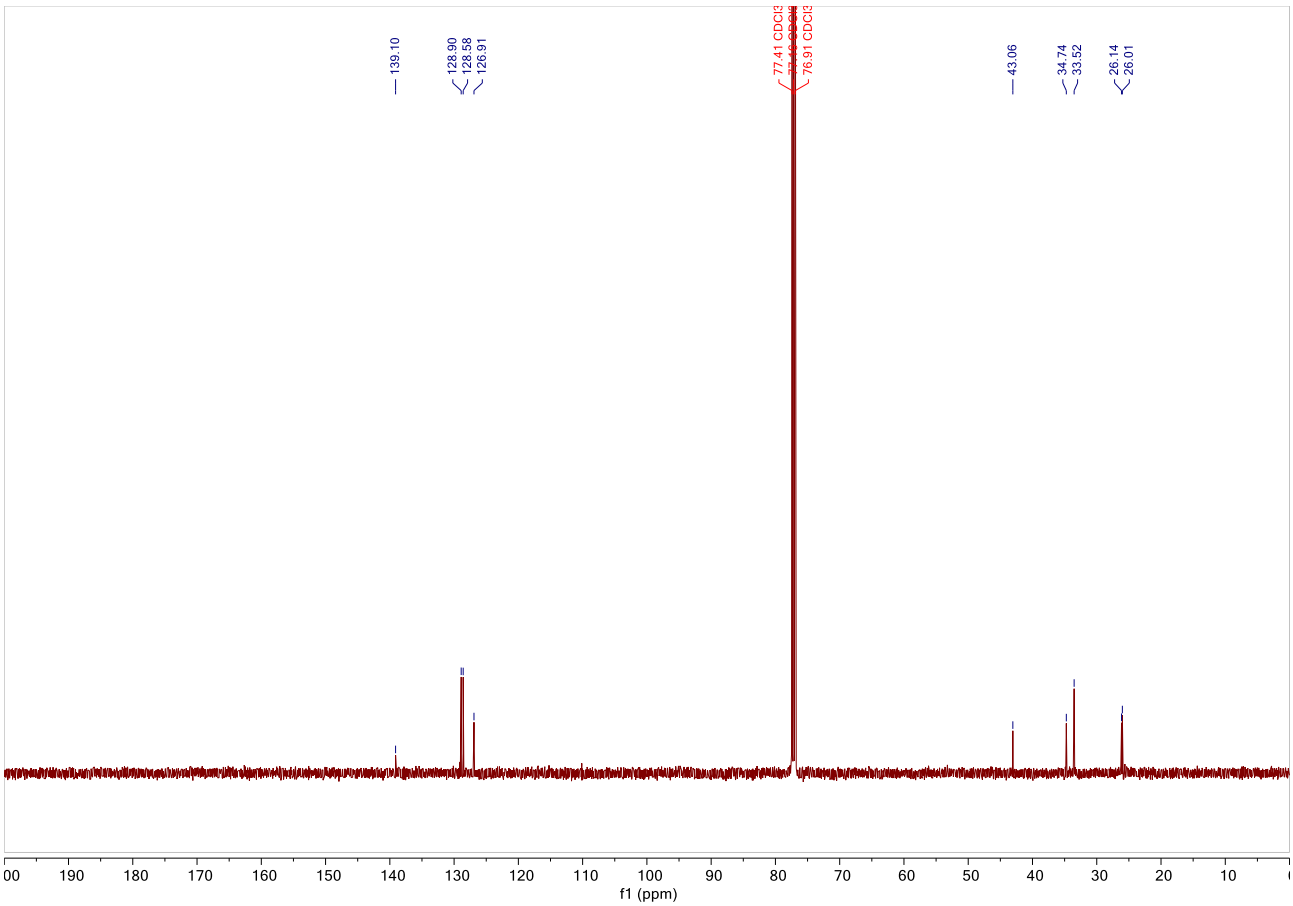
^{13}C NMR (100 MHz, $CDCl_3$)



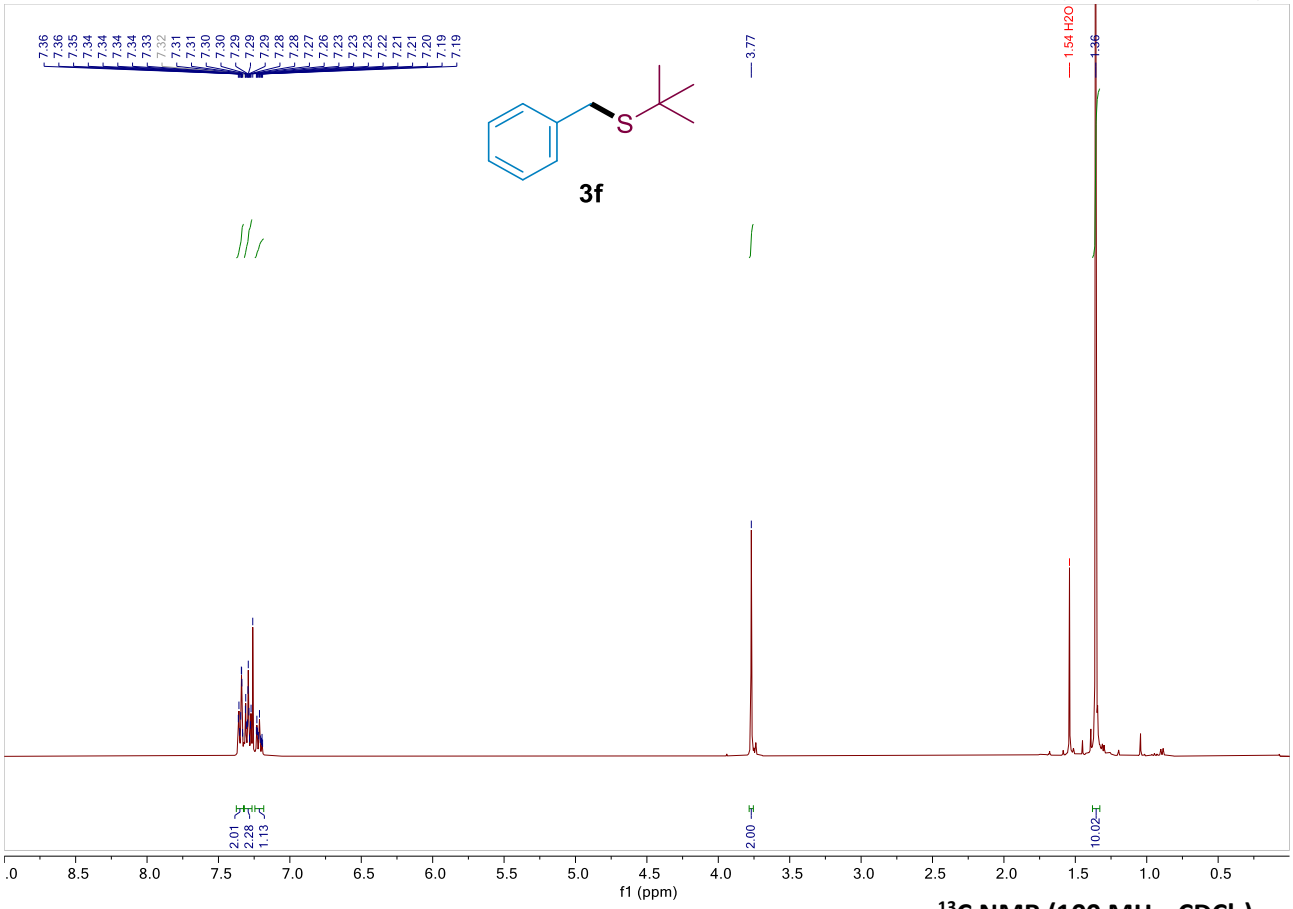
^{1}H NMR (500 MHz, $CDCl_3$)



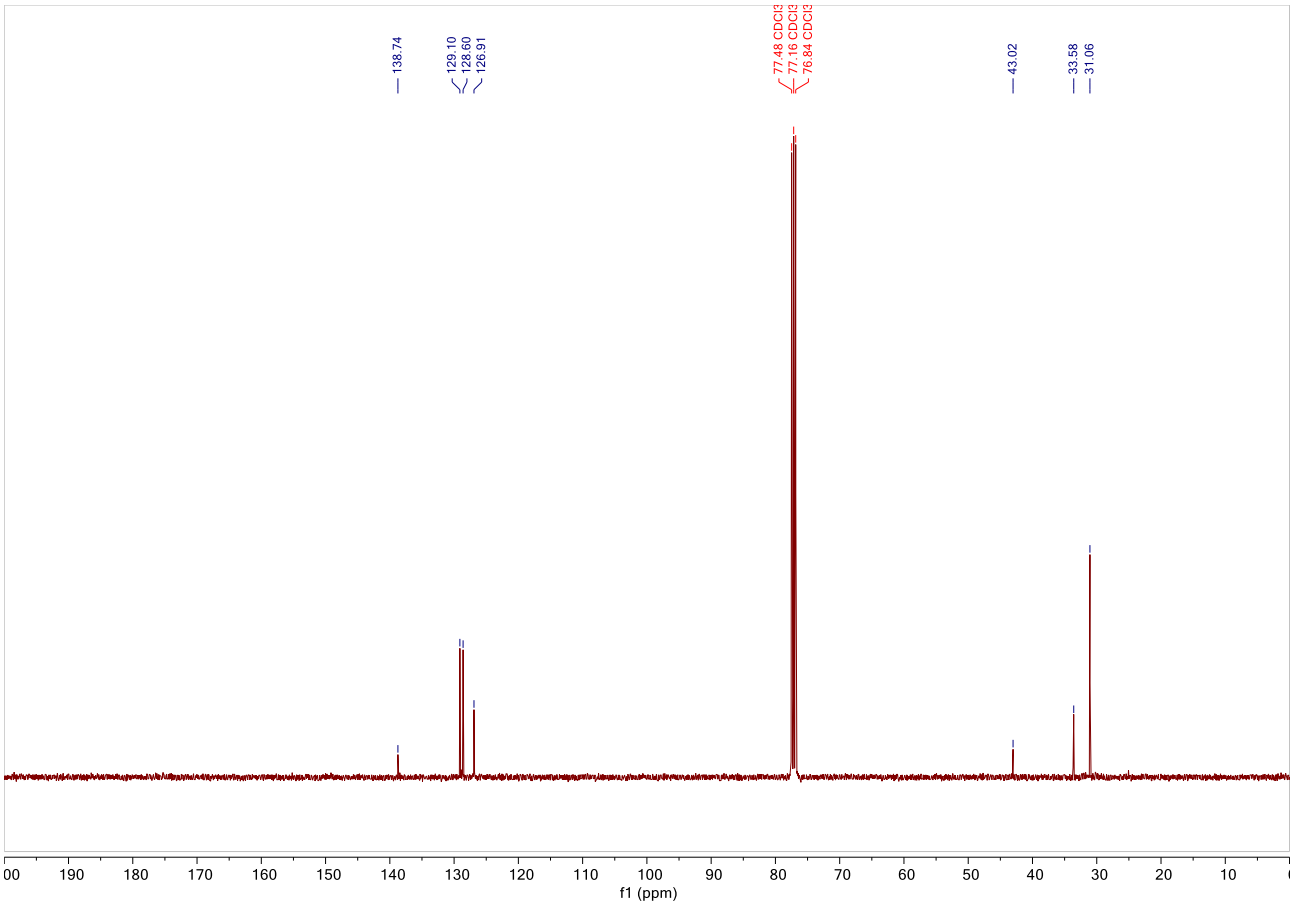
^{13}C NMR (125 MHz, $CDCl_3$)



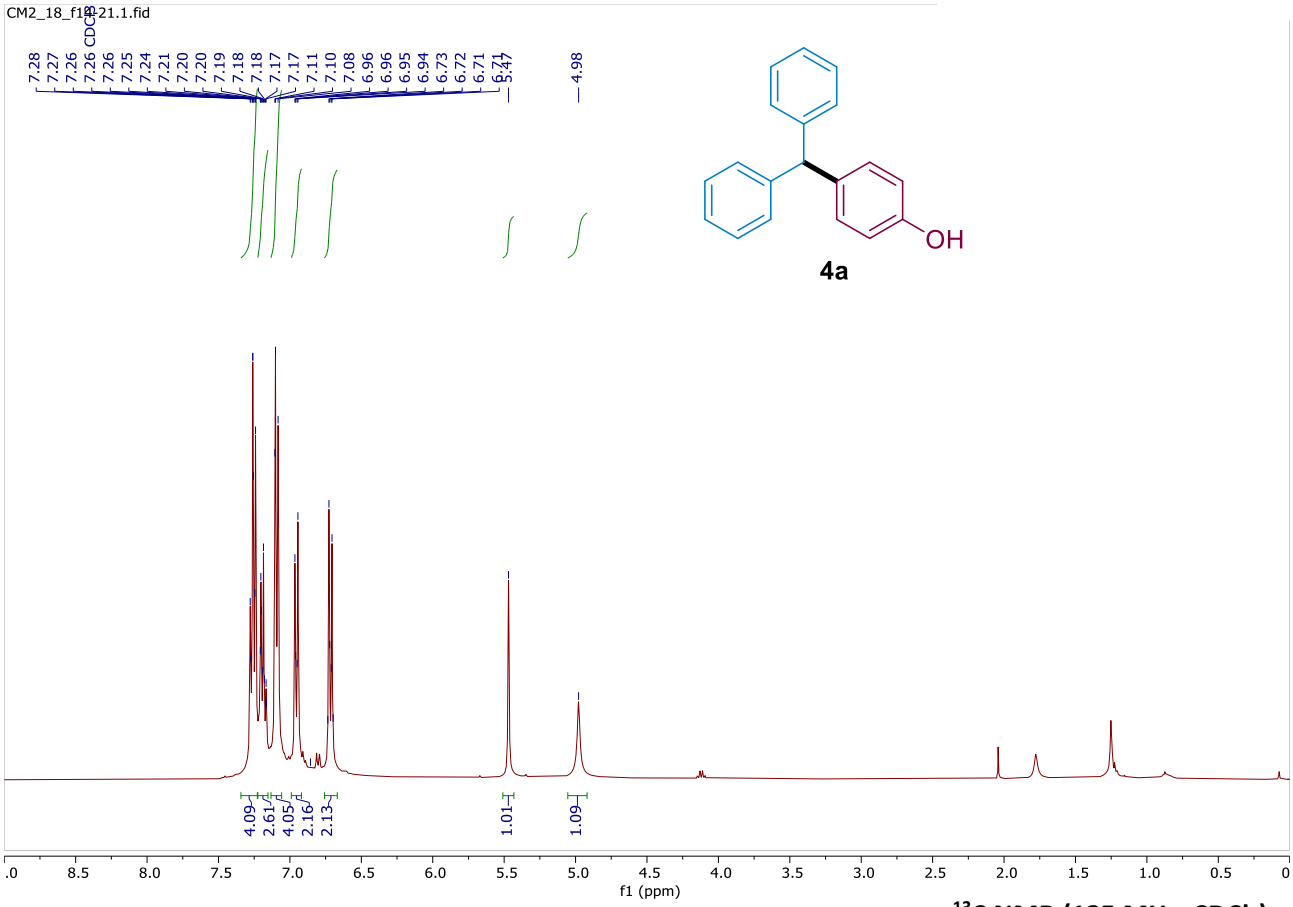
^{1}H NMR (400 MHz, $CDCl_3$)



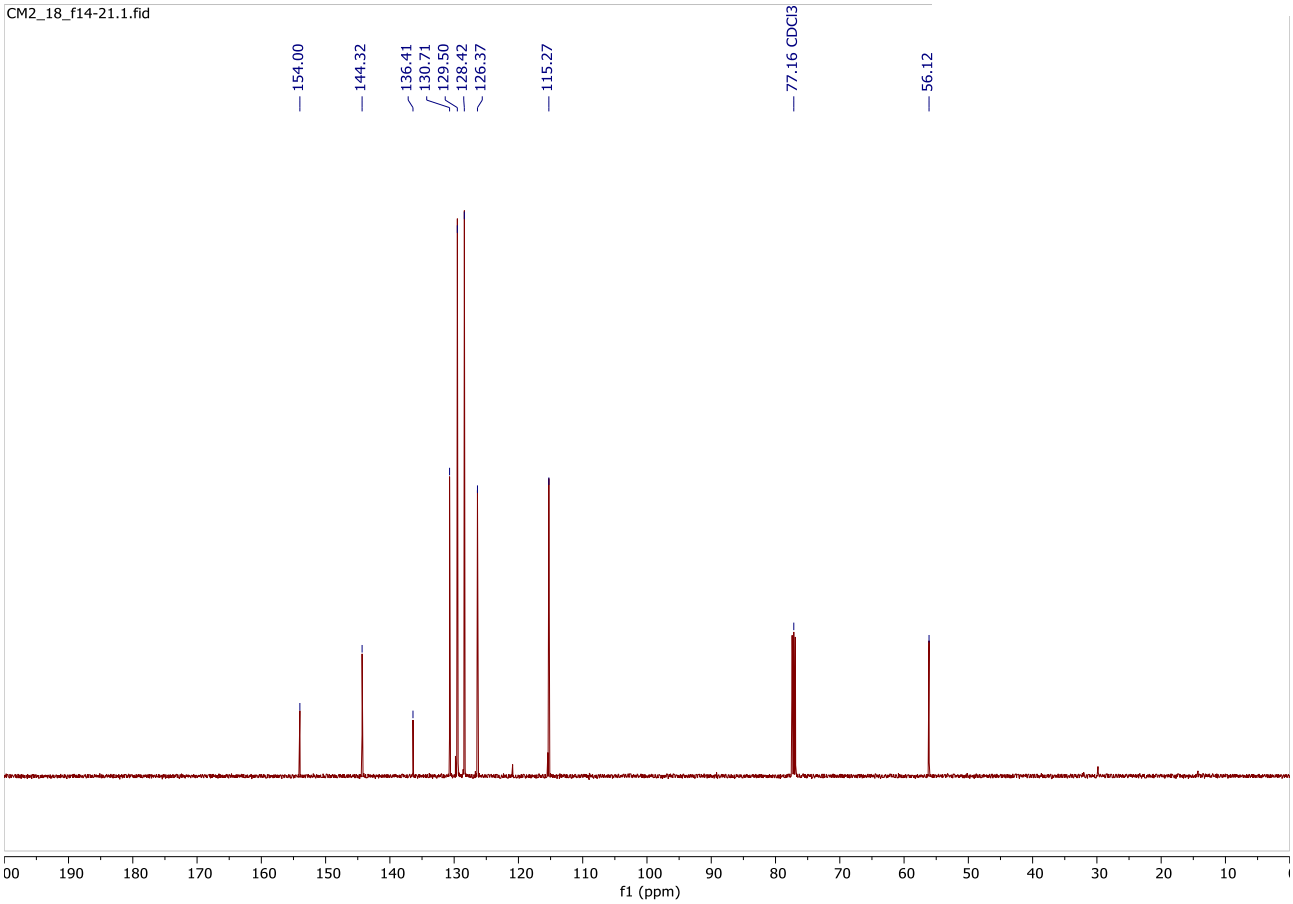
^{13}C NMR (100 MHz, $CDCl_3$)



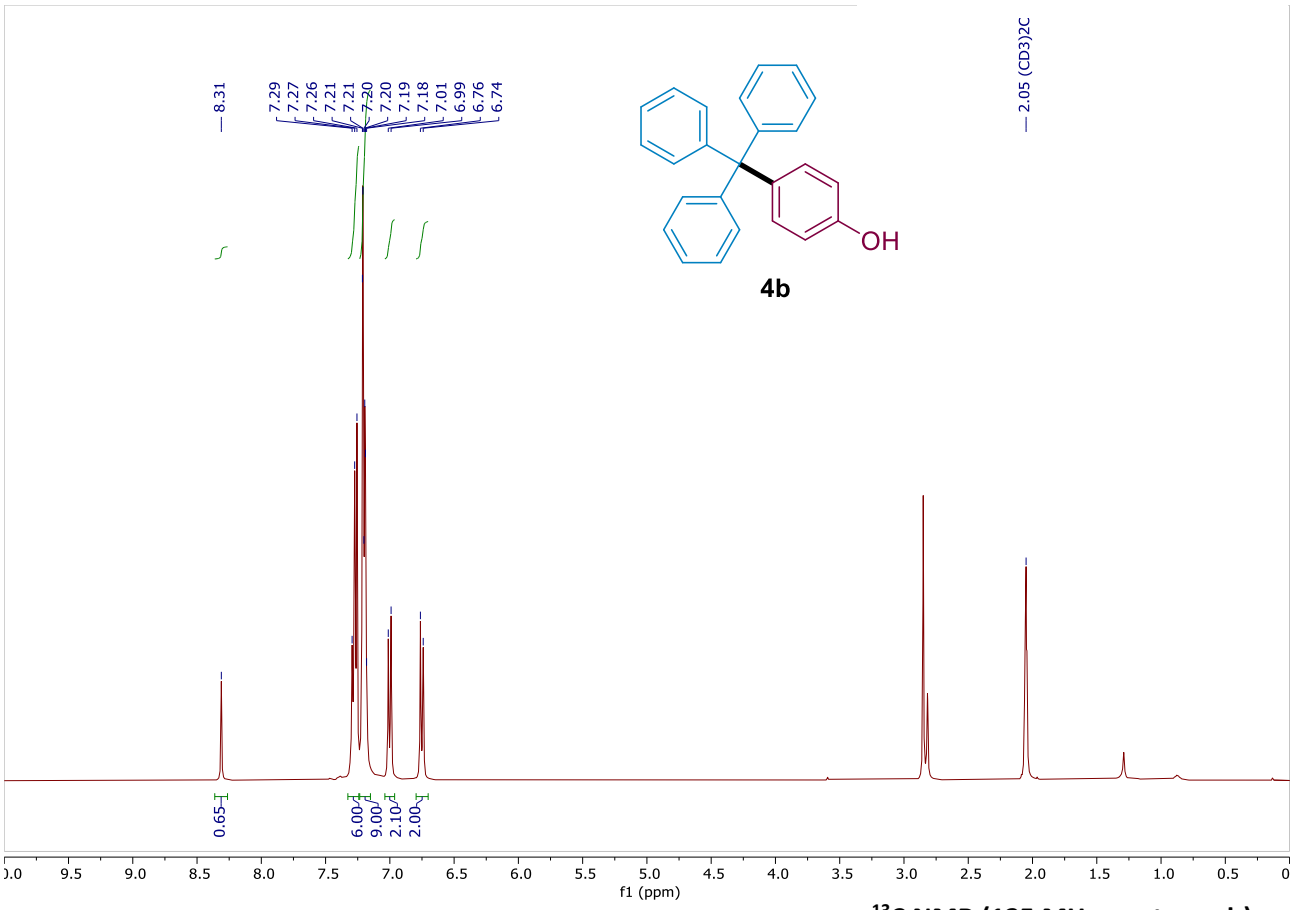
^{1}H NMR (400 MHz, $CDCl_3$)



^{13}C NMR (125 MHz, $CDCl_3$)

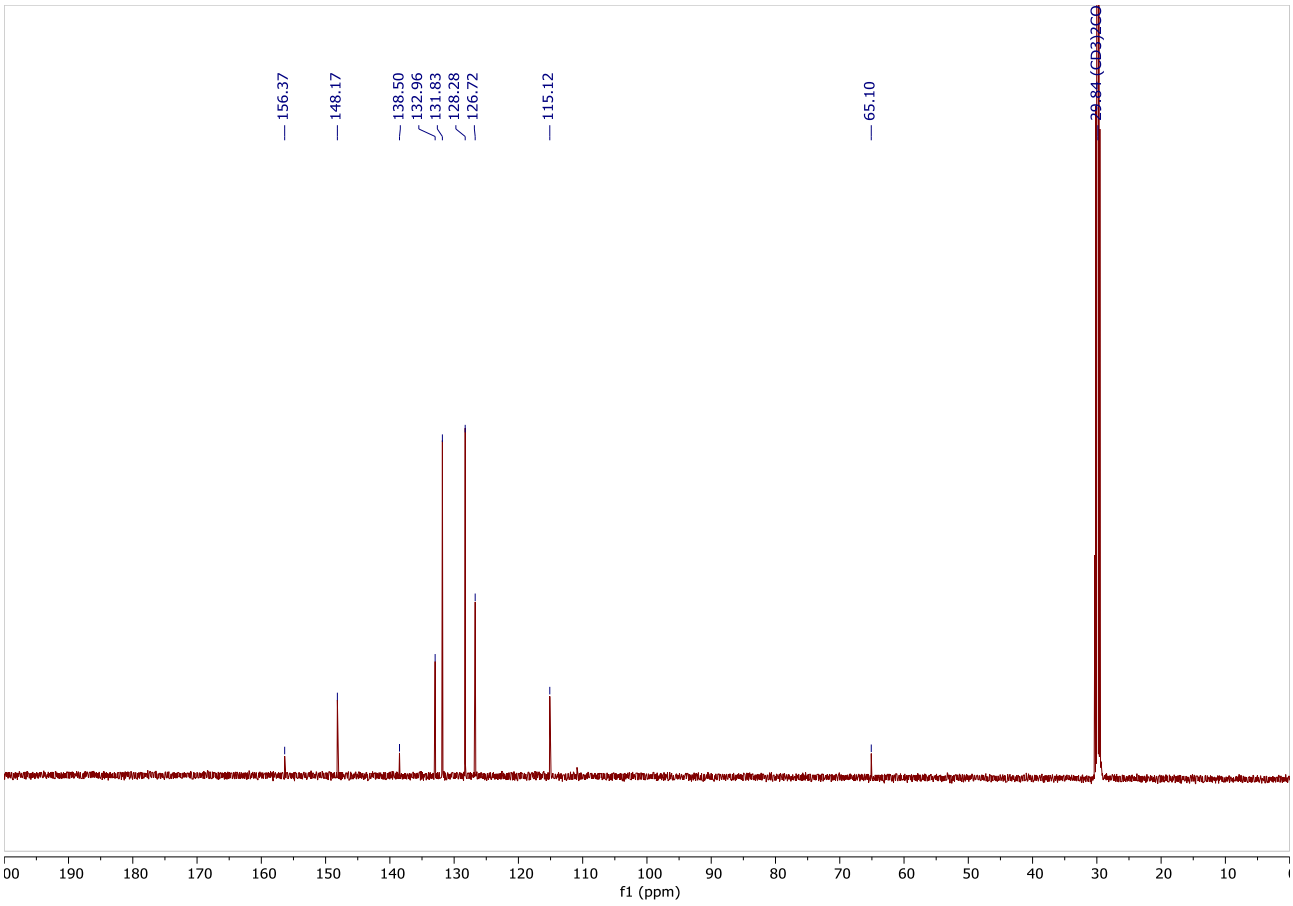


^{1}H NMR (400 MHz, acetone-d_6)

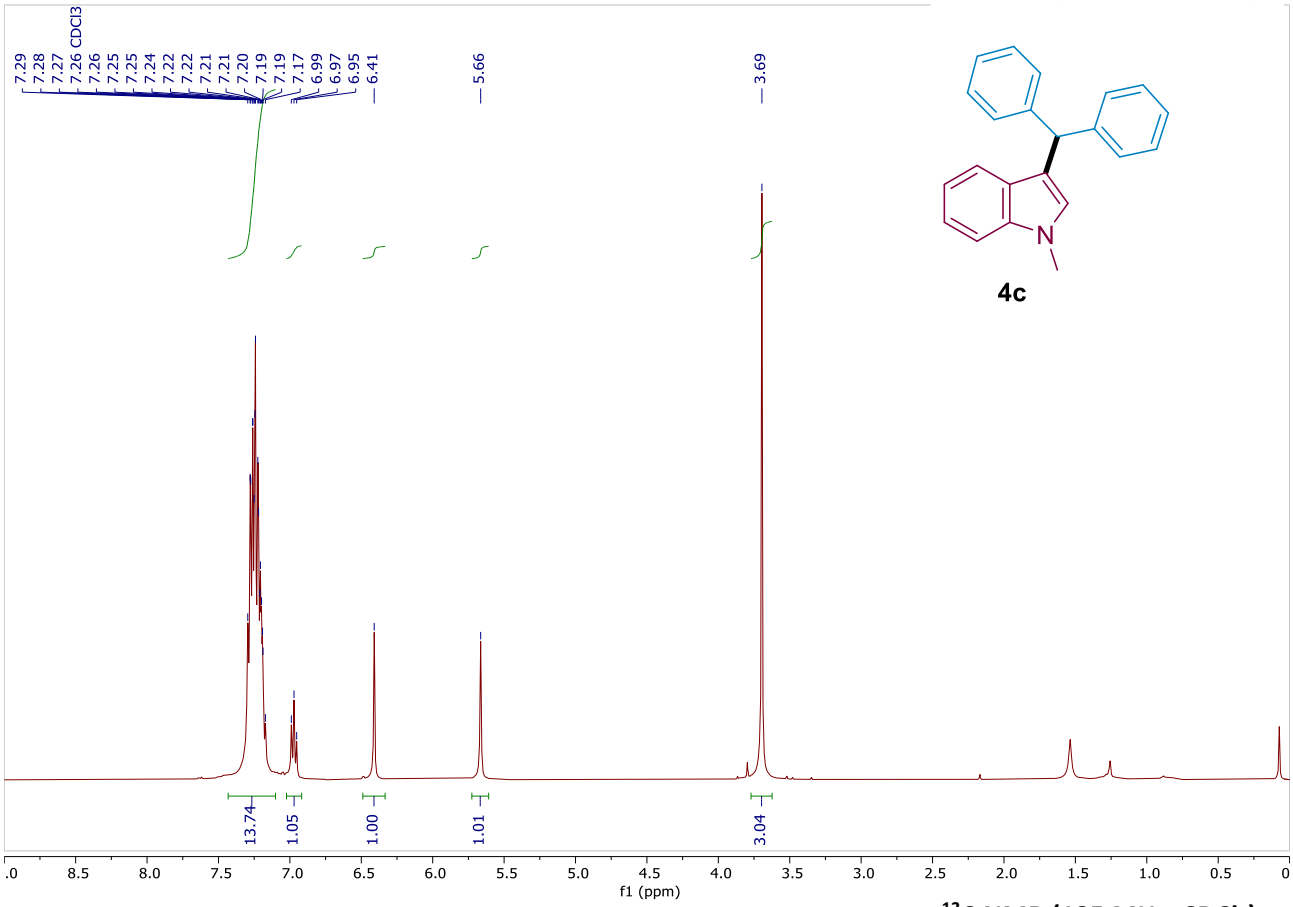


4b

^{13}C NMR (125 MHz, acetone-d_6)

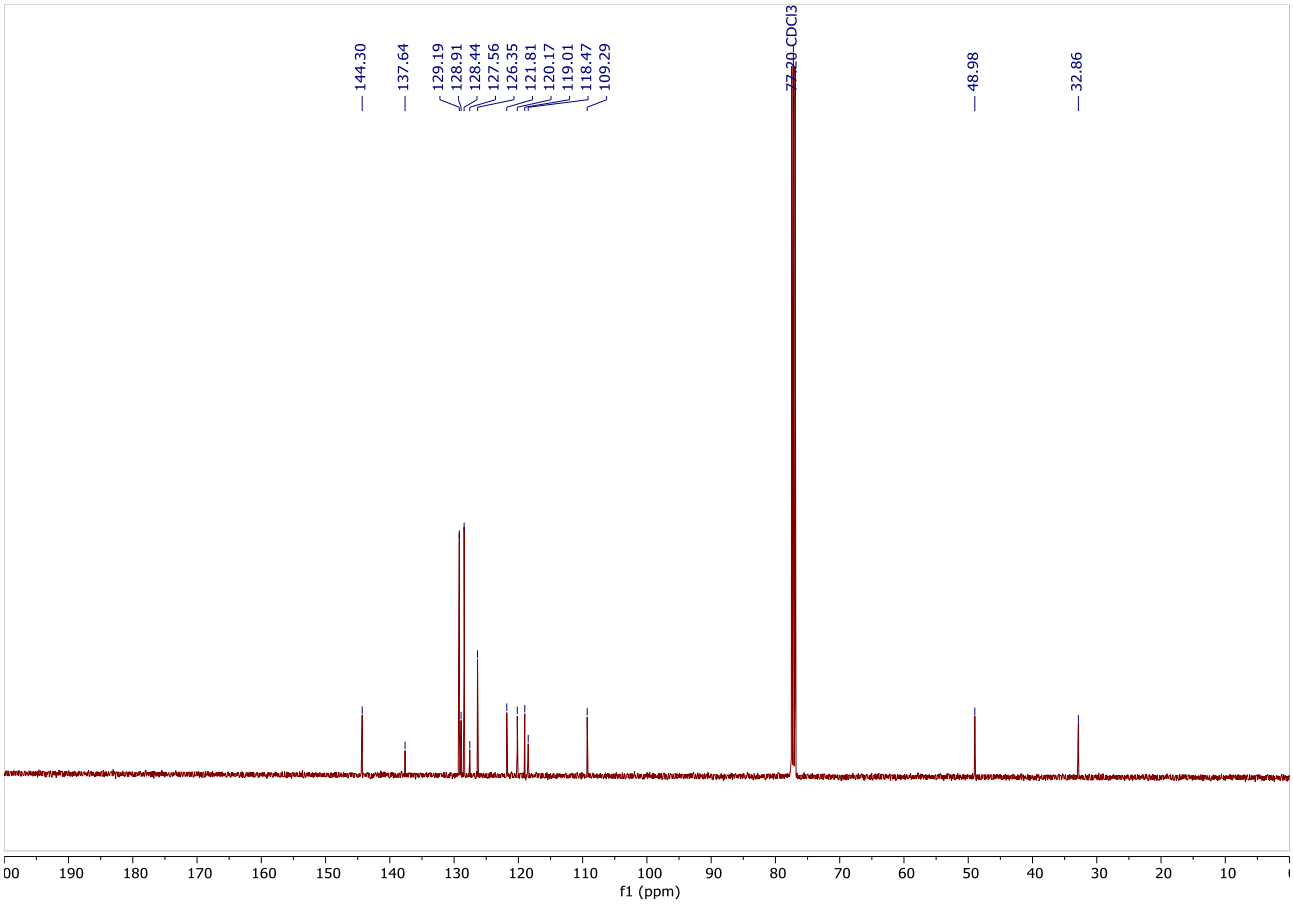


^{1}H NMR (400 MHz, $CDCl_3$)

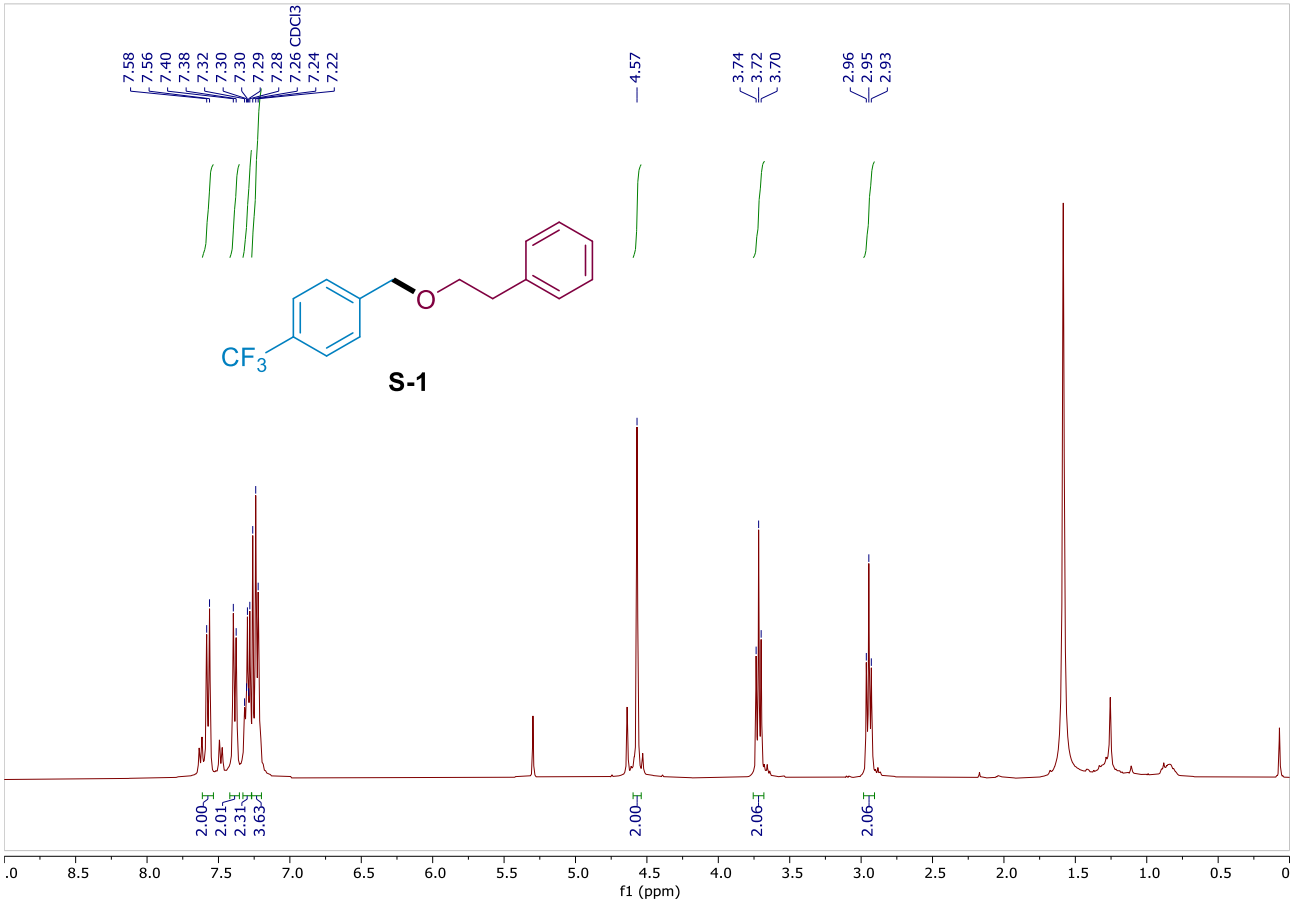


4c

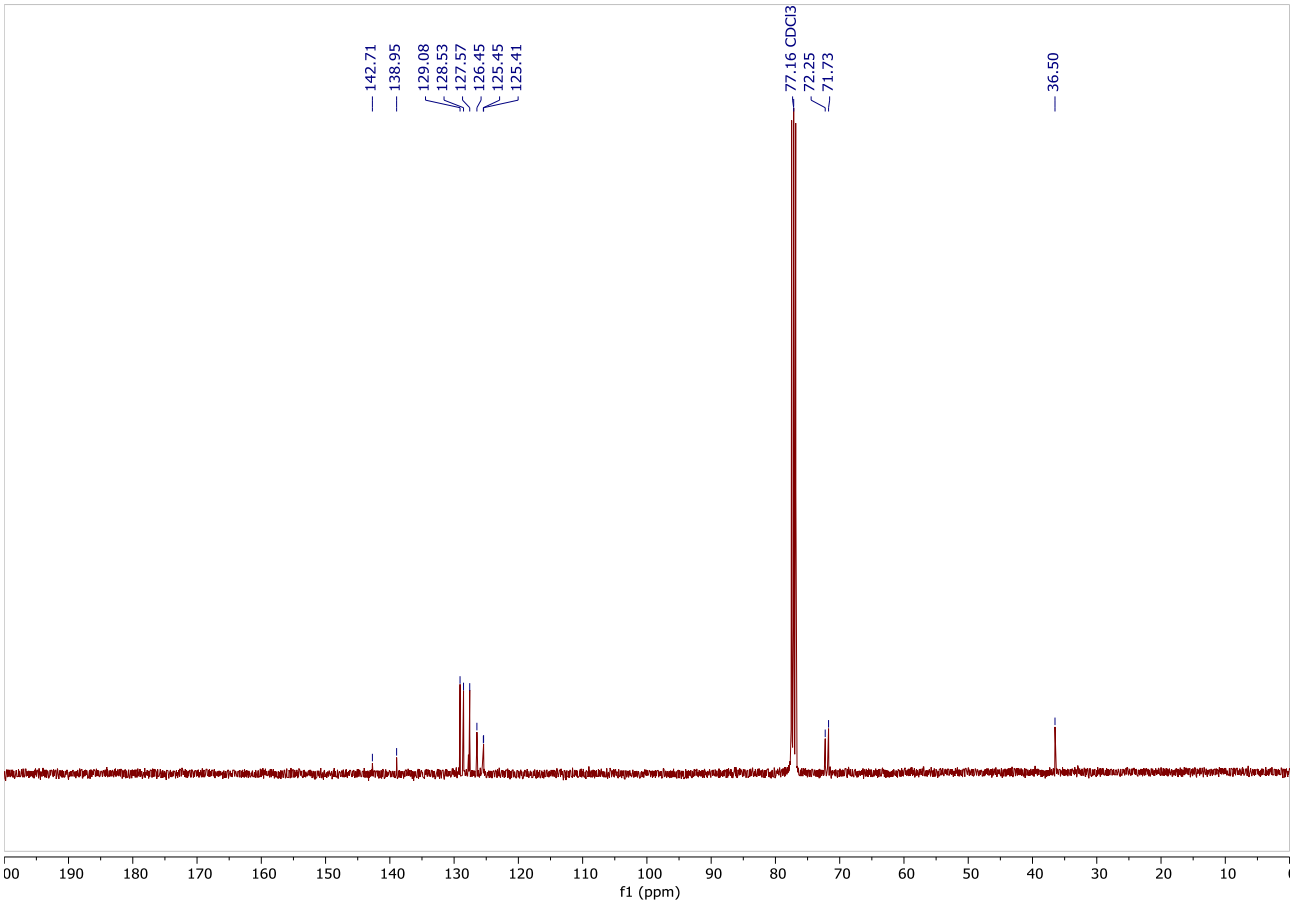
^{13}C NMR (125 MHz, $CDCl_3$)



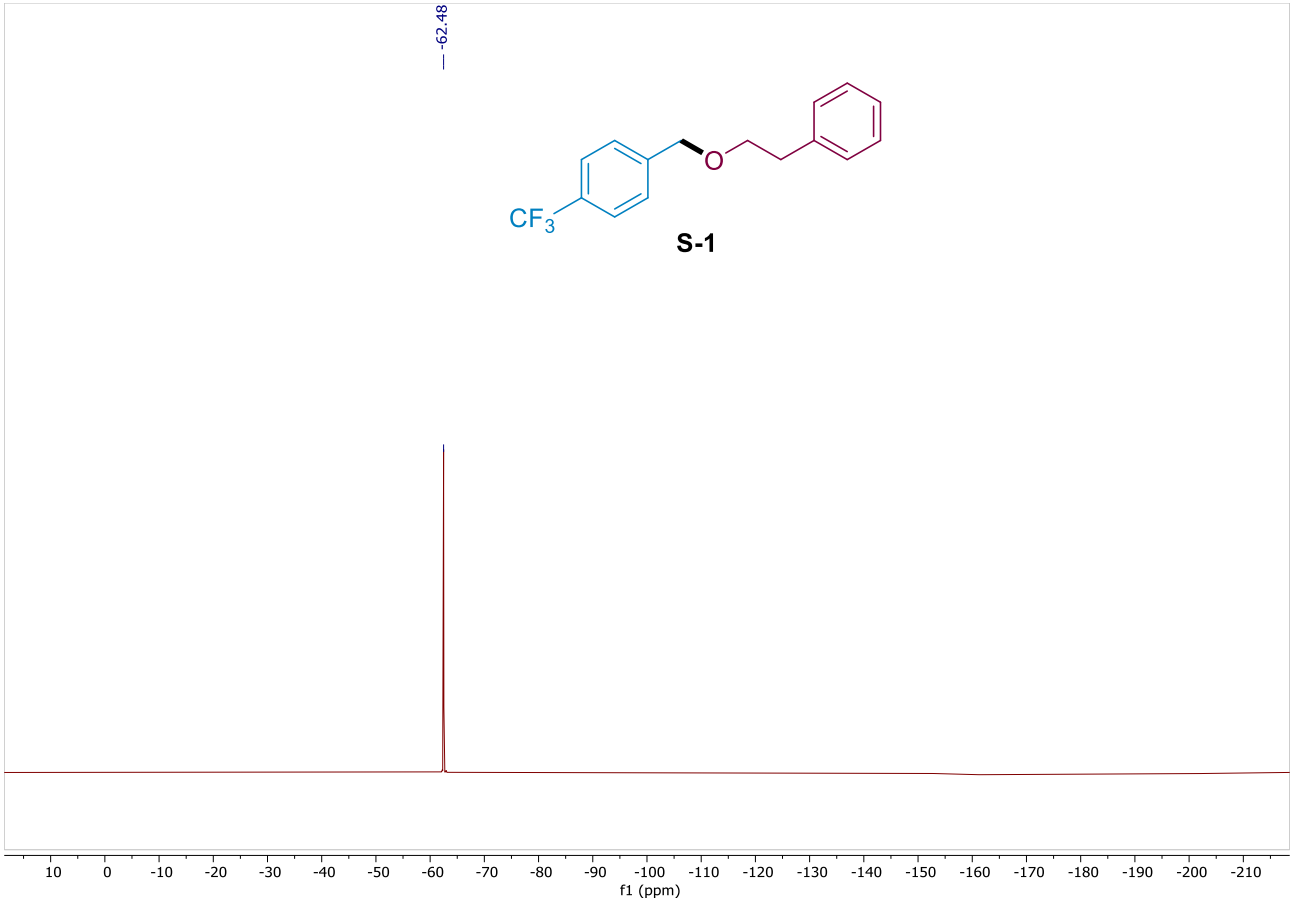
^{1}H NMR (400 MHz, $CDCl_3$)



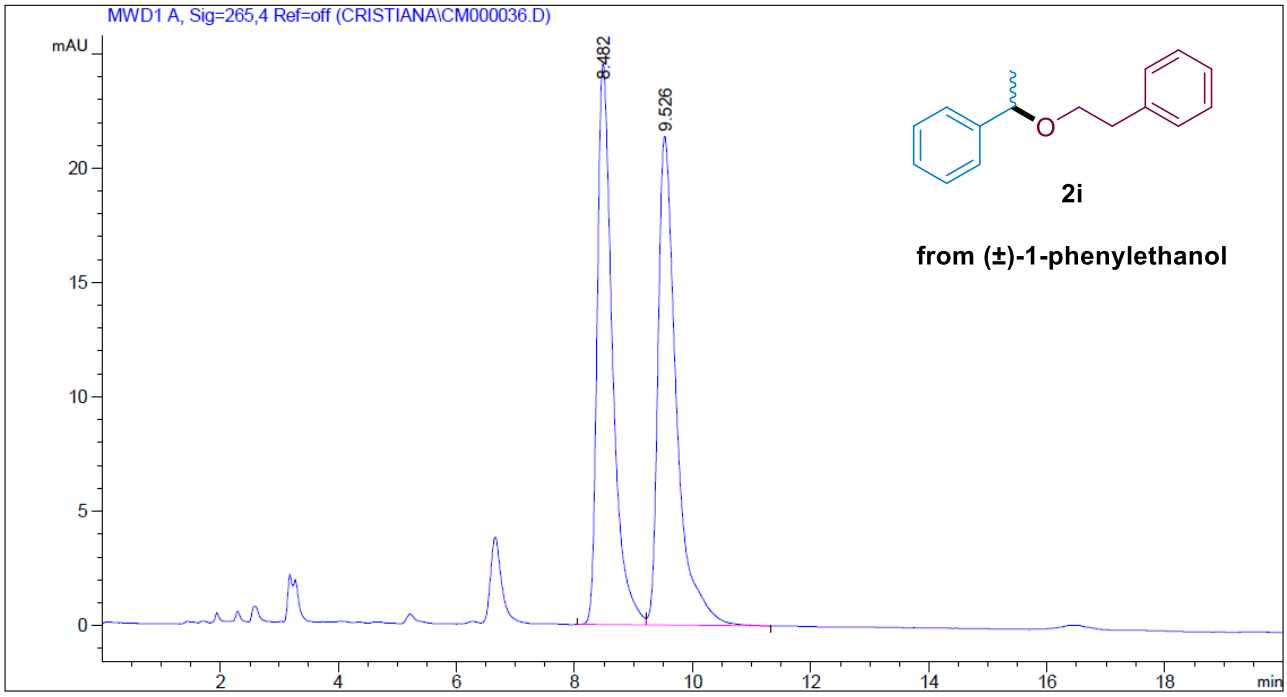
^{13}C NMR (100 MHz, $CDCl_3$)



^{19}F NMR (376 MHz, $CDCl_3$)

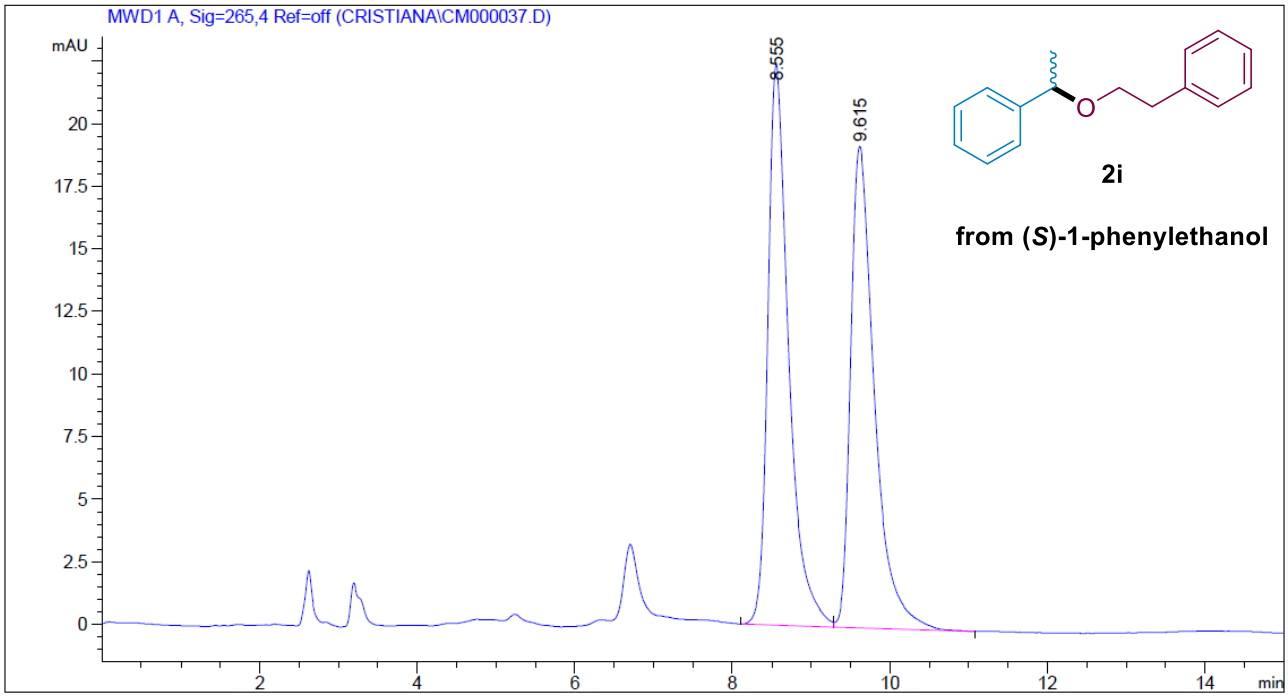


8. HPLC chromatograms



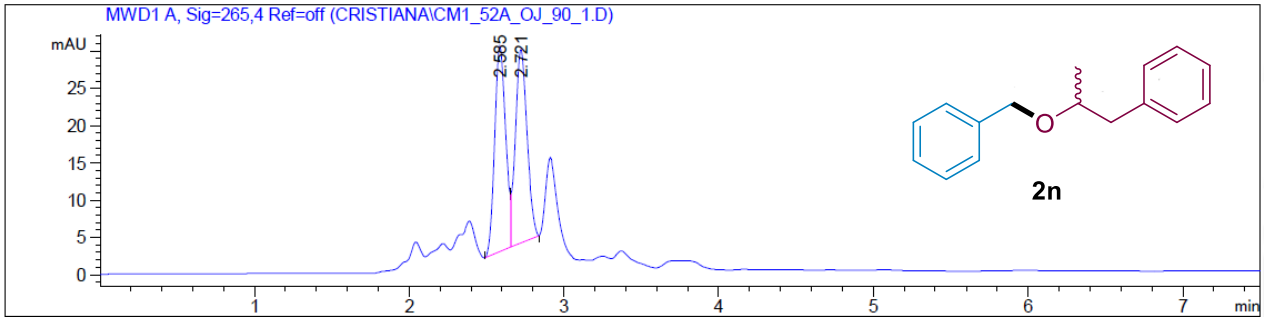
Signal 1: MWD1 A, Sig=265,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.482	BV	0.2706	442.54480	24.51878	48.9236
2	9.526	VB	0.3241	462.01852	21.38008	51.0764
Totals :				904.56332	45.89885	



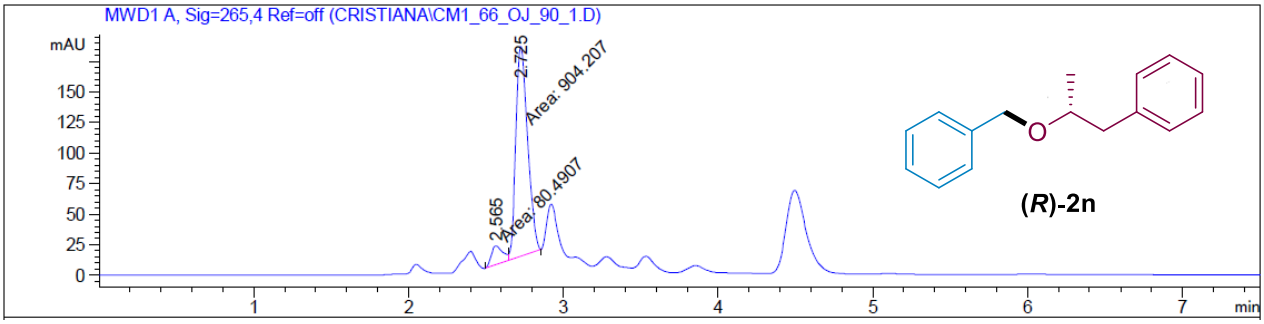
Signal 1: MWD1 A, Sig=265,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.555	BV	0.2775	413.32761	22.37652	50.5380
2	9.615	VB	0.3174	404.52692	19.23355	49.4620
Totals :				817.85452	41.61007	



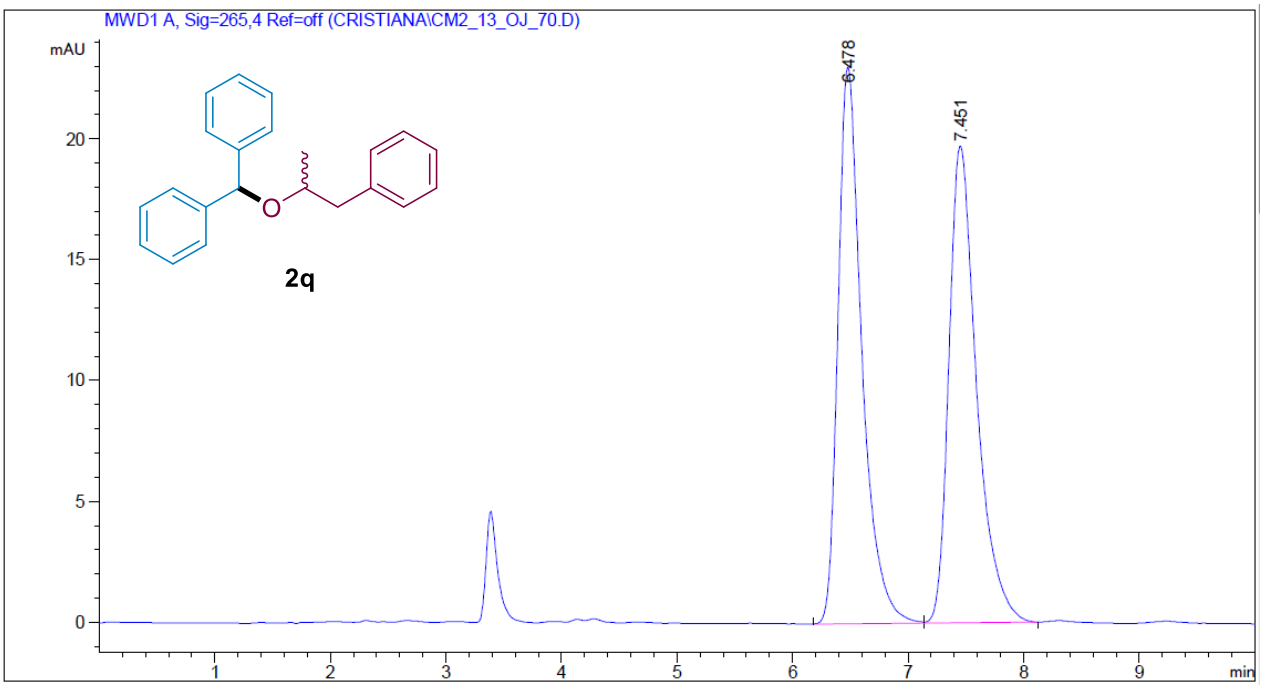
Signal 1: MWD1 A, Sig=265,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	2.585	BV	0.0746	133.70844	27.55894	49.7160
2	2.721	VB	0.0806	135.23611	26.04620	50.2840
Totals :				268.94455	53.60514	



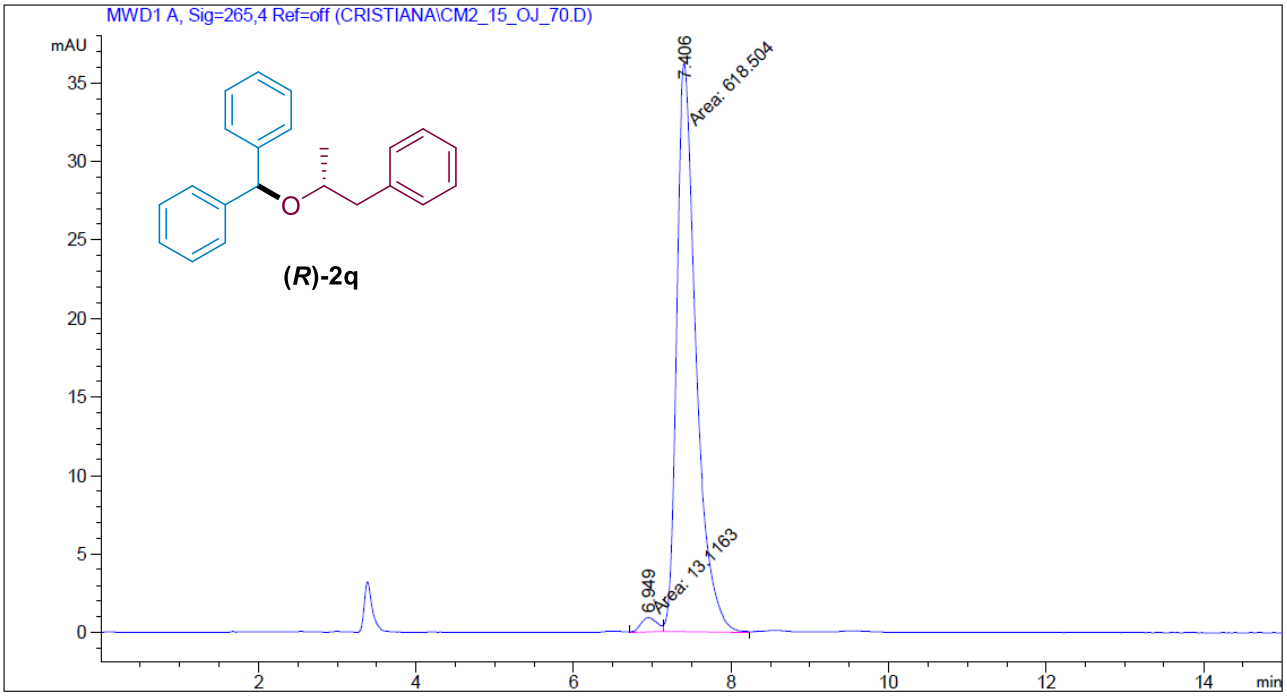
Signal 1: MWD1 A, Sig=265,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	2.565	MF	0.0853	80.49066	15.73408	8.1741
2	2.725	FM	0.0872	904.20709	172.85590	91.8259
Totals :				984.69775	188.58997	



Signal 1: MWD1 A, Sig=265,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.478	BV	0.2157	331.19159	23.03609	50.1926
2	7.451	VB	0.2503	328.64987	19.72999	49.8074
Totals :				659.84146	42.76608	



Signal 1: MWD1 A, Sig=265,4 Ref=off

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.949	MM	0.2401	13.11626	9.10289e-1	2.0766
2	7.406	MM	0.2849	618.50433	36.18497	97.9234
Totals :				631.62060	37.09526	