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Ruthenium Hydride Catalyzed Silylvinylation of Alkynes

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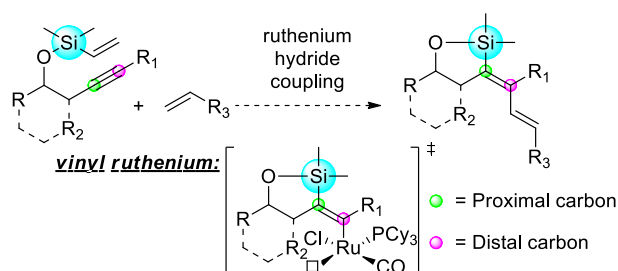
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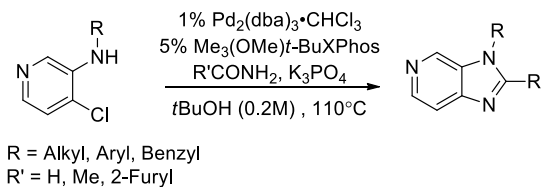
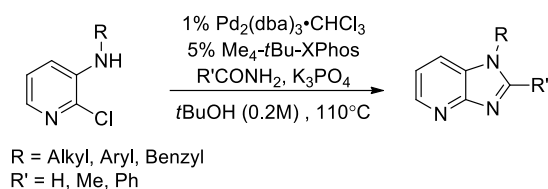
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ABSTRACT

The intermolecular ruthenium hydride catalyzed coupling of internal alkynes with subsequent insertion of olefin acceptors is described. This approach utilizes a vinyl silicon tether to provide complete regiocontrol, a stereoselective *anti-exo-dig* cyclization which affords a tetrasubstituted olefin with a new vinylsilane, and a highly functionalized *Z,E* diene motif. Subsequent studies for a highly selective intramolecular *trans*-silylvinylation of internal alkynes catalyzed by $\text{RuHCl}(\text{CO})(\text{SIMes})(\text{PPh}_3)$ is reported. The use of methyl vinyl ketone as an additive increased the efficiency of this transformation. This process was expanded upon using ethylene gas as an additive and provides a net 5-*exo-dig* *trans*-silylvinylation of internal alkynes. Ethylene decreased reaction times and promoted altered selectivity at increased pressure. Furthermore, the chemoselectivity was attenuated when alkyl substituted alkynes afforded silylvinylation at 80 psi of ethylene. Terminal alkynes were utilized in this transformation at increased ethylene pressure and produced *syn*-silylvinylation products.



Imidazo[4,5-*c*]pyridines were synthesized in three steps utilizing a palladium catalyzed amidation-cyclization strategy. N-Aryl substrates were synthesized using copper catalyzed amidation of 3-amino-N-Boc-4-chloropyridine. Complementary protocols for the selective chlorination of imidazo[4,5-*c*]pyridines at C2 and C7 positions were also developed. An improved protocol for the synthesis of imidazo[4,5-*b*]pyridines and pyrazines using palladium catalyzed amidation of 2-chloro-3-aminopyridines is described. The process utilizes Xantphos and a binary solvent system comprised of 1,4-dioxane and *tert*-amyl alcohol. The improved conditions were extended to provide a method for the regioselective coupling of polychlorinated aminopyridines.



Ruthenium Hydride Catalyzed Silylvinylation of Alkynes

by

Robert J. Wilson

B.S. Medicinal Chemistry, University at Buffalo, 2007

Dissertation

Submitted in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in Chemistry

Syracuse University

December 2015

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There are so many people that have influenced my life and the decisions I have made to bring me to this point. I am grateful for past mentors, friends and colleagues that have all been a part of my journey.

I would first like to thank my advisor Dr. Clark. Arriving in Syracuse I knew where I was headed and had a lot of ambition. Dr. Clark provided motivation and continuously challenged me to do better and find solutions to difficult problems. His knowledge of the literature amazed me and I tried to learn something new from him every day. Without Dan I would not have gone to graduate school let alone accomplished all that I have since I've been here. I feel rewarded to have worked with such a talented organic chemist and the team that he brought together.

I also would not be moving on in my career without the encouragement from Dr. Chisholm and Dr. Totah. Thank you both for being a large part of my graduate experience. I appreciate the other members of my committee Dr. Hougland and Dr. Sponsler for reading my dissertation and offering guidance and support. I am especially grateful toward Dr. Sweder for stepping in at the last minute to chair the committee and keep everyone in check.

I would like to thank my parents and sister for always being kind and helping me through difficult times. Mom, your courage and strength through difficult times has made me realize that going to school for all these years was easy. Dad, without your life lessons I wouldn't be the person I am today. I also never would have played golf and I don't know whether to be happy or mad about that. Aliesha, you were hard to grow up with and I am sure you feel the same way toward me. Now that we're adults I look back and I couldn't have asked for a better sister. My niece and

nephew are a perfect reflection of you and the love that you share with everyone. My family is my rock and I would not have been able to get this far without them.

My colleagues, Adam Rosenberg, Lauren Kaminsky and Ijaz Ahmed, were some of the greatest people that I have ever worked with and I wouldn't trade in any days spent with them in lab; except maybe March 18th 2011. Adam consistently thought we were in danger when we would laugh too loud and came running to our aid sometimes with the fire extinguisher in hand. Ijaz and I developed a work out plan to push each other to lose our "first year 40" and without him I still have trouble getting to the gym. Lauren and I worked next to each other for five years. We developed and finished projects together, we helped each other through long and difficult days, we laughed at Dan's early morning interrogations that always began with "und!" and ended with "here's what I'd do...." Grad school would not have been worth it to me without these three by my side.

I am grateful for the guidance from past group members Jinbo and Shasha. Jinbo always had a philosophical discussion awaiting you and Shasha would be singing in the background. These two were always encouraging and taught me several things pertaining to chemistry and life. To the present members, Alex Dixon and Chris Wilhelmsen, you two better not screw up all the work I've put in. Best of luck in all your upcoming decisions and don't forget to relax every once in a while.

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with you makes everything ten times more fun and without you things are too normal. “If I had a star to give, I’d give it to you. Long as you live, would you have the time to watch it shine or ask for the moon and heaven too? I’d give it all to you. Maybe I’ve got no star to spare or anything fine or even rare, only if you let me be your world, would I ever give this world to you.” Let’s just keep on dancin’ and singin’ across the nation, are you ready for a brand new beat. I can’t wait to see what tomorrow brings.

TABLE OF CONTENTS

ABSTRACT.....	I
ACKNOWLEDGEMENTS	V
TABLE OF CONTENTS	VIII
LIST OF SCHEMES	XI
LIST OF TABLES	XIV
LIST OF FIGURES	XVI
LIST OF ABBREVIATIONS	XVII
PREFACE.....	XX
1.0 RUTHENIUM HYDRIDE CATALYZED SILYLVINYLATION OF ALKYNES:	
INTRODUCTION.....	1
1.1 INTERMOLECULAR RUTHENIUM HYDRIDE CATALYZED	
COUPLINGS	9
<i>1.2.1 Ruthenium Hydride Coupling of Alkynes and Acrylates</i>	<i>9</i>
<i>1.2.2 Stereo- and Regioselective Formation of Silyl-Dienyl Boronates</i>	<i>15</i>
1.2 ETHYLENE TRANSFER.....	33
<i>1.3.1 Intramolecular Silylvinylation</i>	<i>33</i>
<i>1.3.2 Silylvinylation Using Ethylene Gas as an Additive</i>	<i>40</i>
<i>1.3.3 Silylvinylation of Terminal Alkynes.....</i>	<i>53</i>
2.0 SYNTHESIS OF IMIDAZOPYRIDINES	60
2.1 INTRODUCTION	60

2.2	DEVELOPMENT OF NEW CONDITIONS USING XANTPHOS AND A MIXED SOLVENT SYSTEM.....	66
2.3	SYNTHESIS OF IMIDAZO[4,5-C]PYRIDINES	70
2.4	DEVELOPMENT OF A REGIOSELECTIVE AMIDE COUPLING	80
3.0	APPENDIX I: EXPERIMENTALS	86
3.1	GENERAL EXPERIMENTAL	86
3.1.1	<i>General Procedures:</i>	86
3.1.2	<i>Instrumentation</i>	87
3.2	SYNTHESIS OF VINYL SILICON TETHERED ALKYNES	88
3.3	INTERMOLECULAR COUPLING DATA	109
3.3.1	<i>Acrylamides and Acrylates</i>	109
3.3.2	<i>Vinyl Boronates</i>	111
3.4	ETHYLENE TRANSFER DATA	128
3.4.1	<i>Intramolecular Ethylene Transfer: MVK</i>	128
3.4.2	<i>Silylvinylation Using Ethylene Gas</i>	131
3.4.3	<i>Silylvinylation of Terminal Alkynes</i>	160
3.5	IMIDAZOPYRIDINE DATA	165
4.0	APPENDIX II: BIBLIOGRAPHY	199
5.0	APPENDIX III: SPECTRA	214
5.1	VINYL SILICON TETHERED ALKYNES	214
5.2	ACRYLAMIDE AND ACRYLATE SPECTRA.....	240
5.3	VINYL BORONATE COUPLING SPECTRA	244
5.4	SILYLVINYLLATION SPECTRA.....	278

5.5	IMIDAZOPYRIDINE SPECTRA	358
6.0	VITAE	428

LIST OF SCHEMES

Scheme 1: Ruthenium Catalyzed Formation of Conjugated Dienes	3
Scheme 2: Mori's Examples of Intramolecular Transformations.....	4
Scheme 3: Hydrovinylation Reaction with Selected Examples.....	5
Scheme 4: Yi's [2+2] Reaction with Electron Deficient Alkynes.....	5
Scheme 5: Evidence for Ruthenium Hydride Mechanism in Yi's Hydrovinylation	6
Scheme 6: Marciniak's Vinyl Boronate Coupling with Selected Examples.....	6
Scheme 7: Plietker's Ruthenium Hydride Coupling.....	7
Scheme 8: Hypothesis for Plietker's Observed Regiochemistry	8
Scheme 9: Literature Examples of <i>Trans</i> -addition to Alkynes.....	11
Scheme 10: Acrylamide Coupling Example.....	13
Scheme 11: Acrylate Coupling with Difficult Substrate	14
Scheme 12: Known Preparations of Vinyl Boronates and Vinyl Silanes.....	15
Scheme 13: Vinyl Boronate Coupling with Alkynes.....	16
Scheme 14: Approach to Vinyl Boronate Couplings.....	19
Scheme 15: Preparation of Vinyl Boronate 1.39b	19
Scheme 16: Independent Synthesis of Boronate Dimer 1.41b	21
Scheme 17: Ruthenium Hydride Coupling Substrate Scope Using Vinyl Boronate 1.39c	29
Scheme 18: Synthetic Derivatization of Silyl-dienyl Boronates	30
Scheme 19: Tandem Hydride Coupling-Suzuki Coupling	31
Scheme 20: Borate Complex Formation and Migratory Insertion of Methyl Group	31

Scheme 21: Reaction Discovery and Proposed Ethylene Transposition	33
Scheme 22: Ethylene Transposition and Cycloisomerization Byproduct.....	34
Scheme 23: Examples of Ethylene used in Organic Transformations.....	40
Scheme 24: Isotopic Labeling Experiment	42
Scheme 25: Substrate Scope for Silylvinylation Using Ethylene Gas.....	44
Scheme 26: Synthetic Elaboration of Dienes.....	48
Scheme 27: Unsuccessful Derivatization.....	50
Scheme 28: Unsuccessful Examples of Cross Metathesis Reactions	50
Scheme 29: Epoxidation Reagents.....	51
Scheme 30: Un-optimized Derivatization of Diene.....	51
Scheme 31: Silylvinylation Substrate Scope of Terminal Alkynes	58
Scheme 32: N-Alkylation of Imidazo[4,5- <i>b</i>]pyridine.....	62
Scheme 33: Senanyake Approach to Imidazo[4,5- <i>b</i>]pyridines.....	63
Scheme 34: Classic example of imidazopyridine synthesis	63
Scheme 35: Soral's retrosynthetic solid phase synthesis of 1- and 3-deazapurines	64
Scheme 36: Previous approaches to imidazopyridines using 2-halo-pyridines.....	65
Scheme 37: Palladium Catalyzed Amidation-Dehydration Strategy.....	65
Scheme 38: Extended amide scope using the improved protocol.....	69
Scheme 39: Production of 4-chloro-3-N-Boc-pyridine 34	71
Scheme 40: Alkylation and Deprotection of 34.....	71
Scheme 41: Amide Coupling Partner Scope.....	77
Scheme 42: Functionalization of imidazo[4,5- <i>c</i>]pyridines	79
Scheme 43: Regioselective Coupling Hypothesis	80

Scheme 44: Regioselective coupling of 2,4 and 2,5-dichloropyridines.....	81
Scheme 45: Regioselective Suzuki Couplings of 2,6-dichloropyridines.....	82
Scheme 46: Regioselective Amidation	82

LIST OF TABLES

Table 1: Initial Catalyst Screen for Vinyl Boronate 1.39a Coupling.....	17
Table 2: Solvent and Equivalents Screen with 1.39a.....	18
Table 3: Vinyl Boronate Screen.....	19
Table 4: Solvent and Equivalents Screen With 1.39b.....	21
Table 5: Ruthenium Hydride Catalyst Screen with 1.39b	22
Table 6: Silyl Dienylboronate Substrates	26
Table 7: Catalyst Screen for Vinyl Boronate Coupling with 1.39c	27
Table 8: Solvent, Temperature and Equivalents Screen with 1.39c	28
Table 9: Screen of Additives for Ethylene Transposition.....	35
Table 10: Catalyst Screen for Ethylene Transposition.....	36
Table 11: Scope of Silylvinylation Using MVK with Aryl-Substituted Alkynes ^{a,b}	38
Table 12: Diene Formation with Alkyl-Substituted Alkynes ^a	39
Table 13: Catalyst Screen for Silylvinylation under 1 Atmosphere Ethylene	42
Table 14: Sequential Increase of Ethylene Pressure	46
Table 15: Electronic Differentiation of Alkyne Terminus at 80 psi Ethylene	47
Table 16: Solvent and Temperature Screen for Silylvinylation of Terminal Alkynes	56
Table 17: Catalyst Screen in CPME	58
Table 18: Substrate scope utilizing Xantphos and a mixed solvent system	67
Table 19: Copper-Catalyzed Amidation Optimization	73
Table 20: Copper-Catalyzed Amidation Scope	74

Table 21: Ligand Screen for Palladium Catalyzed Amidation	75
Table 22: Palladium Catalyzed Amidation/Cyclization	76
Table 23: Comparison of Xantphos and DPE Phos	82
Table 24: Base and Solvent Screen for Regioselective Coupling Using DPE Phos.....	83
Table 25: Palladium and Ligand Screen for Regioselective Coupling	84

LIST OF FIGURES

Figure 1: Examples of Cross-Coupling Reactions to Form Conjugated Dienes	2
Figure 2: Natural products that contain diene motif	2
Figure 3: Silicon Tethered Coupling Approach.....	9
Figure 4: Mechanistic Proposal	10
Figure 5: Ruthenium Hydride Catalyzed Alkyne-Acrylate Coupling	12
Figure 6: Vinyl Boronate Coupling Mechanistic Hypothesis	24
Figure 7: Mechanistic Hypothesis for Ethylene Addition to Alkynes	42
Figure 8: Reactions of internal alkyl alkynes at 80 psi.....	47
Figure 9: Hydrosilylation and Silylformylation of Terminal Alkynes	54
Figure 10: Ruthenium Hydride Catalyzed Silylvinylation of Terminal Alkynes (This Work)	55
Figure 11: Common Nitrogen Based Heterocycles	60
Figure 12: Imidazopyridine Nomenclature	60
Figure 13: Molecules possessing imidazopyridine structures	61
Figure 14: Ligand Structures Used in Palladium Catalyzed Amidation.....	75
Figure 15: Bidentate Ligands Examined for Regioselective Palladium Catalyzed Amidation	84

LIST OF ABBREVIATIONS

[α]	specific rotation
Å	angstrom(s)
Ac	acetyl
Anal.	combustion elemental analysis
aq	aqueous
Ar	aryl
Bn	Bzl benzyl
BOC	Boc <i>tert</i> -butoxycarbonyl
Bu	<i>n</i> -Bu normal (primary) butyl
<i>s</i> -Bu	<i>sec</i> -butyl
<i>t</i> -Bu	<i>tert</i> -butyl
Bz	benzoyl
°C	degrees Celsius
CBZ	Cbz benzyloxycarbonyl
cm	centimeter(s)
cm ⁻¹	wavenumber(s)
Cy	cyclohexyl
DABCO	1,4-diazabicyclo[2.2.2]octane
DBU	1,8-diazabicyclo[5.4.0]undec-7-ene
DCE	1,2-dichloroethane
DCM	dichloromethane
DMA	dimethylacetamide
DMAP	4-(<i>N,N</i> -dimethylamino)pyridine

DME	1,2-dimethoxyethane
DMF	dimethylformamide
DMSO	dimethyl sulfoxide
g	gram(s)
HPLC	high-performance liquid chromatography
HRMS	high-resolution mass spectrometry
Hz	hertz
IR	infrared
<i>J</i>	coupling constant
k	kilo
K	kelvin(s) (absolute temperature)
L	liter(s)
LAH	lithium aluminum hydride
LDA	lithium diisopropylamide
LHMDS	lithium hexamethyldisilazane,
μ	micro
M	molar (moles per liter)
Me	methyl
Mes	2,4,6-trimethylphenyl (mesityl)
mM	millimolar (millimoles per liter)
mol	mole(s)
Ms	methylsulfonyl (mesyl)
MTBE	methyl <i>tert</i> -butyl ether
N	normal (equivalents per liter)
NBS	<i>N</i> -bromosuccinimide
NCS	<i>N</i> -chlorosuccinimide
NHC	N-heterocyclic carbene
NIS	<i>N</i> -iodosuccinimide
nm	nanometer(s)
NMP	<i>N</i> -methylpyrrolidone
NMR	nuclear magnetic resonance

Nu	nucleophile
Ph	phenyl
piv	pivaloyl
ppm	part(s) per million
PPTS	pyridinium <i>para</i> -toluenesulfonate
Pr	propyl
<i>i</i> Pr	isopropyl
<i>R_f</i>	retention factor (in chromatography)
SN1	unimolecular nucleophilic substitution
SN2	bimolecular nucleophilic substitution
SN'	nucleophilic substitution with allylic rearrangement
TBAB	tetrabutylammonium bromide
TBAC	tetrabutylammonium chloride
TBAF	tetrabutylammonium fluoride
TBS	<i>tert</i> -butyldimethylsilyl
Tf	trifluoromethanesulfonyl (triflyl)
TFA	trifluoroacetic acid
THF	tetrahydrofuran
THP	tetrahydropyran-2-yl
TIPS	triisopropylsilyl
TLC	thin-layer chromatography
TMEDA	<i>N,N,N',N'</i> -tetramethyl-1,2-ethylenediamine
TMS	trimethylsilyl; tetramethylsilane
Tr	triphenylmethyl (trityl)
Ts	<i>para</i> -toluenesulfonyl (tosyl)

PREFACE

This dissertation has been adapted from the following articles co-written by the author.

“Copper- and Palladium-Catalyzed Amidation Reactions for the Synthesis of Substituted Imidazo[4,5-c]pyridines.” Wilson, R. J.; Rosenberg, A. J.; Kaminsky, L.; Clark, D. A. *J. Org. Chem.* **2014**, 79, 2203-2212.

“An Improved Synthesis of Imidazo[4,5-b]pyridines and Imidazo[4,5-b]pyrazines by Palladium Catalyzed Amidation using Xantphos in a 1,4-Dioxane:tert-Amyl Alcohol Solvent System.” Rosenberg, A. J.; Ahmed, I.; Wilson, R. J.; Williams, T. M.; Kaminsky, L.; Clark, D. A. *Adv. Synth. Catal.* **2014**, 356, 3465-3470.

“Ethylene Transposition: Ruthenium Hydride Catalyzed Intramolecular trans-Silylvinylation of Internal Alkynes.” Liu, S.; Zhao, J.; Kaminsky, L.; Wilson, R. J.; Marino, N.; Clark, D. A. *Org. Lett.* **2014**, 16, 4456-4459.

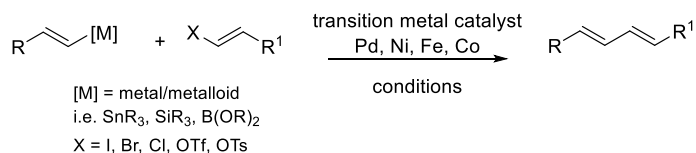
“Stereo- and Regioselective Formation of Silyl-Dienyl Boronates.” Kaminsky, L.; Wilson, R. J.; Clark, D. A. *Org. Lett.* **2015**, 17, 3126-3129.

“Ruthenium Hydride Catalyzed Silylvinylation of Internal Alkynes Using Ethylene as an Additive.” Wilson, R. J.; Kaminsky, L.; Ahmed, I.; Clark, D.A. *J. Org. Chem.* **2015**, 80, 8290-8299.

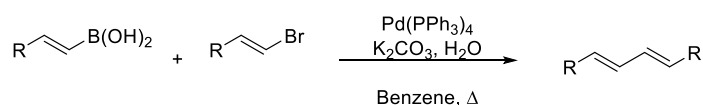
1.0 RUTHENIUM HYDRIDE CATALYZED SILYL VINYLATION OF ALKYNES: INTRODUCTION

Transition metal catalyzed reactions have become some of the most valuable tools in organic synthesis. Organometallic complexes are frequently used in cross-coupling reactions to form new bonds that are described as efficient and selective. The protocols for metal catalyzed coupling reactions have been developed extensively and are based on the work of several pioneers including the 2010 Nobel Laureates Richard Heck, Akira Suzuki, and Ei-ichi Negishi. Several well known cross coupling methods used to form new carbon-carbon bonds include: Suzuki–Miyaura,¹ Heck,² Negishi,³ Stille,⁴ Kumada,⁵ Sonogashira,⁶ and Hiyama (Figure 1).⁷ These modern cross coupling techniques often require each component to contain a functional group that can participate readily in the cross coupling. The participating partners are generally halides or pseudo-halides which are matched with an organometallic species.⁸ In most cases alkynes are transformed into an activated alkene species when functionalized dienes are desired. Well defined functionalized conjugated dienes are prevalent in natural products (Figure 2). The palladium cross-coupling methods used to generate these moieties often have toxic byproducts such as tin.

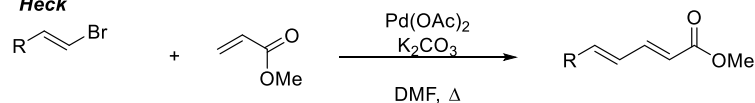
General cross-coupling to form dienes



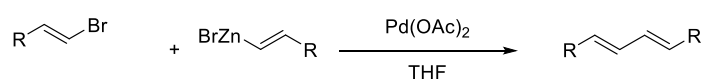
Suzuki-Miyaura



Heck



Negishi



Stille

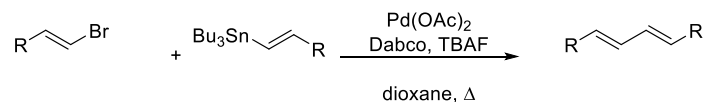


Figure 1: Examples of Cross-Coupling Reactions to Form Conjugated Dienes

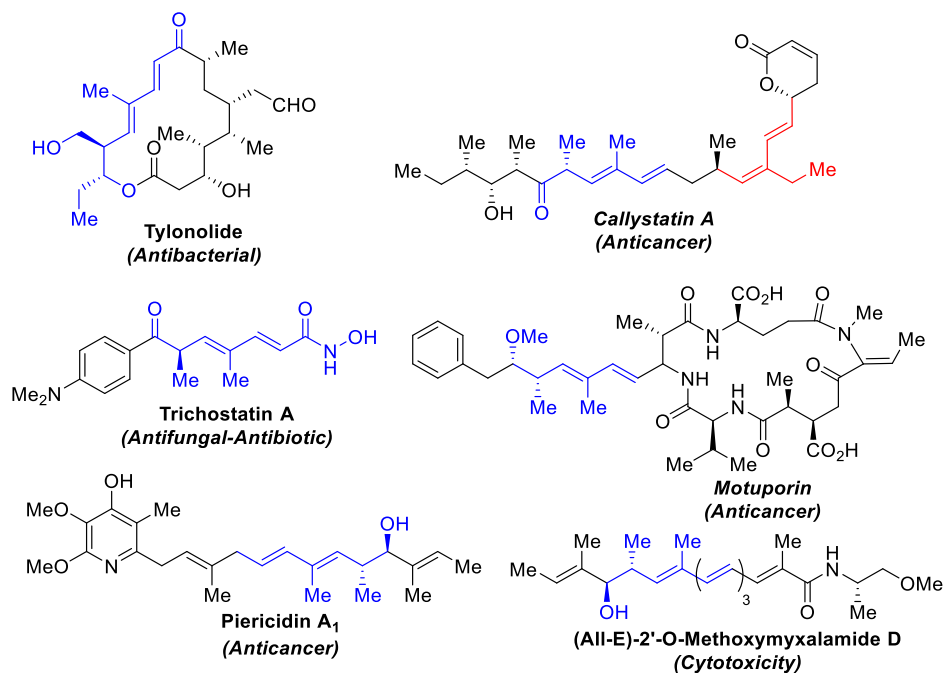
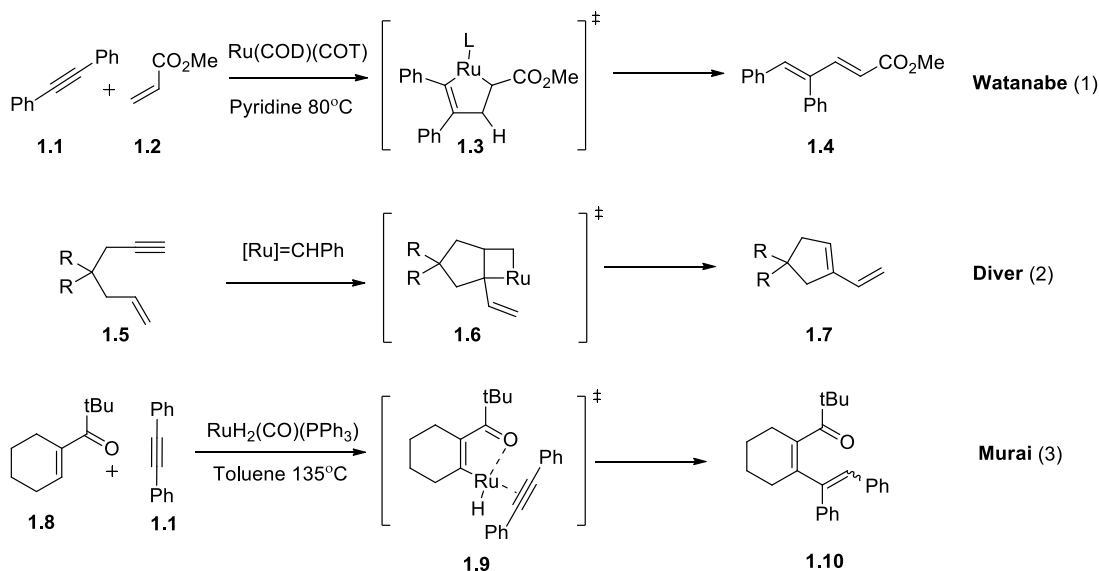


Figure 2: Natural products that contain diene motif

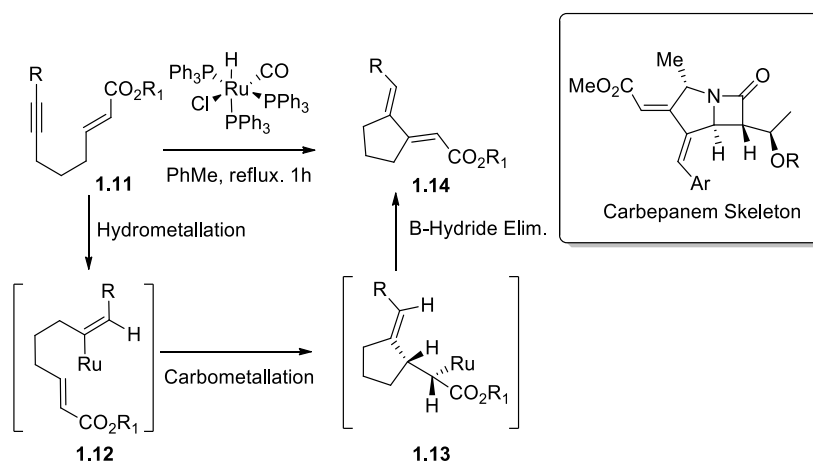
Ruthenium catalyzed coupling reactions on the other hand, have become a reliable method for the construction of new carbon-carbon bonds.⁹ One major advantage of ruthenium catalysis is that no pre-activation of either coupling partner is required. Ruthenium catalyzed cross coupling reactions frequently convert alkynes and alkenes into dienes. The formation of conjugated dienes by ruthenium catalysis can proceed through several different mechanisms. Watanabe¹⁰ and Trost^{8, 9} have developed ruthenium catalyzed reactions which proceed through metallacycle intermediates (Scheme 1, Equation 1), while Grubbs,¹¹ Diver^{12, 13} and many others have demonstrated the effectiveness of ruthenium vinyl carbenes (Scheme 1, Equation 2).¹²⁻¹⁸ Moreover, Murai revealed the use of a ruthenium dihydrido complex in C-H functionalization chemistry (Scheme 1, Equation 3).¹⁹ These methods have been thoroughly explored and continue to evolve. Alternative ruthenium hydride methods²⁰ that do not require a directing group have not been as extensively examined for the synthesis of dienes. Ruthenium hydride catalyzed coupling of alkynes and alkenes can lead to highly substituted dienes of great synthetic value.²¹

Scheme 1: Ruthenium Catalyzed Formation of Conjugated Dienes



Examples of intramolecular transformations to form conjugated dienes using ruthenium hydrides were reported by Mori.²² In the presence of catalytic amounts of $\text{RuHCl}(\text{CO})(\text{PPh}_3)_3$, Mori demonstrated the intramolecular transformation of enynes to dienes. Mechanistically, Mori proposed a three step sequence which proceeds via 1) hydrometallation of the alkyne, 2) carbometallation of the alkene and 3) subsequent β -hydride elimination (Scheme 2). Mori demonstrated the utility of this transformation in the synthesis of carbapanem skeletons. This process showed excellent functional group compatibility.²³

Scheme 2: Mori's Examples of Intramolecular Transformations

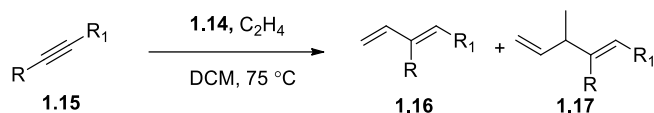


Selected Examples	R	R ₁	Time (h)	Yield (%)
1	Me	(CH ₂) ₃ Ph	9	62
2	Ph	Et	18	57
3	4-MeO-Ph	Et	18	82
4	4-Me-Ph	Et	18	67
5	4-CF ₃ -Ph	Et	18	53

Other groups have produced 1,3 dienes utilizing ruthenium hydride catalysts through intermolecular transformations of alkynes with alkenes. Yi reported a hydrovinylation of alkynes using $[(\text{PCy}_3)_2(\text{CO})(\text{Cl})\text{Ru}=\text{CHCH}=\text{C}(\text{CH}_3)_2]^+\text{BF}_4^-$ (**1.14**) and ethylene gas (Scheme 3).²⁴ The substrate compatibility for Yi's hydrovinylation was limited to symmetrical internal alkynes.

When terminal alkynes were subjected to these conditions chemoselectivity was an issue and a mixture of products **1.16** and **1.17** were observed.

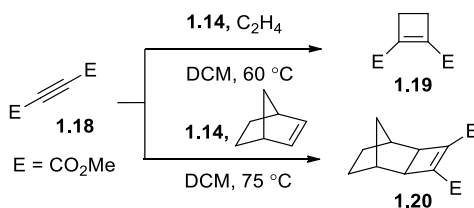
Scheme 3: Hydrovinylation Reaction with Selected Examples



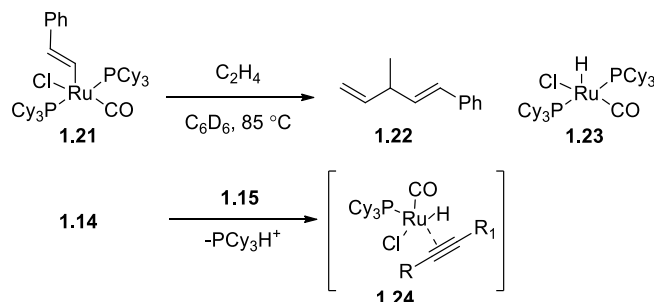
Entry	R	R ₁	Ratio (1.16 : 1.17)	Time (h)	Yield (%)
1	Ph	Ph	98:2	5	91
2	<i>n</i> -Pr	<i>n</i> -Pr	98:2	7	90
3	H	<i>p</i> -Tol	74:26	2	95
4	H	SiEt ₃	94:6	2	82
5	H	CH ₂ CH ₂ OH	92:8	2	57

When electron deficient internal alkynes (**1.18**) were subjected a [2+2] reaction predominated and compound **1.19** was isolated in 70% yield (Scheme 4). The reaction with norbornene also produced a cyclobutene ring **1.20** under similar conditions. Yi hypothesized the formation of the hydrovinylation products **1.16** or **1.17** can occur via sequential insertion of alkyne and ethylene to metal-hydride and metal-vinyl species. The hypothesis was tested using ruthenium-vinyl species **1.21** and ruthenium-hydride **1.23**.

Scheme 4: Yi's [2+2] Reaction with Electron Deficient Alkynes

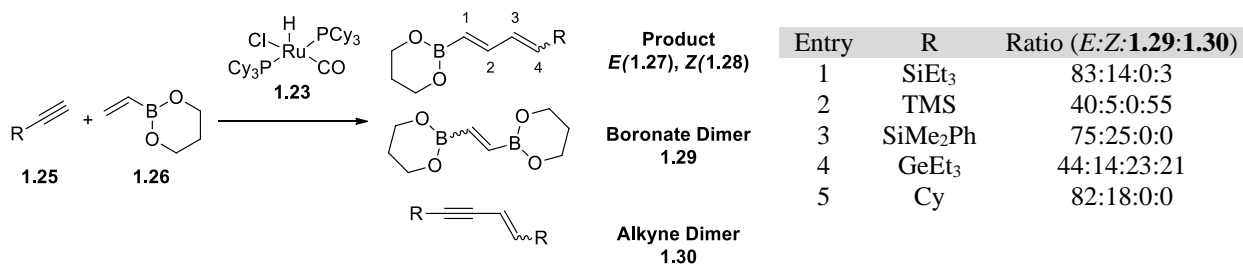


The reaction of **1.21** and ethylene in C₆D₆ produced a 1:1 mixture of **1.22** and **1.23** (Scheme 5). This suggests that these three ruthenium complexes (**1.14**, **1.21** and **1.23**) proceed through a common intermediate (**1.24**) in the hydrovinylation reaction.

Scheme 5: Evidence for Ruthenium Hydride Mechanism in Yi's Hydrovinylation

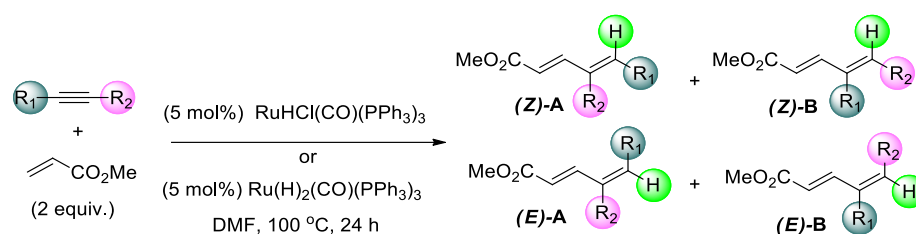
Yi's hydrovinylation of symmetrical internal alkynes using ruthenium hydride **1.23** provides excellent reactivity but chemoselectivity was an issue. Furthermore, there were no unsymmetrical internal alkynes tested lending the reader to believe they were not compatible or provided a mixture of regioisomers.

Marciniec utilized ruthenium hydride **1.23** to couple terminal alkynes with vinyl boronates (Scheme 6).²⁵ Marciniec also observed a selectivity issue. The reaction proceeded to deliver a mixture of stereoisomers (**1.27**, **1.28**) along with boronate (**1.29**) and alkyne dimerization (**1.30**) as byproducts. Internal alkynes were not investigated leaving room for improvement in this area. However, the products obtained were interesting and possessed dual functionality at the 1 and 4 positions of the 1,3-diene motif.

Scheme 6: Marciniec's Vinyl Boronate Coupling with Selected Examples

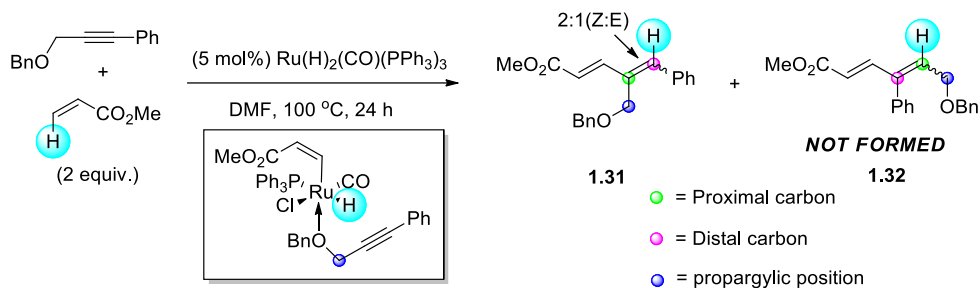
Plietker investigated the coupling of alkynes with acrylates and acrylamides (Scheme 7).²⁶ The reaction was stereo and regioselective when using terminal alkynes resulting in (*Z*)-**A** with a 57% isolated yield. When symmetrical internal alkynes were subjected to these conditions stereoselectivity was reduced. When unsymmetrical internal alkynes were examined the regioselectivity also became an issue.

Scheme 7: Plietker's Ruthenium Hydride Coupling



Entry	R ₁	R ₂	A:B	Z:E	Yield (%)
1	Ph	H	99:1	98:2	57
2	Pr	Pr	-	91:9	76
3	C ₃ H ₁₁	Me	50:50	91:9	65
4	Ph	C ₃ H ₇	11:89	98:2	83

Ruthenium hydrides show promise as catalysts in the synthesis of dienes, however, they do not seem to be broadly applicable in the transformation of unsymmetrical internal alkynes. Plietker reported a single example that showed high levels of regiocontrol (Scheme 8). In this case the presence of the propargylic benzyl ether provided a possible coordination to the metal that could facilitate a regioselective delivery of the hydride. Despite excellent regiocontrol, stereoselectivity was still poor with **1.31** obtained as a 2:1, *Z*:*E* ratio and regioisomer **1.32** was not formed in this reaction.

Scheme 8: Hypothesis for Plietker's Observed Regiochemistry

The limitations in selectivity with unsymmetrical internal alkynes suggested a deficit in these methods. However, as demonstrated in the example above, selectivity can be improved by preorganizing substrates. Connecting a linker or temporary silicon tether to an alcohol at the homopropargylic position was envisioned to provide a solution to control both regio and stereoselectivity.²⁷

1.1 INTERMOLECULAR RUTHENIUM HYDRIDE CATALYZED COUPLINGS

1.2.1 Ruthenium Hydride Coupling of Alkynes and Acrylates

Initial investigations using ruthenium hydride catalysis from the Clark group were conducted by Dr. Shasha Liu and Dr. Jinbo Zhao.²⁸ It was discovered that a vinyl silicon moiety attached to an alcohol at the homo-propargyl position could assist the delivery of ruthenium across an alkyne π system (Figure 3). Mechanistically, the ruthenium hydride is delivered across the vinyl moiety followed by the loss of ethylene (Figure 4). The initial hypothesis for addition to the alkyne was a *syn* addition of a silyl ruthenium intermediate (**Id**). Contrary to the hypothesis the product observed showed an interesting *anti-exo-dig*-addition to the alkyne (**Ie**). The *anti* isomer obtained was verified by 1D and 2D experiments conducted by Liu *et al.*²⁸

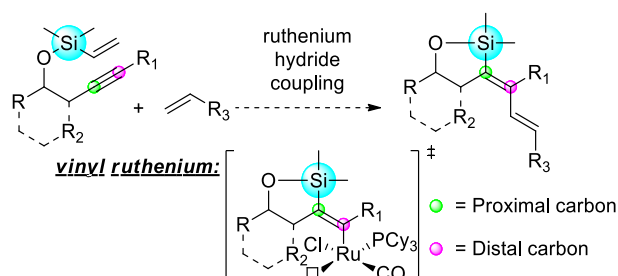


Figure 3: Silicon Tethered Coupling Approach

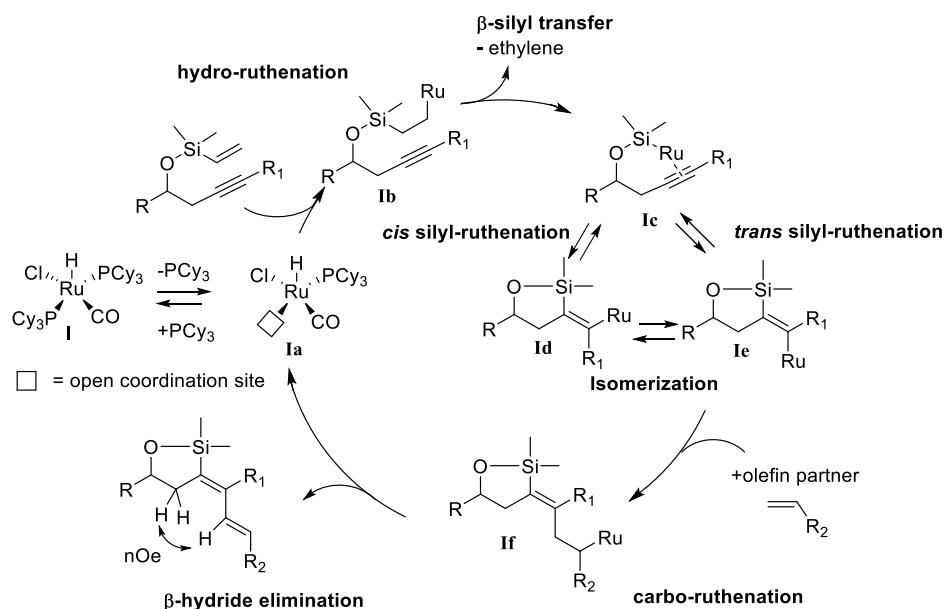
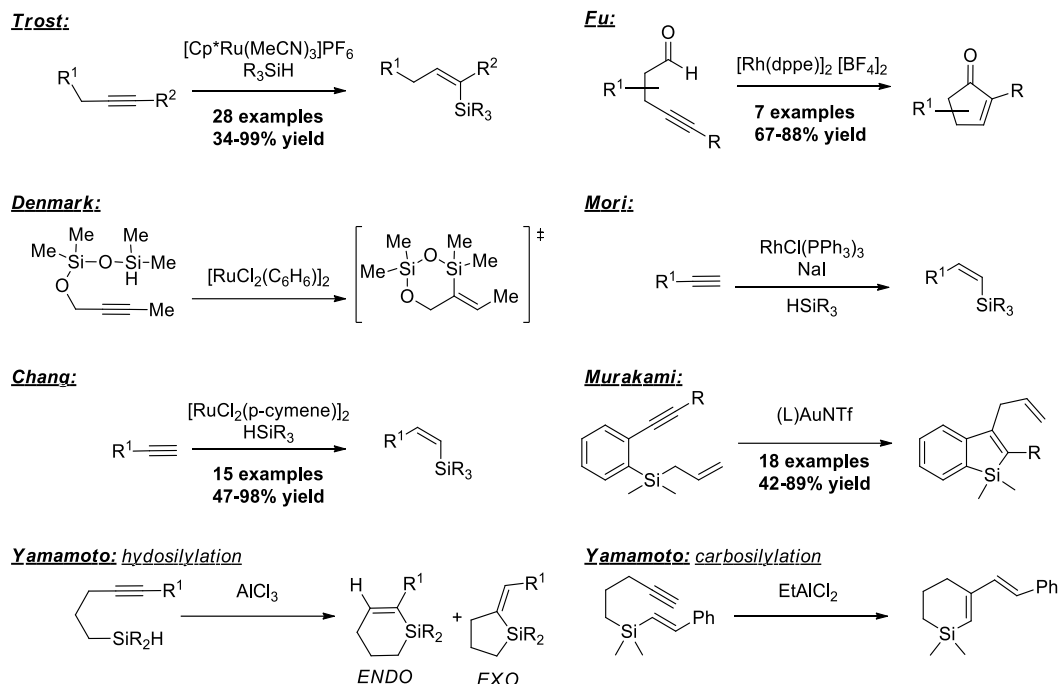


Figure 4: Mechanistic Proposal

The observed *anti* addition process was unpredicted due to the rarity of a direct *trans* addition to alkynes. Other groups have observed *trans* addition to alkynes (Scheme 9). Trost,²⁹ Denmark,³⁰ and Chang³¹ have observed anti-hydrosilylation products using some ruthenium catalysts. Direct *trans*-addition across alkynes has also been observed by Fu^{32, 33} and Mori³⁴ using rhodium, and Murakami³⁵ using gold. Lastly, Yamamoto observed a *trans*-carbosilylation using Lewis acid catalysts.^{36, 37}

Scheme 9: Literature Examples of *Trans*-addition to Alkynes

The initial work conducted by the Clark group utilized ruthenium hydride catalysts to couple unsymmetrical internal alkynes with alkenes (Figure 5). The reaction was found to work well with acrylates and on large scale. A screen of acrylates revealed bulkier acrylates such as *L*-menthol acrylate produced the highest yields in this reaction. This could be a result of varying volatility with the smaller acrylates such as methyl and ethyl acrylate. The reaction conditions were amenable to the use of various aryl substituted alkynes, while alkyl substituted alkynes proved to be a bit more sensitive. Alkyl alkynes provided lower yields and produced a mixture of stereoisomers. The alkyl alkynes required a large excess of acrylates for full conversion to dienes, and so lower boiling acrylates were used to facilitate the isolation of product. Several olefin coupling partners were examined under these conditions but only acrylates worked well (Figure 5).

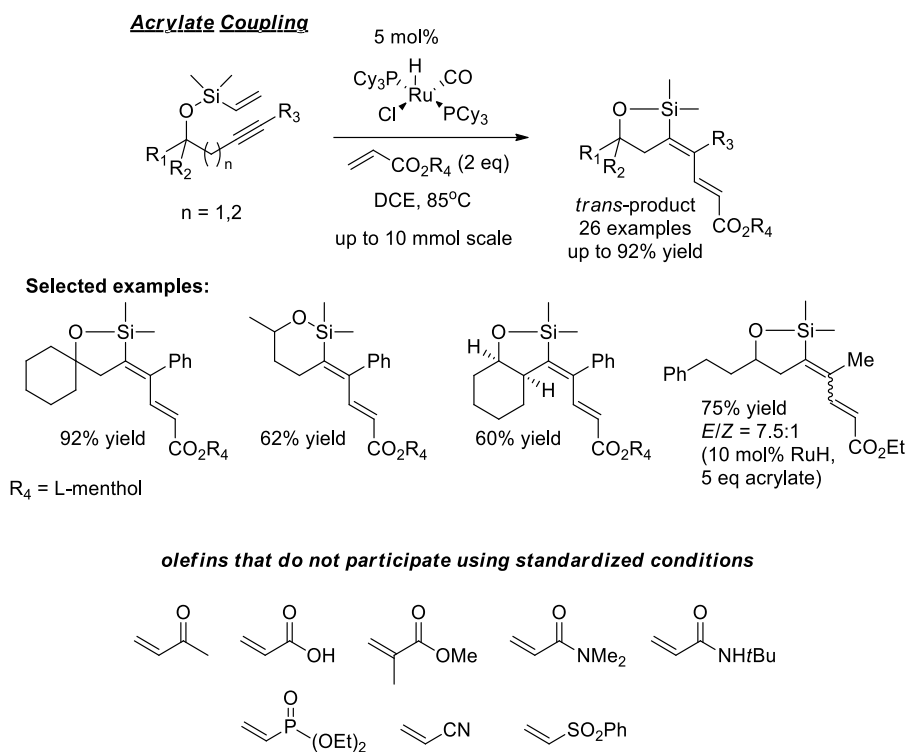
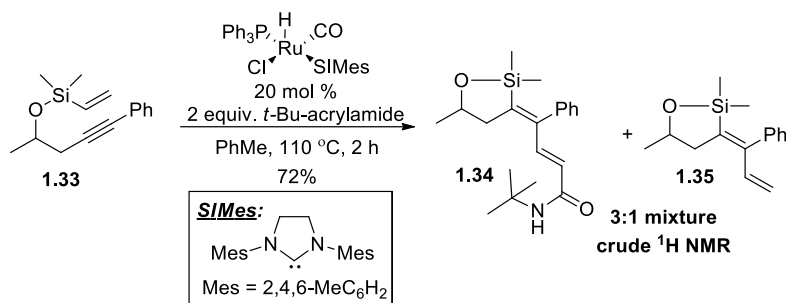


Figure 5: Ruthenium Hydride Catalyzed Alkyne-Acrylate Coupling

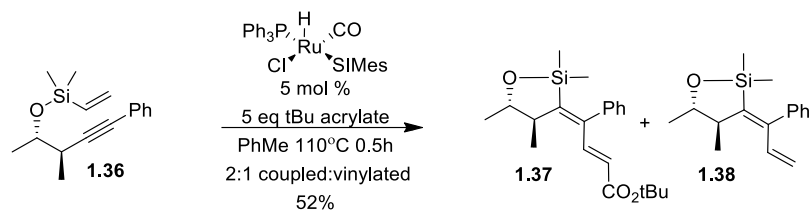
While screening catalysts for the acrylate coupling, specifically $\text{RuHCl(CO)(SIMes)(PPh}_3\text{)}$, **1.35** (Scheme 10, *i.e.* ethylene transfer) was discovered as a byproduct. New endeavors were undertaken to selectively produce the ethylene transfer reaction. Unreactive olefin coupling partners from previous studies were also desired. Conditions were examined in an attempt to couple acrylamides. As aforementioned, the acrylate coupling was optimized and the reaction performed the best at 85°C. Since the standard conditions did not work for acrylamides the more reactive complex $\text{RuHCl(CO)(SIMes)(PPh}_3\text{)}$ was examined. This complex promoted partial coupling with acrylamides along with some ethylene transfer (Scheme 10). Increasing the reaction temperature to 110 °C in toluene allowed for full conversion of **1.33**

and provided a 3:1 mixture of acrylate incorporated (**1.34**) to vinylated ene (**1.35**) products. In an effort to reduce the byproduct formation some additives were examined. Lewis acid additives were believed to coordinate to the acrylamide lowering the LUMO and making the requisite conjugate addition easier. Lewis acid additives could also prevent the amide carbonyl from coordinating to the ruthenium. However, additives such as MgCl_2 , AlCl_3 and CuCl did not improve the reaction; in fact, they were deleterious and shut down reactivity.

Scheme 10: Acrylamide Coupling Example



While there were many other possibilities and combinations that could be attempted in order to improve this reaction, no further work was conducted. Instead the acrylamide coupling reaction protocol was implemented to couple acrylates with difficult alkynes (Scheme 11). Alkynes that were previously unreactive or demonstrated poor conversion were deemed difficult substrates. The methyl substitution pattern of alkyne **1.36** made for a surprisingly low yielding (<10%) reaction with $\text{RuHCl}(\text{CO})(\text{PCy}_3)_2$ (Scheme 11). However, using $\text{RuHCl}(\text{CO})(\text{SI}^i\text{Mes})(\text{PPh}_3)$ the product (**1.37**) was delivered in 52% yield and could be readily separated from the vinylated byproduct (**1.38**).

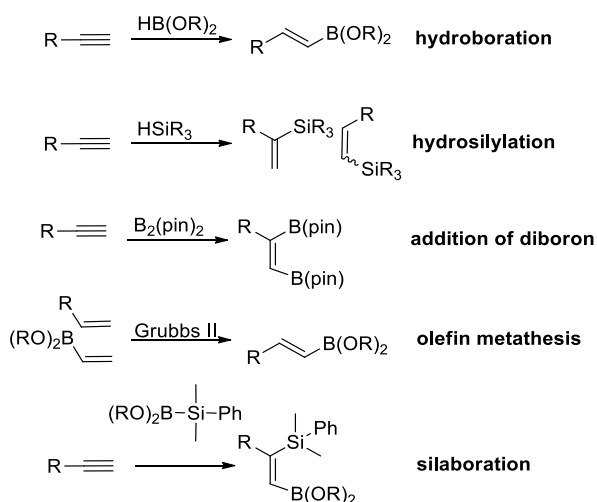
Scheme 11: Acrylate Coupling with Difficult Substrate

At the outset of this project several coupling partners were desired that could produce bifunctional dienes. A selective coupling between vinyl silicon tethered alkynes and other vinyl metalloid (germanes, silanes, boronates and tin) species was envisioned. Additional investigations into coupling vinyl boronates and in selectively achieving an intramolecular vinyl transfer reaction will be discussed in the following chapters of this thesis.

1.2.2 Stereo- and Regioselective Formation of Silyl-Dienyl Boronates

Vinyl boronates³⁸⁻⁴⁰ and vinyl silanes⁴¹ are considered valuable reagents and are often used as synthetic intermediates in catalytic transformations.^{25, 42} The Suzuki-Miyaura cross-coupling with organoboranes is perhaps the most utilized transition metal catalyzed C-C bond forming reaction.^{43, 44} Alternatively, organosilanes have been utilized efficiently in Fleming-Tamao oxidations⁴⁵ and Hiyama couplings.⁴⁶ Given the significant use of vinyl boronates and vinyl silanes, a great deal of effort has been applied to incorporate these functionalities into complex molecules. Methods used to prepare vinyl silanes and vinyl boronic esters include hydroboration⁴⁷ or hydrosilylation²⁹ of alkynes, metal catalyzed addition of diboron reagents,⁴⁸⁻⁵⁰ olefin metathesis with vinyl boronates^{11, 51, 52} and silaboration chemistry (Scheme 12).⁵³⁻⁵⁶

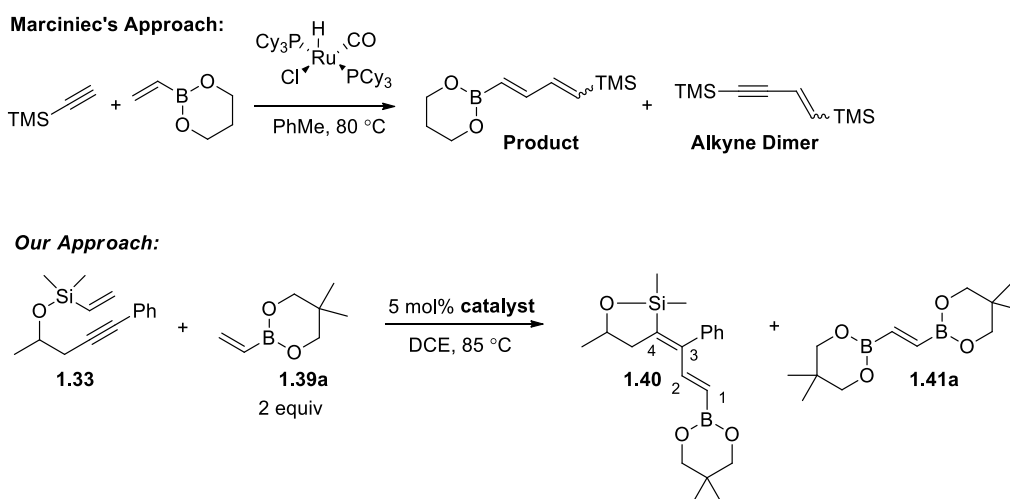
Scheme 12: Known Preparations of Vinyl Boronates and Vinyl Silanes



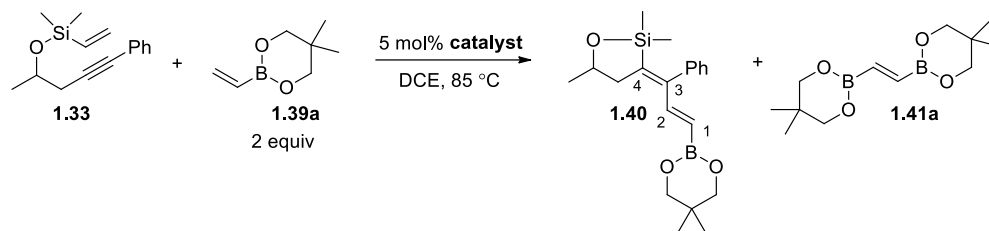
The successful application of the ruthenium hydride methodology, recently developed in the Clark lab,²⁸ to the coupling of unsymmetrical internal alkynes and vinyl boronates would diversify this category of valuable intermediates. The coupling would deliver regio- and stereodefined silyl-dienylboronates with varied functional handles at the 1 and 4 position of a diene

scaffold (Scheme 12, **1.40**). Marciniec has previously prepared bifunctional dienes of a similar nature from silyl-acetylenes and vinyl boronates; however, a mixture of stereoisomers and alkyne dimerization was obtained (Scheme 12).²⁵ In addition to complex vinyl silanes and boronates this approach would also produce tetra-substituted olefins and *Z,E* diene systems. Tetra-substituted olefins are valuable intermediates which are a considerable challenge to obtain stereo and regioselectively.⁵⁷ Despite their prevalence in natural product scaffolds, *Z, E* diene motifs are also quite difficult to obtain.⁵⁸⁻⁶⁰ This coupling method provides a straightforward solution to both challenges.

Scheme 13: Vinyl Boronate Coupling with Alkynes



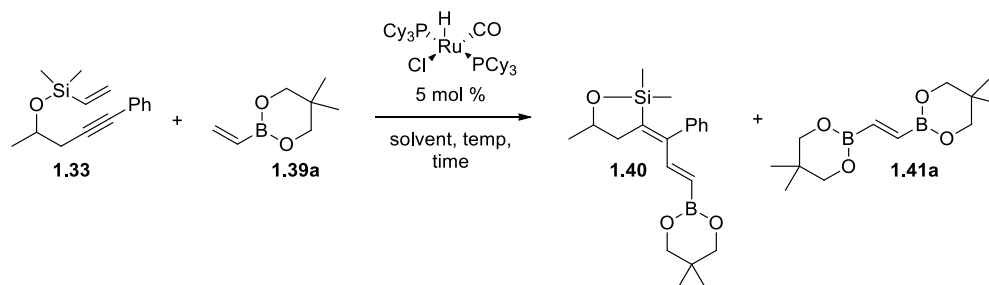
This study began by examining alkyne **1.33** and vinyl boronate **1.39a** using the standard conditions from the acrylate coupling methodology.²⁸ Ruthenium hydride catalysts were evaluated and $\text{RuHCl}(\text{CO})(\text{PCy}_3)_2$ was chosen due to the highest crude yield and minimal byproduct (**1.41a**) formation (Table 1).

Table 1: Initial Catalyst Screen for Vinyl Boronate **1.39a** Coupling

Entry	Catalyst	Crude Yield 1.40 (%) ^a	Crude Yield 1.41a (%) ^a
1 ^d	RuHCl(CO)(PCy₃)₂	87	9
2 ^{c,d}	RuHCl(CO)(SIMes)(PPh₃)	23	12
3 ^{b,d}	RuHCl(CO)(Pi-Pr₃)₂	69	4
4 ^b	RuHCl(CO)(Pt-Bu₂Me)₂	55	14
5 ^d	RuHCl(CO)(Pn-BuAd₂)₂	Not determined	32
6 ^b	RuH(OSiPh₃)(CO)(Pt-Bu₂Me)₂	17	0

^a Determined by ¹H NMR vs. mesitylene internal standard. ^b Starting material observed after 9 hours. ^c Reaction complete after 2 hours. ^d Reaction run by Lauren Kaminsky.

A solvent screen with varying temperatures was also performed (Table 2). Toluene and 1,4-dioxane were suitable solvents for this reaction at 85°C providing crude yields of 72% and 78% respectively (entries 7, 8). When DCE was used as the solvent at 85°C the reaction was complete in 9 h and produced the highest crude yield of 87% (entry 6). Lowering the reaction temperature required longer reaction times and produced lower yields (entries 1-5). However, at reduced temperature the amount of dimer byproduct (**1.41a**) was reduced. In DCE at 85°C the vinyl boronate to alkyne ratio was examined (entries 11, 12). This ratio played a crucial role in the reaction. With 1.2, 1.5 and 2.0 equivalents of boronate the crude yields by ¹H NMR were 62, 65 and 87 percent respectively. This effect is presumably due to dimerization (**1.41a**) of the vinyl boronate which consumes the boronate prior to the desired coupling.

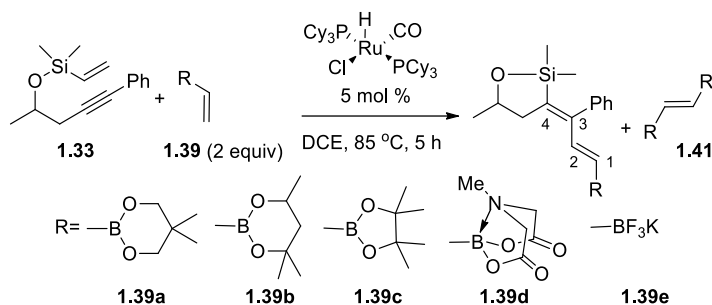
Table 2: Solvent and Equivalents Screen with **1.39a**

Entry	Solvent	Equiv. 1.39a	Temp. (°C)	Time (h)	Crude Yield 1.40 (%) ^{a,d}	Crude Yield 1.41a (%) ^a
1 ^b	DCM	2	45	7	27	0
2 ^b	DCE	2	60	15	53	1
3 ^b	DCE	2	70	15	65	2
4 ^b	THF	2	70	9	64	0
5 ^c	MeCN	2	70	9	No reaction	-
6 ^c	DCE	2	85	9	87	9
7 ^c	PhMe	2	85	5.5	72 (53)	1
8 ^c	1,4-dioxane	2	85	5.5	78 (59)	3
9	DMF	2	105	9	No reaction	-
10 ^b	PhCF ₃	2	105	9	45	0
11 ^c	DCE	1.5	85	9	66	3
12 ^c	DCE	1.2	85	9	63	2

^a Determined by ¹H NMR vs. mesitylene internal standard. ^b Starting material observed after designated reaction time.

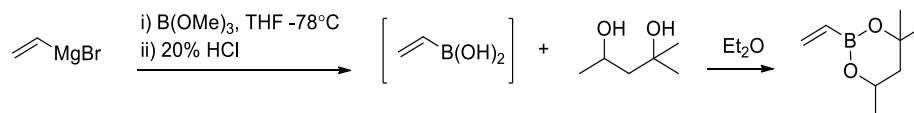
^c Reaction run by Lauren Kaminsky. ^d Isolated yield reported in parenthesis.

Product isolation was difficult with nearly 20 percent loss from the observed crude yields (Table 2, entries 7, 8). This result was most probably due to boronate hydrolysis upon exposure to silica gel. Attempting to deactivate the silica gel with triethylamine, trimethylchlorosilane, or boric acid⁶¹ showed no increase in isolated yield. Using neutral alumina provided similar results to silica gel. Several additional vinyl boronates were explored in an attempt to improve product isolation (Table 3). Careful examination of the literature revealed several promising candidates that were commercially available or readily prepared (Scheme 14).

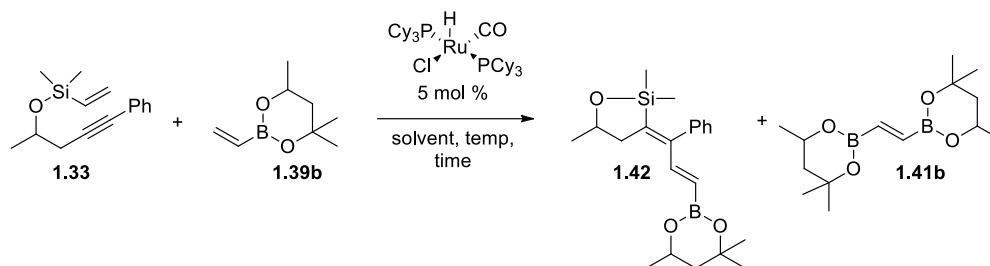
Scheme 14: Approach to Vinyl Boronate Couplings**Table 3:** Vinyl Boronate Screen

Entry	Boronate	Time (h)	Crude yield (%)	Isolated Yield (%)
1	1.39a	5.5	72	53
2	1.39b	5	75	55
3	1.39c	3	70	55
4	1.39d	9	No reaction	-
5	1.39e	9	No reaction	-

Pinacol boronate **1.39c** was easily prepared but highly volatile with a tendency to polymerize.⁶² Standard reaction conditions using **1.39c** and alkyne substrate **1.33** delivered a crude ¹H NMR yield of 70%, which was lower than observed with the neopentyl boronate **1.39a**. Burke and coworkers introduced MIDA compound **1.39d**,⁶³ while Molander and coworkers produced compound **1.39e**.⁶⁴ These are both air stable solids that have repeatedly demonstrated their usefulness in cross coupling chemistry;⁶⁴ however, these two reagents did not function in the desired reaction. We found that the most successful boronate was the hexylene glycol derived **1.39b**. Compound **1.39b** was easily prepared from readily available materials in multigram quantities following the procedure of Whiting.⁶²

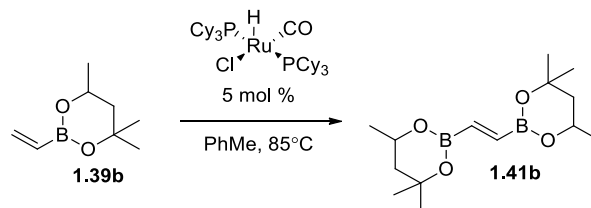
Scheme 15: Preparation of Vinyl Boronate **1.39b**

The ruthenium hydride catalyzed coupling reaction was conducted using alkyne **1.33** and boronate **1.39b**. Boronate dimer **1.41b** was found to co-elute with the products during isolation and some fractions had to be discarded. In order to minimize the formation of boronate dimer, solvent and temperature were once again evaluated (Table 4). Toluene, DCE and 1,4-dioxane performed well at 85 °C (entries 1-3). Refluxing THF (entry 4) gave no dimer but required a longer reaction time with compromised (58%) product yield. No reactivity was observed in refluxing acetonitrile (entry 5) presumably due to solvent coordination to the ruthenium. Additional temperatures were also explored with toluene. Lowering the temperature lead to longer reaction times and decreased the amounts of both dimer and product being formed (entry 6). Increasing the temperature to 100 °C gave a 78% crude yield of **1.42** but also increased the amount of dimer **1.41b** (entry 7). Toluene at 85 °C proved optimal for the reaction (entry 2) with regard to both reaction time and amount of dimer formation. Dimer **1.41b** was independently synthesized using these optimized reaction conditions to verify its structure (Scheme 15). Once again two equivalents of vinyl boronate to alkyne were observed to be the most beneficial ratio of reactants for the reaction.

Table 4: Solvent and Equivalents Screen With **1.39b**

entry	solvent	equiv. 1.39b	temp (°C)	time (h)	yield 1.42 (1.41b) ^a
1 ^b	DCE	2	85	5	75 (5)
2 ^b	PhMe	2	85	3.5	75 (3)
3 ^b	1,4-dioxane	2	85	4	67 (3)
4 ^b	THF	2	70	7	58 (0)
5 ^b	MeCN	2	70	7	No reaction
6	DCE	2	70	7	77 (2)
7	PhMe	2	70	7	63 (1)
8	PhMe	2	60	10	59 (1)
9	DCE	2	60	10	59 (1)
10	PhMe	2	100	3	78 (5)
11	PhMe	1.5	100	7	57 (3)
12	PhMe	1.2	100	7	58 (4)

^a percent yield determined by crude ¹H NMR versus mesitylene as an internal standard ^b reaction run by Lauren Kaminsky

Scheme 16: Independent Synthesis of Boronate Dimer **1.41b**

A catalyst screen was conducted in an attempt to impede the formation of **1.41b** while potentially increasing the amount of **1.42** (Table 5).⁶⁵ The overall goals for the proper catalyst were to retain reactivity with appropriate selectivity and short reaction time. Ruthenium complexes with various steric and electronic properties were prepared and tested. Ruthenium

hydride complex $\text{RuHCl}(\text{CO})(\text{PCy}_3)_2$ was shown to be superior to analogous hydride catalysts (entry 1). $\text{RuHCl}(\text{CO})(\text{Pi-Pr}_3)_2$ demonstrated good yield of product (72 %) but required longer reaction times. The remaining electron rich bisphosphine complexes (Table 5, entries 3-5) catalyzed the reaction with reasonable times but at compromised yield and increased dimer formation. $\text{RuHCl}(\text{CO})[\text{Pi-Pr}_2(3,5\text{-bis(trifluoromethyl)phenyl})]_2$ with electron deficient phosphine ligands, exhibited poor catalytic activity in the coupling. After significant development, standard reaction conditions were implemented and used in a substrate scope. The standard conditions were as follows; 5 mol % $\text{RuHCl}(\text{CO})(\text{PCy}_3)_2$ with 2 equivalents of **1.39b** in toluene (0.5M in alkyne) at 85 °C.

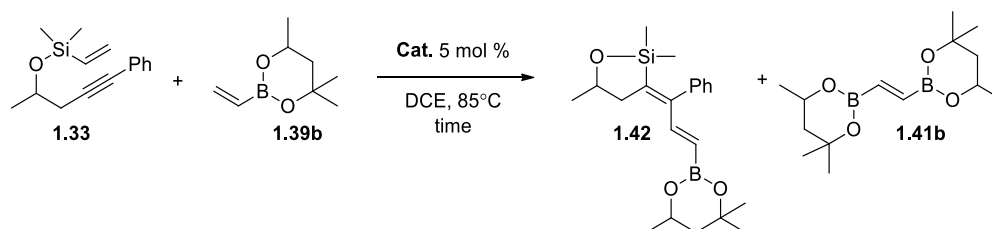


Table 5: Ruthenium Hydride Catalyst Screen with **1.39b**

entry	catalyst	time (h)	yield 1.42 (%) ^a	dimer (1.41b) ^a
1 ^b	$\text{RuHCl}(\text{CO})(\text{PCy}_3)_2$	3.5	75	3
2 ^b	$\text{RuHCl}(\text{CO})(\text{Pi-Pr}_3)_2$	8	72	4
3	$\text{RuHCl}(\text{CO})(\text{Pt-Bu}_2\text{Me})_2$	5	67	10
4 ^b	$\text{RuHCl}(\text{CO})(\text{Pt-Bu}_2\text{Cy})_2$	2	61	11
5 ^b	$\text{RuHCl}(\text{CO})(\text{PCy}_2\text{t-Bu})_2$	8	60	6
6 ^c	$\text{RuHCl}(\text{CO})(\text{PR}_3)_2$	8	15	0

^a percent yield determined by crude ¹H NMR versus mesitylene as an internal standard. ^b reaction run by Lauren Kaminsky. ^c PR3 = (3,5-bis(trifluoromethyl)phenyl)diisopropylphosphine

Mechanistically (Figure 6), the hypothesis is that dissociation of one phosphine ligand from $\text{RuHCl}(\text{CO})(\text{PCy}_3)_2$ reveals a 14-electron ruthenium species (I). Once the active catalytic species is produced, substrate coordination, hydorruthenation of the vinyl silane (II) and β -silyl transfer occur to deliver silyl ruthenium intermediate (III). Considering the presence of two vinyl metalloid

species in the reaction (vinyl boronate and tethered vinyl silicon), it is assumed that since dimer formation can be inhibited by changes in reaction conditions that the vinyl silicon is more reactive than the vinyl boron leading to preferential hydorruthenation of the vinyl silicon tethered alkyne substrate. At this stage an intramolecular silyl-ruthenation of the alkyne provides vinyl ruthenium (IV). In view of the *trans* addition product obtained, the silyl-ruthenation of the alkyne can occur from a direct *trans*-addition^{29, 30} or *cis*-addition followed by isomerization.²⁸ The isomerization can occur through a polarization of the olefinic bond and formation of a zwitterionic species. At the zwitterionic stage free rotation allows for the *trans* orientation to be attained. Intermolecular insertion of the vinyl boronate and β -hydride elimination liberates the product and regenerates the active hydride catalyst. A similar mechanistic possibility is depicted to show the formation of boronate dimer (**1.41**).

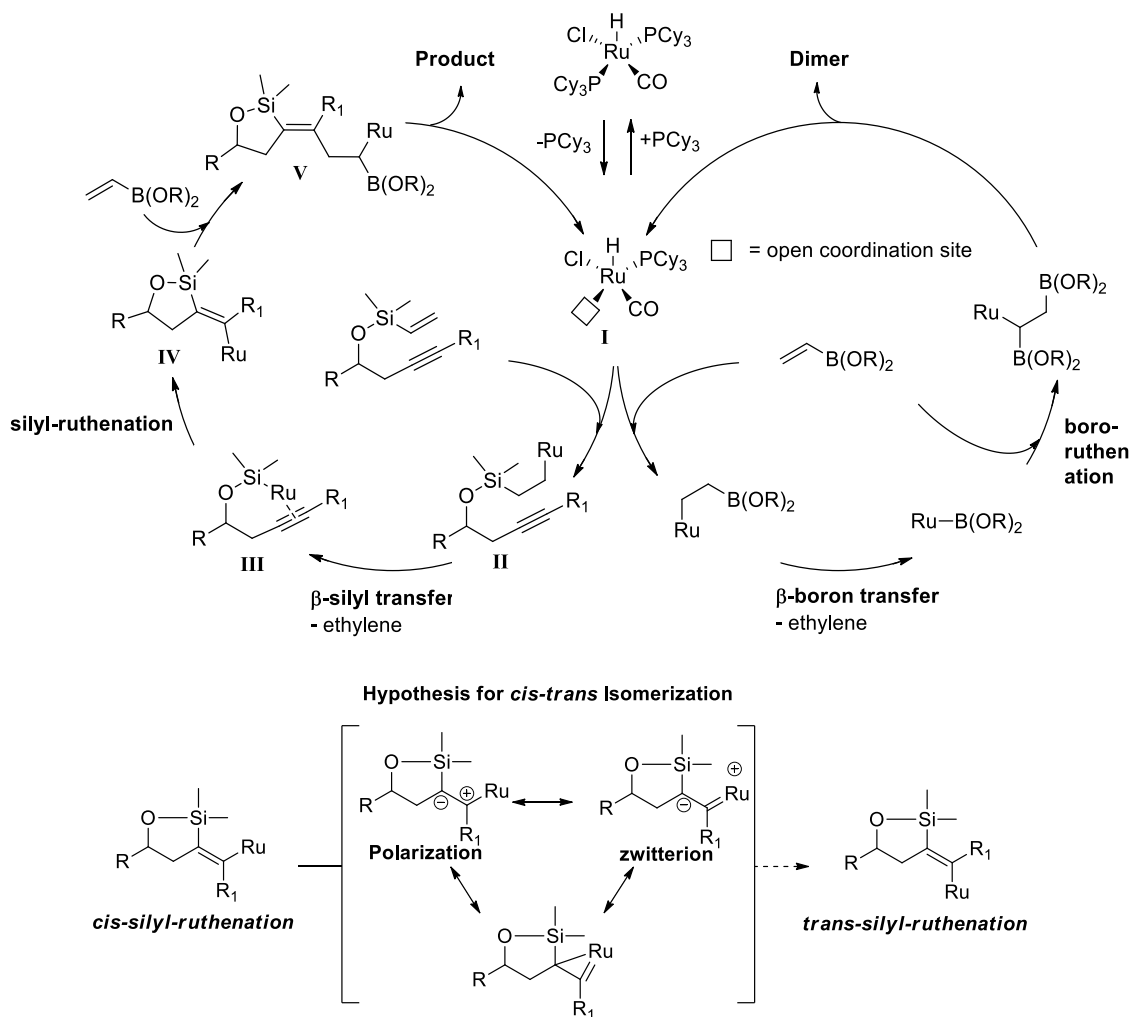
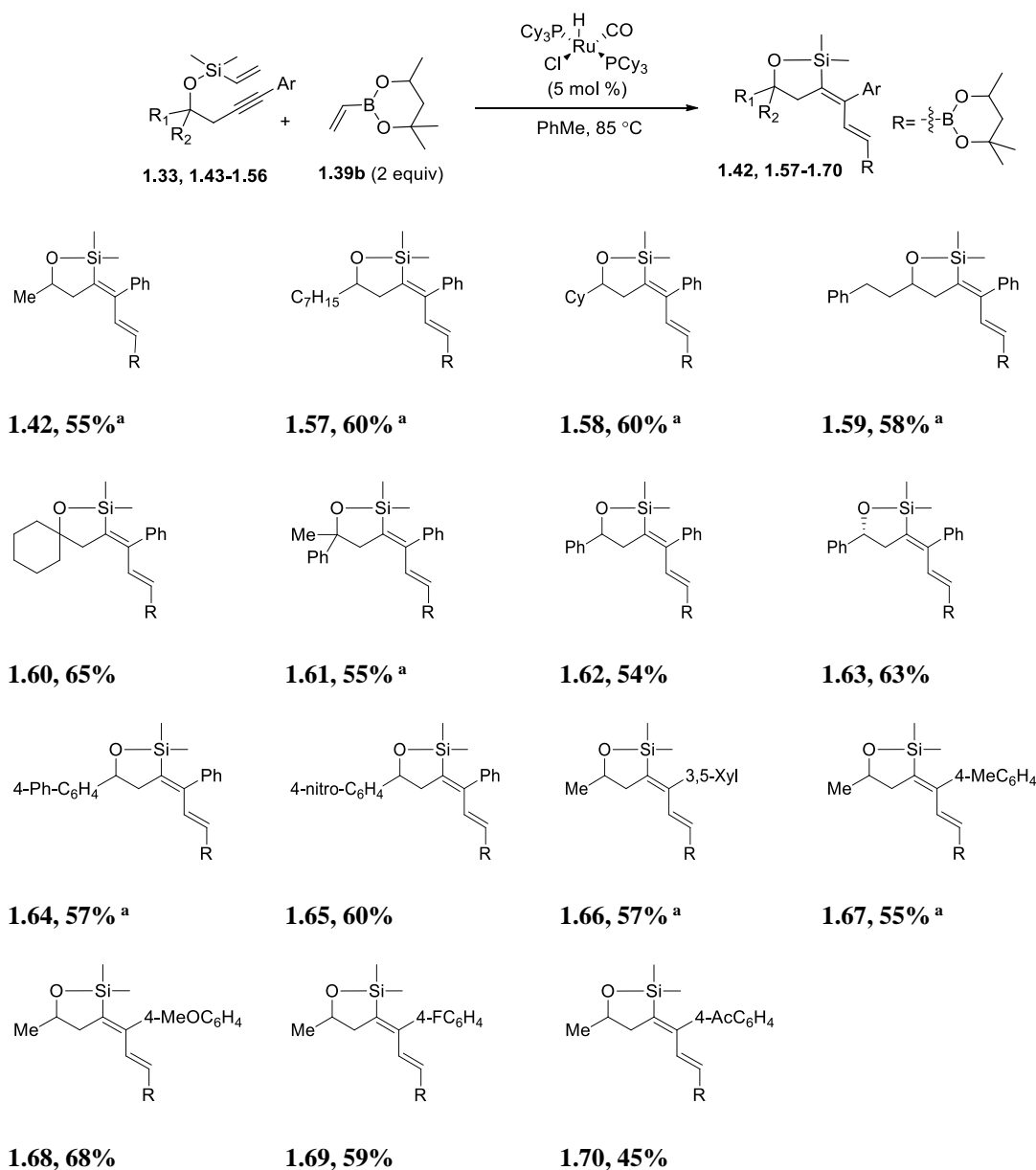


Figure 6: Vinyl Boronate Coupling Mechanistic Hypothesis

With optimized conditions in hand, a study of substrate scope was conducted, and the reaction worked well with various alkyne substrates (Table 6). Racemic alkyne substrates were prepared in one of two ways: propargyl Grignard addition to aldehydes or ketones, or anionic acetylide epoxide openings. These two methods produced homopropargyl alcohols which were silylated using chloro dimethyl vinyl silane in the presence of imidazole and DMAP at 0 °C. The substrate scope began with altering alkyl functionality at R_1 and maintaining a phenyl ring at the alkyne terminus. Homopropargylic alkyl functionality was well tolerated with methyl (**1.42**, 55%),

n-heptyl (**1.57**, 60%), cyclohexyl (**1.58**, 60%) and dihydrocinnamyl (**1.59**, 58%) providing dienes **1.42**, **1.57-1.59** in good yields. Tertiary homopropargylic tethered alcohols also performed well generating dienes **1.60** (65%) and **1.61** (55%) efficiently. Aryl substituents at the homopropargyl position, phenyl (**1.62**, 54% and **1.63**, 63%), biphenyl (**1.64**, 57%) and *para*-nitro (**1.65**, 60%) also worked well. Next, aryl substitution on the pendant alkyne was examined. It was observed that *ortho* substitution (*i.e.* 2-chlorophenyl-) did not participate in the reaction, presumably due to steric crowding. Fortunately, aryl substituents bearing *meta* substitution worked well and gave 3,5-xylyl substrate **1.66** in 57% yield. Altering the electronic structure of the aryl group at the *para* position it was observed that methyl (**1.67**, 55%) and the electron donating methoxy group (**1.68**, 68%) provided higher yields than an electron withdrawing acetyl group (**1.70**, 45%). Fluorine substitution was also compatible and diene **1.69** was obtained in 59% yield. Dienes **1.62** and **1.64** were synthesized on a 2 mmol scale and the isolated yields obtained were within $\pm 3\%$ of those conducted at 0.3 mmol.

Table 6: Silyl Diénylboronate Substrates

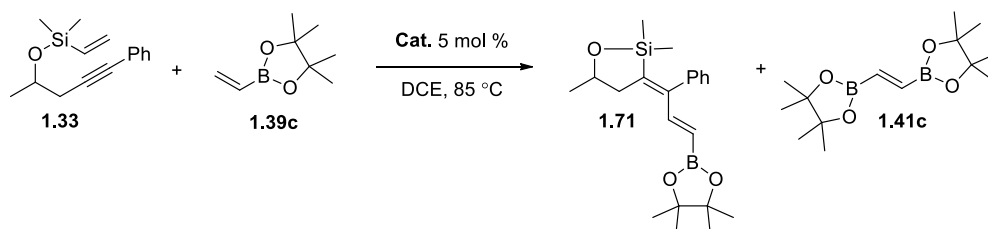
^a reactions conducted by Lauren Kaminsky

With the isolated yields of dienes **1.42**, and **1.57-1.70** under 70% a few substrates with the pinacol boronate **1.39c** were inspected (Table 7). These substrates produced a lower crude yield but the dienes proved more stable to isolation with minimal product loss during chromatography.

Going back to the drawing board ruthenium catalysts were investigated in order to identify, solvents and temperature then finally vinylboronate **1.39c** equivalents that could provide the best results.

As previously observed with boronates **1.39a** and **1.39b**, ruthenium catalyst RuHCl(CO)(PCy₃) performed the best compared to the other ruthenium hydride sources examined. RuHCl(CO)(*Pt*-Bu₂Me)₂ provided very similar results but greater amounts of dimer (**1.41c**) were observed and this hydride source was disregarded. It was decided that 5 mol % RuHCl(CO)(PCy₃)₂ would be used for the remainder of the evaluation.

Table 7: Catalyst Screen for Vinyl Boronate Coupling with **1.39c**



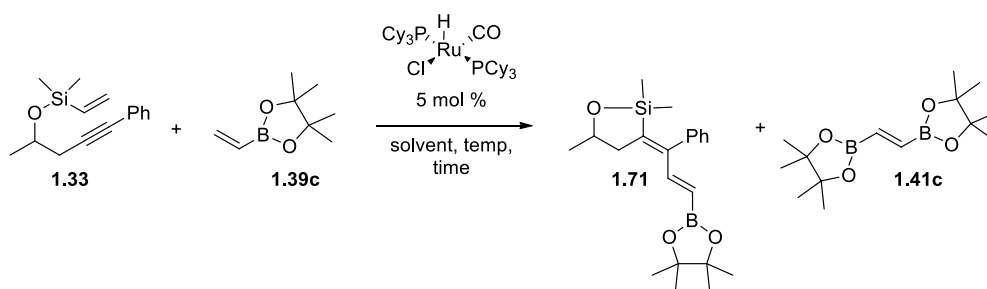
entry	catalyst	time (h)	yield 1.71 (%) ^a	dimer (1.41c) ^a
1	RuHCl(CO)(PCy ₃) ₂	3	70	3
2	RuHCl(CO)(SIMes)(PPh ₃)	1	21	4
3	RuHCl(CO)(<i>Pi</i> -Pr ₃) ₂	3	53	10
4	RuHCl(CO)(<i>Pt</i> -Bu ₂ Me) ₂	3	71	12
5	RuHCl(CO)(<i>Pt</i> -Bu ₂ Cy) ₂	1	43	34
6	RuHCl(CO)(PPh ₃) ₃	10	0	8

^a percent yield determined by crude ¹H NMR versus mesitylene as an internal standard

As seen in Table 8, lower temperatures required longer reaction times and diminished yields were observed (Table 8, entries 1-4). The reaction in DCE heated to 85 °C was superior to other solvents at the same temperature, and this solvent was chosen along with two equivalents of **1.39c** as the standard conditions. Attempting the reaction using vinyl boronate **1.39c** as solvent

(1.0M in alkyne) proved unsuccessful, as the dimerization product **1.41c** was observed in a nearly equal ratio to the desired product **1.71** (entry 10).

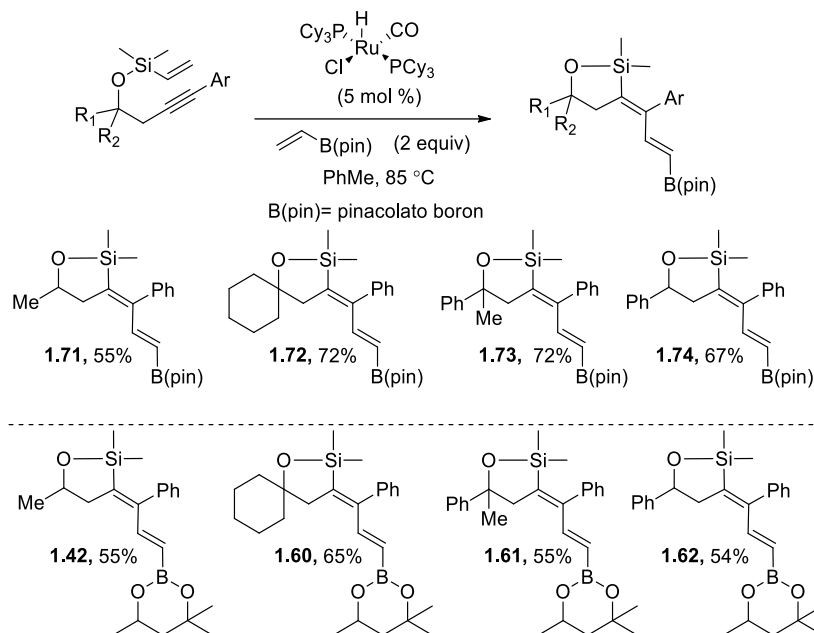
Table 8: Solvent, Temperature and Equivalents Screen with **1.39c**



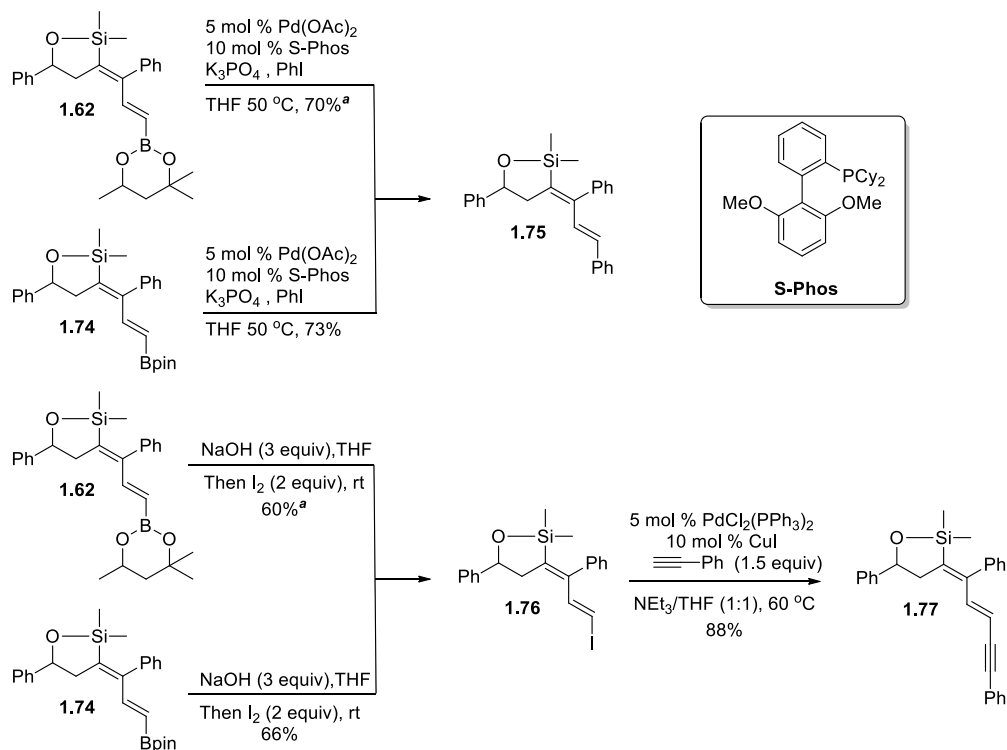
entry	solvent	equiv. 1.39c	temp (°C)	time (h)	yield 1.71 (1.41c) ^a
1	DCM	2	50	24	No reaction
2	DCE	2	70	8	60 (3)
3	THF	2	70	8	42 (4)
4	DCE:THF (1:1)	2	70	14	60 (9)
5	1,4-dioxane	2	85	3	57 (5)
6	DCE	2	85	3	70 (3)
7	DME	2	85	3	59 (0)
8	PhMe	2	85	3	56 (5)
9	DCE	1.2	85	5	54 (2)
10	-	Neat (1.0M)	85	3	38 (20)
11	1,4-dioxane	2	100	3	66 (7)
12 ^b	DCE	2	85	6	60 (3)

^a percent yield determined by crude ¹H NMR versus mesitylene as an internal standard ^b **1.39c** and alkyne **1.33** were added as a 0.5M solution in DCE to reaction via syringe pump over 1 h.

In regard to Scheme 17, the isolated yield of diene **1.71** using the pinacol boronate **1.39c** was consistent with diene **1.42** using the hexylene glycol boronate **1.39b**; however, dienes **1.72-1.74** displayed increased isolated yields of 7-18% when compared to **1.60-1.62**, respectively.

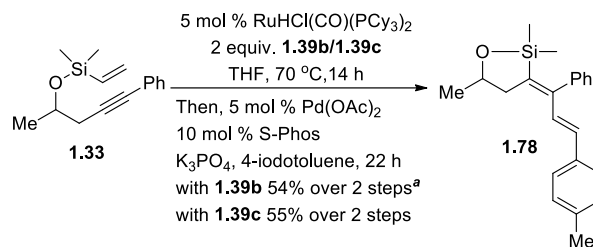
Scheme 17: Ruthenium Hydride Coupling Substrate Scope Using Vinyl Boronate **1.39c**

The silyl-dienyl boronates obtained from these reactions could be further manipulated into more diverse molecules by the use of various metal-catalyzed coupling methods (Scheme 18).^{41,}
⁴⁶ Suzuki coupling⁶⁶ with diene **1.62** or **1.74** and iodobenzene produced **1.75** in comparable yields with retention of configuration. Iodo-deboration⁵² of the same dienes provided silyl-dienyl iodide **1.76** in 60% and 66% isolated yields, respectively. Iodide **1.76** was subsequently used as a coupling partner under Sonogashira⁶ conditions to afford dienyne **1.77** in 88 % yield.

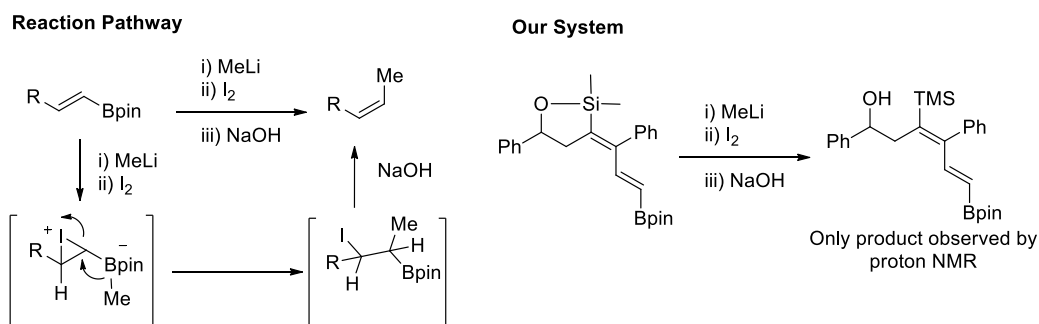
Scheme 18: Synthetic Derivatization of Silyl-dienyl Boronates

^a reactions conducted by Lauren Kaminsky

After significant examination, suitable conditions⁶⁷ were established for the tandem silyl-boration of alkyne **1.33** and in-situ Suzuki coupling of diene **1.62** with 4-iodotoluene (Scheme 19). This protocol provided diene **1.78** in 54% isolated yield over two steps. With identical conditions and diene **1.74** Suzuki coupled product **1.78** was obtained in a 55% isolated yield over two steps.

Scheme 19: Tandem Hydride Coupling-Suzuki Coupling^a reaction conducted by Lauren Kaminsky

Attempts to form the *Z,Z* dienyl bromide⁵² from diene **1.62** were not successful and gave a complex mixture with mostly proto-desilylation. Several other reactions were attempted for derivatization that resulted in undesired transformations. For example, diene **1.74** was treated with methyl lithium in an attempt to form the borate complex *in situ* (Scheme 20).⁶⁸ Once the borate complex is formed the addition of iodine should induce a migratory insertion of the methyl group, followed by NaOH mediated deiodoboration. However, when this protocol was subjected to silyldienyl-boronate **1.74**, methyl lithium was selective for the vinyl silicon moiety and we observed a new vinyl trimethyl silane by proton NMR.

Scheme 20: Borate Complex Formation and Migratory Insertion of Methyl Group

The formation of silyl-dienyl boronates by a *trans*-silylation protocol with internal alkynes and vinyl boronates has been successfully demonstrated. Highly substituted dienes were formed in a single step and were transformed into more complex diene products by Suzuki couplings and

iodo-deboration. The vinyl iodide was transformed under Sonagashira coupling conditions to produce a diene-yne. The silyl-dienylboronate motif will be explored further toward the synthesis of more complex molecules and natural products.

Our initial reports of intermolecular ruthenium hydride catalyzed couplings using alkynes and olefin acceptors was rewarding. We developed a stereo and regioselective approach toward conjugated dienes through an *anti-exo-dig* cyclization. The products have an exocyclic diene with a tetrasubstituted double bond containing four different substituents. Other similar protocols used to form tetrasubstituted olefins from alkynes have been reported in the literature.⁶⁹⁻⁷² However, processes like silylformylation occur via *syn* addition to the alkyne.^{73,74-77} There are a select few examples that provide *anti* addition products to alkynes and the silylvinylation of internal alkynes using ruthenium hydrides now fits in this category.^{29, 78, 79}

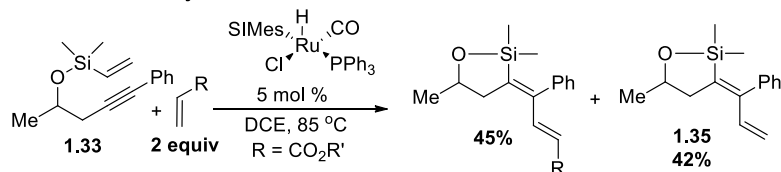
1.2 ETHYLENE TRANSFER

1.3.1 Intramolecular Silylvinylation

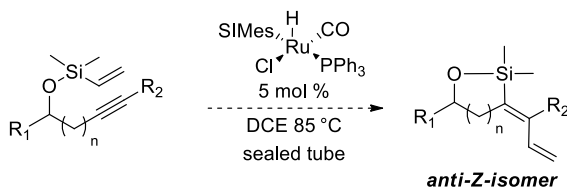
The unexpected discovery of an ethylene transfer reaction occurred during the preliminary screening of ruthenium hydride catalysts (Scheme 21). A terminal diene **1.35** was observed in a nearly 1:1 ratio with acrylate incorporation when $\text{RuHCl}(\text{CO})(\text{SiMe}_3)\text{PPh}_3$ was used as the hydride source. Given the novelty and atom economy of the process we sought to optimize conditions to obtain vinylated product (**1.35**).

Scheme 21: Reaction Discovery and Proposed Ethylene Transposition

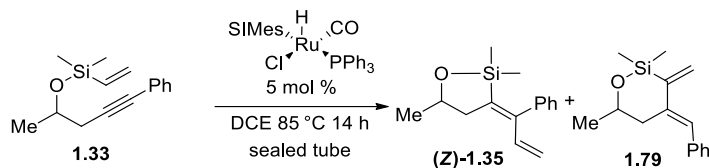
Reaction Discovery:



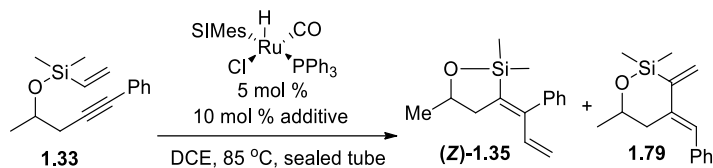
Ethylene Transposition:



We anticipated that the exclusion of a coupling partner in a sealed environment would produce a smooth intramolecular ethylene transfer. The reaction was stirred for 14 h at 85 °C in a sealed tube using DCE as solvent and only 70 percent conversion of alkyne was observed (Scheme 22). Under these conditions we observed for the first time a cycloisomerization byproduct (**1.79**) along with desired diene product (**Z-1.35**). The cycloisomerization of substituted enynes was unanticipated; however, the process has been reported previously using ruthenium hydrides.²² The byproducts were easily separated by column chromatography and independently characterized.

Scheme 22: Ethylene Transposition and Cycloisomerization Byproduct

In retrospect, the intermolecular couplings were complete in less than 9 hours. Taking this into consideration led us to the assumption that olefin additives may be required for this reaction to go to completion (Table 9). We chose to screen primarily electron deficient olefin additives due to the inherent lack of reactivity that we had previously observed in the intermolecular coupling. As shown in Table 9, using no additive (entry 1) produced better results than many other additives. Acrylamides and acyclic vinyl ketones afforded full conversion and high yield of the product with an excellent ratio of **(Z)-1.35** to **1.79** (entry 7-8). The use of cyclohexanone as an additive suggests that η -4-coordination to the ruthenium may not be a requirement (entry 9). We also examined using ethylene (entry 10), however, a mixture of inseparable stereoisomers of **1.35** were obtained. Methyl vinyl ketone (MVK) was chosen as the additive as it provided the highest ratio of **(Z)-1.35** to **1.79**, and its volatility facilitated its removal from the reaction mixture.

Table 9: Screen of Additives for Ethylene Transposition

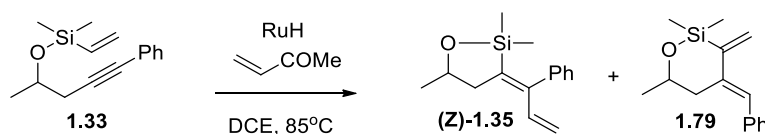
Entry	Additive	Crude yield ^a (%)	Ratio ^b (Z:1.79)
1	-	70	3.1:1
2		50	1.9:1
3		55	4.5:1
4		Trace	-
5		77	3.8:1
6		76	3.7:1
7		100	5.8:1
8		100	5.7:1
9	cyclohexenone	80	3:1
10 ^c	C ₂ H _{4(g)} 1 atm	100	17:1

^aYield based on remaining **1.33** by ¹H NMR versus mesitylene as an internal standard. Reactions conducted by JinboZhao and Shasha Liu. ^bRatio of (Z)-**1.35** and **1.79** was determined by ¹H NMR versus mesitylene as an internal standard. ^c **1.35** was obtained as a mixture of isomers (10:1, Z:E) as observed by ¹H NMR. Reaction conducted by Robert J Wilson

The initial catalyst screen during the acrylate study revealed ruthenium hydride complex RuHCl(CO)(SIMes)(PPh₃) bearing an NHC ligand to be the only complex to provide vinylated product (Z)-**1.35**. With this complex in the presence of MVK, alkyne **1.33** was successfully transformed and (Z)-**1.35** and **1.79** were observed in an 85:15 ratio (Table 10, entry 1). Altering this complex by one degree of unsaturation to the NHC backbone [RuHCl(CO)(IMes)(PPh₃), entry 2] or phosphine exchange [RuHCl(CO)(SIMes)(PCy₃), entry 3] offered little improvement in conversion and yield for this reaction. Attempts to generate the active NHC complex *in situ* from commercially available RuHCl(CO)(PPh₃)₃ and SIMes·HCl did not provide any reaction. Assessment of catalyst loading and MVK concentration was also investigated to further optimize this reaction. In a 1:1 ratio of MVK to RuHCl(CO)(SIMes)(PPh₃), 83% conversion was attained in only 5 hours. Addition of 10 mol % MVK (2:1 ratio, MVK:RuHCl(CO)(SIMes)(PPh₃))

provided the best results for both yield and product ratio ((**Z**)-**1.35**:**1.79**). Interestingly, it was found that the loading of complex $\text{RuHCl}(\text{CO})(\text{SiMe}_3)(\text{PPh}_3)$ could be decreased when a high concentration of MVK was maintained. This came at the expense of reaction time and the possibility of less than full conversion. The current hypothesis is that the additive protects the ruthenium catalyst from decomposition.^{80, 81} Several solvents worked well in this reaction including toluene and 1,2-dichloroethane (DCE). Unfortunately a full solvent screen was not conducted. DCE was used first and excellent yields were obtained. Later on it was discovered that 1,4-dioxane could be used as a chelating solvent that also worked as the additive with many of the substrates.

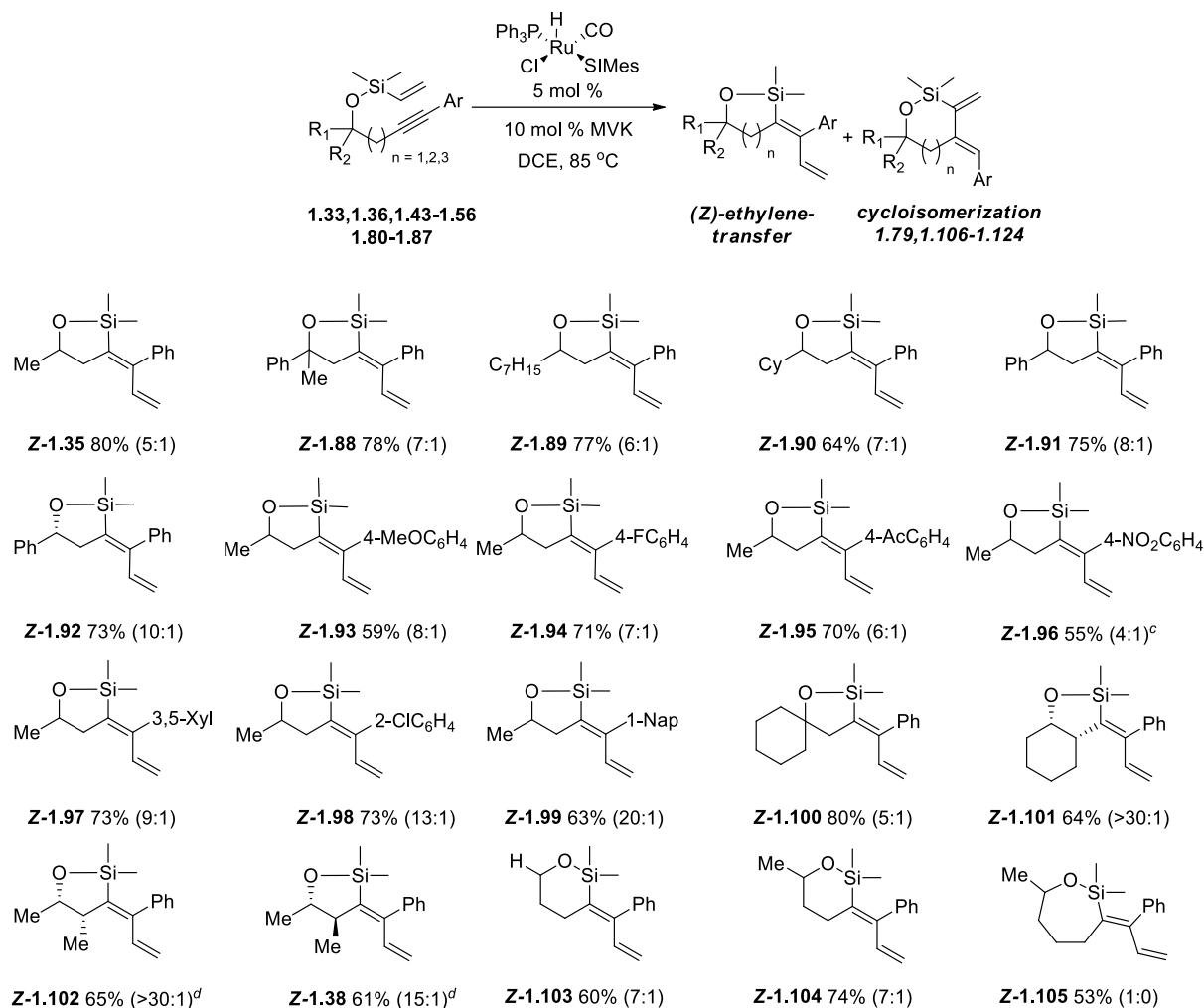
Table 10: Catalyst Screen for Ethylene Transposition



Entry	RuH (5 mol %)	MVK (mol %)	Time (h)	Conv. (%)	ratio ((Z)- 1.35 : 1.79)
1	$\text{RuHCl}(\text{CO})(\text{SiMe}_3)(\text{PPh}_3)$	10	5	100	85:15
2	$\text{RuHCl}(\text{CO})(\text{IMes})(\text{PPh}_3)$	10	12	65	54:10
3	$\text{RuHCl}(\text{CO})(\text{SiMe}_3)(\text{PCy}_3)$	20	23	45	25:4
4	$\text{RuHCl}(\text{CO})(\text{Pt-Bu}_2\text{Me})_2$	20	24	50	1:18
5	$\text{RuHCl}(\text{CO})(\text{PPh}_3)_3$	10	24	No reaction	-

The substrate scope of this reaction was also examined (Table 11) using 5 mol % catalyst $\text{RuHCl}(\text{CO})(\text{SiMe}_3)(\text{PPh}_3)$, and 10 mol % MVK. Alkynes bearing a phenyl group at the terminus were examined first. Dienes **Z**-**1.35** and **Z**-**1.88-1.92** were produced from the corresponding phenyl alkynes. These substrates performed very well, delivering products in good yields (64-80%) with ratios of *ethylene transfer* to *cycloisomerization* consistently around 5:1 and 10:1 (ratios in parenthesis). Both electron rich functionality **Z**-**1.93** and electron withdrawing functionality **Z**-**1.95** and **Z**-**1.96** were well tolerated. Compound **Z**-**1.96** was crystallized and the structure as

depicted was verified through X-ray diffraction. All other structures have been determined through NOESY experiments or by analogy. Compound **Z-1.94** which bears a fluorine moiety was prepared in 71% yield. A 3,5-xylyl moiety at the alkyne provided diene **Z-1.97** in 73% yield. Bulky ortho substituents such as chlorine and 1-naphthyl were well tolerated and afforded **Z-1.98** in 73% yield and **Z-1.99** in 63% yield respectively. These structures (**Z-1.98** and **Z-1.99**) appear as mixtures of atropisomers by proton NMR. Alkynes **1.84** and **1.85** which possess both propargylic and homopropargylic functionality provided >30:1 ratios of products **Z-1.101** and **Z-1.102** in 64% and 65% yield, respectively. Compound **Z-1.38**, which represents a *trans* relationship at the propargyl and homopropargyl positions also provided an excellent ratio of 15:1 in 61% yield. Six-membered oxo-silylcycles could also be formed efficiently regardless of Thorpe-Ingold factors.⁸² Compounds **Z-1.103** and **Z-1.104** were obtained in 59% and 74% yields, respectively. Of note, seven-membered ring product **Z-1.105** was formed in 53% yield using this methodology. Ojima *et al.* have observed that forming seven-membered rings using rhodium catalyzed silylformylation proceeds to give a mixture of products with only trace amounts of the desired product observable by ¹H NMR and GC-MS.^{83, 84} In our case, the corresponding eight-membered ring was not observed in the ¹H NMR of the crude reaction mixture.

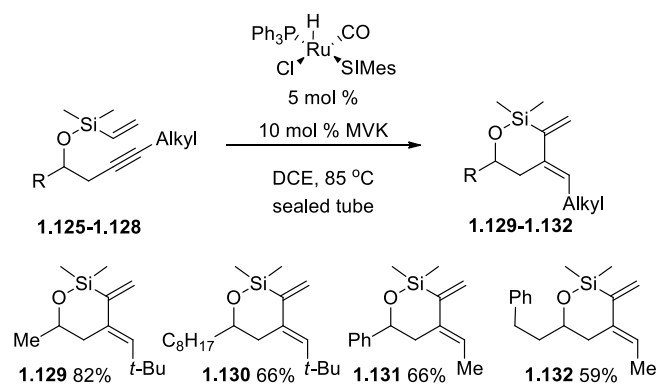
Table 11: Scope of Silylvinylation Using MVK with Aryl-Substituted Alkynes^{a,b}

^aYields represent only isolated vinylation products **Z**. ^bRatios in parenthesis represent the ratio of vinylation product **Z** to cycloisomerization product as determined by ¹H NMR of the crude reaction mixture. ^cStructure verified by Dr. Nadia Marino via X-ray crystallography. ^dReactions conducted by Robert J Wilson, all others conducted by Shasha Liu and Jinbo Zhao

A primary goal of the silylvinylation project was to attain stereo, regio and chemoselectivity for alkynes bearing alkyl groups. Alkyl groups appended to diene motifs are more prevalent than aryl moieties in natural products. Our efforts to convert alkyl bearing alkyne substrates with these transposition conditions formed only cycloisomerization products (Table 12).

Cycloisomerization was the only outcome regardless of the alkyl substituent attached to the alkyne (1.129-1.132).

Table 12: Diene Formation with Alkyl-Substituted Alkynes^a



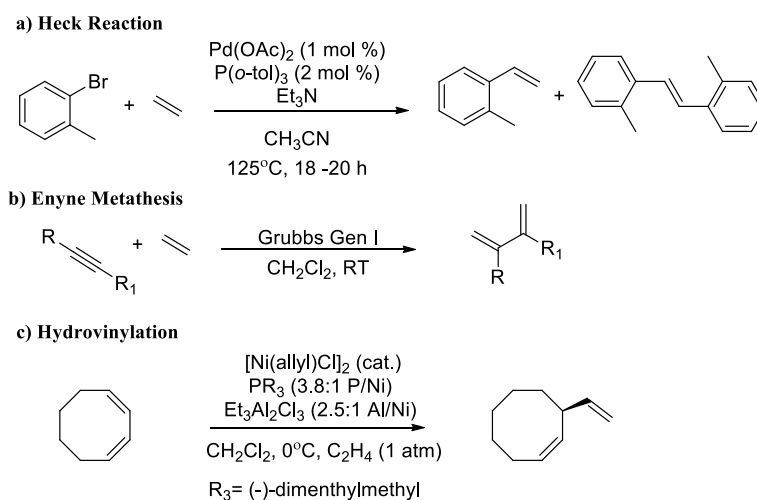
^a reactions conducted by Shasha liu and Jinbo Zhao

The undesired cycloisomerization proved troublesome and a new method was required to avoid this result. Since the concentration and ratio of additive to catalyst played a favorable role in this ethylene transposition we sought to compare these results with the use of ethylene gas. Previously, an isomeric olefin mixture was observed when ethylene gas was utilized as an additive. This was originally observed as a deleterious effect and ethylene was disregarded as the additive of choice. It was predicted that increasing the amount of additive to exponentially greater quantities would produce more efficient catalytic turnover and possibly reduce or eradicate the cycloisomerization byproduct.

1.3.2 Silylvinylation Using Ethylene Gas as an Additive

Alkenes are one of the most useful functional groups because they are tolerant to many conditions and known to undergo a variety of transformations.⁸⁵ Ethylene is the simplest alkene that is made in enormous quantities with nearly 150 million lbs produced daily.⁸⁶ It is also an economical resource ideal for vinylation chemistry as only one hydrogen atom is lost during the process.⁸⁵ Ethylene has been utilized in numerous organic transformations including Mizoroki–Heck reactions,^{87, 88} enyne metathesis¹⁷ and hydrovinylation (Scheme 23).^{24, 89, 90} Our previous screen of additives for silylvinylation revealed ethylene as an interesting choice. As a gas the excess additive quickly dissipates and is no longer a concern in the reaction mixture. The use of ethylene gas as an additive provided us with more rapid conversion to product but at the expense of stereocontrol. Using ethylene warranted a more thorough investigation for the silylvinylation of alkynes. The silylvinylation of internal alkynes delivers a well-defined tetra-substituted olefin, a new vinyl group and vinylsilane of significantly increased complexity.⁴² Vinyl silicon species are of particular interest due to their use in carbon-carbon bond forming reactions^{41, 46} allowing for further synthetic manipulations.

Scheme 23: Examples of Ethylene used in Organic Transformations



Our main goal for this study was to improve the ethylene insertion process and to expand our repertoire of alkynes to include alkyl substituted substrates. Secondary goals included eradication of cycloisomerization byproducts (*i.e.* **1.79**), reduction of catalyst loading and decreasing reaction times.

Based on the product formation observed previously, we suggest a mechanism which can illustrate the ruthenium hydride catalyzed vinylation of internal alkynes (Figure 7). Phosphine dissociation from complex $\text{RuHCl}(\text{CO})(\text{SiMe}_3)(\text{PPh}_3)$ provides ruthenium complex **A** which undergoes olefin insertion to provide alkyl-ruthenium **B**. Silane **B** liberates ethylene while the silicon transfers to ruthenium to give silyl-ruthenium intermediate **C**. Although we do not favor a direct *trans*-addition across the alkyne pi-system, the process has been observed by others (*vide supra*, section 1.2.1). Our mechanistic proposal suggests that *cis*-metallation (**C** to **D**) is followed by isomerization (**D** to **E**) and is supported by empirical data (*vide infra*). Subsequent insertion of ethylene into vinyl ruthenium **E** and beta-hydride elimination of **F** liberates the product and regenerates ruthenium hydride **A** to complete the catalytic cycle. We anticipated that the addition of ethylene to the reaction would increase the conversion of alkyne by silylvinylation in preference to the undesired cycloisomerization. Additionally, the use of ethylene could provide some understanding of the mechanism of this reaction; our hypothesis being that increasing the amount of ethylene in the reaction would trap proposed *cis*-isomer **D** prior to isomerization to *trans*-isomer **E**. Using ethylene- d_4 we observed incorporation of exogenous ethylene into the product (Scheme 24). This outcome affirms that the ethylene being added to the system can be incorporated into the product. Another aspect of this study was to obtain silylvinylation of internal alkyl substituted alkynes. Previously, ethylene transposition of these alkynes provided solely cycloisomerization products presumably through intermediates **G** and **H** (Figure 7).

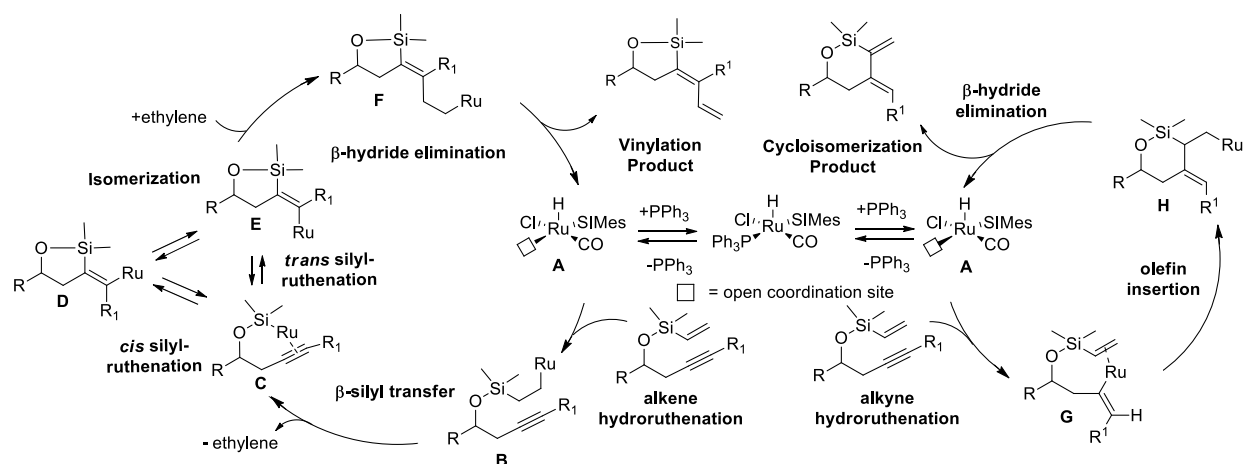


Figure 7: Mechanistic Hypothesis for Ethylene Addition to Alkynes

Scheme 24: Isotopic Labeling Experiment

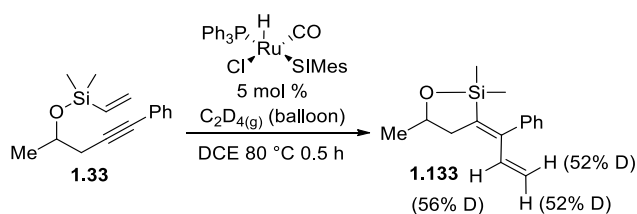
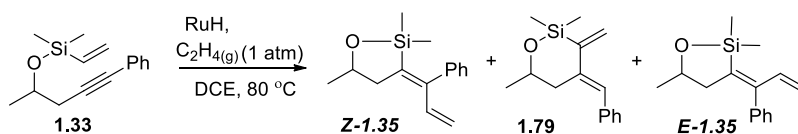


Table 13: Catalyst Screen for Silylvinylation under 1 Atmosphere Ethylene

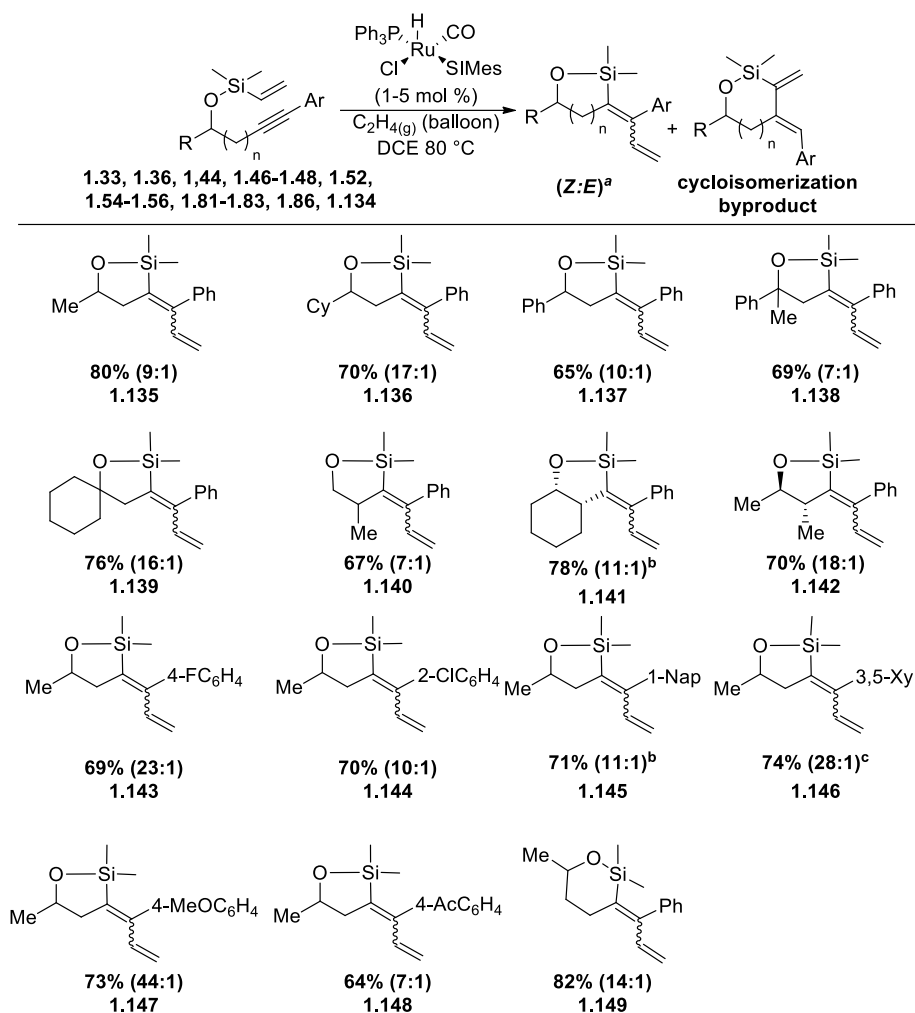


entry	catalyst	time (h)	Conversion	Z:1.79:E	yield Z-1.35 (%) ^a
1	$\text{RuHCl}(\text{CO})(\text{SIMes})(\text{PPh}_3)$	1	100	18:1:2	91
2*	$\text{RuHCl}(\text{CO})(\text{PCy}_3)_2$	7	89	55:4:1	55
3*	$\text{RuHCl}(\text{CO})(\text{Pt-Bu}_2\text{Cy})_2$	7	43	1:0:0	23
4*	$\text{RuHCl}(\text{CO})(\text{Pt-Bu}_2\text{Me})_2$	7	33	6:1:0	18
5 ^c	$\text{RuHCl}(\text{CO})\text{PR}_3$	7	29	1:0:0	11

^aYield determined by ^1H NMR vs mesitylene internal standard. *5 mol % catalyst was used.

^c $\text{PR}_3 = (3,5\text{-bis(trifluoromethyl)phenyl})\text{diisopropylphosphine}$.

This investigation began by reacting alkyne **1.33** with 1 mol% of $\text{RuHCl}(\text{CO})(\text{SIMes})(\text{PPh}_3)$ under an atmosphere (balloon) of ethylene in 1,2-dichloroethane (DCE) at 80 °C. A rapid (1 h) reaction was observed that produced silylvinylation product **1.35** as a 9:1 mixture of *Z* and *E* isomers (Table 13, entry 1). The observed result supports the claim that syn-metallation (*i.e.* formation of **D**) followed by isomerization occurs to give **E** which proceeds to the silylvinylation products observed. Further examination of catalysts revealed that complex $\text{RuHCl}(\text{CO})(\text{SIMes})(\text{PPh}_3)$ was the optimum ruthenium hydride catalyst and in many cases 1 mol % was sufficient to provide the desired products. Alternatively, ruthenium hydride complexes that bear two large phosphine ligands instead of the NHC, do provide some of the silylvinylation products. These complexes (Table 13, entries 2-5) required higher catalytic loadings and longer reaction times. It was observed that the more electron rich complexes afforded higher conversion and larger quantities of product (Table 13). Presumably $\text{RuHCl}(\text{CO})(\text{SIMes})(\text{PPh}_3)$ is superior due to the greater donating ability of the NHC⁹¹ and the enhanced lability of the less basic PPh_3 ligand.⁹² The bis phosphine complexes also provided less desired product than $\text{RuHCl}(\text{CO})(\text{SIMes})(\text{PPh}_3)$. Other solvents such as toluene and 1,4-dioxane were also found to be suitable for this reaction at 80 °C.

Scheme 25: Substrate Scope for Silylvinylation Using Ethylene Gas

^aRatios determined by ¹H NMR using mesitylene as an internal standard. Products were isolated as a mixture of *Z/E* isomers. ^bReaction conducted by Lauren Kaminsky. ^cReaction conducted by Ijaz Ahmed.

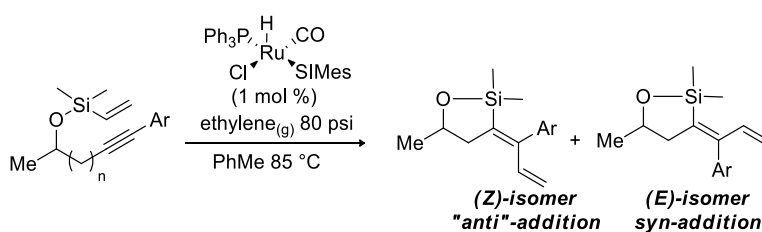
The substrate scope was examined using complex RuHCl(CO)(SiMes)(PPh₃) in DCE at 80 °C (Scheme 25). The substrates were developed by keeping the aryl group constant and altering groups at the homo-propargyl and propargyl positions. The reaction tolerated methyl and cyclohexyl groups at the homo-propargyl position and gave **1.135** and **1.136** in 80% and 70% yield, respectively. Aryl groups were also well tolerated and **1.137** was formed in 65% yield.

Multiple substitutions at the homopropargyl position afforded **1.138** in 69% and **1.139** in 76% yield. Previously, using MVK as an additive, only partial conversion to diene **1.140** was observed; here **1.140** was rapidly produced in 67% yield. Products **1.141** (78%) and **1.142** (70%) demonstrate that the reaction works well with substitution in the *syn* or *anti* relationship at the propargyl and homopropargyl locants. Next, variation of the aryl moiety at the alkyne terminus was examined. As anticipated, *para*-substitution was well tolerated with the 4-fluorophenyl providing **1.143** in 69% yield as essentially a single isomer. Chlorines were also amenable to these reaction conditions giving **1.144** in 70% yield. The *ortho*-chloro substituent did not hamper the efficiency of the reaction, nor did *ortho*-substituted groups like 1-naphthyl which gave **1.145** in 71% yield. The 3,5-xylyl moiety afforded **1.146** in 74% yield without difficulty. Electronics of the aryl group was also examined using 4-anisole and 4-acetophenone derivatives which provided **1.147** in 73% yield and **1.148** in 64% yield. Interestingly, although the yields are comparable, the ratio of isomers was substantially different in these cases. Finally, six membered oxasilacycle **1.149** was formed in 82% yield under these conditions.

The aryl substrates provided excellent selectivity for silylvinylation versus cycloisomerization ($\geq 20:1$) compared to previous results (5-8:1, section **1.3.1**). With these results it was envisioned that higher concentration of ethylene (increased pressure) would further reduce or eliminate the cycloisomerization byproducts. Using alkyne **1.33** the amount of ethylene was systematically increased by 20 psi. The amount of the (*E*) isomer (syn-addition product) observed increased as a function of pressure. As speculated, the cycloisomerization byproduct was not observed over the pressure range studied (Table 14). To ascertain whether the pressure or concentration was influencing the outcome, a control experiment with increased argon pressure

was conducted. At 80 psi of argon the reaction was retarded and approximately 23% conversion with only 11% of the (*Z*) isomer observed by ^1H NMR. This supports the hypothesis that increased ethylene concentration thwarts isomerization and produces greater quantities of *syn*-silylvinylation or the (*E*) isomer. To the best of our knowledge increased ethylene pressure has not been shown to overcome inherent selectivity of a substrate for stereocontrol.

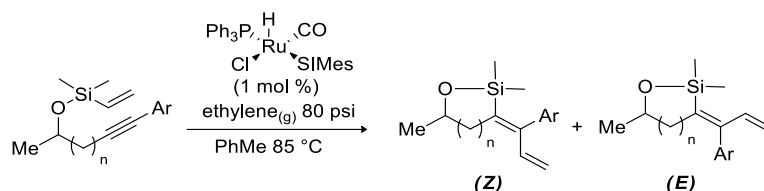
Table 14: Sequential Increase of Ethylene Pressure



entry	pressure ^a	ratio (Z:E) ^b
1	balloon	9:1 ^c
2	20 psi	6:1
3	40 psi	2.5:1
4	60 psi	1:1.4
5	80 psi	1:1.7
6	80 psi (Ar _(g))	1:0 ^d

^aReactions were pressurized at room temperature prior to heating. ^bDetermined by ^1H NMR. ^cCycloisomerization was observed for the standard reaction. ^d23% conversion and 11% *Z* observed.

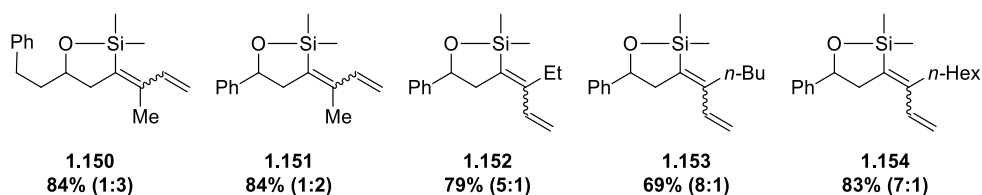
The silylvinylation pressure study also revealed an interesting electronic trend. The *E*:*Z* ratio of silylvinylation products was influenced by the electronics of the alkyne (Table 15). Electronic neutral and weakly withdrawing alkynes gave ~1:2 ratio of *Z*:*E* (entry 1 and 2 respectively). Electron rich alkynes (entry 3) produce the *Z* isomer as the major product, while electron deficient alkynes provide the *E* isomer (entry 4). Increasing the ring size from five to six surprisingly yielded a 25:1 ratio of *Z*:*E* (entry 5). These preliminary results warrant further examination i.e. higher pressures and increased reaction times, to determine the intrinsic electronic preference.

Table 15: Electronic Differentiation of Alkyne Terminus at 80 psi Ethylene

entry	substrate	time (h)	conv. (%)	ratio (Z:E)	yield (%) ^a
1	Ar = Ph	4	100	1:1.7	(99) ^b
2	Ar = 4-F	4	100	1:1.3	85
3	Ar=4-OMe	6	100	3:1	91
4	Ar = 4-Ac	24	100	1:7	86
5	Ar = Ph, n= 2	24	100	25:1	72

^aYield in parenthesis determined by ¹H NMR with mesitylene as an internal standard. ^b Reaction by Lauren Kaminsky

The study continued by examining substrates that had previously proceeded *via* cycloisomerization (*i.e.* alkyl-substituted alkynes, section 1.3.1) or were aberrant at lower ethylene pressure. To our delight, excellent results were obtained when alkyl-substituted alkynes were employed in this reaction (Figure 8).

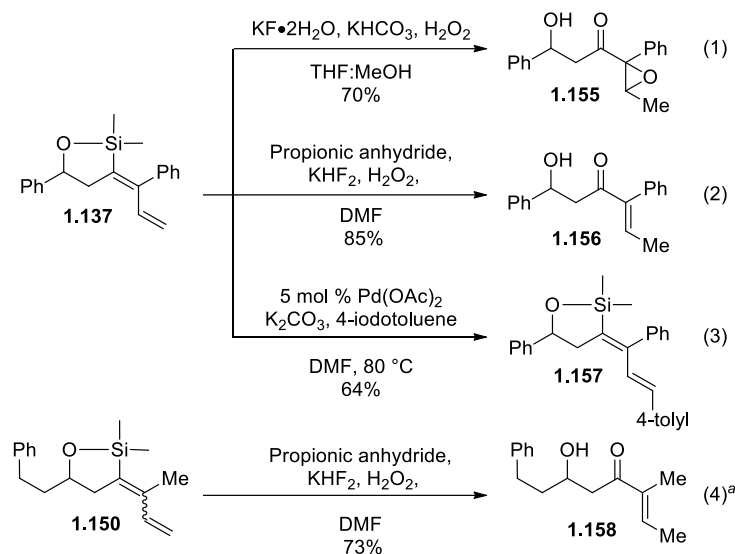
**Figure 8:** Reactions of internal alkyl alkynes at 80 psi.

Structures are depicted as the major isomer. Ratio (Z:E) determined by ¹H NMR and confirmed by nOe or NOESY experiments.

Methyl substituted dienes **1.150** and **1.151** were formed in 84% yield, both favoring the *syn*-addition as the major product. Increasing the alkyl chain by one carbon to ethyl gave **1.152** in 79% yield; adding three carbons gave *n*-butyl **1.153** in 69% yield, and further extension to *n*-hexyl provided **1.154** in 83% yield. In the later three cases, *anti*-addition products were the predominantly observed. Given the similar steric environment existing around these alkyl groups,

we suggest that the observed product ratios are due to the subtle increase in electron donating ability of these substrates.

Scheme 26: Synthetic Elaboration of Dienes

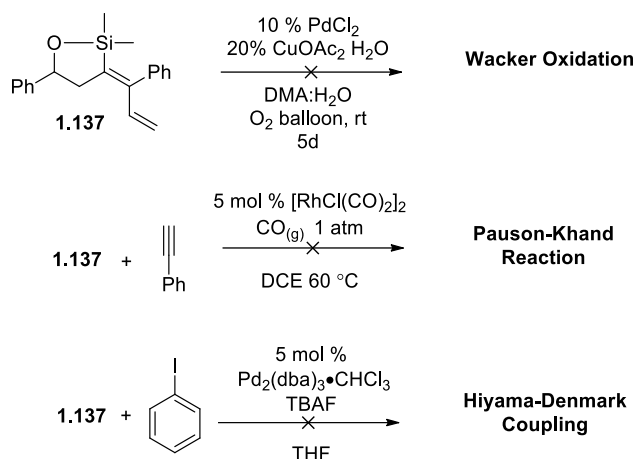


^a reaction conducted by Lauren Kaminsky

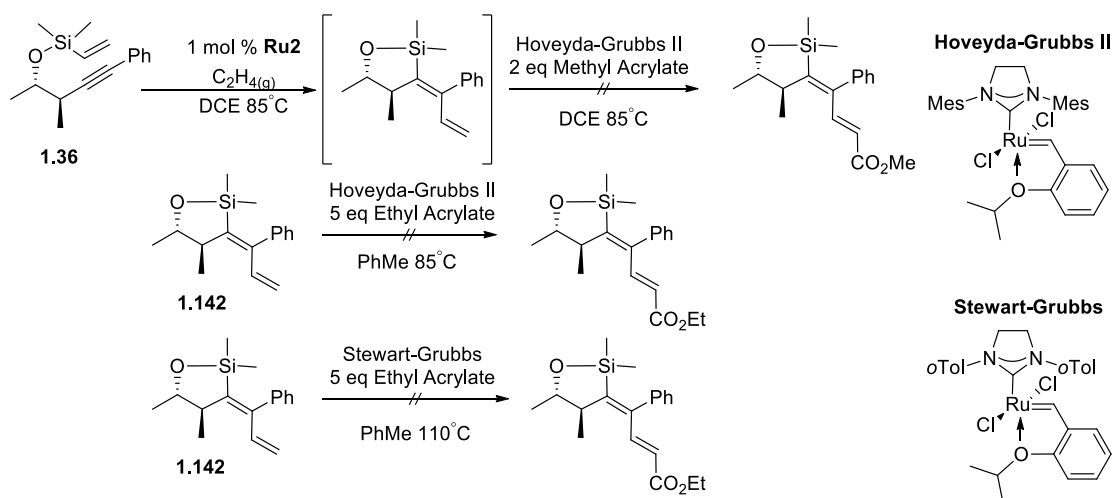
It was considered essential to demonstrate the synthetic utility of these systems. Fleming–Tamao oxidation⁴⁵ under neutral conditions provided only slow decomposition of diene **1.137**. Utilizing basic conditions (Scheme 26, eq. 1) afforded α,β -epoxy ketone **1.155** in 70% yield. Presumably, the excess basic peroxide facilitates a Michael addition into the newly formed α,β -unsaturated ketone (i.e. **1.156**). In order to avoid this undesired Michael addition acidic conditions were explored. Propionic anhydride, KHF_2 , and peroxide were added to the silane in DMF, and enone **1.156** was obtained in 85% isolated yield as a single isomer (eq. 2). These complementary methods provided access to β' -hydroxy-ketones in good yield. Several attempts to utilize the vinyl silyl moiety in Hiyama–Denmark⁹³ chemistry resulted in undesired reactions. It was discovered that one of the undesired products was in fact a Heck product (**1.157**). When diene **1.137** was

subjected to the palladium catalyzed conditions using $[(C_3H_5)PdCl]_2$, CuI, $KF \cdot 2H_2O$, and 4-iodotoluene in DMF at room temperature compound **1.157** was observed in low yield. After some experimentation the reaction of diene **1.137** with $Pd(OAc)_2$, K_2CO_3 , and 4-iodotoluene in DMF at 80 °C afforded **1.157** in 64% yield (eq. 3). We are currently exploring conditions that will selectively couple the silicon with Aryl halides to directly access all carbon tetrasubstituted olefins. Additionally, Tamao oxidation was particularly useful with compound **1.150** which was successfully converted into enone **1.158** (eq. 4). In fact, introducing an *E/Z* olefin mixture into the reaction was of no consequence as compound **1.158** was isolated in 73% yield as a single double bond isomer.

Other transformations were conducted which provided diene decomposition or less than optimal yields. Reactions such as cyclopropanation and ozonolysis quickly destroyed the diene and no discernable products were obtained. Other chemical transformations such as Wacker oxidations⁹⁴, Pauson–Khand reactions⁹⁵ and Hiyama-Denmark^{46, 96, 97} reactions either provided no reaction, slow decomposition or small quantities of undesired products (Scheme 27).

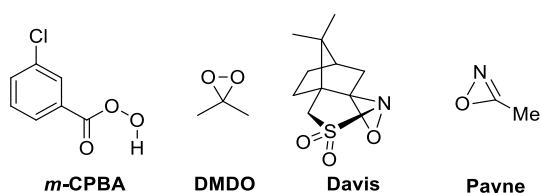
Scheme 27: Unsuccessful Derivatization

Olefin cross metathesis was attempted with a few Grubbs type catalysts and several olefins including acrylic acid, acrylates, acrylamides, N-hydroxy-acrylamides, allyl alcohol and vinyl boronates. All attempts were negative using these alkenes (Scheme 28). Previously, using alkyne **1.33** and 1-hexene the reaction succeeded and could be conducted in tandem with the silylvinylation reaction (conducted by Jinbo Zhao⁶⁵).

Scheme 28: Unsuccessful Examples of Cross Metathesis Reactions

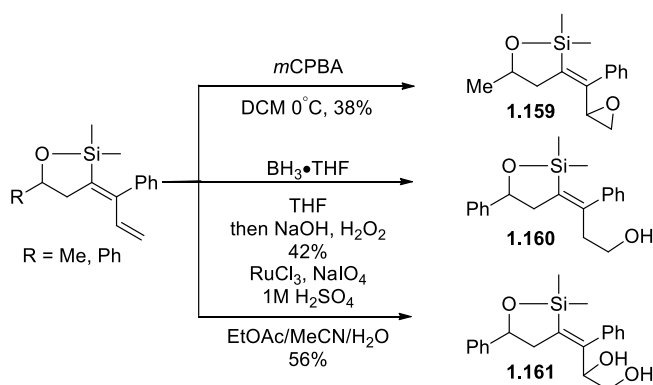
A few general reactions were successful but formed low yields of products. Several epoxidation reactions were conducted, and it is theorized that most of the reagents used for this transformation (*m*-CPBA⁹⁸, DMDO⁹⁹, Davis oxaziridine¹⁰⁰, and Payne oxidation¹⁰¹) are not selective for the terminal olefin (Scheme 29). In some cases the vinyl silicon was destroyed or Tamao products were observed by ¹H NMR, along with some epoxide formation.

Scheme 29: Epoxidation Reagents



Nevertheless, using *m*-CPBA in DCM provided racemic epoxide **1.159** in a 38% yield (Scheme 30). The hydroboration/oxidation provided alcohol **1.160** with minor impurities after isolation. Dihydroxylation followed by cleavage of the terminal olefin would be an extremely useful transformation. It would generate a novel *anti*-“silylformylation” product that is difficult to obtain. The dihydroxylation reaction was discovered to work in moderate yield using acidic conditions developed by Plietker *et al.*^{102, 103} The oxidative cleavage of diol **1.161** requires future investigation.

Scheme 30: Un-optimized Derivatization of Diene



Ethylene gas was successfully utilized in the ruthenium hydride catalyzed silylvinylation of internal alkynes. It was demonstrated that this protocol was useful for the synthesis of highly substituted conjugated dienes. When the reaction was conducted at increased pressure of ethylene (80 psi) competing cycloisomerization of the starting enyne was inhibited and not observed. Additionally, it was demonstrated that alkyl substituted alkynes produced silylvinylation products in excellent yield. The resulting dienes were transformed into epoxy-ketones and enones using complementary oxidation conditions. Finally, a regio- and stereoselective Heck coupling was reported which further enhances the scope of this chemistry beyond simple vinyl moieties.

1.3.3 Silylvinylation of Terminal Alkynes

Alkynes are key functional groups used in the preparation of many organic molecules. Transformations of alkynes often include the production of alkenes. Catalytic transformations of terminal alkynes that provide chemists with reliable functional handles appended to the resultant alkene are perpetually in demand. Some of the most useful transformations include hydrosilylation^{30, 104-106} and silylformylation.^{69, 75, 77, 107, 108} Transition metal-catalyzed hydrosilylation of terminal alkynes are highly predictable resulting in well defined vinylsilanes.¹⁰⁹ Intermolecular hydrosilylation of terminal alkynes can produce three isomers, the *trans*- β , the *cis*- β or the α adducts. This of course can be attenuated depending on factors including temperature and catalyst.¹⁰⁴ Transitioning an intermolecular reaction into an intramolecular reaction using temporary silicon tethers helps to define a more robust system with added predictability.²⁷ In addition to being highly selective, these reactions create complex silanes which offer a versatile functional handle for further manipulation.¹¹⁰ For example, intramolecular hydrosilylation of terminal alkynes is in most cases regio and stereo specific. Silylformylation is a remarkably efficient intramolecular transformation of terminal alkynes.^{71, 84} Included in this regime of chemistry are several tandem processes that produce very diversely functionalized molecules. Denmark has consistently improved and utilized silylation chemistry followed by palladium catalyzed coupling of the activated silicon species.^{41, 111} While in another realm, Leighton elegantly provided the community with silylformylation/allyl and crotylsilylation methods to produce polyols.^{108, 112}

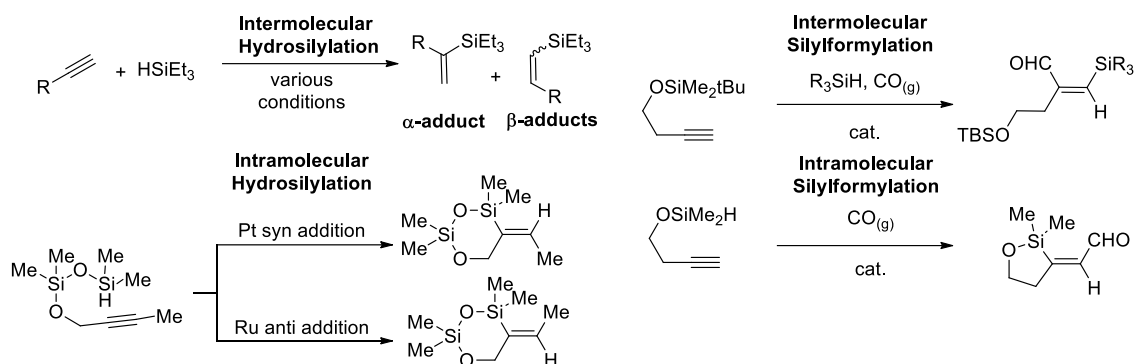


Figure 9: Hydrosilylation and Silylformylation of Terminal Alkynes

Intramolecular ruthenium catalyzed transformations of terminal alkynes consist mainly of cycloisomerization,^{9, 113, 114} enyne metathesis^{17, 115, 116} and hydrosilylation.^{29, 30, 117, 118} We have recently developed a regioselective ruthenium hydride catalyzed silylvinylation of internal alkynes for the synthesis of conjugated dienes.^{28, 65, 119} These methods produce oxasilacycles via *trans-exo-dig* cyclizations. The catalytic *trans* addition to alkynes is rare but not unprecedented.^{29-31, 33-35} However, the empirical data gathered in these laboratories does not favor a direct *trans* addition in the silylvinylation of alkynes.^{28, 65} In previous studies with increased concentration of ethylene gas we observed higher chemoselectivity for vinylation over cycloisomerization with the sacrifice of stereochemistry. Presumably a traditional *syn* addition to the alkyne followed by an isomerization affords the observed products. It is believed that the isomerization is only partially observed due to the rapid incorporation of exogenous ethylene. Given the utility of this transformation, development of a complementary route toward the selective *syn* silylvinylation of alkynes was desired. Herein the execution of this protocol using vinyl siloxy tethered terminal alkynes is reported.

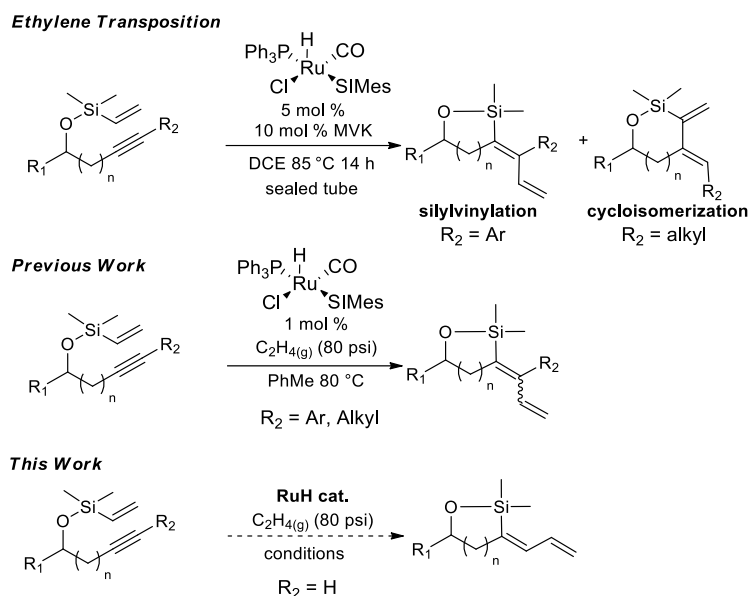
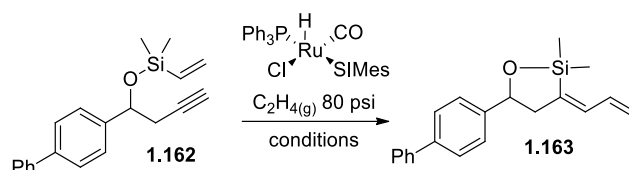


Figure 10: Ruthenium Hydride Catalyzed Silylvinylation of Terminal Alkynes (This Work)

It was initially observed that higher concentrations of ethylene gas promote a more smooth transition to silylvinylation products, albeit as a mixture of stereoisomers (section 1.3.2). This study began with a solvent and temperature screen utilizing $\text{RuHCl}(\text{CO})(\text{SIMes})(\text{PPh}_3)$ at 80 psi of ethylene gas. Complex $\text{RuHCl}(\text{CO})(\text{SIMes})(\text{PPh}_3)$ had previously out performed other hydride catalysts $[\text{RuHCl}(\text{CO})(\text{PCy}_3)_2]$, $\text{RuHCl}(\text{CO})(\text{Pt-Bu}_2\text{Me})_2$, $\text{RuHCl}(\text{CO})(\text{Pt-Bu}_2\text{Cy})_2$, and $\text{RuHCl}(\text{CO})(\text{PCy}_2t\text{-Bu})_2$ bearing two phosphine ligands with ethylene transposition (section 1.3.1),⁶⁵ and with silylvinylation at 1 atmosphere of ethylene (section 1.3.2). Alkyne silylvinylation at increased pressure of ethylene had previously performed well in toluene at 80 °C. Extrapolation of these conditions with terminal alkynes for 24 hours (table 16, entry 1) consumed the starting material with only 40 % crude yield of product. Considering the high temperature and pressure it was thought that the ene-yne (*i.e.* 1.162) is transformed to a diene based on the proposed mechanism (Figure 7, section 1.3.2) followed by possible polymerization, isomerization or decomposition. Ruthenium hydrides are known to polymerize olefins¹²⁰ and

isomerize 1,3-dienes at high temperature.¹²¹ The reaction time and temperature were gradually decreased and revealed a positive trend. At 60°C after 3 hours the reaction was complete and a crude yield of 68% was obtained. Seeking to further increase the yield of this reaction we set out to elucidate the ideal conditions to avoid the possible deleterious pathways. Previously, non-polar solvents such as toluene and DCE performed well (Table 16).

Table 16: Solvent and Temperature Screen for Silylvinylation of Terminal Alkynes



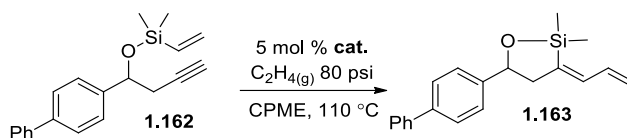
Entry	Solvent	Temp. (°C)	Time (h)	Conversion (%)	Yield (%) ^f
1 ^a	PhMe	80	24	100	40
2 ^a	DCE	80	24	100	45
3 ^a	Dioxane	80	24	100	54
4 ^a	Dioxane	60	24	52	33
5 ^a	PhMe	60	3	100	68
6 ^a	THF	60	23	100	60
7 ^a	CPME ^c	60	18	38	21
8 ^a	THF	50	18	66	50
9 ^a	PhMe	50	24	-	-
10 ^a	DCE	50	24	-	-
11 ^a	MeTHF	50	23	61	48
12 ^b	THF	120	1	100	60
13 ^b	CPME	120	1	100	60
14 ^c	Dioxane	110	0.5	100	63
15 ^c	CPME	110	0.5	100	65
16 ^c	MeTHF	110	0.5	60	40
17 ^{cd}	CPME	100	0.5	100	73
18 ^{cd}	Dioxane	100	0.5	100	75
19 ^{cd}	CPME	90	0.5	>95	76
20 ^{cd}	Dioxane	90	0.5	>95	73

^a reaction conditions: Alkyne (0.3 mmol), RuH (2 mol %), solvent (0.2M). ^bRuH (5 mol %), solvent (0.05M). ^c RuH (5 mol %), solvent (0.1M). ^d Reaction conducted by Alex Dixon. ^e CPME = cyclopentyl methyl ether. ^f determined by ¹H NMR using mesitylene as an internal standard

Along with toluene and DCE we chose other conventional solvents used in organometallic reactions. Ethereal solvents like THF and 1,4-dioxane required longer reaction times at 60°C but

produced **1.163** in 60% crude yield. However, using 1,4-dioxane under these conditions did not fully consume alkyne **1.162**. At 60°C in toluene the reaction was not complete after 2h. Increased temperatures have the benefit of decreasing the reaction time so we conducted the reaction in high dilution THF (0.05M) at 120°C for 1h. To our surprise the crude yield was 60%, only 2% lower than the 24 h reaction at 60°C. When 1,4-dioxane was examined at increased temperature diene **1.163** was produced in 67% crude yield with no other discernable byproducts in just 30 minutes. Two other ethereal solvents, 2-methyl-THF and cyclopentyl methyl ether (CPME), are green alternatives to the customary ethers (Et₂O, THF, 1,4-dioxane and MTBE).^{122, 123} At 120 °C in CPME the reaction afforded the desired product **1.163** in 65% crude yield. Lowering the temperature to 100 °C in both CPME and 1,4-dioxane gave full conversion and 73% and 75% crude yields, respectively. With only a two percent difference in crude yield of **1.163**, CPME was deemed a suitable replacement for the more hazardous choices.

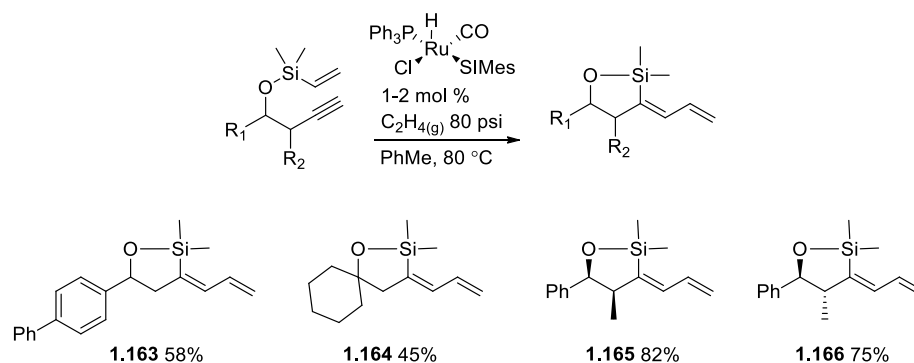
Seeking to enhance the formation of product **1.163** a catalyst screen was performed. Previous results with bis-phosphine ruthenium hydrides indicated little improvement from RuHCl(CO)(SIMes)(PPh₃) (section **1.3.2**). However, bis-phosphine ruthenium hydrides were examined (Table 17, Entries 2-5) and compared to complex RuHCl(CO)(SIMes)(PPh₃). Surprisingly, complex RuHCl(CO)(PCy₃)₂ reacted with alkyne **1.162** but only produced 21 % of the desired diene **1.163**. The remainder of the catalysts performed admirably specifically RuHCl(CO)(PCy₂*t*-Bu)₂. The dicyclohexyl-*tert*-butyl phosphine ligand appears to exhibit similar properties as the SIMes (NHC) ligand associated with RuHCl(CO)(SIMes)(PPh₃).

Table 17: Catalyst Screen in CPME

entry	catalyst	time (h)	conv. (%)	yield 1.163 (%) ^a
1	RuHCl(CO)(SIMEs)(PPh ₃)	0.5	100	65
2	RuHCl(CO)(PCy ₃) ₂	0.5	80	21
3	RuHCl(CO)(<i>Pt</i> -Bu ₂ Me) ₂	0.5	90	52
4	RuHCl(CO)(<i>Pt</i> -Bu ₂ Cy) ₂	0.5	100	44
5	RuHCl(CO)(PCy ₂ <i>t</i> -Bu) ₂	0.5	100	55

^a Crude yield determined by ¹H NMR using mesitylene as an internal standard

Unfortunately, the current equipment does not safely allow for greater than 80 psi of ethylene gas. However, with the results obtained four alkynes were subjected to the conditions previously established (Scheme 31). In toluene at 80 °C, four alkynes were reacted with RuHCl(CO)(SIMEs)(PPh₃) and dienes **1.163-1.166** were obtained in good yields. The methyl group appended to the propargylic position appears to be a stabilizing factor due to the increased yields of **1.165** and **1.166**.

Scheme 31: Silylvinylation Substrate Scope of Terminal Alkynes

Further analysis of reaction conditions is being investigated. The analysis includes temperature, time and catalyst loading. A thorough substrate survey is underway which may

include terminal alkynes with a variety of vinyl silicon tethers, homopropargyl substituents and variation at the propargylic position.

In conclusion, we have developed a *syn*-selective silylvinylation of terminal alkynes. The reaction provides exocyclic conjugated dienes in good yields. The reaction proceeds rapidly (0.5 h) with 5 mol % loading of $\text{RuHCl(CO)(SIMes)PPh}_3$ at 110 °C in several solvents, and especially well with cyclopentyl methyl ether. The catalyst loading can be lowered at the expense of reaction time. Alkyl substitution at the propargylic position appears to be beneficial to the stability of the diene products. Further synthetic elaboration of the diene products to deliver other useful organic building blocks will be presented in due course.

2.0 SYNTHESIS OF IMIDAZOPYRIDINES

2.1 INTRODUCTION

Heterocyclic structures, specifically those containing nitrogen, are prevalent in pharmaceutical drugs and are used to treat many diseases. Nitrogenous heterocycles are also frequently utilized in several other useful areas including structural modifications in medicinal chemistry research, natural product synthesis and pesticides manufacturing (Figure 11).

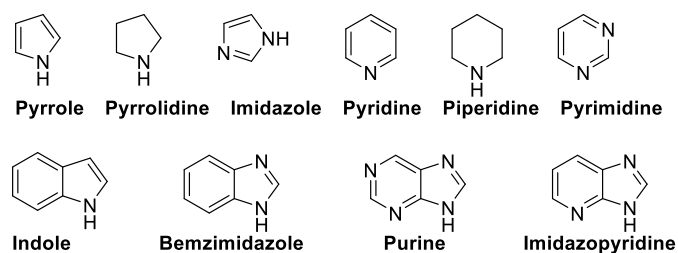


Figure 11: Common Nitrogen Based Heterocycles

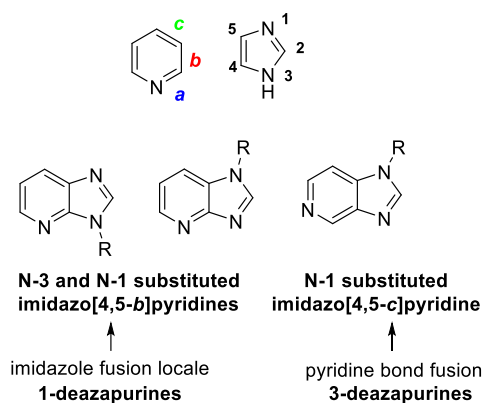


Figure 12: Imidazopyridine Nomenclature

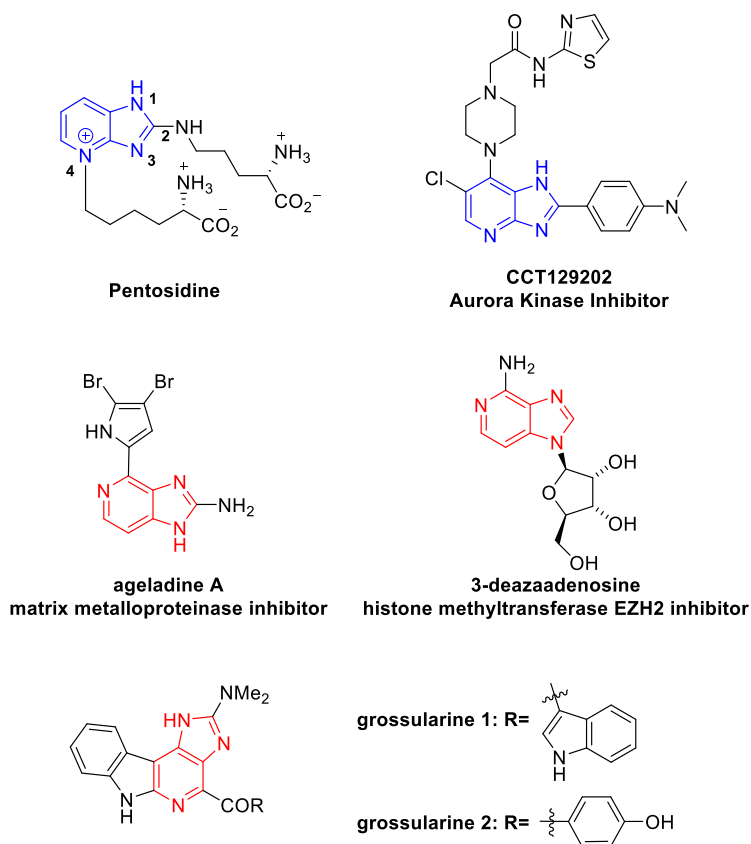
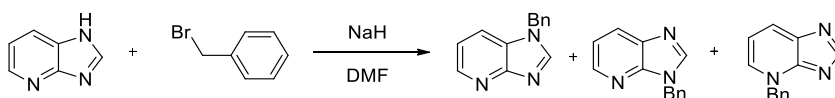


Figure 13: Molecules possessing imidazopyridine structures

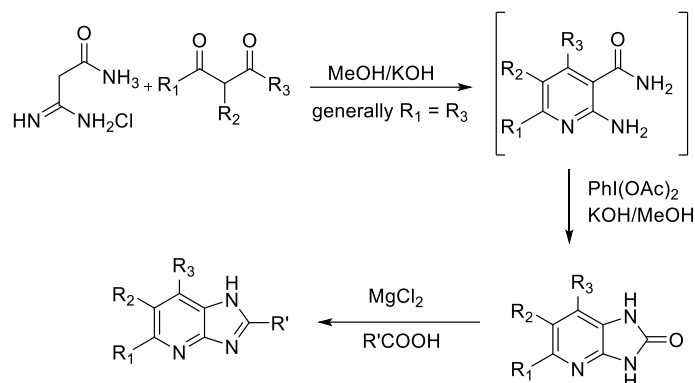
One class of heterocycle of particular interest is the imidazopyridines (Figure 12). Imidazopyridines are biologically relevant structures commonly utilized in pharmaceuticals. These molecules possess many beneficial qualities that medicinal chemists seek, including solubility and the capacity for hydrogen bonding.¹²⁴⁻¹³⁸ These structures appear as building blocks in many drug-like molecules and central scaffolds in natural products (Figure 13).^{129-131, 139-148} The imidazopyridine scaffold represents a diverse group of nitrogenous heterocycles. There are several classes of imidazopyridines depending on the location of the pyridine and imidazole ring fusion. The deazapurines or imidazo[4,5-(*b/c*)]pyridines are often scaffolds utilized in drug candidates because they are isosteric with the nucleotide purine bases, adenine and guanine. Imidazo[4,5-*b*]pyridines and imidazo[4,5-*c*]pyridines have been thoroughly investigated and several

pharmacological properties have been noted. For example, Ageladine A (Figure 13), is an anti-cancer natural product isolated from marine sponge.¹⁴⁹ One specific natural product, pentosidine, was a molecule of interest for its potential use as a biochemical marker.¹⁵⁰ Access to pentosidine required an efficient approach to the imidazopyridine core in a regiodefined method. A simple protection or N-alkylation of commercially available imidazo[4,5-*b*]pyridine cannot be controlled regiospecifically and results in a mixture of three isomers (Scheme 32). Therefore a more specific and straightforward approach to the imidazopyridine core was needed in order to synthesize pentosidine.

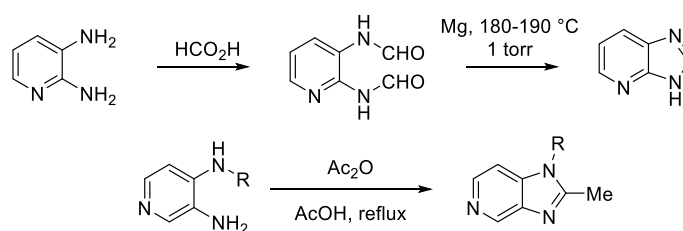
Scheme 32: N-Alkylation of Imidazo[4,5-*b*]pyridine

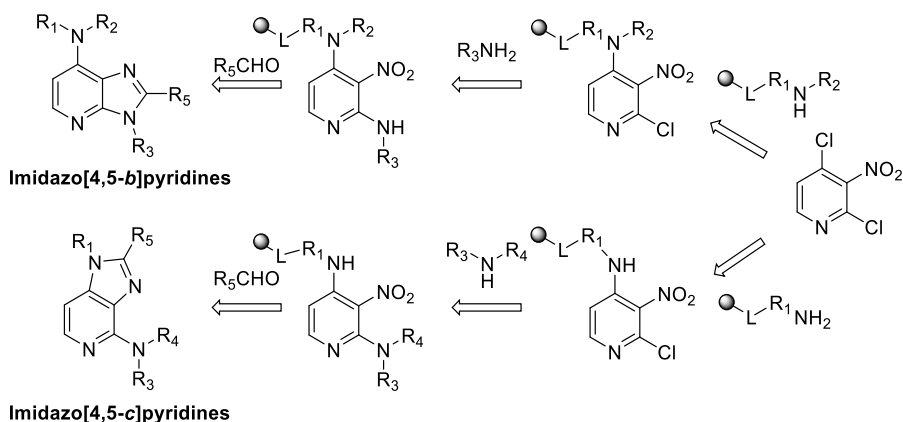


In general, the most current methods for the production of imidazo[4,5-*b*]pyridines in a regiospecific fashion require multiple synthetic steps.^{133, 151-158} For example, Senanayake developed a three step sequence to produce a modest selection of alkyl substituted imidazopyridines. The sequence began with the condensation of 1,3-dicarbonyl derivatives and malonamidines with subsequent Hofmann rearrangement mediated by PhI(OAc)₂ to provide cyclic urea derivatives. Finally, the urea carbonyl was activated with magnesium and condensed with carboxylic acids to provide substitution at the 2-position of the imidazole core (Scheme 33). However, this elegant procedure suffered from the lack of N-substitution.

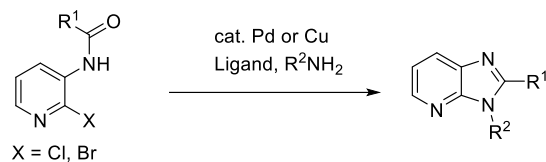
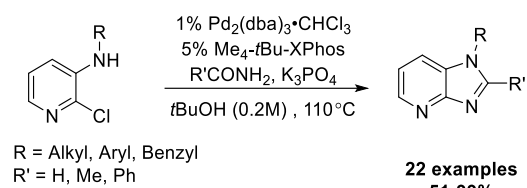
Scheme 33: Senanyake Approach to Imidazo[4,5-*b*]pyridines

In other classical syntheses, imidazopyridines are built from *ortho*-diaminopyridines, often requiring harsh conditions (Scheme 34).¹⁵⁹ This approach to the imidazopyridine scaffold also lacks regioselective N-substitution or requires tedious synthetic sequences to access them. For instance, a more recent and divergent approach utilizes a solid-supported synthesis of 1- and 3-deazapurines (Scheme 35).¹⁶⁰ This method requires five or more steps with overall yields ranging from 20-70% and 40-80% purity. Also, because the starting pyridine contains a 3-nitro group access to substitution at the 3-position was not accomplished.

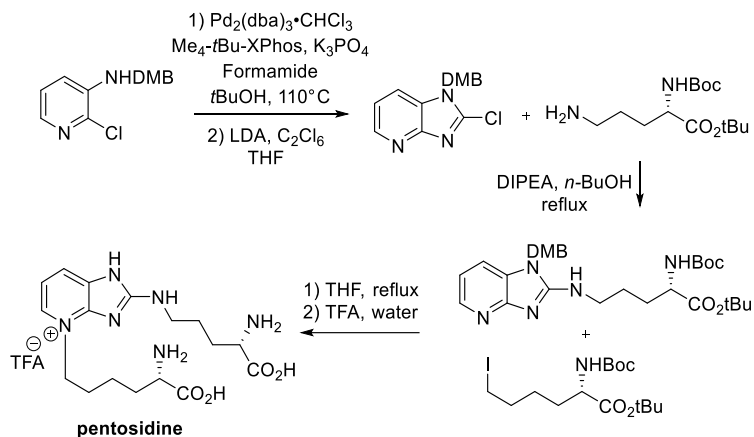
Scheme 34: Classic example of imidazopyridine synthesis

Scheme 35: Soural's retrosynthetic solid phase synthesis of 1- and 3-deazapurines

A new straightforward approach to the imidazo[4,5-*b*]pyridine scaffold in an efficient and regioselective manner was in demand. Previous syntheses of imidazo[4,5-*b*]pyridines by the Buchwald¹⁶¹ and Ma¹⁶² groups, utilized 2-halo-3-acylaminopyridines coupled with amines to give N-3-substituted products (Scheme 36). However, these approaches did not permit N-1 substitution. In 2012 Clark *et al.* developed a strategy utilizing a palladium catalyzed amide coupling reaction with a successive dehydration to form N-1 substituted imidazo[4,5-*b*]pyridines regioselectively (Scheme 37).¹⁵⁷ The strategy utilized readily available 2-chloro-3-aminopyridines that were substituted with various functionality at the 3-amino group. Since then the method was utilized to synthesize the core imidazopyridine of pentosidine. The total synthesis of pentosidine was accomplished in six steps beginning with a reductive amination to protect the 3-amino group followed by the formation of the imidazopyridine core. The remaining steps included regioselective chlorination at the 2-position followed by a nucleophilic aromatic substitution and pyridine-N-alkylation. The final step required a global deprotection in TFA and provided pentosidine in a remarkable overall yield of 30% (Scheme 37).

Scheme 36: Previous approaches to imidazopyridines using 2-halo-pyridines**Buchwald and Ma's approach:****Scheme 37:** Palladium Catalyzed Amidation-Dehydration Strategy

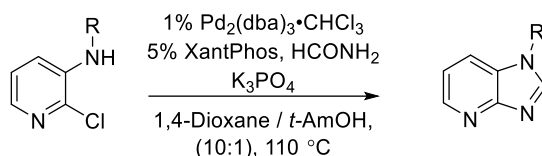
22 examples
51-99%

Synthetic Route to Pentosidine

2.2 DEVELOPMENT OF NEW CONDITIONS USING XANTPHOS AND A MIXED SOLVENT SYSTEM

The synthesis of pentosidine demonstrated the power and utility of an amide coupling-dehydration strategy. This work had established that bulky biaryl phosphine ligands were necessary to facilitate the amide coupling. Due to the high cost of these ligands, the use of alternate phosphine based ligands which were more economically viable was pursued. Since the inception of this project it was sought to improve the generality and practicality of this process. Also, a more diverse substrate scope with regard to chloro-pyridines and amide coupling partners was envisioned. In particular, the use of electron deficient benzyl moieties was ineffective using our previous protocol. Substrates that had unhindered chlorides (*i.e.* 4-chlorobenzyl) were also not compatible with our previous method.

In our previous study we observed no reaction when Xantphos was used in *tert*-butanol. However, others had previously achieved Pd-catalyzed amide couplings using xantphos in aprotic solvents.¹⁶³⁻¹⁶⁵ Xantphos was re-evaluated using aprotic solvents and the desired imidazopyridine was obtained along with a minor amount of dehalogenated pyridine. It was hypothesized that the dehalogenation reaction could be attenuated by using a protic co-solvent such as *tert*-butanol used in the previous study. After a great deal of optimization, it was found that using Xantphos as a ligand in a mixed solvent system (1,4-dioxane and *tert*-amyl alcohol) gave imidazo[4,5-*b*]pyridines in excellent yield (Table 18).¹⁶⁶

Table 18: Substrate scope utilizing Xantphos and a mixed solvent system**New Conditions:**

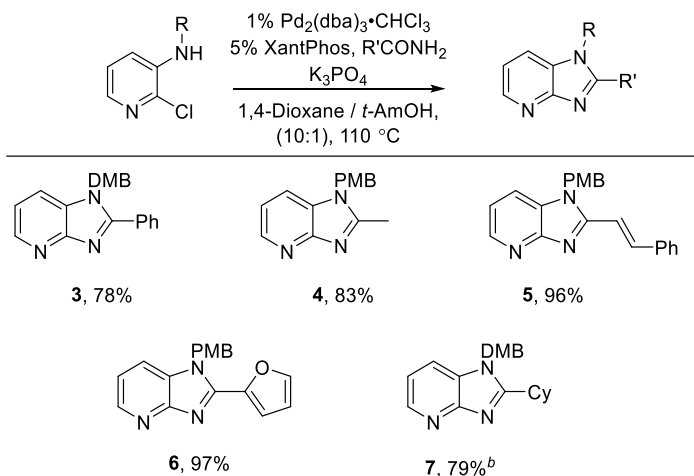
Entry	R	Yield (%) ^b	Product
1	1a CH ₂ (4-OMeC ₆ H ₄)	93	2a
2	1b CH ₂ (2,4-OMeC ₆ H ₃)	81	2b
3	1c CH ₂ (2,5-OMeC ₆ H ₃)	85	2c
4	1d CH ₂ (4-Me ₂ NC ₆ H ₄)	94	2d
5	1e CH ₂ (3-FC ₆ H ₄)	94	2e
6	1f CH ₂ (4-FC ₆ H ₄)	96	2f
7	1g CH ₂ (2-ClC ₆ H ₄)	79	2g
8	1h CH ₂ (4-ClC ₆ H ₄)	94	2h
9 ^c	1i CH ₂ (4-PhC ₆ H ₄)	70	2i
10	1j CH ₂ Ph	85	2j
11	1k (<i>R</i>)-CH(CH ₃)Ph	96	2k
12 ^{c,d}	1l CH ₂ (3,5-OMeC ₆ H ₃)	71	2l
13	1m CH ₂ (4-CF ₃ C ₆ H ₄)	95	2m
14 ^e	1n CH ₂ (3-NO ₂ C ₆ H ₄)	57	2n
15 ^{c,d,f}	1o CH ₂ (4-CNC ₆ H ₄)	70	2o
16	1p Ph	94	2p
17	1q CH ₂ (C ₆ H ₁₁)	77	2q
18 ^c	1r Cy	63	2r
19	1s Cyp	85	2s
20	1t <i>i</i> -Pr	91	2t

^a) Reaction Conditions: **1** (0.4 mmol), Pd₂(dba)₃·CHCl₃ (0.004 mmol, 1 mol %), XantPhos (0.02 mmol, 5 mol %), formamide (0.6 mmol), K₃PO₄ (0.6 mmol), solvent (0.2 M), 110°C, 6.5h. ^b) Isolated Yields ^c) 90% conversion based on crude ¹H NMR using mesitylene as an internal standard. ^d) 2 mol% Pd₂(dba)₃·CHCl₃ and 10 mol% XantPhos. ^e) 65% conversion based on crude ¹H NMR using mesitylene as an internal standard. ^f) reaction conducted by RJW

Indeed, the new approach displayed an expanded substrate scope compared to the previous conditions which utilized the biaryl ligand set. Electron-donating substituents (Table 18, entries 1-4), as well as halogenated substrates (Table 18, entries 5-8) performed well, giving 79-94% yields. Notably, using our previous conditions, the *o*-chlorobenzyl substrate **1g** provided **2g** in 51% yield;

this new protocol provided a much improved 79% yield of **2g** (Table 18, entry 7). The *p*-chlorobenzyl substrate **1h** was not amenable to our previous conditions and resulted in multiple coupling events followed by decomposition of **1h**. Under the current conditions **2h** was formed in 94% yield (Table 18, entry 8). Benzyl and 4-biphenylbenzyl substrates were also well tolerated under the reaction conditions (Table 18, entries 9 and 10). As anticipated, chiral substrate **1k** showed no racemization and provided **2k** in excellent 96% yield (Table 18, entry 11). Additionally, the new reaction conditions showed superiority when electron deficient benzyl were subjected to the protocol. Compound **1l** bearing inductively withdrawing methoxy groups provided **2l** in 71% yield. Pyridine **1m** bearing a trifluoromethyl group afforded 95% yield of **2m** (entry 13). In addition, *m*-nitrobenzyl **1n** and *p*-cyano **1o** gave **2n** and **2o** in 57% (65% conversion by ¹H NMR) and 70% (90% conversion by ¹H NMR) yields, respectively (Table 18, entries 14 and 15). Nitro groups previously proved detrimental to the reaction and substantial decomposition of the starting material and poor yields were observed for **2n**. Aryl substituents continue to perform well, with **1p** giving a 94% yield of **2p** (Table 18, entry 16). *N*-Alkyl substrates were again well tolerated. Substrate **1q** with the sterically encumbered cyclohexylmethyl and cyclohexyl **1r** gave **2q** and **2r** in 77% and 63% yields, respectively (Table 18, entries 17 and 18). Pyridines **1s** and **1t** bearing cyclopentyl and isopropyl moieties afforded **2s** in 85% and **2t** in 91% yield (Table 18, entries 19 and 20).

A more diverse series of amides were also compatible (Scheme 38). Benzamide and acetamide previously produced yields in the low 60%, and here these amides provided yields of 78% and 83% respectively. Previously no reaction was observed using the remaining amides. Under the improved protocol *trans*-cinnamamide (96%), cyclohexane carboxamide (79%) and furanamide (97%) all provided the respective substituted imidazopyridines.

Scheme 38: Extended amide scope using the improved protocol

Reaction Conditions: pyridine (0.4 mmol), Pd₂(dba)₃·CHCl₃ (0.004 mmol, 1 mol %), Xantphos (0.02 mmol, 5 mol %), Amide (0.6 mmol), K₃PO₄ (0.6 mmol), solvent (0.2 M), 110°C. All yields are isolated. ^b Amide used as limiting reagent, conducted by RJW.

This protocol using less expensive bidentate ligand xantphos and a mixed solvent system greatly enhanced the access to functionalized imidazo[4,5-*b*]pyridines. Further studies utilizing this protocol will be discussed in the subsequent chapters.

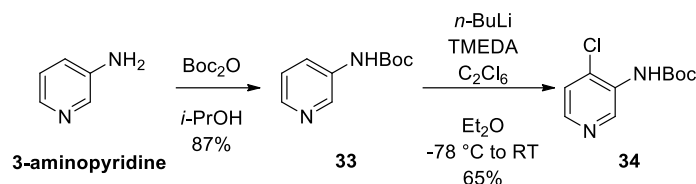
2.3 SYNTHESIS OF IMIDAZO[4,5-C]PYRIDINES

The construction of imidazo[4,5-*b*]pyridines previously discussed showed the utility and control that can be achieved with these systems. It was easy to target the more rare imidazo[4,5-*c*]pyridine using the protocol. Imidazo[4,5-*c*]pyridines are currently being investigated for the inhibition of hepatitis C virus replication,^{167, 168} cyclin-dependent kinase inhibitors (*i.e.* grossularine 1 and 2)¹⁶⁹ and other biologically relevant targets.^{140, 170-178} Suffering from the same problems as imidazo[4,5-*b*]pyridines, substituted imidazo[4,5-*c*]pyridines are also difficult to obtain selectively.¹⁷¹ However, these recent endeavors provided a means to obtain these medicinally relevant targets with ease.

To begin with the appropriately substituted 3-amino-4-chloropyridines, a short synthesis was required in order to explore a cross coupling route. Previously, the method used for substitution of the N-3 nitrogen of the analogous 3-amino-2-chloropyridine utilized reductive amination,¹⁷⁹ or Chan-Lam coupling.^{180, 181} Attempts to substitute the 3-amino-4-chloropyridines using these techniques did not lead to preparative yields. Due to these unforeseen difficulties an alternative route to these systems was desired. The known material, 4-chloro-3-N-Boc-pyridine **34**,¹⁸² was produced from the corresponding 3-N-Boc-pyridine via directed metallation and chlorination.¹⁸³⁻¹⁸⁸ This method provided a more stable precursor as an entry into N-substituted pyridines (Scheme 39). Compound **34** was easily prepared and utilized readily accessible materials that were air and moisture stable. Another reason to manufacture **34** was due to the instability of commercially available 3-amino-4-chloropyridine which decomposes readily even after recrystallization. Starting from 3-aminopyridine, Boc protection in aqueous isopropanol gave compound **33** in 87% yield.¹⁸⁹ Treating compound **33** with *n*-BuLi in the presence of TMEDA at

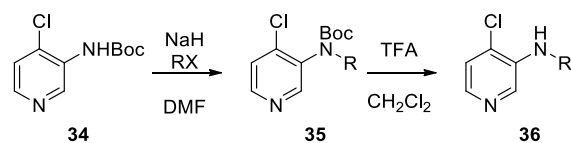
-78 °C followed by chlorination gave compound **34** in 65% yield. The directed metallation is currently being investigated in our laboratory utilizing 1,2-dimethoxy ethane as a replacement solvent which does not require the addition of TMEDA to facilitate this reaction.

Scheme 39: Production of 4-chloro-3-N-Boc-pyridine **34**

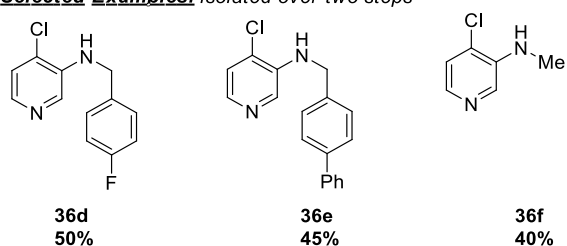


With ample amounts of **34** in hand, various N-3 substituted 4-chloro-3-N-Boc-pyridines were produced. Base mediated alkylation of the carbamate nitrogen provided N-alkyl and N-benzyl products from the corresponding alkyl or benzyl halides; and removal of the Boc group was accomplished by TFA in DCM (Scheme 40).

Scheme 40: Alkylation and Deprotection of **34**



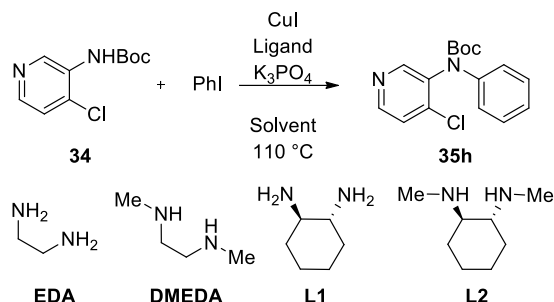
Selected Examples: isolated over two steps



Substituting aryl and heteroaryl functionality by this strategy was not practical. A metal catalyzed coupling would suffice for these substitutions. Palladium catalysis was disregarded because of the activated aryl chlorine present in **34**. Palladium in this case could produce

competitive couplings or dehalogenation that would likely limit the substrate scope. Copper was envisioned as an ideal catalyst for the N-C coupling of an aryl halide and the carbamate nitrogen. Copper catalyzed amidation chemistry dates back to the early 1900's and recently has become a reliable method for nitrogen substitution.¹⁹⁰ Basic pyridines are known to interfere with copper catalyzed reactions, and pyridine itself is occasionally used as a ligand.¹⁹¹ Nevertheless, copper catalyzed conditions were investigated to deliver the desired N-3 aryl substituted pyridine products.

Studies commenced with copper (I) iodide and diamine ligands previously used for copper-catalyzed amidation (Table 19).^{190, 192-194} None of the desired product (**35h**) was observed using *N,N'*-Dimethylethylenediamine (DMEDA) as a ligand in either DMF or toluene; although 79% conversion and 43% yield of **35h** was obtained in 1,4-dioxane (entries 1-3). Ethylenediamine (EDA), a less encumbered ligand, gave 71% conversion and an increased 59% yield of **35h** (entry 4). The more rigid *trans*-1,2-diaminocyclohexane gave similar results when the reaction was carried out in toluene (entry 5); when 1,4-dioxane was utilized complete conversion and 96% isolated yield of **35h** was obtained (entry 6). The more electron-rich *N,N'*-dimethyl analog **L2** gave moderate conversion (72%) but only trace **35h** (entry 7). These results coincide with the underlying hypothesis described by Buchwald.¹⁹⁰ The unencumbered diamine ligands aid the coupling of bulky secondary amides.^{190, 193}

Table 19: Copper-Catalyzed Amidation Optimization

Entry ^{ab}	Ligand	Solvent	Conversion ^c (%)	Yield ^c (%)
1	DMEDA	DMF	100	0
2	DMEDA	Tol	100	0
3	DMEDA	Dioxane	79	43
4	EDA	Dioxane	71	59
5	L1	Tol	70	65
6	L1	Dioxane	100	96^d
7	L2	Dioxane	72	trace

^a Reactions conducted by Adam Rosenberg ^b Reaction Conditions: 10 mol% CuI, 20 mol% Ligand, 2 Eq. Base, 0.5 M. ^c Using mesitylene as an internal standard ^d Isolated yield.

With optimized copper-amidation conditions elucidated, the substrate scope of the C-N coupling reaction followed by TFA mediated carbamate deprotection was explored (Table 20). As shown previously, iodobenzene gave 96% yield of **35h** and Boc deprotection under acidic conditions then provided **36h** in 97% yield (entry 1). Analogous conditions using 4-iodotoluene gave **35i** in 76% yield and **36i** in 92% yield (entry 2). Aryl bromides were also effective substrates for the copper catalyzed amidation conditions. Electron-poor 4'-bromoacetophenone and 4-bromo-trifluorotoluene gave **35j** in 90% and **35k** in 79%, respectively (entries 3 and 4). Electron-rich arylbromides 4-bromoanisole (entry 5) and 3,5-dimethylbromobenzene (entry 6) gave partial conversion for the amidation and the crude reaction mixtures were deprotected for ease of isolation to give **36l** and **36m** in 47% and 66% yield respectively, over two steps. The use of halopyridines

as coupling partners did not adversely affect the amidation or deprotection reactions as 3-bromopyridine gave **35n** in 88% and Boc deprotection afforded **36n** in 89% yield (entry 8).

Table 20: Copper-Catalyzed Amidation Scope

Entry ^a	ArX	yield of amidation ^b (%)	yield of deprotection ^b (%)
1 ^d	R=H	96 (35h)	97 (36h)
2	R=Me	76 (35i)	92 (36i)
3	R=Acetyl	90 (35j)	89 (36j)
4	R=CF ₃	79 (35k)	89 (36k)
5	R=OMe	-	47 (36l) ^c
6		-	66 (36m) ^c
7		88 (35n)	89 (36n)

^a reaction conditions: 1) 1 equiv. **34**, 1.1 equiv. ArX, 10 mol% CuI, 20 mol% **L1**, 2 equiv. K₃PO₄, 1,4-dioxane (0.5 M); 2) 25% TFA in CH₂Cl₂. ^b isolated yield ^c yield over two steps. ^d reaction conducted by Adam Rosenberg

With the desired N-substituted 3-amino-4-chloropyridine substrates in hand, investigations into the palladium catalyzed formation of the desired imidazo[4,5-*c*]pyridines began. Substrate **36h** (3-amino-N-phenyl-4-chloropyridine) was chosen to evaluate conditions for the synthesis of imidazo[4,5-*c*]pyridine **37h** (Figure 14, Table 21).¹⁵⁷ The newly developed Me₃(OMe)-*t*-BuXPhos¹⁹⁵ ligand was utilized in place of the Me₄*t*-BuXPhos or *t*-BuBrettPhos ligands previously employed. This ligand performed well giving the desired product **37h** in 90% yield. The

cBRIDP¹⁹⁶ ligand developed by Takasago afforded 81% yield, and Singer's BippyPhos¹⁹⁷ gave 87% yield of product **37h**. TrippyPhos¹⁹⁸ furnished only trace amounts of **37h**. No product was observed for other ligands, for example: RuPhos, tri-*tert*-butylphosphine, tricyclohexylphosphine, and Xantphos.

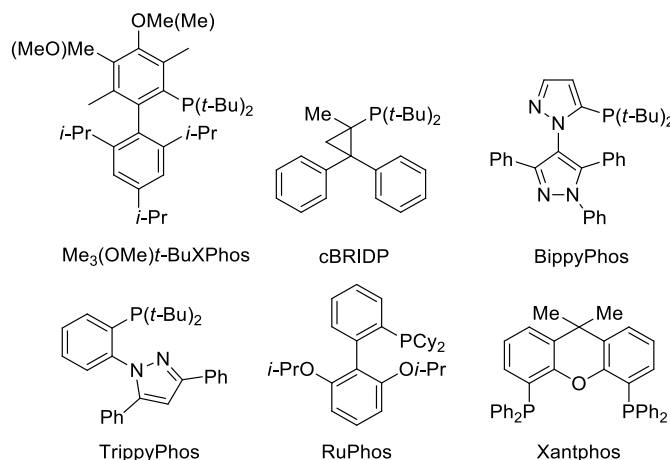


Figure 14: Ligand Structures Used in Palladium Catalyzed Amidation

Table 21: Ligand Screen for Palladium Catalyzed Amidation

$ \begin{array}{c} \text{36h} + \text{H}_2\text{N}-\text{C}(=\text{O})-\text{H} \xrightarrow[\text{t-BuOH (0.2M), 110}^\circ\text{C, 4h}]{(1 \text{ mol}\%) \text{ Pd}_2(\text{dba})_3 \cdot \text{CHCl}_3, (5 \text{ mol}\%) \text{ Ligand, (1.5 equiv) K}_3\text{PO}_4} \text{37h} \end{array} $			
Entry	Ligand	Conversion (%) ^b	Yield(%) ^b
1 ^d	Me ₃ (OMe) <i>t</i> -BuXPhos	100	90 ^c
2 ^d	cBRIDP	100	81
3 ^d	BippyPhos	100	87
4	TrippyPhos	10	trace
5	RuPhos	15	0
6 ^e	(<i>t</i> -Bu ₃ PH)BF ₄	17	0
7 ^e	(Cy ₃ PH)BF ₄	18	0
8 ^e	Xantphos	17	0

^a Reaction Conditions: **36h**, Pd (1 mol %), ligand (5 mol %), 1.5 eq. Formamide, 0.2 M *t*-BuOH, 110 °C, 4 h. ^b Using mesitylene as an internal standard. ^c Isolated yield. ^d Reaction carried out by Adam Rosenberg. ^e Reaction carried out by Lauren Kaminsky.

With useful palladium-catalyzed amidation conditions in hand, attention turned to examining the reaction scope. As illustrated in Table 22, benzyl derivatives **36a-36e** performed well in this reaction (52-85% yield); with electron-donating, electron-withdrawing, aryl and fluorine substitution all being tolerated (entries 1-5). Methyl (**36f**) and *n*-propyl (**36g**) substitution gave **37f** in 58% and **37g** 85% yields, respectively (entries 6 and 7). The aryl substituted derivatives provided the cyclized products **37h-37m** in excellent 80–91% yields, with both electron-poor and electron-rich systems performing admirably (entries 8-13). Additionally, bis-pyridine moiety **36n** was well tolerated under the reaction conditions giving **37n** in 86% yield (entry 14).

Table 22: Palladium Catalyzed Amidation/Cyclization

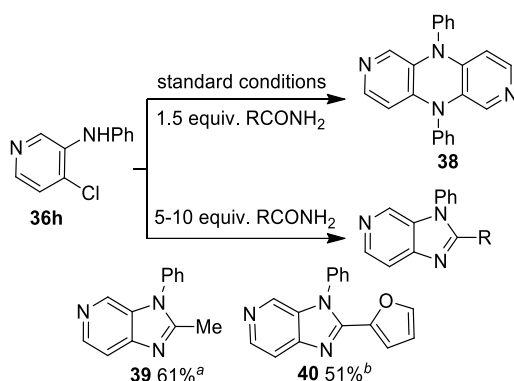
Entry ^a	R	yield (%) ^b	product
1 ^c	36a CH ₂ (C ₆ H ₅)	84	37a
2 ^c	36b CH ₂ (2,5-OMe-C ₆ H ₃)	85	37b
3 ^d	36c CH ₂ (3,5-OMe-C ₆ H ₃)	52	37c
4	36d CH ₂ (4-F-C ₆ H ₄)	75	37d
5	36e CH ₂ (4-Ph-C ₆ H ₄)	75	37e
6	36f Me	58	37f
7 ^c	36g <i>n</i> -Pr	85	37g
8 ^c	36h Ph	90	37h
9	36i 4-Me-Ph	89	37i
10	36j 4-Ac-Ph	87	37j
11	36k 4-CF ₃ -Ph	91	37k
12	36l 4-OMe-Ph	80	37l
13	36m 3,5-Xylyl	90	37m
14	36n 3-Pyridine	86	37n

^a reaction conditions: 1 equiv. **36**, Pd (1 mol %), ligand (5 mol %), 1.5 equiv. formamide, 1.5 equiv. K₃PO₄, 0.2 M *t*-BuOH, 110 °C, 4 h. ^b isolated yield. ^c reaction conducted by Adam Rosenberg. ^d reaction conducted by Lauren Kaminsky

The use of substituted amides under conditions optimized for formamide only lead to the formation of dimer **38** (Scheme 41). Since amides are less nucleophilic than anilines,¹⁹⁹ substrate

36h must out-compete the amide for binding to palladium, leading to a facile dimerization. In the absence of amide under otherwise identical reaction conditions the formation of **38** was also observed. This unwanted dimerization could be thwarted by increasing the amount of amide from 1.5 to ≥ 5 equivalents. Using these slightly modified conditions C2-substituted imidazo[4,5-*c*]pyridines **39** and **40** could be obtained in 61% and 51% yields, respectively.

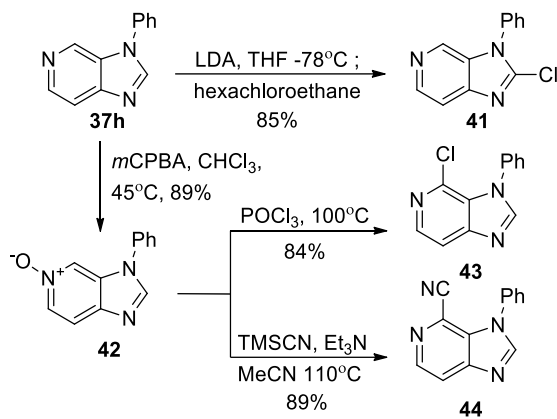
Scheme 41: Amide Coupling Partner Scope



conditions: 1 equiv. **36h**, Pd (2 mol %), ligand (10 mol %), 2 equiv. K_3PO_4 , ^a 10 equiv. acetamide, ^b 5 equiv. furanamide, 0.2 M *t*-BuOH, 110 °C, 4 h.

In order to demonstrate the utility of the imidazo[4,5-*c*]pyridine system further synthetic elaboration of the reaction products was explored (Scheme 42). Selective-deprotonation of **37h** at C2 with LDA and quenching the resulting lithiate with hexachloroethane produced compound **41** in 85% yield. Alternatively, *m*CPBA can be used to oxidize **37h** to pyridine-N-oxide **42** in 89% yield. Pyridine-N-oxide **42** was subsequently treated with $POCl_3$ at 100°C for 2 hours to form aryl chloride **43** regioselectively in 84% yield.²⁰⁰ Thus, we have demonstrated complementary regioselective chlorination protocols to obtain functionalized chloro- imidazo[4,5-*c*]pyridines **41**

and **43**. Additionally, treatment of **42** with TMSCN and triethylamine in acetonitrile²⁰¹ gave the Reissert-Henze product **44** in 89% yield as a single regioisomer.

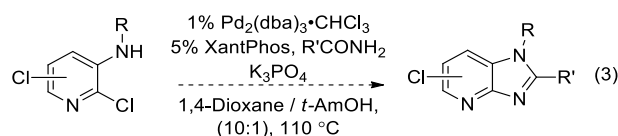
Scheme 42: Functionalization of imidazo[4,5-*c*]pyridines

In summary, copper-catalyzed conditions for the arylation of 3-amino-4-chloropyridine **34** with aryl and heteroaryl halides, providing a high-yielding and direct route to monoarylated 3-amino-4-chloropyridines were developed. Subsequent palladium catalyzed amidation produced imidazo[4,5-*c*]pyridines in excellent yields using amide coupling partners. Further functionalization of the imidazo[4,5-*c*]pyridines by halogenation and cyanation was demonstrated yielding diverse imidazo[4,5-*c*]pyridine scaffolds primed for further manipulation.

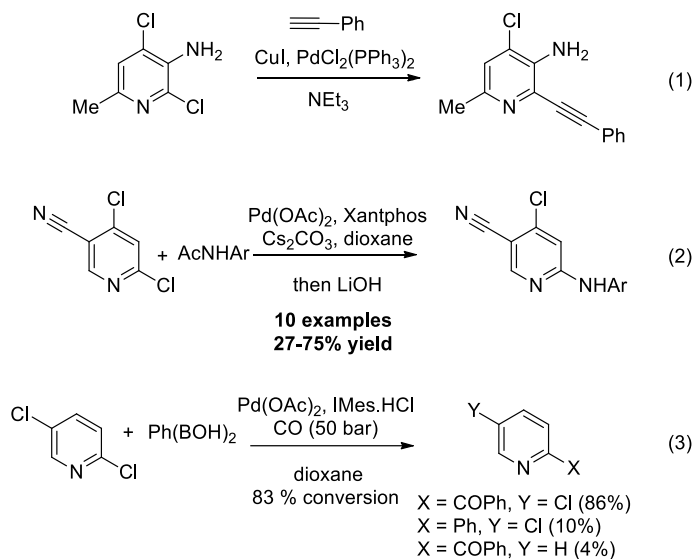
2.4 DEVELOPMENT OF A REGIOSELECTIVE AMIDE COUPLING

It was envisioned that the xantphos improved protocol would be applicable to a regioselective amide coupling of polychlorinated pyridines. The process would yield imidazopyridines with an additional chloride for further synthetic elaboration. N-substituted 3-aminopyridines that contain chlorine entities at the 2-position along with the 4, 5 or 6 positions were considered and based on previous studies the amide coupling is hypothesized to be selective for the 2-position (Scheme 43).

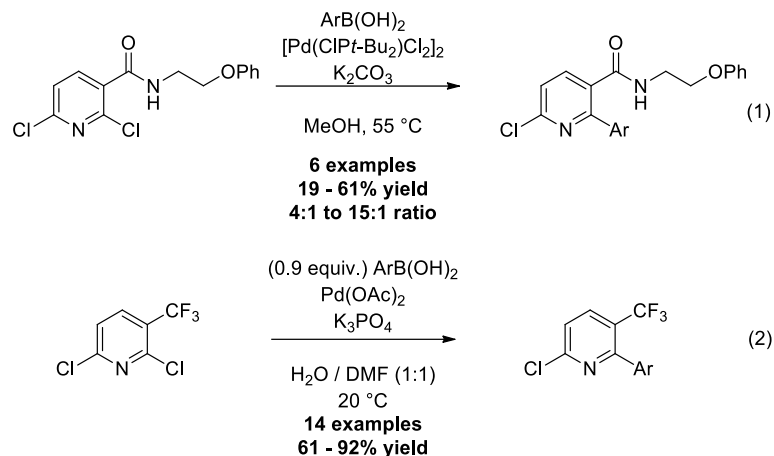
Scheme 43: Regioselective Coupling Hypothesis



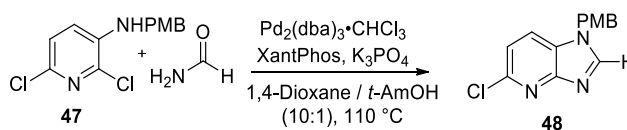
Regiospecific palladium catalyzed methodologies using polychloro heterocyclic systems have been reported by other groups. In 2000, scientists at Amgen demonstrated a selective Sonogashira coupling at the 2-position of 2,4-dichloro-3-amino-6-methylpyridine (Scheme 44, eq 1).²⁰² Similarly, Delvare and co-workers developed an amide coupling that was also selective for the 2-position of 2,4-dichloropyridines (Scheme 44, eq 2).²⁰³ Altering the substrate to a 2,5-dichloropyridine, Castanet *et al.* performed a carbonylative Suzuki coupling that provided a good yield of the desired products (Scheme 44, eq 3).²⁰⁴

Scheme 44: Regioselective coupling of 2,4 and 2,5-dichloropyridines

Another example of a regiospecific coupling using Suzuki chemistry with 2,6-dichloropyridine system was discovered. In 2003, Yang and co-workers attempted to produce 6-amino-2-arylnicotinamides from the 2,6-dichloronicotinic acid precursor (Scheme 45, eq 1). When the carbonyl moiety was substituted as an ester, the reaction in methanol favored a coupling at the 2-position in a 2.5 to 1 ratio. This result was attributed to the ester selectively chelating with the palladium. When the ester was exchanged with a stronger chelating amide the selectivity improved favoring coupling at the 2-position in a 15:1 ratio.²⁰⁵ More recently, Langer and co-workers conducted Suzuki reactions with 2,6-dichloropyridines. Langer found that by using the boronic acid as the limiting reagent selective coupling at the 2-position of 2,6-dichloro-3-trifluoromethylpyridine was observed (Scheme 45, eq 2).²⁰⁶

Scheme 45: Regioselective Suzuki Couplings of 2,6-dichloropyridines

From our studies it was gathered that bidentate ligands were un-cooperative in the synthesis of imidazo[4,5-*c*]pyridines leaving the activated chlorine at the 4 position intact. It was also discovered that regioselective amidation could be attained under the Xantphos conditions and it was demonstrated with 2-chloro-*N*-(4-chlorobenzyl)pyridin-3-amine. There were a few concerns for the regioselective coupling under the new Xantphos mixed solvent conditions. With multiple chlorides on the pyridine ring there certainly could be some reduction products or over coupling. Pyridine **47** was examined with the *standard* Xantphos conditions previously elucidated (Section 2.2). After eleven hours a 77% conversion with a 44% crude yield was observed. Direct comparison with DPEPhos under identical conditions after only four hours there was a 95% conversion with 64% crude yield observed (Table 22).

Scheme 46: Regioselective Amidation**Table 23:** Comparison of Xantphos and DPE Phos

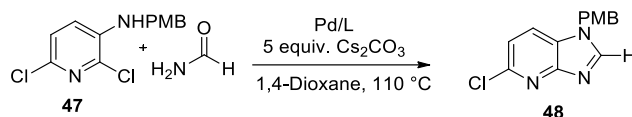
Entry	Ligand	Time (h)	Conv. (%)	Yield 48 (%)
1	Xantphos	11	77	44
2	DPE Phos	4	95	64

With excellent conversion but relative low yield a combination of conditions were examined. Increasing the amount of *t*-amyl-OH beyond a ratio of 4:1 was detrimental to the crude yield of product (Table 24, entries 1 and 2). Changing from potassium phosphate to cesium carbonate, another inorganic base commonly used in catalysis, had a dramatic increase in yield (Table 24, entry 3). Increasing the amount of base used to 5 equivalents reduced the reaction time to 4 h and provided **48** in a 70% crude yield. At this point it was noticed that further reducing the amount of alcohol co-solvent had no change. The co-solvent was eliminated and the reaction was found to be identical to entries 7 and 8 using 5 equivalents of cesium carbonate. With this much base the reaction needed to be stirred vigorously for good mixing.

Table 24: Base and Solvent Screen for Regioselective Coupling Using DPE Phos

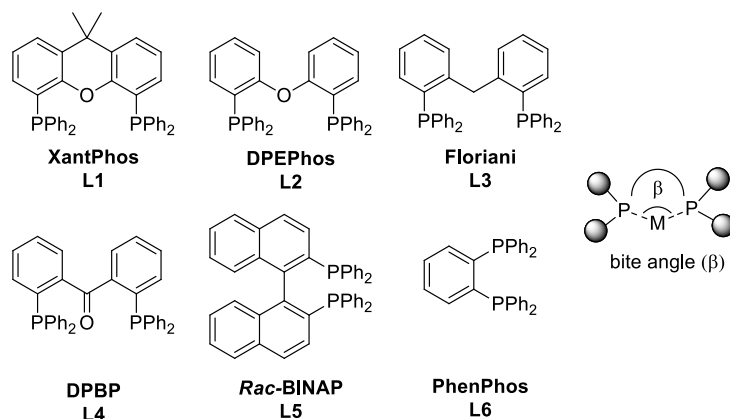
Entry	Base (equiv.)	Solvent ^a	Time	Conv. (%)	Yield 48 (%)
1	K ₃ PO ₄ (1.5)	2:1	3.5	85	45
2	K ₃ PO ₄ (2)	1:0	6.5	87	48
3	Cs ₂ CO ₃ (2)	10:1	4	95	64
4	Cs₂CO₃ (2)	4:1	4	90	75
5	Cs ₂ CO ₃ (2)	2:1	4	87	50
6	Cs ₂ CO ₃ (2)	1:1	4	84	60
7	Cs ₂ CO ₃ (5)	10:1	4	96	70
8	Cs ₂ CO ₃ (5)	20:1	2	96	70
9	Cs₂CO₃ (5)	1:0	2	96	70

^aSolvent ratio represents 1,4-dioxane:*t*-amyl alcohol

Table 25: Palladium and Ligand Screen for Regioselective Coupling

Entry	Pd Source ^a	Ligand	Bite Angle (L)	Time (h)	Conv.(%)	Yield (%)
1	Pd ₂ (dba) ₃ ·CHCl ₃	L1	108°	6	78	45
2	Pd ₂ (dba) ₃ ·CHCl ₃	L2	107°	2	96	70
3	PdCl ₂	L2	107°	2	-	-
4	Pd(OAc) ₂	L2	107°	2	91	66
5	Pd(TFA) ₂	L2	107°	2	95	63
6	[Pd(allyl)Cl] ₂	L2	107°	2	95	56
7	Pd(OAc) ₂	L3	111°	6	95	46
8	Pd(OAc) ₂	L4	113°	6	52	44
9	Pd(OAc) ₂	L5	97°	2	-	-
10	Pd(OAc) ₂	L6	87°	4	20	-

^aStandard conditions: 4 mol % Pd (2 mol % for dinuclear sources), 10 mol % L

**Figure 15:** Bidentate Ligands Examined for Regioselective Palladium Catalyzed Amidation

To evaluate the activity of certain combinations of catalysts and ligands the model reaction conditions contain **47**, 1.5 equivalents of formamide and 5 equivalents of cesium carbonate in 1,4-dioxane at 110 °C (Table 25). The combination of Pd₂(dba)₃·CHCl₃ and DPE Phos **L2** provided excellent conversion and good yield (entry 2). Altering the palladium source can impact the formation of the active catalyst species, however, this had a minimal effect over the sources that were screened and PdCl₂ did not work (entry 3). Presumably the active catalyst was not formed in

this example. Palladium acetate provided a clean reaction with barely any discerable impurities in the crude ^1H NMR and it was utilized for the ligand screen (entries 4, 7-10). Bi-dentate ligands with similar characteristics were examined. When Xantphos (**L1**) and DPE Phos (**L2**) are bound to metals they have similar bite angles of 108° and 107° respectively. Although bite angles are flexible in organometallic complexes, it is believed that this was playing a crucial role in the reaction. These two (**L1** and **L2**) performed similarly in previous experiments; however, mono-dentate ligands (PCy_3 , $\text{P}(o\text{-Tol})_3$ and $\text{P}(2\text{-Furyl})_3$) and ligands with smaller bite angles (**L5**, 97° and **L6**, 87°) delivered no product in this reaction. The Floriani ligand (**L3**),^{207, 208} and DPBP (**L4**),²⁰⁹⁻²¹¹ were examined for the small differences to **L1** and **L2**. The Floriani ligand **L3** lacks the oxygen hetero atom which may have a weak interaction with the palladium in the transition state.²¹² The reaction with **L3** was much slower than with **L2** and only delivered 46% crude yield of **48**. It is theorized that the weak interaction with the heteroatom may be beneficial to the reductive elimination step of the elementary catalytic process. The DPBP (**L4**) ligand possessing a carbonyl functional group was analyzed. The carbonyl should have a stronger interaction with the metal than an ethereal moiety. The reaction using **L4** was slower than previous ligands but at only 52% conversion of **47** we observed 44% crude yield of **48**. It is speculated that a longer reaction time with **L4** would produce the greatest quantity of **48**.

In summary, we have discovered reaction conditions for the regioselective amidation of 2,6-dichloro-3-aminopyridine **47** to provide the chlorinated imidazopyridine **48**. Further exploration of the reaction conditions (reaction time, temperature, catalyst/ligand ratio) and substrate scope will be carried out to improve this reaction. Additional work will be required for the production of 2,4-dichloro-3-aminopyridines and subsequent evaluation of these moieties.

3.0 APPENDIX I: EXPERIMENTALS

3.1 GENERAL EXPERIMENTAL

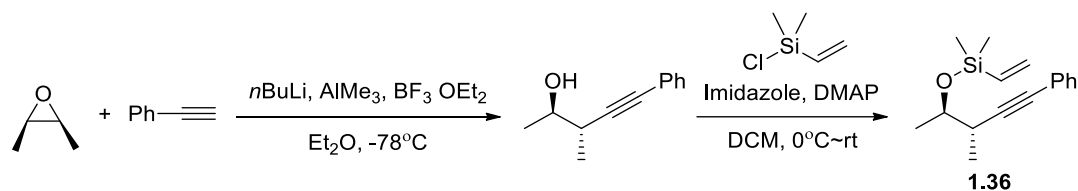
3.1.1 General Procedures: Unless otherwise indicated, all reactions were conducted in oven (140°C) or flame-dried glassware using distilled and degassed solvents under positive pressure of dry argon with standard Schlenk techniques. All air-sensitive reagents were stored in an MBraun labmaster glovebox containing dry argon gas. Dry tetrahydrofuran (THF), toluene, acetonitrile (CH₃CN), diethyl ether (Et₂O) and methylene chloride (DCM) were obtained by passing commercially available pre-dried, oxygen-free formulations through two activated alumina columns using an MBraun MB-SPS solvent purification system. Stainless steel syringes or cannulae that had been oven-dried (140°C) and cooled under an argon atmosphere or in a desiccator were used to transfer air- and moisture-sensitive liquids. Yields refer to chromatographically and spectroscopically (¹H NMR) homogeneous materials, unless otherwise stated. Reactions were monitored by thin-layer chromatography (TLC) carried out on pre-coated glass plates of silica gel (0.25 mm) 60 F₂₅₄ from EMD Chemicals Inc. using the indicated solvent system. Visualization was accomplished with ultraviolet light (UV 254 nm), or by shaking the plate in a sealed jar containing silica gel and Iodine. Alternatively, plates were treated with one of the following solutions (this was accomplished by holding the edge of the TLC plate with forceps or tweezers and immersing the plate into a wide-mouth jar containing the desired staining solution) and carefully heating with a hot-air gun (450°C) for approximately 1-2 min (NOTE: excess stain was removed by resting the TLC on a paper towel prior to heating): 10% phosphomolybdic acid in ethanol, 1% potassium permanganate/7% potassium carbonate/0.5% sodium hydroxide aqueous solution, and/or anisaldehyde in ethanol with 10% sulfuric acid. Flash column chromatography was performed using Silia Flash® P60 silica gel (40-63 μm) from Silicycle. All work-up and purification procedures were carried out with reagent grades solvents (purchased from VWR) in air.

3.1.2 Instrumentation: Infrared (IR) spectra were recorded on a Thermo Nicolet IR-100 spectrometer, ν_{max} in cm^{-1} , and were obtained from samples prepared as thin films between NaCl plates. ^1H NMR spectra were recorded on Bruker Avance DPX-300 (300 MHz) spectrometer and Bruker Avance III HD (400 MHz) spectrometer with CryoProbe Prodigy. Chemical shifts are reported in parts per million (ppm) and are calibrated using residual undeuterated solvent as an internal reference (CDCl_3 : δ 7.26 ppm; CD_3OD : δ 3.31 ppm). Data are reported as follows: chemical shift, multiplicity, coupling constants (Hz), and integration. The following abbreviations or combinations thereof were used to explain the multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, pent = pentet, sext = sextet, sept = septet, m = multiplet, br = broad. ^{13}C NMR spectra were recorded on Bruker Avance DPX-300 (75 MHz) spectrometer and Bruker Avance III HD (100 MHz) spectrometer with CryoProbe Prodigy with complete proton decoupling. Chemical shifts are reported in ppm and are calibrated using residual undeuterated solvent as an internal reference (CDCl_3 : δ 77.16 ppm; CD_3OD : δ 49.00 ppm). ^{19}F NMR spectra were recorded on a Bruker Avance DPX-300 (282.4 MHz) spectrometer. Chemical shifts are reported in ppm and are calibrated using solvent as an external reference (CFCl_3 : δ 0.00 ppm). Melting points (m.p.) are uncorrected and were recorded using an Electrothermal Mel-Temp® melting point apparatus. Elemental Analyses were performed on a Costech ECS 4010 elemental analyzer with a thermal conductivity detector and 2 meter GC column maintained at 65°C.

3.2 SYNTHESIS OF VINYL SILICON TETHERED ALKYNES

Reagents and Catalysts: Reagents and ligands were purchased at the highest commercial quality and used without further purification, unless otherwise stated.

Alkynes not listed were prepared according to the literature procedure.^{28, 65}



To a solution of phenylacetylene (2.6 mL, 24 mmol) in Et₂O (100 mL) at -78°C was added *n*BuLi (2.5 M in hexane, 9.6 mL, 24 mmol) over 20 min. After stirring at -78°C for an additional 20 min, trimethylaluminum (2.0 M in hexane, 12 mL, 24 mmol) was added via addition funnel over 5 min. The reaction was stirred at -78°C for 30 min, -45°C for 30 min, and then cooled to -78°C , whereupon *cis*-2,3-epoxybutane (20 mmol) in Et₂O (11 mL) was added over 10 min. After stirring for 15 min, boron trifluoride diethyl etherate (2.8 mL, 22 mmol) in Et₂O (11 mL) was added slowly over 15 min and stirred at -78°C for 1 h. Methanol (36 mL) was added dropwise via addition funnel over 10 min, then the reaction was allowed to warm to rt over 25 min before sat. NH₄Cl_(aq) (36 mL) was added. After stirring at rt for an additional 30 min, the reaction mixture was diluted with water (150 mL), extracted with Et₂O (3 x 100 mL), dried over Na₂SO₄, filtered, and concentrated *in vacuo*. The residue was purified by flash column chromatography (hexane:Et₂O = 5:1) on silica gel to give the alcohol (1.36 g, 39%) as an orange oil. The reaction of the alcohol (508 mg, 2.9 mmol), imidazole (395 mg, 5.8 mmol), DMAP (71 mg, 0.58 mmol)

and vinyltrimethylchlorosilane (0.6 mL, 4.35 mmol) in DCM (20 mL) afforded the silyl ether **1.36** (660 mg, 88%) as a colorless oil.

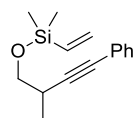
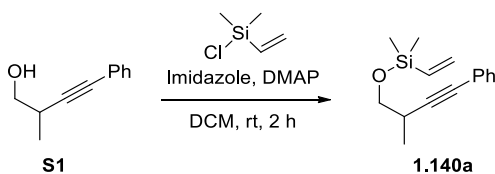
TLC (hexanes:Et₂O = 10:1): R_f = 0.83

¹H NMR (400 MHz, CDCl₃): δ 7.41-7.37 (m, 2 H), 7.30-7.24 (m, 3 H), 6.18 (dd, *J* = 20.1, 14.7 Hz, 1H), 6.01 (dd, *J* = 14.7, 3.9 Hz, 1H), 5.79 (dd, *J* = 20.2, 3.9 Hz, 1H), 3.96-3.90 (m, 1H), 2.75-2.68 (m, 1H), 1.23 (d, *J* = 6.2 Hz, 3H), 1.21(d, *J* = 7.0 Hz, 3H), 0.21 (s, 6H)

¹³C NMR (100 MHz, CDCl₃): δ 138.1, 133.1, 131.7, 128.2, 127.6, 124.1, 92.6, 81.9, 71.0, 34.5, 20.1, 15.5, -1.2, -1.3

IR (film): 3082, 2977, 2879, 2233, 1573, 1252, 1155, 915

Anal. calcd for C₁₆H₂₂OSi: C 74.36, H 8.58; found: C 74.08, H 8.67.



Dimethyl((2-methyl-4-phenylbut-3-yn-1-yl)oxy)(vinyl)silane (1.140a): To a flame dried 50 mL round bottom flask with a magnetic stir bar was added alcohol **S1**²¹³ (1.08 g, 6.75 mmol), DCM (20 mL), DMAP (165 mg, 1.35 mmol) and imidazole (919 mg, 13.5 mmol). Vinyltrimethylchlorosilane was added dropwise (1.39 mL, 10.125 mmol) to the resulting solution and the reaction stirred at RT for 2 h. The reaction mixture was poured into sat. NH_4Cl (aq.) (30 mL), extracted with DCM (2 x 20 mL), dried over MgSO_4 , filtered and concentrated *in vacuo* to give a yellow residue. The yellow residue was purified via flash column chromatography (1% diethyl ether/hexanes) to yield **1.140a** as a clear oil (1.37 g, 84%).

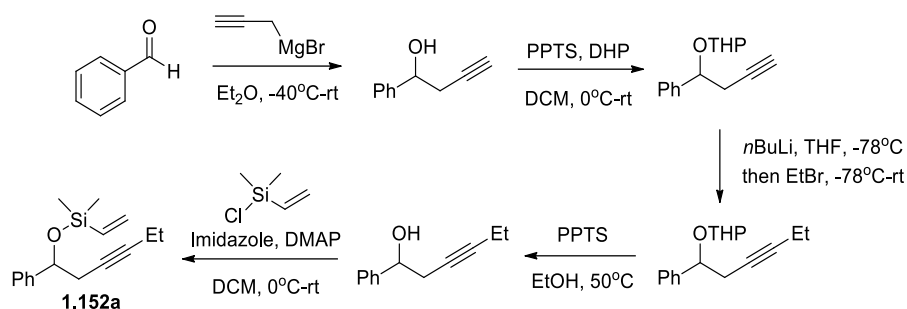
R_f = 0.72 (10% diethyl ether/hexanes)

¹H NMR (400 MHz, CDCl_3): δ = 7.40-7.38 (m, 2H), 7.28-7.25 (m, 3H), 6.15 (dd, J = 20.0, 15.0 Hz, 1H), 6.03 (dd, J = 14.8, 4.0 Hz, 1H), 5.81 (dd, J = 20.0, 4.2 Hz, 1H), 3.76 (dd, J = 9.8, 6.0 Hz, 1H), 3.53 (dd, J = 9.8, 7.6 Hz, 1H), 2.81 (sext., J = 6.8 Hz, 1H), 1.25 (d, J = 6.8 Hz, 3H), 0.22 (s, 6H)

¹³C NMR (100 MHz, CDCl_3): δ = 137.4, 133.5, 131.7, 128.3, 127.7, 123.8, 92.1, 81.6, 67.1, 29.7, 17.5, -1.9

IR (film): ν = 3053, 2967, 2909, 1596, 1490, 1253, 1086, 837 cm^{-1}

Anal. calcd. for $\text{C}_{15}\text{H}_{20}\text{OSi}$: C 73.71, H 8.25; found: C 73.83, H 8.19



Dimethyl((1-phenylhex-3-yn-1-yl)oxy)(vinyl)silane (1.152a): To a flame dried 250 mL 3-neck round bottom flask equipped with a pressure equalizing addition funnel, large magnetic stir bar and freshly prepared propargyl magnesium bromide (0.63M in Et₂O, 145 mmol) at -40°C was added benzaldehyde (9.9 mL, 97 mmol) dropwise. The reaction stirred at RT for 4 h, then poured into 1M HCl (200 mL). The layers were separated and the organics were dried over MgSO₄, filtered and concentrated *in vacuo* to give a yellow oil (13.7 g). To a flame dried 500 mL round bottom flask with magnetic stir bar was added the resulting crude alcohol (13.7 g, 94 mmol), DCM (235 mL) and PPTS (2.36 g, 9.39 mmol). The yellow solution was cooled to 0°C (ice/H₂O bath) and DHP (17.1 mL, 188 mmol) was added dropwise. The reaction mixture stirred at RT for 4 hours and then was quenched by sat. NaHCO_{3(aq)} (100 mL). The layers were separated and the organics were dried over MgSO₄, filtered and concentrated *in vacuo* to give a yellow oil (22.4 g). To a flame dried 500 mL 3-neck round bottom flask equipped with a pressure equalizing addition funnel and large magnetic stir bar was added the resulting crude alkyne (5.0 g, 21.7 mmol) and THF (130 mL). The yellow solution was cooled to -78°C (dry ice/acetone bath) and *n*BuLi (10.4 mL, 2.5M, 26.0 mmol) was added dropwise. After stirring for 1 h, bromoethane (7.3 mL, 98 mmol) was added dropwise then the solution was warmed to RT and stirred overnight. The reaction mixture was quenched by the addition of sat. NH₄Cl_(aq) (100 mL) at -78°C (dry ice/acetone bath). The layers were separated and the aqueous was extracted with Et₂O (2 x 50 mL). The combined organics were

dried over MgSO_4 , filtered and concentrated *in vacuo* to give a orange oil (5.36 g). To an oven dried 100 mL round bottom flask with magnetic stir bar was added the resulting orange oil (5.36 g, 21 mmol), EtOH (50 mL) and PPTS (1.56 g, 6.2 mmol). The orange solution stirred at 50°C for 4 h, then was cooled to RT and concentrated *in vacuo*. The residue was dissolved in DCM and washed with brine (2 x 50 mL). The organics were dried over MgSO_4 , filtered and concentrated *in vacuo* to give a brown oil. Purification via flash column chromatography (gradient elution with 5-10% EtOAc/hexanes) gave alcohol as a yellow oil (1.48 g, 41% over 3 steps). To an oven dried 100 mL round bottom flask with magnetic stir bar was added alcohol (1.48 g, 8.5 mmol), DCM (45 mL), imidazole (1.16 g, 17 mmol) and DMAP (208 mg, 1.7 mmol). The solution was cooled to 0°C (ice/ H_2O bath) and vinyltrimethylchlorosilane (1.8 mL, 12.7 mmol) was added dropwise. The resulting yellow suspension stirred at RT overnight. The reaction was quenched with sat. $\text{NH}_4\text{Cl}_{(\text{aq})}$ (50 mL) and the organics were dried over Na_2SO_4 , filtered and concentrated *in vacuo* to give a yellow residue. Purification via flash column chromatography (gradient elution with 1-3% diethyl ether/hexanes) gave alkyne **1.152a** as a pale yellow oil (1.39 g, 63%).

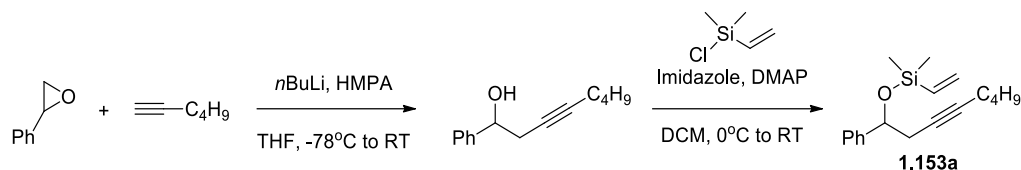
$R_f = 0.59$ (10% diethyl ether/hexanes)

^1H NMR (400 MHz, CDCl_3): $\delta = 7.30$ (m, 5H), 6.09 (dd, $J = 20.0, 14.8$ Hz, 1H), 5.97 (dd, $J = 4.0, 14.8$ Hz, 1H), 5.74 (dd, $J = 4.0, 20.0$ Hz, 1H), 4.78 (dd, $J = 6.0, 7.6$ Hz, 1H), 2.51 (m, 2H), 2.14 (qt, $J = 10.0, 2.4$ Hz, 2H), 1.09 (t, $J = 7.6$ Hz, 3H), 0.17 (s, 3H), 0.12 (s, 3H)

^{13}C NMR (100 MHz, CDCl_3): $\delta = 144.2, 137.9, 133.3, 128.2, 127.5, 126.2, 83.7, 76.8, 74.5, 31.2, 14.3, 12.7, -1.3, -1.4$

IR (film): $\nu = 3051, 2973, 2373, 1438, 1252, 1070\text{ cm}^{-1}$

Anal. calcd. for $\text{C}_{16}\text{H}_{22}\text{OSi}$: C 74.36, H 8.58; found: C 74.31, H 8.58



Dimethyl((1-phenyloct-3-yn-1-yl)oxy)(vinyl)silane (1.153a): To a flame dried 250 mL 3-neck round bottom flask with a pressure equalizing addition funnel and magnetic stir bar was added 1-hexyne (4.1 g, 49.9 mmol) and THF (50 mL). The solution was cooled to -78°C (dry ice/acetone bath) and *n*BuLi (30 mL, 1.66M, 49.9 mmol) was added dropwise via addition funnel. After stirring at -78°C for 1 h, a solution of styrene oxide (5 g, 41.6 mmol) in HMPA (10.9 mL, 62.4 mmol) was added dropwise via addition funnel. After 10 minutes, the reaction mixture was allowed to warm to RT. The reaction was poured into 100 mL water and extracted with diethyl ether. The organic layer was washed with 1M HCl and brine, dried over MgSO_4 , filtered and concentrated *in vacuo* to afford a yellow oil (1.57 g, 18%). To a flame-dried 250 mL round bottom flask with stir bar was added the crude alcohol (1.57 g, 7.76 mmol) and DCM (50 mL). To the yellow solution was sequentially added imidazole (1.06 g, 15.52 mmol,) and DMAP (0.2 equiv.). The resulting mixture was cooled to 0°C (ice/ H_2O bath) and vinyltrimethylchlorosilane was added dropwise. After stirring at 0°C for 10 minutes, the resulting suspension was allowed to warm to RT. After 4 h, the reaction was quenched with sat. $\text{NH}_4\text{Cl}_{(\text{aq})}$ (30 mL) and extracted with DCM (3 x 30 mL). The combined organics were washed with brine (2 x 50 mL), dried with $\text{MgSO}_{4(\text{s})}$, filtered and concentrated to yield a yellow oil. The oil was purified via flash column chromatography (2% diethyl ether/hexanes) to yield **1.153a** as a clear oil (1.73 g, 78%).

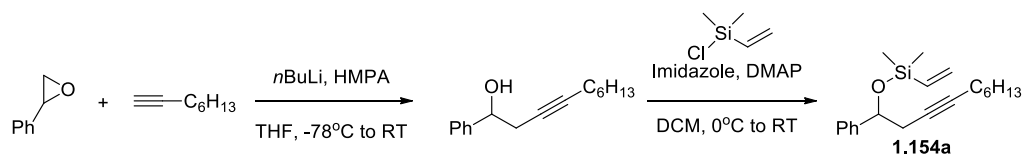
R_f = 0.64 (10% diethyl ether/hexanes)

¹H NMR (400 MHz, CDCl₃): δ = 7.35-7.22 (m, 5H), 6.08 (dd, 1H, *J* = 20.0, 14.8 Hz), 5.96 (dd, 1H, *J* = 14.8, 4.2 Hz), 5.74 (dd, 1H, *J* = 20.0, 4.2 Hz), 4.77 (t, 1H, *J* = 6.3 Hz), 2.61-2.44 (m, 2H), 2.12 (tt, 2H, *J* = 9.2, 6.8, 2.4 Hz), 1.47-1.32 (m, 4H), 0.88 (t, 3H, *J* = 7.2 Hz), 0.16 (s, 3H), 0.11 (s, 3H)

¹³C NMR (100 MHz, CDCl₃): δ = 144.1, 137.8, 133.2, 128.1, 127.4, 126.1, 82.2, 74.4, 31.1, 31.1, 22.0, 18.6, 13.8, -1.3, -1.5

IR (film): ν = 3030, 2957, 2931, 2871 cm⁻¹

Anal. calcd. for C₁₈H₂₆OSi: C 75.46, H 9.15; found: C 75.29, H 9.05



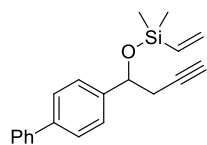
Dimethyl((1-phenyldec-3-yn-1-yl)oxy)(vinyl)silane (1.154a): Prepared following the procedure for **20a**: 1-octyne (3.5 mL, 24 mmol), *n*BuLi (9.6 mL, 2.5M, 24 mmol), styrene oxide (2.28 mL, 20 mmol) in HMPA (5.2 mL, 30 mmol). The reaction was poured into 100 mL water and extracted with diethyl ether. The organic layer was washed with 1M HCl and brine, dried over MgSO₄, filtered and concentrated *in vacuo* to afford a yellow oil (2.74g, 59%). To a flame dried 100 mL round bottom flask was added the crude alcohol (1.39 g, 6.04 mmol), DCM (20 mL), DMAP (147 mg, 1.21 mmol) and imidazole (822 mg, 12.08 mmol). Vinyltrimethylchlorosilane (1.25 mL, 9.06 mmol) was added dropwise to the yellow solution and the resulting suspension stirred overnight. The reaction mixture was poured into sat. NH₄Cl (aq.) (30mL), extracted with DCM (2 x 20 mL), dried with MgSO₄, filtered and concentrated *in vacuo* to give a yellow residue. Purification via column chromatography (1% diethyl ether/hexanes) to yield **1.154a** as a clear oil (1.21 g, 64%). **R_f** = 0.37 (2% diethyl ether/hexanes)

¹H NMR (400 MHz, CDCl₃): δ = 7.35-7.28 (m, 3H), 7.25-7.22 (m, 2H), 6.08 (dd, *J* = 20.0, 15.2 Hz, 1H), 5.96 (dd, *J* = 14.8, 4.4 Hz, 1H), 5.81 (dd, *J* = 20.2, 4.2 Hz, 1H), 4.77 (t, *J* = 6.5 Hz, 1H), 2.60-2.44 (m, 2H), 2.13-2.08 (m, 2H), 1.47-1.23 (m, 8H), 0.89 (t, *J* = 6.6 Hz, 3H), 0.16 (s, 3H), 0.11 (s, 3H)

¹³C NMR (100 MHz, CDCl₃): δ = 144.1, 137.7, 133.2, 128.1, 127.4, 126.1, 82.2, 74.3, 31.5, 31.1, 29.0, 28.7, 22.7, 18.2, 14.2, -1.3, -1.5

IR (film): ν = 2932, 2859, 1594, 1454, 1252, 1090, 836 cm⁻¹

Anal. calcd. for C₂₀H₃₀OSi: C 76.37, H 9.61; found: C 76.21, H 9.56



((1-1'([1,1'-biphenyl]-4-yl)but-3-yn-1-yl)oxy)dimethyl(vinyl)silane

(1.162): To a flame-dried 100 mL round bottom flask was added imidazole (1.00

g, 14.76 mmol) and DMAP (0.181 g, 1.48 mmol), dichloromethane (40 mL), and alcohol (1.30 g, 7.38 mmol). The mixture was allowed to stir until complete dissolution and then cooled to 0 °C in an ice-water bath. vinyl dimethyl chlorosilane (0.93 mL, 6.71 mmol) was then added dropwise. After addition, the reaction was allowed to warm to room temperature. After 7 h, the reaction was complete as judged by TLC analysis and quenched with the addition of sat. 40 mL aq NH₄Cl. The organic layer was dried with Na₂SO₄ and concentrated *in vacuo* to yield a yellow oil. The crude product was purified on a silica gel column using 250 mL of 10:1 hexanes:ether to give the product (1.63 g, 79%) as a yellow oil.

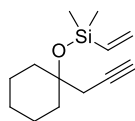
TLC R_f (10% EtOAc / Hexanes): 0.39

¹H NMR (400 MHz, CDCl₃) δ= 7.47 (m, 10 H), 6.11 (dd, J = 20 Hz, 14.8 Hz, 1H), 5.99 (dd, J = 4.4 Hz, 14.8 Hz, 1 H), 5.77 (dd, J = 4.4 Hz, 20 Hz, 1 H), 4.88 (t, J = 6.4 Hz, 1 H), 2.62 (ddd, J = 2.8 Hz, 6.8 Hz, 16.4 Hz, 2H), 1.99 (t, J = 2.8 Hz, 1 H), 0.20 (s, 3 H), 0.15 (s, 3 H)

¹³C NMR (100 MHz, CDCl₃) δ= 142.7, 141.0, 140.5, 137.6, 133.6, 128.9, 127.3, 127.2, 127.0, 126.5, 81.6, 73.5, 70.3, 30.7, -1.32, -1.48

FT-IR (NaCl, thin film) ν = 3305, 2121 cm⁻¹.

Anal. Calc. for C₂₀H₂₂OSi: C, 78.38; H, 7.24; Found: C, 78.36; H, 7.14



Dimethyl((1-1(prop-2-yn-1-yl)cyclohexyl)oxy)(vinyl)silane (1.164a): To a flame-dried 100 mL round bottom flask was added imidazole (1.00 g, 14.76 mmol) and DMAP (0.181 g, 1.48 mmol), dichloromethane (40 mL), and alcohol (1.02 g, 7.38 mmol). The mixture was allowed to stir until complete dissolution and then cooled to 0 °C in an ice-water bath. Vinyl dimethyl chlorosilane (0.93 mL, 6.71 mmol) was then added neat, via syringe, dropwise. After addition, the reaction was allowed to warm to room temperature. After 25 h, the reaction was complete as judged by TLC analysis and quenched with the addition of 40 mL sat. aq NH₄Cl. The organic layer was dried with Na₂SO₄ and concentrated *in vacuo* to yield a colorless oil. The crude product was purified on a silica gel column using 250 mL of 20:1 hexanes:ether to give the product (1.26 g, 85%) as a colorless oil.

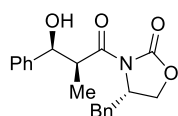
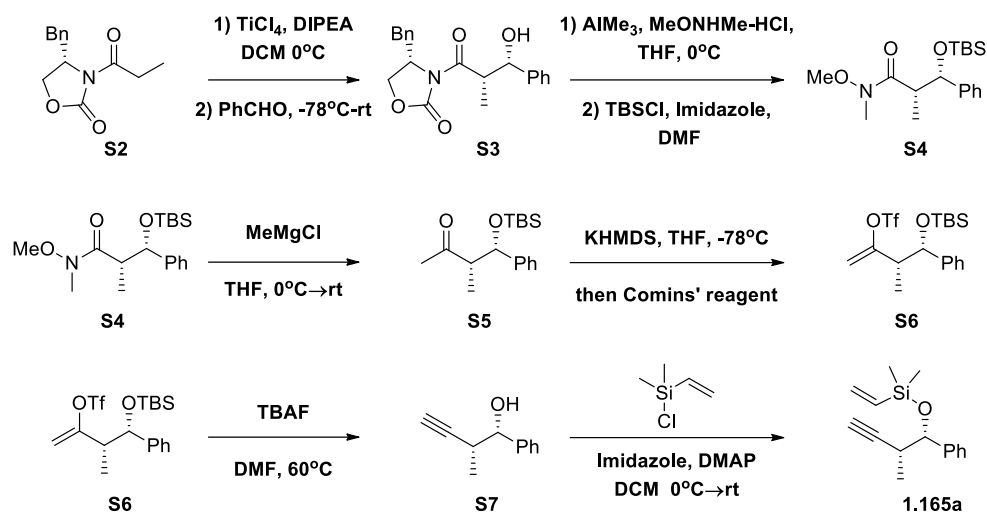
TLC R_f (5% EtOAc / Hexanes): 0.61

¹H NMR (400 MHz, CDCl₃) δ= 6.22 (dd, J = 20.4 Hz, 14.8 Hz, 1H), 5.93 (dd, J = 4 Hz, 10.8 Hz, 1H), 5.76 (dd, J = 14.4 Hz, 3.6 Hz, 1H), 2.39 (d, J = 2.8 Hz), 2.01 (t, J = 2.8 Hz), 1.44 (m, 10H), 0.22 (s, 6H)

¹³C NMR (100 MHz, CDCl₃) δ= 140.2, 131.7, 81.8, 75.0, 70.8, 37.6, 33.0, 25.7, 22.4, 0.9

FT-IR (NaCl, thin film) ν = 3313, 2121 cm⁻¹.

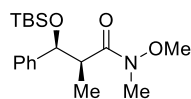
Anal. Calc. for C₁₃H₂₂OSi: C, 70.21; H, 9.97; Found: C, 70.35; H, 10.20



Syn-Aldol adduct S3: To a 1 L round bottom flask (3-neck) equipped with an addition funnel was added oxazolidinone **S2** (10.00 g, 42.9 mmol) and dichloromethane (430 mL). The solution was cooled to -15 °C in an ice-brine bath.

To the solution was added TiCl_4 (4.9 mL, 45 mmol), dropwise and the reaction mixture is allowed to stir for 20 minutes. Diisopropylethylamine (8.2 mL, 47.2 mmol) is then added dropwise over a period of 10 minutes, and the resulting solution is allowed to stir for 1 hour, before adding N-methyl-2-pyrrolidone (4.1 mL, 42.9 mmol) dropwise, and stirring for an additional 15 minutes. Benzaldehyde (4.8 mL, 47.2 mmol) is then added dropwise. After 1.5 h, the reaction is complete as judged by TLC analysis. The reaction mixture is quenched with saturated aqueous NH_4Cl (400 mL) and the aqueous phase extracted with dichloromethane (3 x 100 mL). The combined organics were dried with MgSO_4 and concentrated *in vacuo* to give an oily solid (13.18 g, 90%). Spectral data matches that in the literature. The crude product was carried on without further purification.

^1H NMR(400 MHz, CDCl_3) δ = 7.28 (m, 10H), 5.10 (d, J = 5.2 Hz, 1H), 4.60 (m, 1H), 4.11 (m, 4H), 3.25 (dd, J = 4.4, 17.6 Hz, 1H), 3.05 (bs, 1H), 2.78 (dd, J = 12.4, 17.6 Hz, 1H), 2.04 (s, 1H), 1.23 (d, J = 9.2 Hz, 3H)



Weinreb Amide (S4):²¹⁴Made by Daniel Nguyen

To an oven-dried 3-neck 500 mL RBF equipped with magnetic stir bar and pressure equalizing addition funnel under Ar_(g) was added Weinreb salt (10.4 g, 106 mmol, 3 equiv) and THF (55 mL). The suspension was cooled to 0°C (ice/H₂O bath) and AlMe₃ (54 mL, 107 mmol, 3.02 equiv) was added dropwise over 30 min. (Caution: Vigorous gas evolution!) Once the addition was complete the cooling bath was removed and the cloudy solution stirred at rt for 30 min. The solution was re-cooled to -15°C (salt/ice/H₂O bath) and a solution of aldol adduct **S3** (12.0 g, 35.4 mmol, 1 equiv) in THF (55 mL) was added dropwise. (Caution: Vigorous gas evolution!) The reaction mixture stirred for 45 min then was quenched by cannula transfer into a 2 L RBF cooled at 0°C (ice/H₂O bath) containing 1:2 DCM/1N HCl_(aq) (780 mL). (Caution: Vigorous gas evolution!) After stirring for 30 min the layers were separated and the aqueous was extracted with DCM (3 x 250 mL). The combined organic layers were washed with brine, dried over Na₂SO₄, filtered and concentrated *in vacuo* to give a yellow oil. To the oil was added DMF (55 mL), imidazole (4.8 g, 71 mmol, 2 equiv) and TBSCl (5.9 g, 39 mmol, 1.1 equiv). The yellow solution stirred at rt overnight then poured into H₂O (200 mL) and extracted with EtOAc (3 x 200 mL). The organic layers were washed with brine, dried over Na₂SO₄, filtered and concentrated *in vacuo* to give a yellow oil. Purification via column chromatography (silica gel 4.5 x 10 cm; gradient elution with 10%-30% EtOAc/hexanes) gave **S4** as a clear oil (10.5g, 88% over two steps). **R_f** (30% EtOAc/hexanes) = 0.56

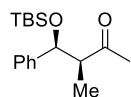
[α]_D²⁴ = -2.1° (*c* = 1.030 in CHCl₃)

¹H NMR (400 MHz, CDCl₃) δ = 7.34-7.17 (m, 5H), 4.80 (d, 1H, *J* = 8.6 Hz), 3.26 (s, 3H), 3.16 (bs, 1H), 2.95 (s, 3H), 1.27 (d, 3H, *J* = 6.8 Hz), 0.87 (s, 9H), 0.04 (s, 3H), -0.22 (s, 3H)

¹³C NMR (100 MHz, CDCl₃) δ = 175.6, 144.3, 128.0, 127.4, 127.0, 76.6, 61.3, 45.5, 31.9, 26.0, 18.4, 15.0, -4.4, -4.8

FT-IR (NaCl, thin film) ν = 3499, 3032, 2959, 1660, 1462, 1256 cm⁻¹

Anal. calcd for C₁₈H₃₁NO₃Si: C 64.05, H 9.26, N 4.15; found: C 63.99, H 9.33, N 4.07.



Methyl Ketone (S5): Made by Daniel Nguyen

To a flame-dried 25 mL RBF equipped with a magnetic stir bar under Ar_(g) was added a solution of Weinreb amide **S4** (1.0 g, 3.0 mmol, 1 equiv) in THF (6 mL). The reaction mixture was cooled to 0°C (ice/water bath) and methylmagnesium chloride (2 mL, 6.0 mmol, 2 equiv) was added dropwise. The reaction stirred at 0°C for 5 min then was warmed to rt and stirred for 3 h. The white suspension was poured into 1M HCl (10 mL) and the layers were separated. The aqueous phase was extracted with ether (3 x 10 mL) then the combined organic extracts were dried over MgSO₄, filtered and concentrated *in vacuo* to give a yellow oil. Purification via column chromatography (silica gel 2.5 x 15 cm; gradient elution with 1%-4% EtOAc/hexanes) gave **S5** as a clear oil (718 mg, 82%).

R_f (15% EtOAc/hexanes) = 0.59

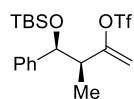
[α]_D²⁴ = -16.9° (*c* = 0.946 in CHCl₃)

¹H NMR (300 MHz, CDCl₃) δ = 7.33-7.21 (m, 5H), 4.83 (d, 1H, *J* = 6.8 Hz), 2.86-2.77 (m, 1H), 1.91 (s, 3H), 1.16 (d, 3H, *J* = 6.9 Hz), 0.88 (s, 9H), 0.03 (s, 3H), -0.22 (s, 3H)

¹³C NMR (75 MHz, CDCl₃) δ = 211.2, 143.4, 128.1, 127.5, 126.3, 76.3, 56.0, 30.5, 25.9, 18.2, 12.6, -4.5, -5.1

FT-IR (NaCl, thin film) ν = 2959, 1715, 1454, 1360, 1256 cm⁻¹

Anal. calcd for C₁₇H₂₈O₂Si: C 69.81, H 9.65; found C 69.65, H 9.52.



Enol Triflate (S6): Made by Daniel Nguyen

To a oven-dried 100 mL RBF equipped with a magnetic stir bar under Ar_(g) was added freshly prepared KHMDS (1M in THF, 7.5 mmol, 1.1 equiv). The pale yellow solution was cooled to -78°C (dry ice/acetone bath) and methyl ketone **S5** (2.0 g, 6.8 mmol, 1 equiv) in THF (6.8 mL) was added dropwise. Comins' reagent²¹⁵ (5.3 g, 13.6 mmol, 2 equiv) in THF (6.8 mL) was subsequently added in one portion. The yellow solution stirred at -78°C for 2 h. The reaction mixture was warmed slightly and quenched with H₂O (15 mL). The layers were separated and the aqueous phase was extracted with DCM (3 x 10 mL). The combined organics were dried over MgSO₄, filtered and concentrated *in vacuo* to give a yellow oil. The residue was purified by column chromatography (silica gel; gradient elution with 1%-2% EtOAc/hexanes) to give **S6** as a clear oil (2.35 g, 81%).

R_f (10% EtOAc/hexanes) = 0.68

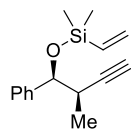
[α]_D²⁴ = +1.4° (*c* = 0.946 in CHCl₃)

¹H NMR (300 MHz, CDCl₃) δ = 7.34-7.21 (m, 5H), 5.17 (d, 1H, *J* = 3.8 Hz), 4.95-4.93 (m, 2H), 2.67-2.59 (m, 1H), 1.05 (d, 3H, *J* = 6.9 Hz), 0.91 (s, 9H), 0.02 (s, 3H), -0.18 (s, 3H)

¹³C NMR (75 MHz, CDCl₃) δ = 158.6, 142.8, 128.2, 127.6, 126.4, 118.8 (q, *J*_{C-F} = 316.4 Hz), 105.5, 74.0, 47.7, 26.0, 18.5, 11.3, -4.5, -5.3

Anal. calcd for C₁₈H₂₇F₃O₄SSi: C 50.92, H 6.41; found C 50.47, H 6.38.

enol triflate **S6** was treated with TBAF to produce alkyne **S7** which was taken on crude to the next step.



dimethyl(((1S,2R)-2-methyl-1-phenylbut-3-yn-1-yl)oxy)(vinyl)silane (1.165a): To a flame-dried 100 mL round bottom flask was added imidazole (.850 g, 12.48 mmol) and DMAP (.153 g, 1.25 mmol), dichloromethane (40 mL), and **S7** (1.00 g, 6.24 mmol). The mixture was allowed to stir until complete dissolution and then cooled to 0 °C in an ice-water bath. Vinyl dimethyl chlorosilane (1.3 mL, 9.36 mmol) was then added neat, via syringe, dropwise. After addition the reaction mixture was allowed to warm to room temperature. After 15 minutes, the reaction was complete as judged by TLC analysis and quenched with the addition of 40 mL sat. aq NH₄Cl. The aqueous phase was extracted with dichloromethane (3 x 20 mL), and the combined organics were washed with brine (40 mL), dried with MgSO₄, concentrated in vacuo to give a slightly colored oil. The crude product was purified on a silica gel column (2.5 x 12 cm) using 100 mL hexanes, 300 mL 99:1 hexanes:ether, 100 mL 30:1 hexanes:ether to give the product (1.28 g, 84%) as a colorless oil.

TLC R_f (10% Ether / Hexanes): 0.75

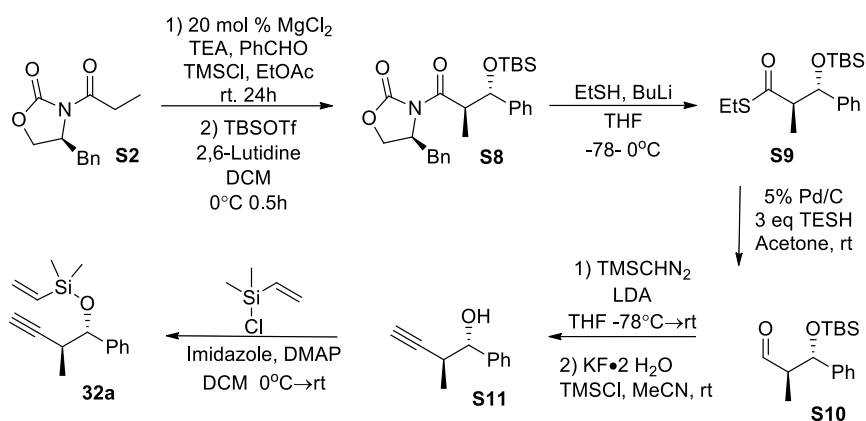
¹H NMR (400 MHz, CDCl₃) δ= 7.29 (m, 5H), 6.04 (dd, J = 14.8, 19.6 Hz, 2H), 5.95 (dd, J = 4.4, 14.8 Hz, 2H), 5.71 (dd, 4.8, 20 Hz, 2H), 4.59 (d, J = 6.8 Hz, 1H), 2.70 (pd, J = 2.8, 7.2 Hz, 1H), 1.99 (d, J = 2.4 Hz, 1H), 1.19 (d, J = 7.2 Hz, 3H), 0.12 (s, 3H), 0.07 (s, 3H)

¹³C NMR (100 MHz, CDCl₃) δ= 142.9, 137.7, 133.3, 128.0, 127.6, 127.1, 86.8, 78.0, 70.4, 35.4, 16.9, -1.31, -1.48

FT-IR (NaCl, thin film) ν = 3310, 2114 cm⁻¹.

[α]_D²³ 589 nm (c 0.51, CHCl₃) = -47.3°

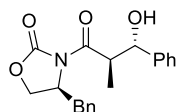
Anal. Calc. for C₁₅H₂₀OSi: C, 73.71; H, 8.25; Found: C, 73.74; H, 8.19



(S)-4-benzyl-3-propionyloxazolidin-2-one (S2): Prepared according to the literature procedure by Gage and Evans²¹⁶ to give colorless needles (92%).

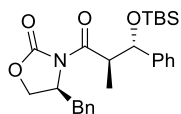
MP: 44-45°C;

¹H NMR (300 MHz, CDCl₃): δ = 7.20-7.37 (m, 5H), 4.72-4.62 (m, 1H), 4.24-4.15 (m, 2H), 3.31 (dd, J = 13.5, 3.3 Hz, 1H), 3.05-2.89 (m, 2H), 2.77 (dd, J = 13.5, 9.6 Hz, 1H), 1.21 (t, J = 7.5 Hz, 3H).

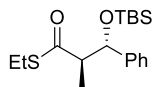


Prepared from **S2** and benzaldehyde according to procedure by Evans *et al.*²¹⁷ To a flame dried 250 mL round bottom flask equipped with a stir bar was added oxazolidinone **S2** (7.0g, 30 mmol) and ethyl acetate (100 mL). To the stirred solution was added MgCl₂ (570 mg, 6 mmol), triethylamine (5.7 mL, 45 mmol), and benzaldehyde (3.66 mL, 36 mmol). The reaction was stirred over night then the yellow solution was filtered through a plug of silica (5 cm x 5 cm) with diethyl ether (500 mL). The volatiles were removed *in vacuo* followed by the addition of methanol (50 mL) and 3 drops of trifluoroacetic acid. The solution was stirred for 1 h; a white precipitate formed, was filtered and washed with methanol (50 mL). The white solid was dried to obtain 8.28 g (81%).

¹H NMR (300 MHz, CDCl₃): δ = 7.45-7.28 (m, 8H), 7.17-7.14 (m, 2H), 4.82 (d, J = 7.8 Hz, 1H), 4.73-4.65 (m, 1H), 4.39-4.30 (m, 1H), 4.22-4.12 (m, 2H), 3.19 (dd, J = 13.5, 3.3 Hz, 1H), 2.67 (dd, J = 13.5, 9.5 Hz, 1H), 1.11 (d, J = 6.6 Hz, 3H).



(S8): To a flame dried 250 mL round bottom flask equipped with a magnetic stir bar and cooled under $\text{Ar}_{(\text{g})}$, was added aldol adduct (8.28 g, 24.4 mmol), DCM (100 mL), and 2,6-lutidine (3.4 mL, 29.3 mmol) with stirring. Once homogenous the solution was cooled to $-45\text{ }^{\circ}\text{C}$ in a dry ice-acetone bath. TBSOTf (6.75 mL, 29.3 mmol) was added dropwise via syringe and the solution was allowed to warm to r.t. The reaction was stirred for 30 mins and was judged complete by TLC. Hexanes (150 mL) were added and the organic layer was washed with water (2 x 100 mL), and Brine (2 x 25 mL). The organic layer was dried with sodium sulfate, filtered, and concentrated *in vacuo* to afford the crude TBS protected product (quant. 11.07 g).



Thioester (S9): To a flame dried 500 mL 3 neck round bottom flask equipped with an addition funnel and a magnetic stir bar was added THF (200 mL) and ethanethiol (6.0 mL, 83 mmol) and cooled to $-78\text{ }^{\circ}\text{C}$ in a dry ice-acetone bath. To the cooled solution was added *n*-BuLi (2.5 M in hexanes, 23 mL, 57.5 mmol) dropwise via addition funnel. After complete addition, the milky white solution was warmed to $0\text{ }^{\circ}\text{C}$ and stirred for 1 h. The crude **S8** (11.07 g, 24.4 mmol) was dissolved in THF (50 mL) and added slowly to the stirred solution. The reaction was judged complete by TLC at 2 h and 200 mL of ethylacetate:hexanes (1:1) was added. The organics were washed with 1M NaOH (3 x 100 mL) and brine (3 x 100 mL), dried with MgSO_4 , filtered and concentrated *in vacuo*. The sticky solid was dissolved in DCM (20 mL) and hexanes (150 mL) were added to precipitate the oxazolidinone. The solid was filtered and washed with hexanes (100 mL). The hexanes were concentrated to afford the thioester (6.5 g, 79% over 2 steps) which was sufficiently pure to continue to the next step.

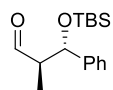
TLC R_f (20% ethyl acetate/hexanes) = 0.89

^1H NMR (400 MHz, CDCl_3) δ = 7.38-7.29 (m, 5H), 4.51 (d, J = 7.1 Hz, 1H), 2.80 (m, 1H), 2.21 (d, J = 2.5 Hz, 1H), 1.10 (d, J = 7.0 Hz, 1H)

^{13}C NMR (100 MHz, CDCl_3) δ = 141.3, 128.4, 128.1, 126.7, 85.5, 77.5, 71.4, 35.1, 17.4

FT-IR (NaCl, thin film) ν = 3568, 3296, 2979, 2879, 1453, 1173, 701 cm^{-1}

Anal. calcd. for $\text{C}_{11}\text{H}_{12}\text{O}$: C, 82.24; H, 8.63; found C 82.13; H, 8.49

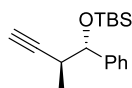


Aldehyde (S10): To a 50 mL round bottom flask equipped with a magnetic stir bar was added 5% Pd/C (692 mg, 0.325 mmol) then **S9** (1.10 g, 3.25 mmol) in acetone (7 mL).

To the stirred solution was added triethylsilane (1.56 mL, 9.75 mmol) dropwise and the mixture was stirred for 7 h. The reaction was filtered through a pad of celite with acetone (60 mL) and the volatiles were removed *in vacuo* to afford a light yellow oil (0.875 g, 96%). *Pd(OAc)₂ can be used and the reaction is complete in 0.5 h. Matches the literature data²¹⁸

TLC R_f (10% ether/hexanes) = 0.54

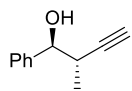
¹H NMR (400 MHz, CDCl₃) δ = 9.81 (d, J = 2.7 Hz, 1H), 7.36-7.25 (m, 5H), 4.76 (d, J = 7.6 Hz, 1H), 2.68 (dp, J = 7.0 Hz, 2.7 Hz, 1H), 0.88 (d, J = 6.7 Hz, 3H), 0.84 (s, 9H), 0.01 (s, 3H), -0.25 (s, 3H)



To a flame dried 100 mL round bottom flask equipped with a magnetic stir bar and cooled under $\text{Ar}_{(\text{g})}$, was added THF (5 mL) and di-isopropylamine (0.55 mL, 3.86 mmol). The solution was cooled to $-78\text{ }^{\circ}\text{C}$ then *n*-BuLi (2.44M in hexanes, 1.58 mL, 3.86 mmol) was added dropwise. The mixture was stirred for 30 minutes followed by the addition of TMSCH_2N_2 (2.0M in hexanes, 1.93 mL, 3.86 mmol) dropwise. After 30 minutes at $-78\text{ }^{\circ}\text{C}$, **S4** (0.833 g, 3.0 mmol) in THF (5 mL) was added dropwise and stirred for 1h then warmed to rt and quenched with water (30 mL). The aqueous layer was extracted with diethyl ether (3 x 20 mL), dried with MgSO_4 , filtered and concentrated *in vacuo*. The crude oil was applied to a silica gel column (2.5 x 15 cm) and eluted with 5% ethyl ether in hexanes to afford 703 mg (86%) of clear oil.

TLC R_f (10% ethyl acetate/hexanes) = 0.94

^1H NMR (300 MHz, CDCl_3) δ = 7.35-7.25 (m, 5H), 4.60 (d, J = 6.0 Hz, 1H), 2.71 (dp, J = 7.0 Hz, 2.4 Hz, 1H), 2.06 (d, J = 2.7 Hz, 1H), 1.01 (d, J = 6.7 Hz, 3H), 0.87 (s, 9H), 0.05 (s, 3H), -0.15 (s, 3H)



(1S,2S)-2-methyl-1-phenylbut-3-yn-1-ol (S11): To a 20 mL scintillation vial equipped with a magnetic stir bar was added the TBS protected alkyne (400 mg, 1.46 mmol), MeCN (3.0 mL, 0.5M), and KF·2H₂O (192 mg, 2.04 mmol). To the stirred suspension was added trimethylchlorosilane (0.28 mL, 2.19 mmol) dropwise and the yellow solution as stirred for 3 h. The reaction was quenched by the dropwise addition of saturated aqueous NaHCO₃ (4 mL), extracted with CH₂Cl₂ (2 x 30 mL) and the combined organic layers were washed with DI H₂O (40 mL) and brine (20 mL). The organics were dried with MgSO₄, filtered and concentrated *in vacuo*. The crude oil was applied to a silica gel column (2.5 x 15 cm) and eluted with 25% ethyl acetate in hexanes to afford 161 mg (69%) of clear oil.

TLC R_f (10% ether/hexanes) = 0.15

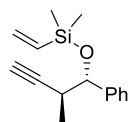
¹H NMR (400 MHz, CDCl₃) δ = 7.38-7.29 (m, 5H), 4.51 (d, *J* = 7.1 Hz, 1H), 2.80 (m, 1H), 2.21 (d, *J* = 2.5 Hz, 1H), 1.10 (d, *J* = 7.0 Hz, 1H)

¹³C NMR (100 MHz, CDCl₃) δ = 141.3, 128.4, 128.1, 126.7, 85.5, 77.5, 71.4, 35.1, 17.4

[α]_D²³ 589 nm (c 0.960, CHCl₃) α_D = -74.8628

FT-IR (NaCl, thin film) ν = 3568, 3296, 2979, 2879, 1453, 1173, 701 cm⁻¹

Anal. calcd. for C₁₁H₁₂O: C, 82.24; H, 8.63; found C 82.13; H, 8.49



dimethyl(((1S,2S)-2-methyl-1-phenylbut-3-yn-1-yl)oxy)(vinyl)silane (1.166a): To a flame-dried 50 mL round bottom flask was added imidazole (150 mg, 2.2 mmol) and DMAP (30 mg, 0.22 mmol), dichloromethane (15 mL), and **S6** (161 mg, 1.01 mmol). The mixture was allowed to stir until complete dissolution and then cooled to 0 °C in an ice-water bath. Vinyl dimethyl chlorosilane (0.21 mL, 1.51 mmol) was then added neat, via syringe, dropwise. After addition, the reaction mixture was allowed to warm to room temperature. After 3 h, the reaction was complete as judged by TLC analysis and quenched with the addition of 40 mL sat. aq NH₄Cl. The organic layer was dried with MgSO₄ and concentrated in *vacuo* to yield a yellow oil. The crude product was purified on a silica gel column eluting with 1% ethyl ether in hexanes to afford the product (219 mg, 89%) as a colorless oil.

TLC R_f (10% ether/hexanes) = 0.79

¹H NMR (400 MHz, CDCl₃) δ = 7.33-7.25 (m, 5H), 6.05 (dd, J = 19.6 Hz, 14.8 Hz, 1H), 5.95 (dd, J = 14.8 Hz, 4.4 Hz, 1H), 5.72 (dd, J = 19.6 Hz, 4.4 Hz, 1H), 4.60 (d, J = 6.4 Hz, 1H), 2.75 (dp, J = 7.0 Hz, 2.4 Hz, 1H), 2.07 (d, J = 2.4 Hz, 1H), 1.02 (d, J = 7.0 Hz, 3H), 0.13 (s, 3H), 0.07 (s, 3H)

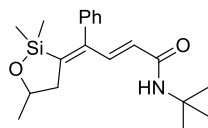
¹³C NMR (100 MHz, CDCl₃) δ = 142.1, 137.6, 127.9, 127.6, 127.0, 86.6, 77.8, 70.0, 35.2, 16.8, -1.3, -1.5

FT-IR (NaCl, thin film) ν = 2979, 2879, 1453, 1173, 701 cm⁻¹

Anal. calcd. for C₁₅H₂₀OSi: C, 73.71; H, 8.25; found C 73.59; H, 8.07

3.3 INTERMOLECULAR COUPLING DATA

3.3.1 *Acrylamides and Acrylates*

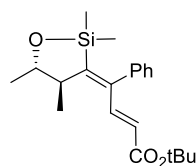


(2E,4Z)-N-(tert-butyl)-4-phenyl-4-(2,2,5-trimethyl-1,2-oxasilolan-3-ylidene)but-2-enamide (1.34): In a glove box, to a 25 mL Schlenk tube

equipped with a magnetic stir bar was added ruthenium hydride complex $\text{RuHCl}(\text{CO})(\text{SIMes})(\text{PPh}_3)$ (36 mg, 0.05 mmol), *tert*-butyl acrylamide (63mg, 0.5 mmol), and alkyne **1a** (62 mg, 0.25 mmol) in 1.0 mL toluene. The tube was sealed and brought out of the glove box and placed under an argon atmosphere. The vessel was immersed into a preheated 110 °C oil bath for 2h. The reaction was judged complete by TLC and was filtered through a plug of silica eluting with dichloromethane. The solution was concentrated *in vacuo* and applied to a SiO_2 column eluting with 10% ethyl acetate in hexanes. The product was obtained as brown oil with unidentified impurities (62 mg, 72%*).

^1H NMR (300 MHz, CDCl_3) δ = 7.73 (d, J = 15Hz, 1H), 7.36-7.31 (m, 5H), 5.37 (d, J = 15Hz, 1H), 5.22 (bs, NH), 4.21-4.15 (m, 1H), 3.08 (dd, J = 16.5, 5.4 Hz 1H), 2.43 (dd, J = 16.5, 8.1Hz 1H), 1.34 (s, 9H), 1.30 (d, J = 6.0 Hz, 3H), -0.09 (s, 3H), -0.20 (s, 3H);

Impurities: 7.12-7.09 (m, 2.4H), 3.77 (s, 0.07H), 3.69 (s, 0.12 H), 3.43 (s, 0.14H), 2.29-2.26 (m, 0.66H);



(2E,4Z)-tert-butyl-4-phenyl-4-(2,2,4,5-tetramethyl-1,2-oxasilolan-3-ylidene)but-2-enoate (1.37): In a glove box, to a 25 mL Schlenk tube was added RuHCl(CO)(SIMes)(PPh₃) (9 mg, 0.0125 mmol), and **1q** (68mg, 0.25 mmol) in

0.5 mL toluene. The vessel was sealed, removed from the glovebox and placed under an argon atmosphere. *Tert*-butyl acrylate (0.2 mL, 1.25 mmol) was added via syringe and the reaction vessel was immersed in a preheated 110 °C oil bath. After 45 minutes the reaction was judged complete by TLC and cooled to room temperature. The solution was filtered through a plug of silica gel, eluted with dichloromethane and concentrated *in vacuo*. The oil obtained was applied to a SiO₂ column and eluted with 1% diethyl ether in hexanes. The fractions obtained were concentrated at reduced pressure to afford clear oil (46 mg, 52%);

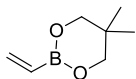
R_f (10% ethyl ether/hexanes): 0.24

¹H NMR (300 MHz, CDCl₃) δ = 7.73 (d, *J* = 15.6 Hz, 1H), 7.32-7.28 (m, 3H), 7.11-7.08 (m, 2H), 5.46 (d, *J* = 15.6 Hz, 1H), 4.11 (q, *J* = 12.6, 6.3 Hz, 1H), 2.97 (q, *J* = 14.4, 7.2 Hz, 1H), 1.43 (s, 9H), 1.22 (d, *J* = 7.2Hz, 3H), 1.16 (d, *J* = 6.3 Hz, 3H), 0.14 (s, 3H), -0.44 (s, 3H);

¹³C NMR (75 MHz, CDCl₃) δ = 167.0, 157.7, 145.8, 141.0, 141.0, 129.5, 128.2, 127.7, 124.1, 80.5, 19.9, 44.8, 28.2, 24.6, 21.9, 2.1, 0.6;

Anal. calcd. for C₂₁H₃₀O₃Si: C, 70.35; H, 8.43; found C, 70.12; H, 8.45;

3.3.2 Vinyl Boronates



Vinyl Boronate (1.39a): Prepared with an adaptation to the literature procedure.³⁸ Freshly prepared vinylmagnesium bromide (0.91M in THF, ~175

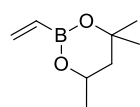
mL) was added dropwise over 1 h to a stirred solution of anhydrous trimethylborate (10.2 mL, 180 mmol) in dry THF (100 mL) at $-78\text{ }^{\circ}\text{C}$ (dry ice/acetone bath) under $\text{Ar}_{(\text{g})}$. The reaction stirred at $-78\text{ }^{\circ}\text{C}$ for 1 h then was warmed to rt, followed by addition of 20% HCl (44 mL). After 10 min, a solution of 2,2-dimethylpropane-1,3-diol (11.3 mL, 90 mmol) in Et_2O (9 mL) was added and the reaction stirred for 1 h. The two phases were separated and the aqueous phase extracted with Et_2O (100 mL). The combined organic extracts were washed with sat. $\text{NaHCO}_{3(\text{aq})}$ (2 x 100 mL) and water (2 x 100 mL), dried over MgSO_4 , filtered and concentrated *in vacuo* to give the crude product as a yellow oil. Distillation under vacuum (b.p. $19\text{--}21\text{ }^{\circ}\text{C}$ at $\sim 0.5\text{ mmHg}$) gave **1.39a** as a clear liquid (43%).

^1H NMR (300 MHz, CDCl_3) δ = 6.07 (dd, 1H, J = 18.9, 4.8 Hz), 5.89–5.85 (m, 1H), 5.77 (dd, 1H, J = 18.9, 13.5 Hz), 3.64 (s, 4H), 0.97 (s, 6H)

^{13}C NMR (75 MHz, CDCl_3) δ = 134.5, 72.1, 31.8, 21.9

^{11}B NMR (96 MHz, CDCl_3) δ = 27.8

Anal. calcd for $\text{C}_7\text{H}_{13}\text{BO}_2$: C 60.06, H 9.36; found: C 59.95, H 9.29

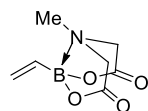


4,4,6-trimethyl-2-vinyl-1,3,2-dioxaborinane (1.39b): prepared according to literature procedure and matched spectroscopic data.³⁸ Distilled under vacuum (34-

35°C at ~0.5 mmHg) to yield a clear oil (45%);

¹H NMR (300 MHz, CDCl₃) δ = 6.04 (dd, J = 18.3, 5.6 Hz, 1H), 5.89-5.86 (m, 1H), 5.76 (dd, J = 18.3, 13.5 Hz, 1H), 4.27-4.16 (m, 1H), 1.79 (dd, J = 14.1, 3.0 Hz, 1H), 1.50 (dd, J = 13.8, 11.7 Hz, 1H), 1.30 (s, 6H), 1.27 (d, J = 6.0 Hz, 3H);

¹¹B NMR (96 MHz, CDCl₃) δ = 27.7;



Vinyl MIDA (1.39d): prepared according to literature protocol and matched spectroscopic data.⁶³ Also commercially available from Sigma-Aldrich.

¹H NMR (300 MHz, Acetone-D₆) δ = 5.97 (dd, J = 18.6, 13.8 Hz, 1H), 5.70-5.63 (m, 2H), 4.22 (d, J = 16.8 Hz, 2H), 4.02 (d, J = 16.8 Hz, 2H), 3.00 (s, 3H);

0.50 mmol, 2.0 equiv) were combined and stirred at 85 °C for 6 h. The residue was purified by column chromatography (silica gel 2.5 x 15 cm; eluted with 5% ether/hexanes) to give **1.60** as a pale brown oil (69 mg, 65%).

$$R_f \text{ (10\% ether/hexanes)} = 0.28$$

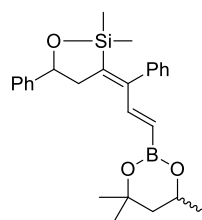
¹H NMR (300 MHz, CDCl₃) δ = 7.43 (d, 1H, *J* = 17.7 Hz), 7.28-7.22 (m, 3H), 7.08-7.05 (m, 2H), 5.19 (d, 1H, *J* = 18.0 Hz), 4.30-4.17 (m, 1H), 2.73 (s, 2H), 1.79 (dd, 1H, *J* = 14.1, 3.0 Hz), 1.70-1.43 (m, 11H), 1.29-1.26 (m, 9H), -0.18 (s, 3H), -0.19 (s, 3H)

¹³C NMR (75 MHz, CDCl₃) δ = 148.7, 146.4, 144.7, 142.1, 129.9, 127.8, 127.0, 80.0, 71.0, 64.9, 46.1, 39.7, 34.8, 31.7, 31.3, 28.2, 25.8, 23.3, 23.1, 22.8, 1.2, 1.1

 ^{11}B NMR (96 MHz, CDCl_3) $\delta = 27.6$

FT-IR (NaCl, thin film) $\nu = 2974, 2933, 1522, 1392, 1291, 1207, 1057, 1035 \text{ cm}^{-1}$

HRMS (ESI) calc. for (C₂₅H₃₇BO₃Si)Na⁺: 447.2497; found 447.2496.



Diene (1.62): Following the general procedure, ruthenium hydride **RuHCl(CO)(PCy₃)₂** (18 mg, 0.025 mmol, 0.10 equiv), alkyne **1.48** (76.5 mg, 0.25 mmol, 1.0 equiv) in toluene (0.5 mL) and vinyl boronate **1.39b** (87 μ L, 0.50 mmol, 2.0 equiv) were combined and stirred at 85 °C for 5.5 h. The residue was

purified by column chromatography (silica gel 2.5 x 15 cm; eluted with 10% ether/hexanes) to give **1.62** as a pale brown oil (58 mg, 54%).

R_f (10% ether/hexanes) = 0.23

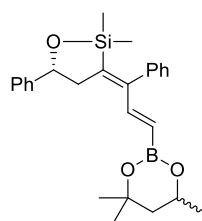
¹H NMR (400 MHz, CDCl₃) δ = 7.47-7.27 (m, 9H), 7.13-7.10 (m, 2H), 5.25 (d, 1H, J = 18.0 Hz), 5.05 (dd, 1H, J = 9.6, 5.2 Hz), 4.24-4.16 (m, 1H), 3.41 (ddd, 1H, J = 16.4, 5.3, 3.6 Hz), 2.65 (ddd, 1H, J = 16.4, 9.6, 2.4 Hz), 1.77 (dd, 1H, J = 13.9, 2.9 Hz), 1.47 (dd, 1H, J = 13.4, 11.8 Hz), 1.27 (s, 6H), 1.24 (dd, 3H, J = 6.2, 1.6 Hz), 0.08 (s, 1.5H), 0.07 (s, 1.5H), -0.19 (s, 1.5H), -0.21 (s, 1.5H)

¹³C NMR (100 MHz, CDCl₃) δ = 148.5, 145.1, 144.7, 144.5, 141.8, 129.8, 128.5, 127.9, 127.4, 127.2, 125.7, 78.1, 71.0, 64.9, 46.1, 42.2, 31.3, 28.2, 23.3, 0.6, 0.5, -0.5, -0.6

¹¹B NMR (128 MHz, CDCl₃) δ = 27.7

FT-IR (NaCl, thin film) ν = 2972, 1582, 1491, 1390, 1302, 1207, 1161, 1030 cm⁻¹

HRMS (ESI) calc. for (C₂₆H₃₃BO₃Si)Na⁺: 455.2184; found 455.2183.



Diene (1.63): Following the general procedure, ruthenium hydride **RuHCl(CO)(PCy₃)₂** (8.7 mg, 0.012 mmol, 0.05 equiv), alkyne **1.49** (74.5 mg, 0.24 mmol, 1.0 equiv) in toluene (0.5 mL) and vinyl boronate **1.39b** (83 μ L, 0.48 mmol, 2.0 equiv) were combined and stirred at 85 °C for 4 h. The residue was

purified by column chromatography (silica gel 2.5 x 15 cm; eluted with 10% ether/hexanes) to give **1.63** as a pale brown oil (68 mg, 63%).

R_f (10% ether/hexanes) = 0.23

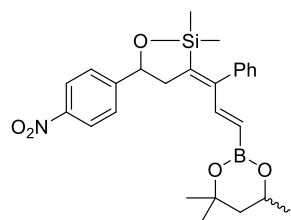
¹H NMR (300 MHz, CDCl₃) δ = 7.46-7.26 (m, 9H), 7.12-7.09 (m, 2H), 5.24 (d, 1H, J = 17.7 Hz), 5.04 (dd, 1H, J = 9.6, 5.4 Hz), 4.24-4.14 (m, 1H), 3.40 (ddd, 1H, J = 16.5, 5.4, 2.7 Hz), 2.64 (app dd, 1H, J = 15.3, 9.9 Hz), 1.76 (dd, 1H, J = 13.8, 2.7 Hz), 1.47 (dd, 1H, J = 13.5, 11.7 Hz), 1.27-1.23 (m, 9H), 0.08 (s, 1.5H), 0.06 (s, 1.5H), -0.20 (s, 1.5H), -0.21 (s, 1.5H)

¹³C NMR (75 MHz, CDCl₃) δ = 148.5, 145.1, 144.7, 144.5, 141.8, 129.8, 128.5, 127.9, 127.4, 127.2, 125.7, 78.1, 71.0, 64.9, 46.0, 42.2, 31.3, 28.2, 23.2, 0.5, 0.4, -0.6, -0.7

¹¹B NMR (96 MHz, CDCl₃) δ = 28.1

FT-IR (NaCl, thin film) ν = 2975, 1719, 1599, 1492, 1392, 1304, 1272, 1030 cm⁻¹

HRMS (ESI) calc. for (C₂₆H₃₃BO₃Si)Na⁺: 455.2184; found 455.2183.



Diene (1.65): Following the general, ruthenium hydride **RuHCl(CO)(PCy₃)₂** (9.1 mg, 0.0125 mmol, 0.05 equiv), alkyne **1.51** (72.4 mg, 0.25 mmol, 1.0 equiv) in toluene (0.5 mL) and vinyl boronate **1.39b** (87 μ L, 0.50 mmol, 2.0 equiv) were combined and stirred at 85 °C for 4 h. The residue was purified by column chromatography (silica gel 2.5 x 15 cm; gradient elution with 10%-15% ether/hexanes) to give **1.65** as a yellow oil (63.1 mg, 60%).

R_f (10% ether/hexanes) = 0.14

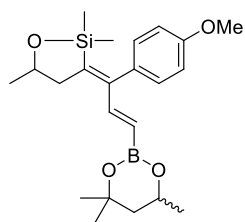
¹H NMR (300 MHz, CDCl₃) δ = 8.22 (d, 2H, J = 8.7 Hz), 7.58 (d, 2H, J = 8.7 Hz), 7.39 (dd, 1H, J = 17.7, 2.4 Hz), 7.31-7.27 (m, 3H), 7.11-7.08 (m, 2H), 5.26 (d, 1H, J = 17.7 Hz), 5.14 (dd, 1H, J = 9.6, 5.4 Hz), 4.23-4.17 (m, 1H), 3.46 (ddd, 1H, J = 16.2, 5.1, 3.9 Hz), 2.56 (ddd, 1H, J = 16.2, 9.6, 3.0 Hz), 1.77 (dd, 1H, J = 14.1, 3.0 Hz), 1.49 (app t, 1H, J = 11.7 Hz), 1.30-1.23 (m, 9H), 0.09 (s, 1.5H), 0.07 (s, 1.5H), -0.19 (s, 1.5H), -0.20 (s, 1.5H)

¹³C NMR (75 MHz, CDCl₃) δ = 152.4, 149.2, 147.2, 144.1, 143.4, 141.6, 129.7, 128.0, 127.4, 126.3, 123.8, 77.1, 71.1, 65.0, 46.0, 41.7, 31.3, 28.2, 23.3, 0.5, 0.4, -0.6, -0.7

¹¹B NMR (96 MHz, CDCl₃) δ = 27.8

FT-IR (NaCl, thin film) ν = 3024, 2973, 2933, 2858, 1585, 1390, 1293, 1249 cm⁻¹

HRMS (ESI) calc. for (C₂₆H₃₂BNO₅Si)Na⁺: 500.2035; found 500.2033.



Diene (1.68): Following the general, ruthenium hydride **RuHCl(CO)(PCy₃)₂** (18 mg, 0.025 mmol, 0.10 equiv), alkyne **1.54** (69.1 mg, 0.25 mmol, 1.0 equiv) in toluene (1.0 mL) and vinyl boronate **1.39b** (87

μL, 0.50 mmol, 2.0 equiv) were combined and stirred at 85 °C for 3 h. The residue was purified by column chromatography (silica gel 2.5 x 15 cm; eluted with 10% ether/hexanes) to give **1.68** as a pale brown oil (68 mg, 68%).

R_f (10% ether/hexanes) = 0.38

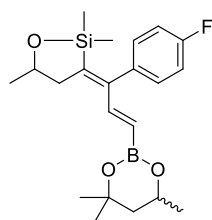
¹H NMR (300 MHz, CDCl₃) δ = 7.41 (dd, 1H, *J* = 18.0, 1.8 Hz), 6.98 (d, 2H, *J* = 8.7 Hz), 6.81 (d, 2H, *J* = 8.7 Hz), 5.21 (d, 1H, *J* = 17.7 Hz), 4.23-4.16 (m, 2H), 3.79 (s, 3H), 3.06 (ddd, 1H, *J* = 16.5, 5.4, 4.2 Hz), 2.38 (ddd, 1H, *J* = 16.2, 8.1, 4.2 Hz), 1.77 (dd, 1H, *J* = 14.1, 3.0 Hz), 1.47 (dd, 1H, *J* = 13.8, 11.4 Hz), 1.32 (d, 3H, *J* = 6.3 Hz), 1.29-1.24 (m, 9H), -0.07 (s, 1.5H), -0.09 (s, 1.5H), -0.21 (s, 1.5H), -0.22 (s, 1.5H)

¹³C NMR (75 MHz, CDCl₃) δ = 158.7, 148.0, 145.7, 144.9, 134.3, 130.9, 113.2, 72.7, 70.9, 64.9, 55.3, 46.1, 40.7, 31.3, 28.2, 24.1, 23.2, 0.8, 0.7, -0.2, -0.3

¹¹B NMR (96 MHz, CDCl₃) δ = 27.9

FT-IR (NaCl, thin film) ν = 2972, 2932, 1607, 1510, 1391, 1303, 1272, 1035 cm⁻¹

HRMS (ESI) calc. for (C₂₂H₃₃BO₄Si)Na⁺: 423.2133; found 423.2132.



Diene (1.69): Following the general, ruthenium hydride **RuHCl(CO)(PCy₃)₂** (9 mg, 0.0125 mmol, 0.05 equiv), alkyne **1.55** (65 mg, 0.25 mmol, 1.0 equiv) in toluene (0.5 mL) and vinyl boronate **1.39b** (87 μ L, 0.50 mmol, 2.0 equiv) were combined and stirred at 85 °C for 3 h. The residue was purified by column chromatography (silica gel 2.5 x 15 cm; eluted with 5% ether/hexanes) to give **1.69** as a pale brown oil (57.1 mg, 59%).

R_f (10% ether/hexanes) = 0.41

¹H NMR (300 MHz, CDCl₃) δ = 7.41 (dd, 1H, J = 18.0, 1.5 Hz), 7.06-6.94 (m, 4H), 5.15 (d, 1H, J = 17.7 Hz), 4.23-4.17 (m, 2H), 3.06 (dd, 1H, J = 16.2, 5.4, 4.2 Hz), 2.39 (ddd, 1H, J = 16.2, 8.1, 3.9), 1.78 (dd, 1H, J = 13.8, 3.0 Hz), 1.50 (app t, 1H, J = 13.8), 1.33 (d, 3H, J = 6.3 Hz), 1.28-1.25 (m, 9H), -0.08 (s, 1.5H), -0.09 (s, 1.5H), -0.21 (s, 1.5H), -0.22 (s, 1.5H)

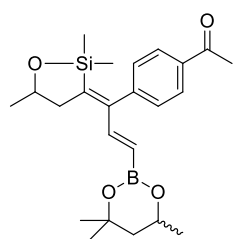
¹³C NMR (75 MHz, CDCl₃) δ = 163.7, 160.5, 147.3, 146.5 (d, J_{C-F} = 1.4 Hz), 144.7, 137.8 (d, J_{C-F} = 3.4 Hz), 131.4 (d, J_{C-F} = 8.0 Hz), 114.8 (d, J_{C-F} = 21.1 Hz), 72.7, 71.1, 65.0, 40.8, 31.3, 28.2, 24.1, 23.3, 0.7, 0.6, -0.3, -0.4

¹¹B NMR (96 MHz, CDCl₃) δ = 27.9

¹⁹F NMR (282.3 MHz, CDCl₃) δ = ((-115.9) – (-116.1)) m

FT-IR (NaCl, thin film) ν = 2976, 1719, 1602, 1508, 1384, 1304, 1259, 1091 cm⁻¹

Anal. calcd for C₂₁H₃₀BFO₃Si: C 64.95, H 7.79; found C 65.04, H 7.72.



Diene (1.70): Following the general, ruthenium hydride **RuHCl(CO)(PCy₃)₂**

(17.4 mg, 0.024 mmol, 0.10 equiv), alkyne **1.56** (69 mg, 0.24 mmol, 1.0 equiv)

in toluene (1.0 mL) and vinyl boronate **1.39b** (83 μ L, 0.48 mmol, 2.0 equiv)

were combined and stirred at 85 °C for 4.5 h. The residue was purified by

column chromatography (silica gel 2.5 x 12 cm; eluted with 15% ethyl acetate/hexanes) to give

1.70 as a pale brown oil (45.0 mg, 45%).

R_f (20% ether/hexanes) = 0.14

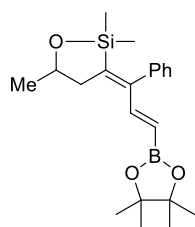
¹H NMR (300 MHz, CDCl₃) δ = 7.90 (m, 2H), 7.41 (dd, 1H, J = 18.0, 1.5 Hz), 7.20-7.17 (m, 2H), 5.11 (d, 1H, J = 18.0 Hz), 4.24-4.16 (m, 2H), 3.10 (ddd, 1H, J = 16.2, 5.4, 3.9 Hz), 2.61 (s, 3H), 2.42 (ddd, 1H, J = 16.5, 8.1, 3.6 Hz), 1.78 (dd, 1H, J = 14.1, 3.0 Hz), 1.49 (dd, 1H, J = 14.1, 11.7 Hz), 1.34 (d, 3H, J = 6.0 Hz), 1.29-1.25 (m, 9H), -0.08 (s, 1.5H), -0.09 (s, 1.5H), 0.21 (s, 1.5H), -0.23 (s, 1.5H)

¹³C NMR (75 MHz, CDCl₃) δ = 198.0, 147.3, 147.2, 146.5, 144.1, 136.0, 130.1, 128.1, 72.6, 71.1, 65.0, 46.1, 40.9, 31.3, 28.2, 26.8, 24.1, 23.2, 0.7, 0.6, -0.2, -0.3

¹¹B NMR (96 MHz, CDCl₃) δ = 28.8

FT-IR (NaCl, thin film) ν = 2923, 1685, 1601, 1560, 1094 cm⁻¹

Anal. calcd for C₂₃H₃₃BO₄Si: C 66.98, H 8.07; found C 66.69, H 8.35.



Diene (1.71): To an oven-dried 25 mL Schlenk tube equipped with a magnetic stir bar in an argon filled glovebox was added ruthenium hydride **RuHCl(CO)(PCy₃)₂** (20 mg, 0.025 mmol, 0.05 equiv) and a solution of alkyne **1.33** (122 mg, 0.5 mmol, 1.0 equiv) and vinyl boronate **1.39c** (155 mg, 1.0 mmol,

2.0 equiv) in toluene (1.0 mL). The sealed reaction vessel was removed from the glovebox and placed under a positive stream of Ar_(g), then the reaction mixture stirred at 85 °C for 4 h. TLC analysis indicated complete consumption of the starting material. The brown solution was cooled to rt, filtered through a plug of silica gel (eluted with DCM) and concentrated *in vacuo* to give a brown oil. The residue was purified by column chromatography (silica gel 2.5 x 15 cm; eluted with 10% ether/hexanes) to give **1.71** as a light brown oil (102 mg, 55%).

R_f (10% ether/hexanes) = 0.12

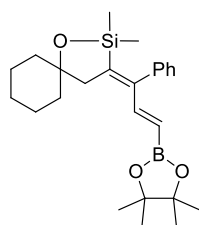
¹H NMR (400 MHz, CDCl₃) δ = 7.50 (d, 1H, *J* = 17.8 Hz), 7.28-7.24 (m, 3H), 7.08-7.05 (m, 2H), 5.26 (d, 1H, *J* = 18.2 Hz), 4.22-4.16 (m, 1H), 3.09 (dd, 1H, *J* = 16.0, 5.3 Hz), 2.41 (dd, 1H, *J* = 16.0, 8.0 Hz), 1.32 (d, 3H, *J* = 6.3 Hz), 1.23 (s, 12H), -0.08 (s, 3H), -0.22 (s, 3H)

¹³C NMR (100 MHz, CDCl₃) δ = 148.0, 147.5, 147.3, 141.3, 129.8, 127.9, 127.2, 83.3, 72.6, 40.8, 24.9, 24.8, 24.0, 0.5, -0.4

¹¹B NMR (128 MHz, CDCl₃) δ = 30.0

FT-IR (NaCl, thin film) ν = 2975, 2928, 1597, 1492, 1344, 1251, 1144, 1060 cm⁻¹

Anal. calcd for C₂₁H₃₁BO₃Si: C 68.10, H 8.44; found C 67.95, H 8.24.



Diene (1.72): Following the general, ruthenium hydride **RuHCl(CO)(PCy₃)₂** (11 mg, 0.015 mmol, 0.05 equiv), alkyne **1.46** (89 mg, 0.3 mmol, 1.0 equiv) in DCE (0.5 mL) and vinyl boronate **1.39c** (93 mg, 0.50 mmol, 2.0 equiv) were combined and stirred at 85 °C for 2.5 h. The residue was purified by column

chromatography (silica gel 2.5 x 15 cm; eluted with 5% ether/hexanes) to give **1.72** as a pale brown oil (91 mg, 72%).

R_f (10% ether/hexanes) = 0.25

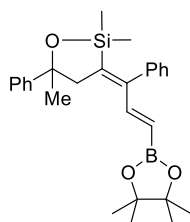
¹H NMR (400 MHz, CDCl₃) δ = 7.66 (d, 1H, *J* = 17.9 Hz), 7.46-7.40 (m, 3H), 7.24-7.22 (m, 2H), 5.42 (d, 1H, *J* = 17.9 Hz), 2.91 (s, 2H), 1.85-1.51 (m, 10H), 1.43 (s, 12H), 0.00 (s, 6H)

¹³C NMR (100 MHz, CDCl₃) δ = 147.3, 147.0, 146.2, 140.4, 128.8, 126.8, 126.1, 82.3, 78.9, 43.0, 38.6, 24.6, 23.8, 21.9, 0.0

¹¹B NMR (128 MHz, CDCl₃) δ = 30.8

FT-IR (NaCl, thin film) ν = 2978, 2931, 2857, 1597, 1444, 1379, 1249, 970, 828 cm⁻¹

Anal. calcd for C₂₅H₃₇BO₃Si: C 70.74, H 8.79; found C 71.08, H 8.64.



Diene (1.73): Following the general procedure, ruthenium hydride **RuHCl(CO)(PCy₃)₂** (11 mg, 0.015 mmol, 0.05 equiv), alkyne **1.47** (96 mg, 0.3 mmol, 1.0 equiv), vinyl boronate **1.39c** (93 mg, 0.50 mmol, 2.0 equiv) and DCE (0.5 mL) were combined and stirred at 85 °C for 2.5 h. The residue was purified

by column chromatography (silica gel 2.5 x 15 cm; gradient elution with 5%-10% ether/hexanes) to give **1.73** as a pale brown oil (89 mg, 67%).

R_f (10% ether/hexanes) = 0.28

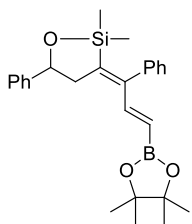
¹H NMR (400 MHz, CDCl₃) δ = 7.60-7.54 (m, 3H), 7.42-7.27 (m, 7H), 7.14-7.12 (m, 2H), 5.34 (d, 1H, *J* = 17.9 Hz), 3.33 (d, 1H, *J* = 16.6 Hz), 3.10 (d, 1H, *J* = 16.6 Hz), 1.61 (s, 3H), 1.32 (s, 12H), 0.00 (s, 3H), -0.09 (s, 3H)

¹³C NMR (100 MHz, CDCl₃) δ = 149.4, 148.6, 147.1, 147.1, 141.5, 129.8, 128.2, 128.0, 127.3, 126.6, 124.8, 83.5, 81.7, 46.6, 32.1, 25.0, 24.9, 0.8, 0.8

¹¹B NMR (128 MHz, CDCl₃) δ = 30.9

FT-IR (NaCl, thin film) ν = 3058, 2978, 2929, 1598, 1444, 1379, 1250, 1205, 1144, 1031, 830 cm⁻¹

Anal. calcd for C₂₆H₃₃BO₃Si: C 72.64, H 7.90; found C 72.70, H 8.14.



Diene (1.74): Following the general procedure, ruthenium hydride **RuHCl(CO)(PCy₃)₂** (11 mg, 0.015 mmol, 0.05 equiv), alkyne **1.48** (96 mg, 0.31 mmol, 1.0 equiv), vinyl boronate **1.39c** (96 mg, 0.62 mmol, 2.0 equiv) and DCE (0.6 mL) were combined and stirred at 85 °C for 5 h. The residue was

purified by column chromatography (silica gel 2.5 x 15 cm; eluted with 10% ether/hexanes) to give **1.74** as a pale brown oil (90 mg, 67%).

R_f (10% ether/hexanes) = 0.16

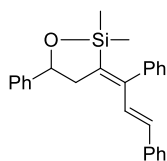
¹H NMR (400 MHz, CDCl₃) δ = 7.50 (d, 1H, *J* = 18.1 Hz), 7.41-7.27 (m, 8H), 7.12-7.09 (m, 2H), 5.29 (d, 1H, *J* = 18.1 Hz), 5.05 (dd, 1H, *J* = 9.5, 5.4 Hz), 3.43 (dd, 1H, *J* = 16.4, 9.5 Hz), 2.65 (dd, 1H, *J* = 16.4, 5.4 Hz), 1.23 (s, 12H), 0.07 (s, 3H), -0.18 (s, 3H)

¹³C NMR (100 MHz, CDCl₃) δ = 148.2, 147.2, 146.8, 144.6, 141.3, 129.8, 128.5, 128.0, 127.4, 127.4, 125.6, 83.4, 78.0, 42.3, 24.9, 0.4, -0.5

¹¹B NMR (128 MHz, CDCl₃) δ = 30.3

FT-IR (NaCl, thin film) ν = 2978, 1598, 1492, 1384, 1306, 1251, 1144, 847 cm⁻¹

Anal. calcd for C₂₆H₃₃BO₃Si: C 72.21, H 7.69; found C 72.29, H 7.39.



Diene (1.75): To an oven-dried 25 mL Schlenk tube equipped with a magnetic stir bar was added silyl boronate **1.74** (50 mg, 0.12 mmol, 1.0 equiv), Pd(OAc)₂ (1.3 mg, 0.006 mmol, 0.05 equiv), S-Phos (5.0 mg, 0.012 mmol, 0.10 equiv) and K₃PO₄

(76.4 mg, 0.36 mmol, 3.0 equiv). The vessel was evacuated then placed under Ar_(g). To the solids was added degassed H₂O (6.5 μL, 0.36 mmol, 3.0 equiv), degassed THF (1.2 mL) and iodobenzene (20 μL, 0.18 mmol, 1.5 equiv). The resulting orange suspension stirred at 50 °C overnight. TLC analysis indicated complete consumption of the starting material. The orange suspension was cooled to rt, filtered through a plug of silica gel (eluted with ether) and concentrated *in vacuo* to give an orange oil. The residue was purified by column chromatography (silica gel 1.5 x 15 cm; gradient elution with 2%-4% ether/hexanes) to give **1.75** as a yellow solid (33.3 mg, 73%).

R_f (10% ether/hexanes) = 0.35

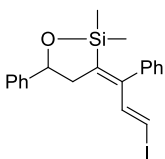
M.P. = 117-118 °C

¹H NMR (400 MHz, CDCl₃) δ = 7.37-7.09 (m, 16H), 6.13 (d, 1H, *J* = 16.0 Hz), 5.02 (m, 1H), 3.30 (dd, 1H, *J* = 16.0, 6.0 Hz), 2.61 (dd, 1H, *J* = 16.0, 9.3 Hz), 0.00 (s, 3H), -0.22 (s, 3H)

¹³C NMR (100 MHz, CDCl₃) δ = 147.3, 144.9, 143.6, 142.1, 137.5, 133.5, 129.9, 128.8, 128.6, 128.2, 128.1, 128.0, 127.6, 127.5, 126.9, 125.6, 78.0, 42.4, 0.6, -0.3

FT-IR (NaCl, thin film) ν = 3059, 3030, 2927, 1599, 1492, 1447, 1249, 1031 cm⁻¹

Anal. calcd for C₂₆H₂₆OSi: C 81.63, H 6.85; found C 81.57, H 6.66.



Vinyl Iodide (1.76): To an oven-dried 50 mL Schlenk tube equipped with a magnetic stir bar under $\text{Ar}_{(\text{g})}$ was added silyl boronate **1.74** (46 mg, 0.11 mmol, 1.0 equiv) and THF (0.24 mL). To the pale yellow solution was added

NaOH (5M in H_2O , 66 μL , 0.33 mmol, 3.0 equiv) dropwise via syringe. After stirring for 20 min, a solution of I_2 (56 mg, 0.22 mmol, 1.5 equiv) in THF (0.3 mL) was added dropwise. The dark red solution stirred at rt for 20 min. TLC analysis indicated complete consumption of the starting material. The reaction was quenched by addition of sat. $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ (1 mL). The aqueous layer was extracted with DCM (3 x 1 mL) and the combined organic layers were dried over Na_2SO_4 , filtered and concentrated *in vacuo* to give an orange oil. The residue was filtered through a plug of silica gel (eluted with chloroform) to give **1.76** as a yellow oil (31.3 mg, 66%).

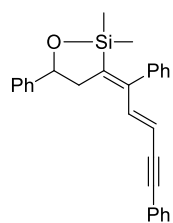
R_f (5% ether/hexanes) = 0.33

^1H NMR (400 MHz, CDCl_3) δ = 7.55 (d, 1H, J = 14.5 Hz), 7.40-7.27 (m, 8H), 7.15-7.13 (m, 2H), 6.07 (d, 1H, J = 14.5 Hz), 5.07 (dd, 1H, J = 9.6, 5.6 Hz), 3.23 (dd, 1H, J = 16.4, 5.3 Hz), 2.54 (dd, 1H, J = 16.4, 9.5 Hz), 0.06 (s, 3H), -0.16 (s, 3H)

^{13}C NMR (100 MHz, CDCl_3) δ = 146.7, 144.5, 144.4, 143.8, 140.5, 129.6, 128.6, 128.4, 127.9, 127.5, 125.5, 84.2, 77.7, 42.3, 0.3, -0.5

FT-IR (NaCl, thin film) ν = 3059, 2958, 1491, 1249, 1030, 703 cm^{-1}

Anal. calcd for $\text{C}_{20}\text{H}_{21}\text{IOSi}$: C 55.56, H 4.90; found C 55.38, H 4.75.



Alkyne (1.77): To an oven dried 50 mL Schlenk tube equipped with magnetic stir bar was added $\text{PdCl}_2(\text{PPh}_3)_2$ (10 mg, 0.014 mmol, 0.05 equiv), CuI (5 mg, 0.028 mmol, 0.10 equiv), phenylacetylene (33 μL , 0.30 mmol, 1.1 equiv) and vinyl iodide **1.76** (120 mg, 0.28 mmol, 1 equiv) in 1:1 NEt_3/THF (2.0 mL). The Schlenk

tube was capped with a rubber septum and two cycles of freeze/pump/thaw were conducted. The reaction was warmed to rt then heated to 60 °C. After 15 min TLC indicated the reaction was complete. The mixture was filtered through a plug of Celite® (eluted with ether), washed with sat. $\text{NH}_4\text{Cl}_{(\text{aq})}$ and brine then dried over MgSO_4 , filtered and concentrated *in vacuo*. The residue was purified by column chromatography (silica gel 2.5 x 15 cm; eluted with 5% EtOAc/hexanes) to give **1.77** as a yellow oil (100 mg, 88%).

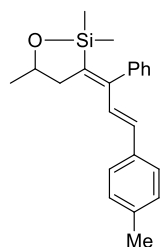
R_f (20% EtOAc/hexanes) = 0.74

^1H NMR (400 MHz, CDCl_3) δ = 7.45-7.34 (m, 9H), 7.33-7.28 (m, 4H), 7.22 (d, 1H, J = 15.8 Hz), 7.21-7.19 (m, 2H), 5.54 (d, 1H, J = 15.8 Hz), 5.13 (dd, 1H, J = 9.3, 5.5 Hz), 3.35 (dd, 1H, J = 16.7, 5.7 Hz), 2.68 (dd, 1H, J = 16.5, 9.3 Hz), 0.10 (s, 3H), -0.11 (s, 3H)

^{13}C NMR (100 MHz, CDCl_3) δ = 146.5, 145.9, 144.6, 140.8, 140.0, 131.6, 129.7, 128.5, 128.5, 128.4, 127.8, 127.4, 125.5, 123.5, 112.9, 94.3, 89.3, 77.8, 42.3, 0.4, -0.4

FT-IR (NaCl, thin film) ν = 3059, 3030, 2959, 2246, 1600, 1489, 1249, 1054, 860 cm^{-1}

Anal. calcd for $\text{C}_{28}\text{H}_{26}\text{OSi}$: C 82.71, H 6.45; found C 82.47, H 6.40.



Diene (1.78): ruthenium hydride **RuHCl(CO)(PCy₃)₂** (20 mg, 0.025 mmol, 0.05 equiv), alkyne **1.33** (122 mg, 0.5 mmol, 1.0 equiv) in THF (1.0 mL) and vinyl boronate **1.39c** (155 mg, 1 mmol, 2 equiv) were combined and stirred at 70 °C overnight. In a separate oven-dried 50 mL Schlenk tube equipped with a magnetic

stir bar was added added Pd(OAc)₂ (6.0 mg, 0.025 mmol, 0.05 equiv), S-Phos (20 mg, 0.05 mmol, 0.10 equiv), 4-iodotoluene (218 mg, 1.0 mmol, 2.0 equiv), K₃PO₄ (2M, freshly prepared and degassed prior, 1.5 mmol, 0.75 mL, 3 equiv) and THF (3 mL, degassed). To the resulting solution was added the crude diene reaction mixture then the mixture stirred at 50 °C overnight. TLC analysis indicated complete consumption of the starting material. The solution was cooled to rt, filtered through a plug of silica gel (eluted with DCM) and concentrated *in vacuo*. The residue was purified by column chromatography (silica gel 2.5 x 12 cm; eluted with 2% ether/hexanes) to give **1.78** (92 mg, 55% over two steps).

R_f (10% ether/hexanes) = 0.18

¹H NMR (400 MHz, CDCl₃) δ = 7.39-7.08 (m, 10H), 6.16 (d, 1H, *J* = 15.9 Hz), 4.30-4.20 (m, 1H), 3.07 (dd, 1H, *J* = 16.2, 5.1 Hz), 2.43 (dd, 1H, *J* = 16.2, 8.4 Hz), 2.32 (s, 3H), 1.36 (d, 3H, *J* = 6.0 Hz), -0.07 (s, 3H), -0.19 (s, 3H)

¹³C NMR (75 MHz, CDCl₃) δ = 147.1, 143.4, 142.0, 137.7, 134.6, 132.9, 129.7, 129.3, 127.9, 127.2, 127.1, 126.6, 72.4, 40.8, 24.0, 21.2, 0.5, -0.4

FT-IR (NaCl, thin film) ν = 3078, 3026, 2966, 2866, 2241, 1603, 1584, 1510, 1491, 1376, 1249, 1124, 1095 cm⁻¹

Anal. calcd for C₂₂H₂₆OSi: C 78.99, H 7.83; found C 78.77, H 7.44.

3.4 ETHYLENE TRANSFER DATA

3.4.1 Intramolecular Ethylene Transfer: MVK

General Experimental for Ethylene Transposition:

In an argon-filled glovebox, a 15 mL sealed tube equipped with a stir bar was charged with $\text{RuHCl(CO)(SIMes)(PPh}_3\text{)}$ (0.05 equiv.), the silyl ether (1.0 equiv.), MVK (0.10 equiv.) and dry DCE (0.5 M). The reaction mixture was sealed with a teflon cap, removed from the glovebox and immersed in a preheated 85°C oil bath. After being stirred at 85°C for the allotted time, the reaction mixture was concentrated *in vacuo* and purified by flash chromatography on silica gel.



According to the general experimental, the reaction of the silyl ether **1.83** (124 mg, 0.5 mmol), MVK (4 μL , 4 mg, 0.05 mmol) and $\text{RuHCl(CO)(SIMes)(PPh}_3\text{)}$ (18 mg, 0.025 mmol) in DCE (1 mL, 0.5 M) afforded the product **Z-1.102** (81 mg, 65%) as a colorless oil.

TLC (hexanes: Et_2O = 10:1): R_f = 0.21

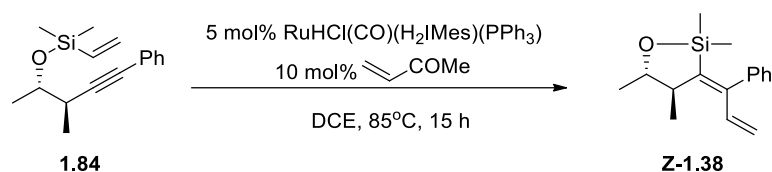
Flash chromatography (2.5 cm $\phi \times$ 15 cm): hexanes: Et_2O = 45:1

^1H NMR (300 MHz, CDCl_3): δ = 7.33-7.27 (m, 3H), 7.13-7.10 (m, 2H), 6.88 (dd, J = 17.4, 10.8 Hz, 1H), 5.23 (dd, J = 10.8, 1.8 Hz, 1H), 4.86 (dd, J = 17.4, 1.8 Hz, 1H), 4.12-4.08 (m, 1H), 2.98-2.93 (m, 1H), 1.27 (d, J = 6.3 Hz, 3H), 1.17 (d, J = 7.2 Hz, 3H), 0.13 (s, 3H), -0.41 (s, 3H)

^{13}C NMR (75 MHz, CDCl_3): δ 150.5, 146.6, 141.5, 135.3, 129.8, 127.9, 127.2, 118.6, 74.5, 42.0, 19.1, 14.3, 1.7, -1.2

IR (film): 3082, 2967, 2869, 1598, 1491, 1141, 743

Anal. calcd for $\text{C}_{16}\text{H}_{22}\text{OSi}$: C 74.36, H 8.58; found: C 74.44, H, 8.98



According to the general experimental, the reaction of the silyl ether **1.84** (258 mg, 1.0 mmol), MVK (8 μL , 0.10 mmol) and $\text{RuHCl(CO)(SIMes)(PPh}_3\text{)}$ (34 mg, 0.05 mmol) in DCE (1.5 mL, 0.67 M) afforded the product **Z-1.38** (157 mg, 61%) as a colorless oil.

TLC (hexanes: Et_2O = 10:1): R_f = 0.38

Flash chromatography (2.5 cm $\phi \times 15$ cm): hexanes: Et_2O = 45:1

$^1\text{H NMR}$ (300 MHz, CDCl_3): δ = 7.33-7.27 (m, 3H), 7.15-7.12 (m, 2H), 6.88 (dd, J = 17.1, 10.5 Hz, 1H), 5.24 (dd, J = 10.5, 1.5 Hz, 1H), 4.88 (dd, J = 17.4, 1.8 Hz, 1H), 4.11-4.06 (m, 1H), 2.86-2.83 (m, 1H), 1.21 (d, J = 7.2 Hz, 3H), 1.17 (d, J = 6.6 Hz, 3H), 0.15 (s, 3H), -0.43 (s, 3H)

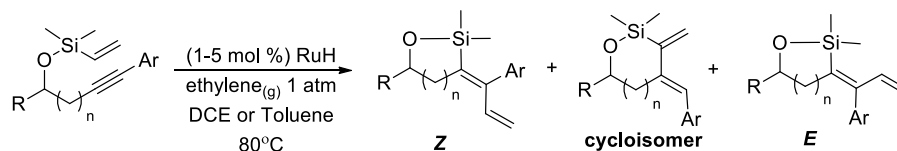
$^{13}\text{C NMR}$ (75 MHz, CDCl_3): δ 148.1, 148.1, 141.8, 135.4, 129.8, 127.9, 127.3, 118.7, 80.0, 44.3, 24.6, 21.3, 2.3, 0.7

IR (film): 3025, 2960, 2867, 1581, 1490, 1250, 842

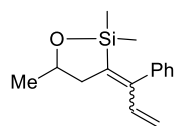
Anal. calcd for $\text{C}_{16}\text{H}_{22}\text{OSi}$: C 74.36, H 8.58; found: C 74.34, H 8.89

3.4.2 Silylvinylation Using Ethylene Gas

General procedure for Silylvinylation at 1 atmosphere ethylene:



An oven dried 50 mL Schlenk tube equipped with a magnetic stir bar was brought into an argon filled glove box. To the Schlenk tube was added $\text{RuHCl}(\text{CO})(\text{SiMe}_3)(\text{PPh}_3)$ (1-5 mol%) followed by the alkyne substrate (1.0 equivalent) in 1,2-dichloroethane or toluene (0.25M). The Schlenk tube was sealed and removed from the glovebox. The solution was purged with ethylene gas for 1-5 minutes via balloon and steel needle. The needle was removed from the solution and placed 3-4 cm above the solvent, then the apparatus was immersed in an 80°C oil bath. The reaction was stirred until complete consumption of the starting material was visualized by thin layer chromatography. Upon completion, the reaction was filtered through a short plug of silica gel (eluted with dichloromethane) and concentrated *in vacuo*. A crude yield was obtained by ^1H NMR with mesitylene (0.33 equivalents) as an internal standard. The crude product was purified via flash chromatography on silica gel.



(Z)-2,2,5-trimethyl-3-(1-phenylallylidene)-1,2-oxasilolane (1.135)

Following the general procedure, RuH (35 mg, 0.046 mmol) and alkyne **1.33** (1.12 g, 4.6 mmol) in toluene (4.6 mL) stirred under ethylene (1 atm) at 80°C for 1 h. Purification via flash column chromatography (2-3% diethyl ether/hexanes) gave diene **1.135** as a clear oil (80% as a *Z/E* mixture).

Crude ratio *Z*:cyclo:*E* = 10:1:1

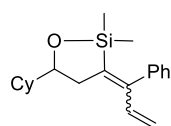
R_f = 0.40 (10% diethyl ether/hexanes)

¹H NMR (400 MHz, CDCl₃): δ = 7.34-7.28 (m, 3H), 7.13-7.10 (m, 2H), 6.86 (dd, *J* = 17.4, 10.8 Hz, 1H), 5.23 (dd, *J* = 10.8, 1.5 Hz, 1H), 4.87 (dd, 17.4, 1.5 Hz, 1H), 4.24-4.16 (m, 1H), 2.96 (dd, *J* = 15.9, 5.1 Hz, 1H), 2.32 (dd, *J* = 15.9, 8.4 Hz, 1H), 1.32 (d, *J* = 6.0 Hz, 3H), -0.07 (s, 3H), -0.20 (s, 3H). **Minor isomer diagnostic peaks:** δ = 6.52 (dd, *J* = 16.8, 10.8 Hz, 1H), 5.08 (d, *J* = 10.5 Hz, 1H), 4.75 (d, *J* = 16.8 Hz, 1H), 1.20 (d, *J* = 6.0 Hz, 3H), 0.42 (s, 3H), 0.39 (s, 3H)

¹³C NMR (100 MHz, CDCl₃): δ = 148.2, 147.2, 144.4, 143.5, 141.6, 139.8, 139.8, 135.9, 129.7, 128.9, 128.3, 127.9, 127.3, 126.9, 118.3, 116.4, 72.7, 72.5, 42.8, 40.7, 24.1, 23.8, 0.7, 0.6, 0.3, -0.3

IR (film): ν = 3056, 2964, 2873, 1581, 1249, 1035, 832 cm⁻¹

Anal. calcd. for C₁₅H₂₀OSi: C 73.71, H 8.25; found: C 73.71, H 8.34



(Z)-5-cyclohexyl-2,2-dimethyl-3-(1-phenylallylidene)-1,2-oxasilolane (1.136)

Following the general procedure, RuH (4 mg, 0.006 mmol) and alkyne **1.44** (78 mg, 0.25 mmol) in DCE (1.0 mL) stirred under ethylene (1 atm) at 80°C for 1 h. Purification via preparative TLC (1% diethyl ether/hexanes) gave diene **1.136** as a clear oil (70% as a *Z/E* mixture).

Crude ratio *Z*:cyclo:*E* = 16:2:1

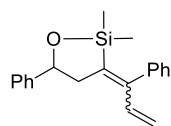
R_f = 0.80 (10% diethyl ether/hexanes)

¹H NMR (400 MHz, CDCl₃): δ = 7.34-7.27 (m, 3H), 7.14-7.11 (m, 2H), 6.89 (dd, *J* = 17.4, 10.5 Hz, 1H), 5.23 (dd, *J* = 10.5, 1.5 Hz, 1H), 4.87 (dd, *J* = 17.4, 1.5 Hz, 1H), 3.80-3.75 (m, 1H), 2.87 (dd, *J* = 16.2, 5.5 Hz, 1H), 2.45 (dd, *J* = 16.2, 8.7 Hz, 1H), 1.96-1.92 (m, 1H), 1.78-1.66 (m, 4H), 1.31-0.98 (m, 6H), -0.08 (s, 3H), -0.22 (s, 3H); **minor isomer diagnostic peaks:** δ = 6.52 (dd, *J* = 17.1, 10.8 Hz, 1H), 5.08 (d, *J* = 10.5 Hz, 1H), 4.75 (d, *J* = 16.8 Hz, 1H), 0.40 (s, 3H), 0.39 (s, 3H)

¹³C NMR (100 MHz, CDCl₃): δ 147.0, 143.7, 141.8, 135.9, 129.8, 127.9, 127.2, 118.2, 80.7, 44.8, 36.0, 29.3, 28.7, 26.3, 26.3, 0.4, -0.2

IR (film): ν = 2925, 2852, 1581, 1449, 1248, 1032 cm⁻¹

Anal. calcd. for C₂₀H₂₈OSi: C 76.86, H 9.03; found: C 76.52, H 8.82



(Z)-2,2-dimethyl-5-phenyl-3-(1-phenylallylidene)-1,2-oxasilolane (1.137)

Following the general procedure, RuH (2 mg, 0.0025 mmol) and alkyne **1.48** (77mg, 0.25 mmol) in DCE (1.0 mL) stirred under ethylene (1 atm) at 80°C for 1 h. Purification via preparative TLC (1:200 diethyl ether/hexanes) gave diene **1.137** as a clear oil (65% as a *Z/E* mixture).

Crude ratio Z:cyclo:E = 10:1:1

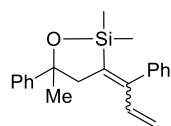
R_f = 0.20 (5% diethyl ether/hexanes)

¹H NMR (400 MHz, CDCl₃): δ = 7.44-7.28 (m, 8H), 7.19-7.16 (m, 2H), 6.87 (dd, *J* = 17.1, 10.5 Hz, 1H), 5.26 (d, *J* = 10.5 Hz, 1H), 5.08 (dd, *J* = 9.5, 5.5 Hz, 1H), 4.92 (d, *J* = 17.1 Hz, 1H), 3.29 (dd, *J* = 16.3, 5.5 Hz, 1H), 2.61 (dd, *J* = 16.3, 9.5 Hz, 1H), -0.09 (s, 3H), -0.15 (s, 3H); **minor isomer diagnostic peaks**: δ = 6.58 (dd, *J* = 17.1, 10.5 Hz, 1H), 5.14 (d, *J* = 10.5 Hz, 1H), 4.81 (d, *J* = 17.1 Hz, 1H), 0.52 (s, 3H), 0.51 (s, 3H)

¹³C NMR (100 MHz, CDCl₃): δ 147.4, 144.4, 142.9, 141.6, 135.8, 129.8, 128.5, 128.0, 127.4, 127.4, 125.6, 118.8, 77.9, 42.0, 0.5, -0.4

IR (film): ν = 3060, 2961, 2880, 1582, 1420, 1250, 781 cm⁻¹

Anal. calcd. for C₂₀H₂₂OSi: C 78.38, H 7.24; found: C 78.43, H 7.02



(Z)-2,2,5-trimethyl-5-phenyl-3-(1-phenylallylidene)-1,2-oxasilolane (1.138)

Following the general procedure RuH (2 mg, 0.0025 mmol) and alkyne **1.47** (80.1 mg, 0.25 mmol) in DCE (1.0 mL) stirred under ethylene (1 atm) at 80°C for 1 h. Purification via preparative TLC (2% diethyl ether/hexanes) gave diene **1.138** as a clear oil (70% as a *Z/E* mixture).

Crude ratio *Z*:cyclo:*E* = 16:2:1

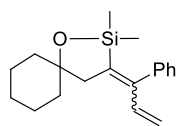
R_f = 0.62 (10% diethyl ether/hexanes)

¹H NMR (300 MHz, CDCl₃): δ = 7.52-7.49 (m, 2H), 7.38-7.30 (m, 5H), 7.27-7.22 (m, 1H), 7.16-7.12 (m, 2H), 6.92 (dd, *J* = 17.4, 10.8 Hz, 1H), 5.27 (dd, *J* = 10.8, 1.2 Hz, 1H), 4.91 (dd, *J* = 17.4, 1.2 Hz, 1H), 3.14 (d, *J* = 16.2 Hz, 1H), 3.03 (d, *J* = 16.2 Hz, 1H), 1.58 (s, 3H), -0.07 (s, 3H), -0.10 (s, 3H); **minor isomer diagnostic peaks:** δ = 6.55 (dd, *J* = 16.8, 10.8 Hz, 1H), 5.10 (dd, *J* = 10.8, 0.9 Hz, 1H), 4.75 (d, *J* = 17.1 Hz, 1H), 2.72 (d, *J* = 16.5 Hz, 1H), 2.60 (d, *J* = 16.5 Hz, 1H), 1.48 (s, 3H), 0.54 (s, 3H), 0.38 (s, 3H)

¹³C NMR (100 MHz, CDCl₃): δ = 149.5, 147.6, 143.1, 141.7, 135.8, 129.8, 128.2, 128.0, 127.4, 126.5, 124.8, 118.6, 81.5, 46.5, 32.2, 1.0, 0.8

IR (film): ν = 3057, 2965, 2887, 1599, 1582, 1492, 1250, 962 cm⁻¹

Anal. calcd. for C₂₁H₂₄OSi: C 78.70, H 7.55; found: C 79.07, H 7.75



(Z)-2,2-dimethyl-3-(1-phenylallylidene)-1-oxa-2-silaspiro[4.5]decane (1.139)

Following the general procedure, RuH (2 mg, 0.0025 mmol) and alkyne **1.46** (74 mg, 0.25 mmol) in DCE (1.0 mL) stirred under ethylene (1 atm) at 80°C for 3 h. Purification via flash column chromatography (1% diethyl ether/hexanes) gave diene **1.139** as a clear oil (76% as a *Z/E* mixture).

Crude ratio Z:cyclo:E = 16:2:1

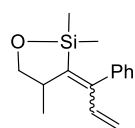
R_f = 0.42 (5% diethyl ether/hexanes)

¹H NMR (300 MHz, CDCl₃): δ = 7.34-7.25 (m, 3H), 7.15-7.12 (m, 2H), 6.89 (dd, *J* = 17.1, 10.8 Hz, 1H), 5.24 (dd, *J* = 10.8, 1.5 Hz, 1H), 4.87 (dd, *J* = 17.1, 1.5 Hz, 1H), 2.65 (s, 2H), 1.70-1.41 (m, 10H), -0.16 (s, 6H); **minor isomer diagnostic peaks**: δ = 6.54 (dd, *J* = 16.8, 10.2 Hz, 1H), 5.06 (d, *J* = 10.8 Hz, 1H), 4.71 (d, *J* = 16.8 Hz, 1H), 2.22 (s, 3H), 0.40 (s, 6H)

¹³C NMR (100 MHz, CDCl₃): δ = 146.5, 143.0, 140.8, 134.9, 128.8, 126.9, 126.2, 117.0, 78.8, 42.7, 38.7, 24.7, 22.2, 0.1

IR (film): ν = 3055, 2931, 2857, 1582, 1443, 1249, 891 cm⁻¹

Anal. calcd. for C₁₉H₂₆OSi: C 76.45, H 8.78; found: C 76.29, H 8.47



(Z)-2,2,4-trimethyl-3-(1-phenylallylidene)-1,2-oxasilolane (1.140)

Following the general procedure, RuH (9.0 mg, 0.0125 mmol) and alkyne **1.140a** (74.6 mg, 0.25 mmol) in DCE (1.0 mL) stirred under ethylene (1 atm) at 80°C for 1.5 h. Purification via flash column chromatography (1% diethyl ether/hexanes) gave diene **1.140** as a clear oil (67% as a *Z/E* mixture).

Crude ratio *Z*:cyclo:*E* = 13:1:2

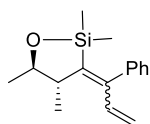
R_f = 0.36 (10% diethyl ether/hexanes)

¹H NMR (300 MHz, CDCl₃): δ = 7.33-7.25 (m, 3H), 7.14-7.10 (m, 2H), 6.90 (dd, *J* = 17.1, 10.5 Hz, 1H), 5.25 (dd, *J* = 10.5, 1.5 Hz, 1H), 4.87 (dd, *J* = 17.1, 1.5 Hz, 1H), 4.00 (dd, *J* = 9.3, 5.1 Hz, 1H), 3.85 (d, *J* = 9.6 Hz, 1H), 3.18-3.09 (m, 1H), 1.21 (d, *J* = 7.2 Hz, 3H), 0.14 (s, 3H), -0.41 (s, 3H); **minor isomer diagnostic peaks**: δ = 6.49 (dd, *J* = 17.1, 10.5 Hz, 1H), 5.09 (dd, *J* = 10.5, 0.9 Hz, 1H), 4.69 (dd, *J* = 17.1, 1.2 Hz, 1H), 2.60-2.52 (m, 1H), 0.85 (d, *J* = 7.2 Hz, 3H), 0.46 (s, 3H), 0.39 (s, 3H)

¹³C NMR (75 MHz, CDCl₃): δ = 148.3, 147.0, 141.5, 135.3, 129.7, 127.9, 127.3, 118.7, 72.5, 38.2, 21.1, 1.6, -1.2

IR (film): ν = 3025, 2960, 2867, 1581, 1490, 1250, 842 cm⁻¹

Anal. calcd. for C₁₅H₂₀OSi: C 73.71, H 8.25; found: C 73.97, H 8.35



(Z)-2,2,4,5-tetramethyl-3-(1-phenylallylidene)-1,2-oxasilolane (1.142)

Following the general procedure, RuH (2 mg, 0.005 mmol) and alkyne **1.36** (64.5 mg, 0.25 mmol) in DCE (1.0 mL) stirred under ethylene (1 atm) at 80°C for 1 h. Purification via flash column chromatography (1% diethyl ether/hexanes) gave diene **1.142** as a clear oil (70% as a *Z/E* mixture).

Crude ratio *Z*:cyclo:*E* = 18:2:1

R_f = 0.38 (10% diethyl ether/hexanes)

¹H NMR (300 MHz, CDCl₃): δ = 7.33-7.27 (m, 3H), 7.15-7.12 (m, 2H), 6.88 (dd, *J* = 17.1, 10.5 Hz, 1H), 5.24 (dd, *J* = 10.5, 1.5 Hz, 1H), 4.88 (dd, *J* = 17.4, 1.8 Hz, 1H), 4.11-4.06 (m, 1H), 2.86-2.83 (m, 1H), 1.21 (d, *J* = 7.2 Hz, 3H), 1.17 (d, *J* = 6.6 Hz, 3H), 0.15 (s, 3H), -0.43 (s, 3H); **minor isomer diagnostic peaks**: δ = 6.52 (dd, *J* = 17.1, 10.5 Hz, 1H), 5.08 (dd, *J* = 10.2, 1.2 Hz, 1H), 4.67 (dd, *J* = 17.1, 1.2 Hz, 1H), 0.44 (s, 3H), 0.42 (s, 3H)

¹³C NMR (75 MHz, CDCl₃): δ = 148.1, 148.1, 141.8, 135.4, 129.8, 127.9, 127.3, 118.7, 80.0, 44.3, 24.6, 21.3, 2.3, 0.7

IR (film): ν = 3025, 2960, 2867, 1581, 1490, 1250, 842 cm⁻¹

Anal. calcd. for C₁₆H₂₂OSi: C 74.36, H 8.58; found: C 74.34, H 8.89.



Following the general procedure, RuH (4 mg, 0.006 mmol) and alkyne **1.55** (79 mg, 0.3 mmol) in toluene (1.2 mL) stirred under ethylene (1 atm) at 80°C for 1 h. Purification via preparative TLC (1% diethyl ether/hexanes) gave diene **1.143** as a clear oil (69% as a *Z/E* mixture).

Crude ratio *Z*:cyclo:*E* = 23:3:1

R_f = 0.27 (10% diethyl ether/hexanes)

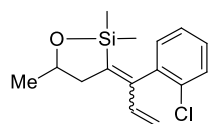
¹H NMR (300 MHz, CDCl₃): δ = 7.11-7.07 (m, 2H), 7.04-6.99 (m, 2H), 6.84 (dd, *J* = 17.1, 10.5 Hz, 1H), 5.23 (d, *J* = 10.5 Hz, 1H), 4.82 (dd, *J* = 17.4, 1.8 Hz, 1H), 4.24-4.16 (m, 1H), 2.94 (dd, *J* = 16.1, 5.0 Hz, 1H), 2.31 (dd, *J* = 16.1, 8.2 Hz, 1H), 1.32 (d, *J* = 6.0 Hz, 3H), -0.06 (s, 3H), -0.18 (s, 3H); **minor isomer diagnostic peaks**: δ = 6.50 (dd, *J* = 16.8, 10.5 Hz, 1H), 5.08 (d, *J* = 10.8 Hz, 1H), 4.73 (d, *J* = 17.1 Hz, 1H), 0.41 (s, 3H), 0.38 (s, 3H)

¹³C NMR (100 MHz, CDCl₃): δ = 162.0 (d, *J*_{C-F} = 249.7 Hz), 146.2, 144.3, 137.7 (d, *J*_{C-F} = 3.4 Hz), 136.0, 131.5 (d, *J*_{C-F} = 8.5 Hz), 118.4, 115.1 (d, *J*_{C-F} = 22.1 Hz), 72.6, 40.8, 24.2, 0.7, -0.1

¹⁹F NMR (376.4 MHz, CDCl₃): δ = (-115.2)-(-115.2)(m); (-115.6)-(-115.7)(m)

IR (film): ν = 3044, 2928, 1507, 1452, 1256, 910 cm⁻¹

Anal. calcd. for C₁₅H₁₉FOSi: C 68.66, H 7.30; found: C 68.82, H 7.26



(Z)-3-(1-(2-chlorophenyl)allylidene)-2,2,5-trimethyl-1,2-oxasilolane (1.144)

Following the general procedure, RuH (11.0 mg, 0.015 mmol) and alkyne **1.81** (84.0 mg, 0.30 mmol) in 1,4-dioxane (1.2 mL) stirred under ethylene (1 atm) at 100°C for 30 minutes. Purification via preparative TLC (1% diethyl ether/hexanes) gave diene **1.144** as a clear oil (70% as a *Z/E* mixture).

Crude ratio *Z*:cyclo:*E* = 12:1:3

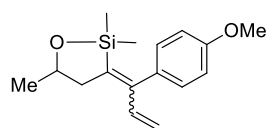
R_f = 0.46 (10% diethyl ether/hexanes)

¹H NMR (300 MHz, CDCl₃, mixture of rotamers): δ = 7.40-7.37 (m, 1H), 7.28-7.23 (m, 2H), 7.13-7.11 (m, 1H), 6.81 (ddd, *J* = 17.2, 10.5, 2.7 Hz, 1H), 5.20 (d, *J* = 7.9 Hz, 1H), 4.69 (d, *J* = 12.9 Hz, 1H), 4.33-4.25 (m, 0.5H), 4.25-4.17 (m, 0.5H), 3.05 (dd, *J* = 16.2, 5.2 Hz, 0.5H), 2.94 (dd, *J* = 16.2, 5.7 Hz, 0.5H), 2.47 (dd, *J* = 16.2, 7.1 Hz, 0.5H), 2.30 (dd, *J* = 16.1, 8.9 Hz, 0.5H), 1.35 (d, *J* = 6.1 Hz, 1.5H), 1.32 (d, *J* = 6.1 Hz, 1.5H), 0.00 (s, 1.5H), -0.08 (s, 1.5H), -0.16 (s, 1.5H), -0.25 (s, 1.5H); **minor isomer diagnostic peaks**: δ = 6.49 (dd, *J* = 16.8, 10.4 Hz, 1H), 5.07 (d, *J* = 10.5 Hz, 1H), 4.60 (d, *J* = 17.0 Hz, 1H), 4.15-4.12 (m, 1H), 0.44 (s, 3H), 0.41 (s, 3H)

¹³C NMR (75 MHz, CDCl₃): δ = 144.8, 144.6, 144.2, 140.0, 140.0, 134.7, 134.6, 134.2, 134.1, 132.2, 129.8, 129.6, 129.5, 129.0, 128.6, 126.6, 126.5, 117.6, 117.6, 116.0, 72.8, 72.7, 40.8, 40.3, 24.2, 24.1, 23.9, 1.1, 0.4, -1.1, -1.9

IR (film): ν = 2966, 2926, 2876, 1584, 1471, 1436, 1250, 835 cm⁻¹

Anal. calcd. for C₁₅H₁₉ClOSi: C 64.61, H 6.87; found: C 64.56, H 6.76



(Z)-3-(1-(4-methoxyphenyl)allylidene)-2,2,5-trimethyl-1,2-oxasilolane

(1.147): Following the general procedure, RuH (4 mg, 0.005 mmol) and

alkyne **1.54** (82 mg, 0.3 mmol) in DCE (1.2 mL) stirred under ethylene (1 atm) at 80°C for 1 h.

Purification via preparative TLC (3% diethyl ether/hexanes) gave diene **1.147** as a clear oil

(73%).

Crude ratio Z:cyclo:E = 44:3:1

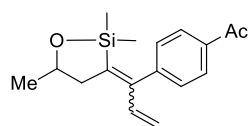
R_f = 0.26 (10% diethyl ether/hexanes)

¹H NMR (400 MHz, CDCl₃): δ = 7.05-7.01 (m, 2H), 6.89-6.80 (m, 3H), 5.22 (dd, *J* = 10.5, 1.5 Hz, 1H), 4.88 (dd, *J* = 17.1, 1.5 Hz, 1H), 4.25-4.14 (m, 1H), 3.82 (s, 3H), 2.93 (dd, *J* = 16.5, 5.4 Hz, 1H), 2.30 (dd, *J* = 16.5, 8.4 Hz, 1H), 1.32 (d, *J* = 6.0 Hz, 3H), -0.05 (s, 3H), -0.18 (s, 3H)

¹³C NMR (100 MHz, CDCl₃): δ = 158.9, 146.8, 143.4, 136.1, 134.1, 130.8, 118.1, 113.2, 72.5, 55.3, 40.7, 24.1, 0.7, -0.1

IR (film): ν = 3087, 2968, 2835, 1608, 1508, 1458, 1246, 1036 cm⁻¹

Anal. calcd. for C₁₆H₂₂O₂Si: C 70.03, H 8.08; found: C 70.03, H 7.81

**(Z)-1-(4-(1-(2,2,5-trimethyl-1,2-oxasilolan-3-ylidene) allyl) phenyl)****ethanone (1.148):** Following the general procedure, RuH (2 mg, 0.0025

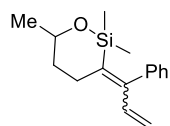
mmol) and alkyne **1.56** (72 mg, 0.25 mmol) in DCE (1.0 mL) was stirred under ethylene (1 atm) at 80°C for 3 h. Purification via flash column chromatography (1% diethyl ether/hexanes) gave diene **1.148** as a clear oil (64% as a *Z/E* mixture).

Crude ratio Z:cyclo:E = 7:1:1**R_f** = 0.20 (10% diethyl ether/hexanes)

¹H NMR (400 MHz, CDCl₃): δ = 7.92 (d, *J* = 8.4 Hz, 2H), 7.24 (d, *J* = 8.4 Hz, 2H), 6.85 (dd, *J* = 17.1, 10.5 Hz, 1H), 5.24 (d, *J* = 10.5 Hz, 1H), 4.79 (d, *J* = 18.0 Hz, 1H), 4.24-4.17 (m, 1H), 2.96 (dd, *J* = 16.2, 5.4 Hz, 1H), 2.62 (s, 3H), 2.34 (dd, *J* = 16.2, 8.2 Hz, 1H), 1.32 (d, *J* = 6.0 Hz, 3H), -0.07 (s, 3H), -0.19 (s, 3H); **minor isomer diagnostic peaks:** δ = 7.97 (d, *J* = 8.4 Hz, 2H), 7.22 (d, *J* = 8.4 Hz, 2H), 6.51 (dd, *J* = 16.8, 10.5 Hz, 1H), 5.11 (d, *J* = 10.5 Hz, 1H), 4.70 (d, *J* = 17.4 Hz, 1H), 4.11-4.04 (m, 1H), 1.20 (d, *J* = 6.0 Hz, 3H), 0.42 (s, 3H), 0.39 (s, 3H)

¹³C NMR (100 MHz, CDCl₃): δ 198.0, 198.0, 146.9, 146.9, 146.2, 145.5, 145.2, 144.5, 139.2, 136.2, 135.9, 135.6, 130.1, 129.3, 128.6, 128.2, 118.6, 116.8, 72.8, 72.5, 42.8, 41.0, 26.8, 26.8, 24.1, 23.8, 0.7, 0.3, -0.0

IR (film): ν = 3087, 2964, 2871, 1684, 1601, 1264, 944 cm⁻¹**Anal. calcd.** for C₁₇H₂₂O₂Si: C 71.28, H 7.74; found: C 70.99, H 7.75



(Z)-2,2,6-trimethyl-3-(1-phenylallylidene)-1,2-oxasilinane (1.149)

Following the general procedure, RuH (4 mg, 0.006 mmol) and alkyne **1.86** (77 mg, 0.3 mmol) in DCE (1.2 mL) stirred under ethylene (1 atm) at 80°C for 1 h. Purification via flash column chromatography (1% diethyl ether/hexanes) gave diene **1.149** as a clear oil (82%).

Crude ratio Z:cyclo:E = 14:1:1

R_f = 0.74 (10% diethyl ether/hexanes)

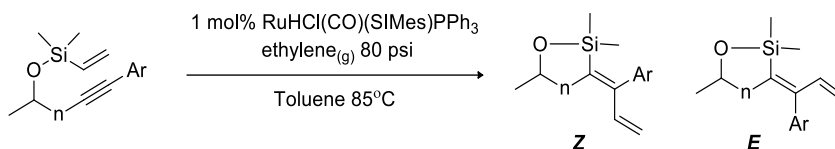
¹H NMR (400 MHz, CDCl₃): δ = 7.30-7.26 (m, 3H), 7.09-7.02 (m, 3H), 5.21 (dd, *J* = 10.8, 1.8 Hz, 1H), 4.73 (dd, *J* = 17.1, 1.8 Hz, 1 H), 4.10-4.03 (m, 1H), 3.08 (ddd, *J* = 15.9, 5.4, 3.3 Hz, 1H), 2.47 (ddd, *J* = 15.9, 12.6, 3.3 Hz, 1H), 1.90-1.83 (m, 1H), 1.61-1.51 (m, 1H), 1.21 (d, *J* = 6.3 Hz, 3H), -0.14 (s, 3H), -0.37 (s, 3H)

¹³C NMR (100 MHz, CDCl₃): δ = 147.2, 141.6, 140.3, 134.3, 130.6, 127.9, 127.3, 118.7, 70.5, 36.1, 29.1, 24.7, 1.6, 0.2

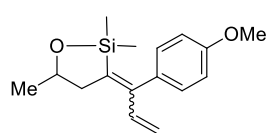
IR (film): ν = 3080, 2965, 2846, 1558, 1490, 1248, 829 cm⁻¹

Anal. calcd. for C₁₆H₂₂OSi: C 74.36, H 8.58; found: C 74.39, H 8.69

General Procedure for high pressure reactions:



An oven dried Fischer Porter bottle equipped with a magnetic stir bar was brought into an argon filled glove box. To the Fischer Porter bottle was added $\text{RuHCl(CO)(SIMes)PPh}_3$ and the alkyne in toluene. The bottle was plugged with a septum and removed from the glove box. The septum was replaced with a Swagelok regulator and the system was purged with ethylene (80 psi) and vented three times, then refilled to 80 psi and heated to 80°C for the allotted time. Upon completion by TLC, the reaction was filtered through a short plug of silica gel (eluted with dichloromethane), concentrated *in vacuo* and a crude yield was obtained by ^1H NMR with mesitylene (0.33 equivalents) as an internal standard. The crude product was purified by flash chromatography on silica gel.



3-(1-(4-methoxyphenyl)allylidene)-2,2,5-trimethyl-1,2-oxasilolane

Following the general procedure, RuH (2 mg, 0.0025 mmol) and alkyne **1.54** (72 mg, 0.25 mmol) in toluene (1.0 mL) stirred under ethylene (80 psi) at 80°C for 4 h. Purification via flash column chromatography (10% diethyl ether/hexanes) gave the diene as a clear oil (91% as a *Z/E* mixture).

Crude ratio *Z:E* = 3:1

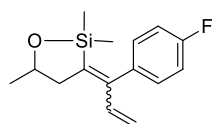
R_f = 0.26 (10% diethyl ether/hexanes)

¹H NMR (300 MHz, CDCl₃): **isomer *Z***: δ = 7.06-7.03 (m, 2H), 6.92-6.80 (m, 3H), 5.21 (d, *J* = 10.5 Hz, 1H), 4.87 (dd, *J* = 17.1, 1.5 Hz, 1H), 4.24-4.14 (m, 1H), 3.81 (s, 3H), 2.93 (dd, *J* = 16.2, 5.4 Hz, 1H), 2.29 (dd, *J* = 16.2, 8.4 Hz, 1H), 1.31 (d, *J* = 6.0 Hz, 3H), -0.05 (s, 3H), -0.17 (s, 3H); **isomer *E***: δ = 7.06-7.03 (m, 2H), 6.92- 6.80 (m, 2H), 6.51 (dd, *J* = 16.8, 10.5 Hz, 1H), 5.07 (d, *J* = 10.5 Hz, 1H), 4.79 (d, *J* = 17.1 Hz, 1H), 4.10-4.03 (m, 1H), 3.82 (s, 3H) 2.43 (dd, *J* = 16.8, 5.1 Hz, 1H), 2.06 (dd, *J* = 16.5, 8.4 Hz, 1H), 1.20 (d, *J* = 6.0 Hz, 3H), 0.41 (s, 3H), 0.38 (s, 3H)

¹³C NMR (75 MHz, CDCl₃): δ = 158.7, 158.3, 147.4, 146.7, 143.3, 139.9, 136.0, 133.9, 130.7, 129.9, 118.0, 116.1, 113.5, 113.1, 72.6, 72.4, 55.2, 55.2, 42.8, 40.6, 24.0, 23.7, 0.7, 0.6, 0.2, -0.3;

IR (film): ν = 2963, 2929, 1608, 1509, 1248 cm⁻¹

Anal. calcd. for C₁₆H₂₂O₂Si: C 70.03, H 8.08; found: C 70.41, H 7.80



3-(1-(4-fluorophenyl)allylidene)-2,2,5-trimethyl-1,2-oxasilolane: Following the general procedure, RuH (2 mg, 0.0025 mmol) and alkyne **1.55** (65.5 mg,

0.25 mmol) in toluene (1.0 mL) stirred under ethylene (80 psi) at 80°C for 4 h. Purification via flash column chromatography (10% diethyl ether/hexanes) gave the diene as a clear oil (85% as a *Z/E* mixture).

Crude ratio *Z:E* = 1:1.3

R_f = 0.27 (10% diethyl ether/hexanes)

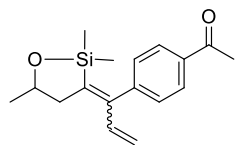
¹H NMR (300 MHz, CDCl₃): **isomer *Z***: δ = 7.12-6.99 (m, 4H), 6.85 (dd, *J* = 17.4, 10.8 Hz, 1H), 5.24 (dd, *J* = 10.8, 1.5 Hz, 1H), 4.82 (dd, *J* = 17.4, 1.2 Hz, 1H), 4.24-4.17 (m, 1H), 2.95 (dd, *J* = 16.2, 5.4 Hz, 1H), 2.31 (dd, *J* = 16.2, 8.4 Hz, 1H), 1.32 (d, *J* = 6.0 Hz, 3H), -0.05 (s, 3H), -0.17 (s, 3H); **isomer *E***: δ = 7.12-6.99 (m, 4H), 6.51 (dd, *J* = 17.1, 10.5 Hz, 1H), 5.09 (dd, *J* = 10.8, 0.6 Hz, 1H), 4.74 (dd, *J* = 17.1, 0.6 Hz, 1H), 4.11-4.02 (m, 1H), 2.38 (dd, *J* = 17.4, 5.1 Hz, 1H), 2.02 (dd, *J* = 16.8, 8.4 Hz, 1H), 1.21 (d, *J* = 6.0 Hz, 3H), 0.42 (s, 3H), 0.39 (s, 3H);

¹³C NMR (75 MHz, CDCl₃): δ = 163.7, 163.4, 160.1, 146.9, 146.1, 145.0, 144.1, 139.7, 137.5, 137.5, 135.9, 135.6, 135.5, 131.3, 131.2, 130.5, 130.4, 118.3, 116.4, 115.4, 115.1, 115.0, 114.7, 72.7, 72.5, 42.8, 40.7, 24.0, 23.7, 0.7, 0.6, 0.3, -0.2

¹⁹F NMR (282.3 MHz, CDCl₃): δ = (-115.6)-(-115.7)(m); δ = (-116.1)-(-116.2)(m)

IR (film): ν = 2966, 2927, 1601, 1506, 1252 cm⁻¹

Anal. calcd. for C₁₅H₁₉FOSi: C 68.66, H 7.30; found: C 68.52, H 7.12



1-(4-(1-(2,2,5-trimethyl-1,2-oxasilolan-3-ylidene)allyl)phenyl)ethanone

Following the general procedure, RuH (2 mg, 0.0025 mmol) and alkyne **1.56** (72 mg, 0.25 mmol) in toluene (1.0 mL) stirred under ethylene (80 psi) at 80°C for 24 h.

Purification via flash column chromatography (10% diethyl ether/hexanes) gave the diene as a clear oil (86% as a *Z/E* mixture).

Crude ratio *Z:E* = 1:7

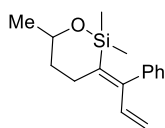
R_f = 0.20 (10% diethyl ether/hexanes)

¹H NMR (300 MHz, CDCl₃): **isomer *Z***: δ = 7.92 (d, *J* = 8.4 Hz, 2H), 7.24 (d, *J* = 8.4 Hz, 2H), 6.85 (dd, *J* = 17.1, 10.5 Hz, 1H), 5.24 (d, *J* = 10.5 Hz, 1H), 4.79 (d, *J* = 18.0 Hz, 1H), 4.24-4.17 (m, 1H), 2.96 (dd, *J* = 16.2, 5.4 Hz, 1H), 2.62 (s, 3H), 1.32 (d, *J* = 6.0 Hz, 3H), -0.07 (s, 3H), -0.19 (s, 3H); **isomer *E***: δ = 7.97 (d, *J* = 8.4 Hz, 2H), 7.22 (d, *J* = 8.4 Hz, 2H), 6.51 (dd, *J* = 16.8, 10.5 Hz, 1H), 5.11 (d, *J* = 10.5 Hz, 1H), 4.70 (d, *J* = 17.4 Hz, 1H), 4.12-4.02 (m, 1H), 2.62 (s, 3H), 2.34 (dd, *J* = 16.8, 5.1 Hz, 1H), 2.00 (dd, *J* = 16.8, 5.4 Hz, 1H), 1.19 (d, *J* = 6.0 Hz, 3H), 0.42 (s, 3H), 0.39 (s, 3H)

¹³C NMR (75 MHz, CDCl₃): δ = 197.8, 145.8, 145.0, 139.0, 135.7, 129.1, 128.4, 116.6, 72.6, 42.7, 26.6, 23.6, 0.6, 0.1

IR (film): ν = 2964, 2925, 1684, 1264 cm⁻¹

Anal. calcd. for C₁₇H₂₂O₂Si: C 71.28, H 7.74; found: C 71.03, H 7.40



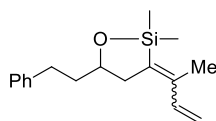
(Z)-2,2,6-trimethyl-3-(1-phenylallylidene)-1,2-oxasilinane: Following the general procedure, RuH (2 mg, 0.0025 mmol) and alkyne **1.86** (57 mg, 0.22

mmol) in toluene (1.0 mL) stirred under ethylene (80 psi) for 24 h. (25:1). Purification via flash column chromatography (10% diethyl ether/hexanes) gave the diene as a clear oil (72%).

Crude ratio *Z:E* = 25:1

¹H NMR (300 MHz, CDCl₃): δ = 7.28-7.27 (m, 3H), 7.09-7.00 (m, 3H), 5.20 (dd, *J* = 10.5, 1.5 Hz, 1H), 4.72 (dd, *J* = 17.1, 1.5 Hz, 1H), 4.11-4.00 (m, 1H), 3.06 (ddd, *J* = 16.2, 5.1, 3.3 Hz, 1H), 2.45 (ddd, *J* = 15.9, 12.6, 3.3 Hz, 1H), 1.90-1.81 (m, 1H), 1.62-1.48 (m, 1H), 1.20 (d, *J* = 6.0 Hz, 3H), -0.15 (s, 3H), -0.38 (s, 3H)

¹³C NMR (75 MHz, CDCl₃): δ = 147.1, 141.5, 140.2, 134.1, 130.4, 127.8, 127.2, 118.7, 70.4, 36.0, 29.0, 24.6, 1.5, 0.1



3-(but-3-en-2-ylidene)-2,2-dimethyl-5-phenethyl-1,2-oxasilolane (1.150):

Following the general procedure, RuH (2 mg, 0.0025 mmol) and alkyne **1.150a** (68 mg, 0.25 mmol) in toluene (1.0 mL) stirred under ethylene (80 psi) at 80°C for 24 h. Purification via flash column chromatography (2% diethyl ether/hexanes) gave diene **1.150** as a clear oil (84%).

Crude ratio Z:E = 1:3

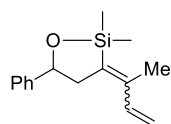
R_f = 0.64 (10% diethyl ether/hexanes)

¹H NMR (300 MHz, CDCl₃): **major isomer E**: δ = 7.32-7.16 (m, 5H), 6.35 (dd, *J* = 16.8, 10.2 Hz, 1H), 5.23 (d, *J* = 17.3 Hz, 1H), 5.06 (d, *J* = 10.7 Hz, 1H), 4.12-4.02 (m, 1H), 2.88-2.67 (m, 4H), 2.27 (dd, *J* = 16.2, 7.6 Hz, 1H), 1.86 (s, 3H), 0.37 (s, 3H), 0.32 (s, 3H); **minor isomer Z**: δ = 6.70 (dd, *J* = 17.3, 10.7 Hz, 1H), 5.28 (d, *J* = 16.8 Hz, 1H), 5.17 (d, *J* = 10.8 Hz, 1H), 1.91 (s, 3H), 0.36 (s, 3H), 0.32 (s, 3H)

¹³C NMR (75 MHz, CDCl₃): δ = 142.8, 142.4, 141.7, 140.4, 140.1, 139.4, 136.1, 128.6, 128.4, 125.8, 114.4, 112.5, 76.0, 75.7, 40.2, 40.1, 39.9, 38.4, 32.3, 20.0, 15.3, 0.9, 0.5, 0.4, 0.0

IR (film): ν = 2957, 2931, 1585, 1453, 1250, 866 cm⁻¹

Anal. calcd. for C₁₇H₂₄OSi: C 74.94, H 8.88; found C 74.88, H 8.99



3-(but-3-en-2-ylidene)-2,2-dimethyl-5-phenyl-1,2-oxasilolane (1.151):

Following the general procedure, RuH (4 mg, 0.005 mmol) and alkyne **1.151a** (80 mg, 0.32 mmol) in toluene (1.3 mL) stirred under ethylene (80 psi) at 80°C for 24 h. Purification via flash column chromatography (1% diethyl ether/hexanes) gave diene **1.151** as a clear oil (84%).

Crude ratio Z:E = 1:2

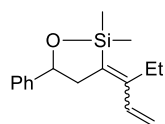
R_f = 0.52 (10% diethyl ether/hexanes)

¹H NMR (400 MHz, CDCl₃): **major isomer E**: δ = 7.39-7.32 (m, 4H), 7.27-7.23 (m, 1H), 6.36 (dd, *J* = 17.1, 10.8 Hz, 1H), 5.23 (d, *J* = 16.9 Hz, 1H), 5.06 (d, *J* = 11.0 Hz, 1H), 5.05-5.00 (m, 1H), 3.02 (dd, *J* = 16.8, 5.7 Hz, 1H), 2.50-2.44 (m, 1H), 1.86 (dd, *J* = 1.6, 0.7 Hz, 3H), 0.41 (s, 3H), 0.39 (s, 3H); **minor isomer Z**: δ = 6.68 (dd, *J* = 17.3, 10.6 Hz, 1H), 5.28 (d, *J* = 17.3 Hz, 1H), 5.15 (d, *J* = 10.6 Hz, 1H), 3.13 (ddd, *J* = 16.2, 5.5, 1.0 Hz, 1H), 1.92 (dd, *J* = 2.2, 1.0 Hz, 3H), 0.40 (s, 3H), 0.38 (s, 3H)

¹³C NMR (100 MHz, CDCl₃): δ = 144.3, 144.2, 142.2, 141.3, 139.8, 139.6, 139.1, 135.5, 128.0, 126.9, 125.1, 114.3, 112.5, 77.7, 77.3, 42.5, 41.1, 19.6, 14.9, 0.0, 0.0, -0.3, -0.4;

IR (film): ν = 3088, 3029, 2956, 2877, 1588, 1251, 1036, 868 cm⁻¹

Anal. calcd. for C₁₅H₂₀OSi: C 73.71, H 8.21; found C 73.43, H 8.20



2,2-dimethyl-3-(pent-1-en-3-ylidene)-5-phenyl-1,2-oxasilolane (1.152):

Following the general procedure, RuH (4 mg, 0.005 mmol) and alkyne **1.152a** (77 mg, 0.3 mmol) in toluene (1.2 mL) stirred under ethylene (80 psi) at 80°C for 1 h. Purification via flash column chromatography (1% diethyl ether/hexanes) gave diene **1.152** as a clear oil (79%).

Crude ratio Z:E = 5:1

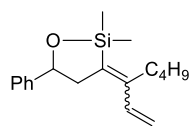
R_f = 0.63 (10% diethyl ether/hexanes)

¹H NMR (400 MHz, CDCl₃): **isomer Z**: δ = 7.38-7.31 (m, 4H), 7.25-7.23 (m, 1H), 6.52 (dd, *J* = 17.7, 11.0 Hz, 1H), 5.29 (d, *J* = 17.7 Hz, 1H), 5.17 (d, *J* = 11.0 Hz, 1H), 5.00 (dd, *J* = 9.0, 5.5 Hz, 1H), 3.10 (dd, *J* = 16.1, 5.5 Hz, 1H), 2.49-2.41 (m, 1H), 2.38-2.24 (m, 2H), 1.10 (t, *J* = 7.8 Hz, 3H), 0.39 (s, 3H), 0.37 (s, 3H); **isomer E**: δ = 6.25 (dd, *J* = 17.3, 10.6 Hz, 1H), 5.25 (d, *J* = 17.3 Hz, 1H), 5.06 (d, *J* = 11.0 Hz, 1H), 3.01 (dd, *J* = 16.5, 5.5 Hz, 1H), 1.01 (t, *J* = 7.8 Hz, 3H)

¹³C NMR (100 MHz, CDCl₃): δ = 148.2, 146.2, 144.7, 144.7, 141.4, 139.2, 138.8, 134.2, 128.4, 127.3, 125.5, 125.4, 114.9, 112.6, 78.0, 77.8, 42.2, 41.7, 28.2, 22.7, 14.9, 13.0, 0.4, 0.1

IR (film): ν = 3088, 2966, 2876, 1586, 1251, 1061, 907 cm⁻¹

Anal. calcd. for C₁₆H₂₂OSi: C 74.36, H 8.58; found: C 74.55, H 8.74



3-(hept-1-en-3-ylidene)-2,2-dimethyl-5-phenyl-1,2-oxasilolane (1.153):

Following the general procedure, RuH (4 mg, 0.005 mmol) and alkyne **1.153a** (86 mg, 0.3 mmol) in toluene (1.2 mL) stirred under ethylene (80 psi) at 80°C for 1 h. Purification via flash column chromatography (1% diethyl ether/hexanes) gave diene **1.153** as a clear oil (69%).

Crude ratio Z:E = 8:1

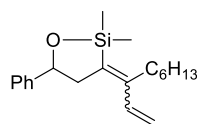
R_f = 0.36 (10% diethyl ether/hexanes)

¹H NMR (400 MHz, CDCl₃): **isomer Z**: δ = 7.31-7.24 (m, 4H), 7.19-7.15 (m, 1H), 6.46 (dd, *J* = 17.6, 10.8 Hz, 1H), 5.21 (d, *J* = 17.6 Hz, 1H), 5.09 (d, *J* = 10.8 Hz, 1H), 4.93 (dd, *J* = 9.5, 5.4 Hz, 1H), 3.02 (dd, *J* = 16.2, 5.4 Hz, 1H), 2.37 (dd, *J* = 16.2, 5.4 Hz, 1H), 2.25-2.13 (m, 2H), 1.43-1.35 (m, 2H), 1.33-1.24 (m, 2H), 0.86 (t, *J* = 7.5 Hz, 3H), 0.32 (s, 3H), 0.30 (s, 3H); **isomer E**: δ = 6.19 (dd, *J* = 17.2, 10.4 Hz, 1H), 4.99 (d, *J* = 10.8 Hz, 1H), 2.93 (dd, *J* = 16.7, 5.4 Hz, 1H), 0.82 (t, *J* = 7.1 Hz, 3H), 0.33 (s, 3H), 0.31 (s, 3H)

¹³C NMR (100 MHz, CDCl₃): δ = 146.8, 145.1, 144.7, 142.0, 139.4, 139.2, 134.7, 128.4, 127.3, 127.3, 125.5, 114.8, 112.7, 78.0, 77.8, 42.5, 41.8, 35.3, 32.6, 30.8, 29.5, 23.3, 23.2, 14.1, 14.1, 0.4, 0.3

IR (film): ν = 3087, 2957, 2873, 1585, 1250, 1036, 867 cm⁻¹

Anal. calcd. for C₁₈H₂₆OSi: C 75.46, H 9.15; found: C 75.65, H 9.26



2,2-dimethyl-3-(non-1-en-3-ylidene)-5-phenyl-1,2-oxasilolane (1.154):

Following the general procedure, RuH (2 mg, 0.0025 mmol) and alkyne **1.154a** (78.2 mg, 0.25 mmol) in toluene (1.0 mL) stirred under ethylene (80 psi) at 80°C for 24 h. Purification via flash column chromatography (1% diethyl ether/hexanes) gave diene **1.154** as a clear oil (83%).

Crude ratio Z:E = 7:1

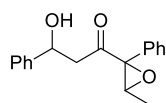
R_f = 0.78 (10% diethyl ether/hexanes)

¹H NMR (300 MHz, CDCl₃): **isomer Z**: δ = 7.40-7.31 (m, 5H), 6.54 (dd, *J* = 17.4, 10.9 Hz, 1H), 5.30 (d, *J* = 17.4 Hz, 1H), 5.17 (d, *J* = 10.9 Hz, 1H), 5.01 (dd, *J* = 9.6, 5.6 Hz, 1H), 3.11 (dd, *J* = 16.2, 5.3 Hz, 1H), 2.46 (dd, *J* = 16.2, 9.6 Hz, 1H), 2.32-2.23 (m, 2H), 1.53-1.43 (m, 2H), 1.40-1.26 (m, 7H), 0.93-0.87 (m, 3H), 0.40 (s, 3H), 0.38 (s, 3H); **isomer E**: δ = 6.27 (dd, *J* = 17.4, 10.9 Hz, 1H), 5.07 (d, *J* = 10.9 Hz, 1H), 3.00 (dd, *J* = 16.8, 5.6 Hz, 1H), 0.41 (s, 3H), 0.39 (s, 3H)

¹³C NMR (75 MHz, CDCl₃): δ = 145.2, 144.7, 139.4, 134.8, 128.5, 127.3, 125.5, 114.9, 78.0, 41.8, 35.7, 31.9, 30.5, 30.0, 22.8, 14.2, 0.3, 0.3

IR (film) ν = 2957, 2931, 1585, 1453, 1250, 866 cm⁻¹

Anal. calcd. for C₂₀H₃₀OSi: C 76.37, H 9.61; found C 76.24, H 9.79

Synthetic Elaboration**3-hydroxy-1-(3-methyl-2-phenyloxiran-2-yl)-3-phenylpropan-1-one (1.155)**

To an oven dried 25 mL round bottom flask equipped with a magnetic stir bar was added diene **1.137** (92 mg, 0.3 mmol) in THF (1.3 mL). To the stirred solution was added sequentially MeOH (2.7 mL), KF dihydrate (282 mg, 3.0 mmol), KHCO₃ (300 mg, 3.0 mmol), and H₂O₂ (2.5 mL, ~23 mmol) dropwise with vigorous stirring. After stirring the cloudy white suspension for 4 h TLC indicated consumption of the starting diene. Na₂S₂O_{3(s)} (~1.0 g) was carefully added in small portions to consume remaining peroxides. The reaction was diluted with EtOAc (20 mL) and washed with brine. The organics were dried over MgSO₄, filtered and concentrated *in vacuo*. The crude oil was purified via flash column chromatography (silica gel 2.5 x 15 cm, eluted with 10% EtOAc/hexanes) to give ketone **1.155** as a clear oil (59 mg, 70% as a mixture of diastereoisomers).

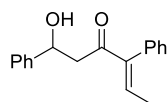
R_f = 0.25 (20% EtOAc/hexanes)

¹H NMR (400 MHz, CDCl₃): δ = 7.45-7.32 (m, 10H), 5.15 (t, *J* = 3.7 Hz, 0.5H), 5.12 (t, *J* = 3.7 Hz, 1H), 3.50 (q, *J* = 5.2 Hz, 0.5H), 3.43 (q, *J* = 5.2 Hz, 0.5H), 3.08-2.82 (m, 3H), 1.06 (d, *J* = 5.3 Hz, 3H)

¹³C NMR (100 MHz, CDCl₃): δ = 207.8, 207.8, 142.7, 142.6, 131.8, 128.6, 128.6, 128.5, 128.3, 128.1, 128.1, 127.8, 127.8, 125.8, 125.7, 69.9, 69.7, 68.1, 59.1, 58.8, 46.3, 45.9, 14.5, 14.4

IR (film): ν = 3511, 3060, 2967, 2926, 1708, 1494, 1022 cm⁻¹

Anal. calcd. for C₁₈H₁₈O₃: C 76.57, H 6.43; found: C 76.44, H 6.41

**(E)-1-hydroxy-1,4-diphenylhex-4-en-3-one (1.156)**

To a flame dried 50 mL round bottom flask equipped with a magnetic stir bar was added diene **1.137** (92 mg, 0.3 mmol, 10:1, *Z:E*), DMF (15 mL), KHF₂ (71 mg, 0.9 mmol), propionic anhydride (0.96 mL, 7.5 mmol), and H₂O₂ (0.85 mL, 7.5 mmol) sequentially. The reaction was stirred at RT for 14 h then poured into water (15 mL), extracted with Et₂O (3 x 15 mL) washed with saturated NaHCO_{3(aq)} (20 mL), dried over MgSO₄, filtered and concentrated *in vacuo*. The crude oil was purified via flash column chromatography (silica gel 1.5 x 12 cm, gradient elution with 10-20% EtOAc/hexanes) to afford ketone **1.156** as a clear oil (68 mg, 85%, 13:1 mixture of double bond isomers).

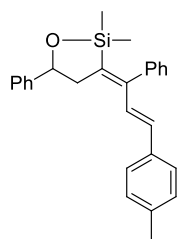
R_f = 0.22 (20% EtOAc/hexanes)

¹H NMR (400 MHz, CDCl₃): δ = 7.41-7.28 (m, 8H), 7.09-7.07 (m, 2H), 7.04 (q, *J* = 7.2 Hz, 1H), 5.18 (dd, *J* = 7.4, 4.8 Hz, 1H) 3.65 (s, 1H), 2.98 (s, 1H), 2.96 (d, *J* = 3.3 Hz, 1H), 1.73 (d, *J* = 7.0 Hz, 3H); **minor isomer diagnostic peaks** δ = 5.53 (q, *J* = 7.4 Hz, 1H), 1.82 (d, *J* = 7.2 Hz, 3H)

¹³C NMR (100 MHz, CDCl₃): δ = 200.7, 143.7, 142.9, 140.2, 135.1, 129.6, 128.4, 128.4, 127.7, 127.5, 125.7, 70.2, 47.8, 15.7

IR (film): ν = 3412, 3058, 2912, 1773, 1670, 1597, 1137, 700 cm⁻¹

Anal. calcd. for C₁₈H₁₈O₂: C 81.17, H 6.81; found: C 81.34, H 6.83



(Z)-2,2-dimethyl-5-phenyl-3-((E)-1-phenyl-3-(p-tolyl)allylidene)-1,2-oxasilolane (1.157)

To an oven dried 50 mL Schlenk tube equipped with magnetic stir bar was added 4-iodotoluene (164 mg, 0.75 mmol), K_2CO_3 (138 mg, 1.0 mmol), $Pd(OAc)_2$ (6.0 mg, 0.025 mmol) and diene **1.137** (180 mg, 0.58 mmol) in DMF (5.0 mL). The reaction mixture was evacuated and purged with argon(g) three times, then stirred at 80°C for 8 h. Once cooled to RT, the solution was diluted with EtOAc (20 mL), washed with water (2 x 30 mL), dried over $MgSO_4$, filtered and concentrated *in vacuo*. The crude oil was purified via flash column chromatography (silica gel 2.5 x 12 cm; 3% EtOAc/hexanes) to afford diene **1.157** as a yellow oil (64%, 126 mg).

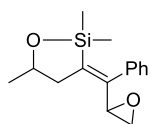
R_f = 0.51 (10% EtOAc/hexanes)

1H NMR (400 MHz, C_6D_6): δ = 7.44 (d, J = 8.2 Hz, 2H), 7.40-7.35 (m, 5H), 7.30-7.28 (m, 1H), 7.25-7.21 (m, 5H), 7.08 (d, J = 7.8 Hz, 2H), 6.19 (d, J = 16.0 Hz, 1H), 5.11 (dd, J = 9.3, 5.3 Hz, 1H), 3.38 (dd, J = 16.3, 5.5 Hz, 1H), 2.69 (dd, J = 16.3, 9.5 Hz, 1H), 2.31 (s, 3H), 0.08 (s, 3H), -0.13 (s, 3H)

^{13}C NMR (100 MHz, C_6D_6): δ = 147.3, 144.8, 142.8, 142.0, 137.9, 134.6, 133.4, 129.8, 129.4, 128.5, 128.1, 127.4, 127.4, 127.0, 126.7, 125.5, 77.9, 42.3, 21.3, 0.5, 0.3

IR (film): ν = 3027, 2958, 1583, 1249, 1031, 862 cm^{-1}

Anal. calcd. for $C_{27}H_{28}O_2$: C 81.77, H 7.12; found: C 81.52, H 7.18



(E)-2,2,5-trimethyl-3-(oxiran-2-yl(phenyl)methylene)-1,2-oxasilolane (1.159):

To a 25 mL Schlenk tube equipped with a magnetic stirbar was added *m*CPBA (85%, 120 mg, 0.58 mmol) and 0.5 mL DCM. The reaction vessel was cooled to 0°C then diene **1.135** (94 mg, 0.38 mmol) in 0.8 ml of DCM was added dropwise via syringe. The reaction was warmed to room temperature and after 1.5 h was complete by TLC. The mixture was diluted with 5 mL of DCM and washed with sat. NaHCO_{3(aq.)} (3 x 15 mL). The organic layer was dried with MgSO₄, filtered and concentrated *in vacuo*. The crude oil was purified on a silica gel column, eluted with 5% ethylacetate/hexanes to afford 37 mg (38%) of a clear oil.

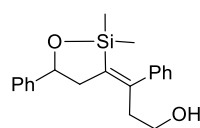
R_f = 0.59 (20% EtOAc/hexanes)

¹H NMR (400 MHz, CDCl₃) δ = 7.38-7.31 (m, 4H), 7.29-7.25 (m, 1H), 6.16 (dd, *J* = 17.0, 10.8 Hz, 1H), 5.37-5.30 (m, 2H), 4.32-4.24 (m, 1H), 1.92-1.82 (m, 2H), 1.31 (d, *J* = 6.0 Hz, 3H), 0.00 (s, 3H), -0.37 (s, 3H)

¹³C NMR (100 MHz, CDCl₃) δ = 139.6, 135.8, 128.2, 127.6, 126.6, 119.2, 72.0, 71.6, 66.2, 41.9, 23.8, -1.7, -2.2

FT-IR (NaCl, thin film) ν = 3030, 2968, 1494, 1251, 1117, 944, 703 cm⁻¹

Anal. calcd. for C₁₅H₂₀O₂Si; C, 69.19; H, 7.74; found C, 69.44; H, 7.37

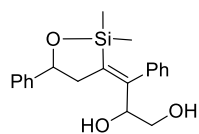


(Z)-3-(2,2-dimethyl-5-phenyl-1,2-oxasilolan-3-ylidene)-3-phenylpropan-1-

ol (1.160): To a 25 mL schlenk tube equipped with a stir bar was added diene **1.137** (100 mg, 0.33 mmol) in 2.0 mL Et₂O. The mixture was cooled to 0 °C and BH₃·THF (1.0M in THF, 0.36 mL) was added dropwise and stirred for 2h. NaOH_(aq) (3M, 2.0 mL) was added followed by H₂O₂ (30%, 2.0 mL) and stirred for an additional 3h. The reaction was poured into 5 mL Na₂S₂O_{3(aq)} and extracted with Et₂O (3 x 10 mL). The organic layer was dried with MgSO₄, filtered and concentrated *in vacuo* to a yellow oil. The oil was applied to a silica gel column (2.5 x 15 cm) eluted with 10% EtOAc in hexanes to afford 68 mg of **1.160**.

R_f = 0.11 (20% EtOAc/hexanes)

¹H NMR (400 MHz, CDCl₃) δ = 7.40-7.17 (m, 10H), 5.03 (dd, *J* = 9.4, 5.5 Hz, 1H), 3.63-3.57 (m, 2H), 3.13 (dd, *J* = 15.6, 5.1 Hz, 1H), 2.88-2.72 (m, 2H), 2.53 (dd, *J* = 16.3, 10.0 Hz, 1H), 0.13 (s, 3H), -0.15 (s, 3H)



(E)-3-(2,2-dimethyl-5-phenyl-1,2-oxasilolan-3-ylidene)-3-phenylpropane-

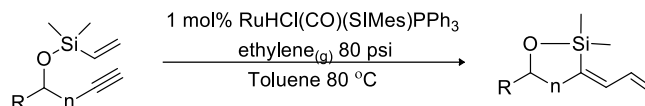
1,2-diol (1.161): To a 25 mL RBF equipped with a stir bar was added NaIO₄ (96 mg, 0.45 mmol) and 0.25 mL water followed by H₂SO₄ (1M, 60 μ L) and the mixture was cooled to 0 °C. RuCl₃ (0.1M in H₂O, 30 μ L) was added and stirred until the solution turned bright yellow. EtOAc (1.0 mL) was added and stirred for 5 min followed by MeCN (1.0 mL) and stirred for 5 minutes. Diene **1.137** (92 mg, 0.3 mmol) in 0.2 mL EtOAc was added then stirred for 1.5h. The solution was poured into a 1:1 mixture of aqueous NaHCO₃:Na₂S₂O₃ (10 mL) and extracted with EtOAc (3 x 10 mL). The organic layer was dried with MgSO₄, filtered and concentrated *in vacuo* to a yellow oil. Crude ¹H NMR indicated 25% **1.137** remained. The crude oil was applied to a silica gel column (2.5 x 15 cm) and eluted with 30% EtOAc in hexanes to afford **1.161** (43 mg, 56% brsm) as a mixture of diastereomers.

R_f = 0.06 (20% EtOAc/hexanes)

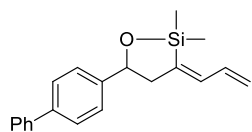
¹H NMR (400 MHz, CDCl₃) δ = 7.39-7.14 (m, 10H), 5.08 (dd, *J* = 8.8, 5.7 Hz, 0.5H), 5.02 (dd, *J* = 9.8, 5.2 Hz, 0.5H), 4.78 (dd, *J* = 8.8, 3.8 Hz, 0.5H), 4.71 (dd, *J* = 8.8, 3.8 Hz, 0.5H), 3.70-3.45 (m, 2H), 3.24 (dd, *J* = 13.4, 5.7 Hz, 0.5H), 3.20 (dd, *J* = 12.9, 5.3 Hz, 0.5H), 2.60 (dd, *J* = 15.7, 8.5 Hz, 0.5H), 2.48 (dd, *J* = 15.9, 9.8 Hz, 0.5H), 0.12 (s, 1.5H), 0.00 (s, 1.5H), -0.10 (s, 1.5H), -0.22 (s, 1.5H) ;

3.4.3 Silylvinylation of Terminal Alkynes

General procedure for high pressure reactions with terminal alkynes:



An oven dried Fischer Porter bottle equipped with a magnetic stir bar was brought into an argon filled glove box. To the Fischer Porter bottle was added $\text{RuHCl(CO)(SIMes)PPh}_3$ and the alkyne in toluene. The bottle was plugged with a septum and removed from the glove box. The septum was replaced with a Swagelok regulator and the system was purged with ethylene (80 psi) and vented three times, then refilled to 80 psi and heated to 80 °C for the allotted time. Upon completion by TLC, the reaction was filtered through a short plug of silica gel (eluted with dichloromethane, ethyl acetate, or diethyl ether), concentrated *in vacuo* and a crude yield was obtained by $^1\text{H NMR}$ with mesitylene (0.33 equivalents) as an internal standard. The crude product was purified by flash chromatography on silica gel.



(Z)-5-([1,1'-biphenyl]-4-yl)-3-allylidene-2,2-dimethyl-1,2-oxasilolane

(1.163): prepared according to the general procedure;

RuHCl(CO)(SIMes)(PPh₃) (2 mg, 0.0025 mmol), alkyne (78 mg, 0.25 mmol) in 1.0 mL toluene, 24h. Flash column chromatography (5% diethylether:hexanes) 58% (45 mg) as a clear oil.

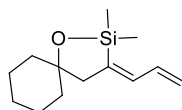
TLC R_f = 0.57 (10% diethylether/hexanes);

¹H NMR (400 MHz, CDCl₃): δ= 7.60-7.56 (m, 4H), 7.45-7.42 (m, 4H), 7.36-7.32 (m, 1H), 6.74 (d, *J* = 10.8 Hz, 1H), 6.31 (dt, *J* = 16.6, 10.4 Hz, 1H), 5.23 (d, *J* = 16.6 Hz, 1H), 5.17 (d, *J* = 10.0 Hz, 1H), 5.06 (dd, *J* = 9.5, 5.3 Hz, 1H), 2.96 (dd, *J* = 15.5, 5.1 Hz, 1H), 2.70-2.63 (m, 1H), 0.43 (s, 3H), 0.42 (s, 3H);

¹³C NMR (100 MHz, CDCl₃): δ= 145.2, 143.0, 140.8, 140.0, 137.7, 137.0, 128.5, 126.9, 126.9, 126.9, 125.7, 117.5, 77.4, 45.6, -0.0, -0.1;

FT-IR (NaCl, thin film) ν = 3028, 2956, 2926, 1592, 1486, 1252, 903 cm⁻¹

Anal. calc. for C₂₀H₂₂OSi, C, 78.38; H, 7.24; found C, 78.30; H, 6.98;



(Z)-3-allylidene-2,2-dimethyl-1-oxa-2-silaspiro[4.5]decane (1.164): prepared

according to the general procedure; $\text{RuHCl}(\text{CO})(\text{SiMe}_3)(\text{PPh}_3)$ (2 mg, 0.003 mmol), alkyne (66 mg, 0.3 mmol) in 1.5 mL toluene, 22h. Flash column chromatography (2% diethylether:hexanes, 1.5 x 12 cm) 45% (30 mg) as a clear oil.

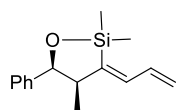
TLC R_f = 0.57 (10% diethylether/hexanes);

^1H NMR (400 MHz, CDCl_3): δ = 6.65 (d, J = 10.6 Hz, 1H), 6.26 (dt, J = 16.7, 10.6 Hz, 1H), 5.16 (d, J = 16.7 Hz, 1H), 5.09 (d, J = 10.1 Hz, 1H), 2.47 (s, 2H), 1.67-1.35 (m, 11H), 0.30 (s, 6H);

^{13}C NMR (100 MHz, CDCl_3): δ = 146.8, 138.0, 137.5, 116.8, 80.1, 48.0, 39.3, 25.7, 23.2, 1.2;

FT-IR (NaCl, thin film) ν = 2932, 2857, 1251, 974, 825 cm^{-1}

Anal. calc. for $\text{C}_{13}\text{H}_{22}\text{OSi}$, C, 70.71; H, 9.97; found C, 70.30; H, 9.70;



(4S,5S,Z)-3-allylidene-2,2,4-trimethyl-5-phenyl-1,2-oxasilolane (1.165):

prepared according to the general procedure; RuHCl(CO)(SIMes)(PPh₃) (4 mg, 0.006 mmol), alkyne (73 mg, 0.3 mmol) in 1.5 mL toluene, 24h. Flash column chromatography (2% diethylether:hexanes) 82% (60 mg) as a clear oil.

TLC R_f = 0.74 (10% diethylether/hexanes);

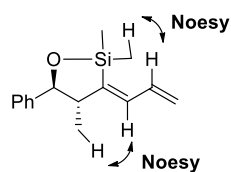
¹H NMR (400 MHz, CDCl₃): δ= 7.32-7.20 (m, 5H), 6.68 (d, *J* = 10.8 Hz, 1H), 6.32 (dt, *J* = 16.6, 10.1 Hz, 1H), 5.24 (d, *J* = 16.6 Hz, 1H), 5.17 (d, *J* = 10.1 Hz, 1H), 5.14 (d, *J* = 5.0 Hz, 1H), 2.88 (m, 1H), 0.64 (d, *J* = 7.1 Hz, 3H), 0.47 (s, 3H), 0.39 (s, 3H);

¹³C NMR (100 MHz, CDCl₃): δ= 152.0, 141.6, 137.7, 137.4, 128.1, 126.9, 126.0, 117.8, 86.7, 47.3, 16.7, 0.8, 0.2;

FT-IR (NaCl, thin film) ν = 3026, 2951, 1590, 1450, 1251, 988 cm⁻¹

[α]_D²³_λ 589 nm (c 0.600, CHCl₃) = -56.01°

Anal. calc. for C₁₅H₂₀OSi, C, 73.71; H, 8.25; found C, 73.71; H, 8.37;



(4R,5S,Z)-3-allylidene-2,2,4-trimethyl-5-phenyl-1,2-oxasilolane (1.166):

prepared according to the general procedure; $\text{RuHCl}(\text{CO})(\text{SIMes})(\text{PPh}_3)$ (4 mg, 0.006 mmol), alkyne (73 mg, 0.3 mmol) in 1.5 mL toluene, 21h. Flash

column chromatography (1-2% gradient elution, diethylether:hexanes, 1.5 x 12 cm) 75% (55 mg)

as a clear oil.

TLC R_f = 0.48 (10% diethylether/hexanes);

^1H NMR (400 MHz, CDCl_3): δ = 7.37-7.26 (m, 5H), 6.57 (dd, J = 10.6, 2.6 Hz, 1H), 6.37 (dt, J = 16.7, 10.6 Hz, 1H), 5.26 (d, J = 16.7 Hz, 1H), 5.18 (d, J = 10.2 Hz, 1H), 4.37 (d, J = 8.9 Hz, 1H), 2.55 (m, 1H), 1.03 (d, J = 6.6 Hz, 3H), 0.43 (s, 3H), 0.40 (s, 3H);

^{13}C NMR (100 MHz, CDCl_3): δ = 149.9, 142.7, 136.9, 136.1, 128.0, 127.4, 126.3, 117.6, 84.9, 48.4, 13.8, 0.0, -0.0;

FT-IR (NaCl, thin film) ν = 3028, 2956, 2926, 1592, 1486, 1252, 903 cm^{-1}

$[\alpha]_D^{23}$ 589 nm (c 0.640, CHCl_3) = -139.70°

Anal. calc. for $\text{C}_{15}\text{H}_{20}\text{OSi}$, C, 73.71; H, 8.25; found C, 73.96; H, 7.99;

3.5 IMIDAZOPYRIDINE DATA

General Experimental A: Copper Coupling

To an oven-dried Schlenk tube equipped with a stir bar was added copper (I) iodide (10 mol %), potassium phosphate (2 eq.), *tert*-butyl-4-chloropyridin-3-yl carbamate **34** (1 eq), and the haloarene (1.1 eq) [if a solid]. The reaction tube was evacuated and refilled with Ar_(g). (+/-)-*trans*-1,2-diaminocyclohexane (**L1**) (20 mol %) was added, followed by 1,4-dioxane (0.5 M) and the haloarene (1.1 eq) [if a liquid]. The reaction was degassed with three vacuum / Ar_(g) purge cycles, equipped with a cold-finger and placed in a pre-heated 110°C oil-bath. The reaction mixture was stirred for the time indicated, cooled to room temperature, and was diluted with EtOAc. The reaction mixture was then filtered through a Celite® plug, concentrated *in vacuo* and applied to a silica gel column eluted with the indicated solvent mixture(s) to give the N-aryl product.

General Experimental B: Boc Deprotection

To an oven-dried round-bottom flask equipped with a stir bar was added Boc-pyridine **35h-35n** (1 eq.) and DCM (0.5 M). The reaction was cooled to 0 °C (ice-water bath) and trifluoroacetic acid (TFA) (0.17 M) was added. The reaction was allowed to warm to room temperature and stirred until TLC analysis indicated consumption of the starting material (**35h-35n**). The reaction was then poured into sat. NaHCO_{3(aq)}, diluted with DCM and the layers were separated. The aqueous layer was extracted with DCM. The combined organic layers were dried over sodium sulfate, decanted and concentrated *in vacuo* to give the desired deprotected product.

General Experimental C: Alkylation/Deprotection

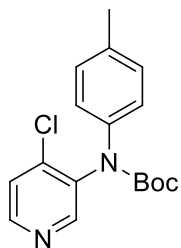
To an oven-dried round-bottom flask equipped with a stir bar was added pyridine **34** (1 eq.) and DMF (0.5 M). The reaction mixture was cooled to 0°C (ice-water bath) and sodium hydride (60 wt% in mineral oil) (1.5 eq.) was added in small portions over a period of ~2 min. The reaction mixture was stirred for 1 hour at 0°C, at which time the appropriate benzyl or alkyl halide (1.5 eq.) was added drop-wise as a solution in DMF. The reaction was allowed to warm to room temperature and stirred until TLC analysis indicated consumption of the starting material. The reaction was quenched by the addition of H₂O and diluted with EtOAc. The layers were separated

and the aqueous layer was extracted with EtOAc. The combined organic layers were washed with H₂O and brine, dried over Na₂SO₄, filtered, and concentrated *in vacuo* to give the crude alkylated product which was used without further purification.

The crude alkylated substrate was dissolved in DCM (0.5M) and added to an oven-dried round-bottom flask equipped with a stir bar. TFA (0.17-0.25 M) was added drop-wise and the reaction stirred at room temperature until TLC analysis indicated consumption of the starting material. The reaction was quenched with sat. NaHCO_{3(aq.)} and the layers were separated. The organic layer was dried over Na₂SO₄, concentrated *in vacuo* and applied to a silica gel column to give the desired product.

General Experimental D: Palladium Amidation of 3-Amino-4-chloropyridines

To an oven-dried 25 mL Schlenk tube equipped with a stirbar was added Pd₂(dba)₃·CHCl₃ (1 mol %), Me₃(OMe)*t*-BuXPhos (5 mol %), K₃PO₄ (1.5 Eq.) and pyridine **36** (1 eq.). The reaction vessel was evacuated under vacuum and refilled with Ar_(g). *t*-BuOH (0.2 M) and formamide (1.5 eq.) were then added via syringe and the reaction mixture was degassed by three vacuum/Ar_(g) purge cycles. The reaction vessel was then equipped with a cold-finger condenser, placed in a pre-heated 110 °C oil-bath and stirred for the specified time. Upon consumption of pyridine **36** (as judged by TLC analysis) the reaction mixture was allowed to cool to room temperature. The reaction mixture was diluted with methanol and passed through a Celite® plug. The crude mixture was concentrated *in vacuo* and applied to a silica gel column eluted with the indicated solvent mixture(s) to give the desired product.



***tert*-butyl 4-chloropyridin-3-yl(*p*-tolyl)carbamate (**35i**)**

Following general experimental A: Copper (I) Iodide (43 mg, 0.22 mmol), potassium phosphate (955 mg, 4.50 mmol), pyridine **34** (500 mg, 2.18 mmol), diamine **L1** (0.06 mL, 0.44 mmol), 4-iodotoluene (539 mg, 2.48 mmol) and 1,4-dioxane (0.5 M) were combined and stirred for 22 h. Purification via flash column chromatography, eluted with 20% EtOAc/Hexanes, gave 540 mg of pyridine **35i** (76%) as an off-white solid.

R_f = 0.64 (30% EtOAc/Hexanes)

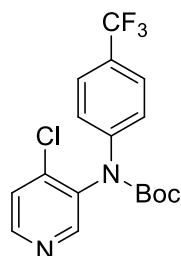
¹H NMR (300 MHz, CDCl₃) δ = 8.50 (s, 1H), 8.40 (d, *J* = 5.1 Hz, 1H), 7.40 (d, *J* = 5.4 Hz, 1H), 7.16-7.09 (m, 4H), 2.31 (s, 3H), 1.42 (s, 9H)

¹³C NMR (75.4 MHz, CDCl₃) δ = 153.0, 151.6, 148.8, 142.9, 138.8, 137.5, 129.5, 125.7, 125.0, 82.0, 28.1, 21.0

FT-IR: (NaCl, thin film) ν = 3036, 2979, 1715, 1554 cm⁻¹

EA: Calculated: C₁₇H₁₉ClN₂O₂; C, 64.05; H, 6.01; N, 8.79; found C, 64.12; H, 6.04; N, 8.99

MP: 98-100°C



***tert*-butyl 4-chloropyridin-3-yl(4-(trifluoromethyl)phenyl)carbamate (**35k**)**

Following general experimental A: Copper (I) Iodide (43 mg, 0.22 mmol), potassium phosphate (955 mg, 4.5 mmol), pyridine **34** (500 mg, 2.18 mmol), diamine **L1** (0.06 mL, 0.45 mmol), 4-trifluoromethylbromobenzene (0.35 mL, 2.48 mmol) and 1,4-dioxane (0.5 M) were combined and stirred for 22 h.

Purification via flash column chromatography, eluted with 20% EtOAc/Hexanes, gave 640 mg of pyridine **35k** (79%) as a yellow oil.

R_f = 0.69 (30% EtOAc/Hexanes)

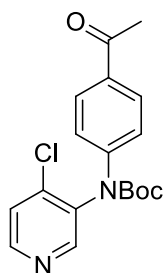
¹H NMR (600 MHz, CDCl₃) δ = 8.50 (s, 1H), 8.48 (d, *J* = 5.4 Hz, 1H), 7.55 (d, *J* = 8.4 Hz, 2H), 7.46 (d, *J* = 5.1 Hz, 1H), 7.36 (d, *J* = 8.7 Hz, 2H), 1.43 (s, 9H)

¹³C NMR (150 MHz, CDCl₃) δ = 152.3, 151.6, 149.5, 144.3, 143.2, 136.5, 127.4 (q, *J*_{C-F} = 32.7 Hz), 126.0 (q, *J*_{C-F} = 3.6 Hz), 125.1, 124.6, 124.0 (q, *J*_{C-F} = 272.8 Hz), 83.0, 28.0

¹⁹F NMR (282.3 MHz, CDCl₃) δ = -62.8

FT-IR: (NaCl, thin film) ν = 2982, 1722, 1615, 1161 cm⁻¹

EA: Calculated: C₁₇H₁₆ClF₃N₂O₂; C, 54.77; H, 4.33; N, 7.51; found C, 54.69; H, 4.10; N, 7.27



***tert*-butyl 4-acetylphenyl(4-chloropyridin-3-yl)carbamate (**35j**)**

Following general experimental A: Copper (I) Iodide (42 mg, 0.22 mmol), potassium phosphate (929 mg, 4.38 mmol), pyridine **34** (500 mg, 2.18 mmol), diamine **L1** (0.06 mL, 0.44 mmol), 4'-bromoacetophenone (480 mg, 2.41 mmol) and 1,4-dioxane (0.5 M) were combined and stirred for 24 h. Purification via flash column chromatography, eluted with 30% EtOAc/Hexanes, gave 686 mg of pyridine **35j** (90%) as a yellow oil.

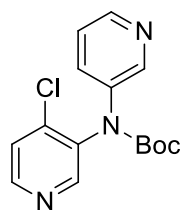
$R_f = 0.27$ (30% EtOAc/Hexanes)

^1H NMR (300 MHz, CDCl_3) δ = 8.45 (s, 1H), 8.43 (d, $J = 5.4$ Hz, 1H), 7.85 (d, $J = 8.4$ Hz, 2H), 7.41 (d, $J = 5.4$ Hz, 1H), 7.26 (d, $J = 8.7$ Hz, 2H), 2.50 (s, 3H), 1.43 (s, 9H)

^{13}C NMR (75 MHz, CDCl_3) δ = 196.9, 152.1, 151.6, 149.5, 145.4, 143.1, 136.5, 133.7, 129.1, 125.1, 123.9, 82.9, 28.0, 26.5

FT-IR: (NaCl, thin film) ν = 2982, 1722, 1615, 1161 cm^{-1}

EA: Calculated: $\text{C}_{18}\text{H}_{19}\text{ClN}_2\text{O}_3$; C, 62.34; H, 5.52; N, 8.08; found C, 61.95; H, 5.28; N, 7.71



***tert*-butyl (4-chloropyridin-3-yl)(pyridin-3-yl)carbamate (**35n**)**

Following general experimental A: Copper (I) Iodide (42 mg, 0.22 mmol), potassium phosphate (929 mg, 4.38 mmol), pyridine **34** (500 mg, 2.18 mmol), diamine **L1** (0.06 mL, 0.44 mmol), 3-bromopyridine (0.24 mL, 2.41 mmol) and 1,4-dioxane (0.5 M) were combined and stirred for 24 h. Purification via flash column chromatography, eluted with 35% EtOAc/Hexanes, gave 590 mg of pyridine **35n** (88%) as a yellow solid.

R_f = 0.14 (30% EtOAc/Hexanes)

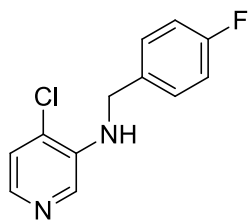
¹H NMR (300 MHz, CDCl₃) δ = 8.53 (s, 1H), 8.47 (d, *J* = 5.4 Hz, 1H), 8.47 (s, 1H), 8.40 (dd, *J* = 4.7, 1.4 Hz, 1H), 7.66 (d, *J* = 7.5 Hz, 1H), 7.45 (d, *J* = 5.4 Hz, 1H), 7.27 (dd, *J* = 8.3, 4.8 Hz, 1H), 1.44 (s, 9H)

¹³C NMR (100 MHz, CDCl₃) δ = 152.4, 151.5, 149.5, 146.6, 143.0, 137.9, 136.2, 132.3, 125.0, 123.3, 82.9, 29.9

FT-IR: (NaCl, thin film) ν = 2980, 1716 cm⁻¹

EA: Calculated: C₁₅H₁₆ClN₃O₂; C, 58.92; H, 5.27; N, 13.74; found C, 58.94; H, 4.98; N, 14.01

MP: 55-57°C



4-chloro-N-(4-fluorobenzyl)pyridin-3-amine (36d):

Following general experimental C: Pyridine **34** (457 mg, 2 mmol), DMF (4 mL) and sodium hydride (60% wt in mineral oil) (120 mg, 3 mmol) were combined and stirred for 1 h, then 1-(chloromethyl)-4-fluorobenzene ² (432 mg, 3 mmol) was added and the reaction mixture was stirred for an additional 2 h. Subsequent workup gave the crude alkylated product which was dissolved in DCM (5 mL) and TFA (1 mL) and stirred for 4 h. Purification via flash column chromatography, eluted with 25% EtOAc/Hexane, gave 236 mg of pyridine **36d** (50% over two steps) as a pale yellow solid.

R_f = 0.71 (50% EtOAc/Hexanes)

¹H NMR (300 MHz, CDCl₃) δ = 7.98 (s, 1H), 7.90 (d, J = 5.1 Hz, 1H), 7.35-7.31 (m, 2H), 7.20 (d, J = 5.1 Hz, 1H), 7.08-7.02 (m, 2H), 4.61 (bs, NH), 4.43 (d, J = 5.4 Hz, 2H)

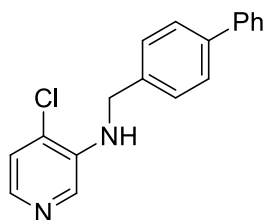
¹³C NMR (75 MHz, CDCl₃) δ = 162.3 (d, J_{C-F} = 244.5 Hz), 140.1, 139.0, 133.7 (d, J_{C-F} = 9 Hz), 133.5, 128.9 (d, J_{C-F} = 8.25 Hz), 127.6, 123.8, 115.7 (d, J_{C-F} = 21.75 Hz), 46.9

¹⁹F NMR (282.3 MHz, CDCl₃) δ = [(-115.1)-(-115.2)](m)

FT-IR: (NaCl, thin film) ν = 3424, 1603 cm⁻¹

EA: Calculated C₁₂H₁₀ClFN₂; C, 60.90; H, 4.26; N, 11.84; found C, 61.23; H, 4.19; N, 12.02

MP: 78-79°C



N-([1,1'-biphenyl]-4-ylmethyl)-4-chloropyridin-3-amine (36e)

Following general experimental C: Pyridine **34** (457 mg, 2 mmol), DMF (4 mL) and sodium hydride (60% wt in mineral oil) (120 mg, 3 mmol) were combined and stirred for 1 h, then 4-(chloromethyl)-1,1'-biphenyl ⁴ (606 mg, 3 mmol) was added and the reaction mixture was stirred for an additional 2 h. Subsequent workup gave the crude alkylated product that was dissolved in DCM (7 mL) and TFA (1 mL) and stirred for 4 h. Purification via flash column chromatography, eluted with 25% EtOAc/Hexanes, gave 240 mg of pyridine **36e** (45% over two steps) as a pale yellow solid.

R_f = 0.5 (50% EtOAc/Hexanes)

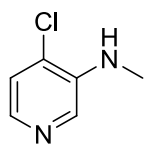
¹H NMR (300 MHz, CDCl₃) δ = 8.06 (s, 1H), 7.91 (d, J = 5.1 Hz, 1H), 7.61-7.56 (m, 4H), 7.47-7.41 (m, 4H), 7.38-7.32 (m, 1H), 7.21 (d, J = 4.8 Hz, 1H), 4.67 (t, J = 5.1 Hz, NH), 4.51 (d, J = 5.4 Hz, 2H)

¹³C NMR (75 MHz, CDCl₃) δ = 140.7, 140.7, 140.3, 139.0, 137.0, 133.9, 128.9, 127.8, 127.7, 127.5, 127.1, 123.8, 47.4

FT-IR: (NaCl, thin film) ν = 3417, 1579 cm⁻¹

EA: Calculated C₁₈H₁₅ClN₂; C, 73.34; H, 5.13; N, 9.50; found C, 73.27; H, 4.88; N, 9.18

MP: 99-101°C

**4-chloro-N-methylpyridin-3-amine (36f)**

Following general experimental C: Pyridine **34** (708 mg, 3.09 mmol), DMF (7 mL) and sodium hydride (60% wt in mineral oil) (223 mg, 5.57 mmol) were combined and stirred for 1 h, then iodomethane (0.58 mL, 9.28 mmol) was added and the reaction mixture was stirred for an additional 2 h. Subsequent workup gave the crude alkylated product that was dissolved in DCM (15 mL) and TFA (5 mL) were combined and stirred for 4 h. Purification via flash column chromatography, eluted with 20% EtOAc/Hexanes, gave 174 mg of pyridine **36f** (40% over two steps) as a light brown solid.

R_f = 0.42 (5% MeOH/DCM)

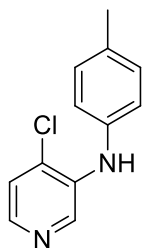
¹H NMR (300 MHz, CDCl₃) δ = 8.02 (s, 1H), 7.89 (d, J = 4.8 Hz, 1H), 7.17 (d, J = 5.1 Hz, 1H), 4.25 (bs, NH), 2.97 (d, J = 5.4 Hz, 3H)

¹³C NMR (75 MHz, CDCl₃) δ = 141.3, 138.5, 132.9, 127.4, 123.6, 30.2

FT-IR: (NaCl, thin film) ν = 3293, 2914, 1582 cm⁻¹

EA: Calculated C₆H₇ClN₂; C, 50.54; H, 4.95; N, 19.65; found C, 50.57; H, 5.18; N, 19.45

MP: 54-55°C



4-chloro-N-(p-tolyl)pyridin-3-amine (36i)

Following general experimental B: Pyridine **35i** (436 mg, 1.4 mmol), DCM (3 mL) and TFA (1.5 mL) were combined and stirred for 24 h to give 280 mg of pyridine **36i** as a yellow solid. (92%)

R_f = 0.39 (30% EtOAc/Hexanes)

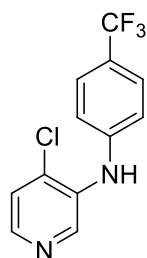
¹H NMR (300 MHz, CDCl₃) δ = 8.45 (s, 1H), 7.98 (d, J = 5.1 Hz, 1H), 7.25 (d, J = 5.1 Hz, 1H), 7.16 (d, J = 8.4 Hz, 2H), 7.08 (d, J = 8.4 Hz, 2H), 5.90 (br s, 1H), 2.34 (s, 3H)

¹³C NMR (75.4 MHz, CDCl₃) δ = 140.5, 138.2, 137.6, 137.2, 133.7, 130.3, 129.3, 124.3, 121.5, 20.9

FT-IR: (NaCl, thin film) ν = 3401, 3233, 3030, 2920, 1571, 1517, 809 cm⁻¹

EA: Calculated: C₁₂H₁₁ClN₂; C, 65.91; H, 5.07; N, 12.81; found C, 65.76; H, 4.71; N, 12.55

MP: 59-60°C



4-chloro-N-(4-(trifluoromethyl)phenyl)pyridin-3-amine (36k)

Following general experimental B: Pyridine **35k** (520 mg, 1.4 mmol), DCM (3 mL) and TFA (1.5 mL) were combined and stirred for 24 h to give 340 mg of pyridine **36k** as a yellow solid. (89%)

R_f = 0.21 (30% EtOAc/Hexanes)

¹H NMR (600 MHz, CDCl₃) δ = 8.67 (s, 1H), 8.15 (d, J = 4.8 Hz, 1H), 7.55 (d, J = 8.4 Hz, 2H), 7.34 (d, J = 5.1 Hz, 1H), 7.14 (d, J = 8.7 Hz, 2H), 6.10 (s, 1H)

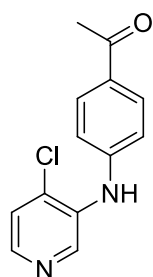
¹³C NMR (150 MHz, CDCl₃) δ = 144.5, 143.3, 140.5, 135.9, 132.7, 127 (q, $J_{\text{C-F}}$ = 3.8 Hz), 124.7, 124.3 (q, $J_{\text{C-F}}$ = 271.0 Hz), 124.2 (q, $J_{\text{C-F}}$ = 32.6 Hz), 117.6

¹⁹F NMR (282.3 MHz, CDCl₃) δ = -62.2

FT-IR: (NaCl, thin film) ν = 3249, 2988, 1616, 1111 cm⁻¹

EA: Calculated: C₁₂H₈ClF₃N₂; C, 52.86; H, 2.96; N, 10.27; found C, 52.88; H, 2.98; N, 10.07

MP: 138-140°C



1-(4-((4-chloropyridin-3-yl)amino)phenyl)ethanone (36j)

Following general experimental B: Pyridine **35j** (440 mg, 1.27 mmol), DCM (3 mL) and TFA (1.5 mL) were combined and stirred for 24 h to give 280 mg of pyridine **36j** as a yellow solid. (89%)

R_f = 0.12 (30% EtOAc/Hexanes)

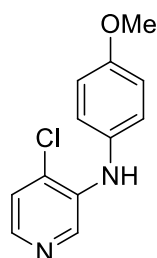
¹H NMR (300 MHz, CDCl₃) δ = 8.72 (s, 1H), 8.17 (d, J = 5.1 Hz, 1H), 7.93 (d, J = 8.7 Hz, 2H), 7.36 (d, J = 5.1 Hz, 1H), 7.11 (d, J = 8.7 Hz, 2H), 6.22 (br s, 1H), 2.56 (s, 3H)

¹³C NMR (75.4 MHz, CDCl₃) δ = 196.6, 146.0, 143.8, 141.3, 135.5, 133.3, 131.2, 130.7, 124.9, 116.6, 26.5

FT-IR: (NaCl, thin film) ν = 3247, 3172, 3049, 1667, 1604, 1565, 813 cm⁻¹

EA: Calculated: C₁₃H₁₁ClN₂O; C, 63.29; H, 4.49; N, 11.36; found C, 63.31; H, 4.14; N, 11.71

MP: 115-116°C



4-chloro-N-(4-methoxyphenyl)pyridin-3-amine (36l)

Following general experimental A: Copper (I) Iodide (20 mg, 0.11 mmol), K_3PO_4 (465 mg, 2.18 mmol), pyridine **34** (250 mg, 1.09 mmol), diamine **L1** (27 μ L, 0.22 mmol), 4-bromoanisole (0.15 mL, 1.2 mmol) and 1,4-dioxane (0.5 M) were combined and stirred for 29 h, cooled to room temperature, diluted with EtOAc, filtered through a Celite® plug and concentrated *in vacuo*. The crude mixture was dissolved in DCM (3 mL) and TFA (1.5 mL) and stirred for 24 h. The reaction was poured into sat. $NaHCO_{3(aq)}$, diluted with DCM, and the layers were separated. The aqueous layer was extracted with DCM and the combined organic layers were dried over Na_2SO_4 , decanted and concentrated *in vacuo* to give brown oil. Purification via flash column chromatography, eluted with 20% EtOAc/Hexanes, gave 120 mg of pyridine **36l** (47% over two steps) as a brown solid.

R_f = 0.24 (30% EtOAc/Hexanes)

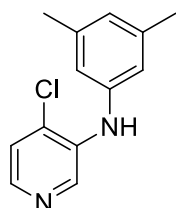
1H NMR (300 MHz, $CDCl_3$) δ = 8.26 (s, 1H), 7.94 (d, J = 5.1 Hz, 1H), 7.24 (d, J = 5.1 Hz, 1H), 7.16 (d, J = 8.7 Hz, 2H), 6.92 (d, J = 9.0 Hz, 2H), 5.82 (br s, 1H), 3.82 (s, 3H)

^{13}C NMR (75.4 MHz, $CDCl_3$) δ = 157.1, 140.0, 139.3, 136.3, 132.7, 128.4, 124.9, 124.2, 115.1, 55.7

FT-IR: (NaCl, thin film) ν = 3234, 3041, 2933, 2835, 1513, 1244 cm^{-1}

EA: Calculated: $C_{12}H_{11}ClN_2O$; C, 61.41; H, 4.72; N, 11.94; found C, 61.48; H, 4.97; N, 11.67

MP: 59-60°C



4-chloro-N-(3,5-dimethylphenyl)pyridin-3-amine (36m)

Following general experimental A: Copper (I) Iodide (20 mg, 0.11 mmol), K_3PO_4 (465 mg, 2.18 mmol), pyridine **34** (250 mg, 1.09 mmol), diamine **L1** (27 μ L, 0.22 mmol), 5-bromo-*m*-xylene (0.17 mL, 1.2 mmol) and 1,4-dioxane (0.5 M) were combined and stirred for 29 h, cooled to room temperature, diluted with EtOAc, filtered through a Celite® plug and concentrated *in vacuo*. The crude mixture was dissolved in DCM (3 mL) and TFA (1.5 mL) and stirred for 24 h. The reaction was poured into sat. $NaHCO_{3(aq)}$, diluted with DCM, the layers were separated and the aqueous layer was extracted with DCM. The combined organic layers were dried over Na_2SO_4 , decanted and concentrated *in vacuo* to give brown oil. Purification via flash column chromatography, eluted with 20% EtOAc/Hexanes, gave 168 mg of pyridine **36m** (66% over two steps) as an off-white solid.

R_f = 0.42 (30% EtOAc/Hexanes)

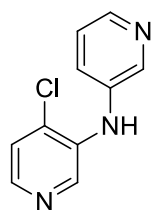
1H NMR (400 MHz, $CDCl_3$) δ = 8.58 (s, 1H), 8.01 (s, 1H), 7.27 (d, J = 3.9 Hz, 1H), 6.81 (s, 2H), 6.74 (s, 1H), 5.88 (s, 1H), 2.30 (s, 6H)

^{13}C NMR (100 MHz, $CDCl_3$) δ = 140.9, 140.3, 139.6, 138.2, 137.7, 129.8, 125.5, 124.4, 118.3, 21.4

FT-IR: (NaCl, thin film) ν = 3402, 1606, 1571, 1075 cm^{-1}

EA: Calculated: $C_{13}H_{13}ClN_2$; C, 67.10; H, 5.63; N, 12.04; found C, 67.17; H, 5.88; N, 11.93

MP: 127-128°C



4-chloro-N-(pyridin-3-yl)pyridin-3-amine (36n)

Following general experimental B: Pyridine **35n** (168 mg, 0.55 mmol), DCM (2 mL) and TFA (1 mL) were combined and stirred for 6 h to give 100 mg of pyridine **36n** as a yellow solid. (89%)

R_f = 0.06 (30% EtOAc/Hexanes)

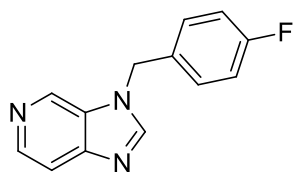
¹H NMR (300 MHz, CDCl₃) δ = 8.49 (s, 1H), 8.46 (d, J = 2.1 Hz, 1H), 8.29 (d, J = 4.5 Hz, 1H), 8.07 (d, J = 5.1 Hz, 1H), 7.48 (d, J = 5.1 Hz, 1H), 7.30 (d, J = 5.1 Hz, 1H), 7.24 (dd, J = 8.1, 4.8 Hz, 1H), 6.28 (br s, 1H)

¹³C NMR (75.4 MHz, CDCl₃) δ = 144.3, 142.4, 142.3, 138.5, 137.5, 136.7, 131.4, 126.4, 124.6, 124.0

FT-IR: (NaCl, thin film) ν = 3172, 3042, 1588, 1326 cm⁻¹

EA: Calculated: C₁₀H₈ClN₃; C, 58.41; H, 3.92; N, 20.43; found C, 58.36; H, 4.14; N, 20.39

MP: 117-118°C


3-(4-fluorobenzyl)-3H-imidazo[4,5-c]pyridine (37d)

Following general procedure D: Pyridine **36d** (95 mg, 0.4 mmol), $\text{Pd}_2(\text{dba})_3 \cdot \text{CHCl}_3$ (4 mg, 0.004 mmol), $\text{Me}_3(\text{OMe})t\text{-butyl-XPhos}^{195}$ (10 mg, 0.02 mmol), K_3PO_4 (128 mg, 0.6 mmol), formamide (0.024 mL, 0.6 mmol) were combined with 2 mL *tert*-butanol in a 25 mL Schlenk tube. After 4 h TLC analysis indicated the reaction was complete. The reaction mixture was cooled to RT, filtered through Celite®, concentrated *in vacuo* and purified on a silica gel column, eluted with 3% MeOH/DCM, to give 68 mg of pyridine **37d** (75%) as a pale yellow solid.

R_f = 0.31 (5% MeOH/DCM)

¹H NMR (300 MHz, CDCl_3) δ = 8.65 (d, J = 0.6 Hz, 1H), 8.39 (d, J = 5.4 Hz, 1H), 8.00 (s, 1H), 7.66 (dd, J = 5.7, 0.9 Hz, 1H), 7.18-7.13 (m, 2H), 7.09-6.96 (m, 2H), 5.34 (s, 2H)

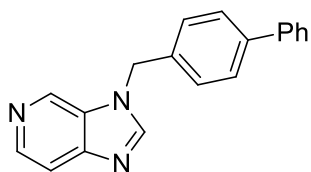
¹³C NMR (75 MHz, CDCl_3) δ = 162.7 (d, $J_{\text{C-F}}$ = 246.75 Hz), 149.1, 145.7, 142.2, 133.7, 131.5, 130.4 (d, $J_{\text{C-F}}$ = 3.45 Hz), 129.2 (d, $J_{\text{C-F}}$ = 7.95 Hz), 116.3 (d, $J_{\text{C-F}}$ = 21.75 Hz), 115.1, 48.8

¹⁹F NMR (282.3 MHz, CDCl_3) δ = -113.0 (m)

FT-IR (NaCl, thin film) ν = 1608 cm^{-1}

EA: Calculated: $\text{C}_{13}\text{H}_{10}\text{FN}_3$; C, 68.71; H, 4.44; N, 18.49; found C, 68.54; H, 4.36; N, 18.32

MP: 107-110°C



3-([1,1'-biphenyl]-4-ylmethyl)-3H-imidazo[4,5-c]pyridine (37e)

Following general procedure D: Pyridine **36e** (95 mg, 0.4 mmol), $\text{Pd}_2(\text{dba})_3 \cdot \text{CHCl}_3$ (4 mg, 0.004 mmol), $\text{Me}_3(\text{OMe})t\text{-butyl-XPhos}^{195}$ (10 mg, 0.02 mmol), K_3PO_4 (128 mg, 0.6 mmol), formamide (0.024 mL, 0.6 mmol) were combined with 2 mL *tert*-butanol in a 25 mL Schlenk tube. After 4.5 h TLC analysis indicated the reaction was complete. The reaction mixture was cooled to RT, filtered through Celite®, concentrated *in vacuo* and purified on a silica gel column, eluted with 4% MeOH/DCM, to give 86 mg of pyridine **37e** (75%) as an off-white solid.

R_f = 0.34 (5% MeOH/DCM)

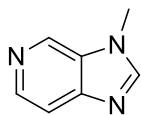
¹H NMR (300 MHz, CDCl_3) δ = 8.76 (s, 1H), 8.46 (d, J = 5.7 Hz, 1H), 8.07 (s, 1H), 7.73 (dd, J = 5.7, 1.2 Hz, 1H), 7.58-7.51 (m, 4H), 7.45-7.26 (m, 5H), 5.44 (s, 2H)

¹³C NMR (75 MHz, CDCl_3) δ = 149.1, 145.8, 142.2, 141.8, 140.1, 133.9, 133.4, 131.6, 128.9, 127.9, 127.8, 127.7, 127.1, 115.1, 49.2

EA: Calculate: $\text{C}_{19}\text{H}_{15}\text{N}_3$; C, 79.98; H, 5.30; N, 14.73; found C, 79.96; H, 5.56; N, 14.39

FT-IR (NaCl, thin film) ν = 1602 cm^{-1}

MP: 189-191°C


3-methyl-3H-imidazo [4,5-*c*]pyridine (37f)²¹⁹

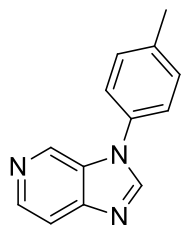
Following general procedure D: Pyridine **36f** (57 mg, 0.4 mmol), Pd₂(dba)₃·CHCl₃ (4 mg, 0.004 mmol), Me₃(OMe)*t*-butyl-XPhos¹⁹⁵ (10 mg, 0.02 mmol), K₃PO₄ (128 mg, 0.6 mmol), formamide (0.024 mL, 0.6 mmol) were combined with 2 mL *tert*-butanol in a 25 mL Schlenk tube. After 5 h TLC analysis indicated the reaction was complete. The reaction mixture was cooled to RT, filtered through Celite®, concentrated *in vacuo* and purified on a silica gel column, eluted with 4% MeOH/DCM, to give 31 mg of pyridine **37f** (58%) as a pale yellow solid.

R_f = 0.17 (5% MeOH/DCM)

¹H NMR (300 MHz, CDCl₃): δ = 8.80 (d, *J* = 0.6 Hz, 1H), 8.42 (d, *J* = 5.4 Hz, 1H), 7.91 (s, 1H), 7.65 (dd, *J* = 5.7 Hz, 0.9 Hz, 1H), 3.89 (s, 3H)

¹³C NMR (75 MHz, CDCl₃) δ = 148.7, 146.2, 142.0, 133.2, 132.3, 114.9, 31.5

MP: 95-97°C



3-(p-tolyl)-3H-imidazo[4,5-c]pyridine (37i):

Following general procedure D: Pyridine **36i** (87 mg, 0.4 mmol), $\text{Pd}_2(\text{dba})_3 \cdot \text{CHCl}_3$ (4 mg, 0.004 mmol), $\text{Me}_3(\text{OMe})t\text{-butyl-XPhos}^{195}$ (10 mg, 0.02 mmol), K_3PO_4 (128 mg, 0.6 mmol), formamide (0.024 mL, 0.6 mmol) were combined with 2 mL *tert*-butanol in a 25 mL Schlenk tube. After 6 h TLC analysis indicated the reaction was complete. The reaction mixture was cooled to RT, filtered through Celite®, concentrated *in vacuo* and purified on a silica gel column, eluted with 4% MeOH/DCM, to give 72 mg of pyridine **37i** (86%) as a light brown solid.

R_f = 0.33(5% MeOH/DCM)

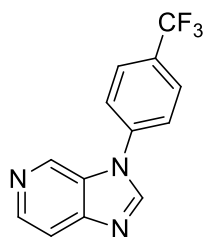
¹H NMR (600 MHz, CDCl_3) δ = 8.90 (s, 1H), 8.48 (d, J = 5.7 Hz, 1H), 8.17 (s, 1H), 7.74 (dd, J = 5.7 Hz, 0.6 Hz, 1H), 7.40-7.36 (m, 4H), 2.43 (s, 3H)

¹³C NMR (150 MHz, CDCl_3) δ = 149.1, 145.0, 142.6, 139.1, 134.3, 133.0, 131.7, 131.0, 123.9, 115.3, 21.2

FT-IR (NaCl, thin film) ν = 3051, 2924, 1518, 1480, 821 cm^{-1}

EA: Calculated: $\text{C}_{13}\text{H}_{11}\text{N}_3$; C, 74.62; H, 5.30; N, 20.08; found C, 74.66; H, 5.54; N, 19.97

MP: 108-109°C



3-(4-(trifluoromethyl)phenyl)-3H-imidazo[4,5-c]pyridine (37k):

Following general procedure D: Pyridine **36k** (108 mg, 0.4 mmol), $\text{Pd}_2(\text{dba})_3 \cdot \text{CHCl}_3$ (4 mg, 0.004 mmol), $\text{Me}_3(\text{OMe})t\text{-butyl-XPhos}^{195}$ (10 mg, 0.02 mmol), K_3PO_4 (128 mg, 0.6 mmol), formamide (0.024 mL, 0.6 mmol) were combined with 2 mL *tert*-butanol in a 25 mL Schlenk tube. After 6 h TLC analysis indicated the reaction was complete. The reaction mixture was cooled to RT, filtered through Celite®, concentrated *in vacuo* and purified on a silica gel column, eluted with 4% MeOH/DCM, to give 96 mg of pyridine **37k** (91%) as a pale yellow solid.

R_f = 0.30 (5% MeOH/DCM)

¹H NMR (600 MHz, CDCl_3) δ = 8.97 (s, 1H), 8.52 (d, J = 5.7 Hz, 1H), 8.25 (s, 1H), 7.88 (d, J = 8.4 Hz, 2H), 7.76 (d, J = 5.7 Hz, 1H), 7.69 (d, J = 8.4 Hz, 2H)

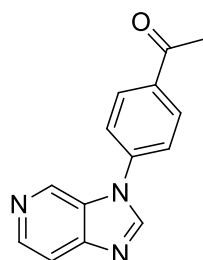
¹³C NMR (150 MHz, CDCl_3) δ = 149.4, 144.4, 143.1, 138.5, 133.9, 131.0, 130.8 (q, $J_{\text{C-F}}$ = 33.3 Hz), 127.8 (q, $J_{\text{C-F}}$ = 3.7 Hz), 123.9, 123.5 (q, $J_{\text{C-F}}$ = 272.9 Hz), 115.5

¹⁹F NMR (282.3 MHz, CDCl_3): δ = -63.0

FT-IR (NaCl, thin film) ν = 3056, 1606, 1334, 1106 cm^{-1}

EA: Calculated: $\text{C}_{13}\text{H}_8\text{F}_3\text{N}_3$; C, 59.32; H, 3.06; N, 15.96; found C, 59.04; H, 2.77; N, 15.67

MP: 166-167 °C



1-(4-(3H-imidazo[4,5-c]pyridin-3-yl)phenyl)ethanone (37j)

Following general procedure D: Pyridine **36j** (98 mg, 0.4 mmol), $\text{Pd}_2(\text{dba})_3 \cdot \text{CHCl}_3$ (4 mg, 0.004 mmol), $\text{Me}_3(\text{OMe})t\text{-butyl-XPhos}^{195}$ (10 mg, 0.02 mmol), K_3PO_4 (128 mg, 0.6 mmol), formamide (0.024 mL, 0.6 mmol) were combined with 2 mL *tert*-butanol in a 25 mL Schlenk tube. After 4 h TLC analysis indicated the reaction was complete. The reaction mixture was cooled to RT, filtered through Celite®, concentrated *in vacuo* and purified on a silica gel column, eluted with 4% MeOH/DCM, to give 83 mg of pyridine **37j** (87%) as a pale yellow solid.

R_f = 0.33 (5% MeOH/DCM)

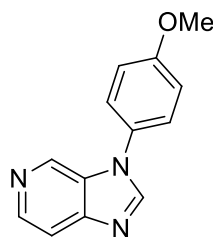
¹H NMR (600 MHz, CDCl_3) δ = 8.99 (s, 1H), 8.51 (d, J = 5.7 Hz, 1H), 8.26 (s, 1H), 8.18 (d, J = 8.7 Hz, 2H), 7.76 (dd, J = 5.7 Hz, 0.9 Hz, 1H), 7.65 (d, J = 8.7 Hz, 2H), 2.65 (s, 3H)

¹³C NMR (150 MHz, CDCl_3) δ = 196.3, 149.3, 144.3, 143.0, 139.1, 136.8, 134.0, 130.9, 130.5, 123.3, 115.4, 26.6

FT-IR (NaCl, thin film) ν = 1677, 1601, 1353, 816 cm^{-1}

EA: Calculated: $\text{C}_{14}\text{H}_{11}\text{N}_3\text{O}$; C, 70.87; H, 4.67; N, 17.71; found C, 70.50; H, 4.76; N, 17.43

MP: 199-201°C



3-(4-methoxyphenyl)-3H-imidazo[4,5-*c*]pyridine (37I)

Following general procedure D: Pyridine **36I** (93 mg, 0.4 mmol), Pd₂(dba)₃·CHCl₃ (4 mg, 0.004 mmol), Me₃(OMe)*t*-butyl-XPhos¹⁹⁵ (10 mg, 0.02 mmol), K₃PO₄ (128 mg, 0.6 mmol), formamide (0.024 mL, 0.6 mmol) were combined with 2 mL *tert*-butanol in a 25 mL Schlenk tube. After 6.5 h

TLC analysis indicated the reaction was complete. The reaction mixture was cooled to RT, filtered through Celite®, concentrated *in vacuo* and purified on a silica gel column, eluted with 3% MeOH/DCM, to give 69 mg of pyridine **37I** (77%) as a pale yellow solid.

R_f = 0.30 (5% MeOH/DCM)

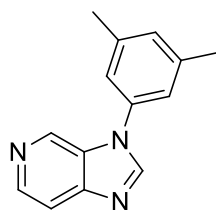
¹H NMR (300 MHz, CDCl₃) δ = 8.86 (s, 1H), 8.49 (d, *J* = 5.7 Hz, 1H), 8.14 (s, 1H), 7.75 (d, *J* = 5.4 Hz, 1H), 7.42 (d, *J* = 8.7 Hz, 2H), 7.08 (d, *J* = 9.0 Hz, 2H), 3.88 (s, 3H)

¹³C NMR (75.4 MHz, CDCl₃) δ = 159.9, 149.0, 145.2, 142.5, 134.3, 132.1, 128.3, 125.7, 115.5, 115.2, 55.8

FT-IR (NaCl, thin film) ν = 2839, 1517, 1253 cm⁻¹

EA: Calculated: C₁₃H₁₁N₃O; C, 69.32; H, 4.92; N, 18.66; found C, 69.44; H, 5.05; N, 18.75

MP: 105-106°C



3-(3,5-dimethylphenyl)-3H-imidazo[4,5-*c*]pyridine (37m):

Following general procedure D: Pyridine **36m** (93 mg, 0.4 mmol), Pd₂(dba)₃·CHCl₃ (4 mg, 0.004 mmol), Me₃(OMe)*t*-butyl-XPhos¹⁹⁵ (10 mg, 0.02 mmol), K₃PO₄ (128 mg, 0.6 mmol), formamide (0.024 mL, 0.6 mmol) were combined with 2 mL *tert*-butanol in a 25 mL Schlenk tube. After 4 h TLC analysis indicated the reaction was complete. The reaction mixture was cooled to RT, filtered through Celite®, concentrated *in vacuo* and purified on a silica gel column, eluted with 4% MeOH/DCM, to give 80 mg of pyridine **37m** (90%) as a pale yellow solid.

R_f = 0.33 (5% MeOH/DCM)

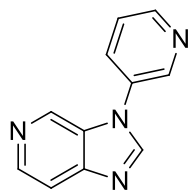
¹H NMR (400 MHz, CDCl₃) δ = 8.96 (s, 1H), 8.51 (d, *J* = 5.4 Hz, 1H), 8.19 (s, 1H), 7.77 (d, *J* = 5.6 Hz, 1H), 7.14 (s, 3H), 2.43 (s, 6H)

¹³C NMR (100 MHz, CDCl₃) δ = 149.2, 144.9, 142.6, 140.5, 135.4, 134.6, 131.6, 130.5, 121.7, 115.3, 21.5

FT-IR (NaCl, thin film) ν = 3060, 2919, 1602, 1494, 1231 cm⁻¹

EA: Calculated: C₁₄H₁₃N₃; C, 75.31; H, 5.87; N, 18.82; found C, 75.64; H, 5.59; N, 18.66

MP: 144-146°C


3-(pyridin-3-yl)-3H-imidazo[4,5-*c*]pyridine (37n)

Following general procedure D: Pyridine **36n** (95 mg, 0.4 mmol), Pd₂(dba)₃·CHCl₃ (4 mg, 0.004 mmol), Me₃(OMe)*t*-butyl-XPhos¹⁹⁵ (10 mg, 0.02 mmol), K₃PO₄ (128 mg, 0.6 mmol), formamide (0.024 mL, 0.6 mmol) were combined with 2 mL *tert*-butanol in a 25 mL Schlenk tube. After 5 h TLC analysis indicated the reaction was complete. The reaction mixture was cooled to RT, filtered through Celite®, concentrated *in vacuo* and purified on a silica gel column, eluted with 4% MeOH/DCM, to give 67 mg of pyridine **37n** (86%) as a yellow solid.

R_f = 0.57 (4% MeOH/DCM)

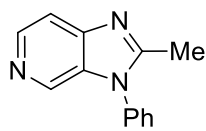
¹H NMR (600 MHz, CDCl₃) δ = 8.94 (s, 1H), 8.88 (d, *J* = 2.4 Hz, 1H), 8.78 (dd, *J* = 4.8 Hz, 1.2 Hz, 1H), 8.55 (d, *J* = 5.4 Hz, 1H), 8.23 (s, 1H), 7.91 (ddd, *J* = 8.0 Hz, 2.4 Hz, 1.2 Hz, 1H), 7.80 (d, *J* = 5.4 Hz, 1H), 7.58 (dd, *J* = 8.0 Hz, 4.8 Hz, 1H)

¹³C NMR (150 MHz, CDCl₃) δ = 150.2, 149.4, 145.3, 144.5, 143.3, 133.8, 132.5, 131.4, 131.4, 124.8, 115.6

FT-IR (NaCl, thin film) ν = 3351, 3058, 2928, 1496, 1249 cm⁻¹

EA: Calculated: C₁₁H₈N₄; C, 67.34; H, 4.11; N, 28.55; found C, 67.40; H, 4.15; N, 28.21

MP: 138-140°C



2-methyl-3-phenyl-3H-imidazo[4,5-c]pyridine (39): To an oven dried 50 mL Schlenk tube was added pyridine **36h** (82 mg, 0.4 mmol), $\text{Pd}_2(\text{dba})_3\text{CHCl}_3$ (8 mg, 0.008 mmol), $\text{Me}_3(\text{OMe})t\text{BuXPhos}^6$ (20 mg, 0.04 mmol), K_3PO_4 (170 mg, 0.8 mmol), and acetamide (236 mg, 4.0 mmol); the reaction vessel was sealed, evacuated under vacuum and purged with $\text{Ar}_{(\text{g})}$. $t\text{BuOH}$ (2.0 mL) was added and the reaction mixture was degassed with three vacuum / $\text{Ar}_{(\text{g})}$ purge cycles, equipped with a cold-finger condenser and placed in a pre-heated 110°C oil-bath. After 4 h TLC analysis indicated the complete consumption of pyridine **36h**. The reaction mixture was cooled to RT, filtered through Celite®, concentrated *in vacuo* and purified on a silica gel column, eluted with 2% MeOH/DCM, to give 51 mg of pyridine **39** (61%) as a yellow solid.

$R_f = 0.26$ (5% MeOH/DCM)

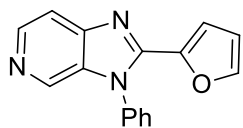
^1H NMR (400 MHz, CDCl_3) $\delta = 8.50$ (s, 1H), 8.42 (d, $J = 5.6$ Hz, 1H), 7.63-7.53 (m, 4H), 7.39-7.36 (m, 2H), 2.53 (s, 3H)

^{13}C NMR (100 MHz, CDCl_3) $\delta = 155.0, 147.9, 142.6, 135.2, 134.3, 133.3, 130.3, 129.5, 126.8, 113.9, 14.5$

FT-IR (NaCl, thin film) $\nu = 3407, 3048, 2926, 1596, 1501, 1392, 822\text{ cm}^{-1}$

EA: Calculated: $\text{C}_{13}\text{H}_{11}\text{N}_3$; C, 74.62; H, 5.30; N, 20.08; found C, 74.77; H, 5.32; N, 19.85

MP: $104\text{-}107^\circ\text{C}$



2-(furan-2-yl)-3-phenyl-3H-imidazo[4,5-c]pyridine (40): To an oven dried

50 mL Schlenk tube was added pyridine **36h** (82 mg, 0.4 mmol), $\text{Pd}_2(\text{dba})_3\text{CHCl}_3$ (8 mg, 0.008 mmol), $\text{Me}_3(\text{OMe})t\text{BuXPhos}^6$ (20 mg, 0.04 mmol), K_3PO_4 (170 mg, 0.8 mmol), and furanamide (222 mg, 2.0 mmol); the reaction vessel was sealed, evacuated under vacuum and purged with $\text{Ar}_{(\text{g})}$. $t\text{BuOH}$ (2.0 mL) was added and the reaction mixture was degassed with three vacuum / $\text{Ar}_{(\text{g})}$ purge cycles, equipped with a cold-finger condenser and placed in a pre-heated 110°C oil-bath. After 5 h TLC analysis indicated the complete consumption of pyridine **36h**. The reaction mixture was cooled to RT, filtered through Celite®, concentrated *in vacuo* and purified on a silica gel column, eluted with 2% MeOH/DCM, to give 53 mg of pyridine **40** (51%) as a yellow solid.

$R_f = 0.21$ (5% MeOH/DCM)

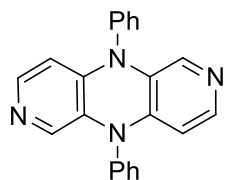
^1H NMR (400 MHz, CDCl_3) $\delta = 8.47$ (s, 1H), 8.47 (d, $J = 5.6$ Hz, 1H), 7.72 (dd, $J = 5.6, 1.2$ Hz, 1H), 7.63-7.59 (m, 3H), 7.50 (dd, $J = 1.2, 0.8$ Hz, 1H), 7.45-7.41 (m, 2H), 6.37 (dd, $J = 3.6, 1.6$ Hz, 1H), 6.29 (dd, $J = 3.6, 0.4$ Hz, 1H)

^{13}C NMR (100 MHz, CDCl_3) $\delta = 147.9, 146.6, 145.2, 144.3, 143.7, 142.9, 135.4, 134.7, 133.6, 130.2, 130.0, 127.6, 114.2, 111.8$

FT-IR (NaCl, thin film) $\nu = 3049, 2924, 2222, 1591, 1502, 1416, 1267, 905, 819 \text{ cm}^{-1}$

EA: Calculated: $\text{C}_{16}\text{H}_{11}\text{N}_3\text{O}$; C, 73.55; H, 4.24; N, 16.08; found C, 73.48; H, 4.28; N, 15.94

MP: $153\text{-}155^\circ\text{C}$



5,10-diphenyl-5,10-dihydrodipyrido[3,4-*b*:3',4'-*e*]pyrazine (38): Pyridine **36h** (82 mg, 0.4 mmol), Pd₂(dba)₃·CHCl₃ (4 mg, 0.004 mmol), Me₃(OMe)*t*-butyl-XPhos¹⁹⁵ (10 mg, 0.02 mmol), K₃PO₄ (128 mg, 0.6 mmol), were combined with 2 mL *tert*-butanol in a 25 mL Schlenk tube. After 16.5 h the

reaction mixture was cooled to RT, filtered through Celite®, concentrated *in vacuo* and purified on a silica gel column, eluted with 5% MeOH/DCM, to give 26 mg of pyrazine **38** (39%) as a yellow solid.

R_f = 0.05 (10% *i*PrOH/DCM)

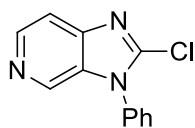
¹H NMR (400 MHz, CD₃OD) δ = 7.68 (d, *J* = 1.5 Hz, 1H), 7.48 (dd, *J* = 6.8, 1.5 Hz, 1H), 7.21-7.17 (m, 2H), 7.05-7.02 (m, 2H), 6.86-6.83 (m, 1H), 6.38 (d, *J* = 6.8 Hz, 1H)

¹³C NMR (100 MHz, CD₃OD) δ = 173.0, 143.4, 136.4, 134.9, 130.7, 122.9, 119.8, 119.3, 113.1

FT-IR (NaCl, thin film) ν = 2928, 2858, 1625, 1590, 1458, 1173, 824 cm⁻¹

EA: Calculated: C₂₂H₁₆N₄; C, 78.55; H, 4.79; N, 16.66; found C, 78.28; H, 4.84; N, 16.75

MP: 168-170°C



2-chloro-3-phenyl-3H-imidazo[4,5-*c*]pyridine (41): Chloride **41** was prepared following a literature procedure.²²⁰ To an oven dried 25 mL Schlenk tube was added pyridine **37h** (49 mg, 0.25 mmol) and 1.0 mL THF. The reaction mixture

was cooled to -78°C (CO₂/acetone bath) and lithium diisopropylamide (2.0M in THF, 0.19 mL) was added drop-wise and the reaction mixture was allowed to stir for 1 h. Hexachloroethane (89 mg, 0.375 mmol) was added as a solution in THF (0.25 mL) and the reaction mixture was warmed to RT over 45 min. The reaction was quenched by the addition of a saturated aqueous solution of ammonium chloride (4 mL) diluted with 5 mL of water and poured into 10 mL of EtOAc. The layers were separated and the aqueous layer was extracted with EtOAc (3 x 5 mL). The combined organic layers were dried over magnesium sulfate, filtered, concentrated *in vacuo* and purified on a silica gel column, eluted with 5% MeOH/ DCM to afford 48 mg of chloride **41** (84%) as a yellow solid.

R_f = 0.40 (5% MeOH/DCM)

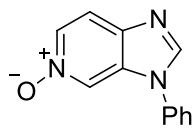
¹H NMR (400 MHz, CDCl₃) δ = 8.58 (s, 1H), 8.52 (d, *J* = 5.7 Hz, 1H), 7.68 (dd, *J* = 6.9, 0.9 Hz, 1H), 7.66-7.60 (m, 3H), 7.49-7.45 (m, 2H)

¹³C NMR (100 MHz, CDCl₃) δ = 146.8, 144.4, 143.0, 134.1, 133.6, 133.2, 130.1, 130.0, 126.9, 114.0

FT-IR (NaCl, thin film) ν = 1638, 1498, 1437, 1366, 1285 cm⁻¹

EA: Calculated: C₁₂H₈ClN₃; C, 62.76; H, 3.51; N, 18.30; found C, 62.94; H, 3.67; N, 18.66

MP: 110°C (decomposition)



3-phenyl-3H-imidazo[4,5-*c*]pyridine 5-oxide (42): To a flame dried 25 mL round bottom flask containing a stir bar was added pyridine **37h** (150 mg, 0.77 mmol) and chloroform (16 mL). After complete dissolution, *m*CPBA (85%, 390 mg, 1.93 mmol) was added as a single portion and the reaction mixture was warmed to 45°C for 2 h. The reaction mixture was cooled to room temp., concentrated *in vacuo* then purified on a silica gel column, eluted with 10% MeOH/ DCM to afford 145 mg of N-oxide **42** (89%) as a white powder.

R_f = 0.02 (EtOAc)

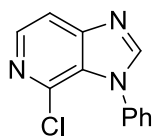
¹H NMR (400 MHz, CDCl₃) δ = 8.56 (d, *J* = 1.0 Hz, 1H), 8.17 (s, 1H), 8.14 (dd, *J* = 6.9, 1.6 Hz, 1H), 7.65 (d, *J* = 6.9 Hz, 1H), 7.57-7.52 (m, 2H), 7.50-7.46 (m, 1H) 7.41-7.39 (m, 2H)

¹³C NMR (100 MHz, CDCl₃) δ = 146.2, 141.9, 135.7, 134.4, 132.1, 130.6, 129.5, 124.6, 123.7, 117.0

FT-IR (NaCl, thin film) ν = 3379, 1506, 1463, 1446, 1204 cm⁻¹

EA: Calculated: C₁₂H₉N₃O; C, 68.24; H, 4.29; N, 19.89; found C, 67.93; H, 4.50; N, 19.56

MP: 174-175°C



4-chloro-3-phenyl-3H-imidazo[4,5-c]pyridine (43): To a 25 mL Schlenk tube containing a stir bar was added N-oxide **42** (42mg, 0.2 mmol) and 0.2 mL of POCl₃.

The reaction mixture was heated in a 120°C oil bath for 2 h then cooled to RT. The reaction mixture was diluted with 5 mL of H₂O and made basic with 1.5 mL of ammonium hydroxide. The aqueous layer was extracted with DCM (3 x 10 mL) and the combined organic layers were dried over MgSO₄, filtered, concentrated *in vacuo* then purified on a silica gel column, eluted with 10% MeOH/ DCM to afford 38 mg of chloride **43** (84%) as an off-white solid.

R_f = 0.50 (5% MeOH/DCM)

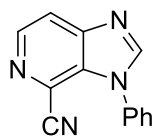
¹H NMR (300 MHz, CDCl₃) δ = 8.27 (d, *J* = 5.5 Hz, 1H), 8.10 (s, 1H), 7.73 (d, *J* = 5.7 Hz, 1H), 7.57-7.53 (m, 3H), 7.46-7.43 (m, 2H)

¹³C NMR (100 MHz, CDCl₃) δ = 150.9, 147.1, 141.5, 134.9, 134.3, 129.7, 129.1, 128.7, 127.7, 115.0

FT-IR (NaCl, thin film) ν = 3054, 1605, 1556, 1240, 980, 821 cm⁻¹

EA: Calculated: C₁₂H₈ClN₃; C, 62.76; H, 3.51; N, 18.30; found C, 62.54; H, 3.66; N, 18.26

MP: 148-151°C



3-phenyl-3H-imidazo[4,5-c]pyridine-4-carbonitrile (44): To an oven dried 15 mL pressure tube containing a stir bar was added N-oxide **42** (53 mg, 0.25 mmol), acetonitrile (0.5 mL), Et₃N (0.05 mL, 0.375 mmol), and trimethylsilylcyanide (0.11 mL, 0.9 mmol). The reaction vessel was sealed with a teflon screw cap and heated in an oil bath at 110°C for 12 h. The reaction mixture was cooled to room temp., diluted with 10 mL DCM and washed with 10mL NaHCO₃ (sat. aq.). The organic layer was dried over MgSO₄, filtered, concentrated *in vacuo* then purified on a silica gel column, eluted with 5% MeOH/ DCM to afford 49 mg of nitrile **44** (89%) as an off-white solid.

R_f = 0.50 (5% MeOH/DCM)

¹H NMR (400 MHz, CDCl₃) δ = 8.63 (d, *J* = 5.6 Hz, 1H), 8.24 (s, 1H), 8.02 (d, *J* = 5.6 Hz, 1H), 7.66-7.63 (m, 3H), 7.52-7.50 (m, 2H)

¹³C NMR (100 MHz, CDCl₃) δ = 150.1, 147.9, 143.4, 133.5, 133.4, 130.7, 130.0, 127.1, 119.2, 117.4, 114.2

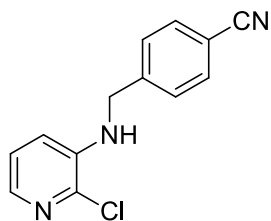
FT-IR (NaCl, thin film) ν = 3115, 3057, 2222, 1595, 1501, 1222 cm⁻¹

EA: Calculated: C₁₃H₈N₄; C, 70.90; H, 3.66; N, 25.44; found C, 70.81; H, 3.59; N, 25.07

MP: 179-181°C

General Procedure E: Reductive Amination

To a flame-dried round-bottom flask equipped with a magnetic stir-bar was added 3-amino-2-chloropyridine (1 equiv.), ethyl acetate (0.78 M) and the appropriate aldehyde (1.2 equiv.). The mixture was allowed to stir until complete dissolution (about 5 min) at which time trifluoroacetic acid (2.0-3.0 equiv.) was added as a single portion via syringe to afford a yellow solution. After stirring at rt for 2 min sodium triacetoxyborohydride (1.2 equiv.) was added in two equal portions 1 minute apart [CAUTION: vigorous gas evolution]; once the reaction was judged complete by TLC analysis, the reaction was quenched by the addition of 20% NaOH_(aq). The pH was adjusted to about 8 by addition of NaOH_(s). The layers were separated and the organic layer was washed with brine, dried over MgSO₄, filtered and concentrated *in vacuo* to afford the crude pyridine which was purified as specified.



4-(((2-chloropyridin-3-yl)amino)methyl)benzonitrile (1o): Adapted

from general procedure E: 3-amino-2-chloropyridine (1.28 g, 10.0 mmol), ethyl acetate (15 mL), 4-formylbenzonitrile (1.44 g, 11.0 mmol), TFA (2.3 mL, 30.0 mmol) and sodium triacetoxyborohydride (2.6 g, 12.0

mmol) were combined and stirred for 1h. After the standard workup, the crude product was recrystallized with 80 mL of 2:1 hexanes:ethyl acetate to give **1o** as colorless prisms (1.48 g, 61%).

A second crop was obtained (0.64 g, 26%); total yield of 87%.

R_f = 0.57 (5% MeOH/DCM)

¹H NMR (400 MHz, CDCl₃) δ = 7.74 (dd, *J* = 4.8, 1.6 Hz, 1H), 7.64 (d, *J* = 8.4 Hz, 2H), 7.44 (d, *J* = 8.8 Hz, 2H), 7.01 (dd, *J* = 8.0, 4.4 Hz, 1H), 4.97 (s, NH), 4.50 (d, *J* = 6.0 Hz, 2H)

¹³C NMR (100 MHz, CDCl₃) δ = 143.5, 140.0, 137.4, 137.3, 132.8, 127.5, 123.4, 118.7, 117.9, 111.6, 47.0

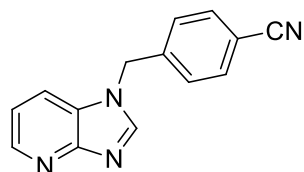
FT-IR: (NaCl, thin film) ν = 3382, 2228, 1585 cm⁻¹

Anal. Calcd. for C₁₃H₁₀ClN₃: C, 64.07; H, 4.14; N, 17.24; found C, 64.03; H, 4.07; N, 17.51

MP: 151-152°C

General Procedure F: Cyclization of 2-Chloro-3-aminopyridines

To an oven-dried 25 mL Schlenk tube equipped with a magnetic stir-bar was added $\text{Pd}_2(\text{dba})_3 \cdot \text{CHCl}_3$ (1 mol %), Xantphos (5 mol %), K_3PO_4 (1.5 equiv.) and the pyridine (1a-1t, 1 equiv.). The reaction vessel was evacuated and refilled with $\text{Ar}_{(\text{g})}$. 1,4-Dioxane:*t*-AmOH (10:1, 0.2 M) and formamide (1.5 equiv.) were then added via syringe and the reaction mixture was degassed by three vacuum/ $\text{Ar}_{(\text{g})}$ purge cycles. The reaction vessel was equipped with a cold-finger, placed in a pre-heated 110 °C oil-bath and stirred for the specified time. Upon consumption of the pyridine (as judged by TLC analysis) the reaction was allowed to cool to RT, diluted with methanol, and passed through a Celite® plug. The solvent was removed *in vacuo* to afford the crude imidazopyridine which was purified as specified.



4-((1H-imidazo[4,5-b]pyridin-1-yl)methyl)benzonitrile (**2o**)

Adapted from general procedure F: $\text{Pd}_2(\text{dba})_3 \cdot \text{CHCl}_3$ (8.0 mg, 0.008 mmol), Xantphos (23 mg, 0.04 mmol), K_3PO_4 (170 mg, 0.8 mmol), 4-(((2-chloropyridin-3-yl)amino)methyl)benzonitrile (**1o**) (97 mg, 0.4

mmol), formamide (24 μL , 0.6 mmol) and 1,4-dioxane:*t*-AmOH (1.85 mL:0.15 mL) were combined and stirred for 19h. The crude product was purified by flash column chromatography (2-5% MeOH in CH_2Cl_2) to yield imidazopyridine **2o** as a light yellow powder (66 mg, 70%).

R_f = 0.12 (5% MeOH/DCM)

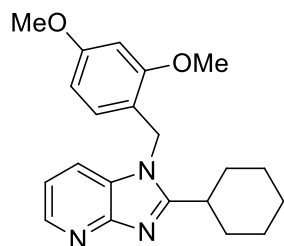
^1H NMR (400 MHz, CDCl_3) δ = 8.52 (dd, J = 4.4 Hz, 1.6 Hz, 1H), 8.14 (s, 1H), 7.58 (d, J = 8.4 Hz, 2H), 7.44 (dd, J = 8.0 Hz, 1.6 Hz, 1H), 7.19 (d, J = 8.0 Hz, 2H), 5.41 (s, 2H)

^{13}C NMR (100 MHz, CDCl_3) δ = 156.5, 145.6, 145.3, 140.1, 133.1, 127.5, 125.9, 118.6, 118.1, 118.1, 112.8, 48.9

FT-IR: (NaCl, thin film) ν = 3391, 2228, 1610, 1494 cm^{-1}

Anal. Calcd. for $\text{C}_{14}\text{H}_{10}\text{N}_4$: C, 71.78; H, 4.30; N, 23.92; found C, 71.63; H, 4.31; N, 23.94

MP: 178-180°C



2-cyclohexyl-1-(2,4-dimethoxybenzyl)-1H-imidazo[4,5-b]pyridine (**7**)

Adapted from general procedure F: Pd₂(dba)₃·CHCl₃ (8.0 mg, 0.008 mmol), Xantphos (23 mg, 0.04 mmol), K₃PO₄ (170 mg, 0.8 mmol), 2-chloro-N-(2,4-dimethoxybenzyl)pyridin-3-amine¹⁵⁷ (134 mg, 0.48 mmol), cyclohexanecarboxamide (51 mg, 0.4 mmol, **Limiting reagent**) and 1,4-dioxane:*t*-AmOH (1.85 mL:0.15 mL) were combined and stirred for 24h.

The crude product was purified by flash column chromatography (1% MeOH in CH₂Cl₂) to yield imidazopyridine **7** as a yellow solid (110 mg, 79%).

R_f = 0.46 (5% MeOH/DCM)

¹H NMR (400 MHz, CDCl₃) δ = 8.43 (dd, *J* = 4.8, 1.2 Hz, 1H), 7.46 (dd, *J* = 8.0, 1.5 Hz, 1H), 7.03 (dd, *J* = 8.0, 4.8 Hz, 1H), 6.55 (d, *J* = 8.4 Hz, 1H), 6.45 (d, *J* = 2.4 Hz, 1H), 6.31 (dd, *J* = 8.4 Hz, 2.4 Hz, 1H), 5.24 (s, 2H), 3.80 (s, 3H), 3.74 (s, 3H), 2.92-2.85 (m, 1H), 1.86-1.84 (m, 6H), 1.76-1.71 (m, 1H), 1.39-1.32 (m, 3H)

¹³C NMR (100 MHz, CDCl₃) δ = 162.2, 160.8, 157.7, 155.9, 144.1, 128.1, 127.5, 117.6, 117.0, 116.2, 104.1, 98.6, 55.4, 55.4, 42.2, 36.5, 31.7, 26.3, 25.7 (29.7, "grease")

FT-IR: (NaCl, thin film) ν = 3419, 3054, 2997, 2933, 2847, 1610, 1584, 837 cm⁻¹

Anal. Calcd. for C₂₁H₂₅N₃O₂: C, 71.77; H, 7.17; N, 11.96; found C, 71.81; H, 7.11; N, 11.99

MP: 134-136°C

4.0 APPENDIX II: BIBLIOGRAPHY

1. Miyaura, N.; Suzuki, A., Palladium-Catalyzed Cross-Coupling Reactions of Organoboron Compounds. *Chem. Rev. (Washington, DC, U. S.)* **1995**, 95, (7), 2457-2483.
2. Heck, R. F., Palladium-Catalyzed Vinylation of Organic Halides. In *Organic Reactions*, John Wiley & Sons, Inc.: 2004.
3. Negishi, E.-i.; Huang, Z.; Wang, G.; Mohan, S.; Wang, C.; Hattori, H., Recent Advances in Efficient and Selective Synthesis of Di-, Tri-, and Tetrasubstituted Alkenes via Pd-Catalyzed Alkenylation-Carbonyl Olefination Synergy. *Acc. Chem. Res.* **2008**, 41, (11), 1474-1485.
4. Stille, J. K., The Palladium-Catalyzed Cross-Coupling Reactions of Organotin Reagents with Organic Electrophiles [New Synthetic Methods (58)]. *Angew. Chem. Int. Ed.* **1986**, 25, (6), 508-524.
5. Tamao, K.; Sumitani, K.; Kumada, M., Selective carbon-carbon bond formation by cross-coupling of Grignard reagents with organic halides. Catalysis by nickel-phosphine complexes. *J. Am. Chem. Soc.* **1972**, 94, (12), 4374-4376.
6. Sonogashira, K.; Tohda, Y.; Hagihara, N., A convenient synthesis of acetylenes: catalytic substitutions of acetylenic hydrogen with bromoalkenes, iodoarenes and bromopyridines. *Tetrahedron Lett.* **1975**, 16, (50), 4467-4470.
7. Hatanaka, Y.; Hiyama, T., Highly Selective Cross-Coupling Reactions of Organosilicon Compounds Mediated by Fluoride Ion and a Palladium Catalyst. *Synlett* **1991**, 1991, (12), 845,853.
8. Trost, B. M.; Ball, Z. T., Addition of Metalloid Hydrides to Alkynes: Hydrometallation with Boron, Silicon, and Tin. *Synthesis* **2005**, 2005, (EFirst), 853,887.
9. Trost, B. M.; Toste, F. D.; Pinkerton, A. B., Non-Metathesis Ruthenium-Catalyzed C-C Bond Formation. *Chem. Rev. (Washington, DC, U. S.)* **2001**, 101, (7), 2067-2096.
10. Mitsudo, T.-a.; Zhang, S.-W.; And, M. N.; Watanabe, Y., Ruthenium complex-catalysed highly selective codimerisation of acetylenes and alkenes. *J. Chem. Soc., Chem. Commun.* **1991**, (8), 598-599.
11. Funk, T. W.; Efskind, J.; Grubbs, R. H., Chemoselective Construction of Substituted Conjugated Dienes Using an Olefin Cross-Metathesis Protocol. *Org. Lett.* **2004**, 7, (2), 187-190.
12. Diver, S. T., Ruthenium vinyl carbene intermediates in enyne metathesis. *Coord. Chem. Rev.* **2007**, 251, (5-6), 671-701.
13. Diver, S. T.; Giessert, A. J., Enyne Metathesis (Enyne Bond Reorganization). *Chem. Rev. (Washington, DC, U. S.)* **2004**, 104, (3), 1317-1382.
14. Castarlenas, R.; Vovard, C.; Fischmeister, C.; Dixneuf, P. H., Allenylidene-to-Indenylidene Rearrangement in Arene-Ruthenium Complexes: A Key Step to Highly Active Catalysts for Olefin Metathesis Reactions. *J. Am. Chem. Soc.* **2006**, 128, (12), 4079-4089.
15. Bieniek, M.; Bujok, R.; Cabaj, M.; Lugan, N.; Lavigne, G.; Arlt, D.; Grela, K., Advanced Fine-Tuning of Grubbs/Hoveyda Olefin Metathesis Catalysts: A Further Step toward an Optimum Balance between Antinomic Properties. *J. Am. Chem. Soc.* **2006**, 128, (42), 13652-13653.
16. Boeda, F.; Clavier, H.; Jordaan, M.; Meyer, W. H.; Nolan, S. P., Phosphabicyclononane-Containing Ru Complexes: Efficient Pre-Catalysts for Olefin Metathesis Reactions. *J. Org. Chem.* **2008**, 73, (1), 259-263.

17. Kitamura, T.; Mori, M., Ruthenium-Catalyzed Ring-Opening and Ring-Closing Enyne Metathesis. *Org. Lett.* **2001**, 3, (8), 1161-1163.
18. Hansen, E. C.; Lee, D., Search for Solutions to the Reactivity and Selectivity Problems in Enyne Metathesis. *Acc. Chem. Res.* **2006**, 39, (8), 509-519.
19. Kakiuchi, F.; Uetsuhara, T.; Tanaka, Y.; Chatani, N.; Murai, S., Ruthenium-catalyzed addition of olefinic C-H bonds in conjugate enones to acetylenes to give conjugate dienones. *J. Mol. Catal. A: Chem.* **2002**, 182-183, (0), 511-514.
20. Lau, C. P.; Ng, S. M.; Jia, G.; Lin, Z., Some ruthenium hydride, dihydrogen, and dihydrogen-bonded complexes in catalytic reactions. *Coord. Chem. Rev.* **2007**, 251, (17-20), 2223-2237.
21. Cook, B. H. O.; Leigh, W. J., Photopericyclic Reactions of Conjugated Dienes and Trienes. In *The Chemistry of Dienes and Polyenes*, John Wiley & Sons, Ltd: 2003; pp 197-255.
22. Nishida, M.; Adachi, N.; Onozuka, K.; Matsumura, H.; Mori, M., Intramolecular Cyclizations of Enynes Using RuClH(CO)(PPh₃)₃. *J. Org. Chem.* **1998**, 63, (25), 9158-9159.
23. Mori, M.; Kozawa, Y.; Nishida, M.; Kanamaru, M.; Onozuka, K.; Takimoto, M., Synthesis of Carbapenam Skeletons Using a Ruthenium-Catalyzed Cyclization. *Org. Lett.* **2000**, 2, (20), 3245-3247.
24. Yi, C. S.; Lee, D. W.; Chen, Y., Hydrovinylation and [2+2] Cycloaddition Reactions of Alkynes and Alkenes Catalyzed by a Well-Defined Cationic Ruthenium-Alkylidene Complex. *Organometallics* **1999**, 18, (11), 2043-2045.
25. Walkowiak, J.; Jankowska-Wajda, M.; Marciniec, B., A New Catalytic Route to Boryl- and Borylsilyl-Substituted Buta-1,3-dienes. *Chem.--Eur. J.* **2008**, 14, (22), 6679-6686.
26. Neisius, N. M.; Plietker, B., The Ruthenium-Catalyzed Hydrovinylation of Internal Alkynes by Acrylates: An Atom Economic Approach to Highly Substituted 1,3-Dienes. *Angew. Chem. Int. Ed.* **2009**, 48, (31), 5752-5755.
27. Bracegirdle, S.; Anderson, E. A., Recent advances in the use of temporary silicon tethers in metal-mediated reactions. *Chem. Soc. Rev.* **2010**, 39, 4114-4129.
28. Zhao, J.; Liu, S.; Marino, N.; Clark, D. A., Regio- and stereoselective trans-silylvinylation of internal alkynes catalyzed by RuHCl(CO)(PCy₃)₂. *Chem. Sci.* **2013**, 4, (4), 1547-1551.
29. Trost, B. M.; Ball, Z. T., Alkyne Hydrosilylation Catalyzed by a Cationic Ruthenium Complex: Efficient and General Trans Addition. *J. Am. Chem. Soc.* **2005**, 127, (50), 17644-17655.
30. Denmark, S. E.; Pan, W., Intramolecular Anti-Hydrosilylation and Silicon-Assisted Cross-Coupling: Highly Regio- and Stereoselective Synthesis of Trisubstituted Homoallylic Alcohols. *Org. Lett.* **2002**, 4, (23), 4163-4166.
31. Na, Y.; Chang, S., Highly Stereoselective and Efficient Hydrosilylation of Terminal Alkynes Catalyzed by [RuCl₂(p-cymene)]₂. *Org. Lett.* **2000**, 2, (13), 1887-1889.
32. Tanaka, K.; Fu, G. C., A Versatile New Method for the Synthesis of Cyclopentenones via an Unusual Rhodium-Catalyzed Intramolecular Trans Hydroacylation of an Alkyne. *J. Am. Chem. Soc.* **2001**, 123, (46), 11492-11493.
33. Tanaka, K.; Fu, G. C., Enantioselective Synthesis of Cyclopentenones via Rhodium-Catalyzed Kinetic Resolution and Desymmetrization of 4-Alkynals. *J. Am. Chem. Soc.* **2002**, 124, (35), 10296-10297.
34. Mori, A.; Takahisa, E.; Kajiro, H.; Hirabayashi, K.; Nishihara, Y.; Hiyama, T., RhCl(PPh₃)₃/NaI Catalyst System for Hydrosilylation of 1-Alkynes: Stereodivergent Syntheses of

E- and Z-Alkenylsilanes with Heteroatom Substituents on Silicon. *Chem. Lett.* **1998**, 27, (5), 443-444.

35. Matsuda, T.; Kadowaki, S.; Yamaguchi, Y.; Murakami, M., Gold-catalysed intramolecular trans-allylsilylation of alkynes forming 3-allyl-1-silaindenes. *Chem. Commun. (Cambridge, U. K.)* **2008**, 24, (24), 2744-2746.

36. Sudo, T.; Asao, N.; Yamamoto, Y., Synthesis of Various Silacycles via the Lewis Acid-Catalyzed Intramolecular Trans-Hydrosilylation of Unactivated Alkynes. *J. Org. Chem* **2000**, 65, (26), 8919-8923.

37. Asao, N.; Shimada, T.; Shimada, T.; Yamamoto, Y., Lewis Acid Catalyzed Stereoselective Carbosilylation. Intramolecular trans-Vinylsilylation and trans-Arylsilylation of Unactivated Alkynes. *J. Am. Chem. Soc.* **2001**, 123, (44), 10899-10902.

38. Lightfoot, A. P.; Twiddle, S. J. R.; Whiting, A., A stereoselective synthesis of 1,6-diphenyl-1,3,5-hexatrienes utilising 4,4,6-trimethyl-2-vinyl-1,3,2-dioxaborinane as a two-carbon alkenyl building block. *Org. Biomol. Chem.* **2005**, 3, (17), 3167-3172.

39. Hansen, E. C.; Lee, D., Synthesis of β,β -Disubstituted Vinyl Boronates via the Ruthenium-Catalyzed Alder Ene Reaction of Borylated Alkynes and Alkenes. *J. Am. Chem. Soc.* **2005**, 127, (10), 3252-3253.

40. Satoh, Y.; Serizawa, H.; Miyaura, N.; Hara, S.; Suzuki, A., Organic synthesis using haloboration reactions 11. A formal carboboration reaction of 1-alkynes and its application to the di- and trisubstituted alkene synthesis. *Tetrahedron Lett.* **1988**, 29, (15), 1811-1814.

41. Denmark, S. E.; Liu, J. H. C., Silicon-Based Cross-Coupling Reactions in the Total Synthesis of Natural Products. *Angew. Chem. Int. Ed.* **2010**, 49, (17), 2978-2986.

42. Marciniak, B., Catalytic Coupling of sp^2 - and sp -Hybridized Carbon-Hydrogen Bonds with Vinylmetalloid Compounds. *Acc. Chem. Res.* **2007**, 40, (10), 943-952.

43. Johansson Seechurn, C. C. C.; Kitching, M. O.; Colacot, T. J.; Snieckus, V., Palladium-Catalyzed Cross-Coupling: A Historical Contextual Perspective to the 2010 Nobel Prize. *Angew. Chem. Int. Ed.* **2012**, 51, (21), 5062-5085.

44. Lennox, A. J. J.; Lloyd-Jones, G. C., Selection of boron reagents for Suzuki-Miyaura coupling. *Chem. Soc. Rev.* **2014**, 43, (1), 412-443.

45. Fleming, I., Tilden Lecture. Some uses of silicon compounds in organic synthesis. *Chem. Soc. Rev.* **1981**, 10, (1), 83-111.

46. Nakao, Y.; Hiyama, T., Silicon-based cross-coupling reaction: an environmentally benign version. *Chem. Soc. Rev.* **2011**, 40, (10), 4893-4901.

47. PraveenGanesh, N.; d'Hond, S.; Chavant, P. Y., Methylpentanediolborane: Easy Access to New Air- and Chromatography-Stable, Highly Functionalized Vinylboronates. *J. Org. Chem* **2007**, 72, (12), 4510-4514.

48. Jang, H.; Zhugralin, A. R.; Lee, Y.; Hoveyda, A. H., Highly Selective Methods for Synthesis of Internal (α -) Vinylboronates through Efficient NHC-Cu-Catalyzed Hydroboration of Terminal Alkynes. Utility in Chemical Synthesis and Mechanistic Basis for Selectivity. *J. Am. Chem. Soc.* **2011**, 133, (20), 7859-7871.

49. Lee, Y.; Jang, H.; Hoveyda, A. H., Vicinal Diboronates in High Enantiomeric Purity through Tandem Site-Selective NHC-Cu-Catalyzed Boron-Copper Additions to Terminal Alkynes. *J. Am. Chem. Soc.* **2009**, 131, (51), 18234-18235.

50. Ishiyama, T.; Matsuda, N.; Murata, M.; Ozawa, F.; Suzuki, A.; Miyauchi, N., Platinum(0)-Catalyzed Diboration of Alkynes with Tetrakis(alkoxy)diborons: An Efficient and Convenient Approach to cis-Bis(boryl)alkenes. *Organometallics* **1996**, 15, (2), 713-720.
51. Morrill, C.; Funk, T. W.; Grubbs, R. H., Synthesis of tri-substituted vinyl boronates via ruthenium-catalyzed olefin cross-metathesis. *Tetrahedron Lett.* **2004**, 45, (41), 7733-7736.
52. Morrill, C.; Grubbs, R. H., Synthesis of Functionalized Vinyl Boronates via Ruthenium-Catalyzed Olefin Cross-Metathesis and Subsequent Conversion to Vinyl Halides. *J. Org. Chem* **2003**, 68, (15), 6031-6034.
53. Suginome, M.; Ito, Y., Regio- and stereoselective synthesis of boryl-substituted allylsilanes via transition metal-catalyzed silaboration. *J. Organomet. Chem.* **2003**, 680, (1-2), 43-50.
54. Suginome, M.; Matsuda, T.; Ito, Y., Nickel-Catalyzed Silaborative Dimerization of Alkynes. *Organometallics* **1998**, 17, (24), 5233-5235.
55. Suginome, M.; Nakamura, H.; Ito, Y., Regio- and stereo-selective silaboration of alkynes catalysed by palladium and platinum complexes. *Chem. Commun. (Cambridge, U. K.)* **1996**, (24), 2777-2778.
56. Burks, H. E.; Morken, J. P., Catalytic enantioselective diboration, disililation and silaboration: new opportunities for asymmetric synthesis. *Chem. Commun. (Cambridge, U. K.)* **2007**, 45, (45), 4717-4725.
57. Flynn, A. B.; Ogilvie, W. W., Stereocontrolled Synthesis of Tetrasubstituted Olefins. *Chem. Rev. (Washington, DC, U. S.)* **2007**, 107, (11), 4698-4745.
58. Wang, Z.; Lu, X.; Lei, A.; Zhang, Z., Efficient Preparation of Functionalized (E,Z) Dienes Using Acetylene as the Building Block. *J. Org. Chem* **1998**, 63, (12), 3806-3807.
59. Charette, A. B.; Berthelette, C.; St-Martin, D., An expedient approach to E,Z-dienes using the Julia olefination. *Tetrahedron Lett.* **2001**, 42, (31), 5149-5153.
60. Woerly, E. M.; Roy, J.; Burke, M. D., Synthesis of most polyene natural product motifs using just 12 building blocks and one coupling reaction. *Nature Chem.* **2014**, 6, (6), 484-491.
61. Hitosugi, S.; Tanimoto, D.; Nakanishi, W.; Isobe, H., A Facile Chromatographic Method for Purification of Pinacol Boronic Esters. *Chem. Lett.* **2012**, 41, (9), 972-973.
62. Lightfoot, A. P.; Maw, G.; Thirsk, C.; Twiddle, S. J. R.; Whiting, A., 4,4,6-Trimethyl-2-vinyl-1,3,2-dioxaborinane: a superior 2-carbon building block for vinylboronate Heck couplings. *Tetrahedron Lett.* **2003**, 44, (41), 7645-7648.
63. Uno, B. E.; Gillis, E. P.; Burke, M. D., Vinyl MIDA boronate: a readily accessible and highly versatile building block for small molecule synthesis. *Tetrahedron* **2009**, 65, (16), 3130-3138.
64. Molander, G. A.; Rivero, M. R., Suzuki Cross-Coupling Reactions of Potassium Alkenyltrifluoroborates *Org. Lett.* **2001**, 4, (1), 107-109.
65. Liu, S.; Zhao, J.; Kaminsky, L.; Wilson, R. J.; Marino, N.; Clark, D. A., Ethylene Transposition: Ruthenium Hydride Catalyzed Intramolecular trans-Silylvinylation of Internal Alkynes. *Org. Lett.* **2014**, 16, (17), 4456-4459.
66. Littke, A. F.; Fu, G. C., A Convenient and General Method for Pd-Catalyzed Suzuki Cross-Couplings of Aryl Chlorides and Arylboronic Acids. *Angew. Chem. Int. Ed.* **1998**, 37, (24), 3387-3388.
67. Fuwa, H.; Suzuki, T.; Kubo, H.; Yamori, T.; Sasaki, M., Total Synthesis and Biological Assessment of (-)-Exiguolide and Analogues. *Chem.-Eur. J.* **2011**, 17, (9), 2678-2688.

68. Xu, S.; Lee, C.-T.; Rao, H.; Negishi, E.-i., Highly ($\geq 98\%$) Stereo- and Regioselective Trisubstituted Alkene Synthesis of Wide Applicability via 1-Halo-1-alkyne Hydro- boration–Tandem Negishi–Suzuki Coupling or Organoborate Migratory Insertion. *Adv. Synth. Catal.* **2011**, 353, (16), 2981-2987.
69. Varchi, G.; Ojima, I., Synthesis of heterocycles through hydrosilylation, silylformylation, silylcarbocyclization and cyclohydrocarbonylation reactions. *Curr. Org. Chem.* **2006**, 10, 1341-1362.
70. Ojima, I.; Vidal, E. S., Extremely Regioselective Intramolecular Silylformylation of Bis(silylamino)alkynes. *Organometallics* **1999**, 18, 5103-5107.
71. Ojima, I.; Ingallina, P.; Donovan, R. J.; Clos, N., Silylformylation of 1-hexyne catalyzed by rhodium-cobalt mixed-metal carbonyl clusters. *Organometallics* **1991**, 10, 38-41.
72. Ojima, I.; Clos, N.; Donovan, R. J.; Ingallina, P., Hydrosilylation of 1-hexyne catalyzed by rhodium and cobalt-rhodium mixed-metal complexes. Mechanism of apparent trans addition. *Organometallics* **1990**, 9, 3127-3133.
73. Varchi, G.; Ojima, I., Synthesis of heterocycles through hydrosilylation, silylformylation, silylcarbocyclization and cyclohydrocarbonylation reactions. *Current Organic Chemistry* **2006**, 10, (12), 1341-1362.
74. Denmark, S. E.; Kobayashi, T., Tandem Intramolecular Silylformylation and Silicon-Assisted Cross-Coupling Reactions. Synthesis of Geometrically Defined α,β -Unsaturated Aldehydes. *J. Org. Chem.* **2003**, 68, 5153-5159.
75. Denmark, S. E.; Liu, J. H.-C., Sequential Silylcarbocyclization/Silicon-Based Cross-Coupling Reactions. *J. Am. Chem. Soc.* **2007**, 129, 3737-3744.
76. Denmark, S. E.; Liu, J. H.-C.; Muhuhi, J. M., Stereocontrolled Total Syntheses of Isodomoic Acids G and H via a Unified Strategy. *J. Org. Chem.* **2011**, 76, 201-215.
77. Denmark, S. E.; Liu, J. H.-C.; Muhuhi, J. M., Total Syntheses of Isodomoic Acids G and H. *J. Am. Chem. Soc.* **2009**, 131, 14188-14189.
78. Matsuda, T.; Kadowaki, S.; Yamaguchi, Y.; Murakami, M., Gold-catalysed intramolecular trans-allylsilylation of alkynes forming 3-allyl-1-silaindenes. *Chem. Commun. (Cambridge, U. K.)* **2008**, 24, 2744-2746.
79. Matsuda, T.; Yamaguchi, Y.; Shigeno, M.; Sato, S.; Murakami, M., Gold-catalysed alkenyl- and arylsilylation reactions forming 1-silaindenes. *Chem. Commun. (Cambridge, U. K.)* **2011**, 47, 8697-8699.
80. Nishida, M.; Adachi, N.; Onozuka, K.; Matsumura, H.; Mori, M., Intramolecular Cyclizations of Enynes Using $\text{RuClH}(\text{CO})(\text{PPh}_3)_3$. *J. Org. Chem.* **1998**, 63, 9158-9159.
81. Giessert, A. J.; Brazis, N. J.; Diver, S. T., Ethylene-Promoted Intermolecular Enyne Metathesis. *Org. Lett.* **2003**, 5, 3819-3822.
82. Jung, M. E.; Piizzi, G., gem-Disubstituent Effect: Theoretical Basis and Synthetic Applications. *Chem. Rev. (Washington, DC, U. S.)* **2005**, 105, 1735-1766.
83. Ojima, I.; Tzamarioudaki, M.; Tsai, C.-Y., Extremely Chemoselective Silylformylation and Silylcarbocyclization of Alkynals. *J. Am. Chem. Soc.* **1994**, 116, 3643-3644.
84. Ojima, I.; Vidal, E.; Tzamarioudaki, M.; Matsuda, I., Extremely Regioselective Intramolecular Silylformylation of Alkynes. *J. Am. Chem. Soc.* **1995**, 117, 6797-6798.
85. Denmark, S. E.; Butler, C. R., Palladium- (and nickel-) catalyzed vinylation of aryl halides. *Chem. Commun. (Cambridge, U. K.)* **2009**, 1, (1), 20-33.

86. Saini, V.; Stokes, B. J.; Sigman, M. S., Transition-Metal-Catalyzed Laboratory-Scale Carbon–Carbon Bond-Forming Reactions of Ethylene. *Angew. Chem. Int. Ed.* **2013**, 52, (43), 11206-11220.
87. Saini, V.; Sigman, M. S., Palladium-Catalyzed 1,1-Difunctionalization of Ethylene. *J. Am. Chem. Soc.* **2012**, 134, (28), 11372-11375.
88. Plevyak, J. E.; Heck, R. F., Palladium-catalyzed arylation of ethylene. *J. Org. Chem.* **1978**, 43, (12), 2454-2456.
89. RajanBabu, T. V., In Pursuit of an Ideal Carbon-Carbon Bond-Forming Reaction: Development and Applications of the Hydrovinylation of Olefins. *Synlett* **2009**, 2009, (06), 853-885.
90. Mans, D. J.; Cox, G. A.; RajanBabu, T. V., Ethylene in Organic Synthesis. Repetitive Hydrovinylation of Alkenes for Highly Enantioselective Syntheses of Pseudopterosins. *J. Am. Chem. Soc.* **2011**, 133, (15), 5776-5779.
91. Gusev, D. G., Donor Properties of a Series of Two-Electron Ligands. *Organometallics* **2009**, 28, (3), 763-770.
92. Dharmasena, U. L.; Foucault, H. M.; dos Santos, E. N.; Fogg, D. E.; Nolan, S. P., N-Heterocyclic Carbenes as Activating Ligands for Hydrogenation and Isomerization of Unactivated Olefins. *Organometallics* **2005**, 24, (6), 1056-1058.
93. Denmark, S. E.; Kobayashi, T., Tandem Intramolecular Silylformylation and Silicon-Assisted Cross-Coupling Reactions. Synthesis of Geometrically Defined α,β -Unsaturated Aldehydes. *J. Org. Chem.* **2003**, 68, (13), 5153-5159.
94. Smith III, A. B.; Cho, Y. S.; Friestad, G. K., Convenient Wacker oxidations with substoichiometric cupric acetate. *Tetrahedron Lett.* **1998**, 39, (48), 8765-8768.
95. Wender, P. A.; Deschamps, N. M.; Williams, T. J., Intermolecular Dienyl Pauson–Khand Reaction. *Angew. Chem. Int. Ed.* **2004**, 43, (23), 3076-3079.
96. Denmark, S. E.; Tymonko, S. A., Sequential Cross-Coupling of 1,4-Bissilylbutadienes: Synthesis of Unsymmetrical 1,4-Disubstituted 1,3-Butadienes. *J. Am. Chem. Soc.* **2005**, 127, (22), 8004-8005.
97. Sahoo, A. K.; Oda, T.; Nakao, Y.; Hiyama, T., Cross-Coupling of Triallyl(aryl)silanes with Aryl Bromides and Chlorides: An Alternative Convenient Biaryl Synthesis. *Adv. Synth. Catal.* **2004**, 346, (13-15), 1715-1727.
98. Scarborough, R. M.; Toder, B. H.; Smith, A. B., A stereospecific total synthesis of (+-)-methylenomycin A and its epimer, (+-)-epimethylenomycin A. *J. Am. Chem. Soc.* **1980**, 102, (11), 3904-3913.
99. Murray, R. W.; Jeyaraman, R., Dioxiranes: synthesis and reactions of methyldioxiranes. *J. Org. Chem.* **1985**, 50, (16), 2847-2853.
100. Davis, F. A.; Towson, J. C.; Weismiller, M. C.; Lal, S.; Carroll, P. J., Chemistry of oxaziridines. 11. (Camphorylsulfonyl)oxaziridine: synthesis and properties. *J. Am. Chem. Soc.* **1988**, 110, (25), 8477-8482.
101. Payne, G. B.; Deming, P. H.; Williams, P. H., Reactions of Hydrogen Peroxide. VII. Alkali-Catalyzed Epoxidation and Oxidation Using a Nitrile as Co-reactant. *J. Org. Chem.* **1961**, 26, (3), 659-663.
102. Plietker, B.; Niggemann, M., An Improved Protocol for the RuO₄-Catalyzed Dihydroxylation of Olefins. *Org. Lett.* **2003**, 5, (18), 3353-3356.

103. Plietker, B.; Niggemann, M.; Pollrich, A., The acid accelerated ruthenium-catalysed dihydroxylation. Scope and limitations. *Org. Biomol. Chem.* **2004**, 2, (8), 1116-1124.
104. Marciniak, B., Hydrosilylation of Alkynes and Their Derivatives. In *Hydrosilylation*, Marciniak, B., Ed. Springer Netherlands: 2009; Vol. 1, pp 53-86.
105. Marciniak, B., *Hydrosilylation: A Comprehensive Review on Recent Advances*. Springer Netherlands: 2009.
106. Clarson, S., Bogdan Marciniak, Hydrosilylation: A Comprehensive Review on Recent Advances. *Silicon* **2009**, 1, (1), 57-58.
107. Leighton, J. L., Stereoselective Rhodium(I)-Catalyzed Hydroformylation and Silylformylation Reactions and Their Application to Organic Synthesis. In *Modern Rhodium-Catalyzed Organic Reactions*, Wiley-VCH Verlag GmbH & Co. KGaA: 2005; pp 93-110.
108. O'Malley, S. J.; Leighton, J. L., Tandem Intramolecular Alkyne Silylformylation-Allylsilylation: A Case of Remote 1,5-Asymmetric Induction. *Angew. Chem. Int. Ed.* **2001**, 40, (15), 2915-2917.
109. Katayama, H.; Taniguchi, K.; Kobayashi, M.; Sagawa, T.; Minami, T.; Ozawa, F., Ruthenium-catalyzed hydrosilylation of terminal alkynes: stereodivergent synthesis of (E)- and (Z)-alkenylsilanes. *J. Organomet. Chem.* **2002**, 645, (1-2), 192-200.
110. Lim, D. S. W.; Anderson, E. A., Synthesis of vinylsilanes. *Synthesis* **2012**, 44, 983-1010.
111. Denmark, S. E.; Sweis, R. F., Organosilicon Compounds in Cross-Coupling Reactions. In *Metal-Catalyzed Cross-Coupling Reactions and More*, Wiley-VCH Verlag GmbH & Co. KGaA: 2014; pp 475-532.
112. Foley, C. N.; Leighton, J. L., Beyond the Roche Ester: A New Approach to Polypropionate Stereotriad Synthesis. *Org. Lett.* **2014**, 16, (4), 1180-1183.
113. Trost, B. M.; Frederiksen, M. U.; Rudd, M. T., Ruthenium-Catalyzed Reactions—A Treasure Trove of Atom-Economic Transformations. *Angew. Chem. Int. Ed.* **2005**, 44, (41), 6630-6666.
114. Mori, M.; Tanaka, D.; Saito, N.; Sato, Y., Ruthenium-Catalyzed Alkenylative Cyclization via Insertion of Alkene into Ruthenacyclopentene. *Organometallics* **2008**, 27, (23), 6313-6320.
115. Mori, M.; Kuzuba, Y.; Kitamura, T.; Sato, Y., Ruthenium-Catalyzed ROM-RCM of Cycloalkene-yne. *Org. Lett.* **2002**, 4, (22), 3855-3858.
116. Saito, N.; Sato, Y.; Mori, M., Synthesis of Cyclic Dienamide Using Ruthenium-Catalyzed Ring-Closing Metathesis of Ene-Ynamide. *Org. Lett.* **2002**, 4, (5), 803-805.
117. Denmark, S. E.; Pan, W., Intramolecular hydrosilylation and silicon-assisted cross-coupling: An efficient route to trisubstituted homoallylic alcohols. *Org. Lett.* **2001**, 3, 61-64.
118. Denmark, S. E.; Pan, W., Intramolecular Syn and Anti Hydrosilylation and Silicon-Assisted Cross-Coupling: Highly Regio- and Stereoselective Synthesis of Trisubstituted Allylic Alcohols. *Org. Lett.* **2003**, 5, 1119-1122.
119. Kaminsky, L.; Wilson, R. J.; Clark, D. A., Stereo- and Regioselective Formation of Silyl-Dienyl Boronates. *Org. Lett.* **2015**, 17, (12), 3126-3129.
120. Ogo, S.; Uehara, K.; Abura, T.; Watanabe, Y.; Fukuzumi, S., Aqueous Polymerization of Styrene Promoted by Water-Soluble Robust Ruthenium Hydride Complexes. *Organometallics* **2004**, 23, (12), 3047-3052.
121. Clark, J. R.; Griffiths, J. R.; Diver, S. T., Ruthenium Hydride-Promoted Dienyl Isomerization: Access to Highly Substituted 1,3-Dienes. *J. Am. Chem. Soc.* **2013**, 135, (9), 3327-3330.

122. MacMillan, D. S.; Murray, J.; Sneddon, H. F.; Jamieson, C.; Watson, A. J. B., Replacement of dichloromethane within chromatographic purification: a guide to alternative solvents. *Green Chem.* **2012**, 14, (11), 3016-3019.
123. MacMillan, D. S.; Murray, J.; Sneddon, H. F.; Jamieson, C.; Watson, A. J. B., Evaluation of alternative solvents in common amide coupling reactions: replacement of dichloromethane and N,N-dimethylformamide. *Green Chem.* **2013**, 15, (3), 596-600.
124. Hu, E.; Andrews, K.; Chmait, S.; Zhao, X.; Davis, C.; Miller, S.; Hill Della Puppa, G.; Dovlatyan, M.; Chen, H.; Lester-Zeiner, D.; Able, J.; Biorn, C.; Ma, J.; Shi, J.; Treanor, J.; Allen, J. R., Discovery of Novel Imidazo[4,5-b]pyridines as Potent and Selective Inhibitors of Phosphodiesterase 10A (PDE10A). *ACS Med. Chem. Lett.* **2014**, [Online early access] DOI: 10.1021/ml5000993.
125. Newhouse, B. J.; Wenglowky, S.; Grina, J.; Laird, E. R.; Voegtli, W. C.; Ren, L.; Ahrendt, K.; Buckmelter, A.; Gloor, S. L.; Klopfenstein, N.; Rudolph, J.; Wen, Z.; Li, X.; Feng, B., Imidazo[4,5-b]pyridine inhibitors of B-Raf kinase. *Bioorg. Med. Chem. Lett.* **2013**, 23, (21), 5986-5999.
126. Bukhryakov, K.; Kurkin, A.; Yurovskaya, M., Synthetic approaches to imidazo[4,5-b]pyridine derivatives (review). *Chem. Heterocycl. Compd. (N. Y., NY, U. S.)* **2011**, 47, (5), 533-557.
127. Lukasik, P. M.; Elabar, S.; Lam, F.; Shao, H.; Liu, X.; Abbas, A. Y.; Wang, S., Synthesis and biological evaluation of imidazo[4,5-b]pyridine and 4-heteroaryl-pyrimidine derivatives as anti-cancer agents. *Eur. J. Med. Chem.* **2012**, 57, (0), 311-322.
128. Bavetsias, V.; Crumpler, S.; Sun, C.; Avery, S.; Atrash, B.; Faisal, A.; Moore, A. S.; Kosmopoulou, M.; Brown, N.; Sheldrake, P. W.; Bush, K.; Henley, A.; Box, G.; Valenti, M.; de Haven Brandon, A.; Raynaud, F. I.; Workman, P.; Eccles, S. A.; Bayliss, R.; Linardopoulos, S.; Blagg, J., Optimization of Imidazo[4,5-b]pyridine-Based Kinase Inhibitors: Identification of a Dual FLT3/Aurora Kinase Inhibitor as an Orally Bioavailable Preclinical Development Candidate for the Treatment of Acute Myeloid Leukemia. *J. Med. Chem.* **2012**, 55, (20), 8721-8734.
129. Cappelli, A.; Pericot Mohr, G. I.; Giuliani, G.; Galeazzi, S.; Anzini, M.; Mennuni, L.; Ferrari, F.; Makovec, F.; Kleinrath, E. M.; Langer, T.; Valoti, M.; Giorgi, G.; Vomero, S., Further Studies on Imidazo[4,5-b]pyridine AT1 Angiotensin II Receptor Antagonists. Effects of the Transformation of the 4-Phenylquinoline Backbone into 4-Phenylisoquinolinone or 1-Phenylindene Scaffolds. *J. Med. Chem.* **2006**, 49, (22), 6451-6464.
130. Chakravarty, P. K.; Naylor, E. M.; Chen, A.; Chang, R. S. L.; Chen, T.-B.; Faust, K. A.; Lotti, V. J.; Kivlighn, S. D.; Gable, R. A., A Highly Potent, Orally Active Imidazo[4,5-b]pyridine Biphenyl Acylsulfonamide (MK-996; L-159,282): A New AT1-Selective Angiotensin II Receptor Antagonist. *J. Med. Chem.* **1994**, 37, (24), 4068-4072.
131. Nicolai, E.; Goyard, J.; Benchetrit, T.; Teulon, J. M.; Caussade, F.; Virone, A.; Delchambre, C.; Cloarec, A., Synthesis and structure-activity relationships of novel benzimidazole and imidazo[4,5-b]pyridine acid derivatives as thromboxane A2 receptor antagonists. *Journal of Medicinal Chemistry* **1993**, 36, (9), 1175-1187.
132. Mishra, A.; Sahu, S.; Dash, N.; Behera, S. K.; Krishnamoorthy, G., Double Proton Transfer Induced Twisted Intramolecular Charge Transfer Emission in 2-(4- N,N -Dimethylaminophenyl)imidazo[4,5-b]pyridine. *J. Phys. Chem. B* **2013**, 117, (32), 9469-9477.

133. Senanayake, C. H.; Fredenburgh, L. E.; Reamer, R. A.; Liu, J.; Larsen, R. D.; Verhoeven, T. R.; Reider, P. J., Magnesium-assisted imidazole formation from unreactive ureas. *Tetrahedron Letters* **1994**, 35, (32), 5775-5778.
134. Yutilov, Y. M.; Alan, R. K., Imidazopyridines: 1- and 3-Deazapurines. In *Advances in Heterocyclic Chemistry*, Academic Press: 2005; Vol. 89, pp 159-270.
135. Magano, J.; Dunetz, J. R., Large-Scale Applications of Transition Metal-Catalyzed Couplings for the Synthesis of Pharmaceuticals. *Chem. Rev. (Washington, DC, U. S.)* **2011**, 111, (3), 2177-2250.
136. Horton, D. A.; Bourne, G. T.; Smythe, M. L., The Combinatorial Synthesis of Bicyclic Privileged Structures or Privileged Substructures. *Chem. Rev. (Washington, DC, U. S.)* **2003**, 103, (3), 893-930.
137. Fernández Sainz, Y.; Raw, S. A.; Taylor, R. J. K., Improved Methodologies for the Preparation of Highly Substituted Pyridines. *J. Org. Chem* **2005**, 70, (24), 10086-10095.
138. Kwong, H.-L.; Yeung, H.-L.; Yeung, C.-T.; Lee, W.-S.; Lee, C.-S.; Wong, W.-L., Chiral pyridine-containing ligands in asymmetric catalysis. *Coord. Chem. Rev.* **2007**, 251, (17-20), 2188-2222.
139. Fuwa, H.; Kobayashi, T.; Tokitoh, T.; Torii, Y.; Natsugari, H., Synthetic studies on 3-arylquinazolin-4-ones: intramolecular nucleophilic aromatic substitution reaction of 2-carboxamido-3-arylquinazolin-4-ones and its application to the synthesis of secondary aryl amines. *Tetrahedron* **2005**, 61, (17), 4297-4312.
140. Temple, C.; Rose, J. D.; Comber, R. N.; Renner, G. A., Synthesis of potential anticancer agents: imidazo[4,5-c]pyridines and imidazo[4,5-b]pyridines. *J. Med. Chem.* **1987**, 30, (10), 1746-1751.
141. Cristalli, G.; Vittori, S.; Eleuteri, A.; Grifantini, M.; Volpini, R.; Lupidi, G.; Capolongo, L.; Pesenti, E., Purine and 1-deazapurine ribonucleosides and deoxyribonucleosides: synthesis and biological activity. *J. Med. Chem.* **1991**, 34, (7), 2226-2230.
142. Cundy, D. J.; Holan, G.; Otaegui, M.; Simpson, G. W., 3-[(3-Hydroxymethyl)-4-hydroxybutyl]imidazo[4,5-b]pyridines a novel antiviral agents. *Bioorg. Med. Chem. Lett.* **1997**, 7, (6), 669-674.
143. Cristalli, G.; Vittori, S.; Eleuteri, A.; Volpini, R.; Camaioni, E.; Lupidi, G.; Mahmood, N.; Bevilacqua, F.; Palu, G., Synthesis and Biological Evaluation of N6-Cycloalkyl Derivatives of 1-Deazaadenine Nucleosides: A New Class of Anti-Human Immunodeficiency Virus Agents. *J. Med. Chem.* **1995**, 38, (20), 4019-4025.
144. Tomczuk, B. E.; Taylor, C. R.; Moses, L. M.; Sutherland, D. B.; Lo, Y. S.; Johnson, D. N.; Kinnier, W. B.; Kilpatrick, B. F., 2-Phenyl-3H-imidazo[4,5-b]pyridine-3-acetamides as nonbenzodiazepine anticonvulsants and anxiolytics. *J. Med. Chem.* **1991**, 34, (10), 2993-3006.
145. Bavetsias, V.; Large, J. M.; Sun, C.; Boulloc, N.; Kosmopoulou, M.; Matteucci, M.; Wilsher, N. E.; Martins, V.; Reynisson, J. h.; Atrash, B.; Faisal, A.; Urban, F.; Valenti, M.; de Haven Brandon, A.; Box, G.; Raynaud, F. I.; Workman, P.; Eccles, S. A.; Bayliss, R.; Blagg, J.; Linardopoulos, S.; McDonald, E., Imidazo[4,5-b]pyridine Derivatives As Inhibitors of Aurora Kinases: Lead Optimization Studies toward the Identification of an Orally Bioavailable Preclinical Development Candidate. *J. Med. Chem.* **53**, (14), 5213-5228.
146. Bavetsias, V.; Sun, C.; Boulloc, N.; Reynisson, J. h.; Workman, P.; Linardopoulos, S.; McDonald, E., Hit generation and exploration: Imidazo[4,5-b]pyridine derivatives as inhibitors of Aurora kinases. *Bioorg. Med. Chem. Lett.* **2007**, 17, (23), 6567-6571.

147. Mantlo, N. B.; Chakravarty, P. K.; Ondeyka, D. L.; Siegl, P. K. S.; Chang, R. S.; Lotti, V. J.; Faust, K. A.; Schorn, T. W.; Chen, T. B., Potent, orally active imidazo[4,5-b]pyridine-based angiotensin II receptor antagonists. *J. Med. Chem.* **1991**, 34, (9), 2919-2922.
148. Casimiro-Garcia, A.; Filzen, G. F.; Flynn, D.; Bigge, C. F.; Chen, J.; Davis, J. A.; Dudley, D. A.; Edmunds, J. J.; Esmaeil, N.; Geyer, A.; Heemstra, R. J.; Jalaie, M.; Ohren, J. F.; Ostroski, R.; Ellis, T.; Schaum, R. P.; Stoner, C., Discovery of a Series of Imidazo[4,5-b]pyridines with Dual Activity at Angiotensin II Type 1 Receptor and Peroxisome Proliferator-Activated Receptor. *J. Med. Chem.* **2011**, 54, (12), 4219-4233.
149. Shengule, S. R.; Loa-Kum-Cheung, W. L.; Parish, C. R.; Blairvacq, M.; Meijer, L.; Nakao, Y.; Karuso, P., A One-Pot Synthesis and Biological Activity of Ageladine A and Analogues. *J. Med. Chem.* **2011**, 54, (7), 2492-2503.
150. Dyer, D. G.; Dunn, J. A.; Thorpe, S. R.; Bailie, K. E.; Lyons, T. J.; McCance, D. R.; Baynes, J. W., Accumulation of Maillard reaction products in skin collagen in diabetes and aging. *J. Clin. Invest.* **1993**, 91, (6), 2463 - 2469.
151. Batt, D. G.; Houghton, G. C., Polyfunctional pyridines from nitroacetamide and β -diketones. A useful synthesis of substituted imidazo [4,5-b] pyridines and related compounds. *J. Heterocycl. Chem.* **1995**, 32, (3), 963-969.
152. Khanna, I. K.; Weier, R. M.; Lentz, K. T.; Swenton, L.; Lankin, D. C., Facile, Regioselective Syntheses of N-Alkylated 2,3-Diaminopyridines and Imidazo[4,5-b]pyridines. *J. Org. Chem.* **1995**, 60, (4), 960-965.
153. Senanayake, C. H.; Fredenburgh, L. E.; Reamer, R. A.; Liu, J.; Roberts, F. E.; Humphrey, G.; Thompson, A. S.; Larsen, R. D.; Verhoeven, T. R.; Reider, P. J.; Sinkai, I., New Approach to the Imidazolotidine Moiety of MK-996. *Heterocycles* **1996**, 42, (2), 821 - 830.
154. M.Ross, G., *Imidazole and Benzimidazole Synthesis*. Academic Press: San Diego, 1997.
155. Deghati, P. Y. F.; BierÄugel, H.; Wanner, M. J.; Koomen, G.-J., Mild and regioselective nitration of 1-deazapurine nucleosides using TBAN/TFAA. *Tetrahedron Lett.* **2000**, 41, (4), 569-573.
156. Yıldırım, I.; Kandemirli, F.; Demir, E., Experimental and Theoretical Studies on the Functionalization Reactions of 4-Benzoyl-1,5-Diphenyl-1H-Pyrazole-3-Carboxylic Acid and Acid Chloride with 2,3-Diaminopyridine. *Molecules* **2005**, 10, (3), 559 - 571.
157. Rosenberg, A. J.; Zhao, J.; Clark, D. A., Synthesis of Imidazo[4,5-b]pyridines and Imidazo[4,5-b]pyrazines by Palladium Catalyzed Amidation of 2-Chloro-3-amino-heterocycles. *Org. Lett.* **2012**, 14, (7), 1764 - 1767.
158. Bukhryakov, K.; Kurkin, A.; Yurovskaya, M., Synthetic approaches to imidazo[4,5-b]pyridine derivatives (review). *Chem. Heterocycl. Compd. (N. Y., NY, U. S.)* 47, (5), 533-557.
159. Yutilov, Y. M., Imidazopyridines: 1- and 3-Deazapurines. In *Adv. Heterocycl. Chem.*, Alan, R. K., Ed. Academic Press: 2005; Vol. Volume 89, pp 159-270.
160. Lemrová, B.; Smyslová, P.; Popa, I.; Ožďian, T.; Zajdel, P.; Soral, M., Directed Solid-Phase Synthesis of Trisubstituted Imidazo[4,5-c]pyridines and Imidazo[4,5-b]pyridines. *ACS Comb. Sci.* **2014**, 16, (10), 558-565.
161. Zheng, N.; Anderson, K. W.; Huang, X.; Nguyen, H. N.; Buchwald, S. L., A Palladium-Catalyzed Regiospecific Synthesis of N-Aryl Benzimidazoles. *Angew. Chem. Int. Ed.* **2007**, 46, (39), 7509-7512.

162. Zou, B.; Yuan, Q.; Ma, D., Synthesis of 1,2-Disubstituted Benzimidazoles by a Cu-Catalyzed Cascade Aryl Amination/Condensation Process. *Angew. Chem. Int. Ed.* **2007**, 46, (15), 2598-2601.
163. Yang, B. H.; Buchwald, S. L., The Development of Efficient Protocols for the Palladium-Catalyzed Cyclization Reactions of Secondary Amides and Carbamates. *Org. Lett.* **1999**, 1, (1), 35-38.
164. Hartwig, J. F.; Kawatsura, M.; Hauck, S. I.; Shaughnessy, K. H.; Alcazar-Roman, L. M., Room-Temperature Palladium-Catalyzed Amination of Aryl Bromides and Chlorides and Extended Scope of Aromatic C–N Bond Formation with a Commercial Ligand. *J. Org. Chem.* **1999**, 64, (15), 5575-5580.
165. Yin, J.; Buchwald, S. L., Palladium-Catalyzed Intermolecular Coupling of Aryl Halides and Amides. *Org. Lett.* **2000**, 2, (8), 1101-1104.
166. Rosenberg, A. J.; Ahmed, I.; Wilson, R. J.; Williams, T. M.; Kaminsky, L.; Clark, D. A., An Improved Synthesis of Imidazo[4,5-b]pyridines and Imidazo[4,5-b]pyrazines by Palladium Catalyzed Amidation using Xantphos in a 1,4-Dioxane:tert-Amyl Alcohol Solvent System. *Adv. Synth. Catal.* **2014**, 356, (16), 3465-3470.
167. Puerstinger, G.; Paeshuyse, J.; Heinrich, S.; Mohr, J.; Schraffl, N.; De Clercq, E.; Neyts, J., Antiviral 2,5-disubstituted imidazo[4,5-c]pyridines: Further optimization of anti-hepatitis C virus activity. *Bioorg. Med. Chem. Lett.* **2007**, 17, (18), 5111-5114.
168. Vliegen, I.; Paeshuyse, J.; De Burghgraeve, T.; Lehman, L. S.; Paulson, M.; Shih, I. H.; Mabery, E.; Boddeker, N.; De Clercq, E.; Reiser, H.; Oare, D.; Lee, W. A.; Zhong, W.; Bondy, S.; Puerstinger, G.; Neyts, J., Substituted imidazopyridines as potent inhibitors of HCV replication. *Journal of Hepatology* **2009**, 50, (5), 999-1009.
169. Schneider, C.; Goyard, D.; Gueyrard, D.; Joseph, B.; Goekjian, P. G., Synthesis of 2-, 3-, and 4-Substituted Pyrido[2,3-b]indoles by C–N, C–O, and C–C(sp) Bond Formation. *Eur. J. Org. Chem.* **2010**, 2010, (34), 6665-6677.
170. Sahli, S.; Frank, B.; Schweizer, W. B.; Diederich, F.; Blum-Kaelin, D.; Aebi, J. D.; Böhm, H.-J.; Oefner, C.; Dale, G. E., Second-Generation Inhibitors for the Metalloprotease Neprilysin Based on Bicyclic Heteroaromatic Scaffolds: Synthesis, Biological Activity, and X-Ray Crystal-Structure Analysis. *Helv. Chim. Acta* **2005**, 88, (4), 731-750.
171. Caron, S.; Do, N. M.; McDermott, R. E.; Bahmanyar, S., Regioselective Synthesis of an Imidazo[4,5-c]pyridine through Selective Acylation of 3,4-Diaminopyridine: Synthesis of CP-885,316. *Org. Process Res. Dev.* **2006**, 10, (2), 257-261.
172. Jiang, B., Preparation of 2-[(Aryl)methyl]sulfinyl-1H-imidazo[4,5-c]pyridine, Useful as an Antiosteoporotic Agent. *Org. Process Res. Dev.* **1998**, 2, (6), 425-427.
173. Mayorov, A. V.; Willis, B.; Di Mola, A.; Adler, D.; Borgia, J.; Jackson, O.; Wang, J.; Luo, Y.; Tang, L.; Knapp, R. J.; Natarajan, C.; Goodnough, M. C.; Zilberberg, N.; Simpson, L. L.; Janda, K. D., Symptomatic Relief of Botulinum Neurotoxin/A Intoxication with Aminopyridines: A New Twist on an Old Molecule. *ACS Chem. Biol.* **2010**, 5, (12), 1183-1191.
174. Frohn, M.; Viswanadhan, V.; Pickrell, A. J.; Golden, J. E.; Muller, K. M.; Bårli, R. W.; Biddlecome, G.; Yoder, S. C.; Rogers, N.; Dao, J. H.; Hungate, R.; Allen, J. R., Structure-guided design of substituted aza-benzimidazoles as potent hypoxia inducible factor-1 \pm prolyl hydroxylase-2 inhibitors. *Bioorg. Med. Chem. Lett.* **2008**, 18, (18), 5023-5026.
175. Cai, J.; Baugh, M.; Black, D.; Long, C.; Jonathan Bennett, D.; Dempster, M.; Fradera, X.; Gillespie, J.; Andrews, F.; Boucharens, S.; Bruin, J.; Cameron, K. S.; Cumming, I.; Hamilton, W.;

- Jones, P. S.; Kaptein, A.; Kinghorn, E.; Maidment, M.; Martin, I.; Mitchell, A.; Rankovic, Z.; Robinson, J.; Scullion, P.; Uitdehaag, J. C. M.; Vink, P.; Westwood, P.; van Zeeland, M.; van Berkom, L.; Bastiani, M.; Meulemans, T., 6-Phenyl-1H-imidazo[4,5-c]pyridine-4-carbonitrile as cathepsin S inhibitors. *Bioorg. Med. Chem. Lett.* **2010**, 20, (15), 4350-4354.
176. Gautam, R. K.; Fujii, S.; Nishida, M.; Kimoto, H.; Cohen, L. A., Synthesis of imidazo[4,5-c]pyridines with a trifluoromethyl group at C-4 and/or C-6. *J. Heterocycl. Chem.* **1994**, 31, (2), 453-455.
177. Khanna, I. K.; Weier, R. M., Regiospecific addition of Grignard reagents to the 4-position of activated imidazo[4,5-c]pyridine. A convenient method for the synthesis of 4-alkyl(ary). *Tetrahedron Lett.* **1993**, 34, (12), 1885-1888.
178. Vallee, F.; Carrez, C.; Pilorge, F.; Dupuy, A.; Parent, A.; Bertin, L.; Thompson, F.; Ferrari, P.; Fassy, F.; Lamberton, A.; Thomas, A.; Arrebola, R.; Guerif, S.; Rohaut, A.; Certal, V.; Ruxer, J.-M.; Delorme, C.; Jouanen, A.; Dumas, J.; Gracpin, C.; Combeau, C.; Goulaouic, H.; Dereu, N.; Mikol, V.; Mailliet, P.; Minoux, H., Tricyclic Series of Heat Shock Protein 90 (Hsp90) Inhibitors Part I: Discovery of Tricyclic Imidazo[4,5-c]pyridines as Potent Inhibitors of the Hsp90 Molecular Chaperone. *J. Med. Chem.* **2011**, 54, (20), 7206-7219.
179. McLaughlin, M.; Palucki, M.; Davies, I. W., Efficient Access to Azaindoles and Indoles. *Org. Lett.* **2006**, 8, (15), 3307-3310.
180. Chan, D. M. T.; Monaco, K. L.; Wang, R.-P.; Winters, M. P., New N- and O-arylations with phenylboronic acids and cupric acetate. *Tetrahedron Lett.* **1998**, 39, (19), 2933-2936.
181. Evans, D. A.; Katz, J. L.; West, T. R., Synthesis of diaryl ethers through the copper-promoted arylation of phenols with arylboronic acids. An expedient synthesis of thyroxine. *Tetrahedron Lett.* **1998**, 39, (19), 2937-2940.
182. Lach, F.; Koza, P., Practical Way to Imidazo[4,5-b] and [4,5-c]Pyridine-2-ones via Cascade Ureidation/Palladium-Catalyzed Cyclization. *ACS Comb. Sci.* **2012**, 14, (9), 491-495.
183. Snieckus, V., Directed ortho metalation. Tertiary amide and O-carbamate directors in synthetic strategies for polysubstituted aromatics. *Chem. Rev. (Washington, DC, U. S.)* **1990**, 90, (6), 879-933.
184. Anctil, E. J. G.; Snieckus, V., The Directed ortho-Metallation (DoM) Cross-Coupling Nexus. Synthetic Methodology for the Formation of Aryl-Aryl and Aryl-Heteroatom-Aryl Bonds. In *Metal-Catalyzed Cross-Coupling Reactions*, Wiley-VCH Verlag GmbH: 2008; pp 761-813.
185. Marsais, F.; Rovera, J.-C.; Turck, A.; Godard, A.; Queguiner, G., Perkin communications. Synthesis of 3-amino-4-phenylpyridines: a novel strategy for the preparation of CD ring models of streptonigrin. *J. Chem. Soc., Perkin Trans. 1* **1990**, 0, (9), 2611-2612.
186. Godard, A.; Rocca, P.; Pomel, V.; Thomas-dit-Dumont, L.; Rovera, J. C.; Thaburet, J. F.; Marsais, F.; Quéguiner, G., Metallation in connection with cross-coupling reactions. Coupling of hindered aryls for the synthesis of 4-phenylpyridines as part of Streptonigrin and Lavendamycin analogues. *J. Organomet. Chem.* **1996**, 517, 25-36.
187. Kelly, T. A.; Patel, U. R., Directed Lithiation of 3-[(tert-Butoxycarbonyl)amino]-2-methoxypyridines: Synthetic Route to Nevirapine and Its 4-Substituted Derivatives. *J. Org. Chem.* **1995**, 60, (6), 1875-1877.
188. Estel, L.; Marsais, F.; Queguiner, G., Metalation/SRN1 coupling in heterocyclic synthesis. A convenient methodology for ring functionalization. *J. Org. Chem.* **1988**, 53, (12), 2740-2744.
189. Watanabe, Y.; Yasuoka, J.; Ikemoto, T. Preparation of piperidin-3-ylcarbamate compound and optical resolution method therefor. WO2009119700A1, 2009.

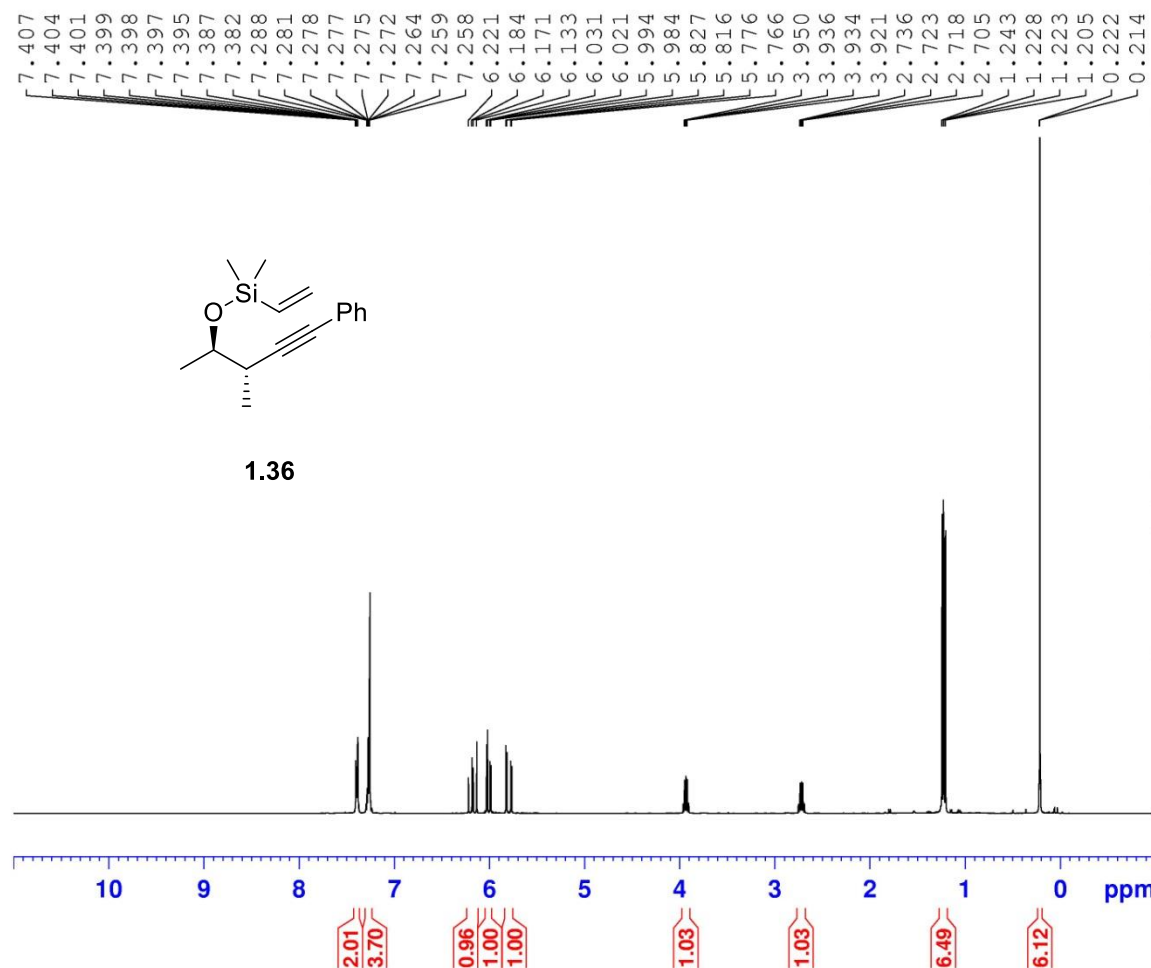
190. Strieter, E. R.; Blackmond, D. G.; Buchwald, S. L., The Role of Chelating Diamine Ligands in the Goldberg Reaction: A Kinetic Study on the Copper-Catalyzed Amidation of Aryl Iodides. *J. Am. Chem. Soc.* **2005**, 127, (12), 4120-4121.
191. Billingsley, K. L.; Anderson, K. W.; Buchwald, S. L., A Highly Active Catalyst for Suzuki–Miyaura Cross-Coupling Reactions of Heteroaryl Compounds. *Angew. Chem. Int. Ed.* **2006**, 45, (21), 3484-3488.
192. Klapars, A.; Antilla, J. C.; Huang, X.; Buchwald, S. L., A General and Efficient Copper Catalyst for the Amidation of Aryl Halides and the N-Arylation of Nitrogen Heterocycles. *J. Am. Chem. Soc.* **2001**, 123, (31), 7727-7729.
193. Klapars, A.; Huang, X.; Buchwald, S. L., A General and Efficient Copper Catalyst for the Amidation of Aryl Halides. *J. Am. Chem. Soc.* **2002**, 124, (25), 7421-7428.
194. Surry, D. S.; Buchwald, S. L., Diamine ligands in copper-catalyzed reactions. *Chem. Sci.* **2010**, 1, (1), 13-31.
195. Ueda, S.; Ali, S.; Fors, B. P.; Buchwald, S. L., Me₃(OMe)tBuXPhos: A Surrogate Ligand for Me₄tBuXPhos in Palladium-Catalyzed C-N and C-O Bond-Forming Reactions. *J. Org. Chem.* **2012**, 77, (5), 2543-2547.
196. Suzuki, K.; Hori, Y.; Kobayashi, T., A New Hybrid Phosphine Ligand for Palladium-Catalyzed Amination of Aryl Halides. *Adv. Synth. Catal.* **2008**, 350, (5), 652-656.
197. Withbroe, G. J.; Singer, R. A.; Sieser, J. E., Streamlined Synthesis of the Bippyphos Family of Ligands and Cross-Coupling Applications. *Org. Process Res. Dev.* **2008**, 12, (3), 480-489.
198. Singer, R. A.; Caron, S.; McDermott, R. E.; Arpin, P.; Do, N. M., Alternative Biarylphosphines for Use in the Palladium-Catalyzed Amination of Aryl Halides. *Synthesis* **2003**, 2003, (11), 1727,1731.
199. Hicks, J. D.; Hyde, A. M.; Cuezva, A. M.; Buchwald, S. L., Pd-Catalyzed N-Arylation of Secondary Acyclic Amides: Catalyst Development, Scope, and Computational Study. *J. Am. Chem. Soc.* **2009**, 131, (46), 16720-16734.
200. Yamanaka, H.; Araki, T.; Sakamoto, T., Site-Selectivity in the Reaction of 3-Substituted Pyridine 1-Oxides with Phosphoryl Chloride. *Chem. Pharm. Bull.* **1988**, 36, (6), 2244-2247.
201. Vorbruggen, H.; Krolkiewicz, K., Trimethylsilanol as Leaving Group; III1. A Simple One-Step Conversion of Aromatic Heterocyclic N-Oxides to α -Cyano Aromatic N-Heterocycles. *Synthesis* **1983**, 1983, (04), 316-319.
202. Norman, M. H.; Chen, N.; Chen, Z.; Fotsch, C.; Hale, C.; Han, N.; Hurt, R.; Jenkins, T.; Kincaid, J.; Liu, L.; Lu, Y.; Moreno, O.; Santora, V. J.; Sonnenberg, J. D.; Karbon, W., Structure–Activity Relationships of a Series of Pyrrolo[3,2-d]pyrimidine Derivatives and Related Compounds as Neuropeptide Y5 Receptor Antagonists. *J. Med. Chem.* **2000**, 43, (22), 4288-4312.
203. Delvare, C.; Koza, P.; Morgentin, R., Highly Regioselective Palladium-Catalyzed C2-Amination of 2,4-Dichloropyridines: Scope and Limitations. *Synthesis* **2011**, 2011, (15), 2431-2436.
204. Maerten, E.; Sauthier, M.; Mortreux, A.; Castanet, Y., Palladium-N-heterocyclic carbene an efficient catalytic system for the carbonylative cross-coupling of pyridine halides with boronic acids. *Tetrahedron* **2007**, 63, (3), 682-689.
205. Yang, W.; Wang, Y.; Corte, J. R., Efficient Synthesis of 2-Aryl-6-chloronicotinamides via PXPd₂-Catalyzed Regioselective Suzuki Coupling. *Org. Lett.* **2003**, 5, (17), 3131-3134.
206. Ahmed, S.; Sharif, M.; Shoaib, K.; Reimann, S.; Iqbal, J.; Patonay, T.; Spannenberg, A.; Langer, P., Synthesis of 2,6-diaryl-3-(trifluoromethyl)pyridines by regioselective Suzuki–Miyaura

- reactions of 2,6-dichloro-3-(trifluoromethyl)pyridine. *Tetrahedron Lett.* **2013**, 54, (13), 1669-1672.
207. Lesueur, W.; Solari, E.; Floriani, C.; Chiesi-Villa, A.; Rizzoli, C., A Bidentate Bisphosphine Functioning in Intramolecular Aliphatic Metalation and as an NMR Spectroscopic Probe for the Metal Coordination Environment. *Inorg. Chem.* **1997**, 36, (15), 3354-3362.
208. Ohshima, T.; Miyamoto, Y.; Ipposhi, J.; Nakahara, Y.; Utsunomiya, M.; Mashima, K., Platinum-Catalyzed Direct Amination of Allylic Alcohols under Mild Conditions: Ligand and Microwave Effects, Substrate Scope, and Mechanistic Study. *J. Am. Chem. Soc.* **2009**, 131, (40), 14317-14328.
209. Saes, B. W. H.; Verhoeven, D. G. A.; Lutz, M.; Klein Gebbink, R. J. M.; Moret, M.-E., Coordination of a Diphosphine–Ketone Ligand to Ni(0), Ni(I), and Ni(II): Reduction-Induced Coordination. *Organometallics* **2015**, 34, (12), 2710-2713.
210. Jing, Q.; Sandoval, C. A.; Wang, Z.; Ding, K., Complete Chiral Induction from Enantiopure 1,2-Diamines to Benzophenone-Based Achiral Bisphosphane Ligands in Noyori-Type RuII Catalysts. *Eur. J. Org. Chem.* **2006**, 2006, (16), 3606-3616.
211. Mikami, K.; Wakabayashi, K.; Yusa, Y.; Aikawa, K., Achiral benzophenone ligand-rhodium complex with chiral diamine activator for high enantiocontrol in asymmetric transfer hydrogenation. *Chem. Commun. (Cambridge, U. K.)* **2006**, (22), 2365-2367.
212. Yin, J.; Buchwald, S. L., Pd-Catalyzed Intermolecular Amidation of Aryl Halides: The Discovery that Xantphos Can Be Trans-Chelating in a Palladium Complex. *J. Am. Chem. Soc.* **2002**, 124, (21), 6043-6048.
213. Nussbaumer, P.; Stütz, A., Regioselective ring opening of α -substituted α -alkynyl oxiranes to 2-substituted 3-buten-1-ols. *Tetrahedron Lett.* **1992**, 33, (49), 7507-7508.
214. Kaminsky, L.; Wilson, R. J.; Clark, D. A., Stereo- and Regioselective Formation of Silyl-Dienyl Boronates. *Org. Lett.* **2015**.
215. Comins, D. L.; Dehghani, A.; Foti, C. J.; Joseph, S. P., *Org. Synth.* **1997**, 74, 77.
216. Evans, D. A.; Gage, J. R., Diastereoselective Aldol Condensation Using A Chiral Oxazolidinone Auxiliary:(2*S*-3*S*)-3-hydroxy-3-phenyl-2-methylpropanoic acid. *Org. Synth.* **1990**, 68, 83.
217. Evans, D. A.; Tedrow, J. S.; Shaw, J. T.; Downey, C. W., Diastereoselective Magnesium Halide-Catalyzed anti-Aldol Reactions of Chiral N-Acyloxazolidinones. *J. Am. Chem. Soc.* **2001**, 124, (3), 392-393.
218. Kurosu, M.; Lorca, M., Highly Diastereofacial Anti-Aldol Reaction: Practical Synthesis of Optically Active anti-2-Alkyl-3-Hydroxycarboxylic Acid Ester Units†. *J. Org. Chem.* **2001**, 66, (4), 1205-1209.
219. Katner, A. S.; Brown, R. F., A novel preparation of thiazolo[5,4-*c*]pyridines and the synthesis of some imidazo[4,5-*c*]pyridines and oxazolo[4,5-*c*]pyridines. *J. Heterocycl. Chem.* **1990**, 27, (3), 563-566.
220. Rosenberg, A. J.; Williams, T. M.; Jordan, A. J.; Clark, D. A., Synthesis of 2-amino-imidazo[4,5-*b*]pyridines. *Org. Biomol. Chem.* **2013**, 11, (18), 3064-3072.

5.0 APPENDIX III: SPECTRA

5.1 VINYL SILICON TETHERED ALKYNES

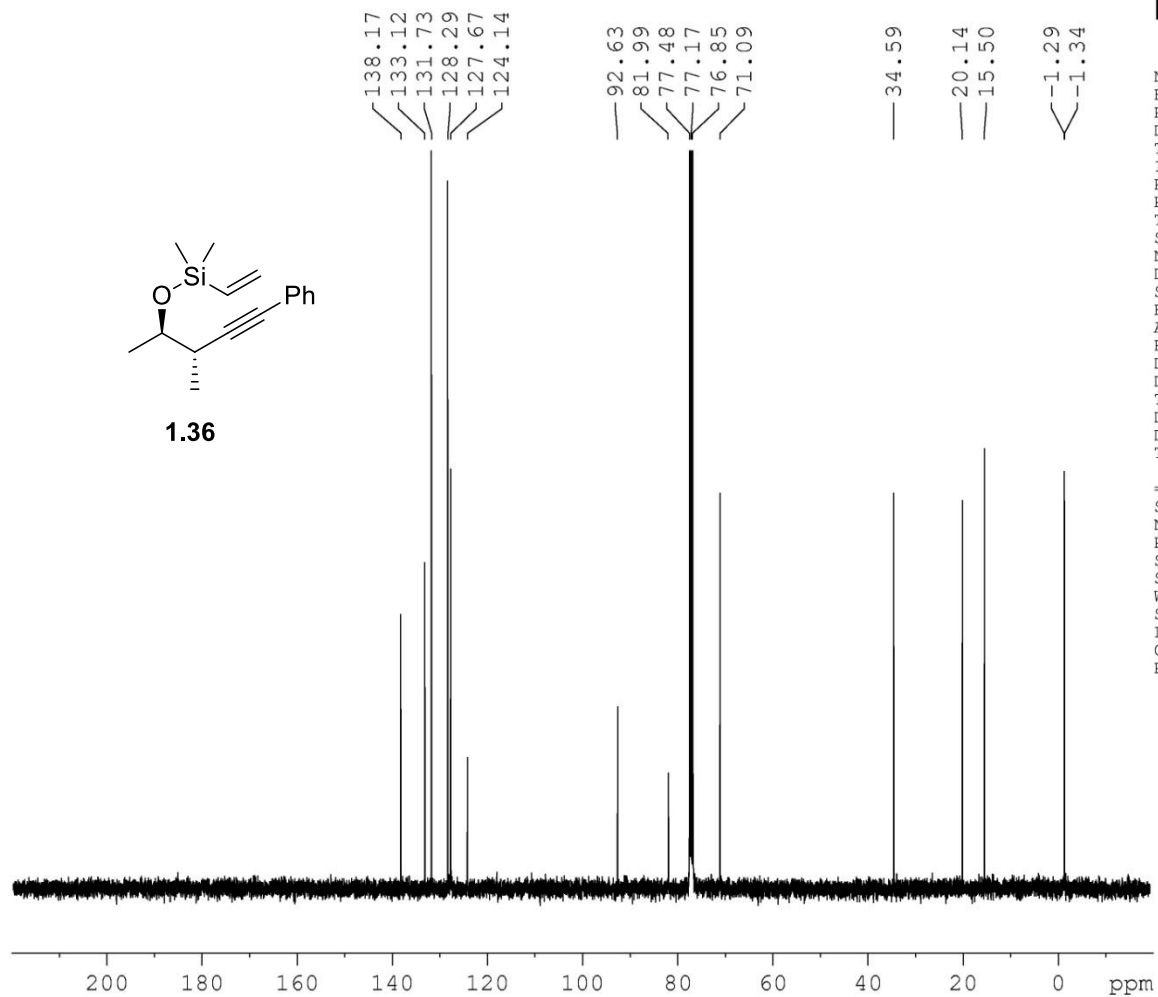
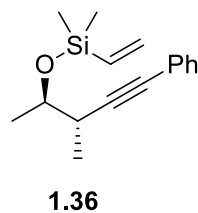
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FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 183
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

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GB 0
PC 1.00

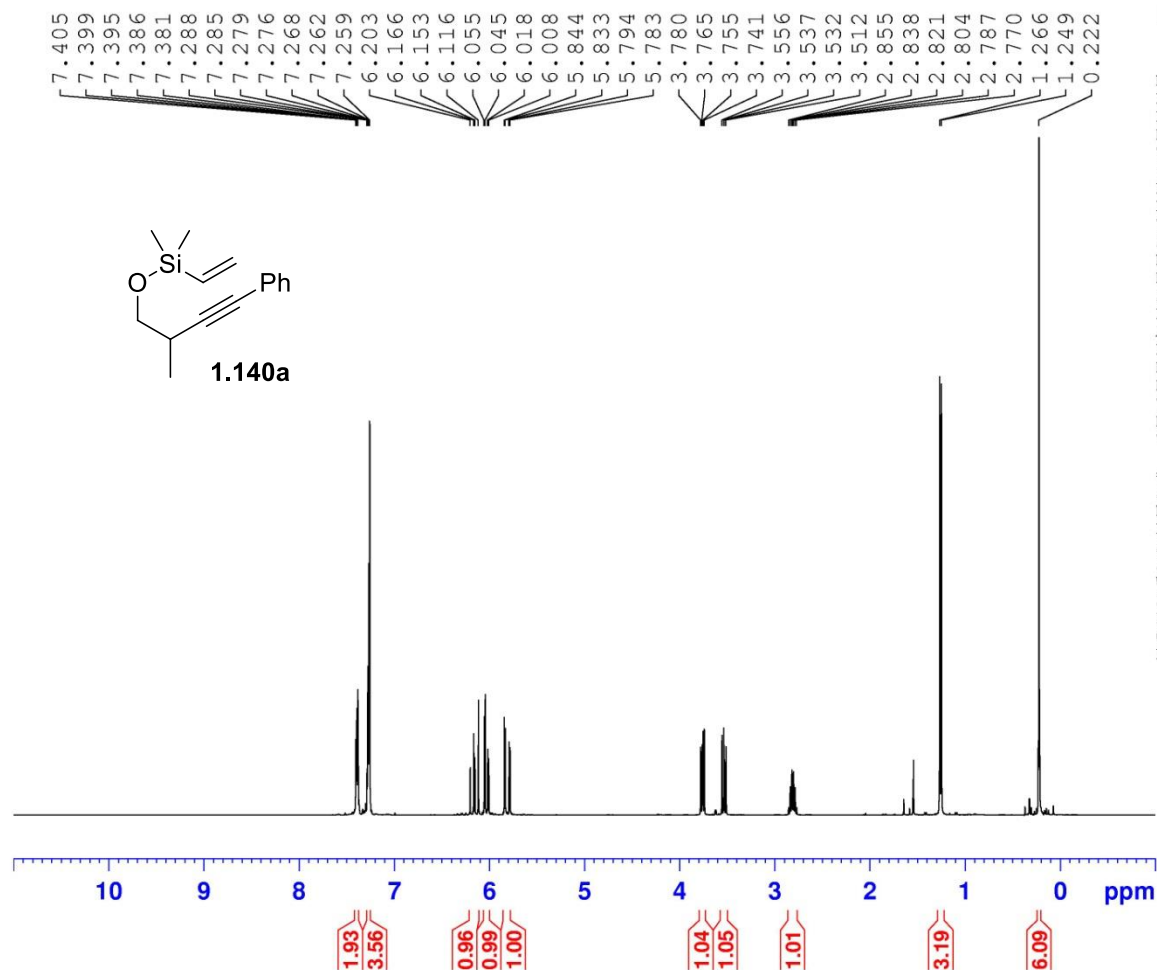
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SOLVENT CDCl3
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DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 80.84
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

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PC 1.40

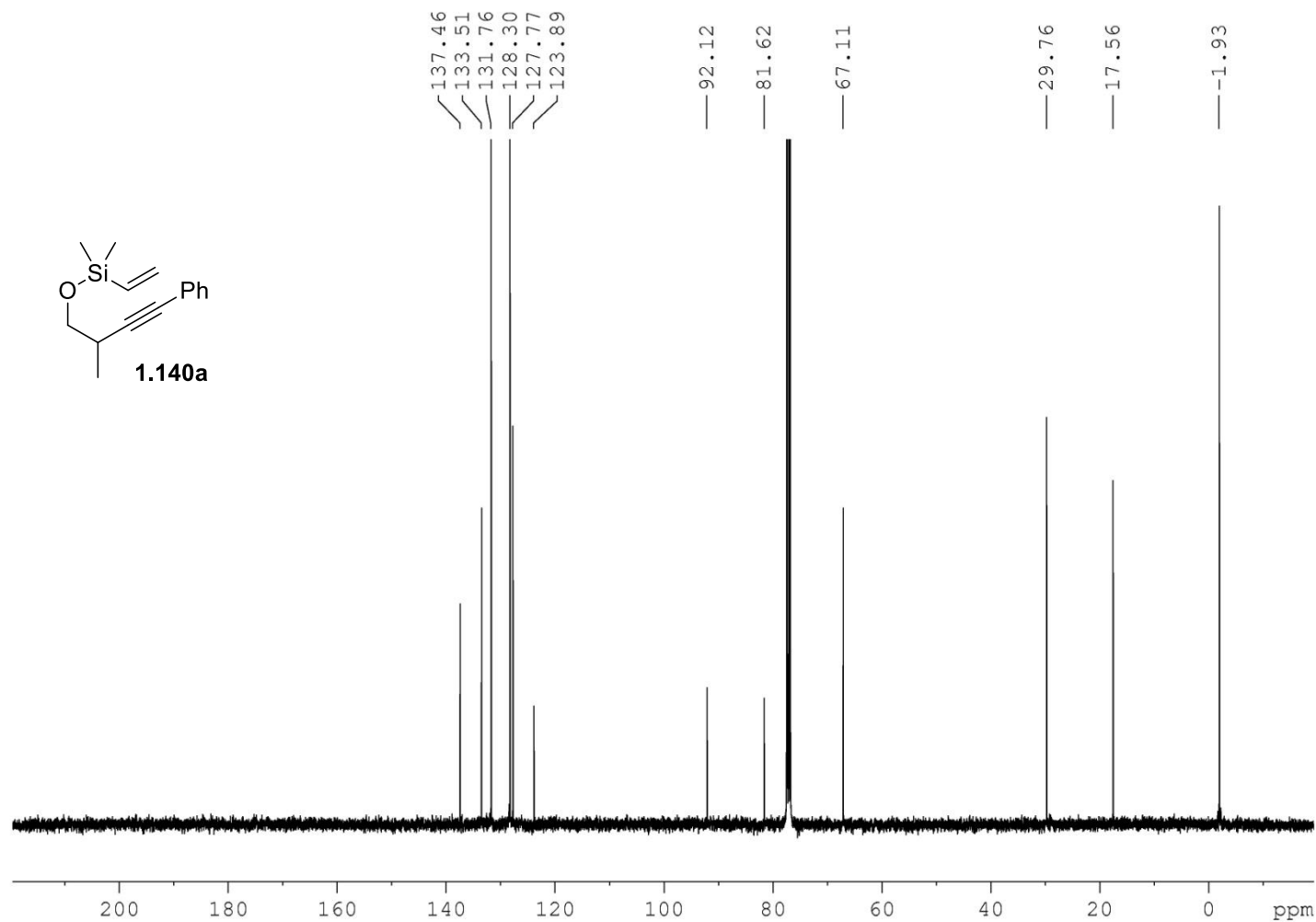
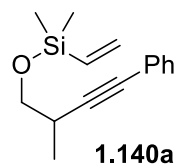
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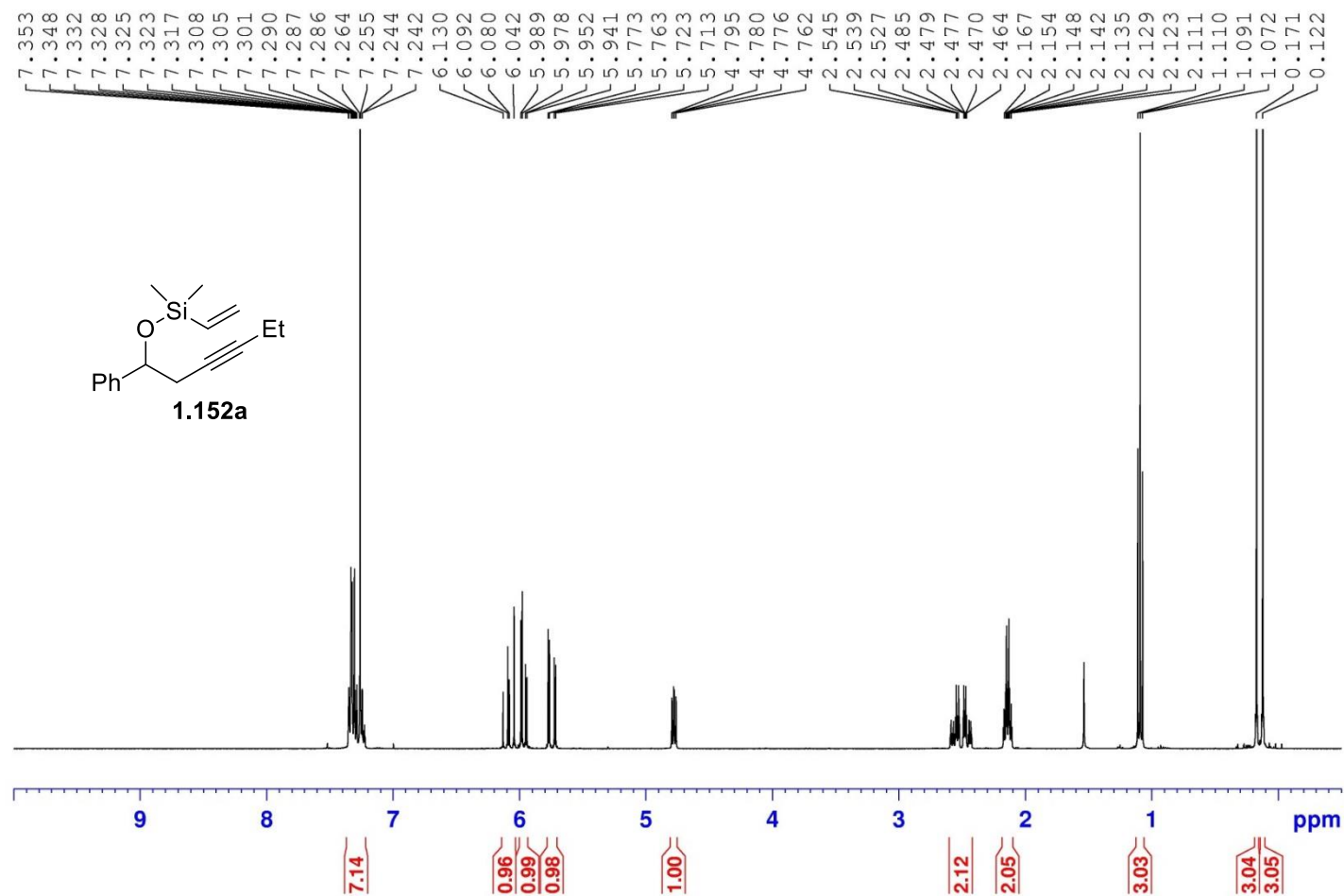
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SOLVENT CDCl3
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DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 183
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

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PC 1.00

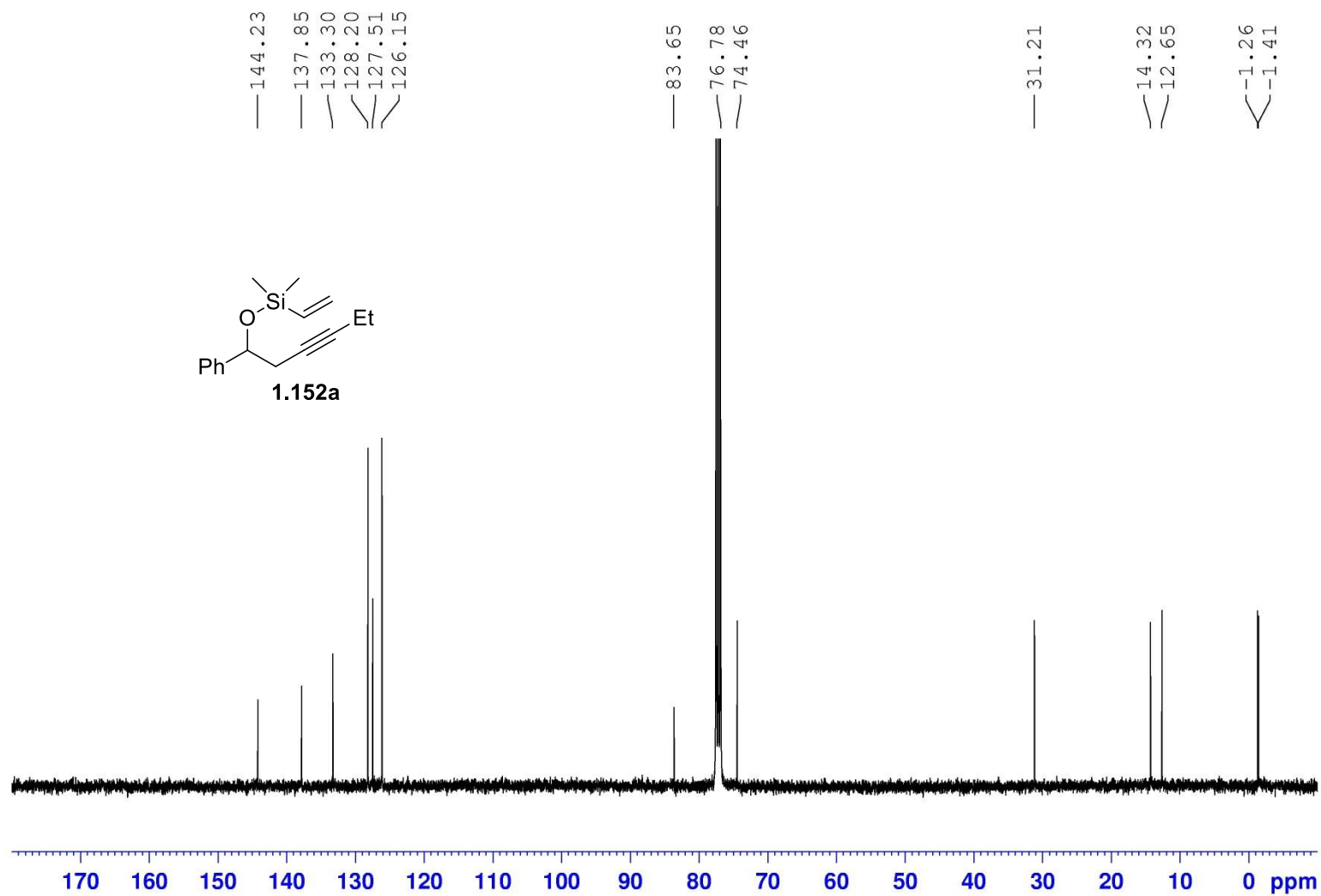
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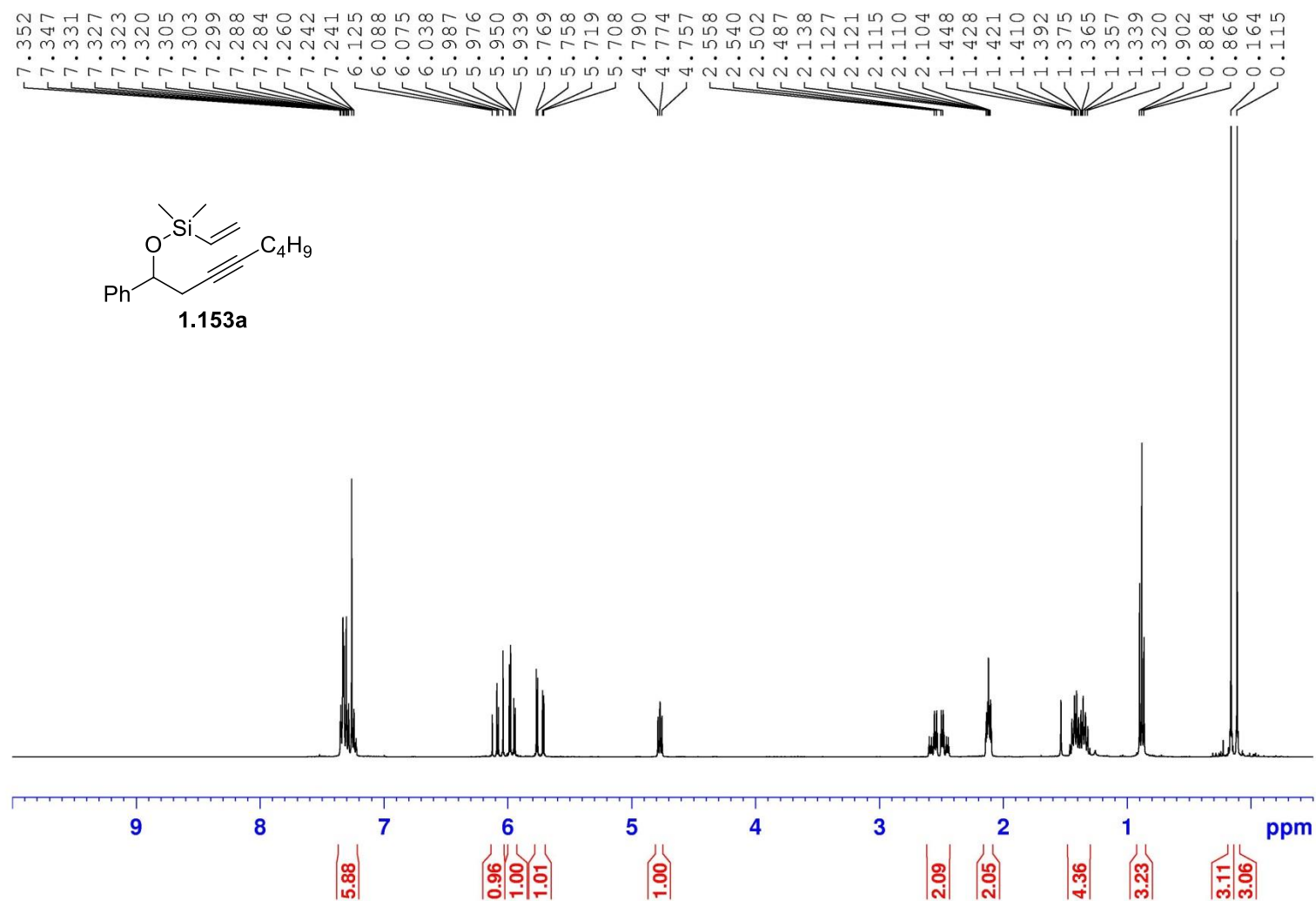
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post-column

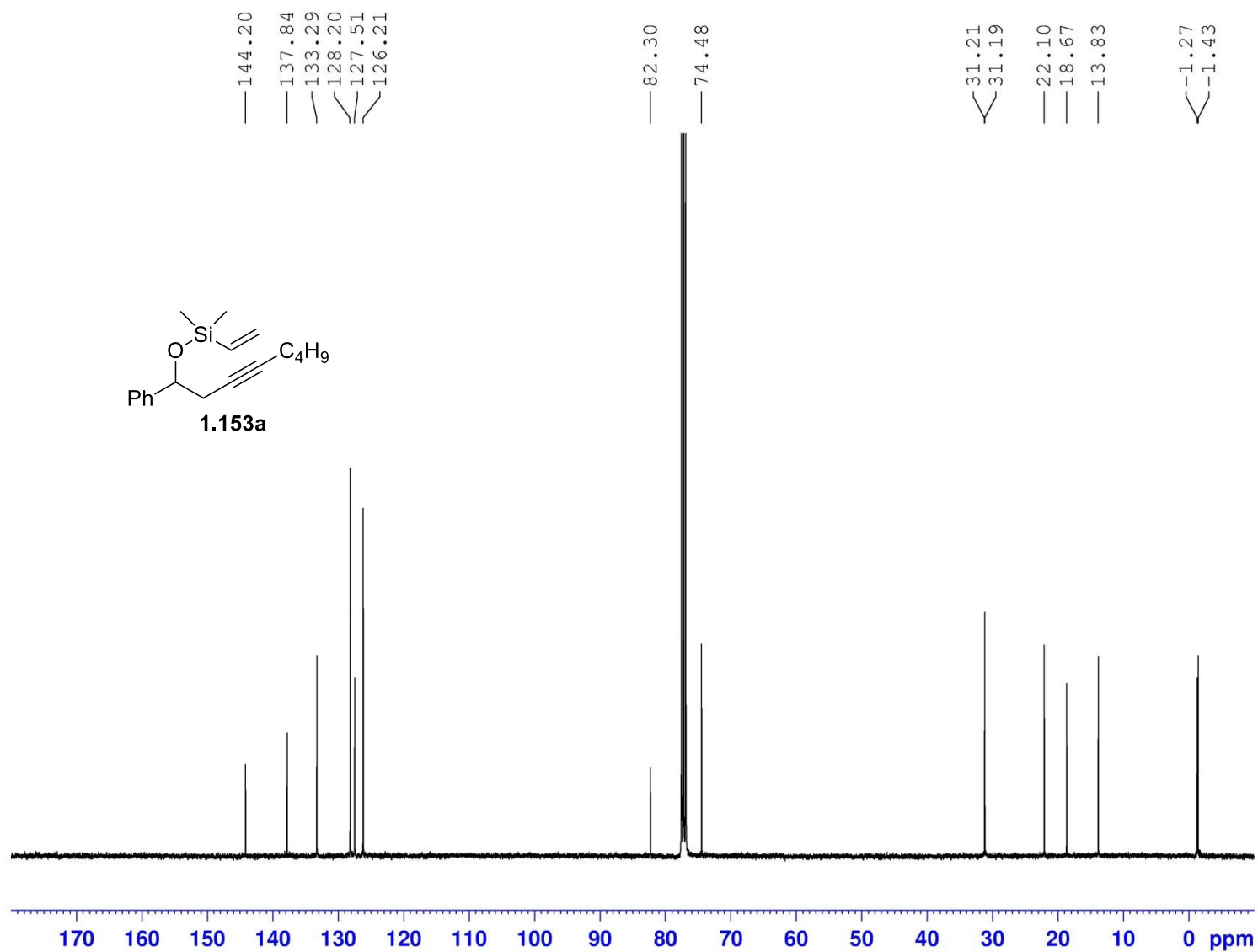


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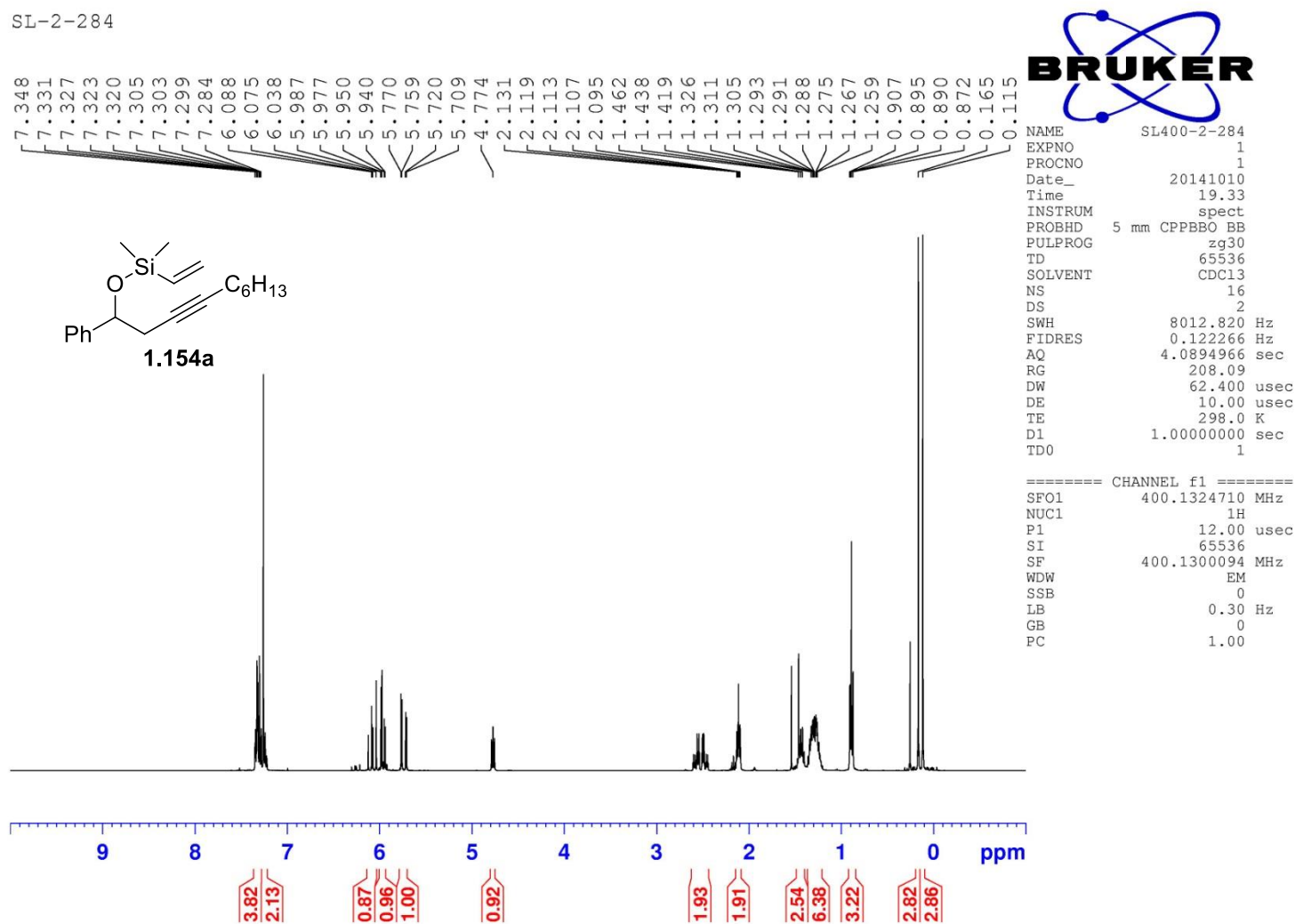


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1H-NMR

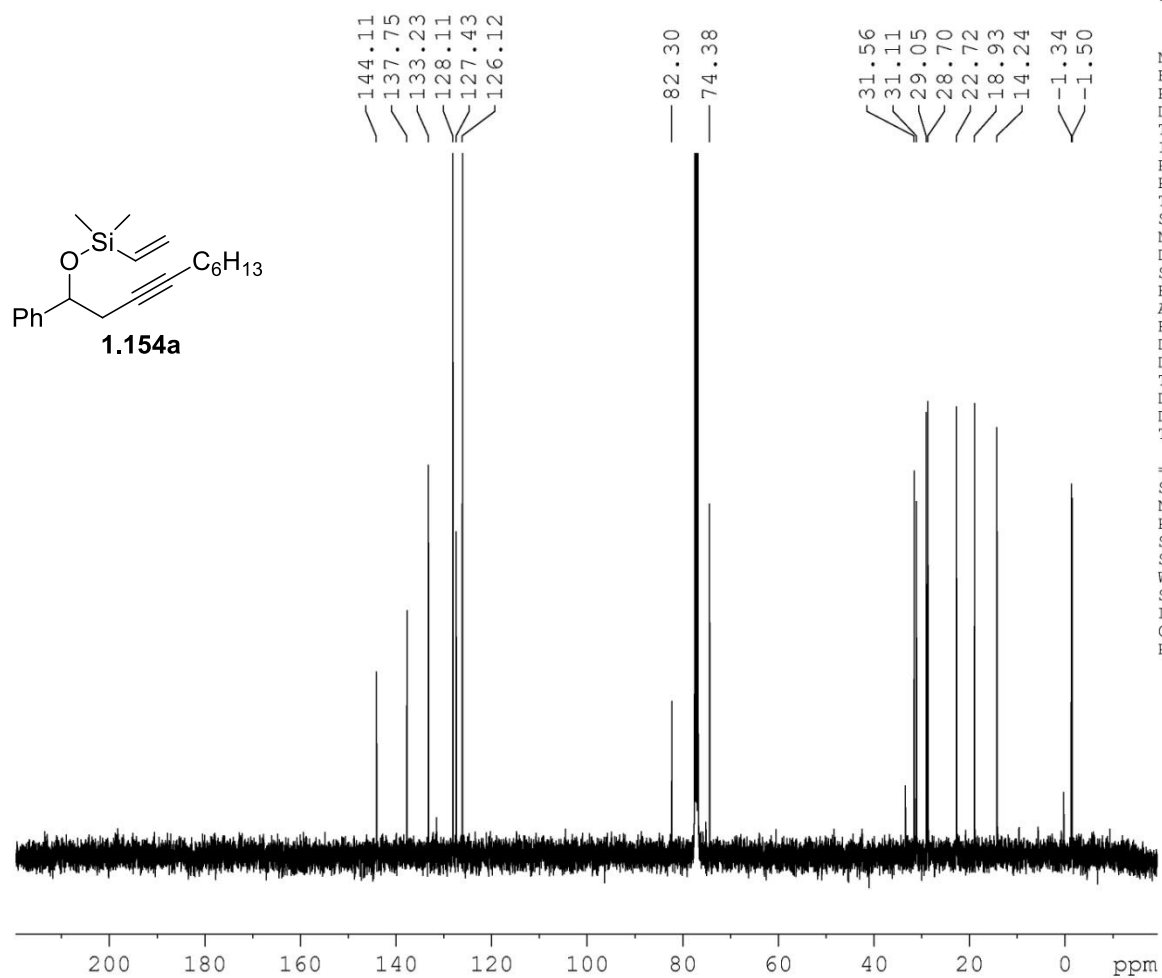




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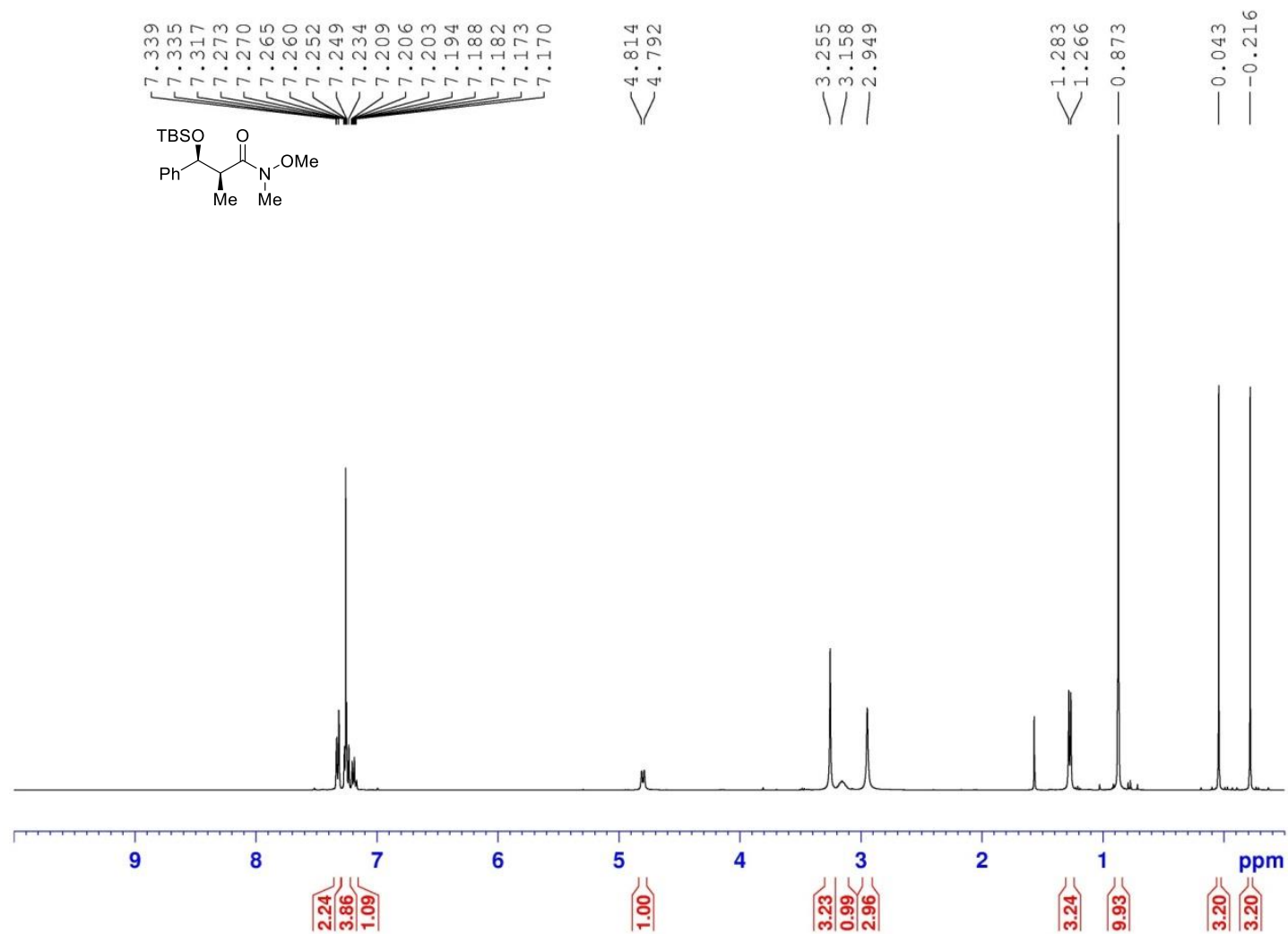


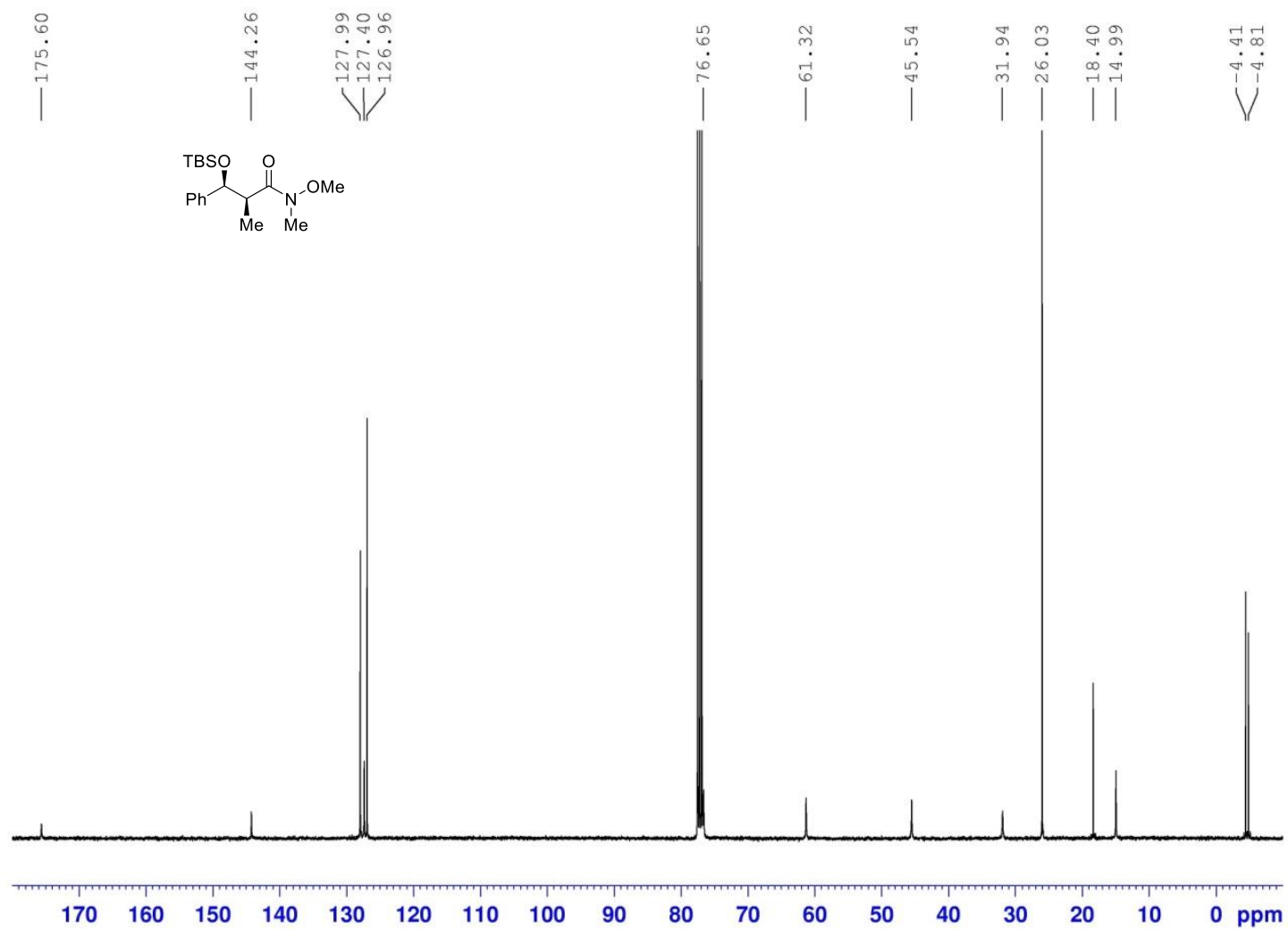
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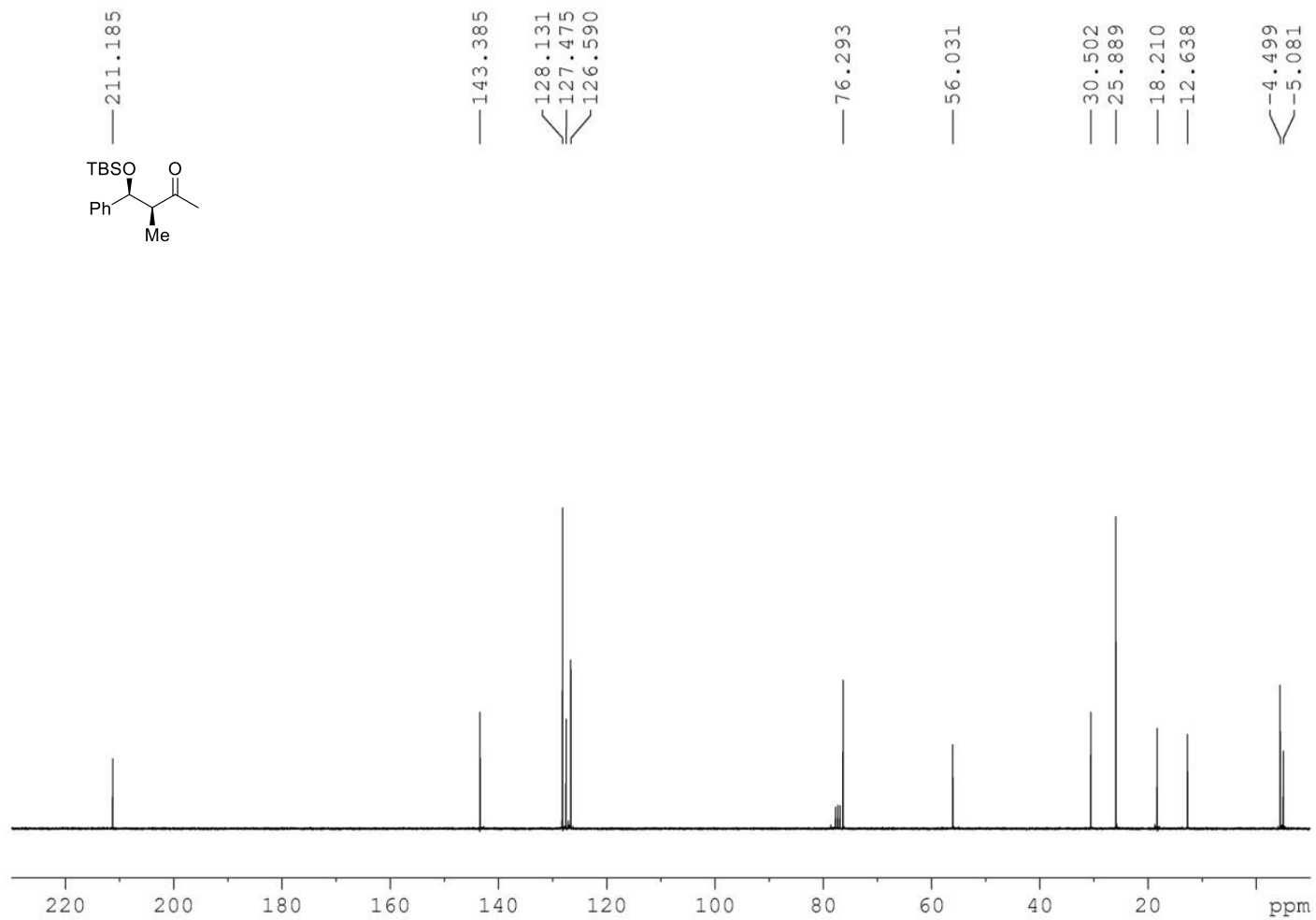
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 FIDRES 0.366798 Hz
 AQ 1.3631988 sec
 RG 91.52
 DW 20.800 usec
 DE 18.00 usec
 TE 298.0 K
 D1 2.00000000 sec
 D11 0.03000000 sec
 TD0 1

===== CHANNEL f1 =====
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 SSB 0
 LB 1.00 Hz
 GB 0
 PC 1.40

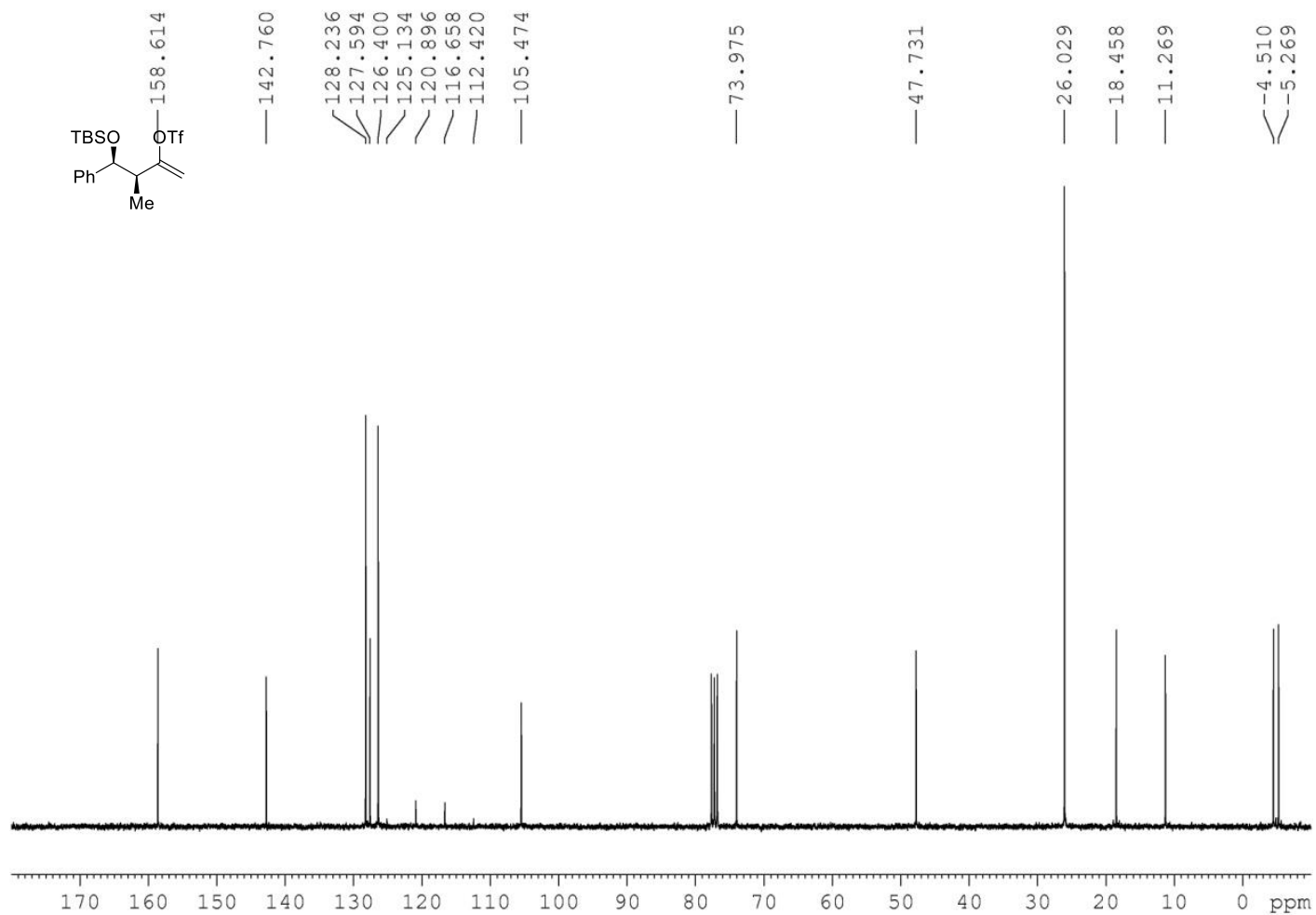


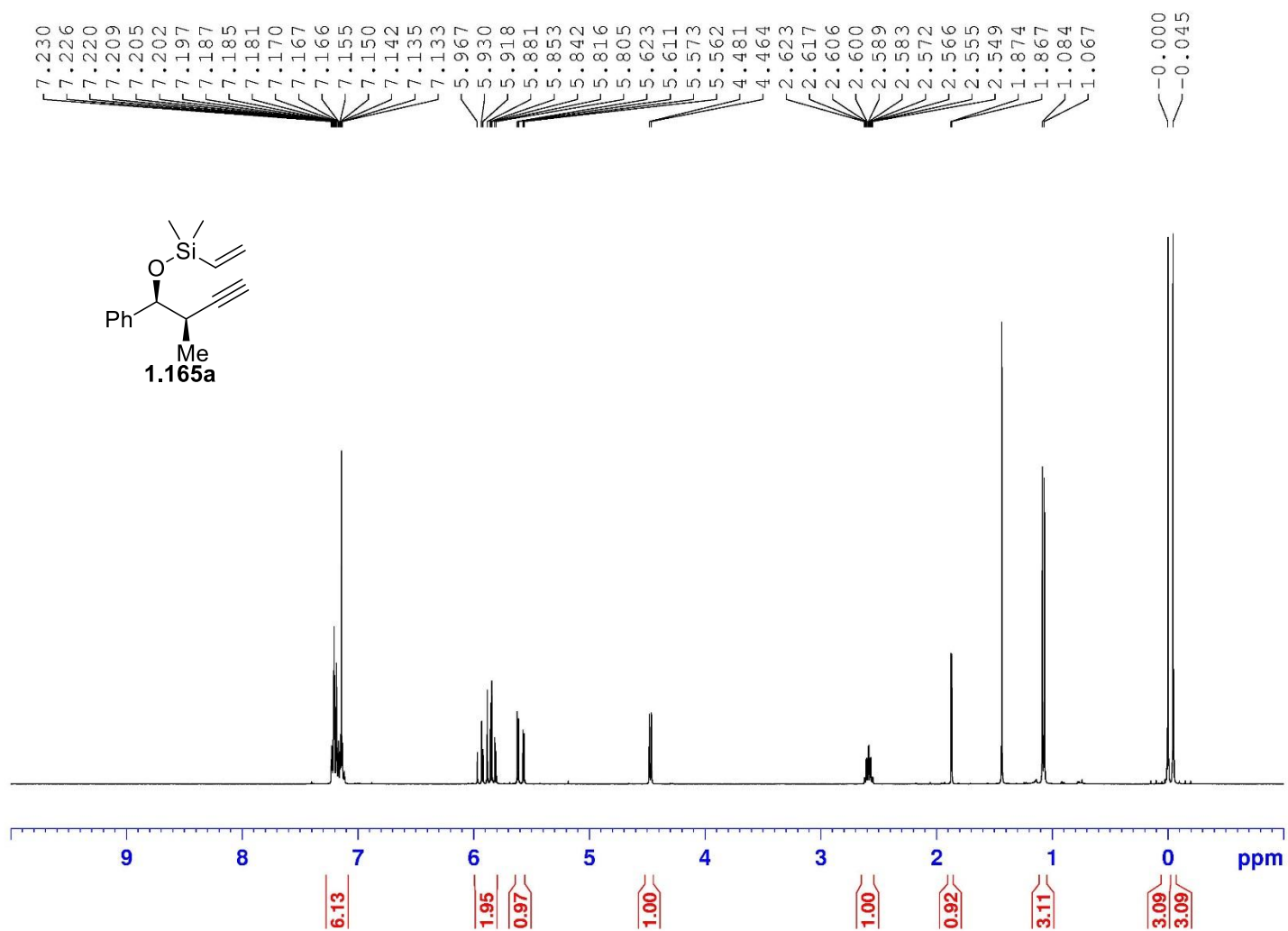


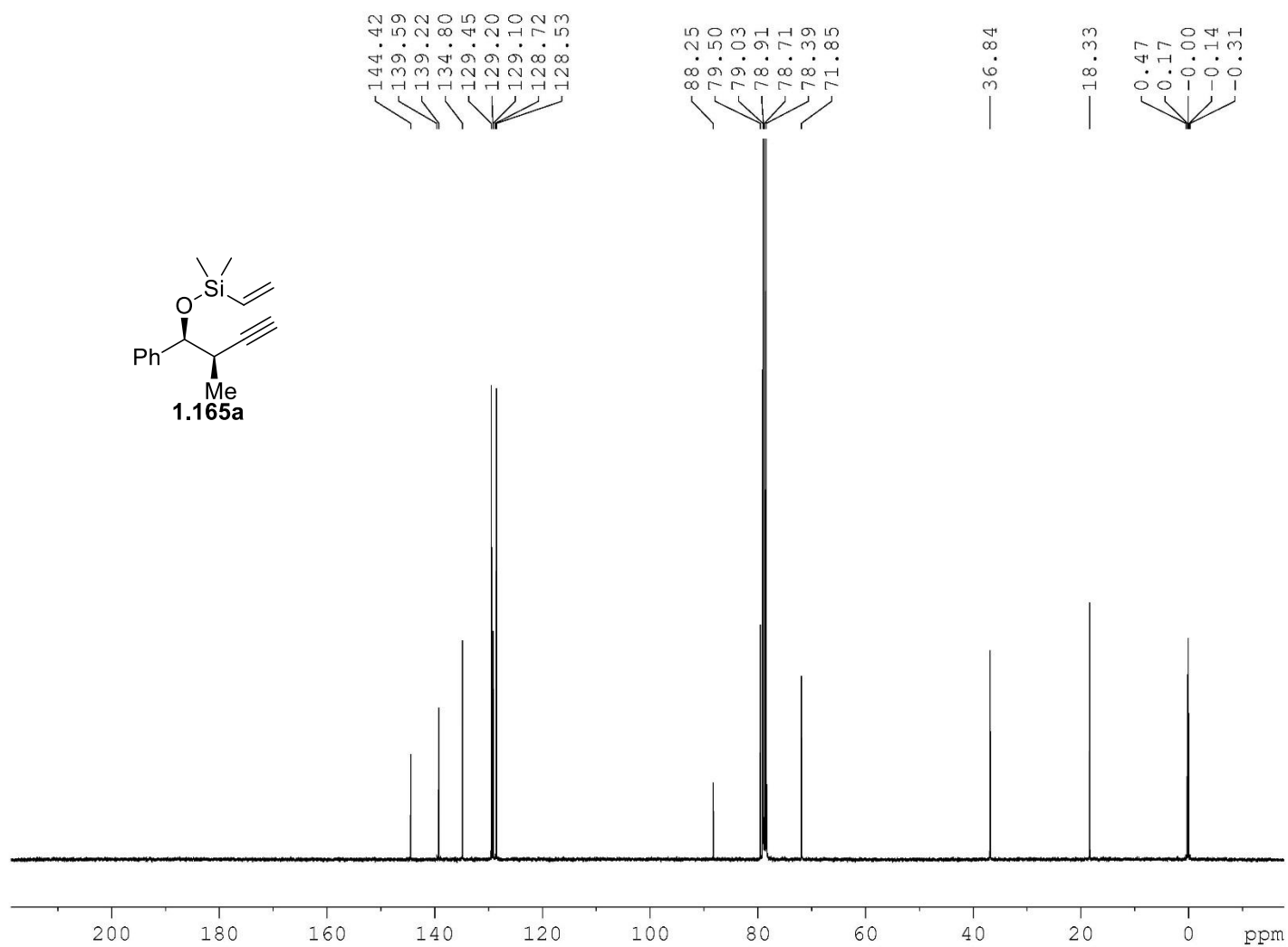
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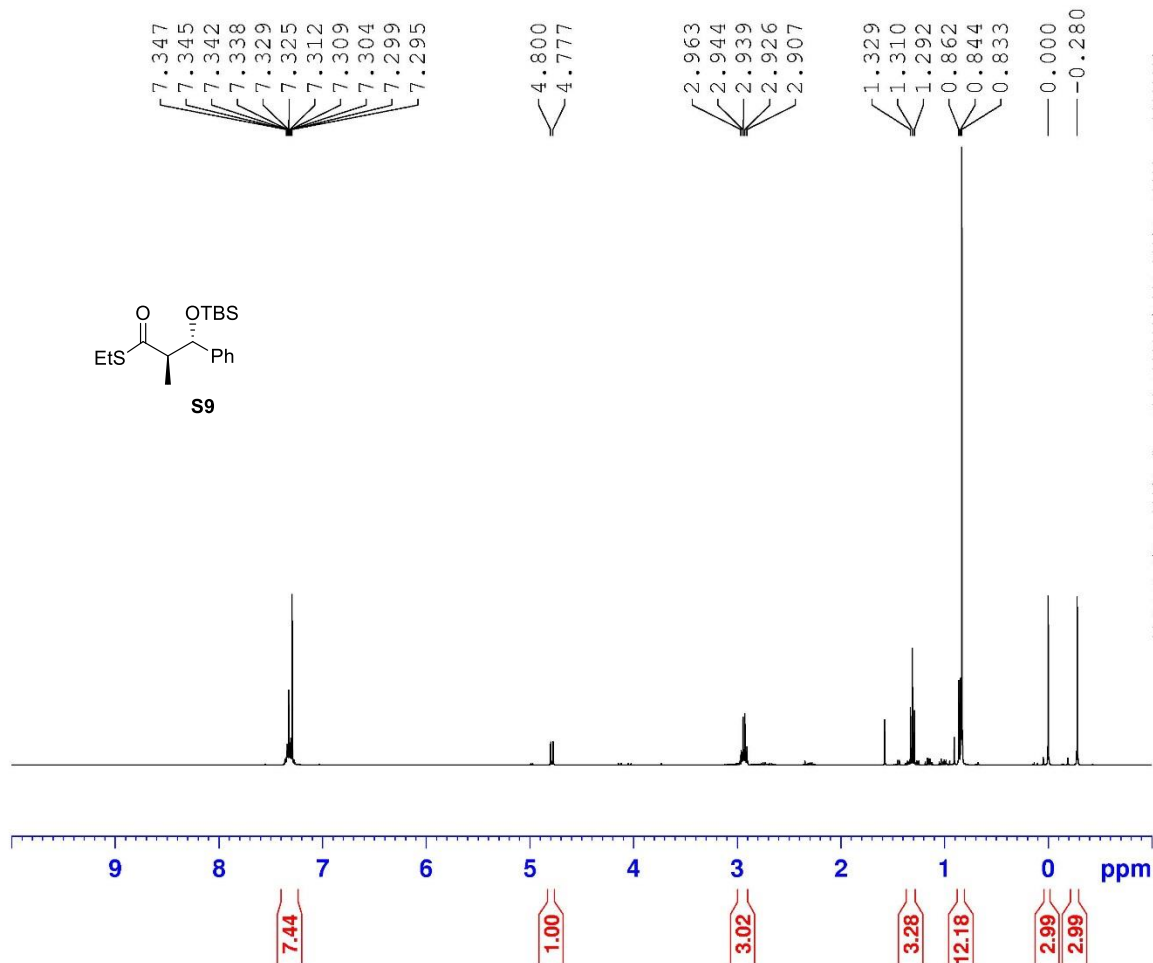
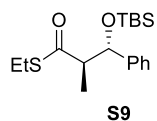
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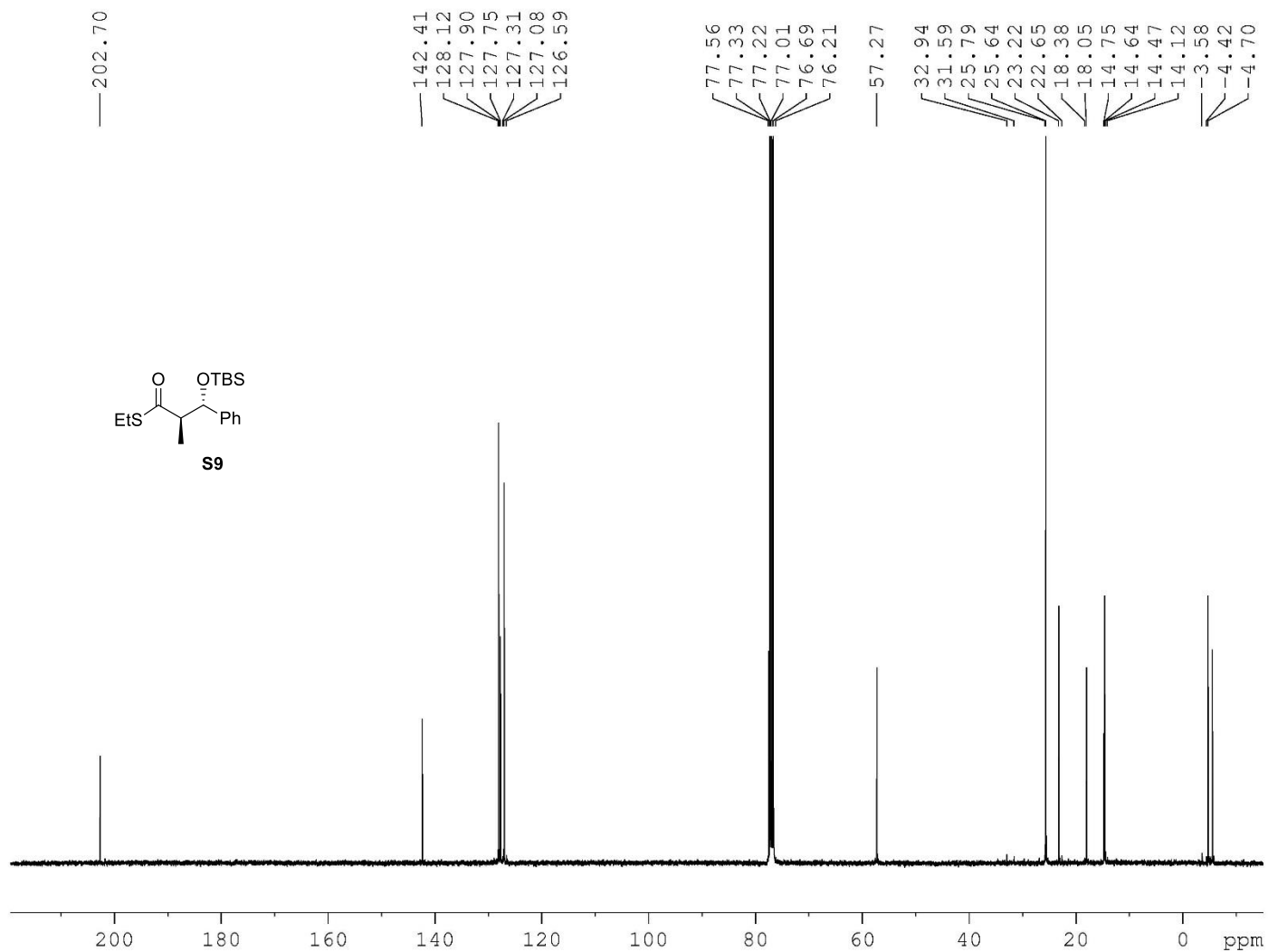


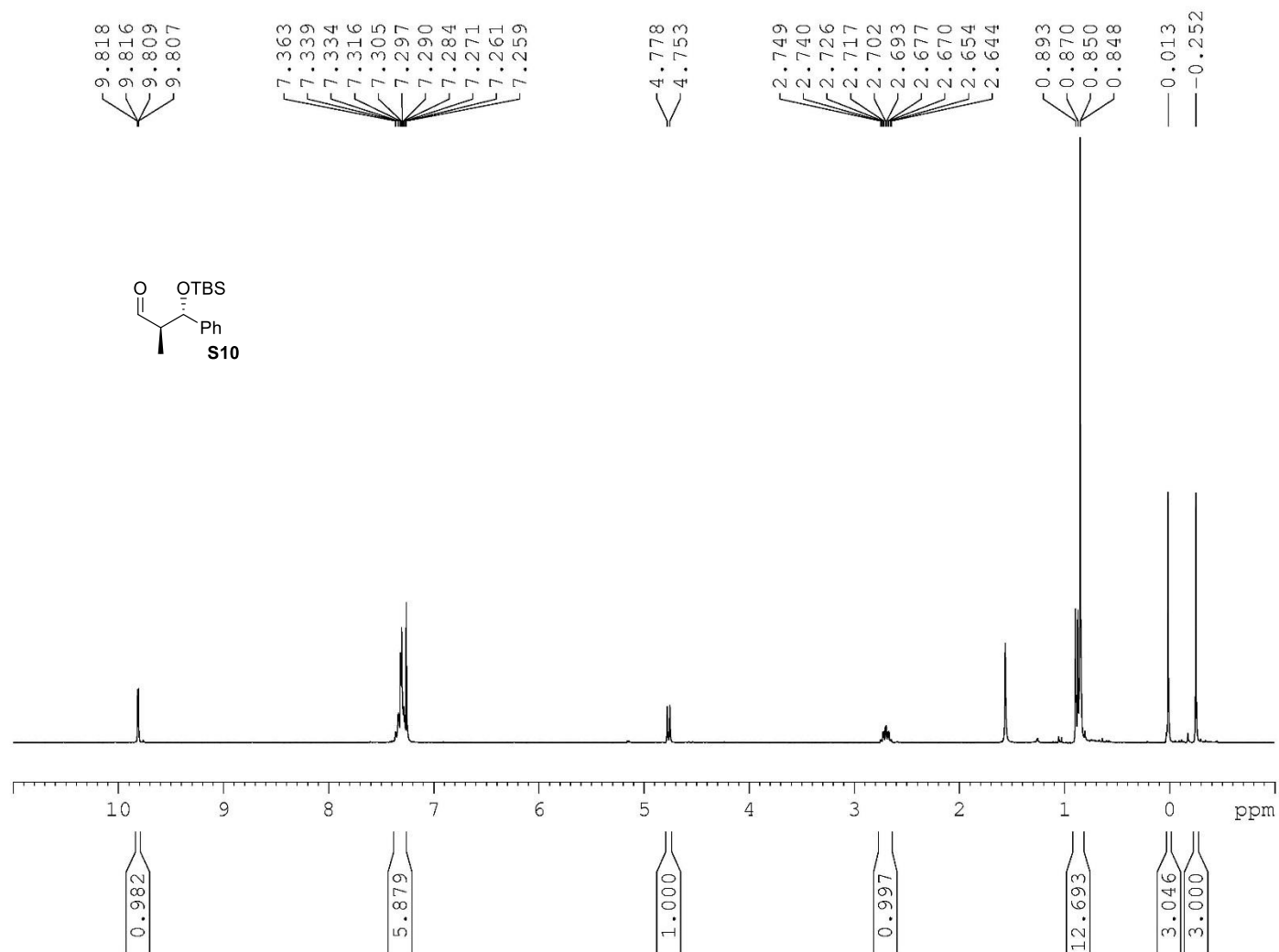
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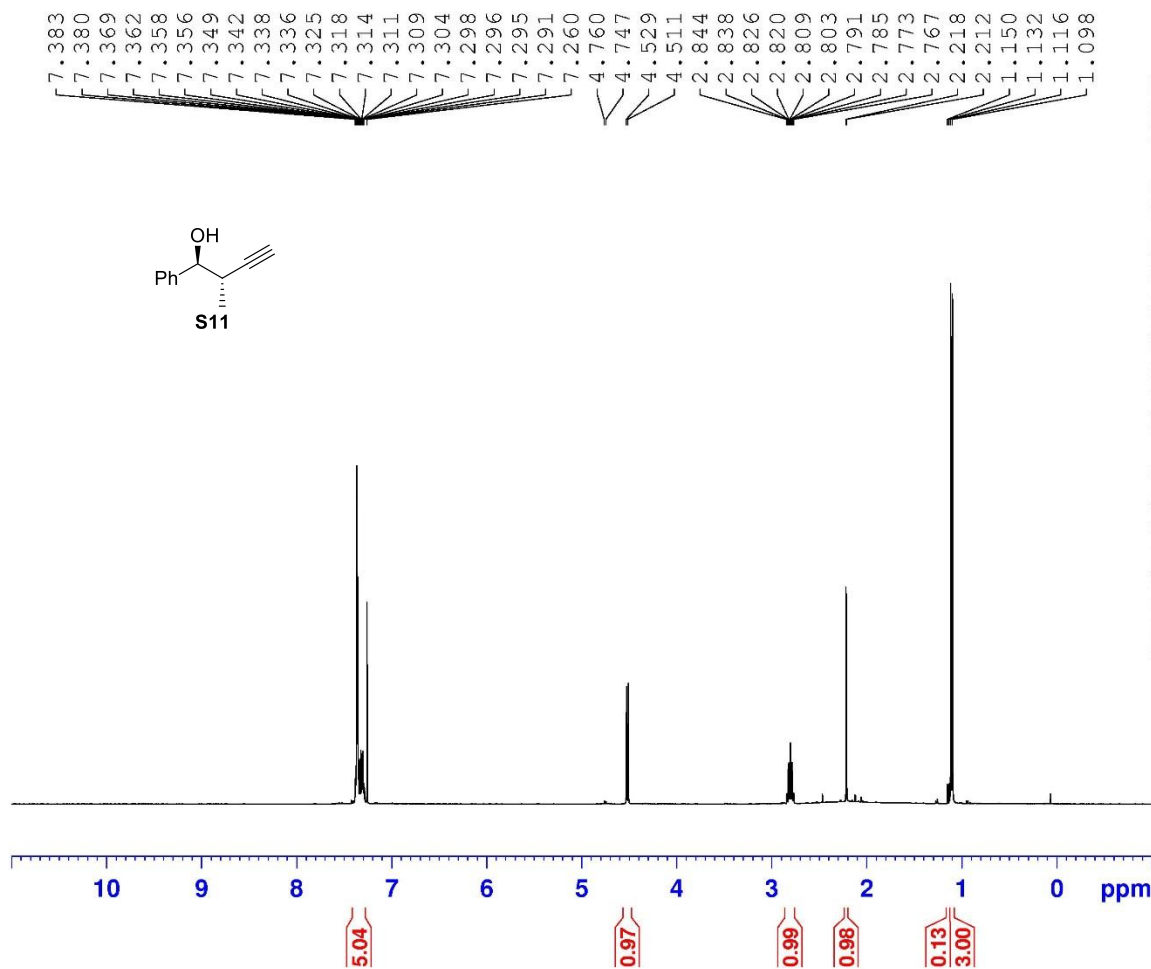
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FIDRES 0.122266 Hz
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RG 208.09
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

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SSB 0
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GB 0
PC 1.00





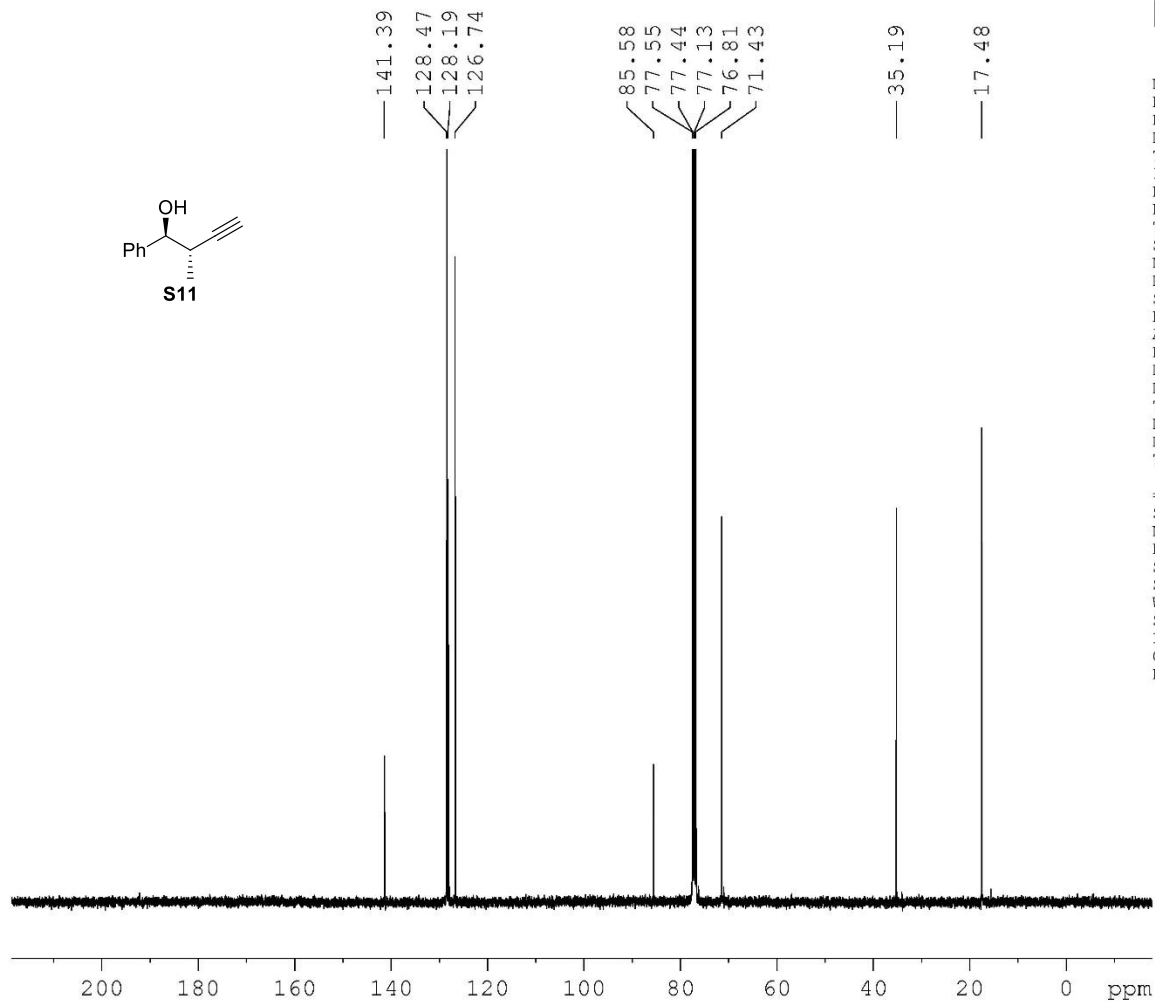
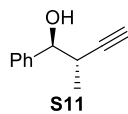
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FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 208.09
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DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

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PC 1.00

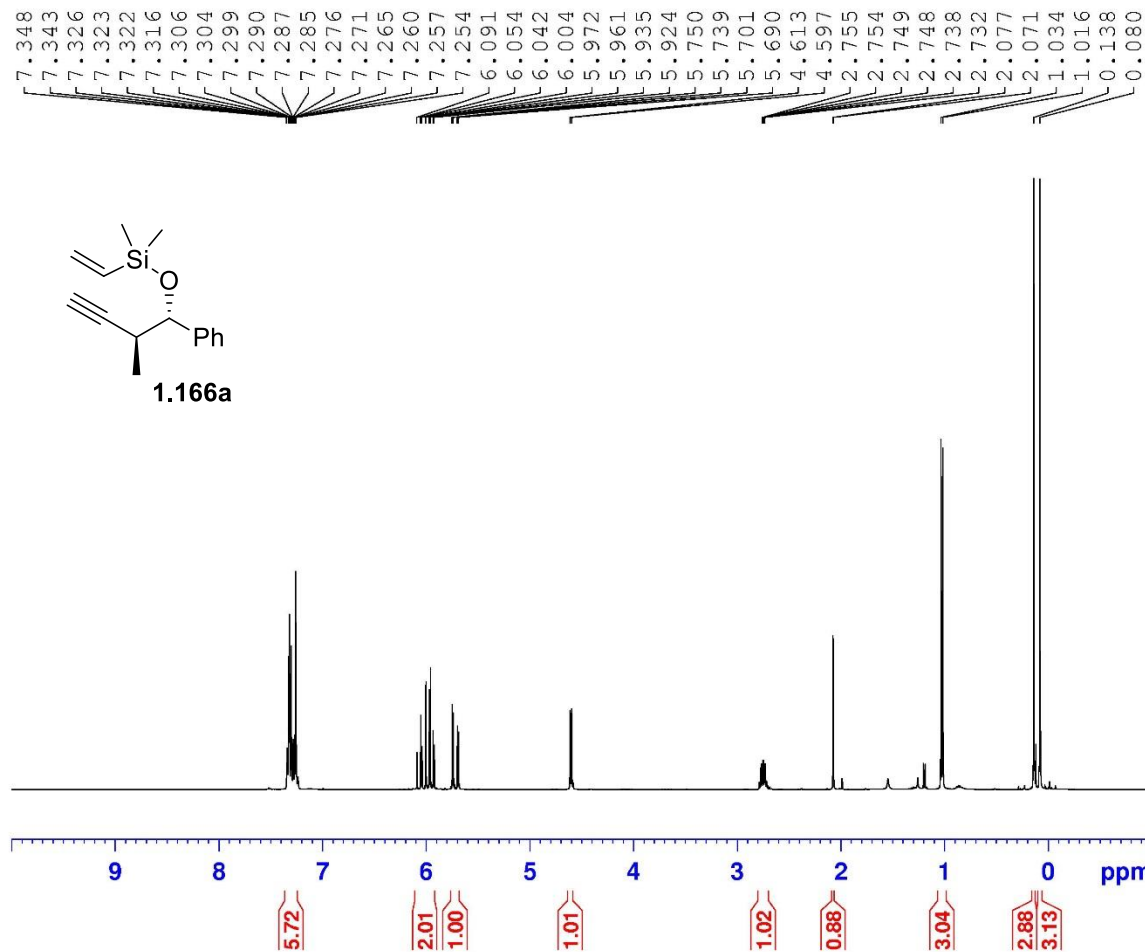
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PULPROG zgpg30
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SOLVENT CDCl3
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DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 50.16
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

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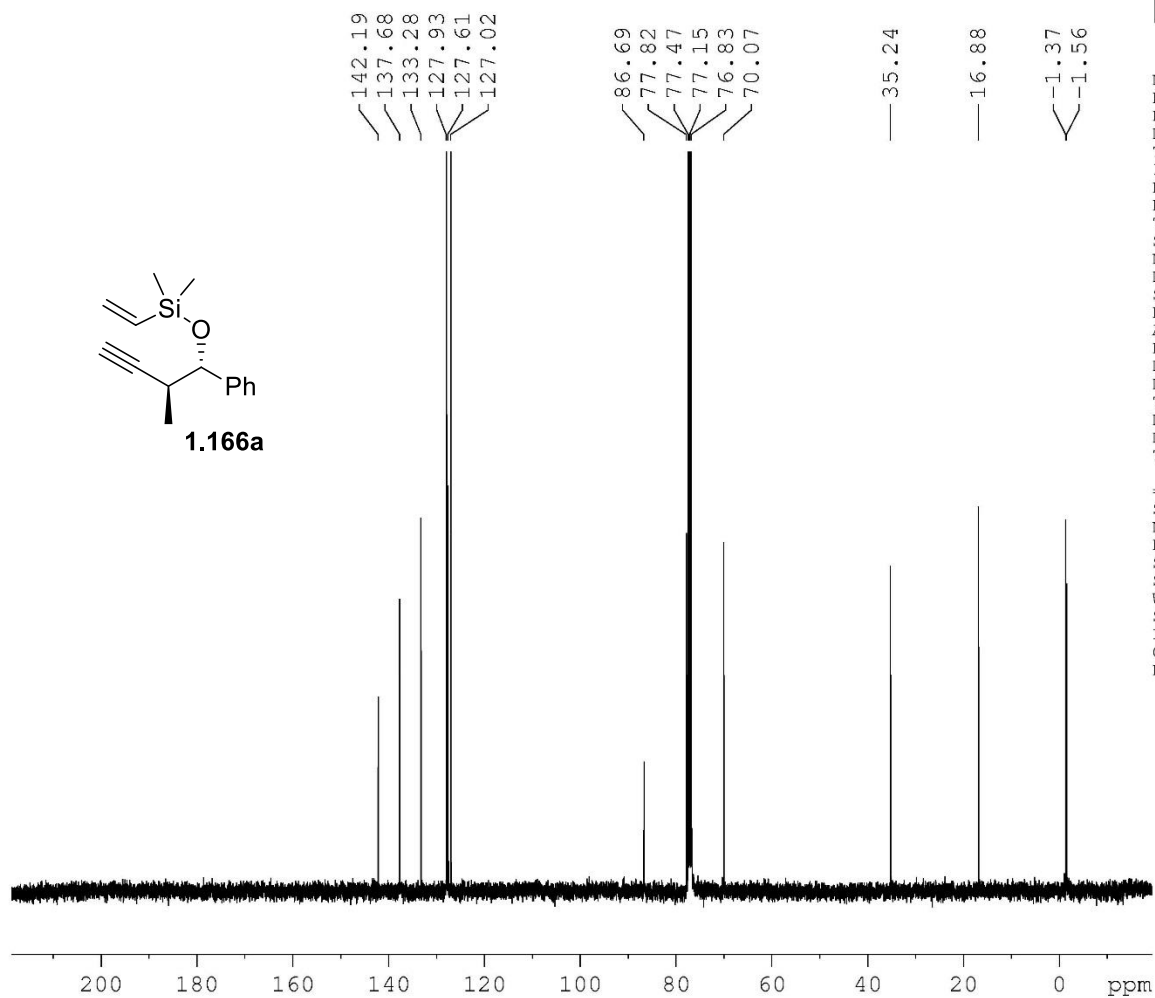
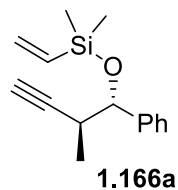
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DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

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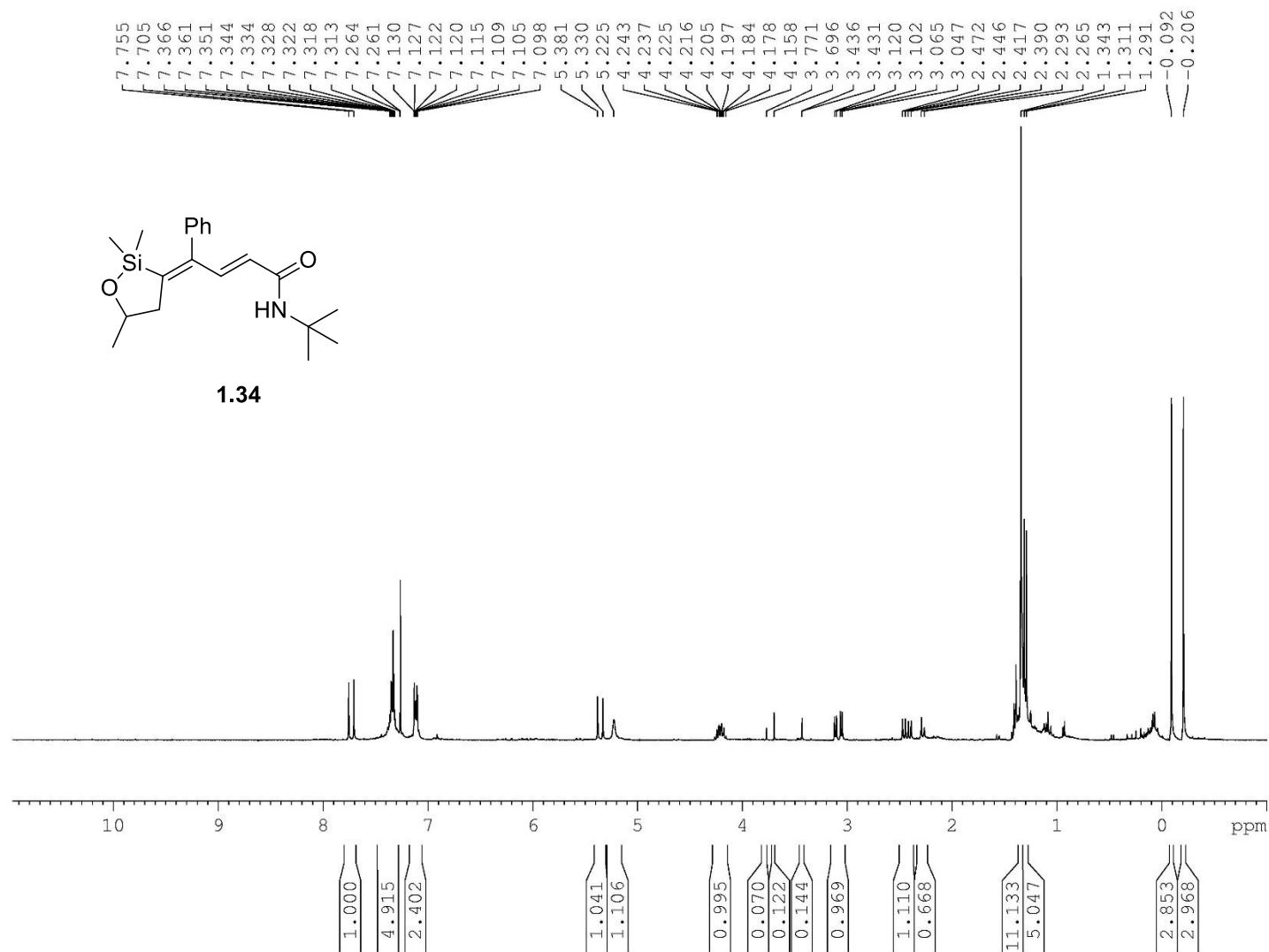
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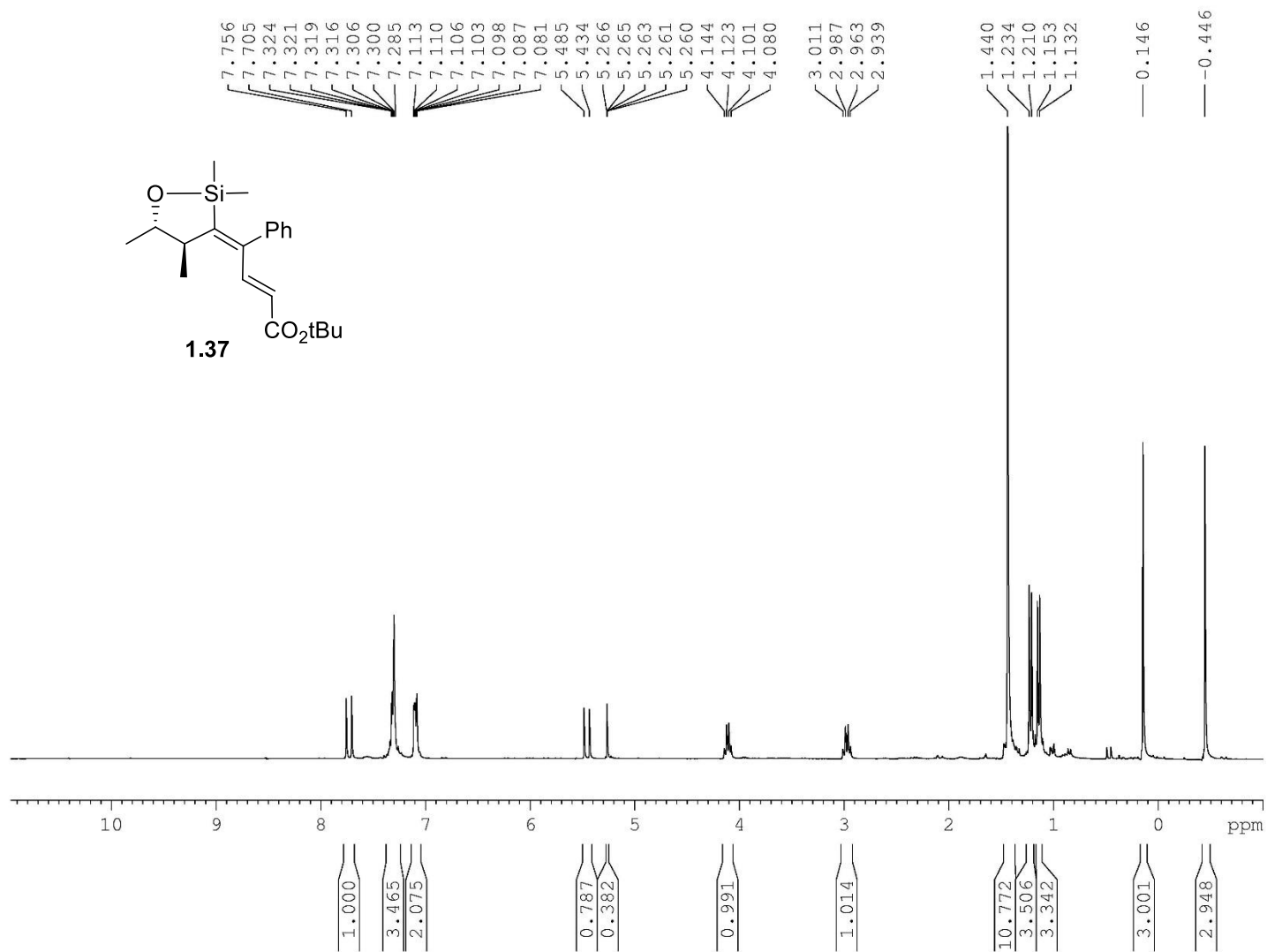


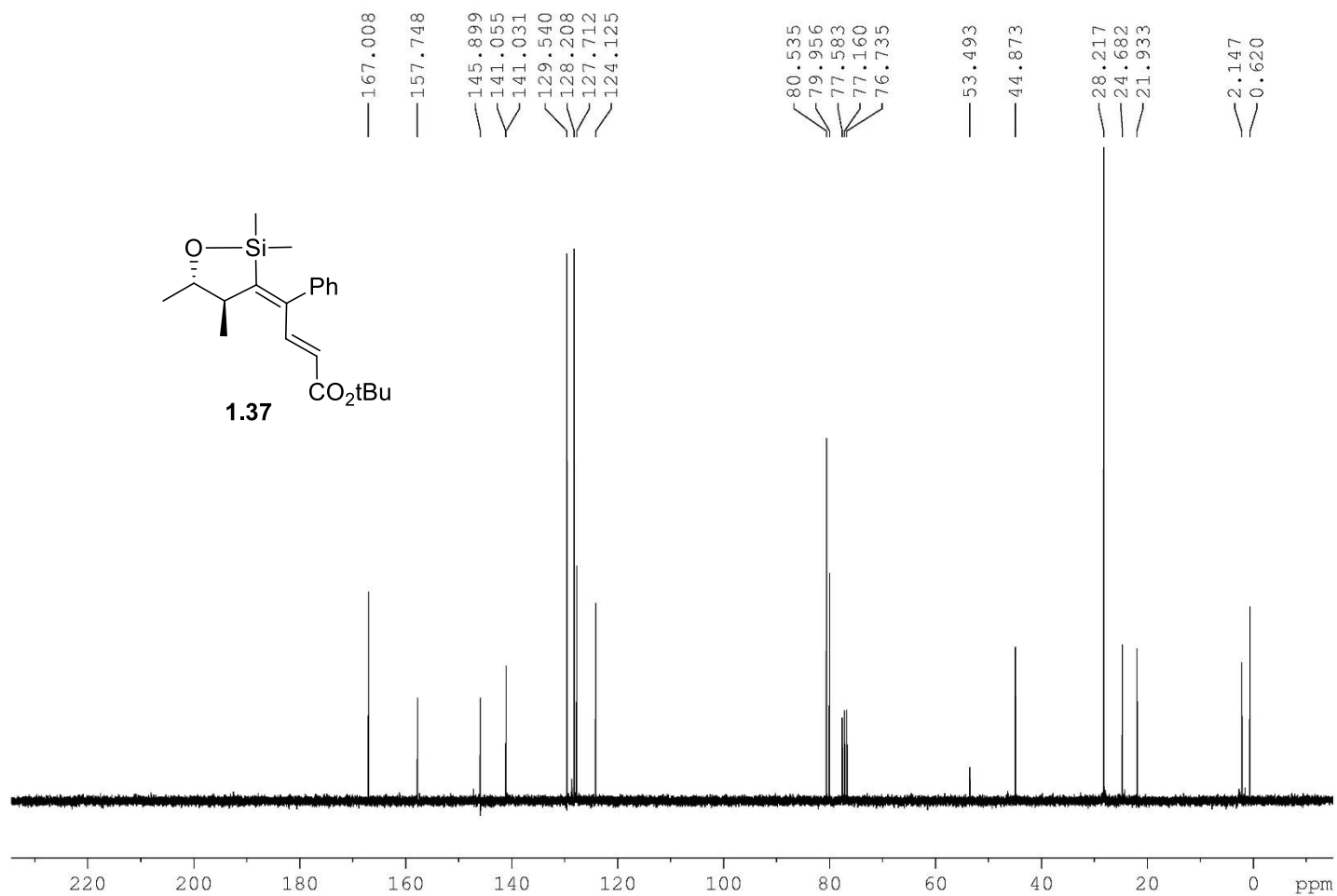
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Time 20.35
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PULPROG zgpg30
TD 65536
SOLVENT CDCl3
NS 240
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 45.77
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
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PC 1.40

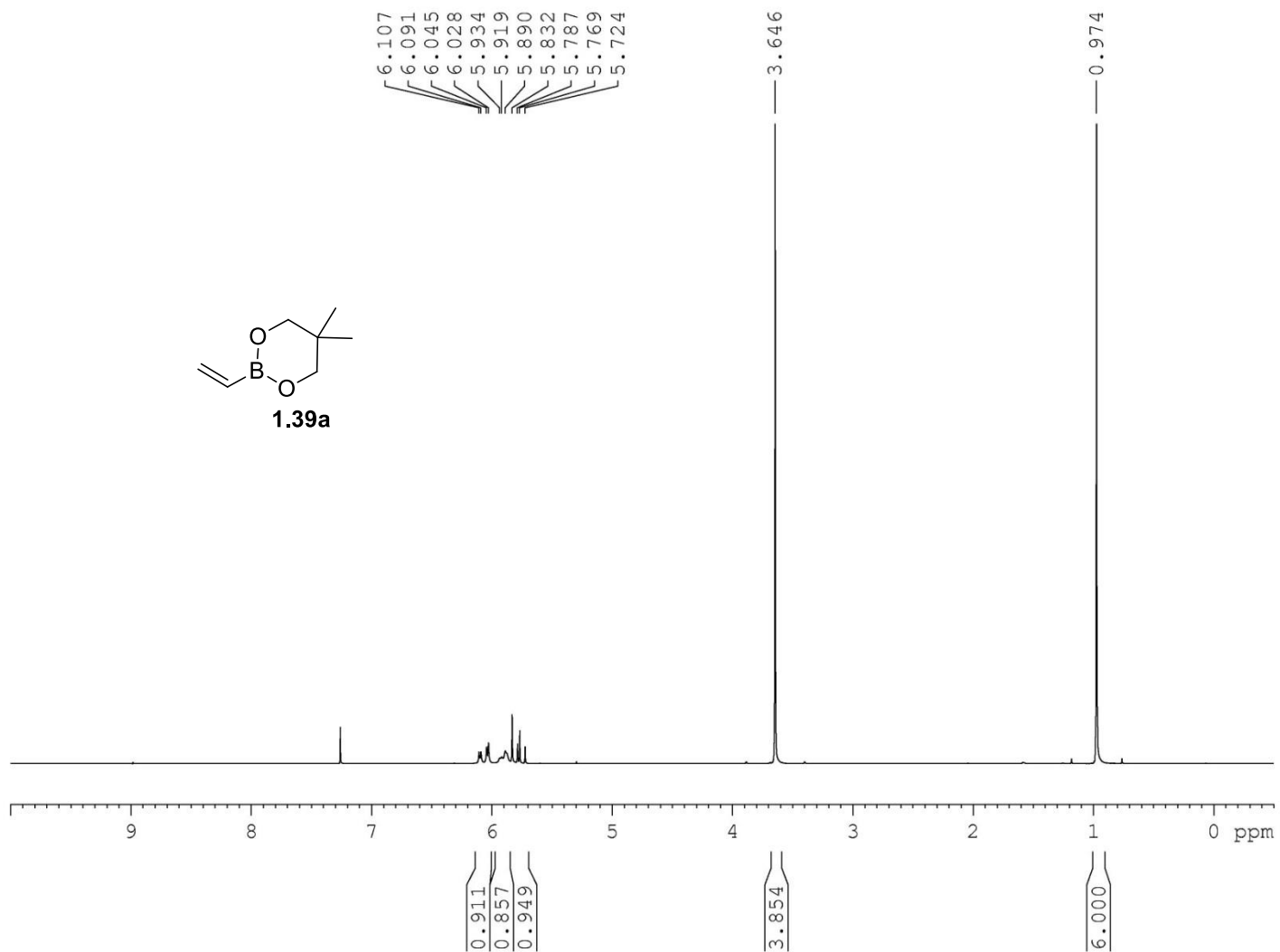
5.2 ACRYLAMIDE AND ACRYLATE SPECTRA

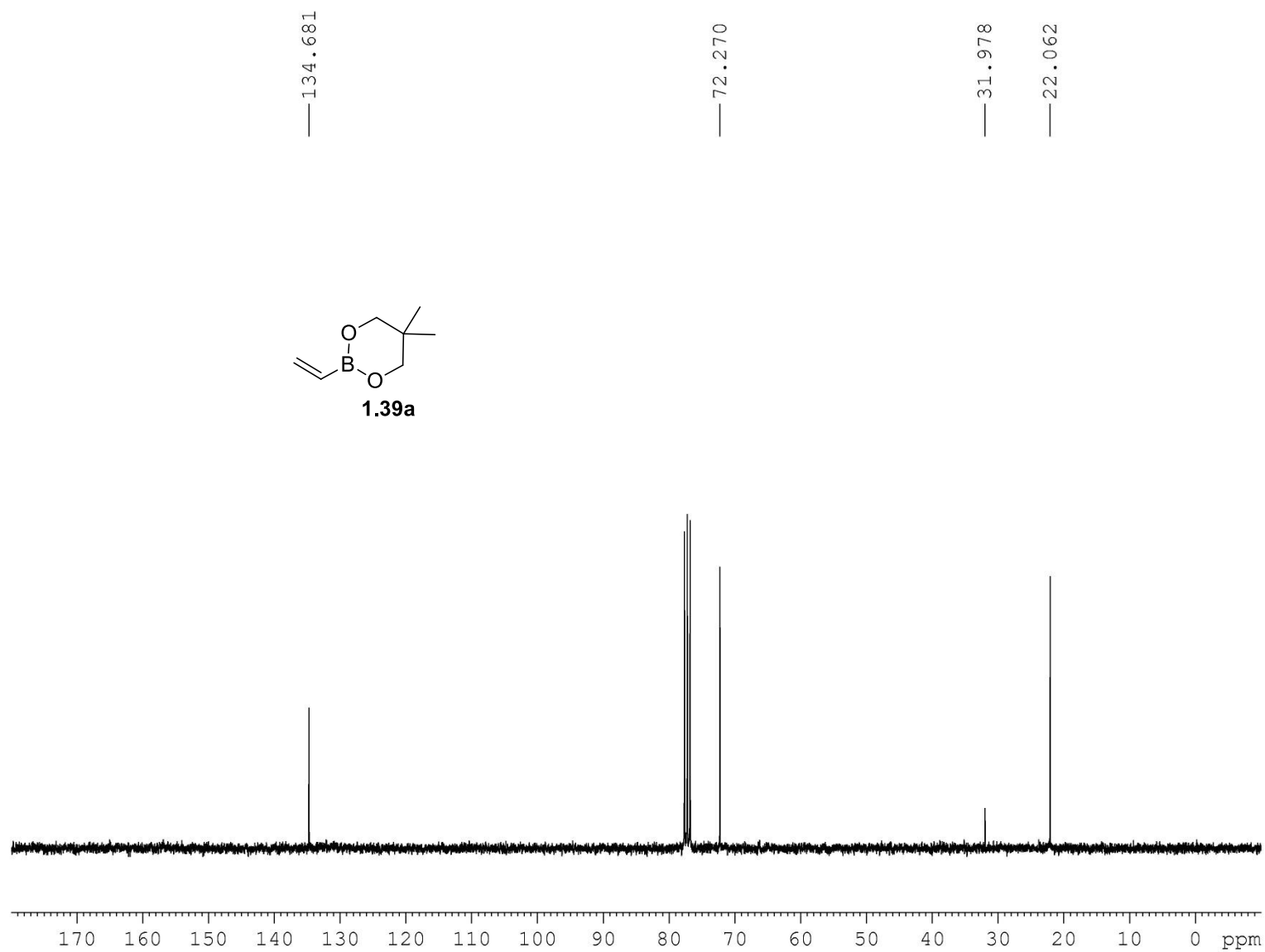


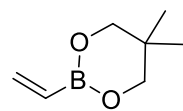




5.3 VINYL BORONATE COUPLING SPECTRA

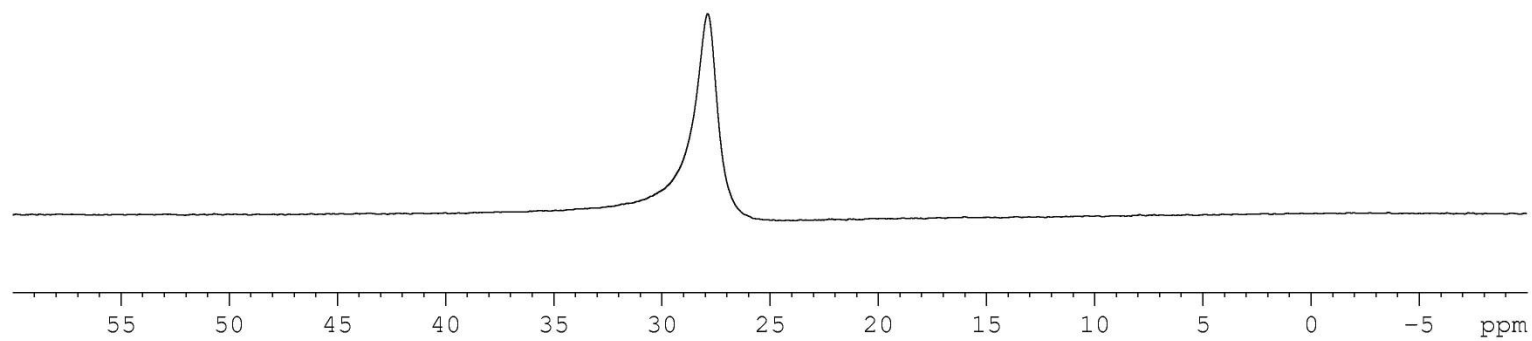


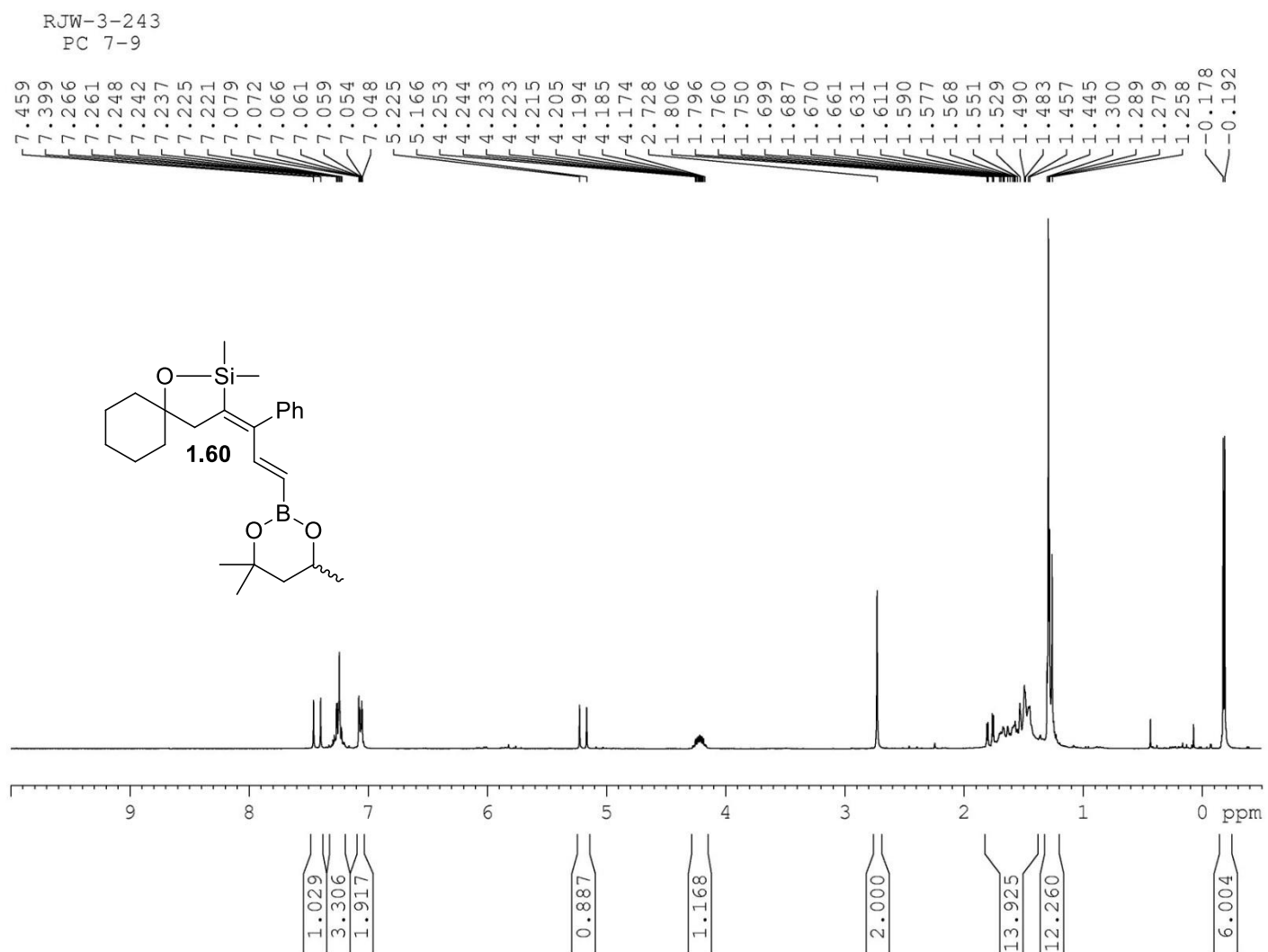




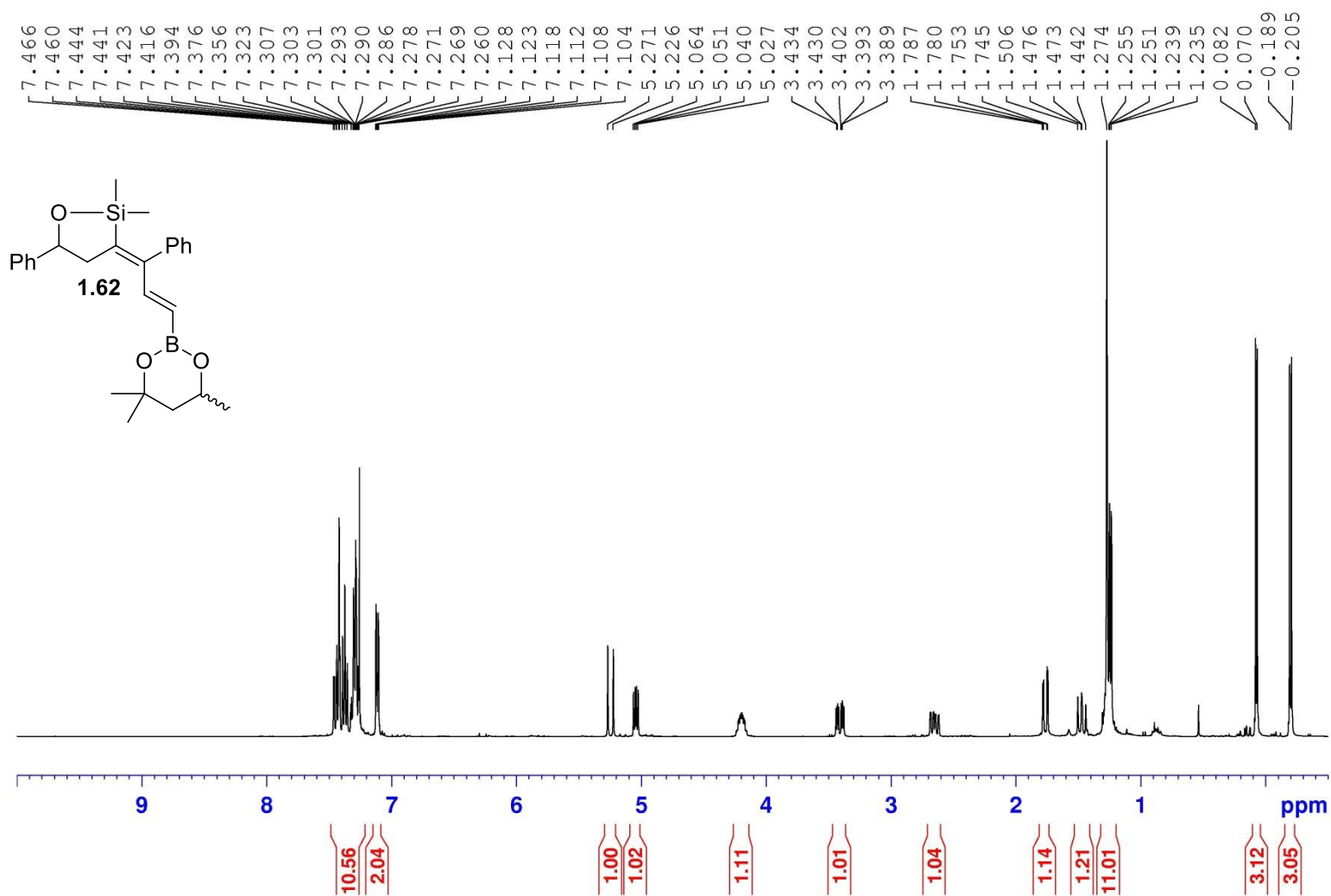
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 ^{11}B NMR

—27.858

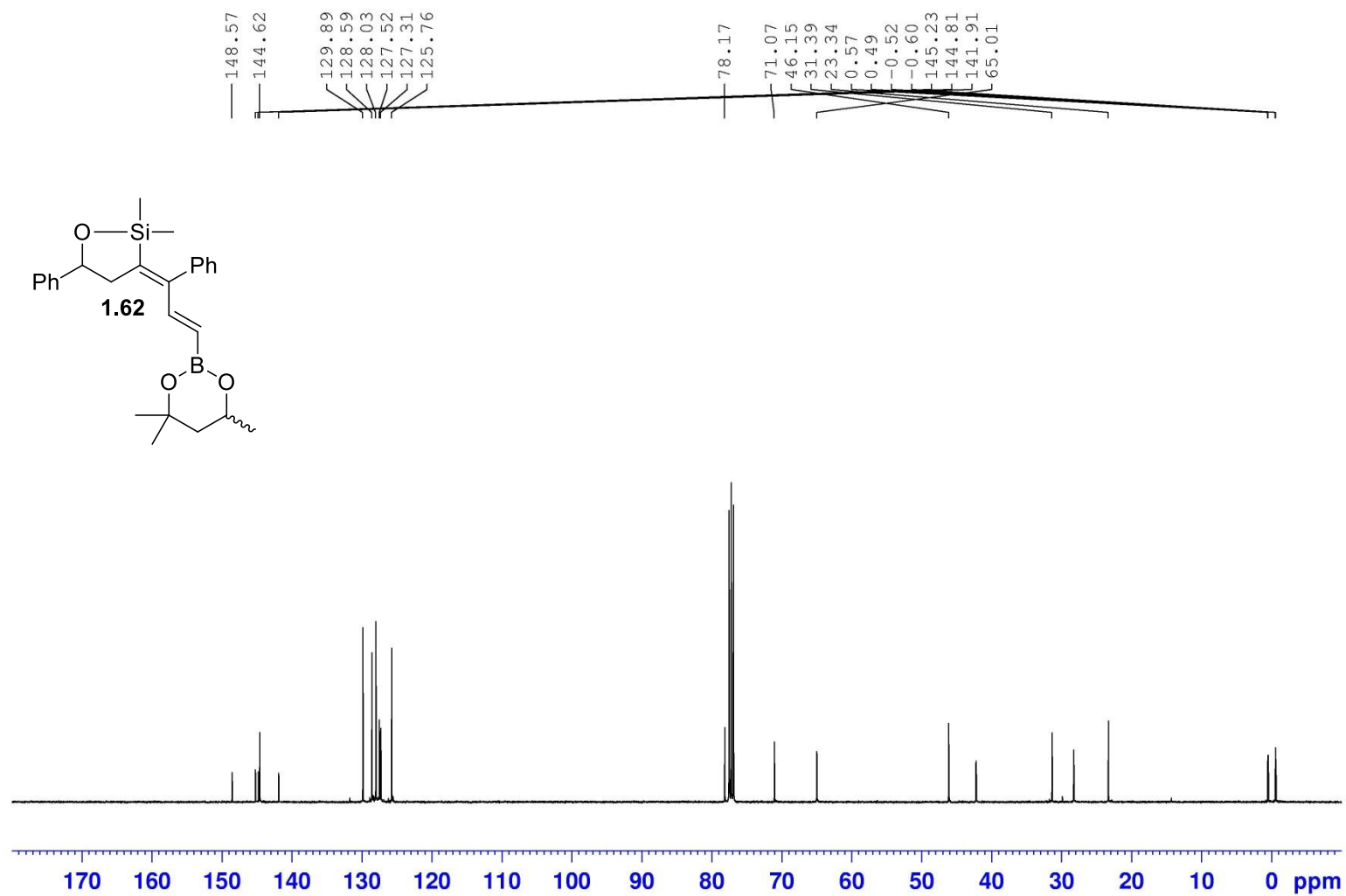




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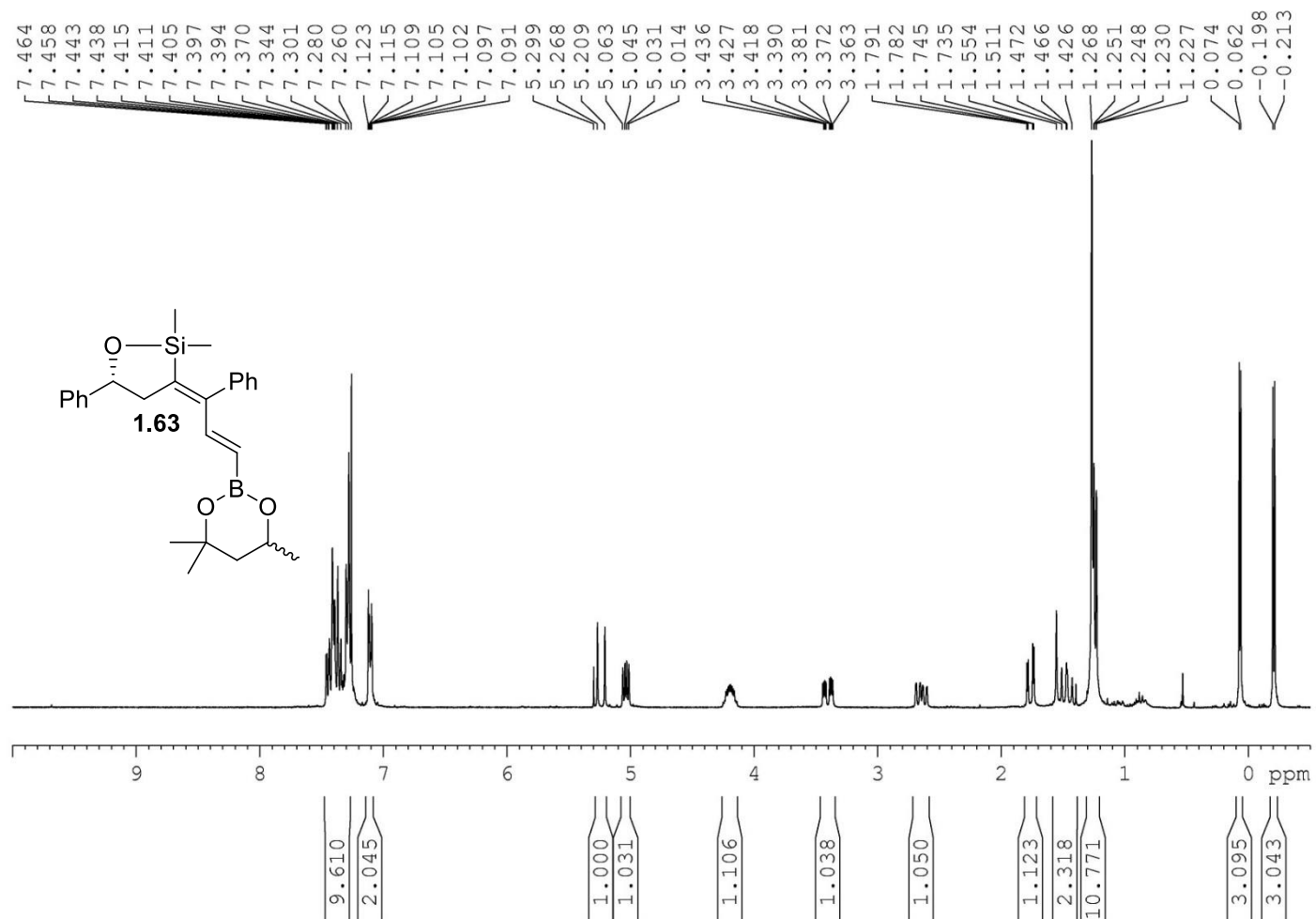
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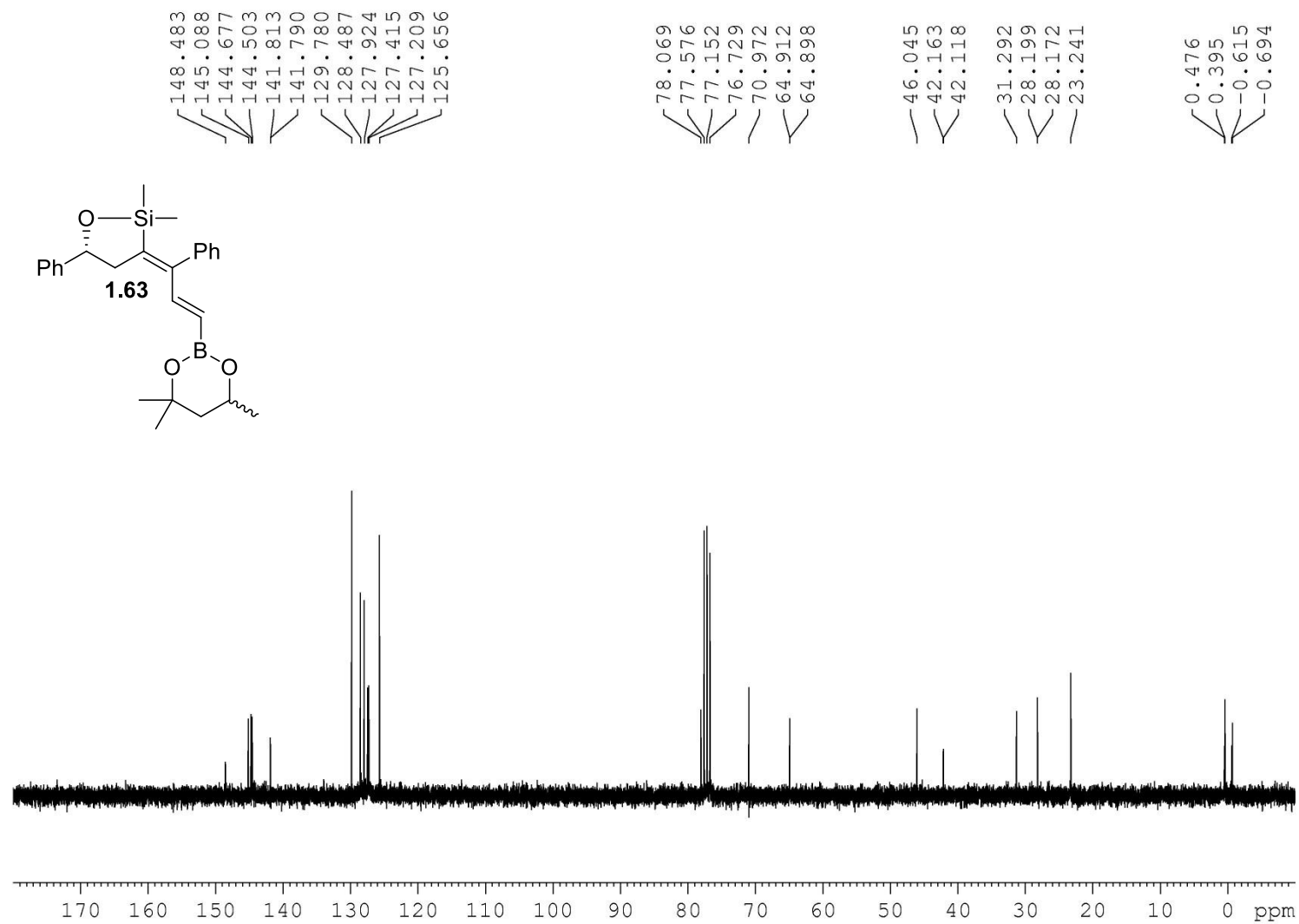
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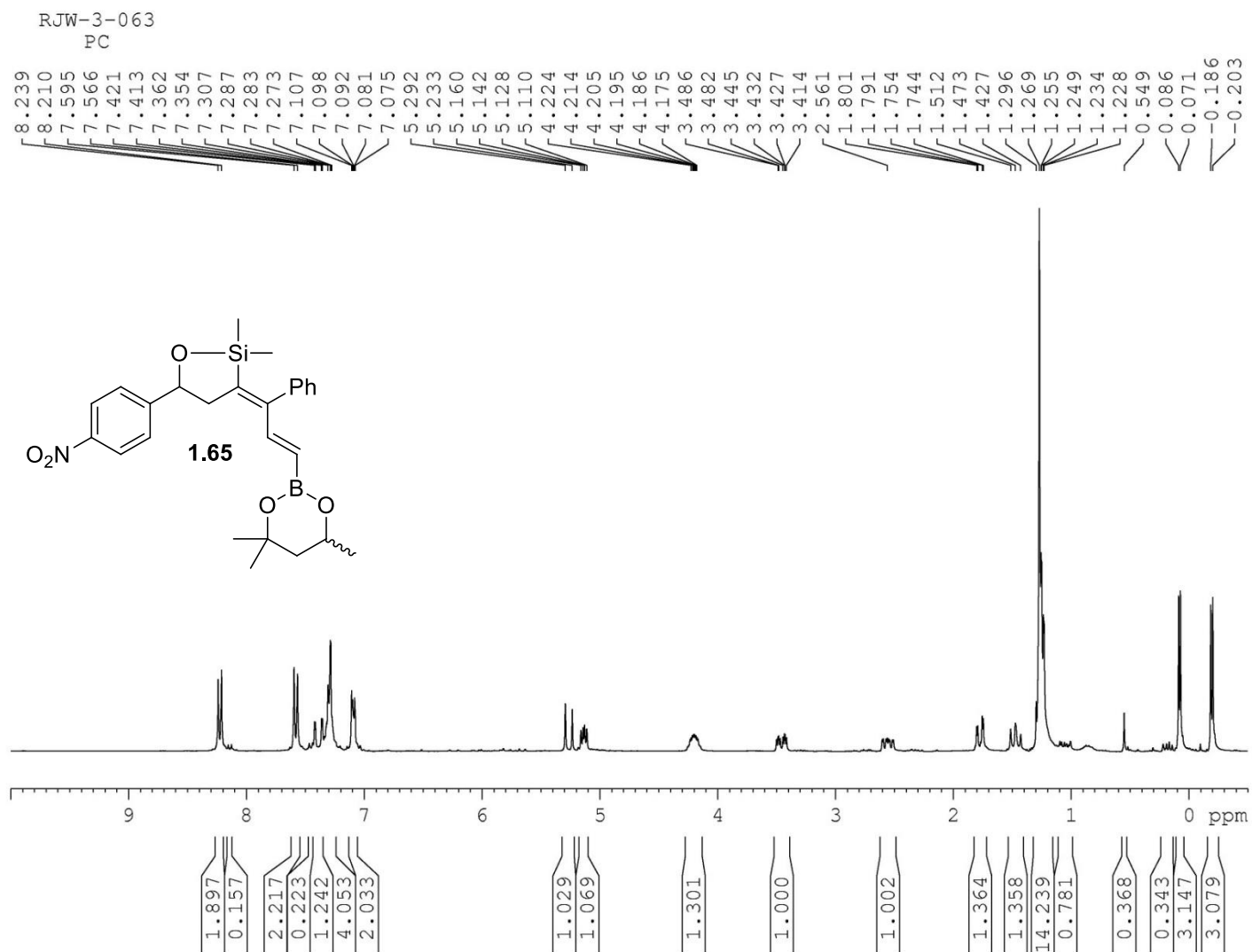
PC

3/6/13

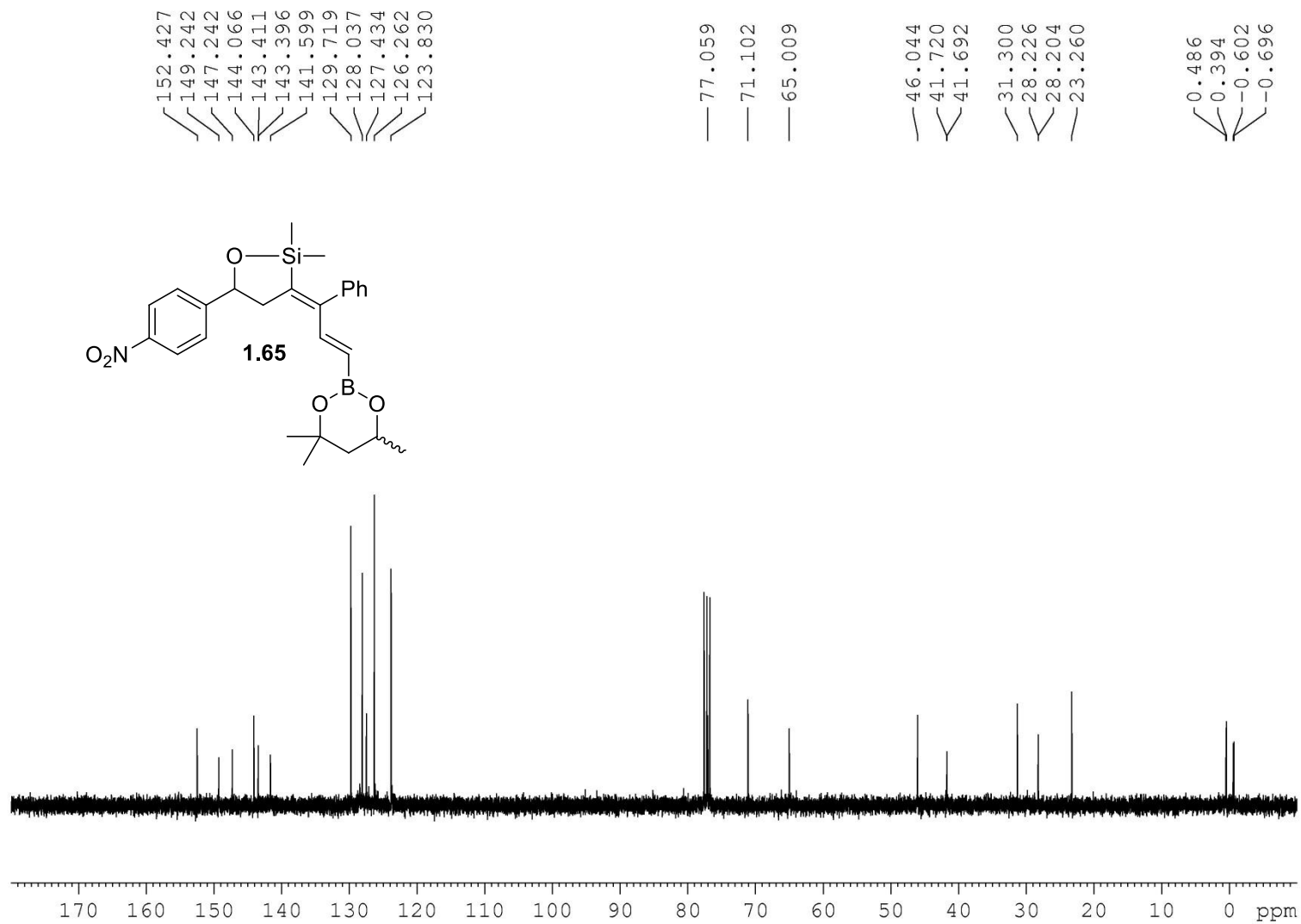


RJW-3-072-C

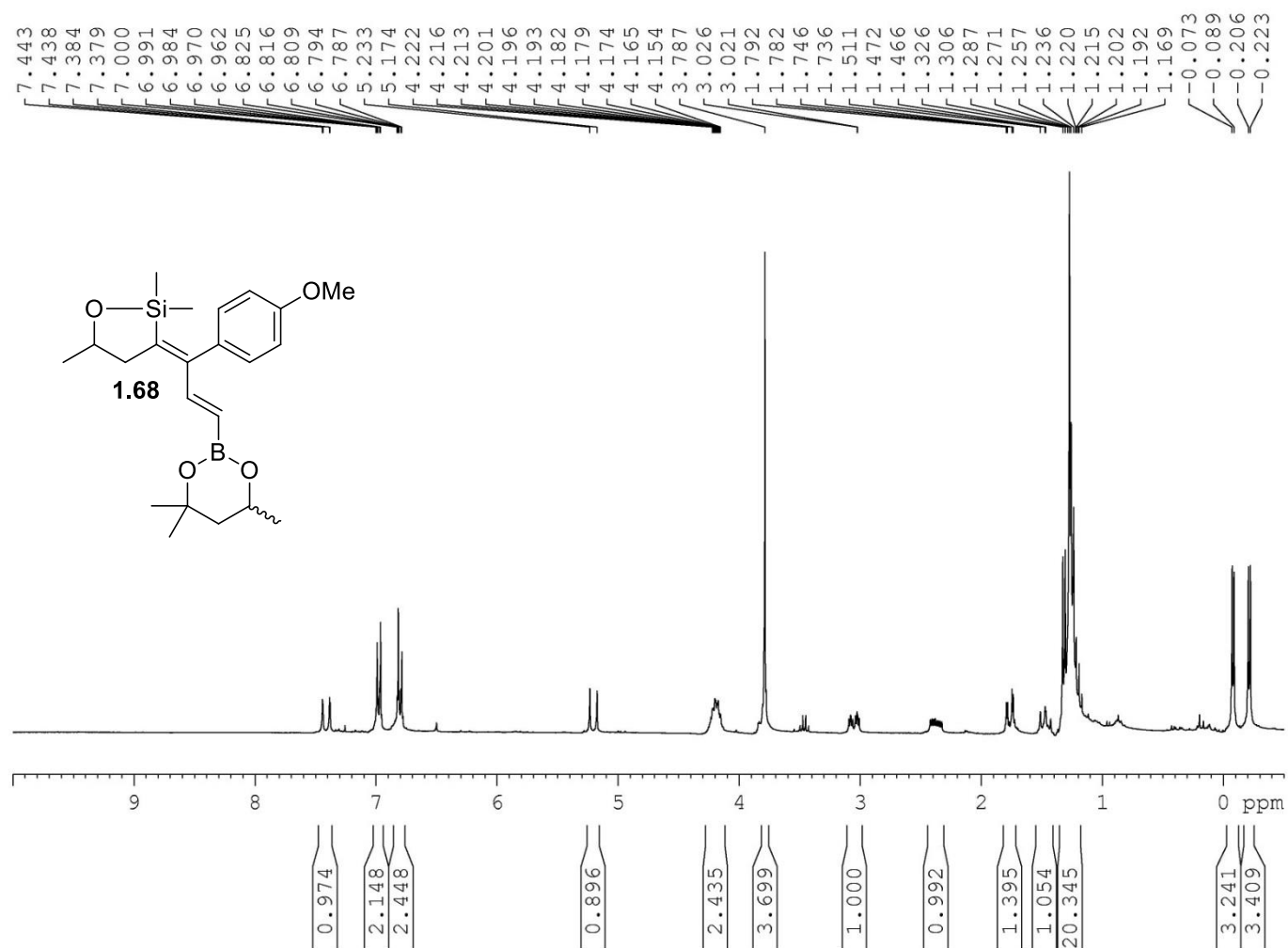




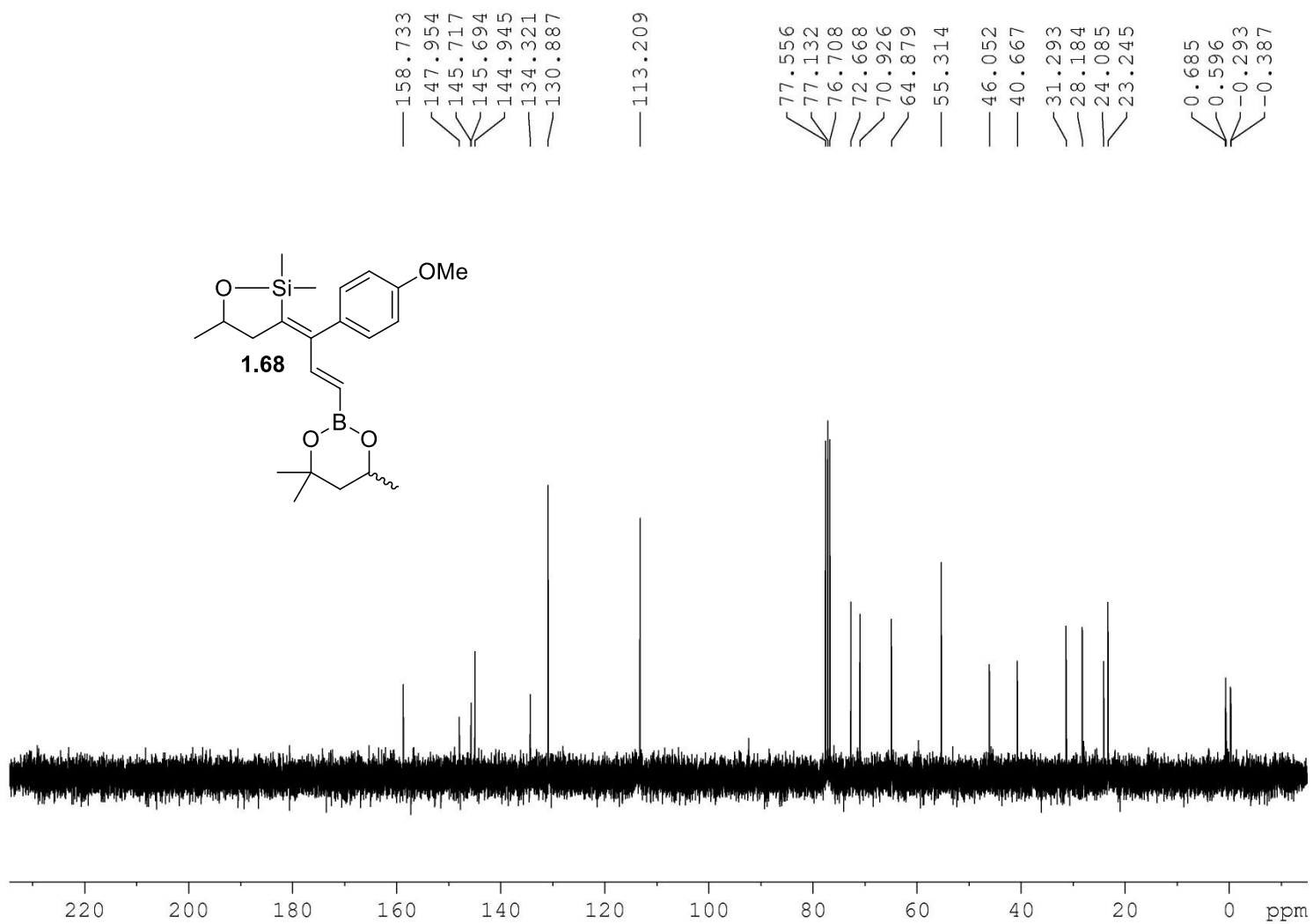
RJW-3-063-C

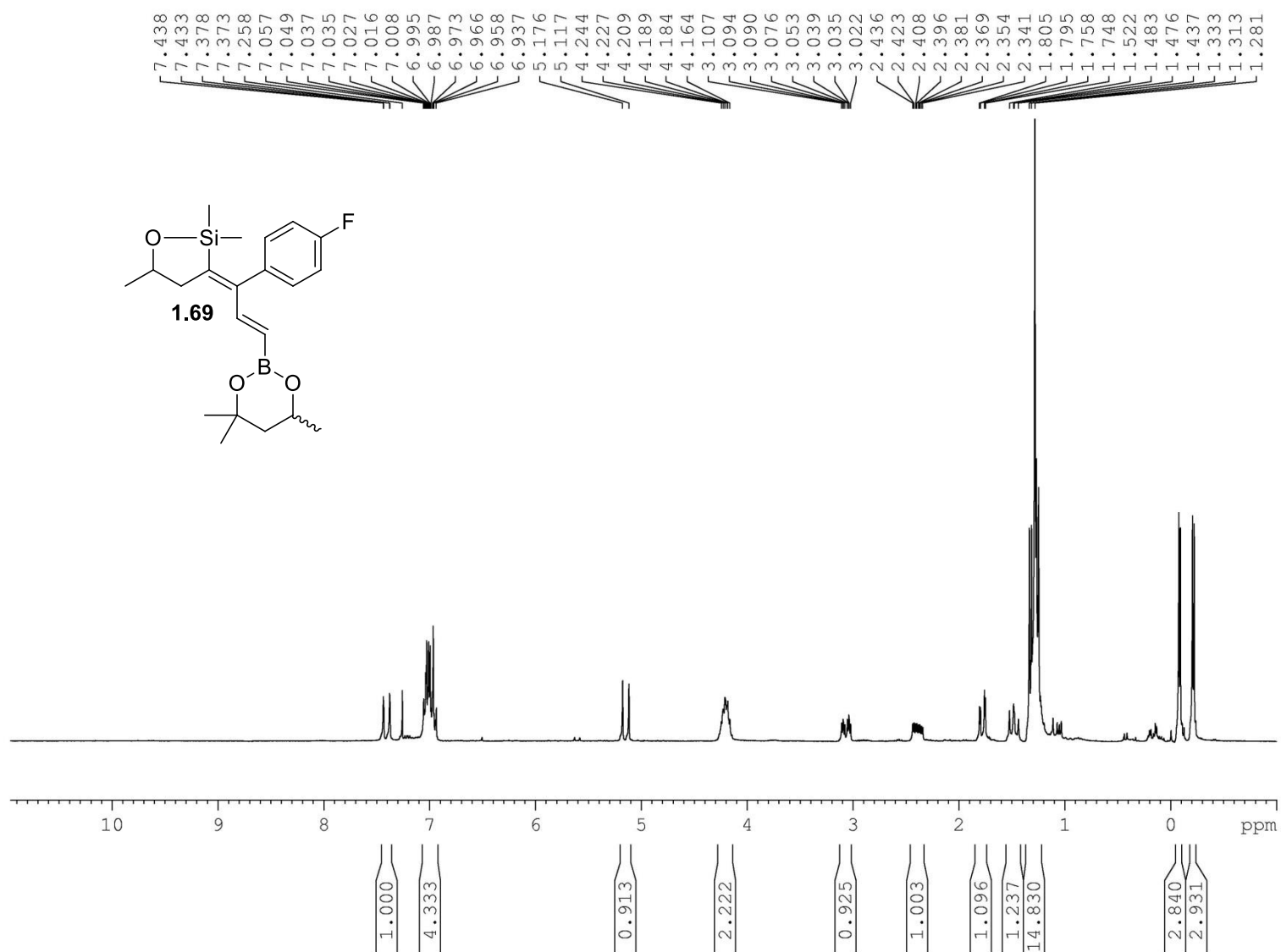


RJW-3-229
PC OMe boronate

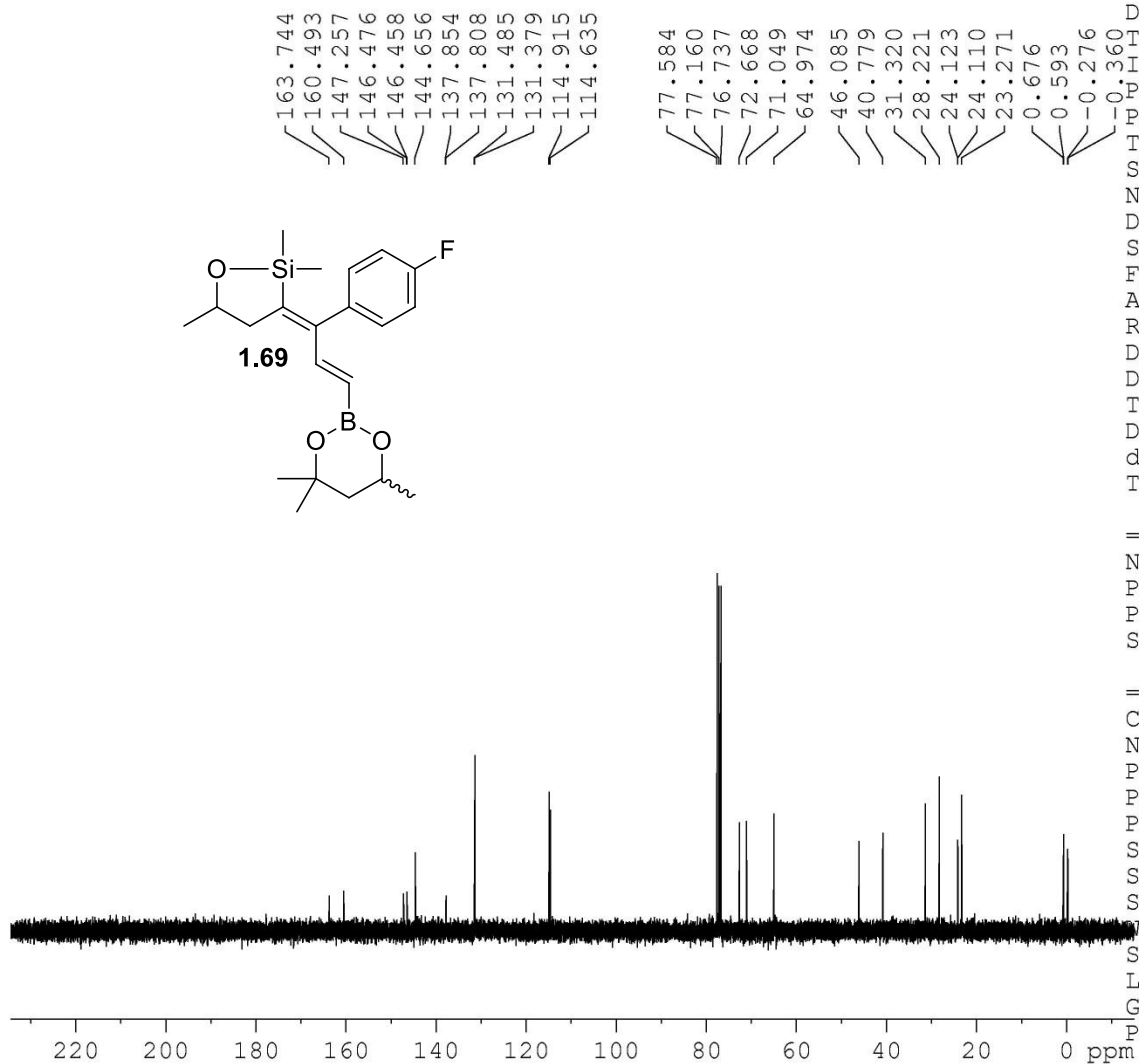
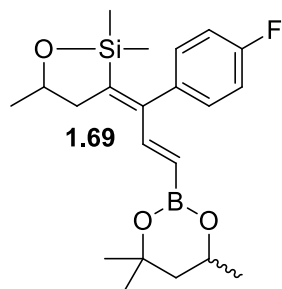


RJW-3-066-C





RJW-3-065-C



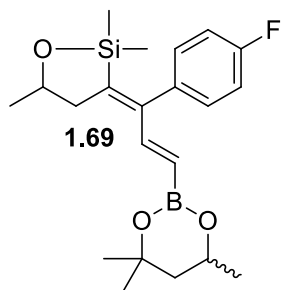
NAME RJW-3-065-C
 EXPNO 2
 PROCNO 1
 Date_ 20121219
 Time 13.38
 INSTRUM spect
 PROBHD 5 mm QNP 1H/1
 PULPROG zgdc30
 TD 65536
 SOLVENT CDC13
 NS 600
 DS 4
 SWH 18832.393 Hz
 FIDRES 0.287360 Hz
 AQ 1.7400308 sec
 RG 8192
 DW 26.550 usec
 DE 6.00 usec
 TE 435.2 K
 D1 1.00000000 sec
 d11 0.03000000 sec
 TD0 1

===== CHANNEL f1 =====
 NUC1 13C
 P1 12.00 usec
 PL1 0.00 dB
 SFO1 75.4760200 MHz

===== CHANNEL f2 =====
 CPDPRG2 waltz16
 NUC2 1H
 PCPD2 95.00 usec
 PL2 0.00 dB
 PL12 18.00 dB
 SFO2 300.1312005 MHz
 SI 32768
 SF 75.4677393 MHz
 WDW no
 SSB 0
 LB 0.00 Hz
 GB 0
 PC 1.40

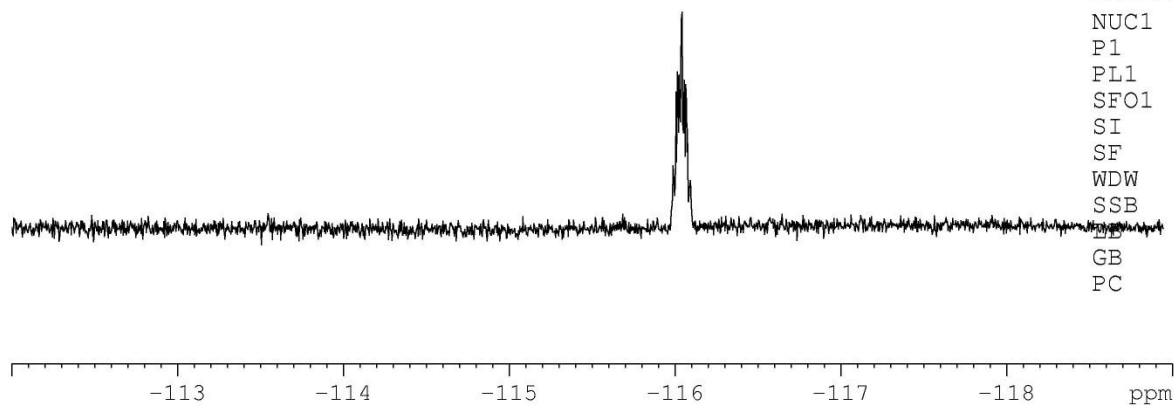
RJW-3-065-F

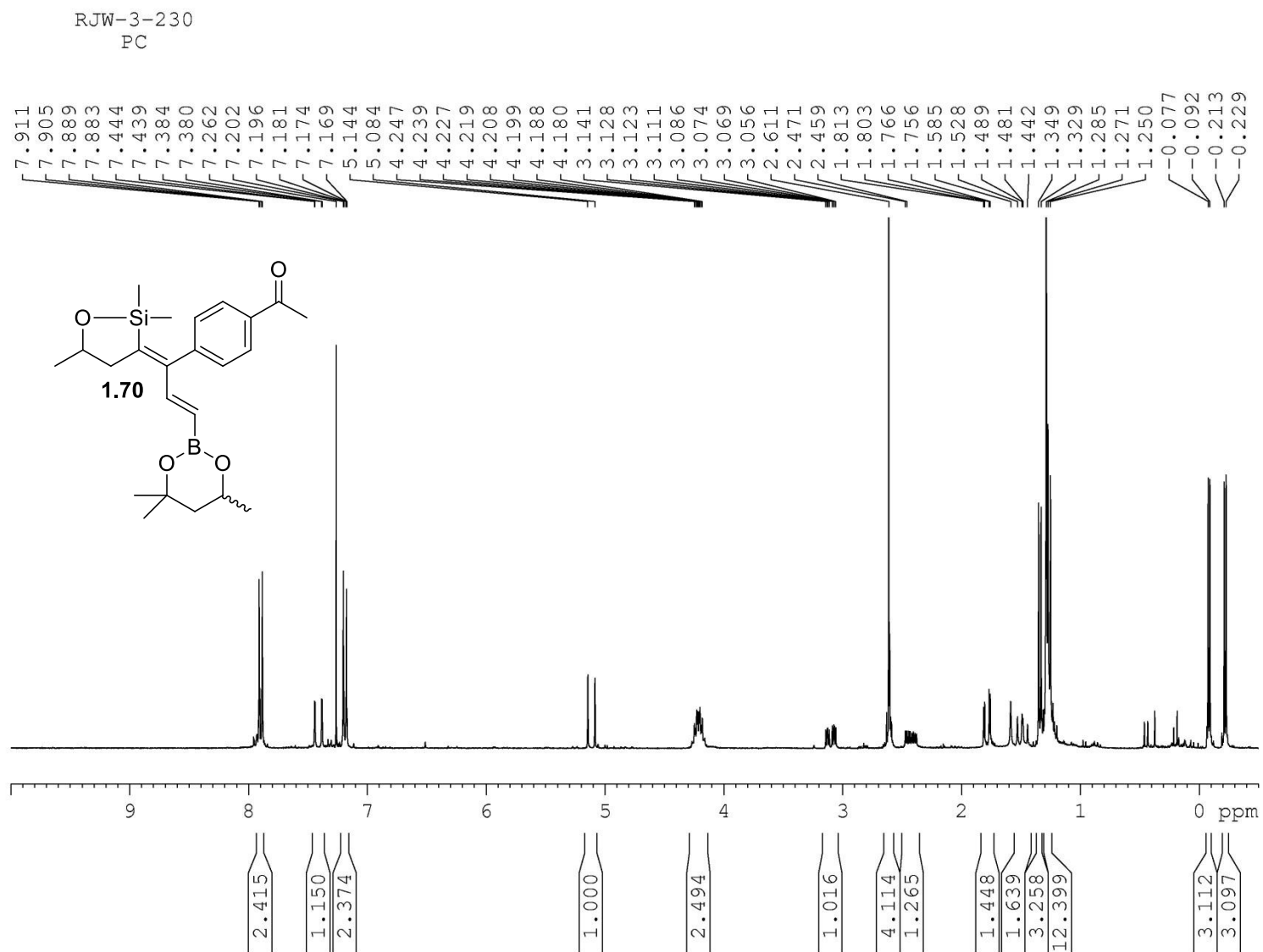
-115.990
-116.007
-116.016
-116.025
-116.042
-116.057
-116.066
-116.075
-116.093



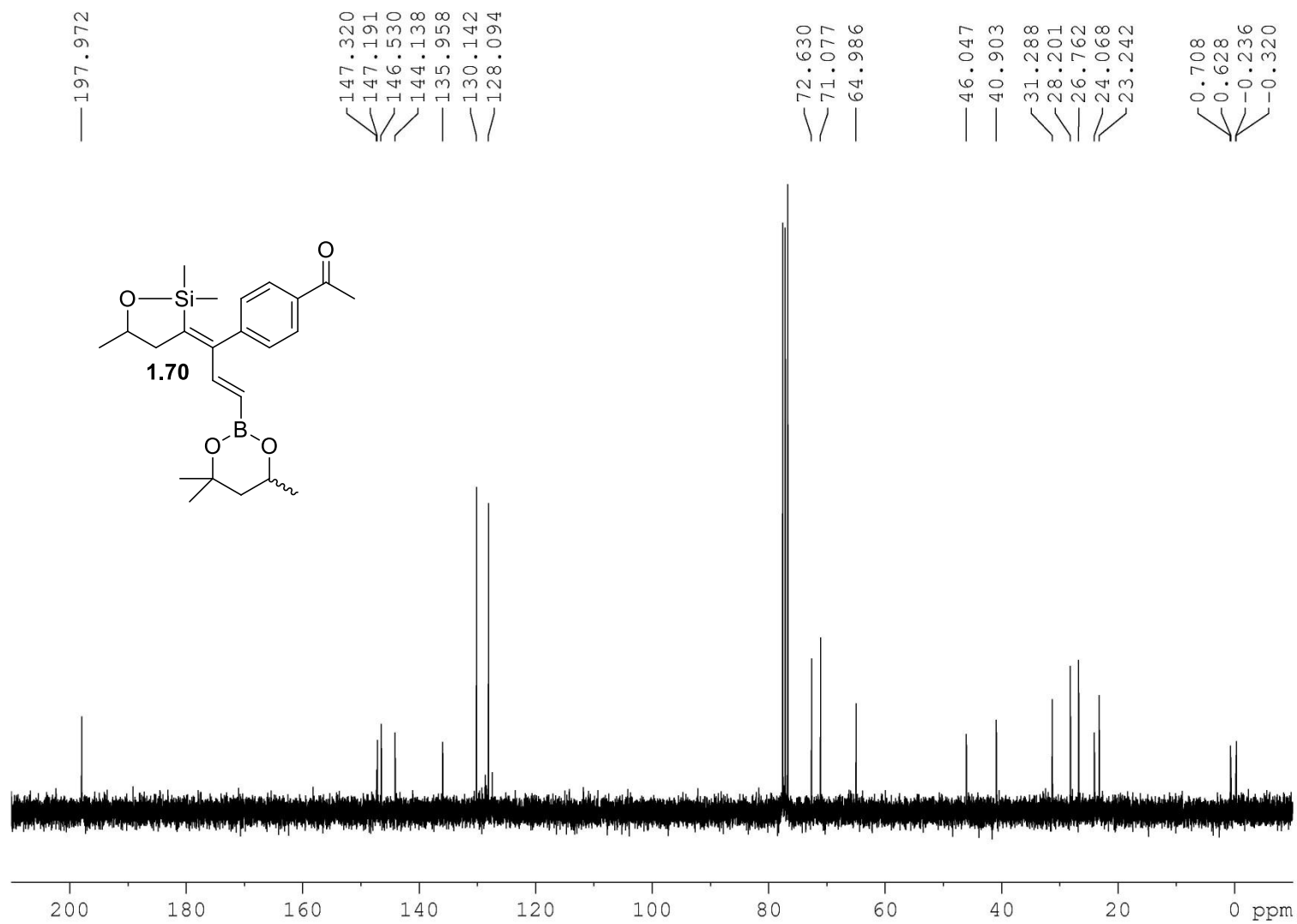
NAME RJW-3-065-F
EXPNO 1
PROCNO 1
Date_ 20121219
Time 13.06
INSTRUM spect
PROBHD 5 mm QNP 1H/1
PULPROG zg
TD 131072
SOLVENT CDCl3
NS 16
DS 4
SWH 67567.570 Hz
FIDRES 0.515500 Hz
AQ 0.9699828 sec
RG 18390.4
DW 7.400 usec
DE 6.00 usec
TE 436.2 K
D1 1.00000000 sec
TD0 1

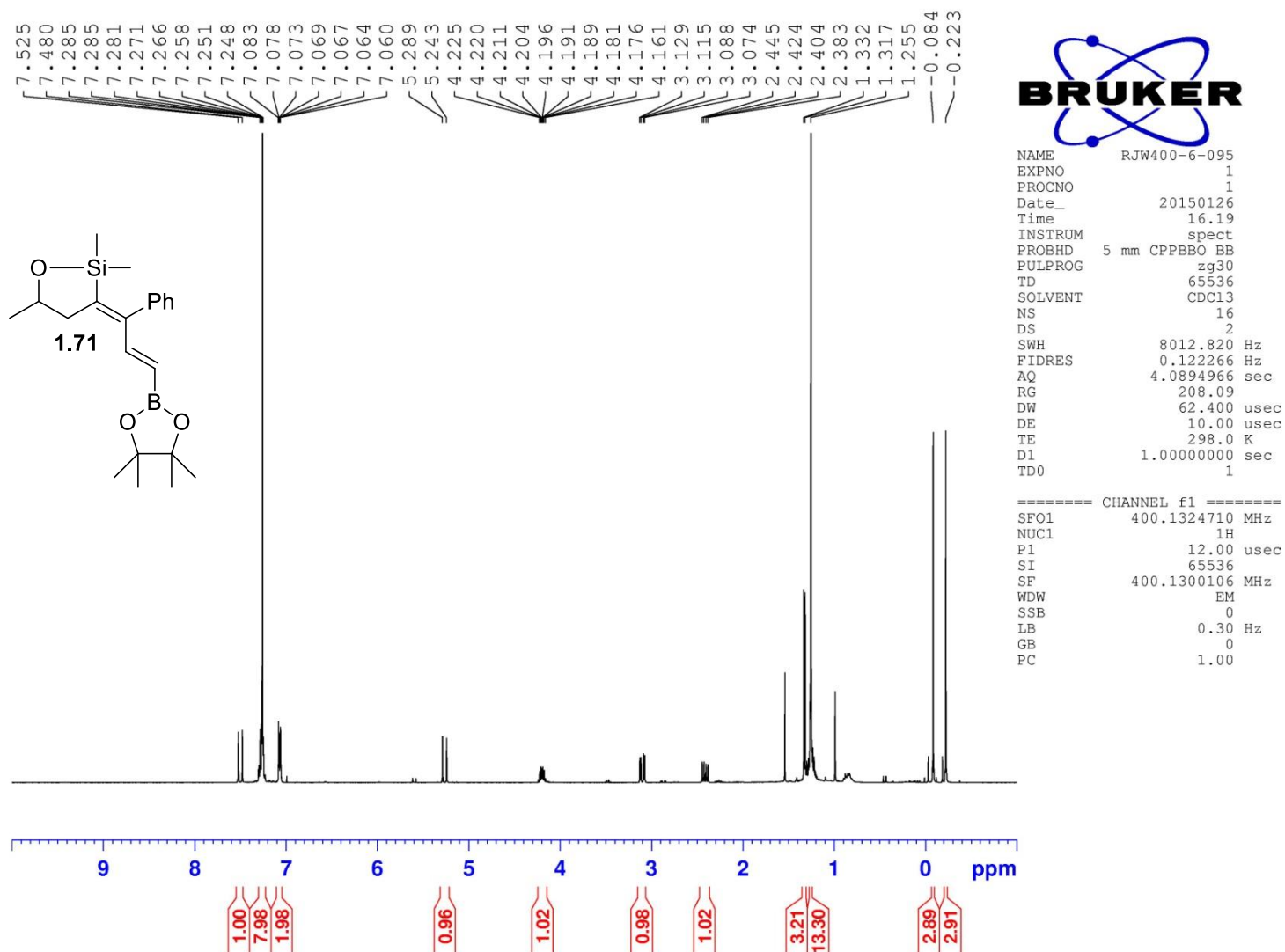
===== CHANNEL f1 =====
NUC1 19F
P1 15.00 usec
PL1 -3.00 dB
SFO1 282.4046735 MHz
SI 65536
SF 282.4044810 MHz
WDW no
SSB 0
LB 0.00 Hz
GB 0
PC 1.00



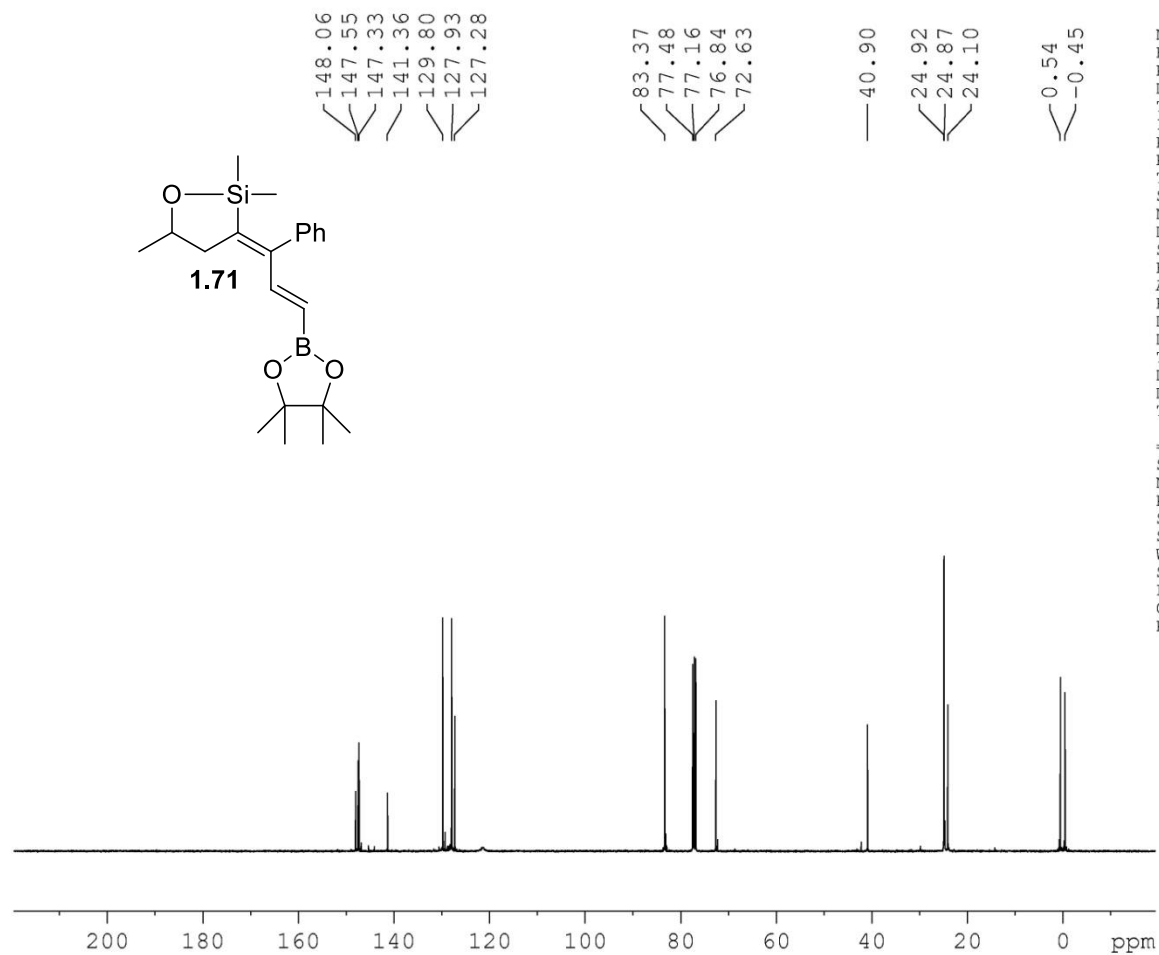
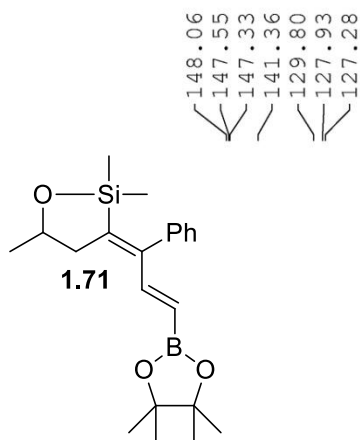


RJW-3-230-C



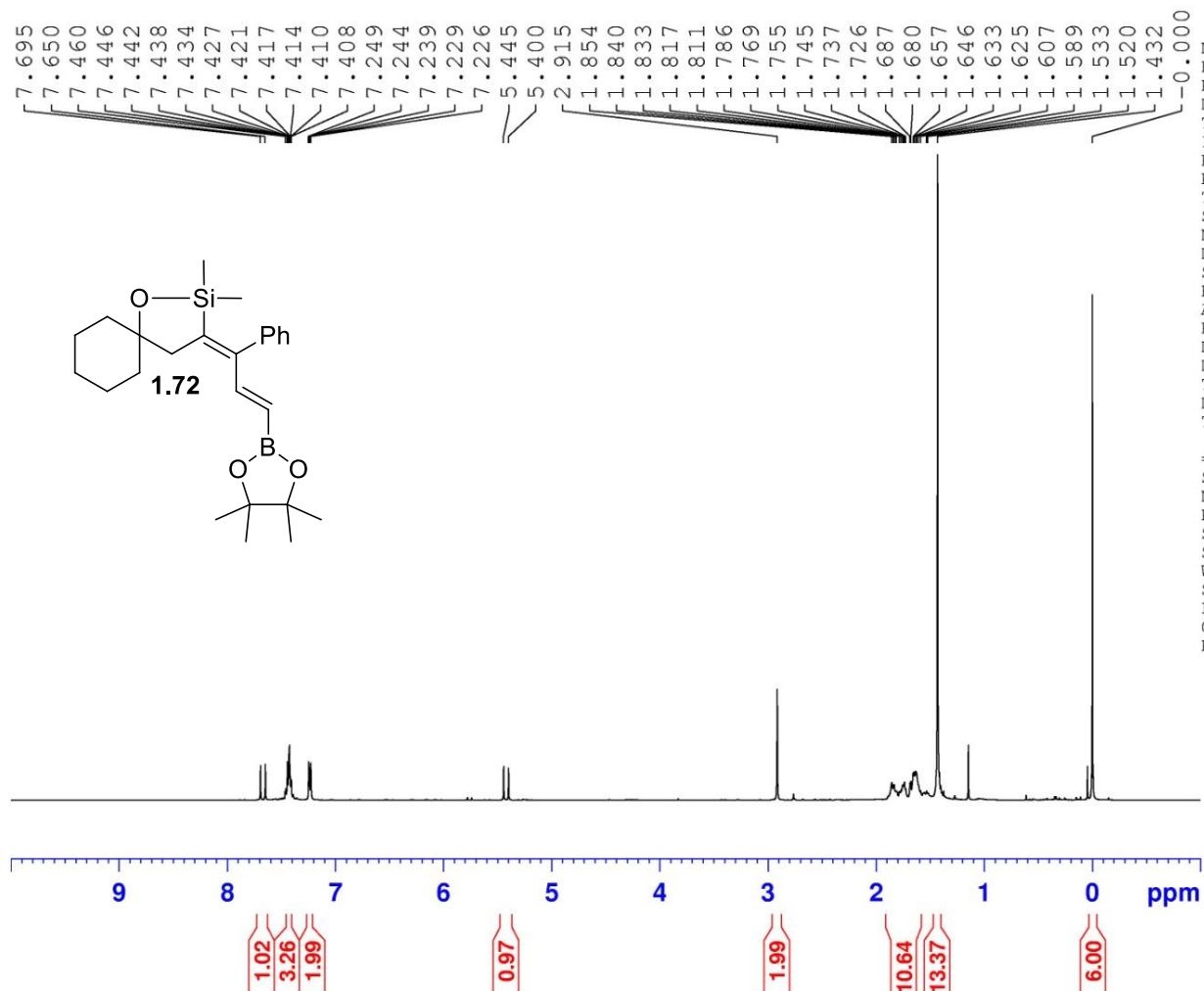
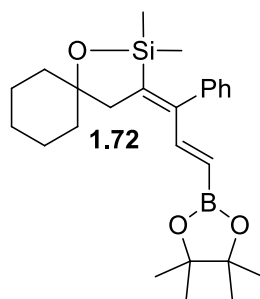


RJW-6-095



NAME RJW400-6-095
EXPNO 5
PROCNO 1
Date_ 20150126
Time 18.06
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDC13
NS 500
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 40.03
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127567 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40



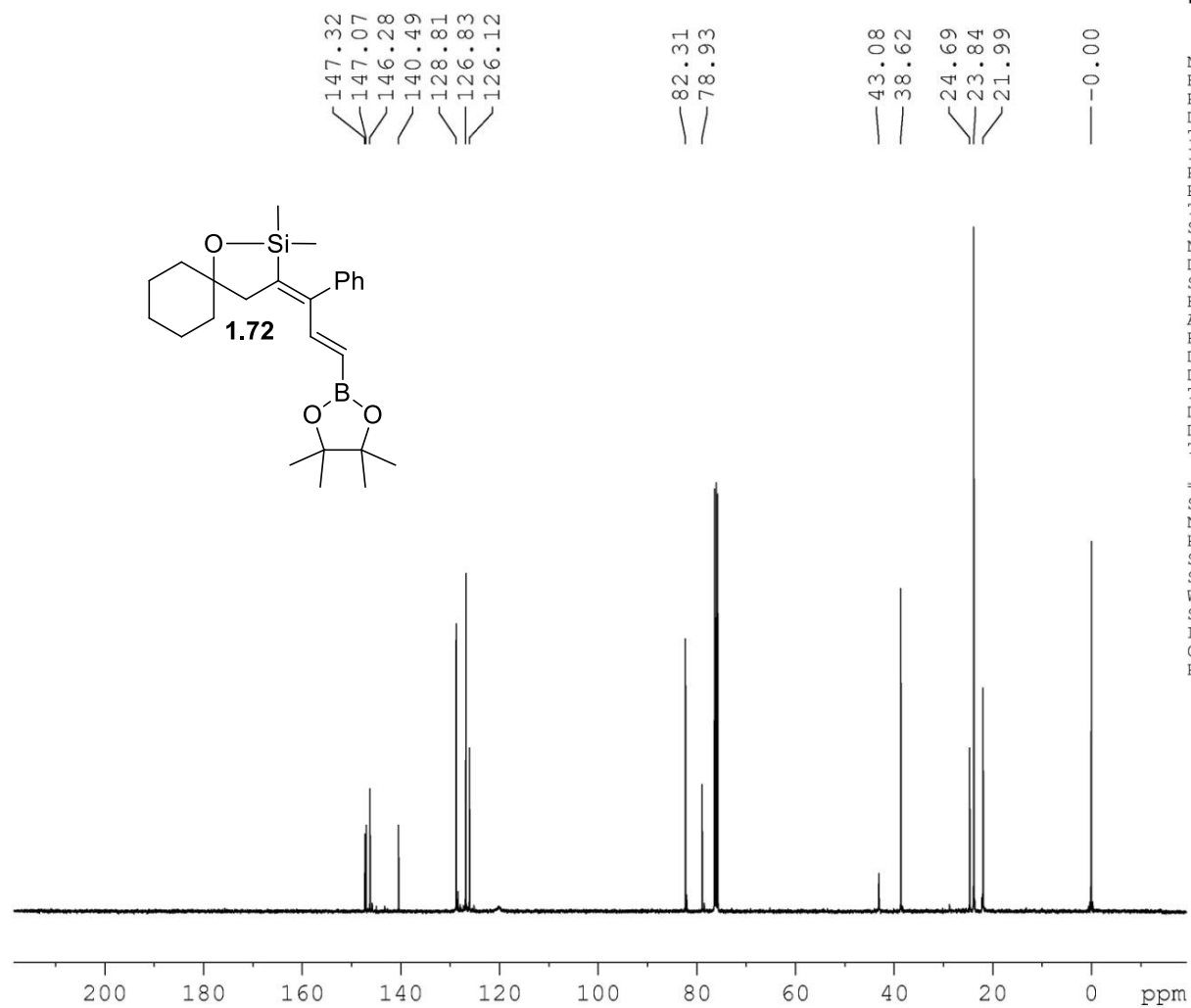
NAME	RJW400-5-236	
EXPNO	2	
PROCNO	1	
Date_	20140725	
Time	18.41	
INSTRUM	spect	
PROBHD	5 mm CPPBBO BB	
PULPROG	zg30	
TD	65536	
SOLVENT	CDCl3	
NS	16	
DS	2	
SWH	8012.820	Hz
FIDRES	0.122266	Hz
AQ	4.0894966	sec
RG	31.86	
DW	62.400	usec
DE	10.00	usec
TE	298.0	K
D1	1.00000000	sec
TD0	1	

```

===== CHANNEL f1 =====
SF01      400.1324710 MHz
NUC1              1H
P1              12.00 usec
SI              65536
SF      400.1299397 MHz
WDW              EM
SSB              0
LB              0.30 Hz
GB              0
PC              1.00

```

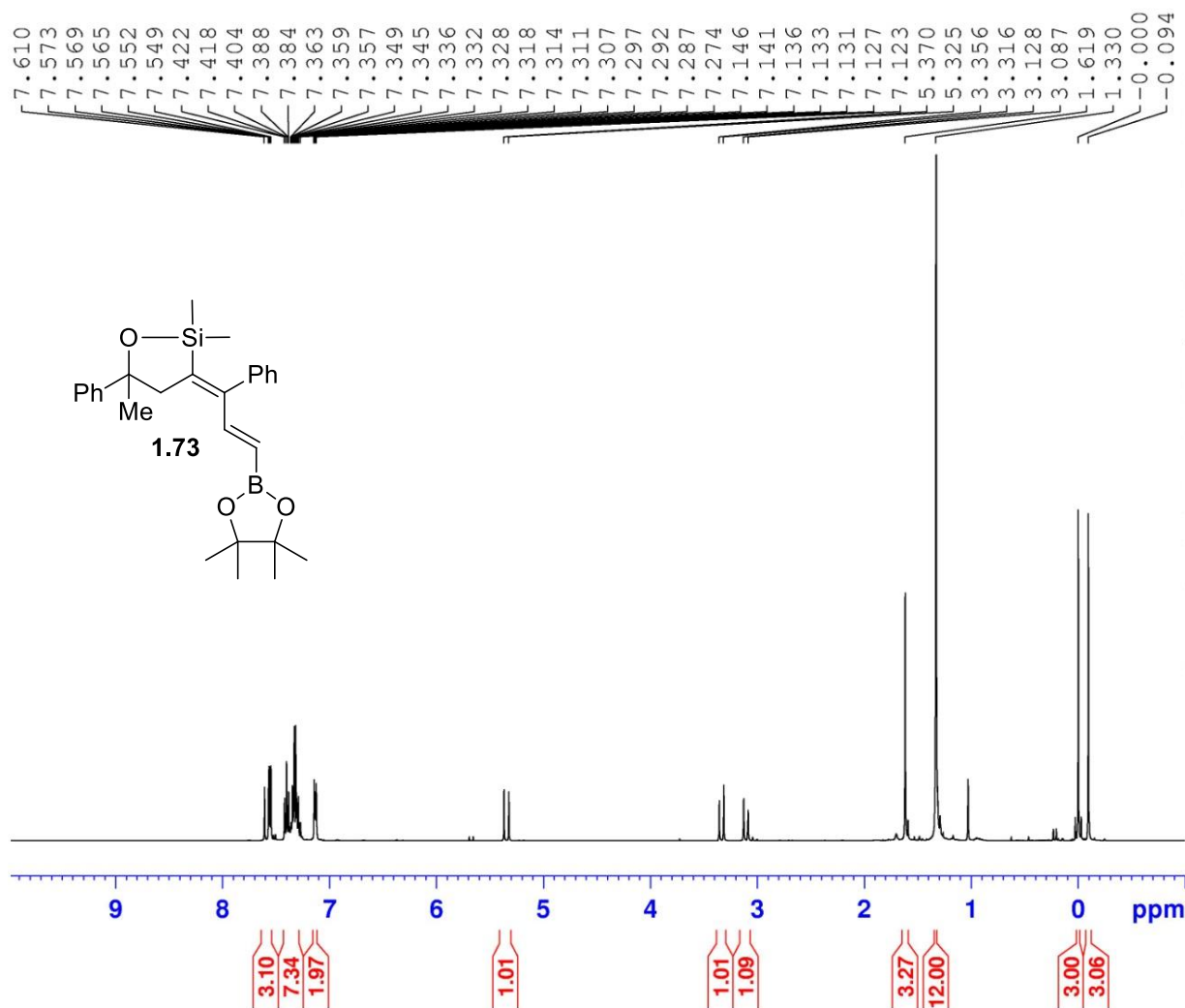
RJW-5-236
PC



NAME RJW400-5-236
EXPNO 4
PROCNO 1
Date_ 20140725
Time 19.01
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDCl3
NS 264
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 45.77
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SF01 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6128640 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

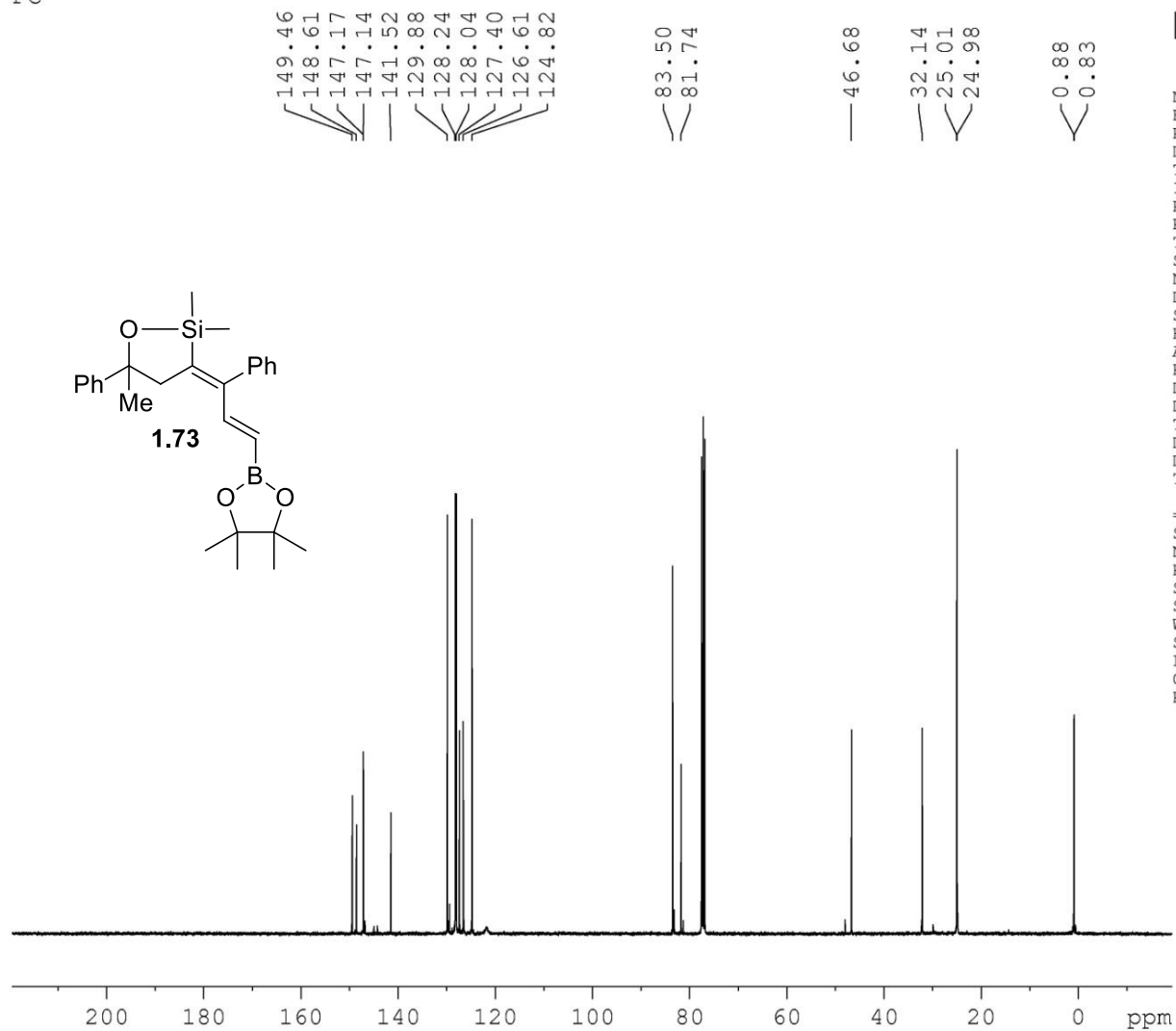
RJW-5-235
PC



NAME RJW400-5-235
EXPNO 2
PROCNO 1
Date_ 20140725
Time 18.35
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDC13
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 31.86
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SF01 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1299862 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

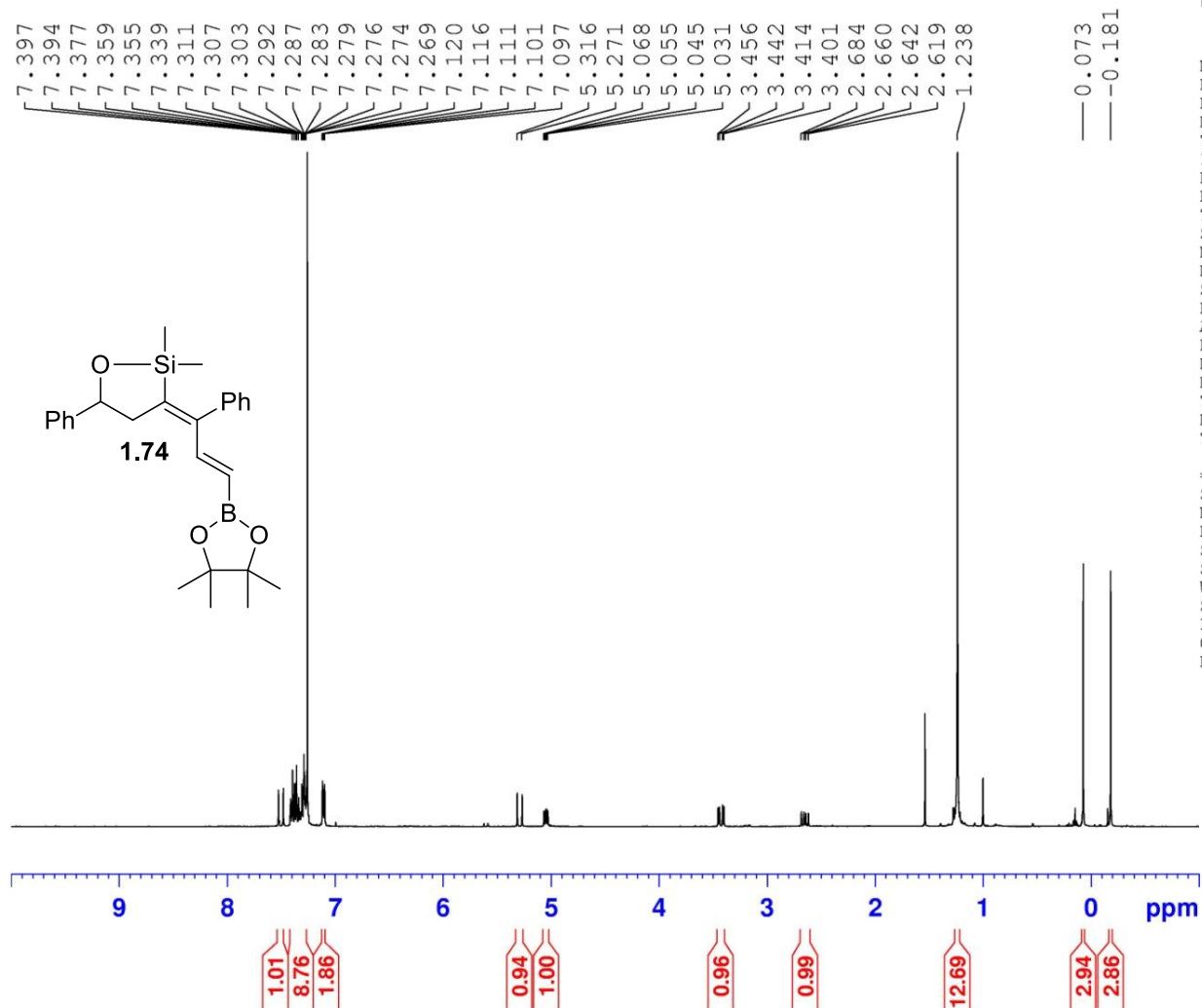
RJW-5-235
PC



NAME RJW400-5-235
EXPNO 4
PROCNO 1
Date_ 20140725
Time 20.46
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDC13
NS 540
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 45.77
DW 20.800 usec
DE 18.00 usec
TE 300.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

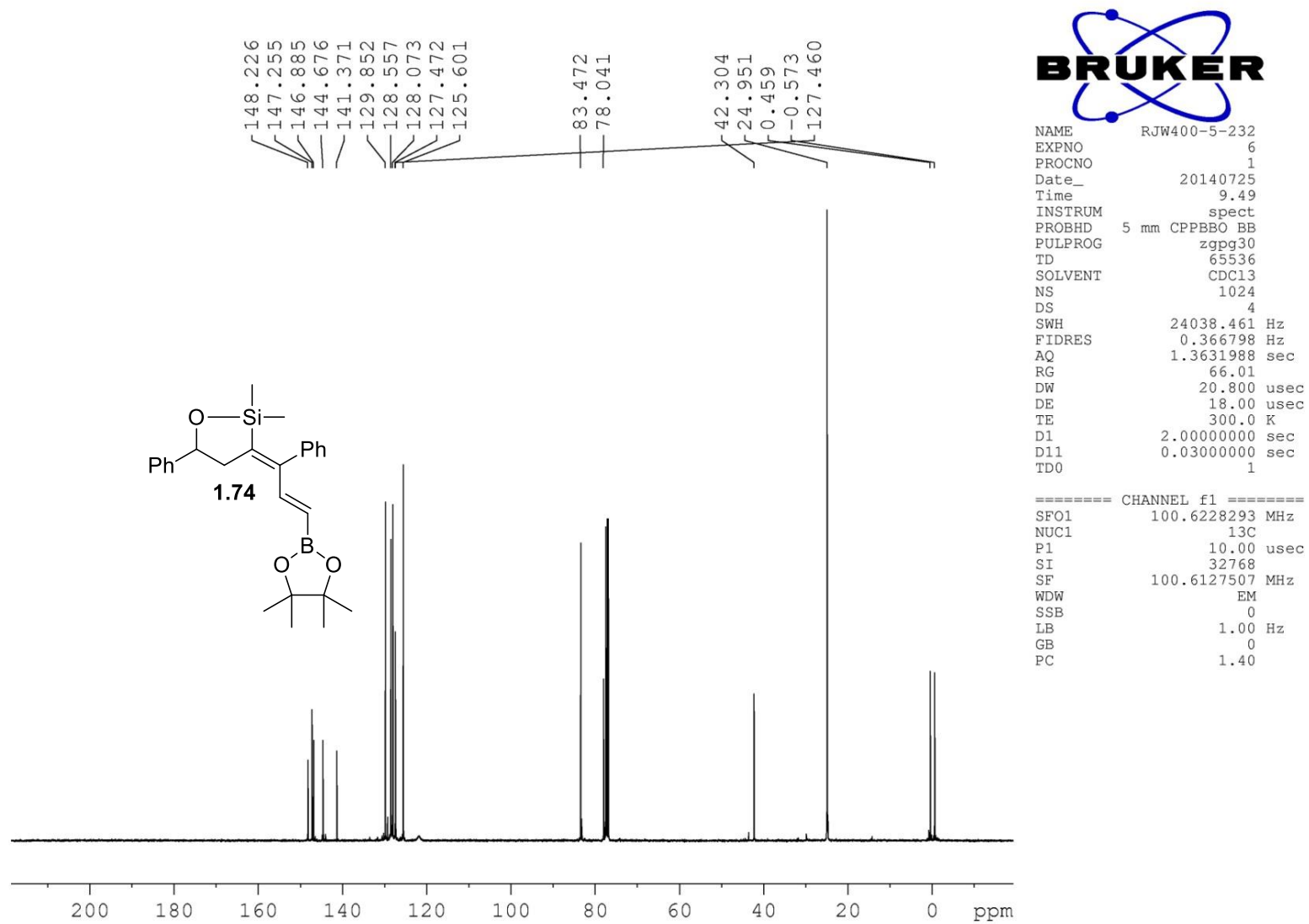
===== CHANNEL f1 =====
SF01 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127498 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

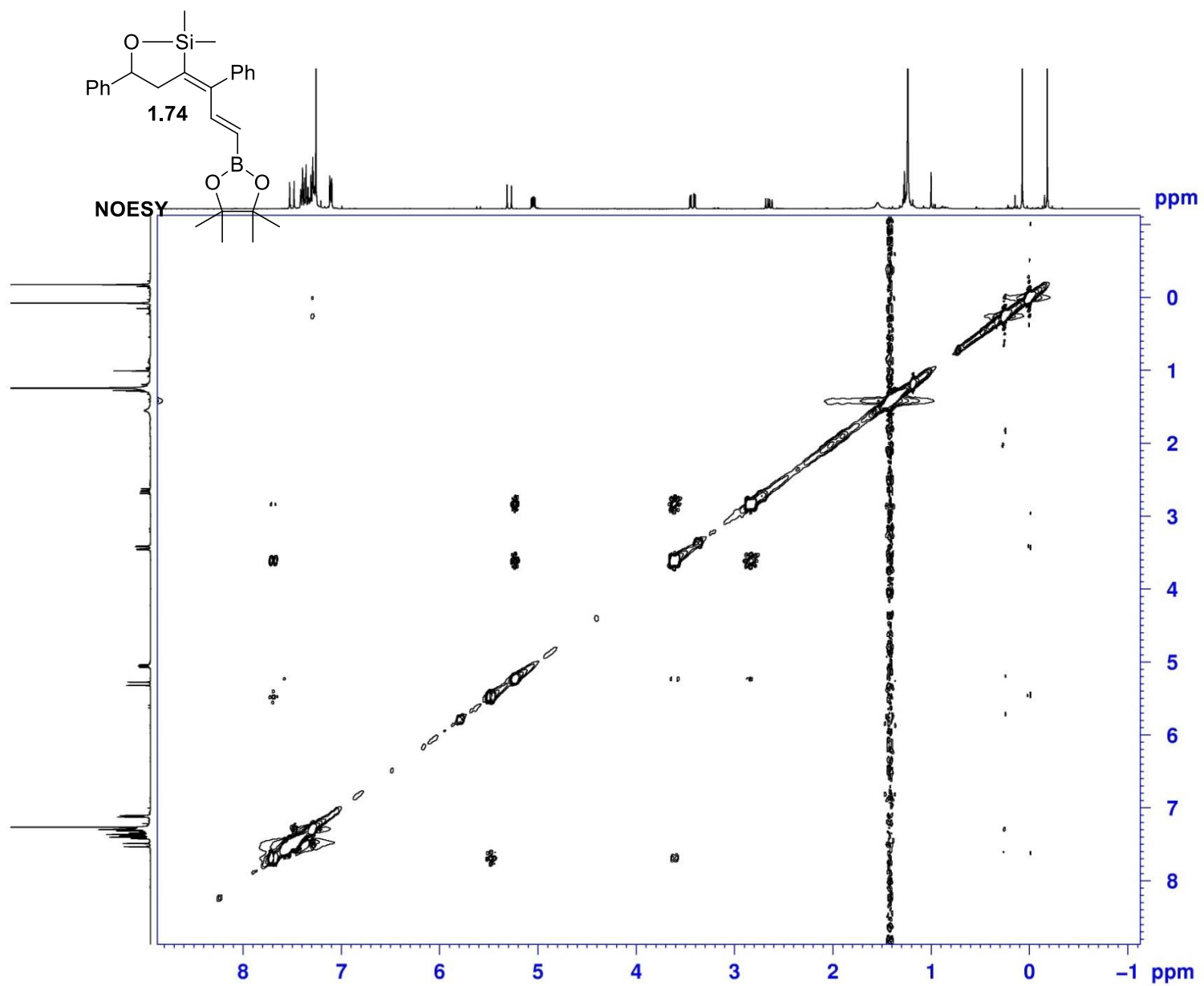
RJW-5-232
PC



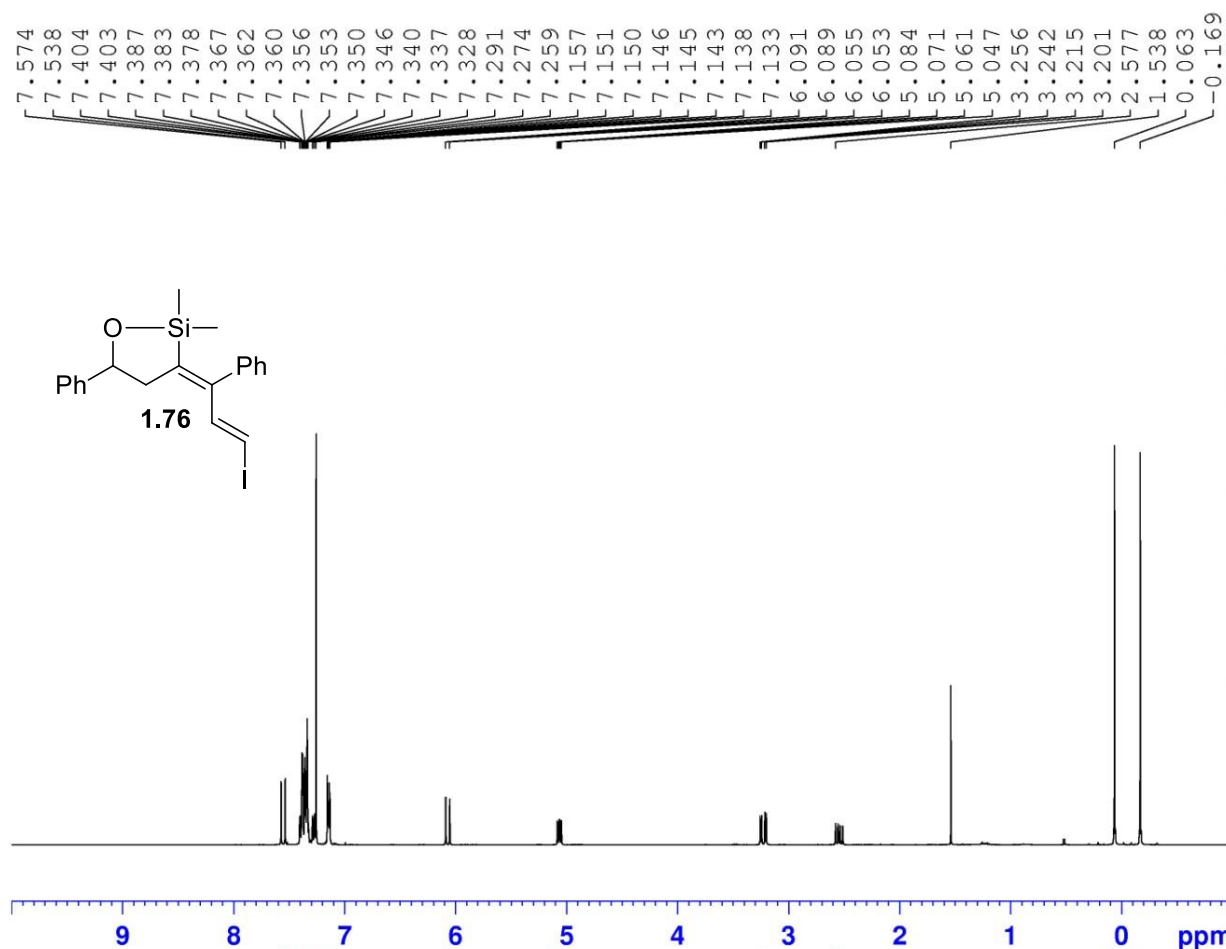
NAME RJW400-5-232
EXPNO 2
PROCNO 1
Date_ 20140724
Time 17.45
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl3
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 208.09
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SF01 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300098 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00



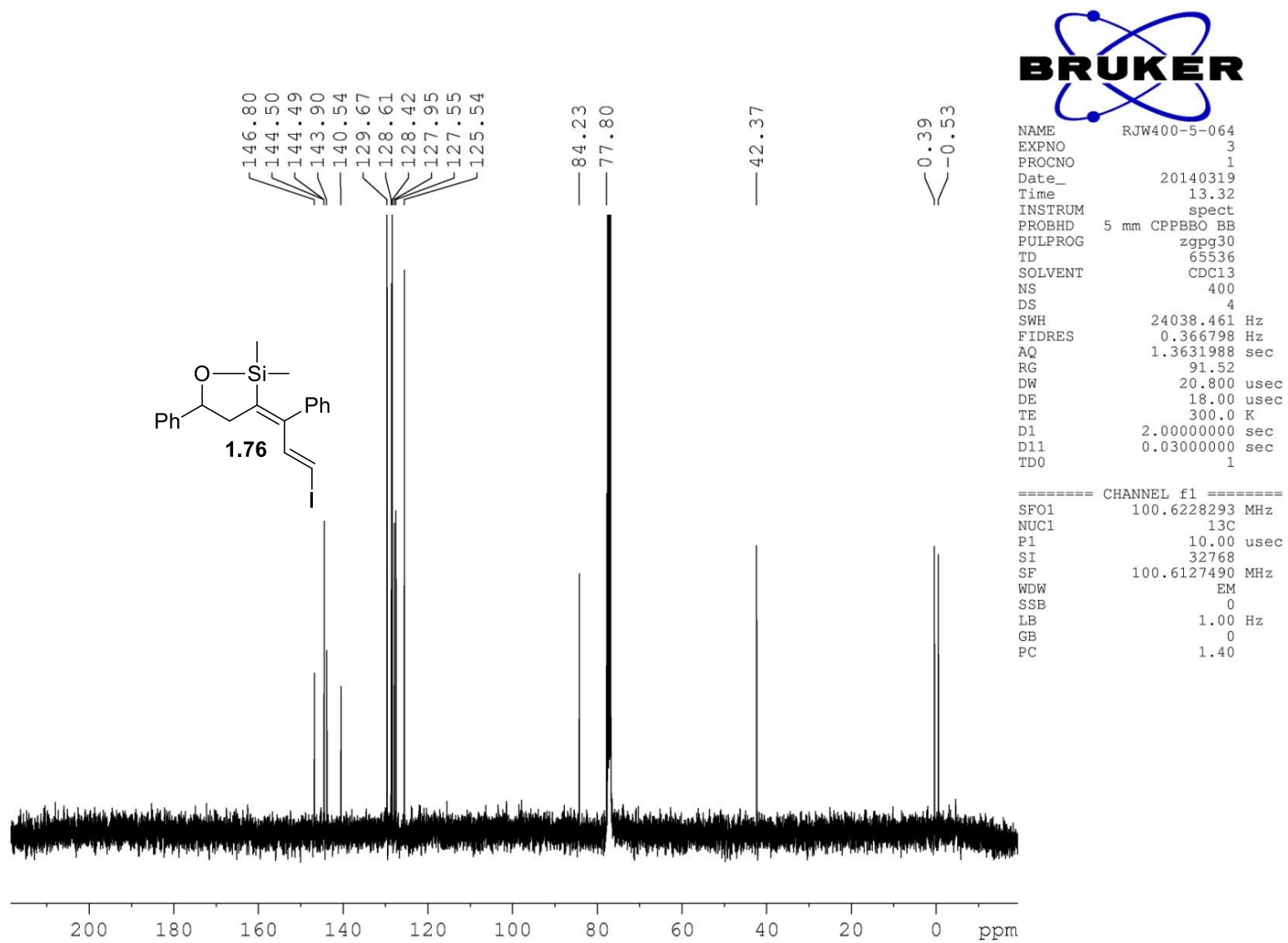


RJW-5-074
PC

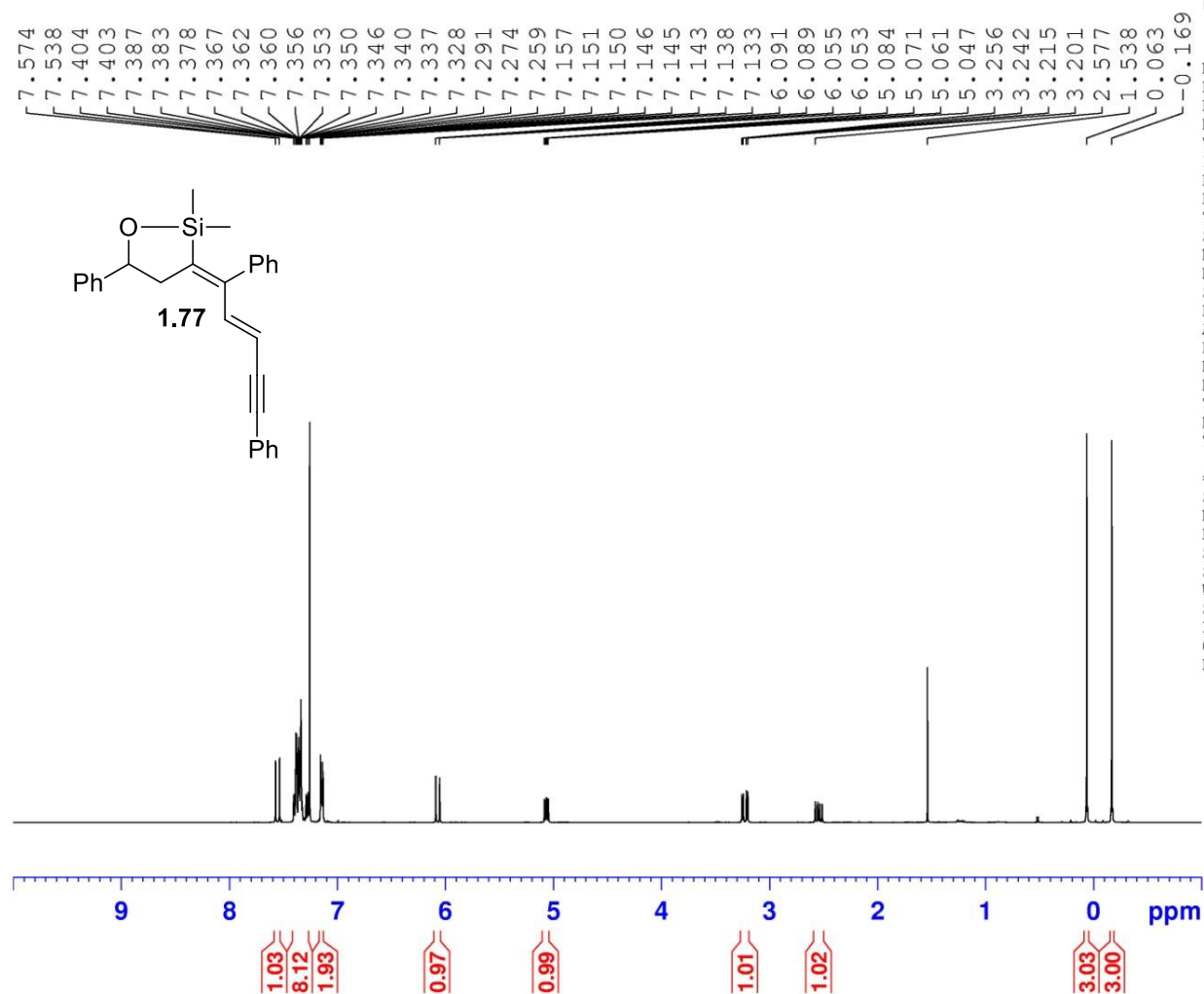


NAME RJW400-5-074
EXPNO 1
PROCNO 1
Date_ 20140321
Time 16.32
INSTRUM spect
PROBHD 5 mm CPMBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl3
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 208.09
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SF01 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300107 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

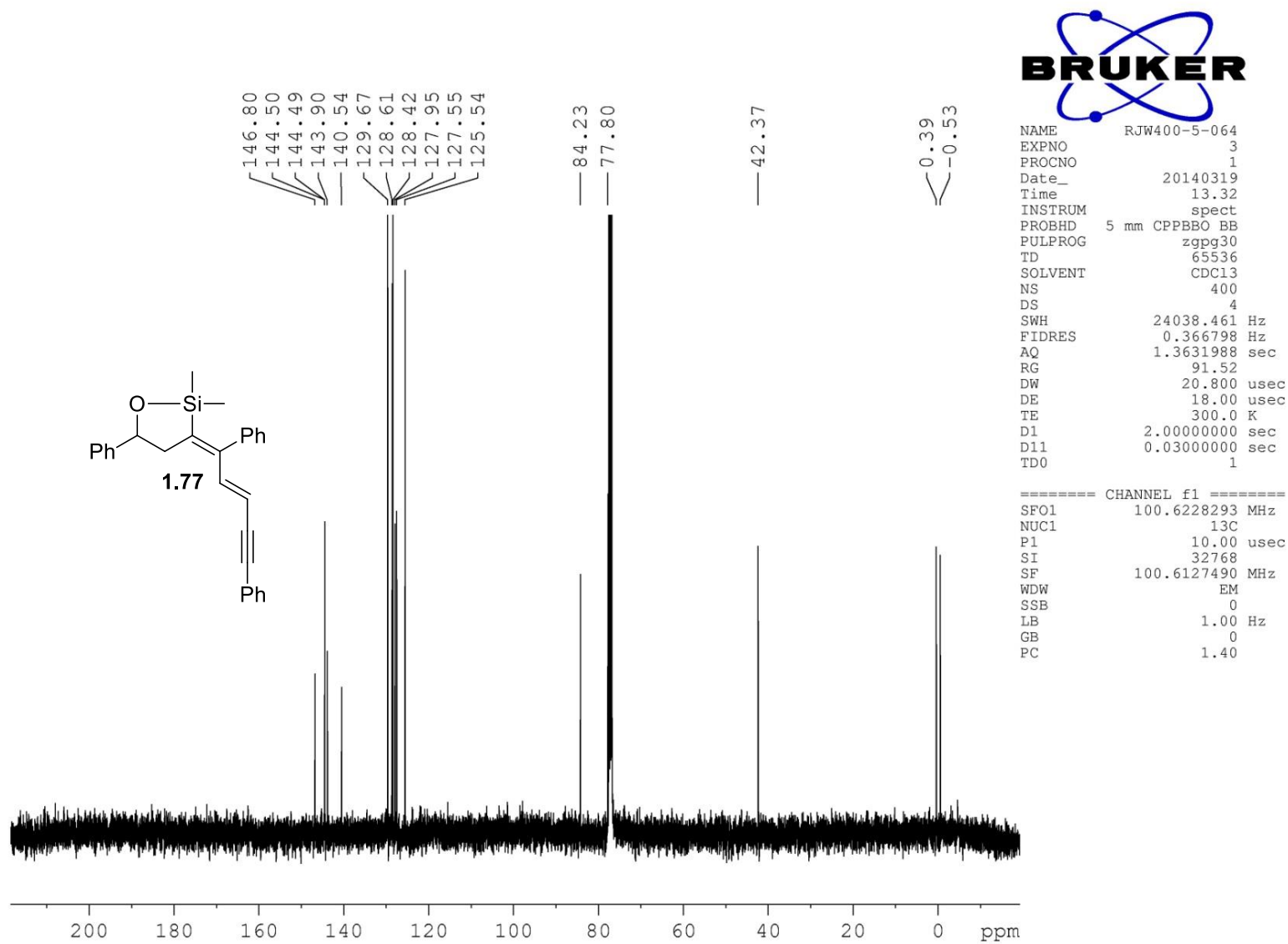


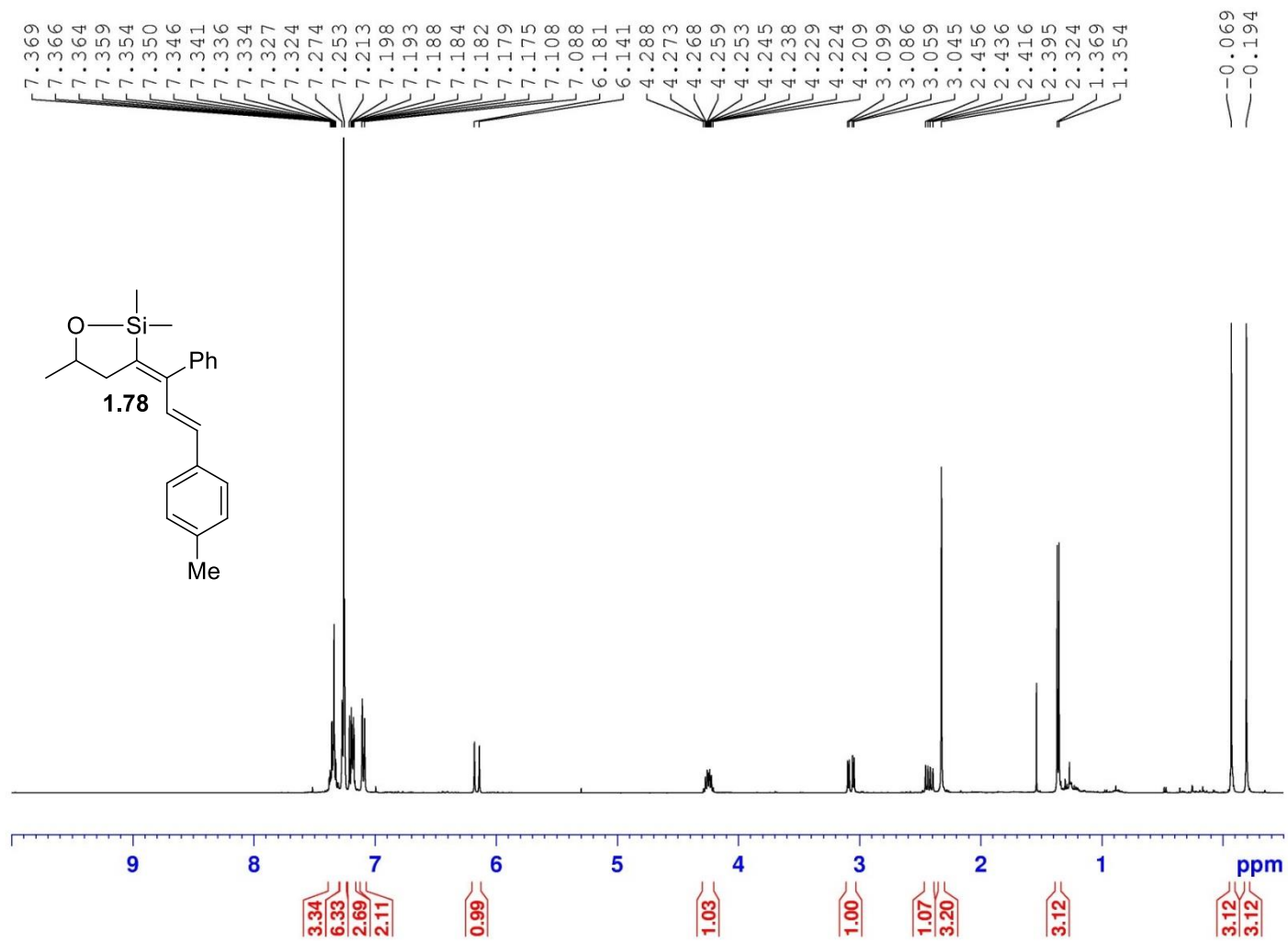
RJW-5-074
PC

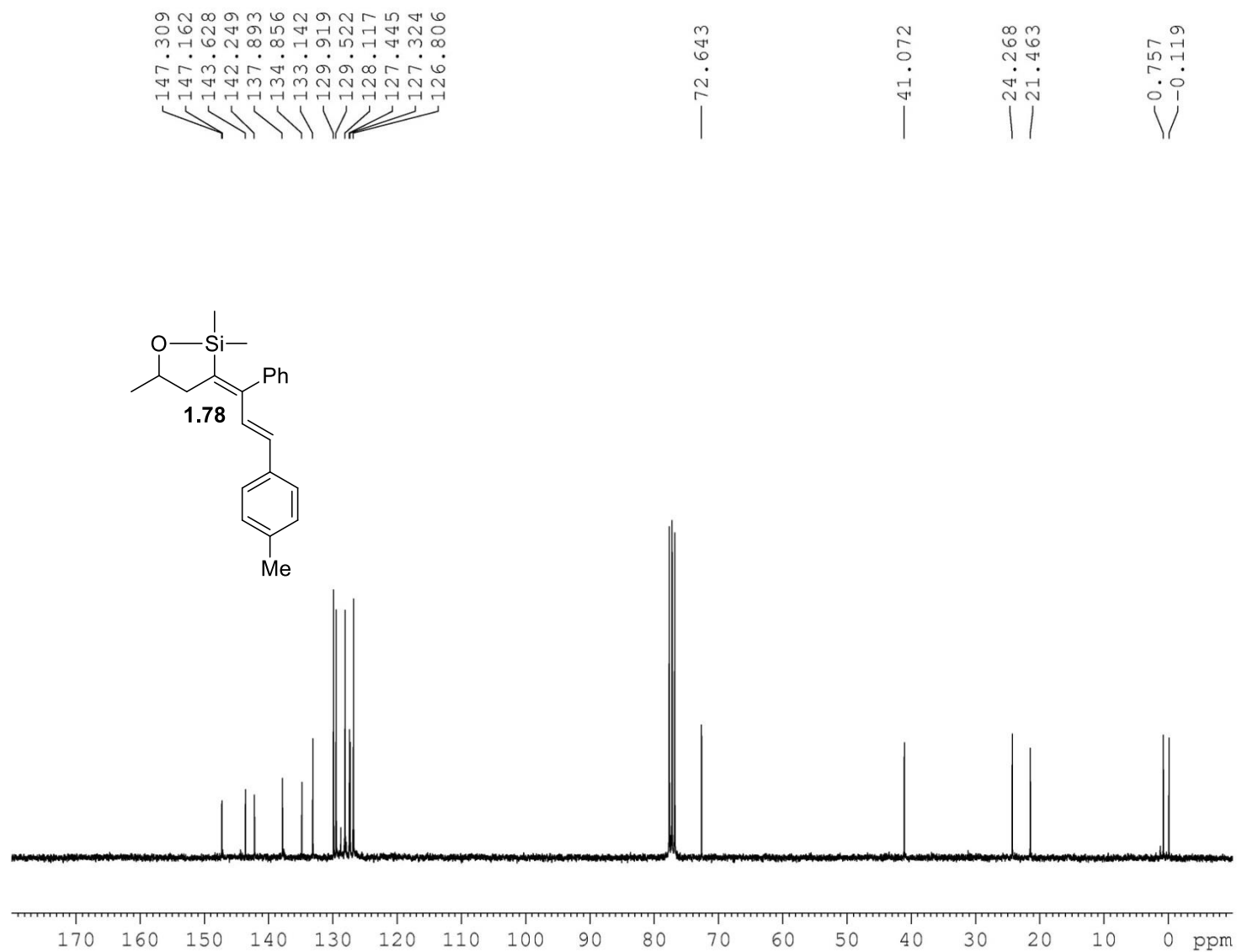


NAME RJW400-5-074
EXPNO 1
PROCNO 1
Date_ 20140321
Time 16.32
INSTRUM spect
PROBHD 5 mm CPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl_3
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 208.09
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

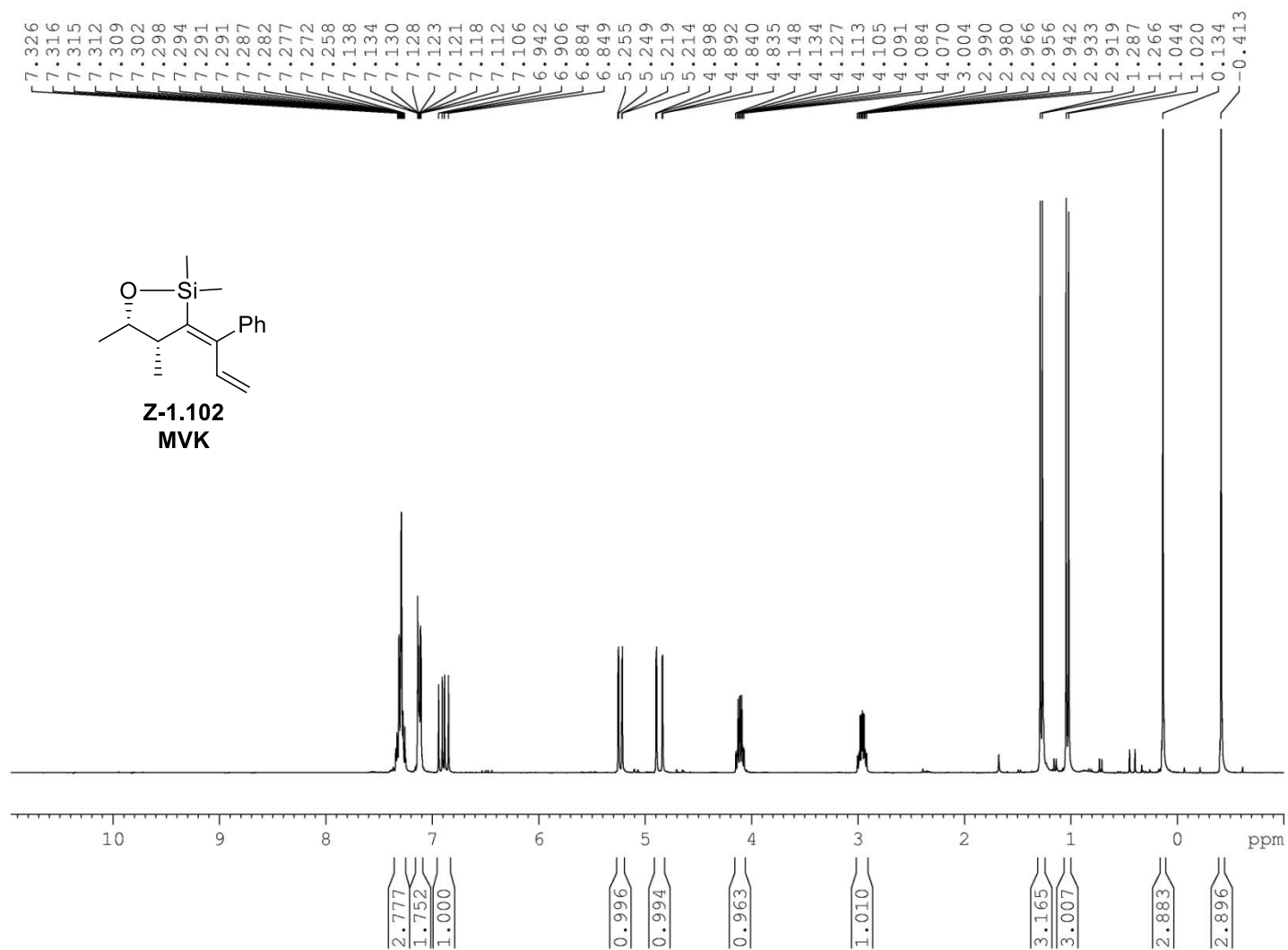
===== CHANNEL f1 =====
SF01 400.1324710 MHz
NUC1 ^1H
P1 12.00 usec
SI 65536
SF 400.1300107 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

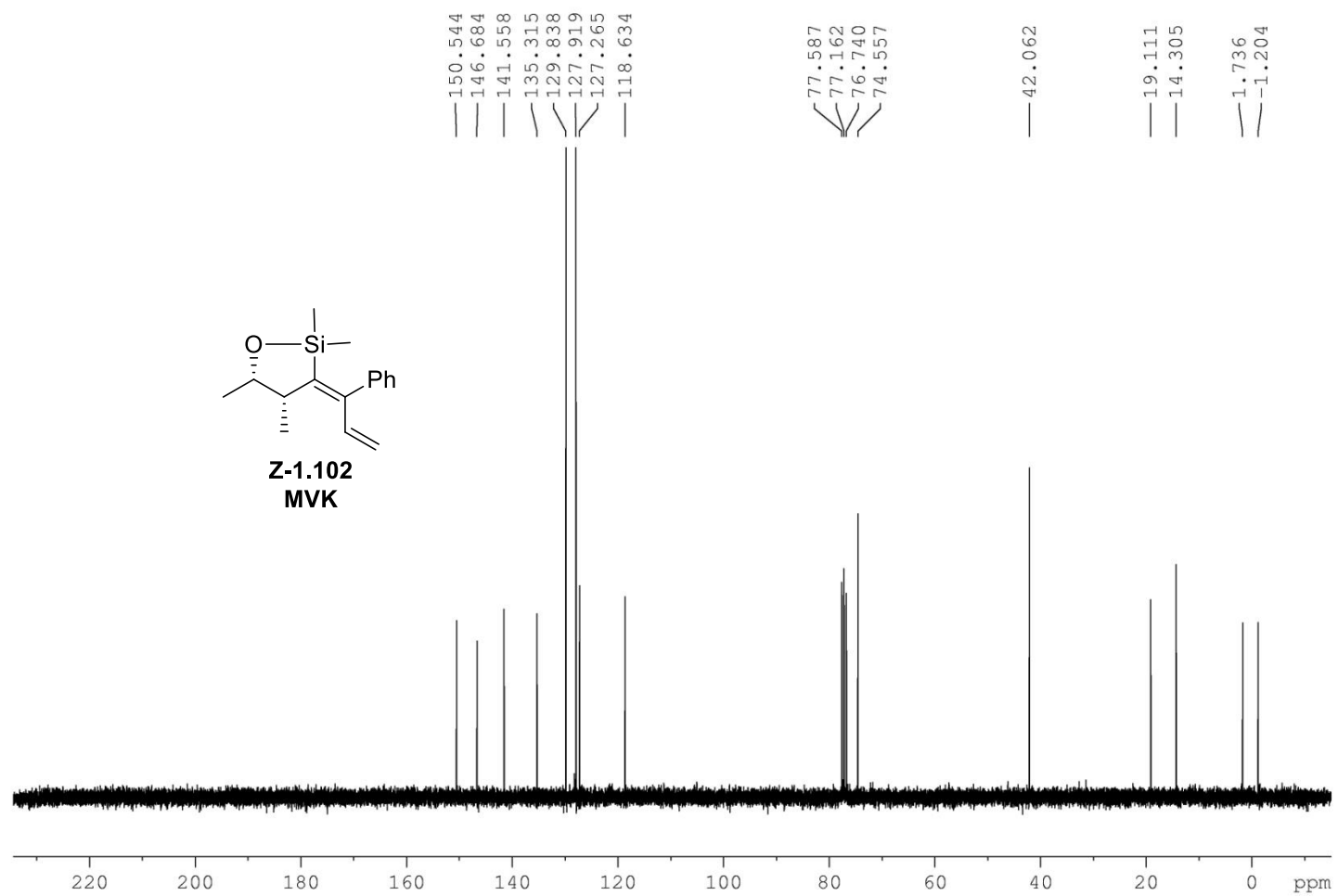


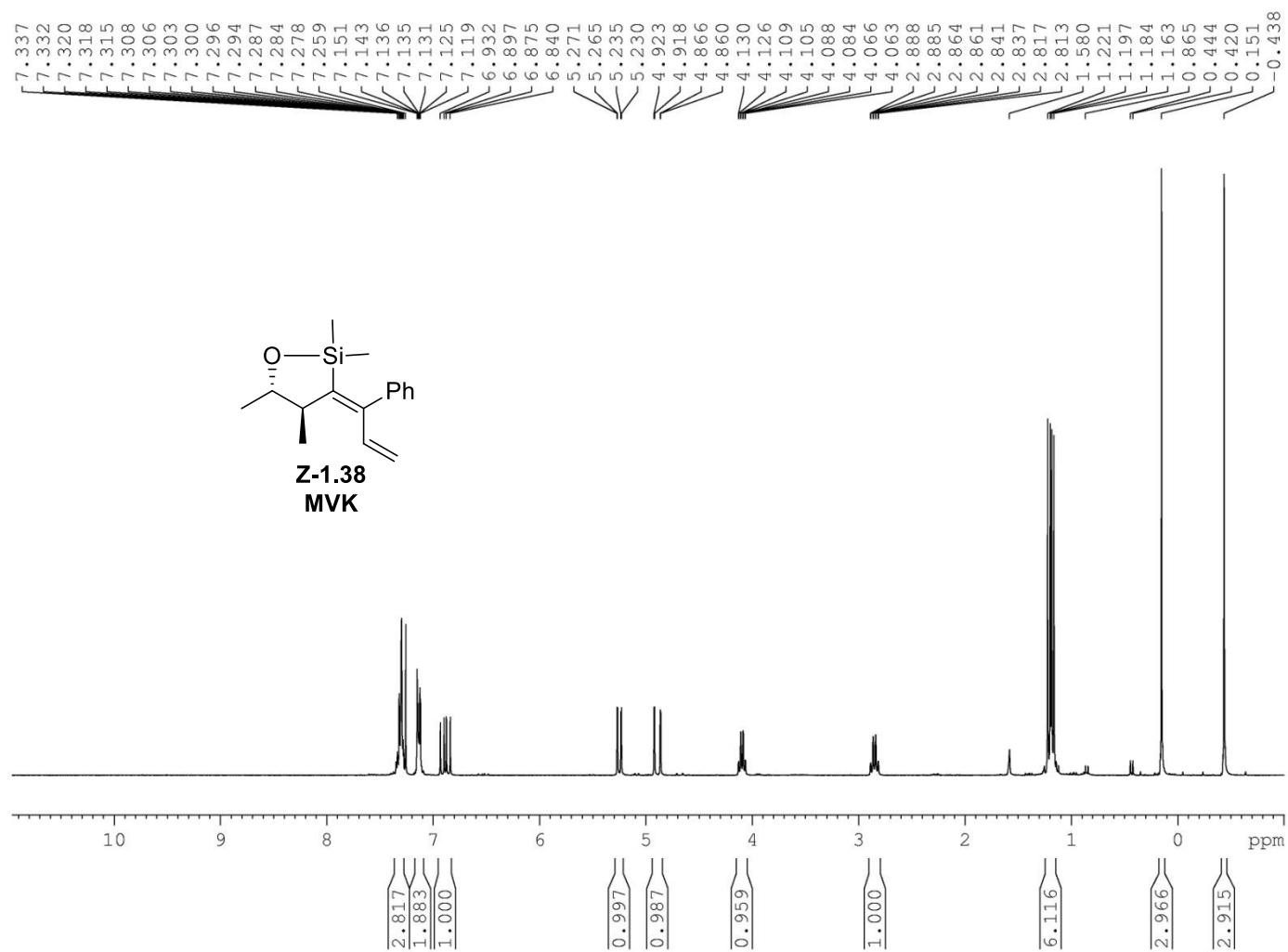


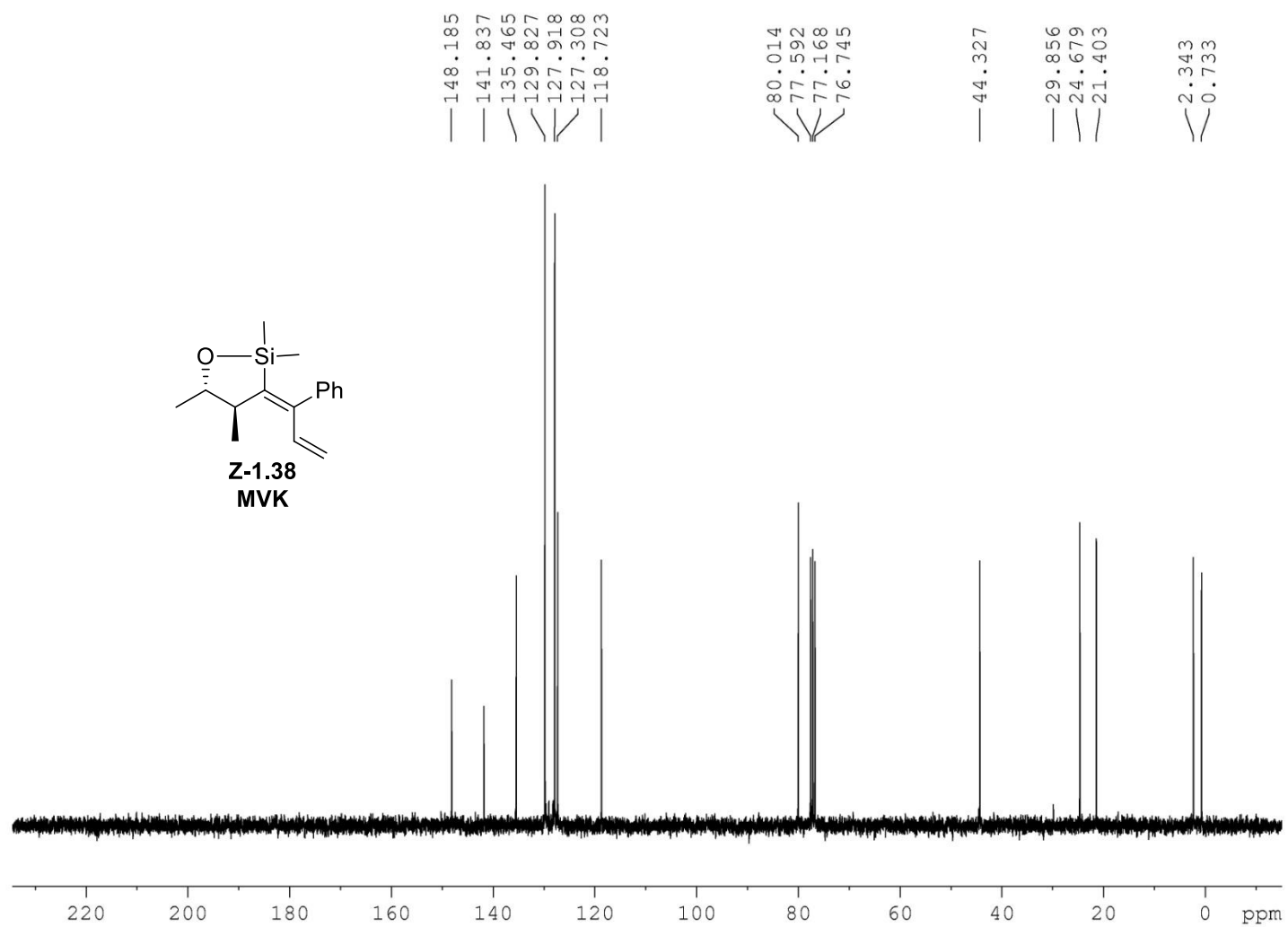


5.4 SILYLVINYLATION SPECTRA

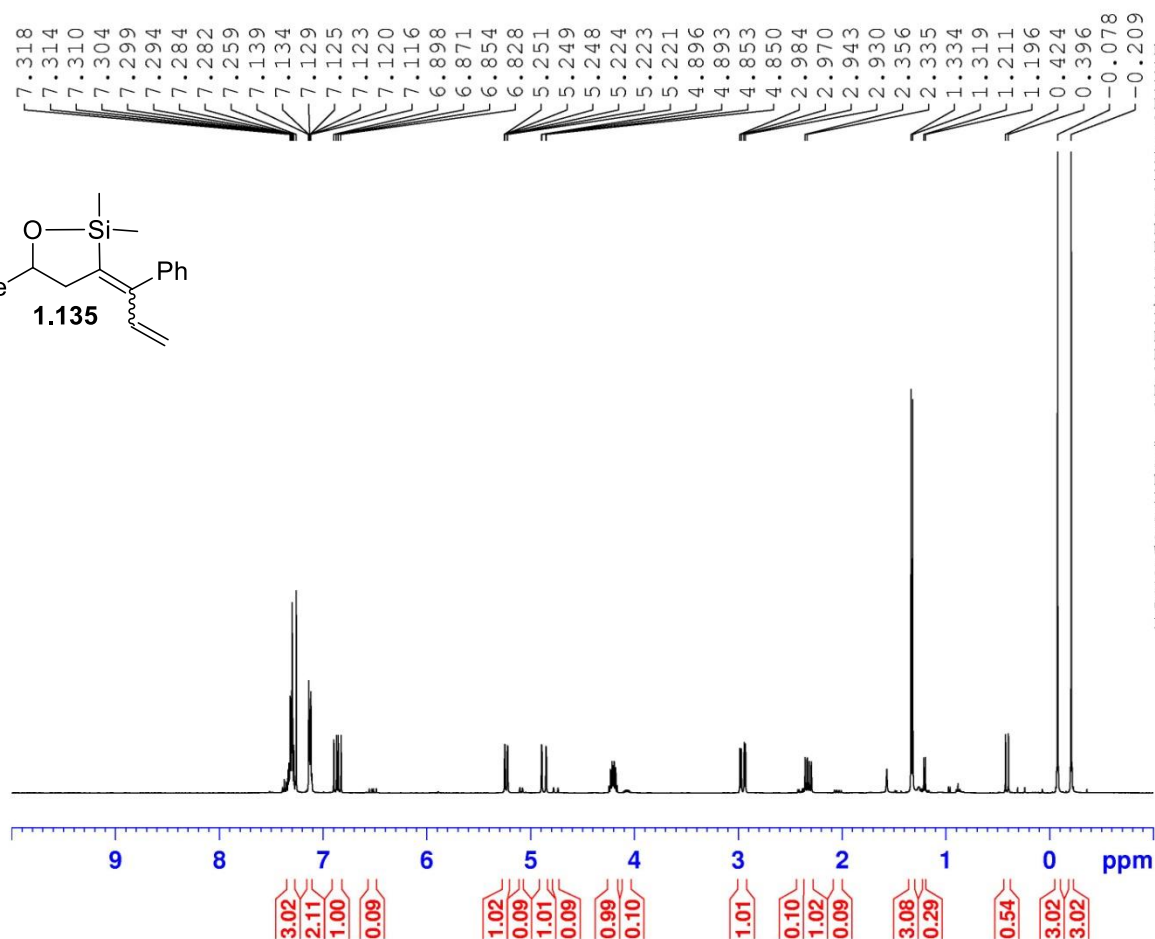
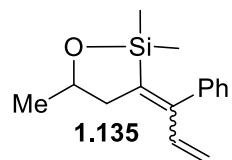








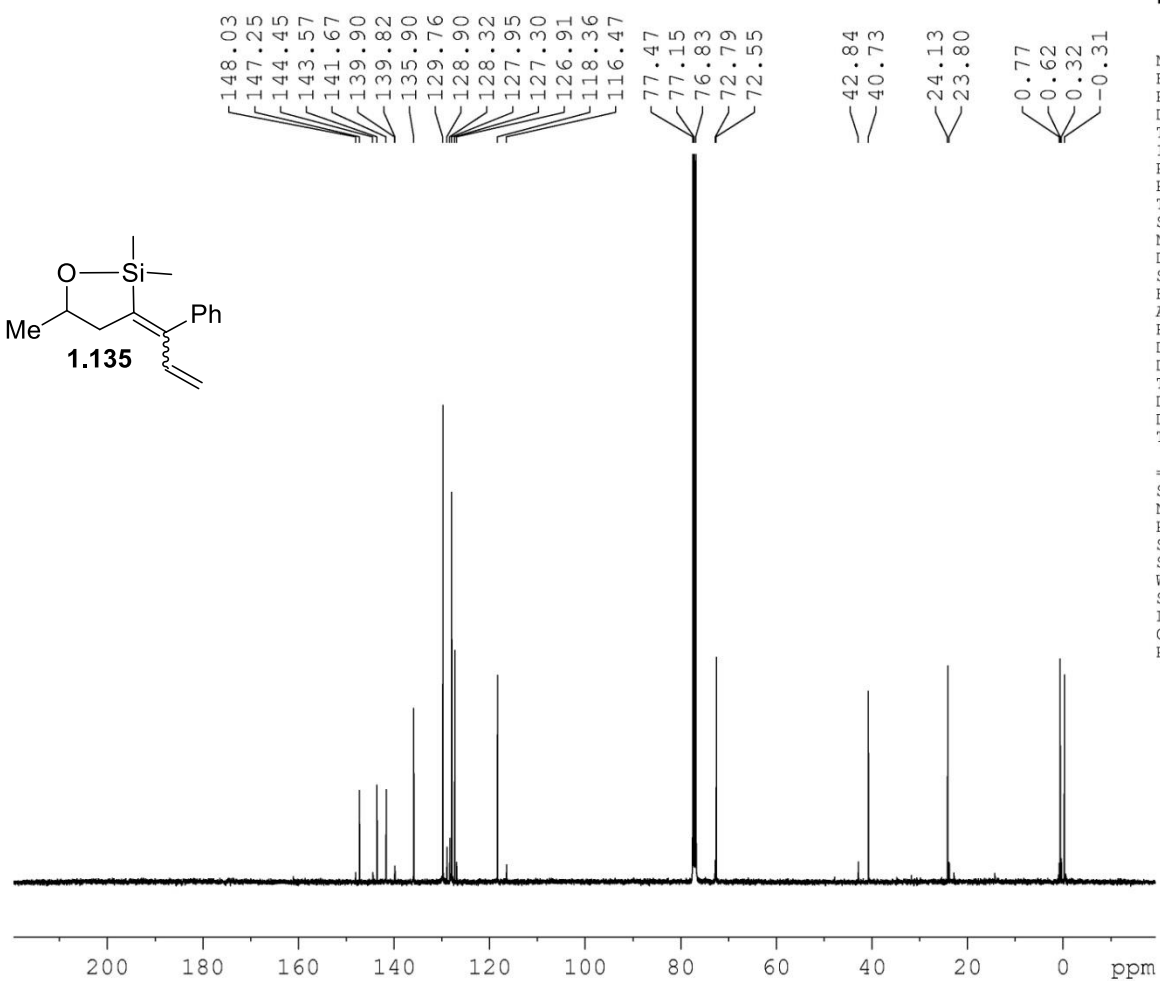
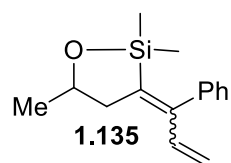
RJW-5-145
PC



NAME RJW400-5-145
EXPNO 2
PROCNO 1
Date_ 20140513
Time 22.59
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDC13
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 183
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300101 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

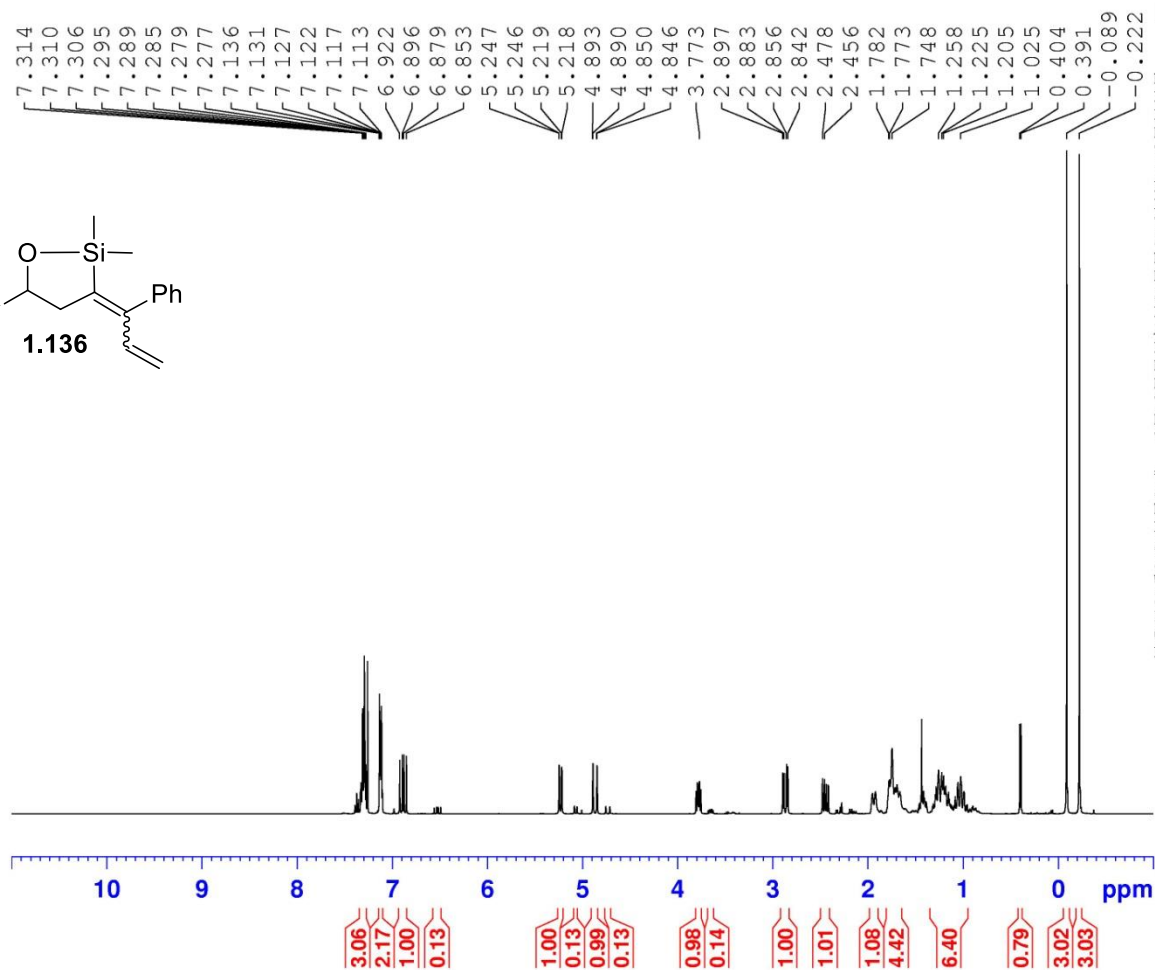
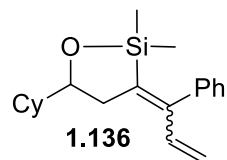
RJW-5-145
PC



NAME RJW400-5-145
EXPNO 3
PROCNO 1
Date_ 20140514
Time 0.00
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDCl3
NS 1024
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 50.16
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127555 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

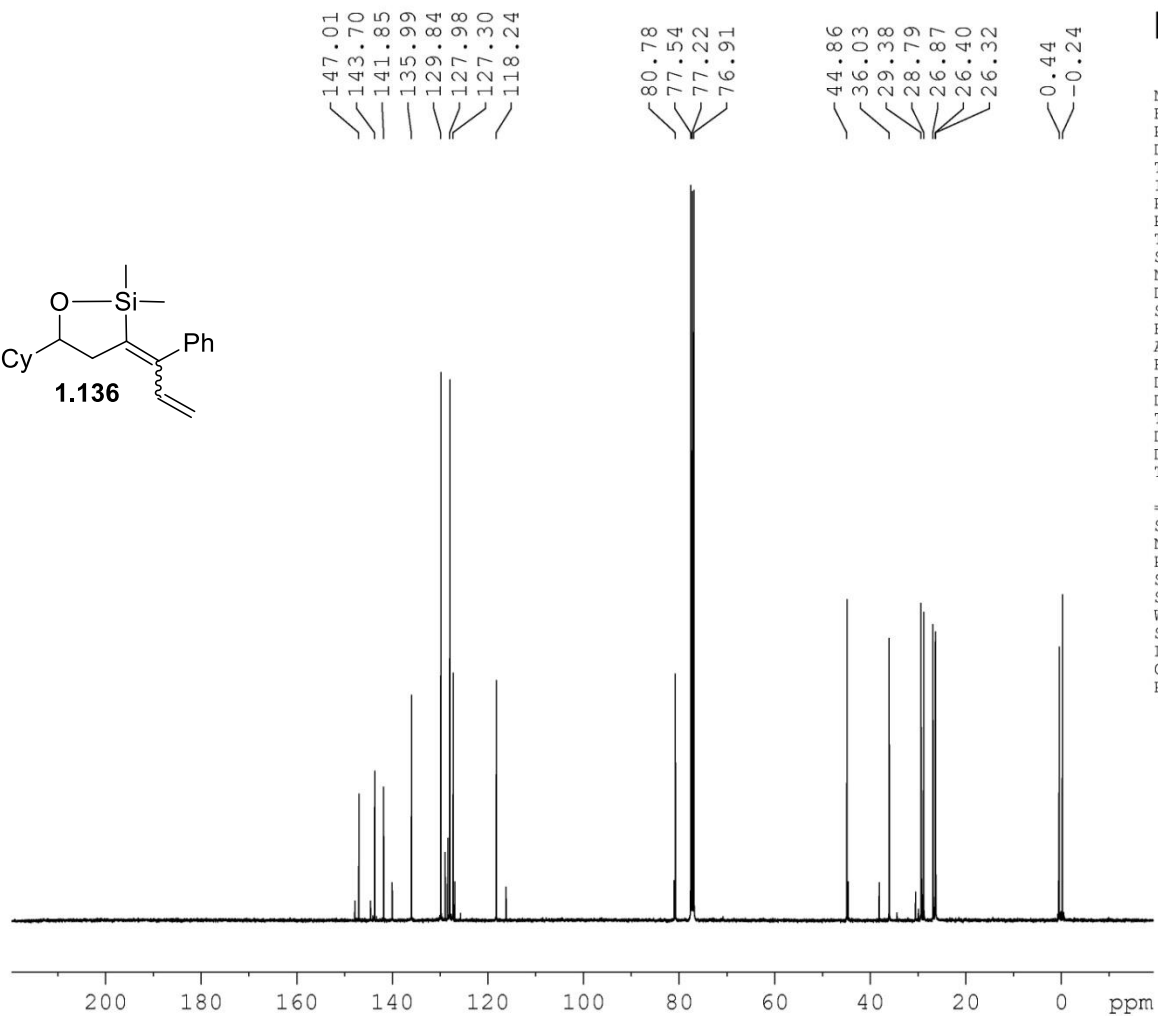
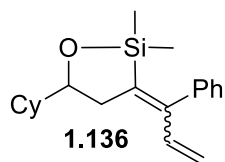
RJW-5-028



NAME RJW400-5-028
 EXPNO 4
 PROCNO 1
 Date_ 20140209
 Time 17.16
 INSTRUM spect
 PROBHD 5 mm CPPBBO BB
 PULPROG zg30
 TD 65536
 SOLVENT CDCl3
 NS 16
 DS 2
 SWH 8012.820 Hz
 FIDRES 0.122266 Hz
 AQ 4.0894966 sec
 RG 58.33
 DW 62.400 usec
 DE 10.00 usec
 TE 298.0 K
 D1 1.00000000 sec
 TD0 1

===== CHANNEL f1 =====
 SFO1 400.1324710 MHz
 NUC1 1H
 P1 12.00 usec
 SI 65536
 SF 400.1300096 MHz
 WDW EM
 SSB 0
 LB 0.30 Hz
 GB 0
 PC 1.00

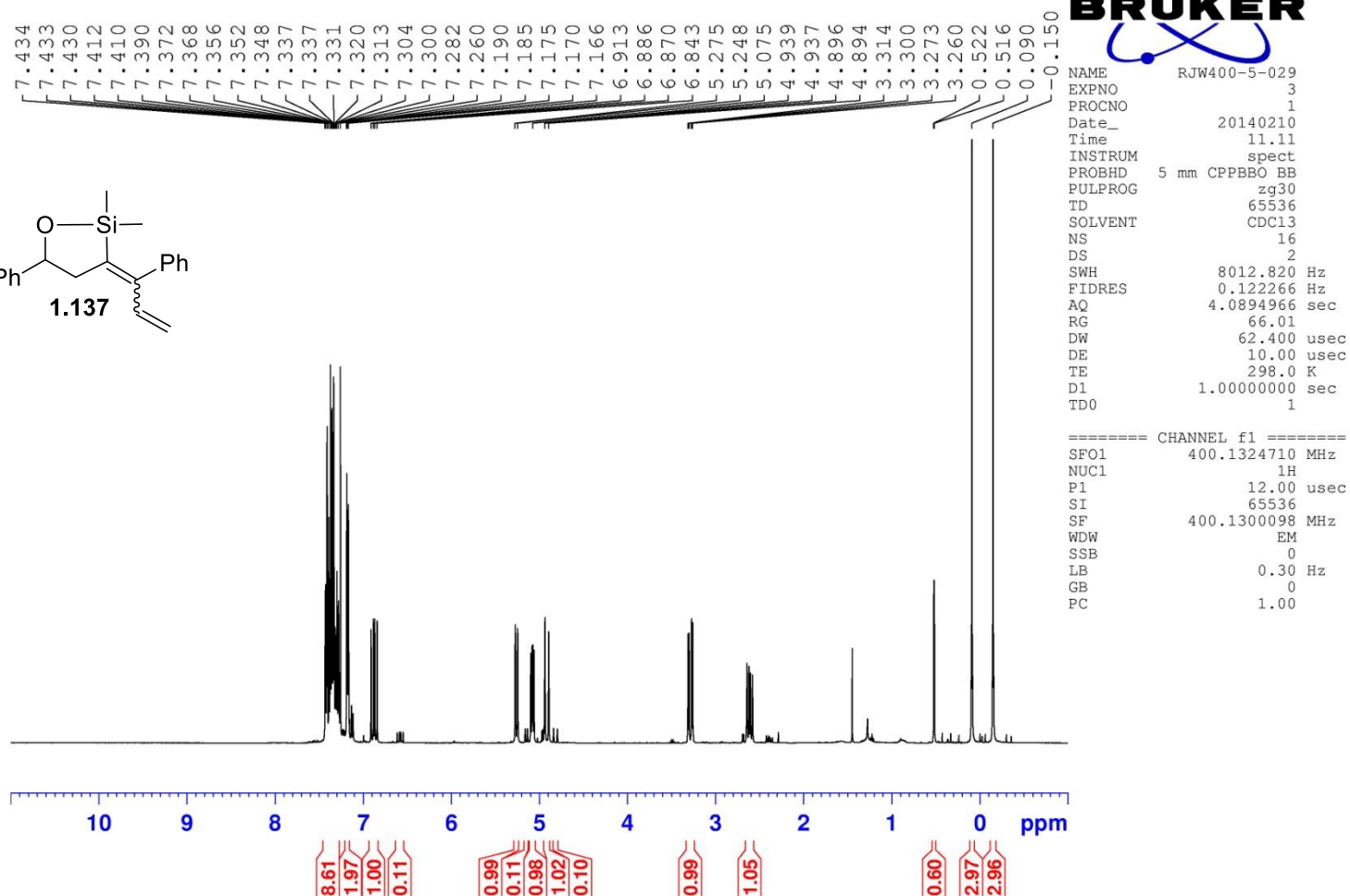
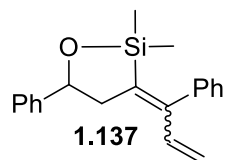
RJW-5-028



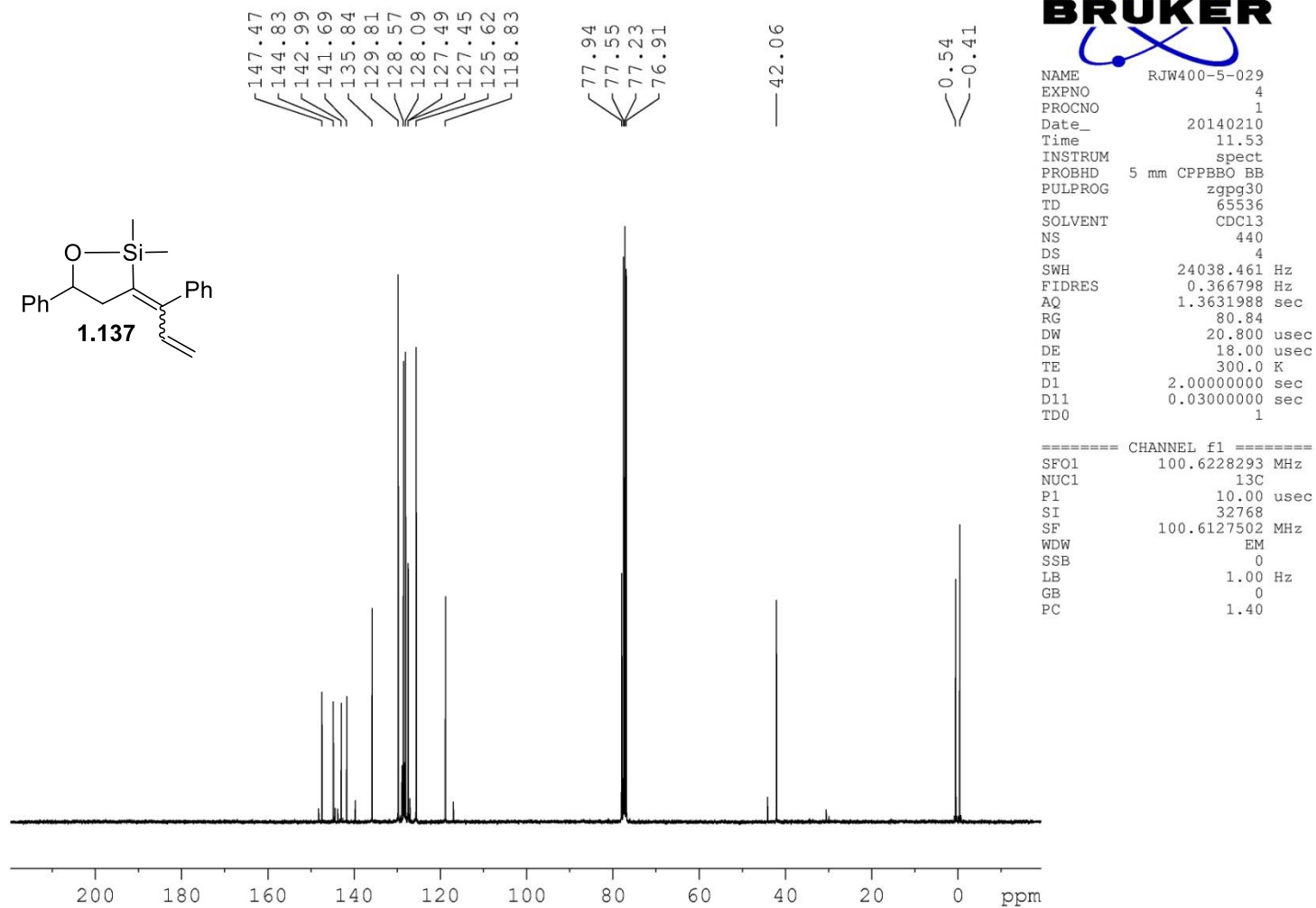
NAME RJW400-5-028
EXPNO 5
PROCNO 1
Date_ 20140209
Time 18.03
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDC13
NS 800
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 91.52
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

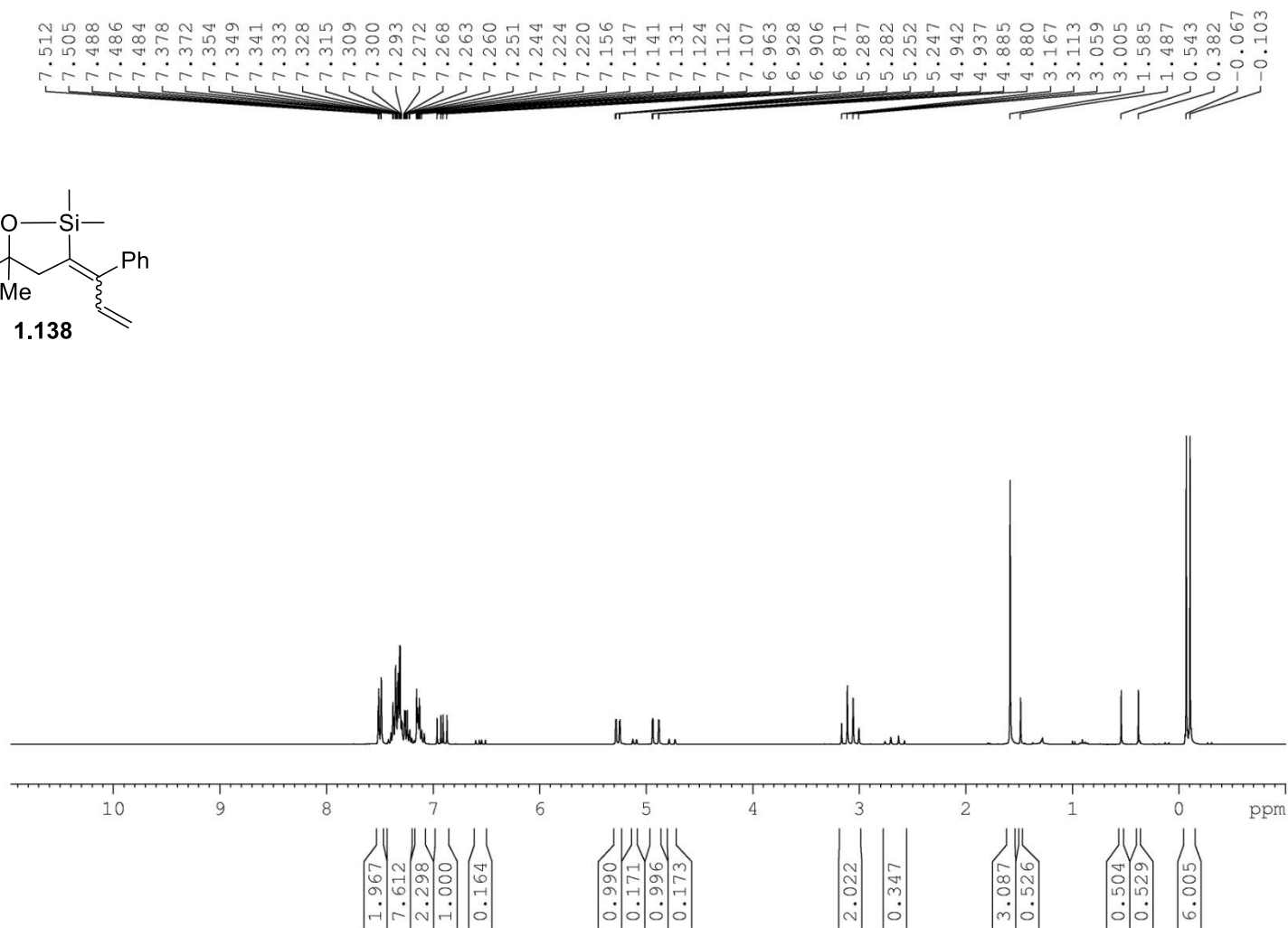
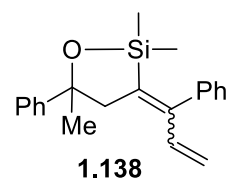
===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127494 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

RJW-5-029
PTLC

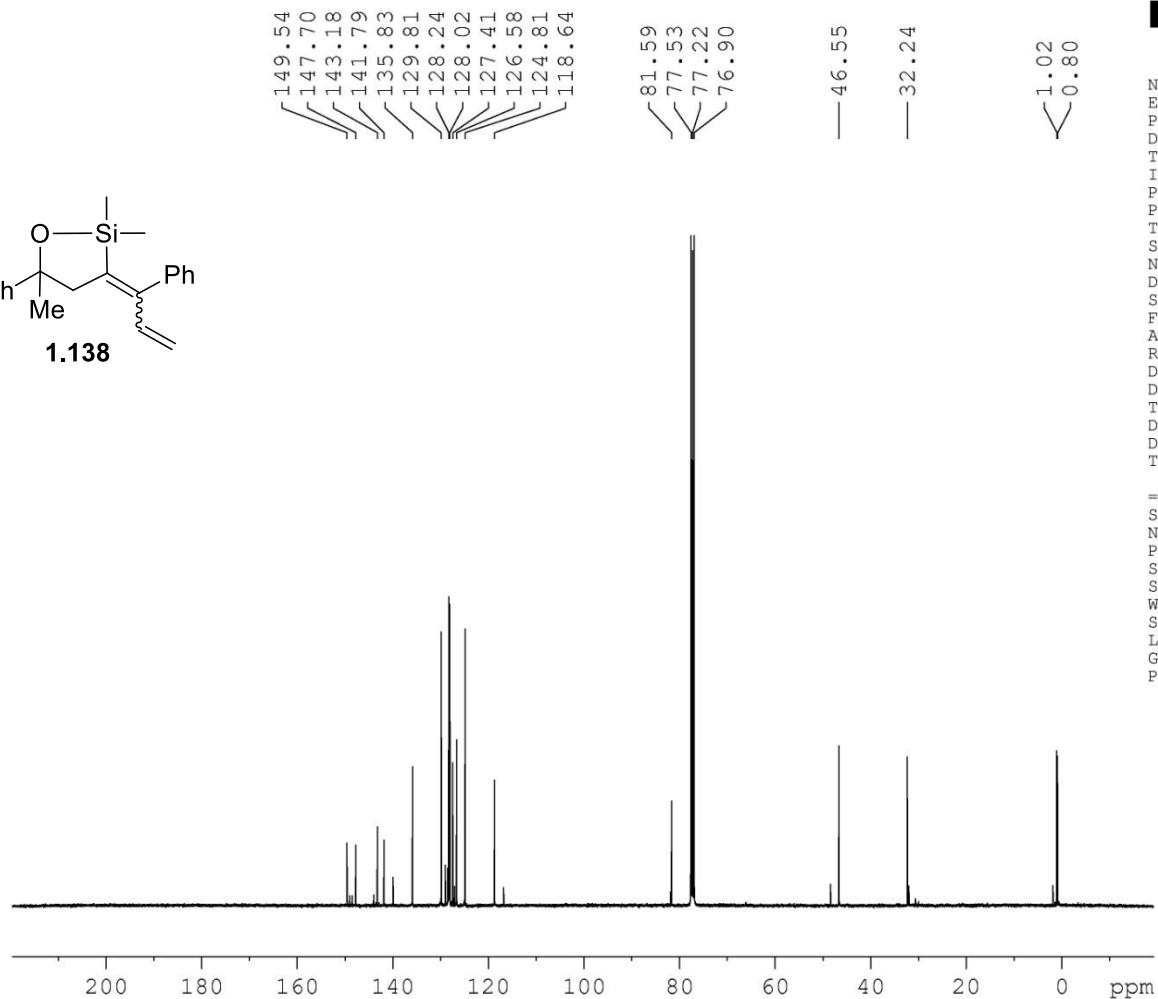
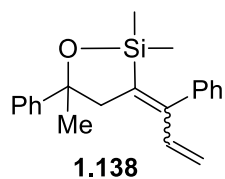


RJW-5-029-C



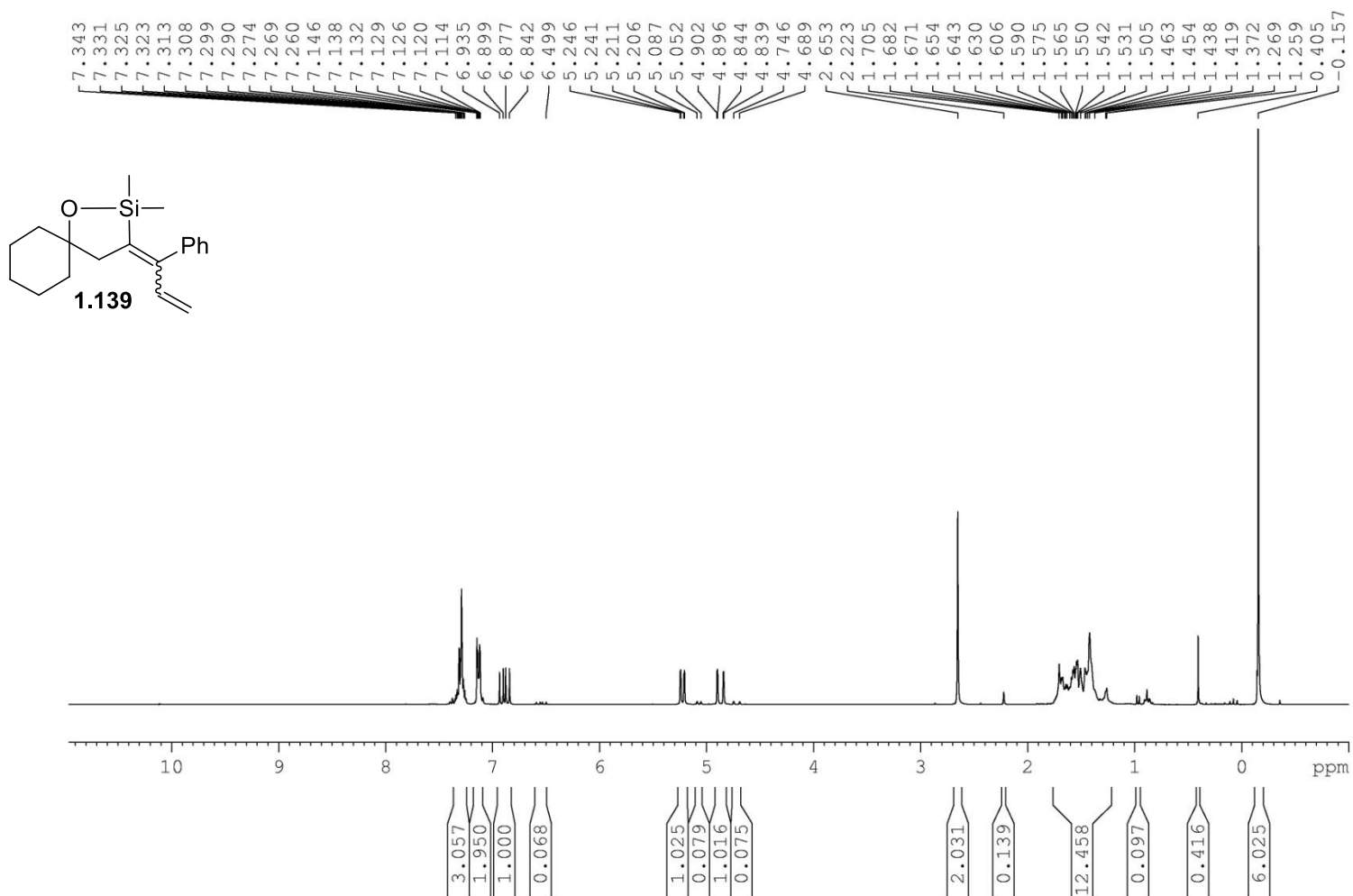


RJW-5-030-C

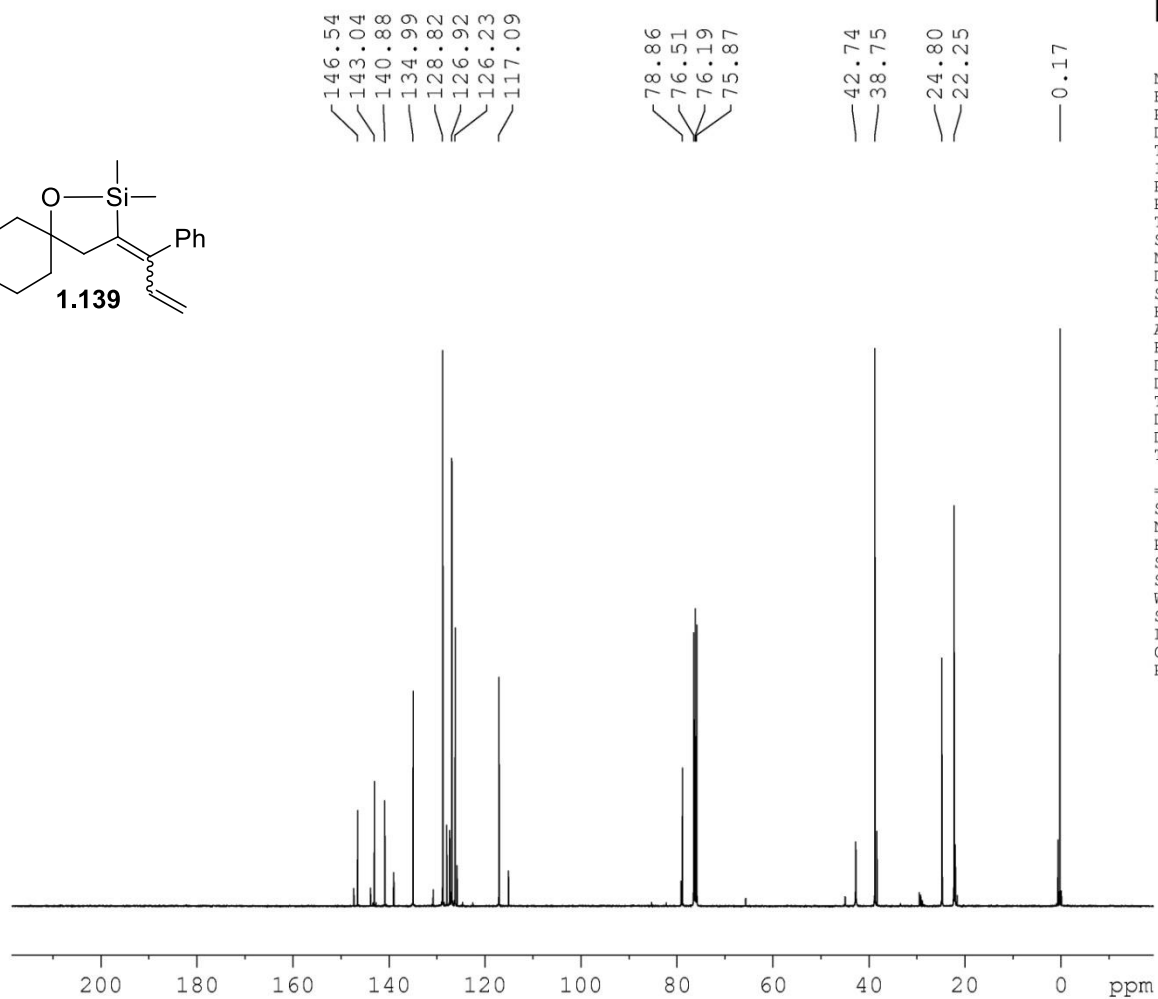
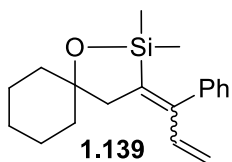


NAME RJW400-5-030
EXPNO 3
PROCNO 1
Date_ 20140209
Time 19.08
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDCl3
NS 1024
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 74.16
DW 20.800 usec
DE 18.00 usec
TE 300.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127496 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

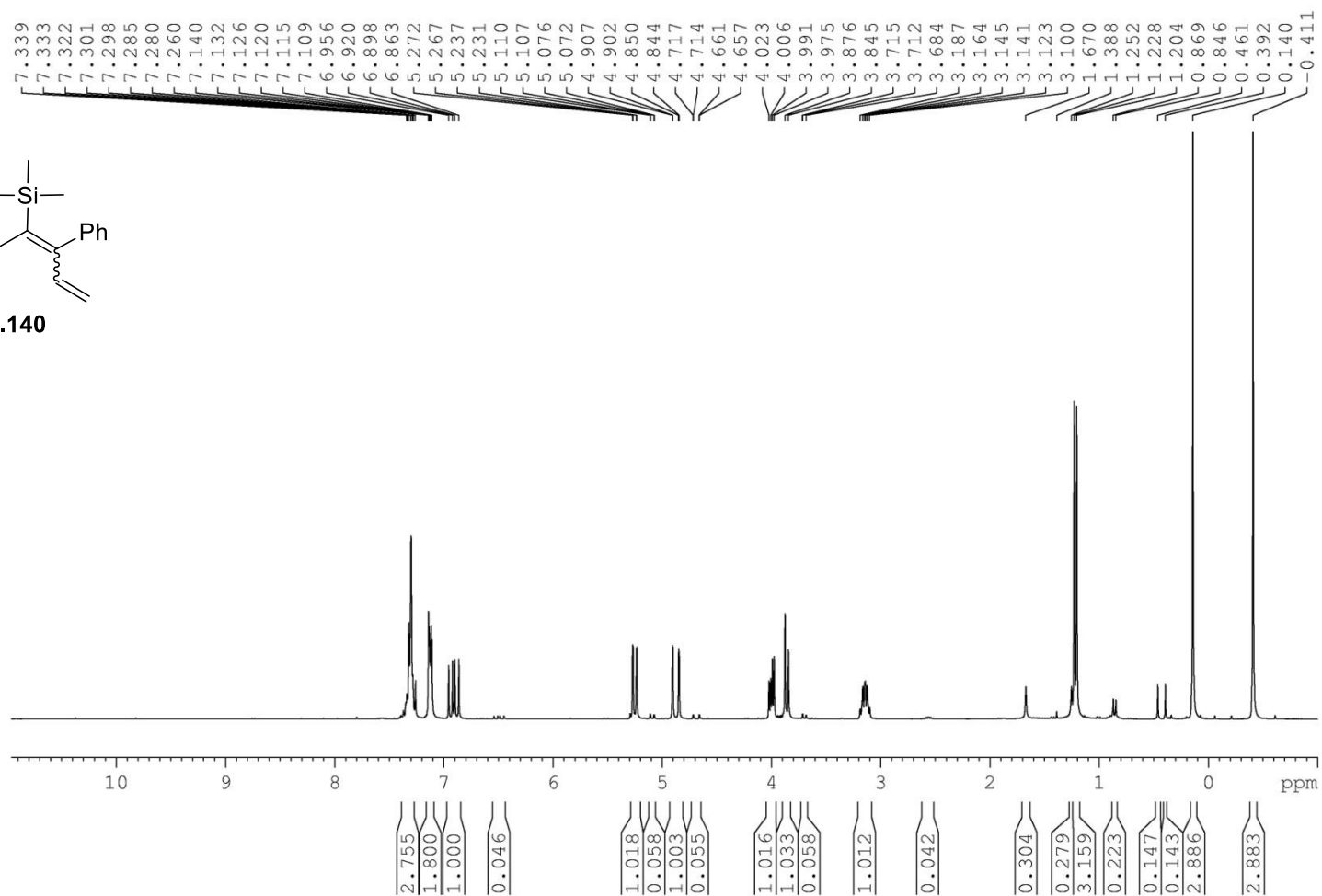
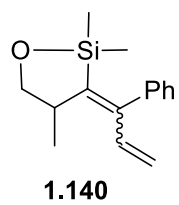


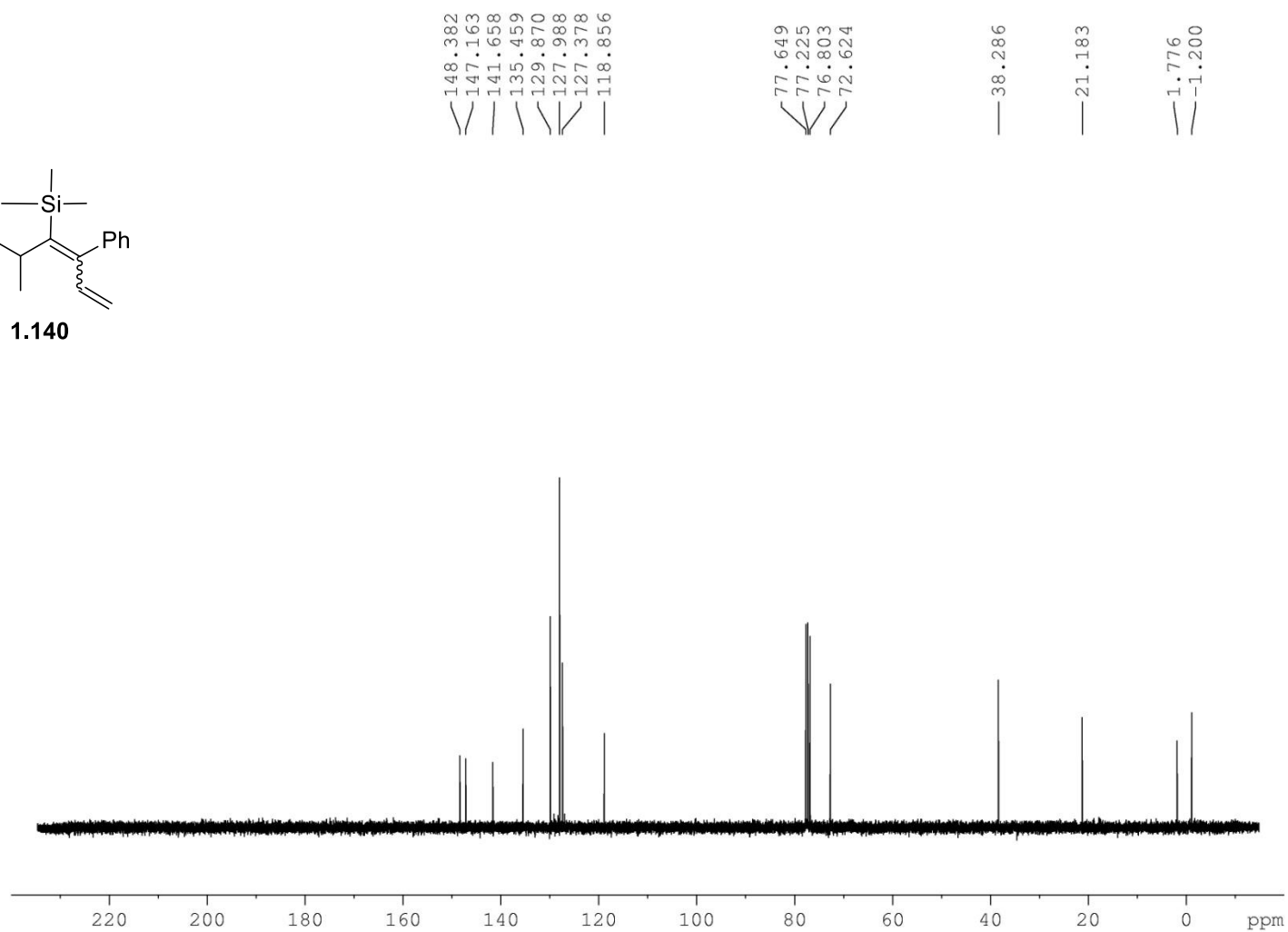
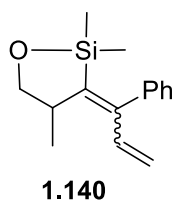
RJW-5-031-C

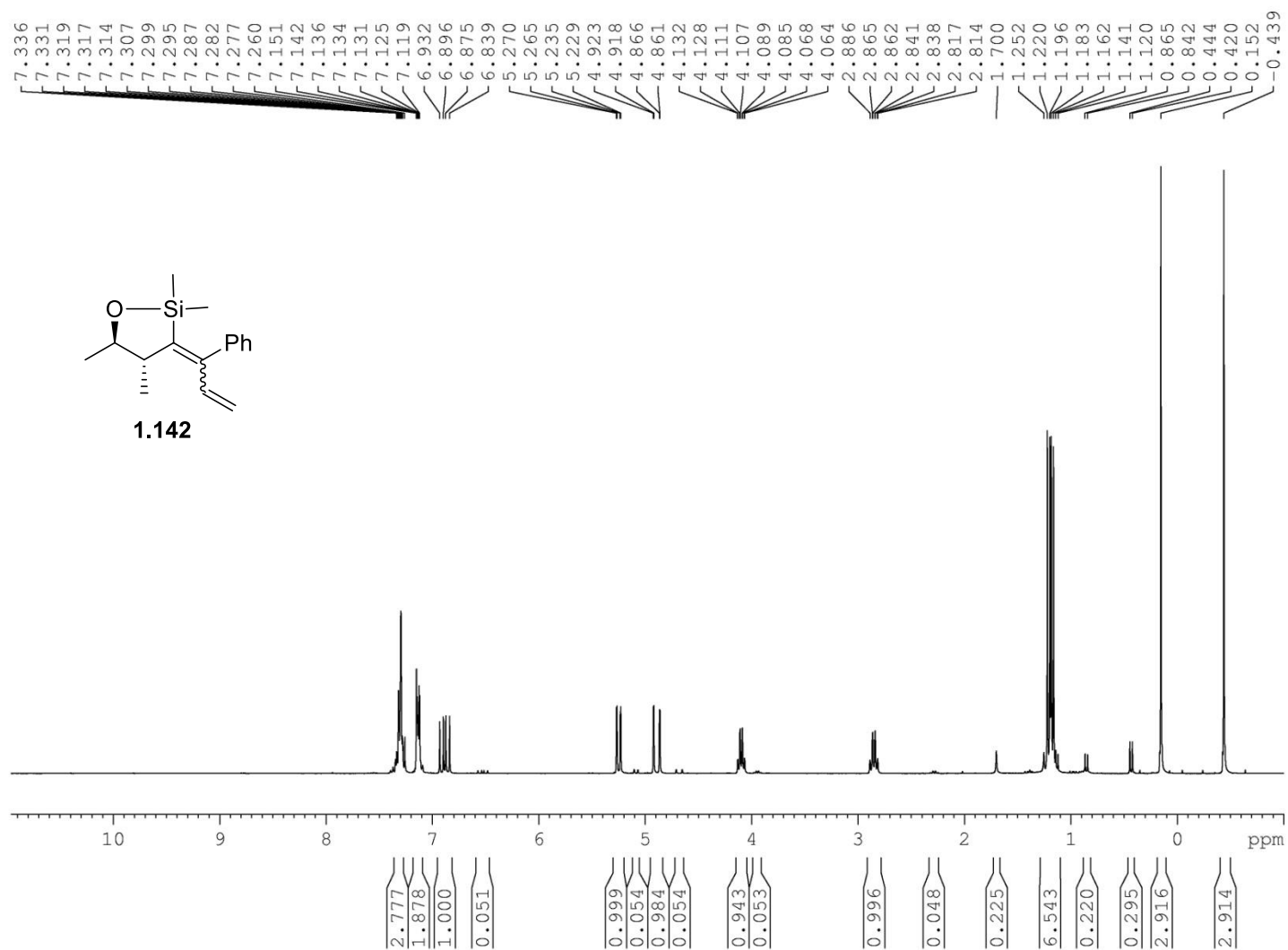


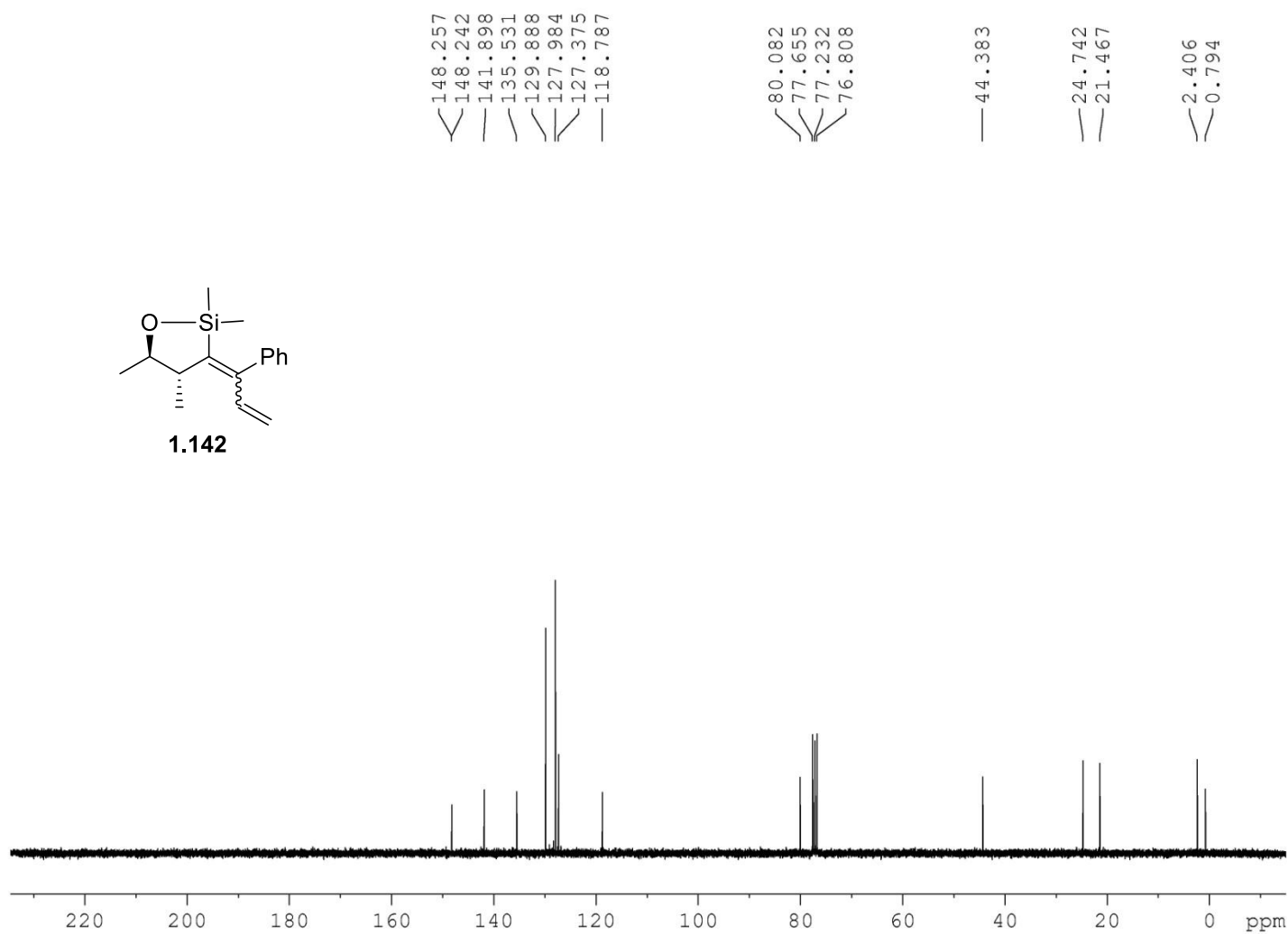
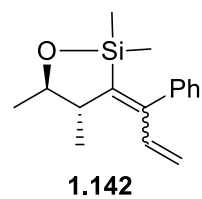
NAME RJW400-5-031
 EXPNO 3
 PROCNO 1
 Date_ 20140210
 Time 20.31
 INSTRUM spect
 PROBHD 5 mm CPPBBO BB
 PULPROG zgpg30
 TD 65536
 SOLVENT CDC13
 NS 1024
 DS 4
 SWH 24038.461 Hz
 FIDRES 0.366798 Hz
 AQ 1.3631988 sec
 RG 58.33
 DW 20.800 usec
 DE 18.00 usec
 TE 300.0 K
 D1 2.00000000 sec
 D11 0.03000000 sec
 TD0 1

===== CHANNEL f1 =====
 SFO1 100.6228293 MHz
 NUC1 13C
 P1 10.00 usec
 SI 32768
 SF 100.6128548 MHz
 WDW EM
 SSB 0
 LB 1.00 Hz
 GB 0
 PC 1.40

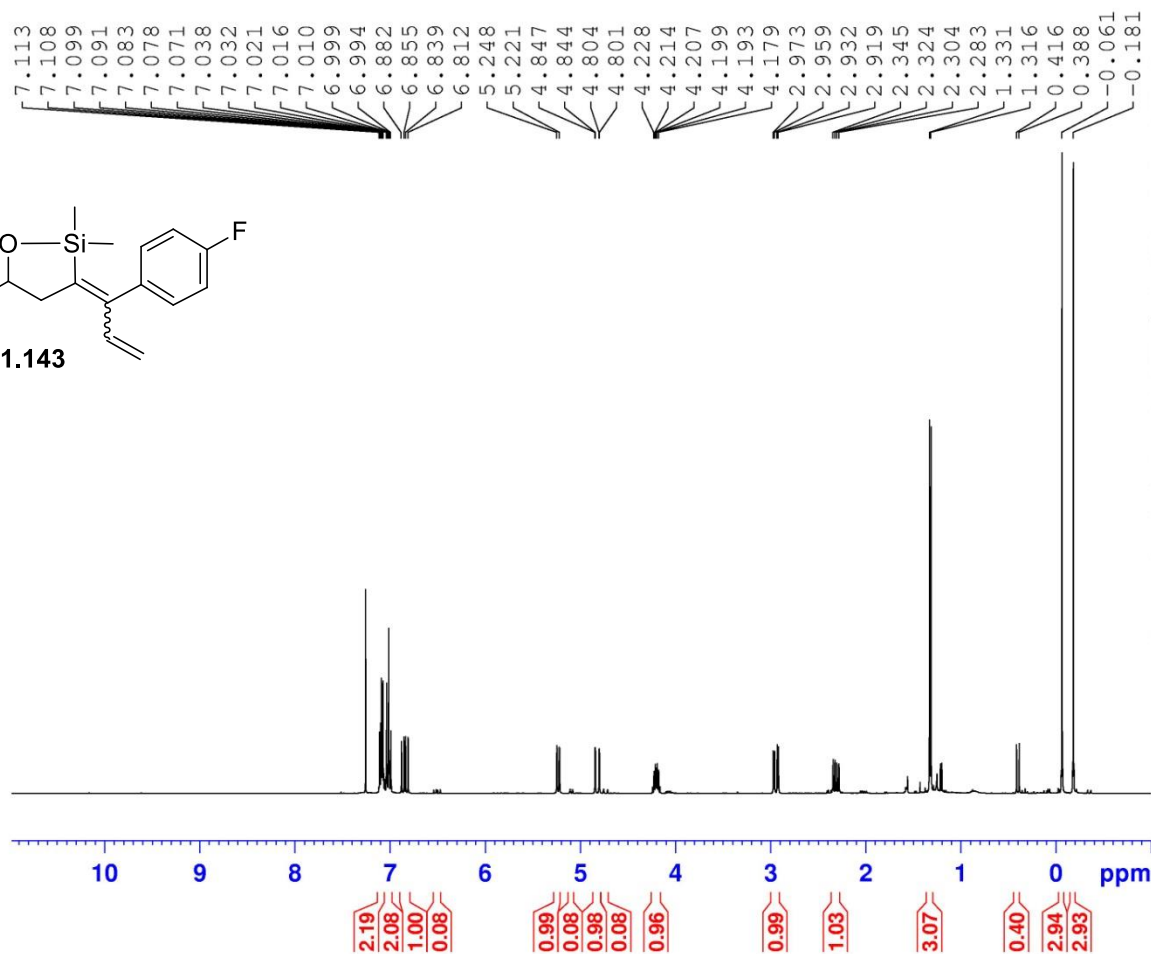
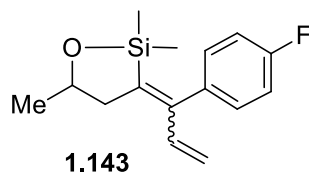








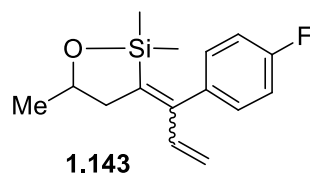
RJW-5-055
4-F PTLC



NAME RJW400-5-055
EXPNO 1
PROCNO 1
Date_ 20140228
Time 14.04
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDC13
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 134.49
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300100 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

RJW-5-055-C
4-F



163.53
161.09
146.24
144.33
137.71
137.68
136.07
131.51
131.43
118.48
115.10
114.89

77.59
77.28
76.96
72.65

40.88

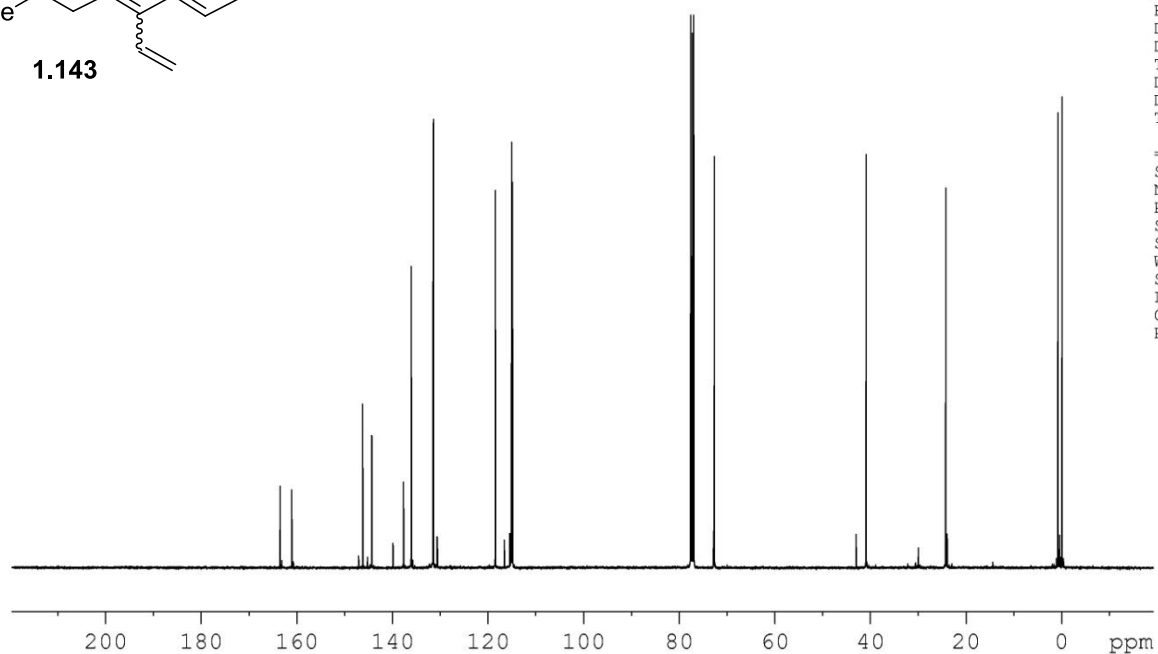
24.23

0.76
-0.10



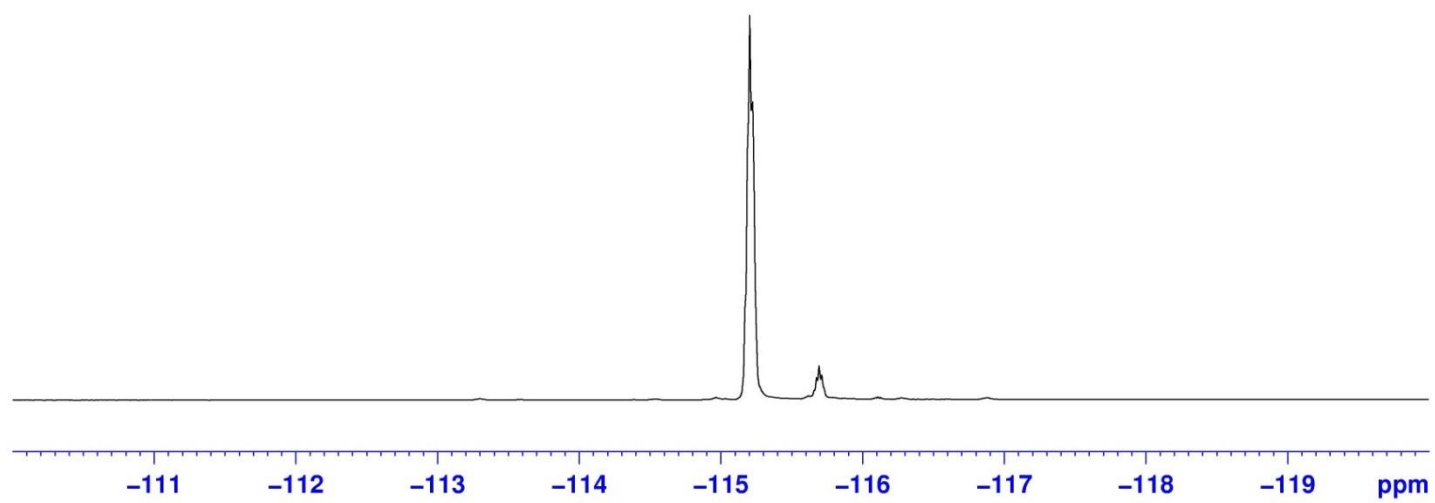
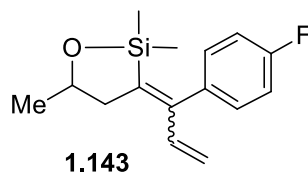
NAME RJW400-5-055
EXPNO 2
PROCNO 1
Date_ 20140228
Time 21.41
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDC13
NS 1024
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 91.52
DW 20.800 usec
DE 18.00 usec
TE 300.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127434 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

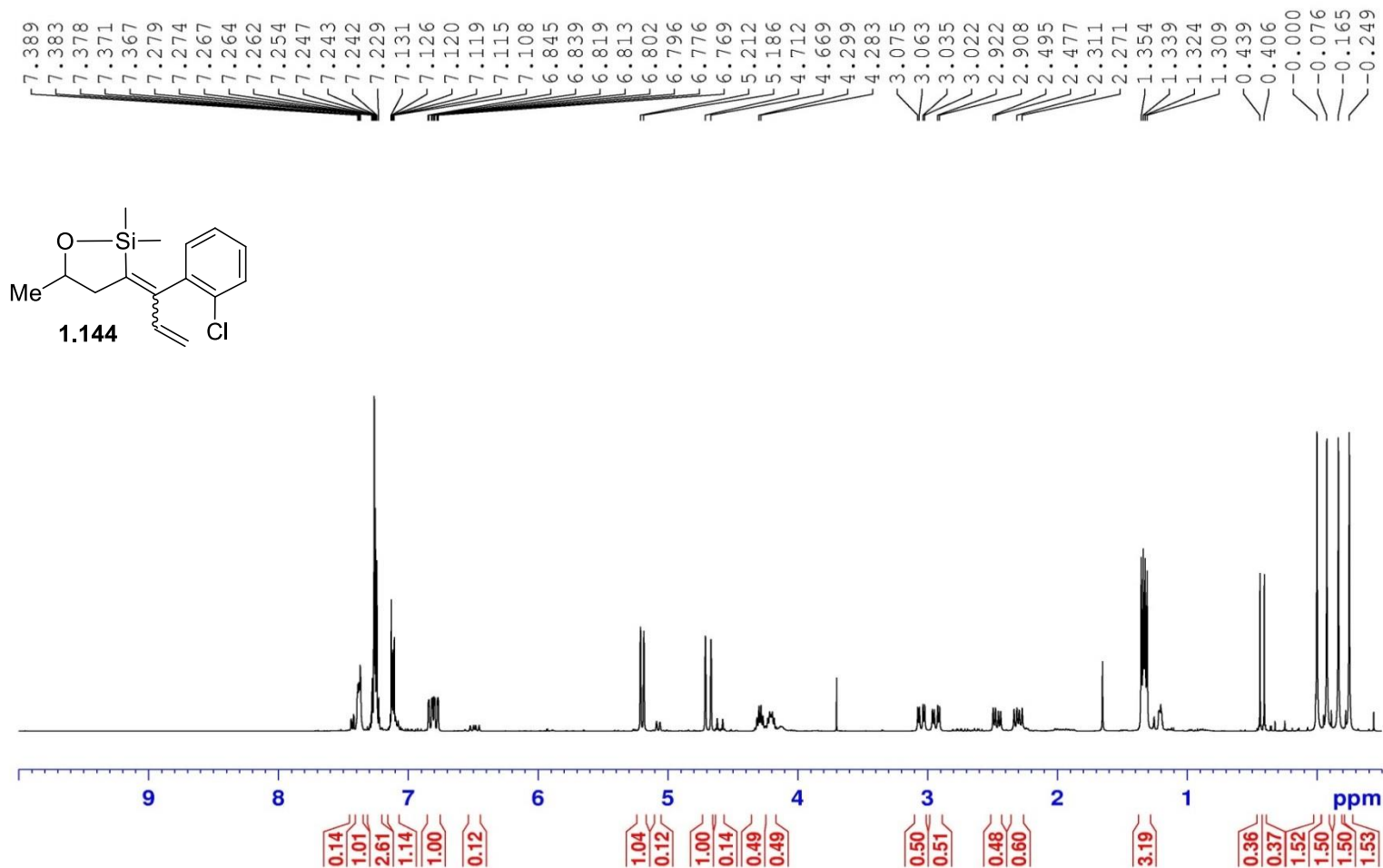


^{19}F NMR (CDCl_3)

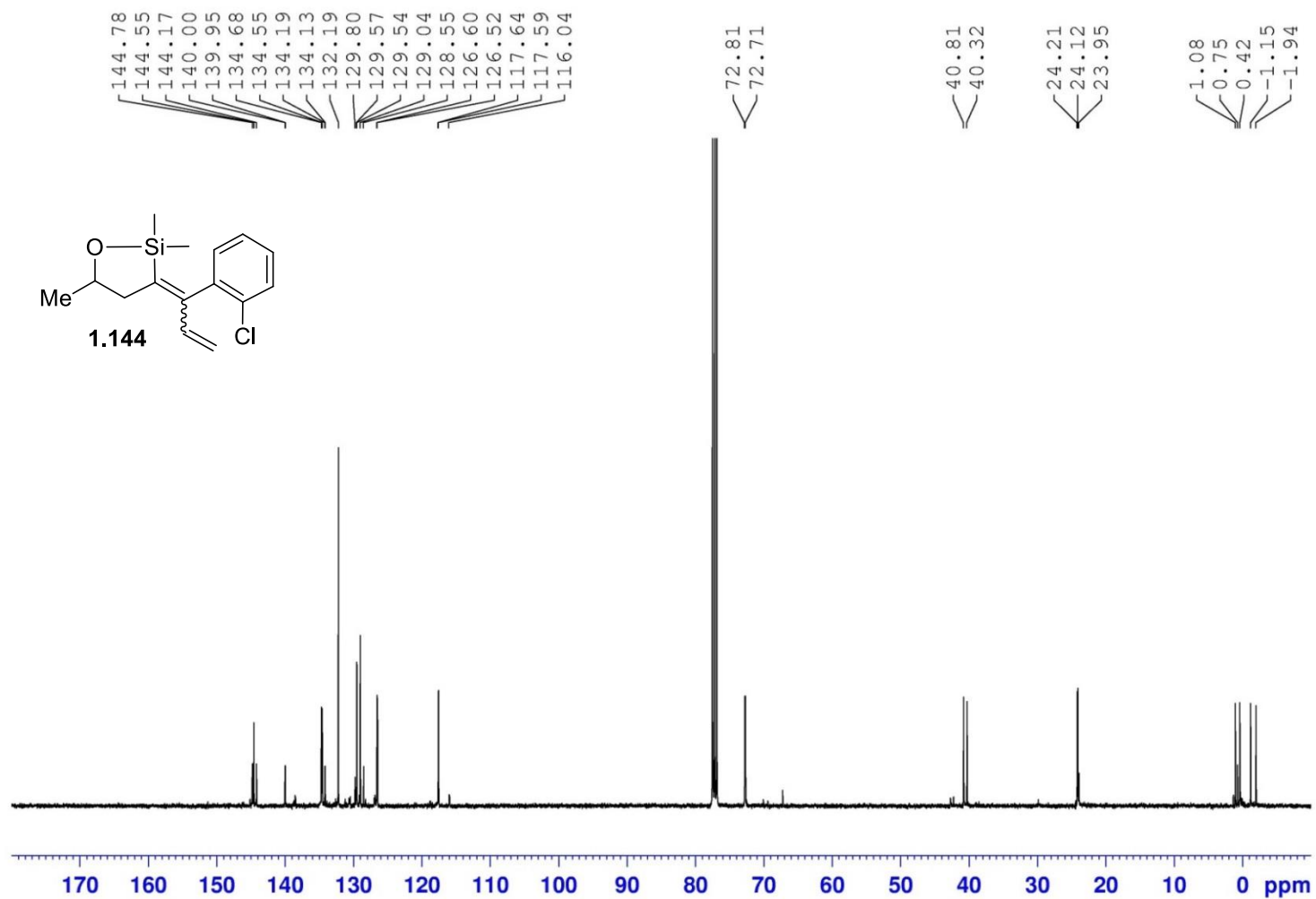
$\begin{matrix} -115.206 \\ -115.221 \end{matrix}$

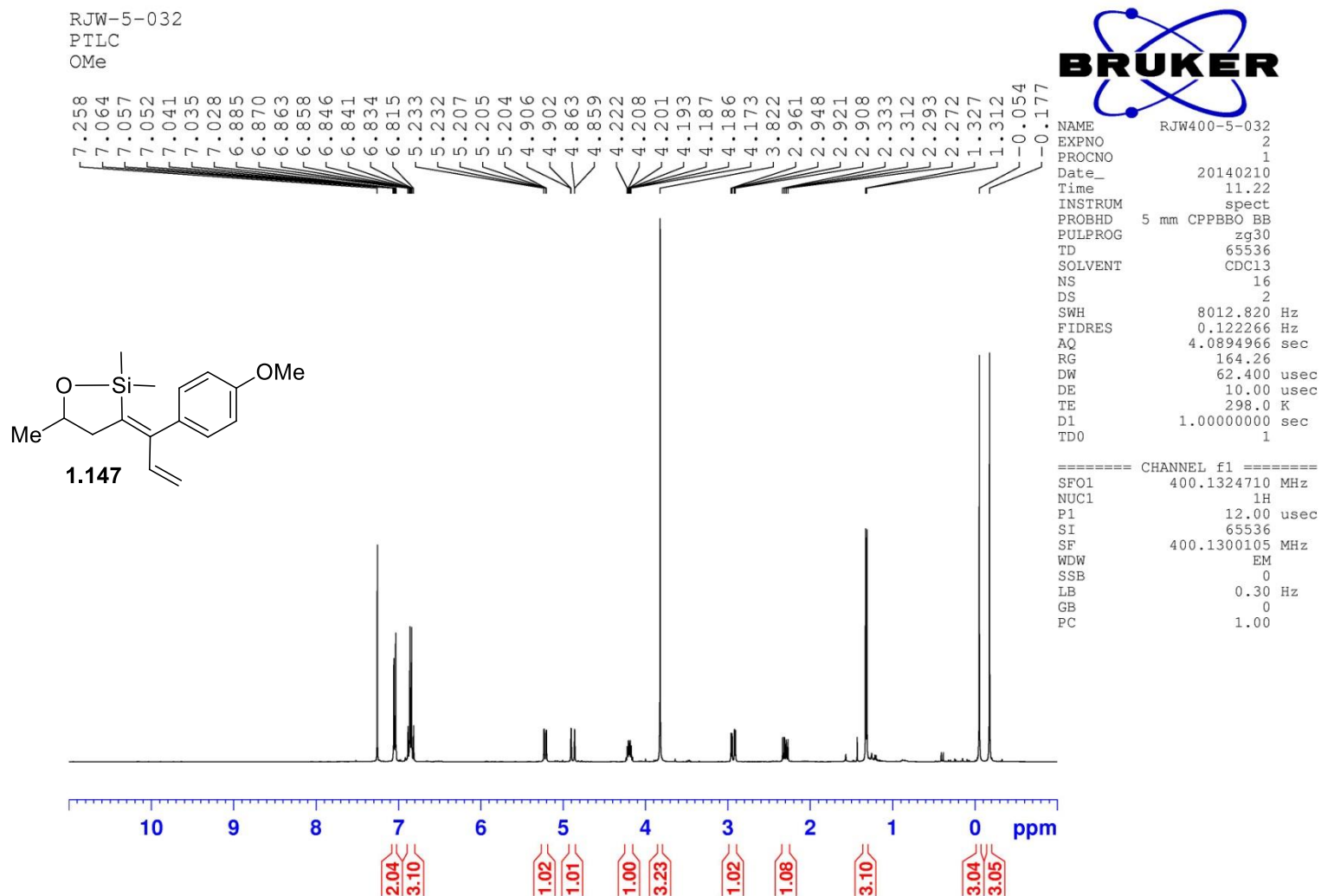


RJW-6-048
PC

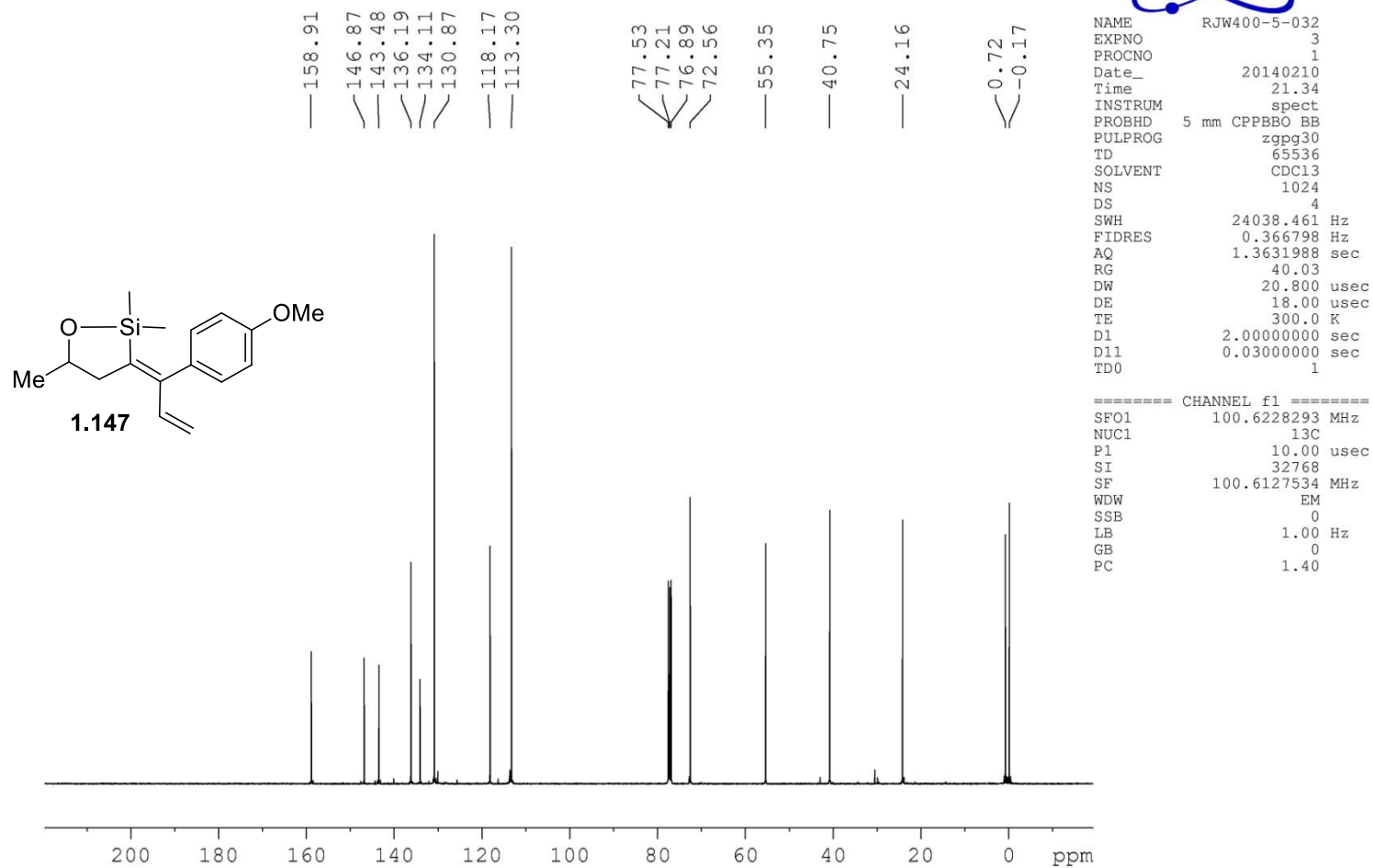


RJW-6-048
PC

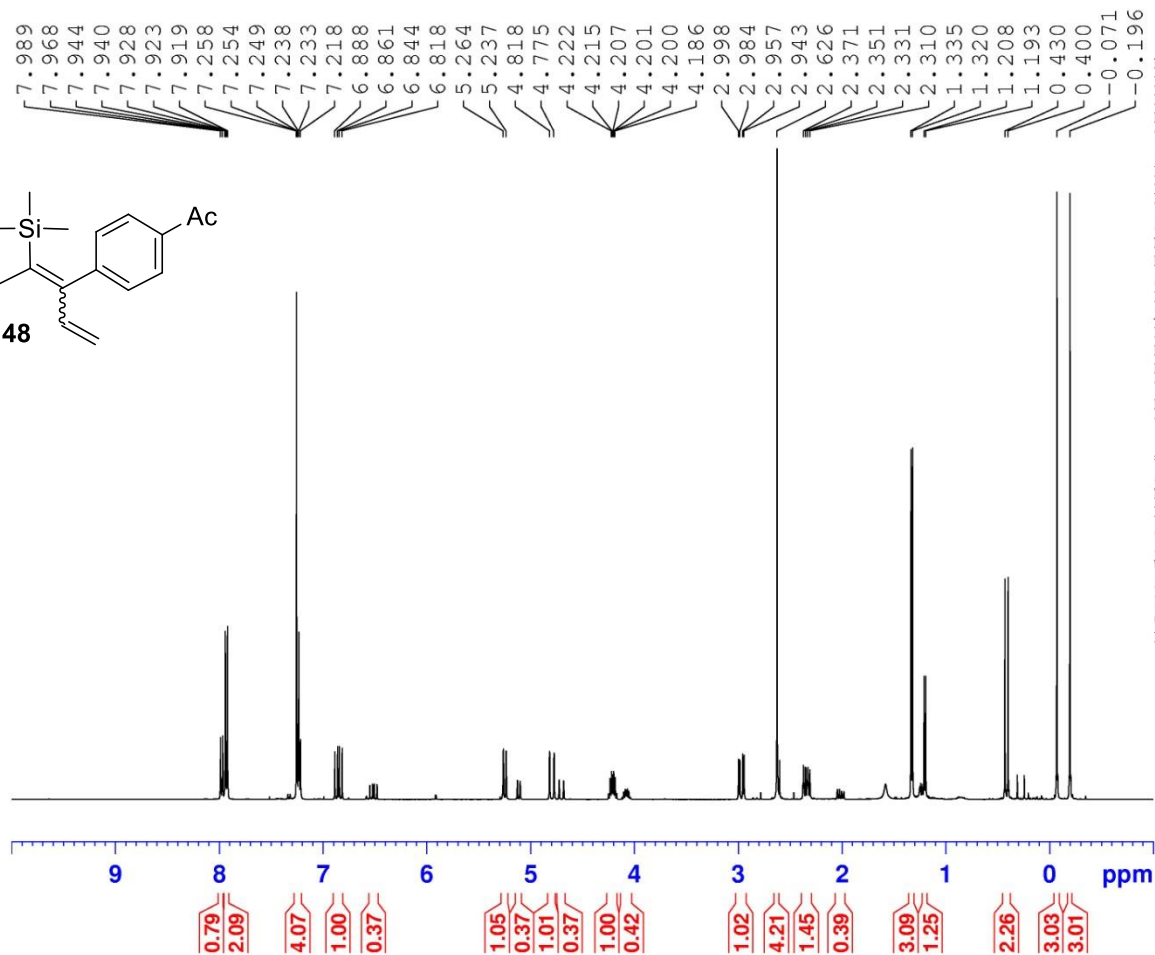
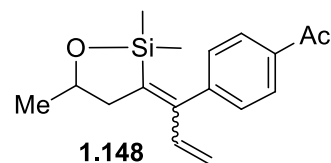




RJW-5-032-C



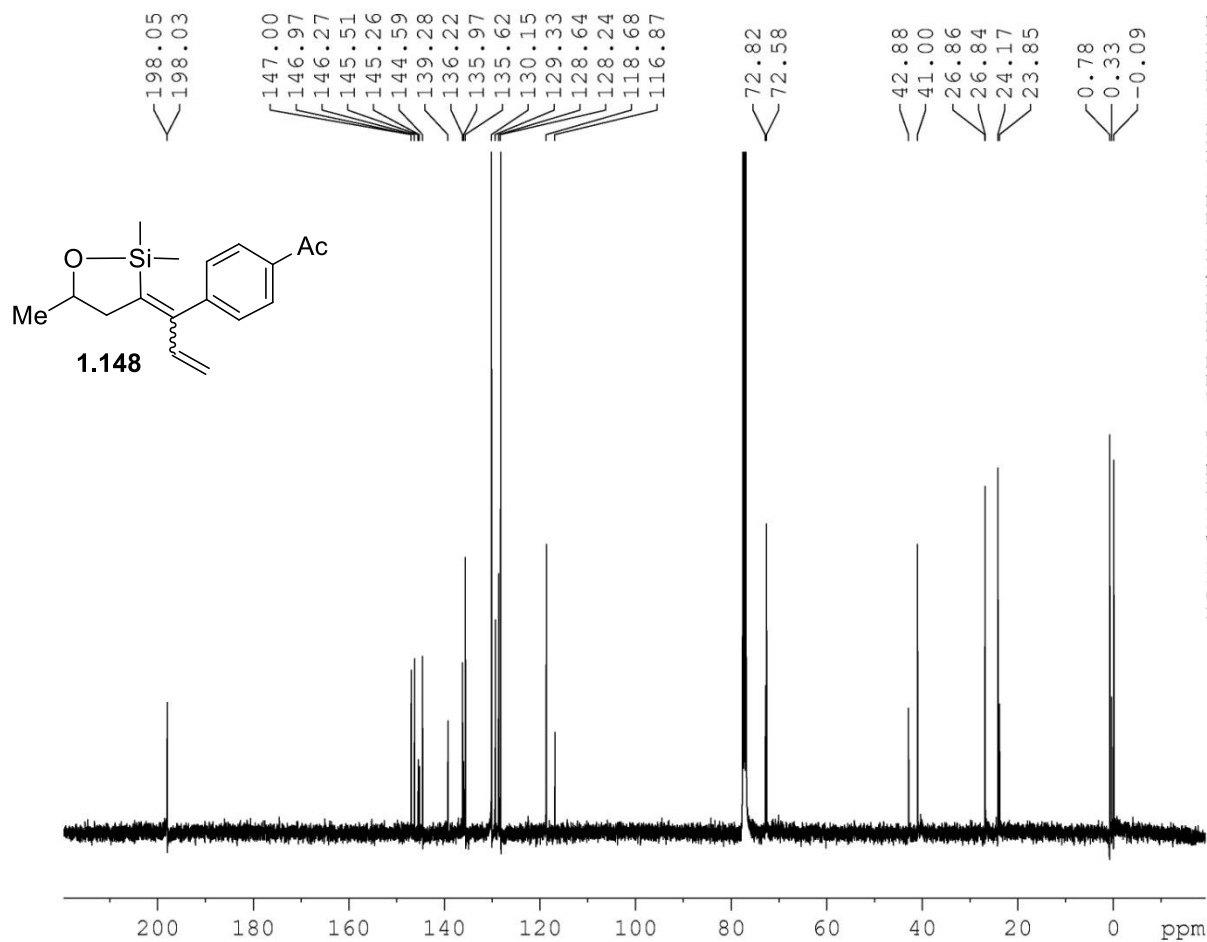
RJW-5-146
PC



NAME RJW400-5-146
EXPNO 2
PROCNO 1
Date_ 20140514
Time 20.09
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDC13
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 208.09
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300106 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

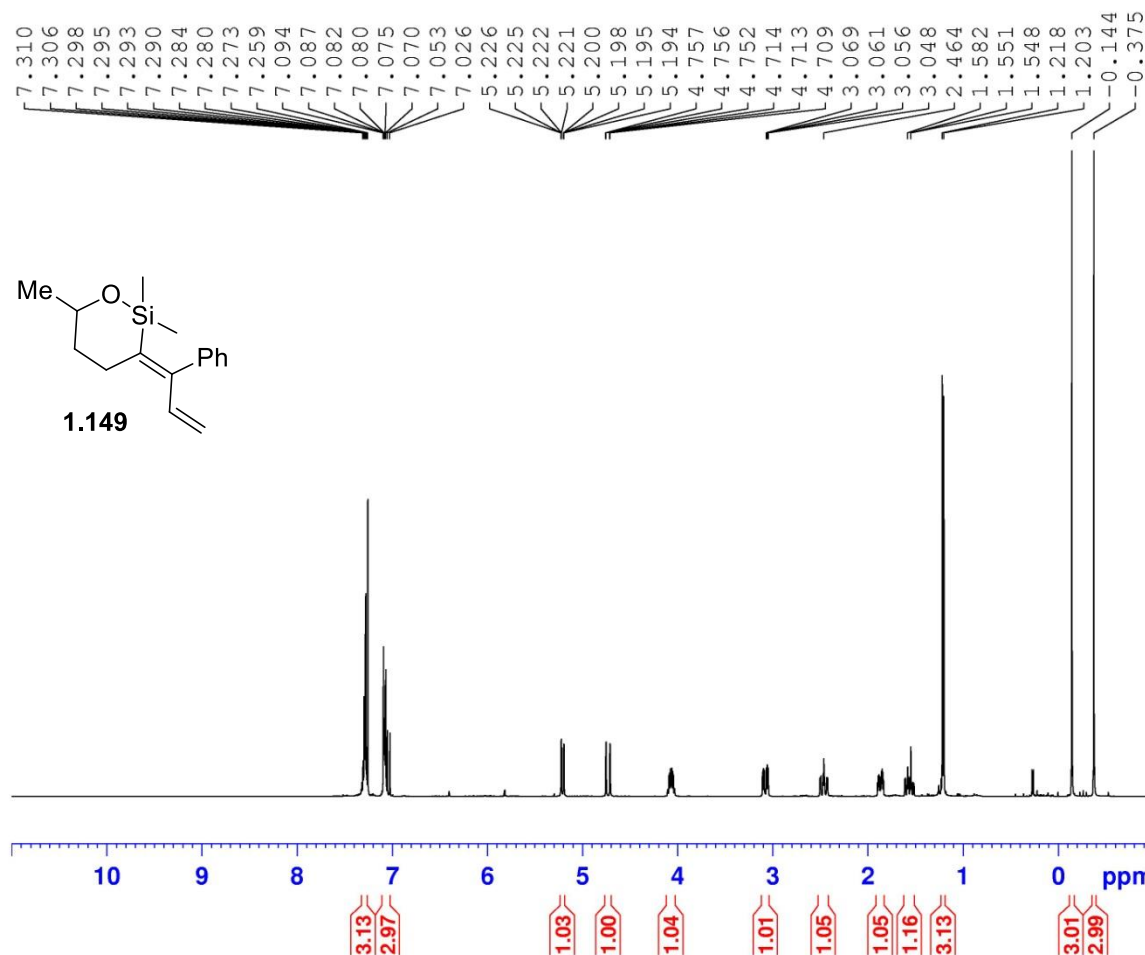
RJW-5-146
PC



NAME RJW400-5-146
EXPNO 3
PROCNO 1
Date_ 20140514
Time 21.44
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDCl3
NS 1024
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 80.84
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 4.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127476 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

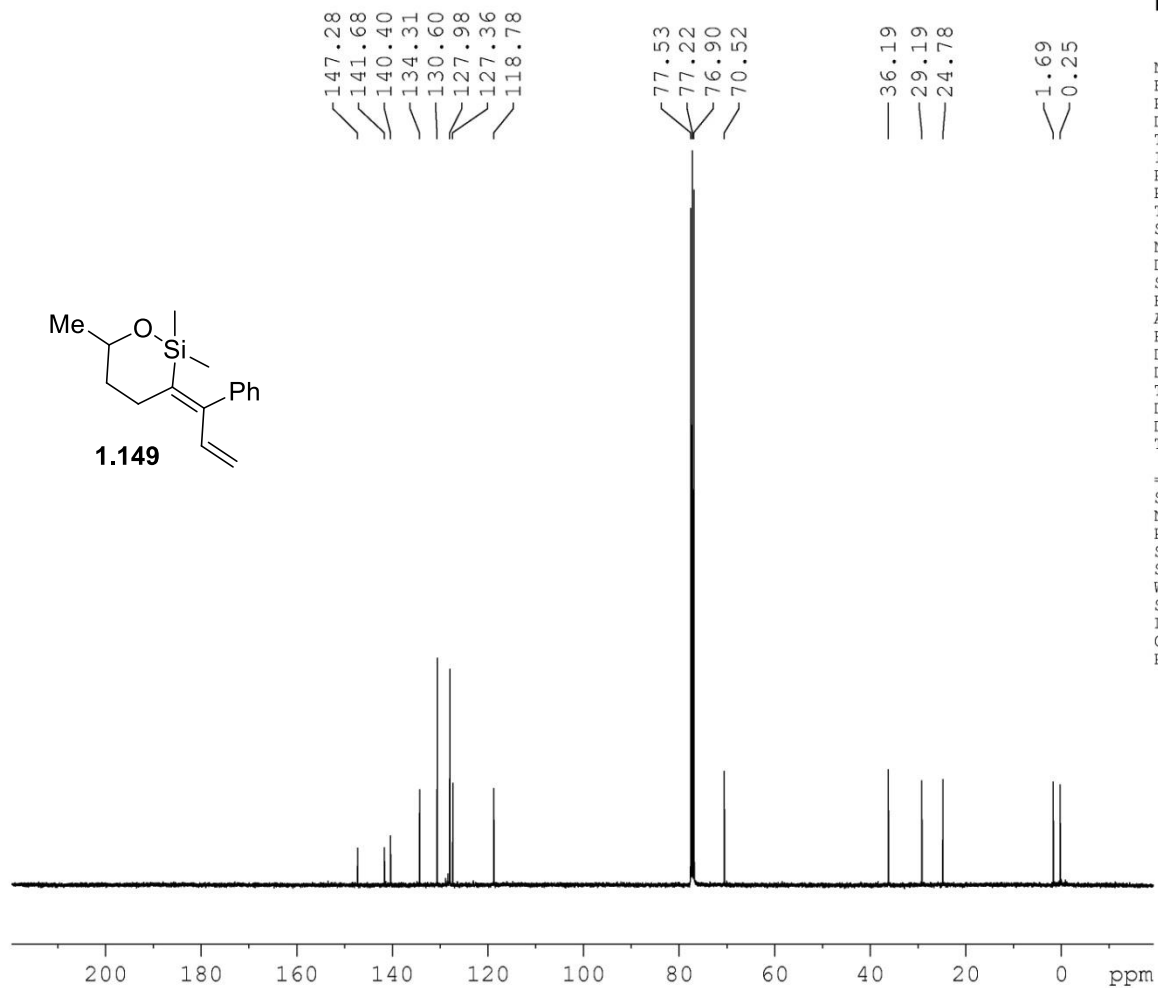
RJW-5-035
PC



NAME RJW400-5-035
EXPNO 2
PROCNO 1
Date_ 20140213
Time 17.33
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl₃
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 183
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

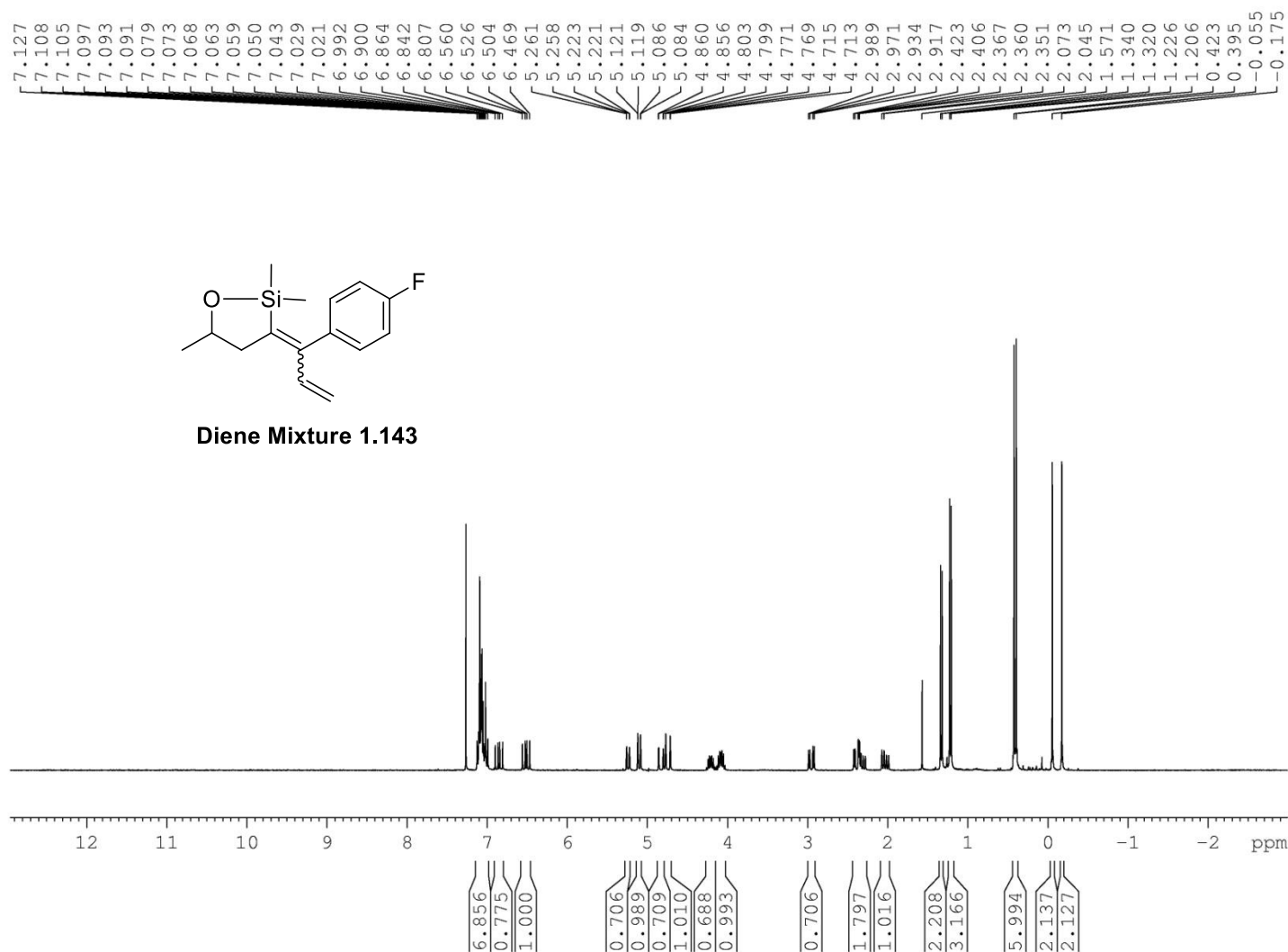
===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300102 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

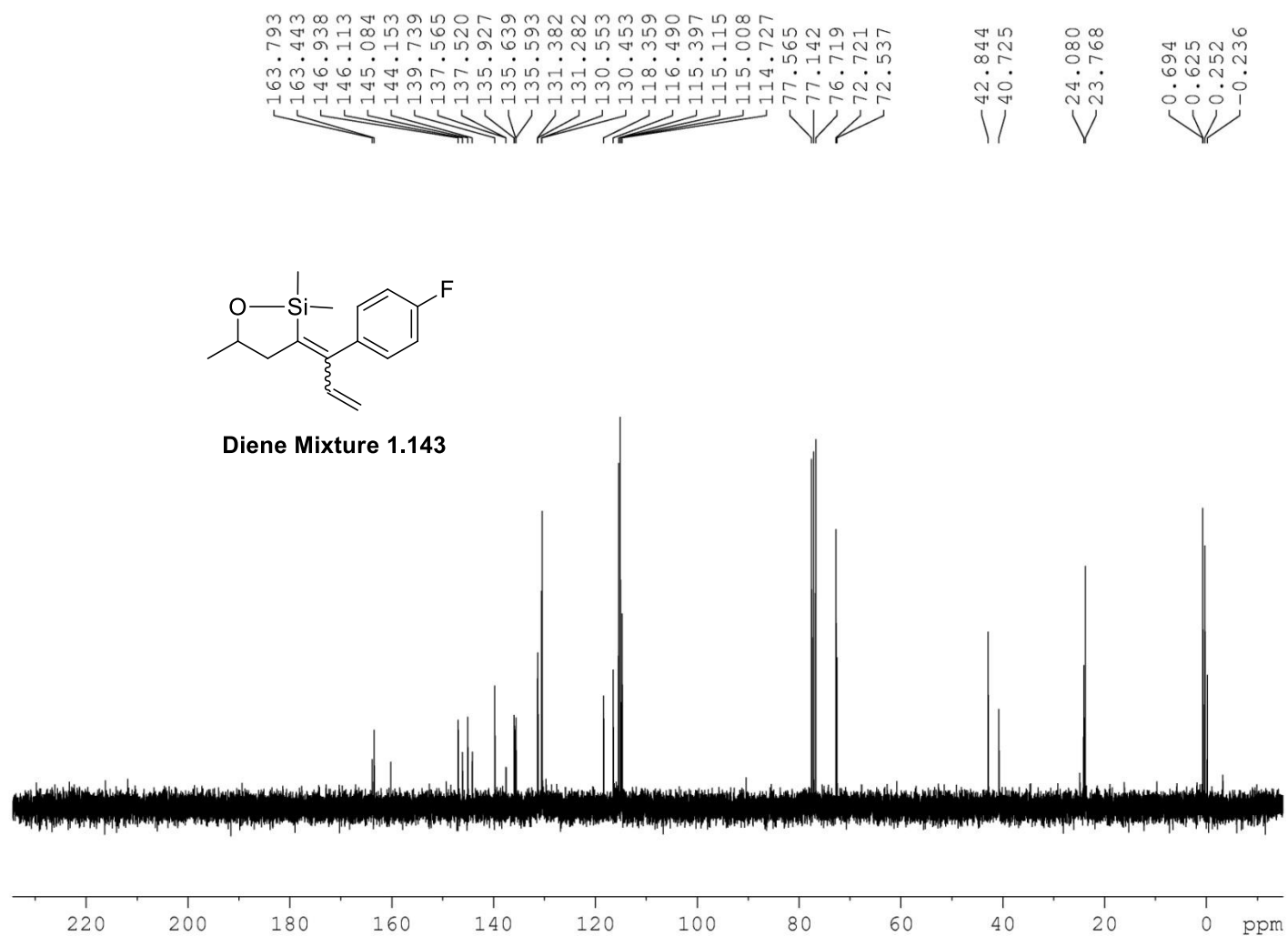
RJW-5-035-C



NAME RJW400-5-035
 EXPNO 3
 PROCNO 1
 Date_ 20140213
 Time 18.14
 INSTRUM spect
 PROBHD 5 mm CPPBBO BB
 PULPROG zgpg30
 TD 65536
 SOLVENT CDCl3
 NS 520
 DS 4
 SWH 24038.461 Hz
 FIDRES 0.366798 Hz
 AQ 1.3631988 sec
 RG 50.16
 DW 20.800 usec
 DE 18.00 usec
 TE 300.0 K
 D1 2.00000000 sec
 D11 0.03000000 sec
 TD0 1

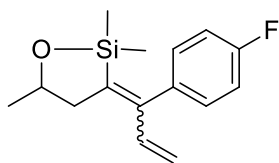
===== CHANNEL f1 =====
 SFO1 100.6228293 MHz
 NUC1 13C
 P1 10.00 usec
 SI 32768
 SF 100.6127485 MHz
 WDW EM
 SSB 0
 LB 1.00 Hz
 GB 0
 PC 1.40



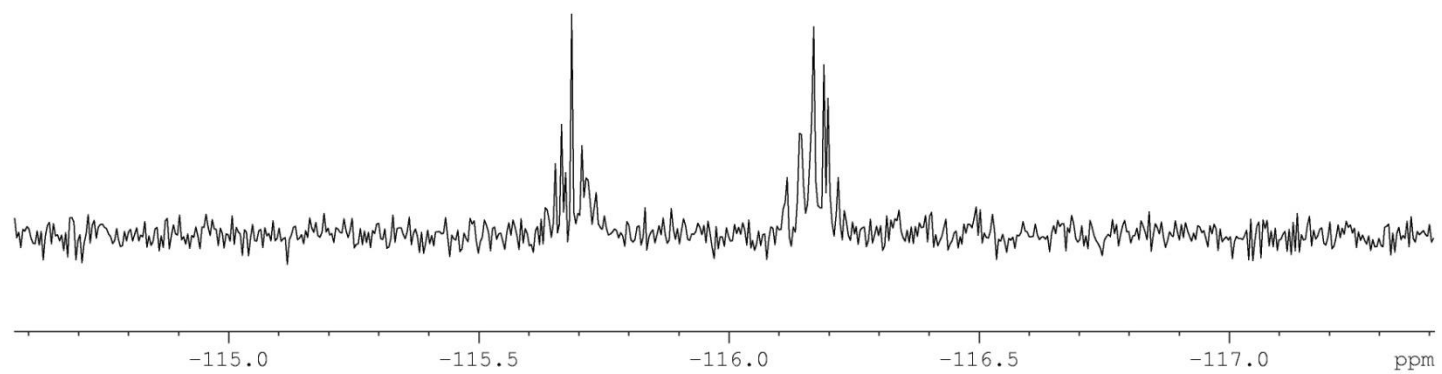


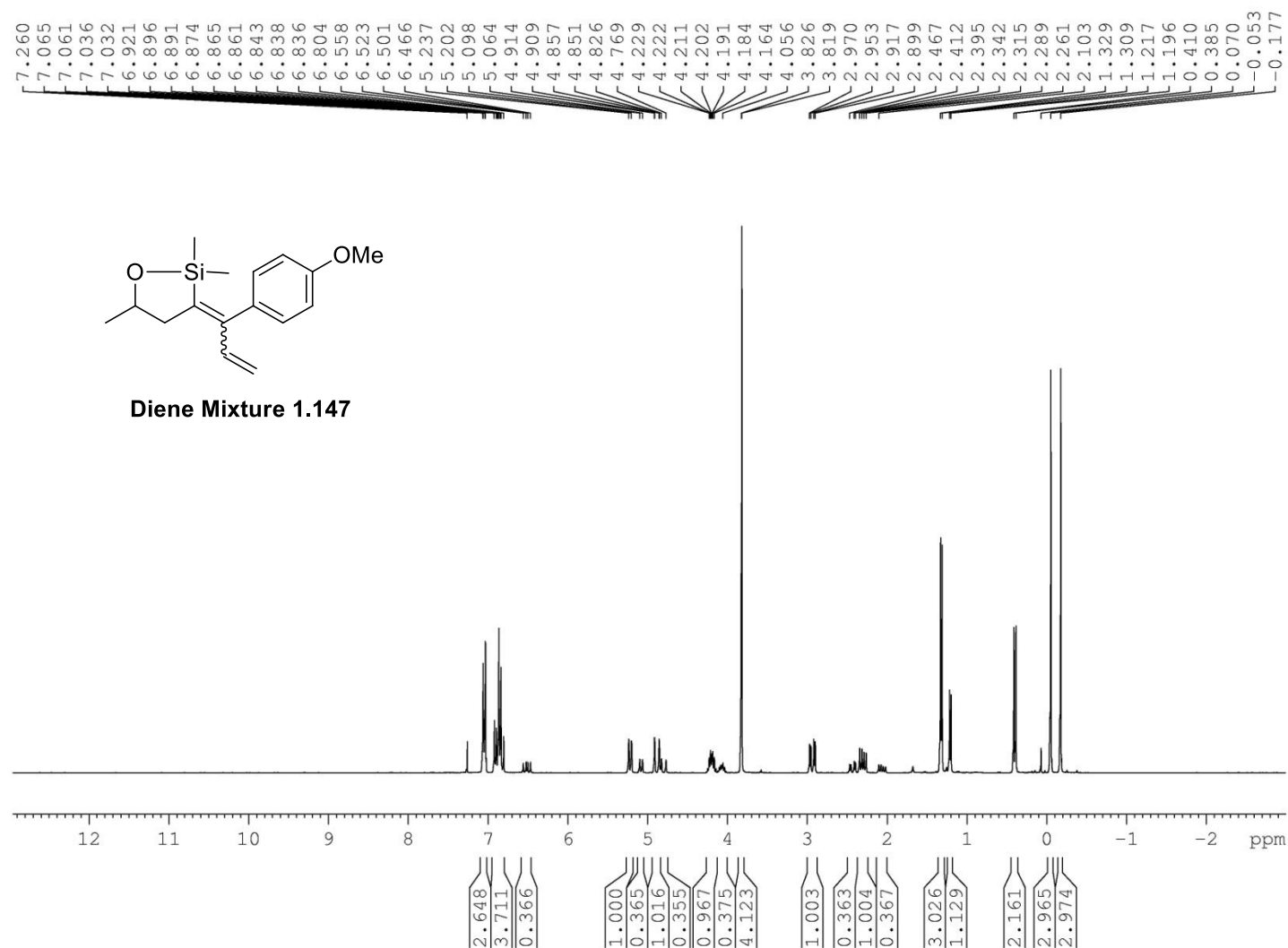
-115.651
-115.663
-115.671
-115.684
-115.704

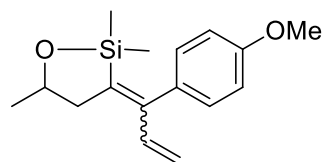
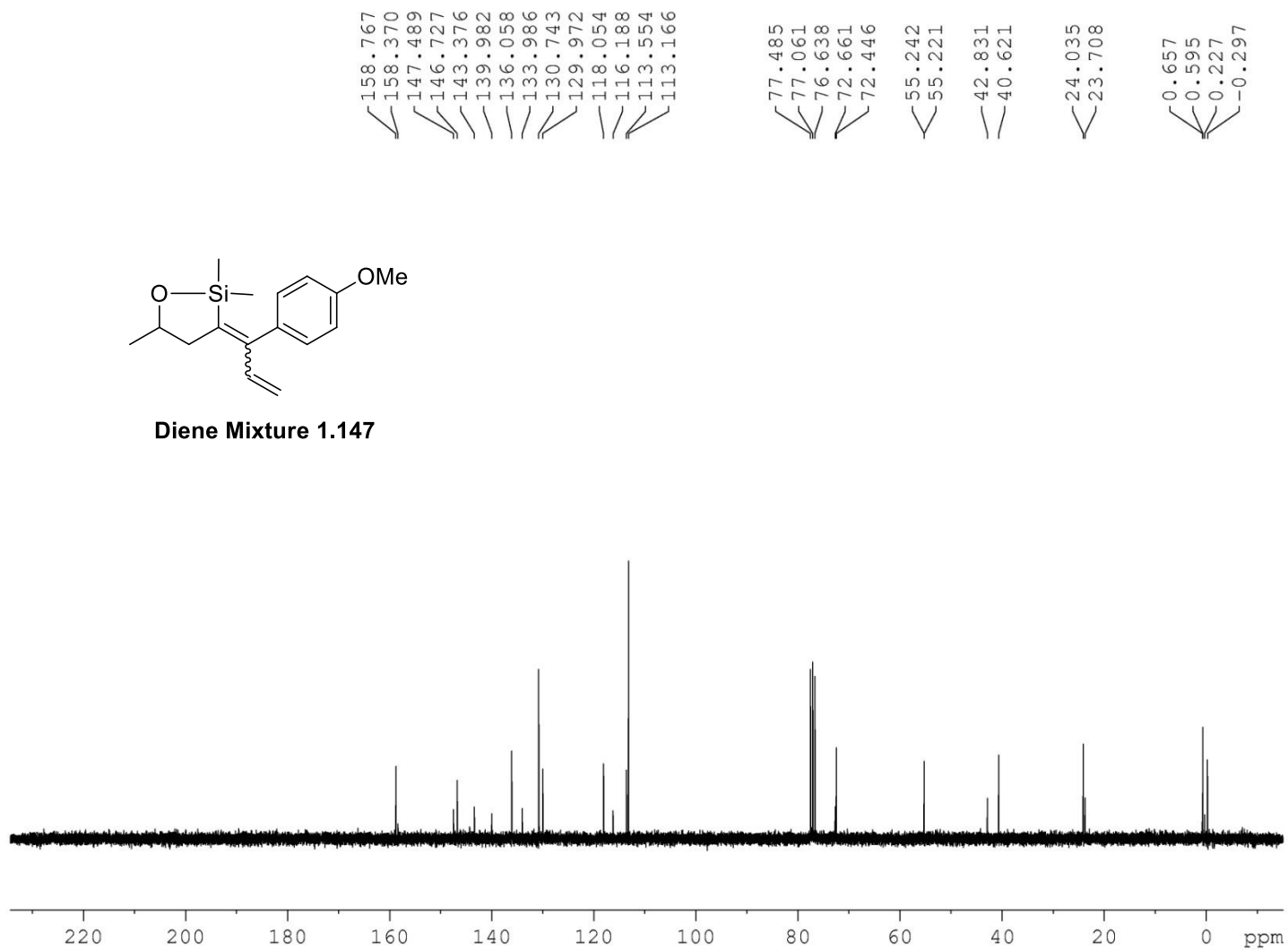
-116.113
-116.141
-116.167
-116.188
-116.196
-116.216

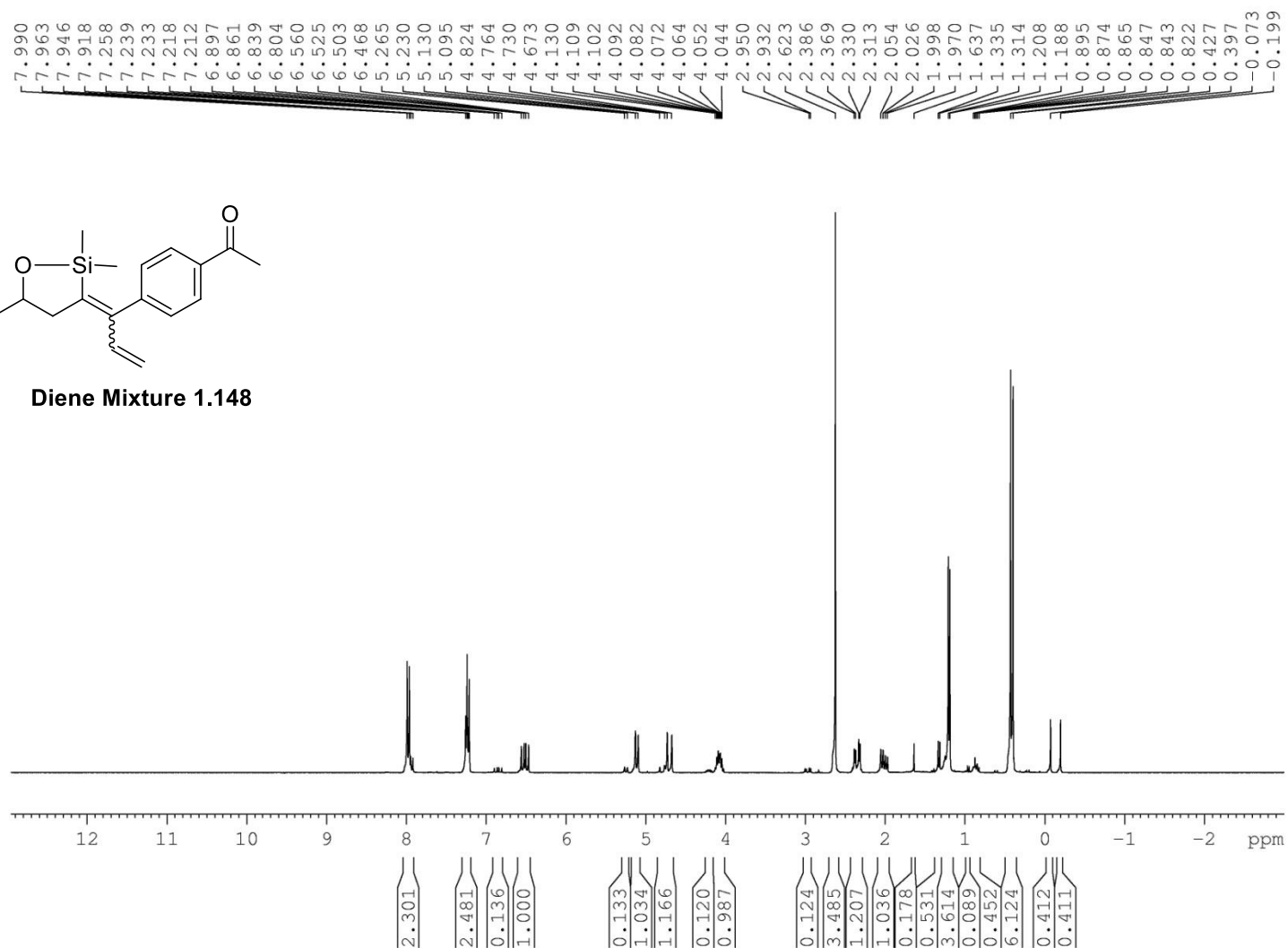
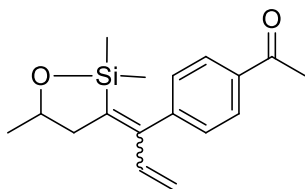


Diene Mixture 1.143

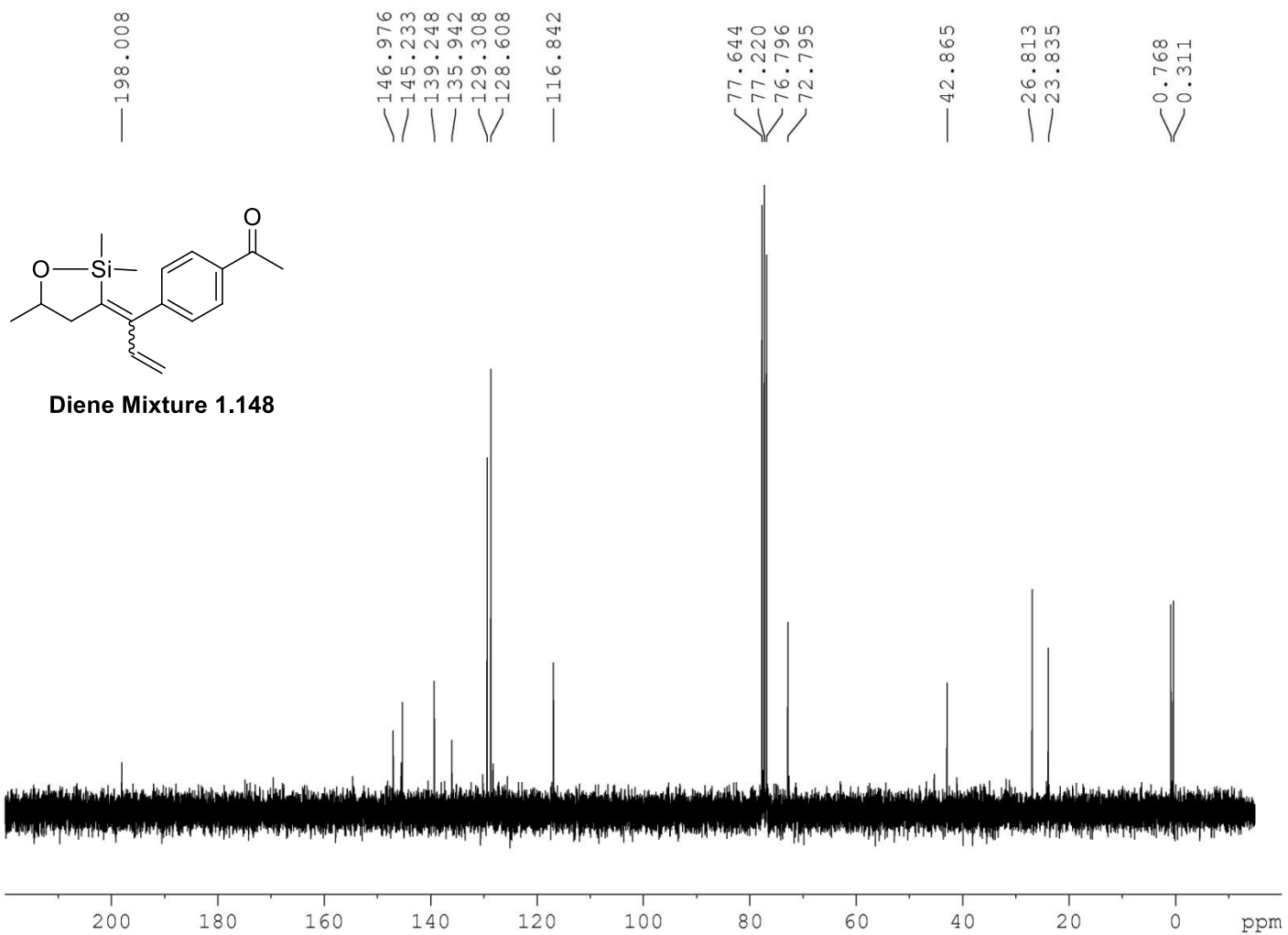


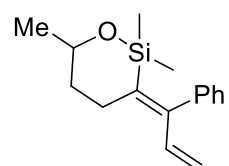
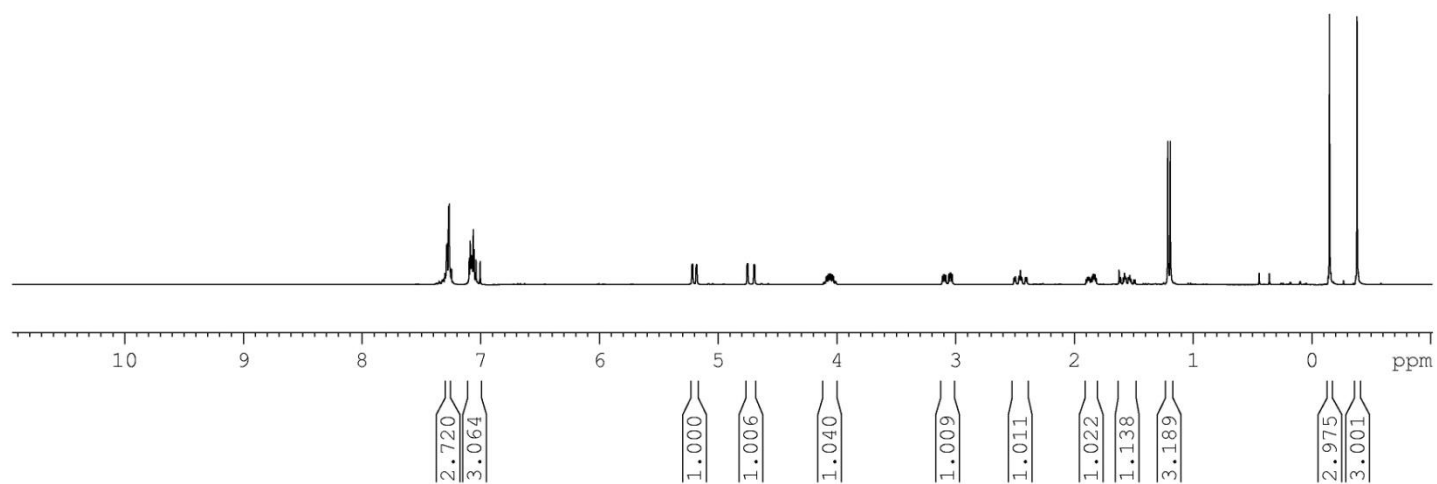


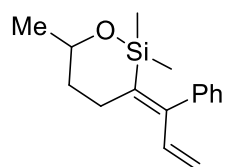
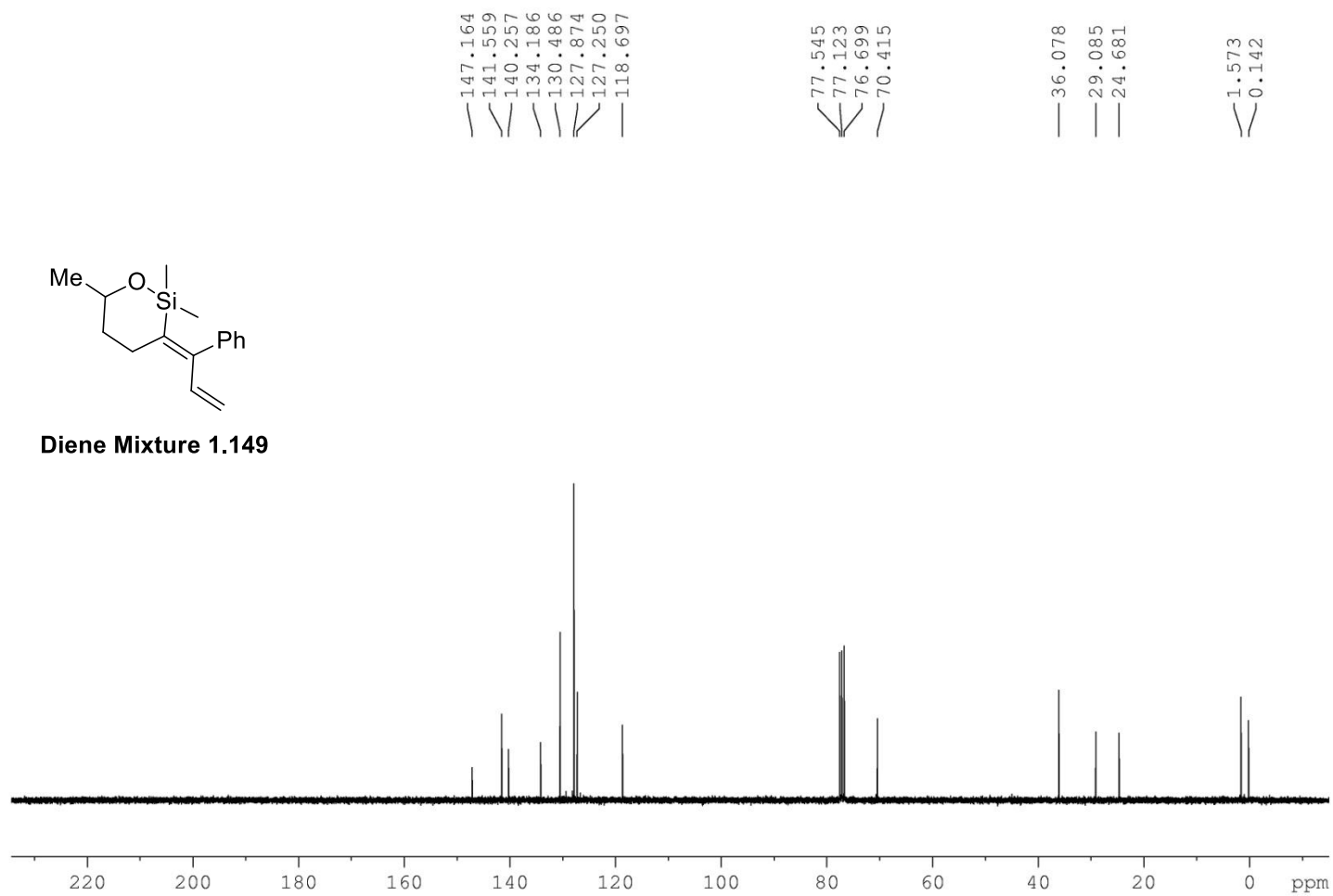
**Diene Mixture 1.147**

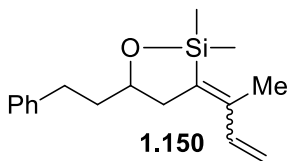


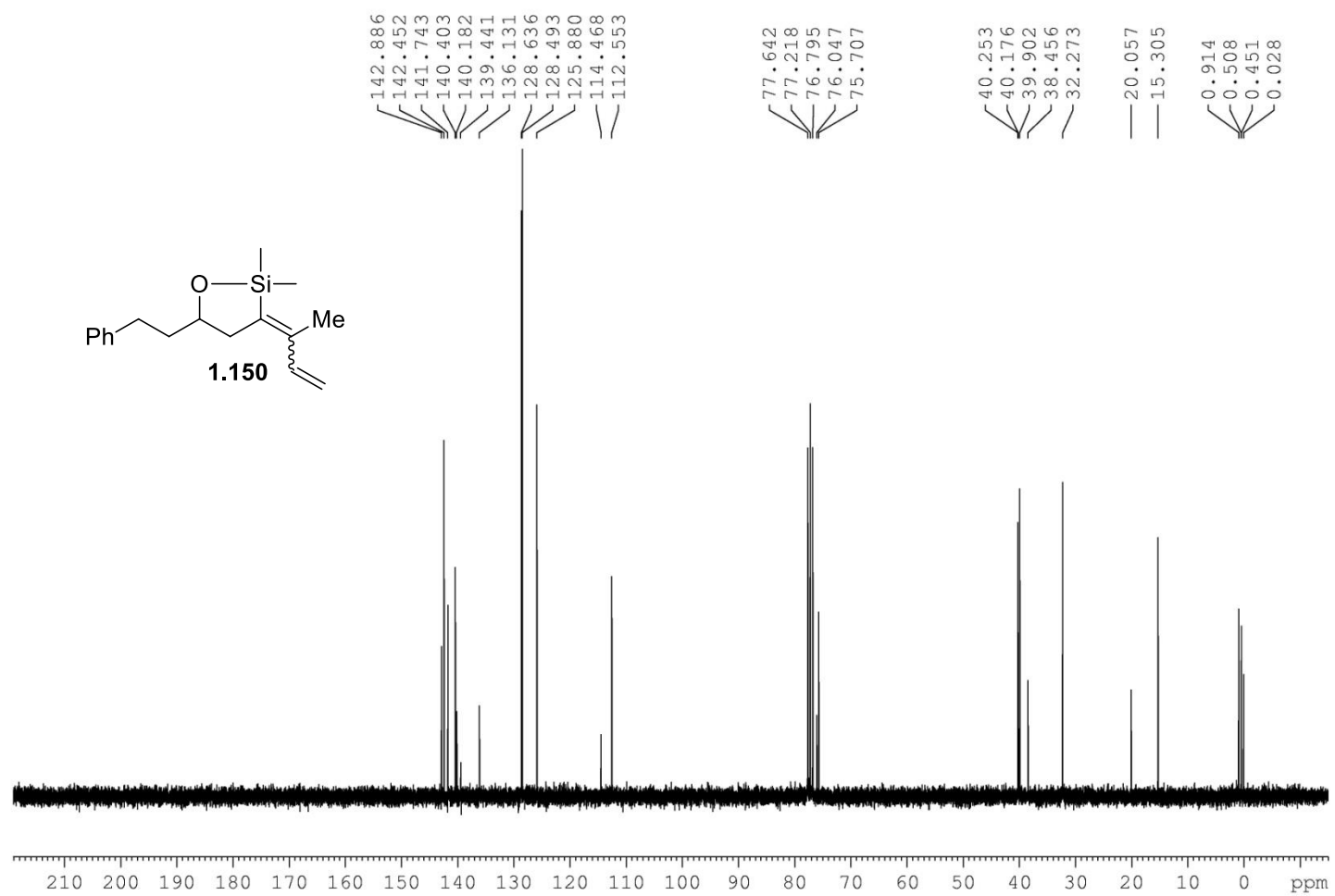
RJW-3-231-C

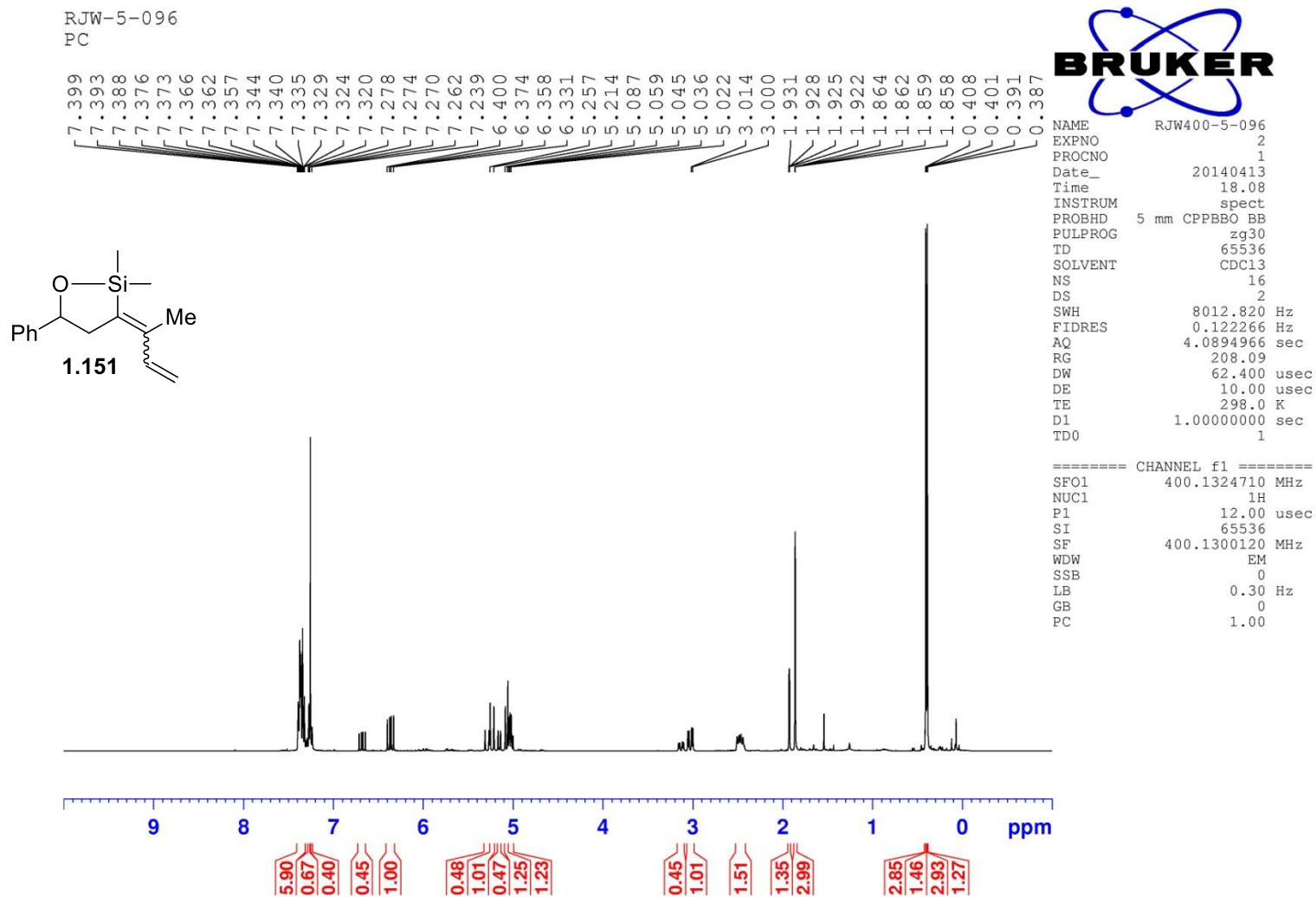


**Diene Mixture 1.149**

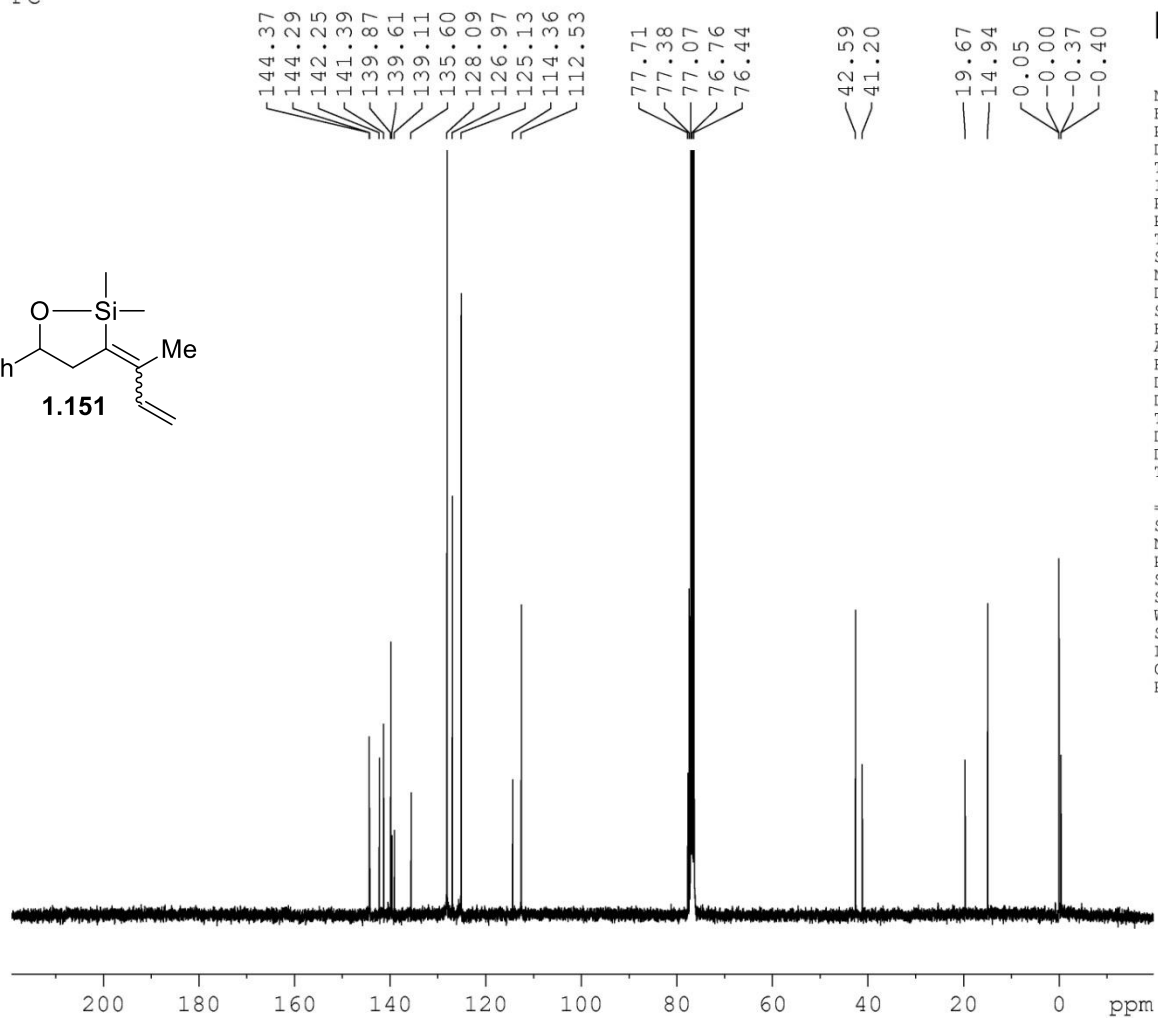
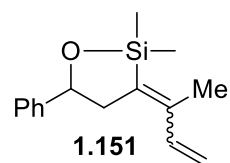
**Diene Mixture 1.149**







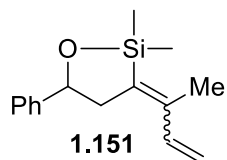
RJW-5-096
PC



NAME RJW400-5-096
EXPNO 3
PROCNO 1
Date_ 20140413
Time 19.43
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDC13
NS 1024
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 80.84
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 4.00000000 sec
D11 0.03000000 sec
TD0 1

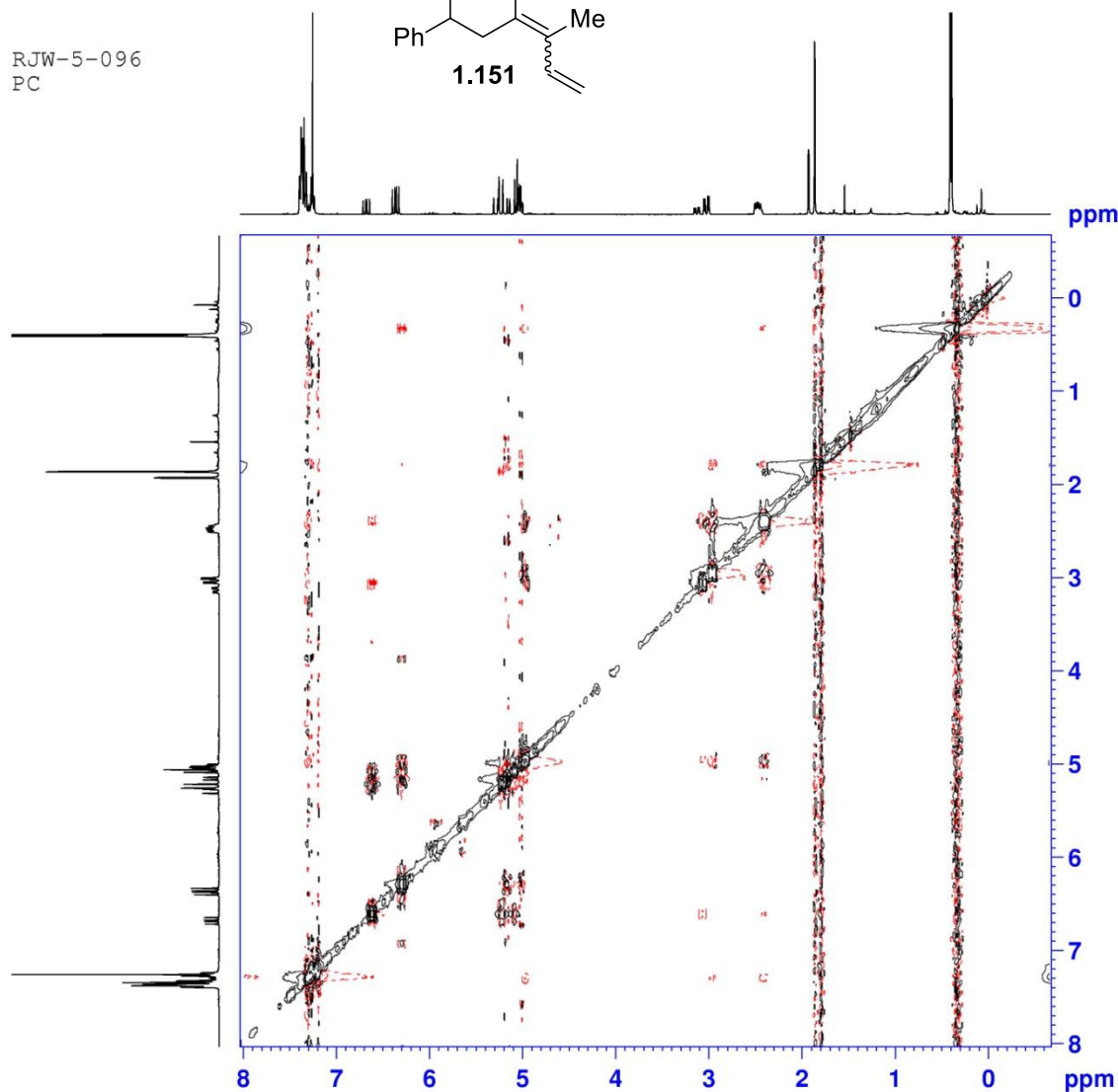
===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127959 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

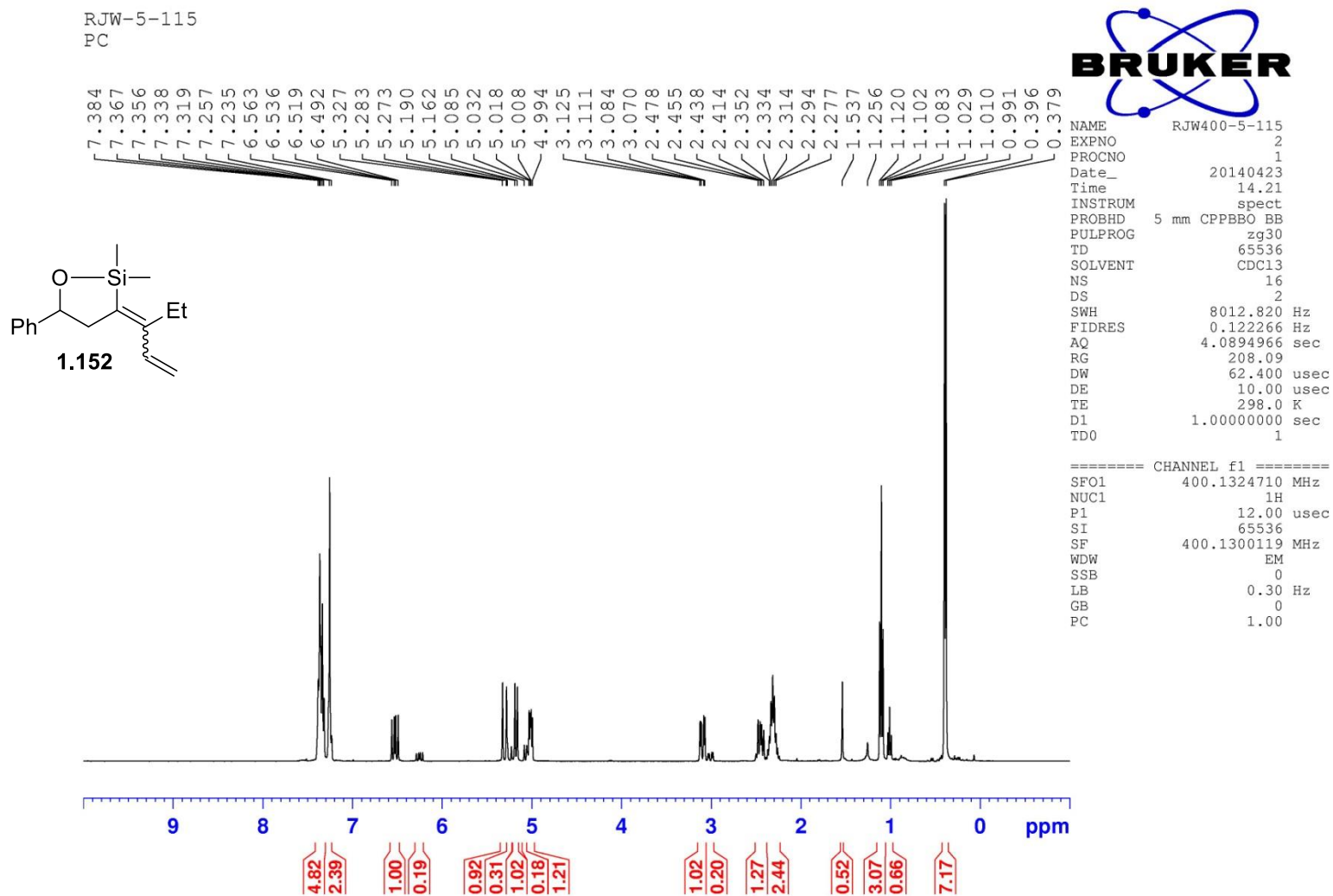
RJW-5-096
PC



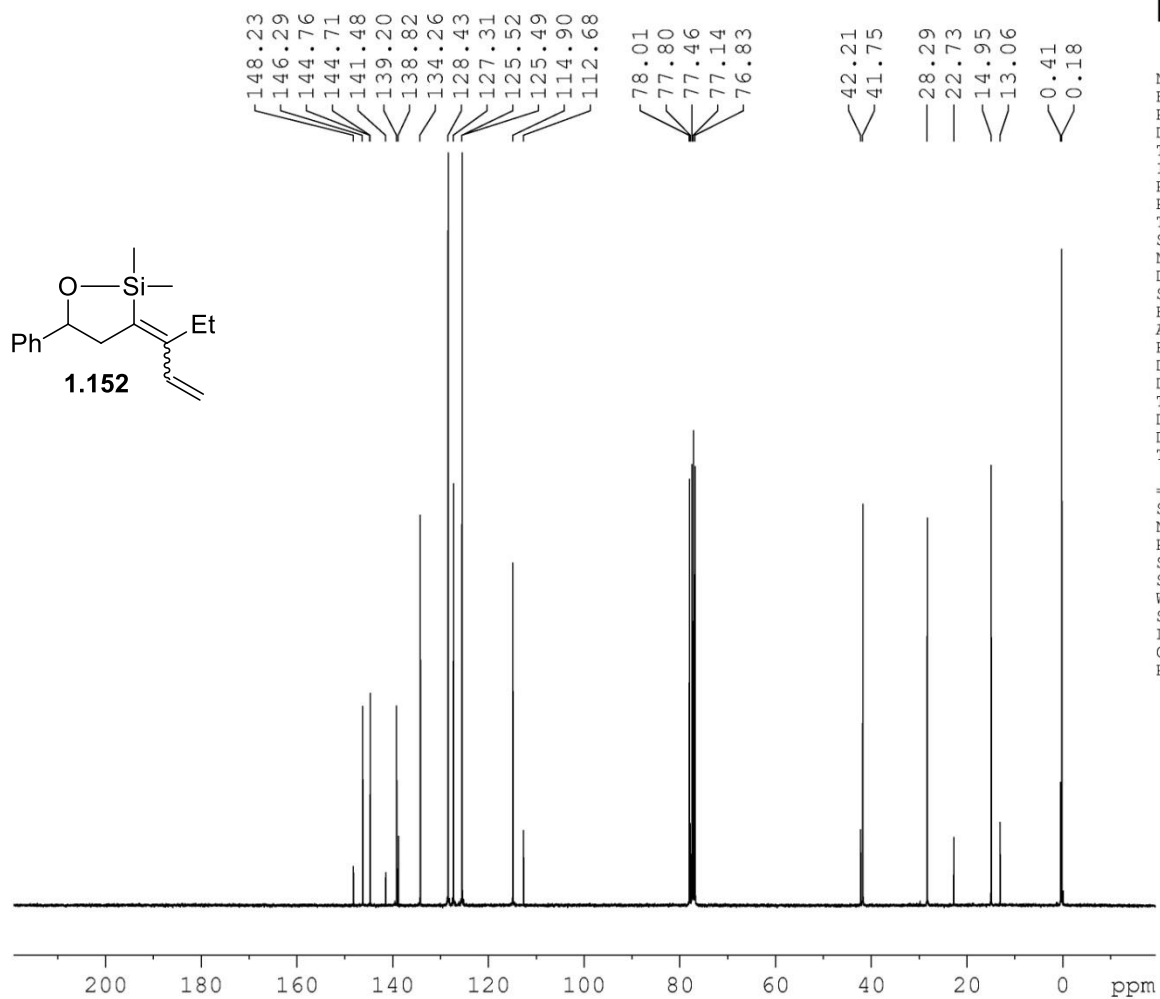
NAME RJW400-5-096
EXPNO 5
PROCNO 1
Date_ 20140413
Time 19.47
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG noesygpphph
TD 2048
SOLVENT CDCl3
NS 4
DS 32
SWH 3496.503 Hz
FIDRES 1.707277 Hz
AQ 0.2929140 sec
RG 134.49
DW 143.000 usec
DE 10.00 usec
TE 298.0 K
D0 0.00012772 sec
D1 1.96313596 sec
D8 0.30000001 sec
D11 0.03000000 sec
D12 0.00002000 sec
D16 0.00020000 sec
IN0 0.00028600 sec

===== CHANNEL f1 =====
SFO1 400.1315070 MHz
NUC1 1H
P1 12.00 usec
P2 24.00 usec
P17 2500.00 usec
ND0 1
TD 256
SFO1 400.1315 MHz
FIDRES 13.658216 Hz
SW 8.738 ppm
FnMODE States-TPPI
SI 1024
SF 400.1300408 MHz
WDW QSINE
SSB 2
LB 0.00 Hz
GB 0
PC 1.00
SI 1024
MC2 States-TPPI
SF 400.1300408 MHz
WDW QSINE
SSB 2
LB 0.00 Hz
GB 0





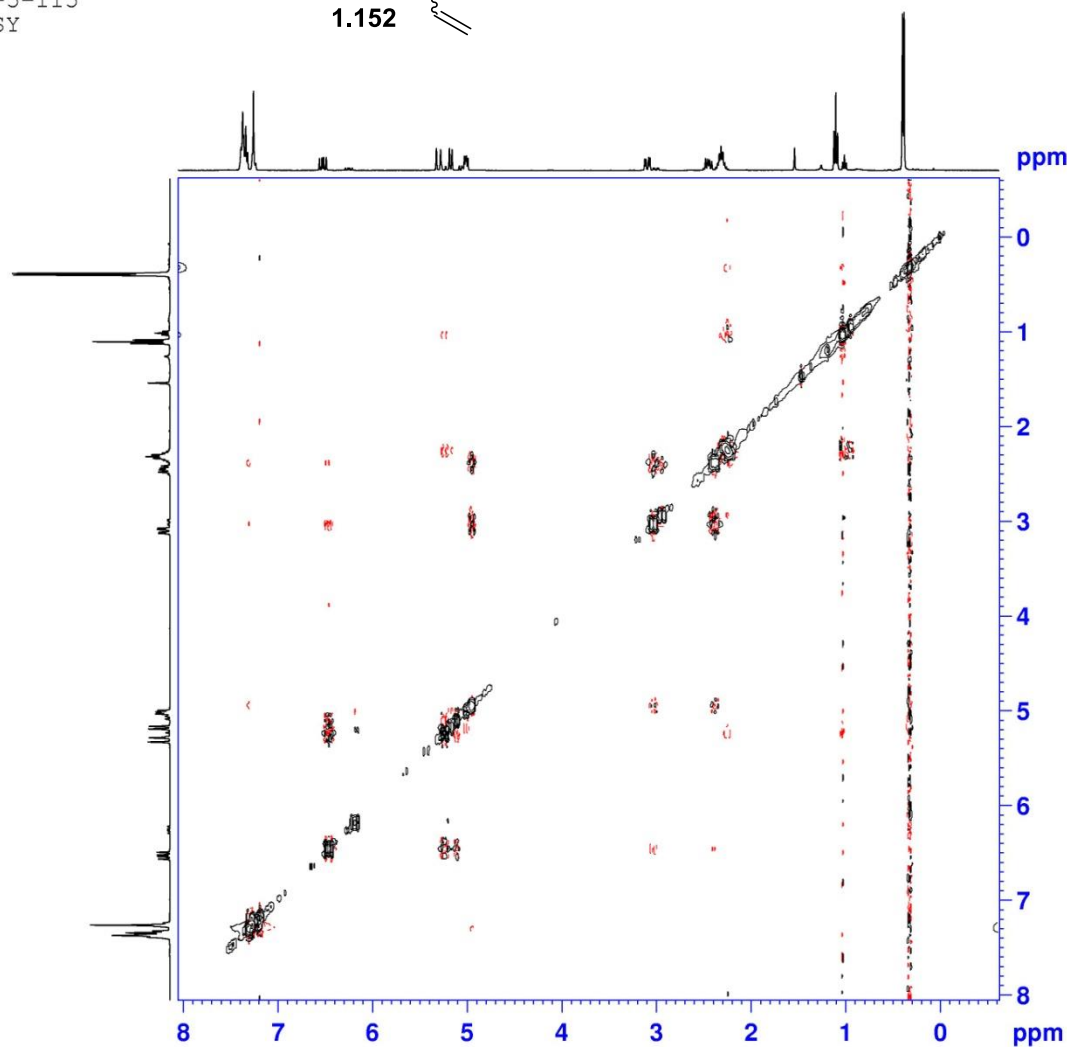
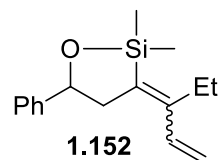
RJW-5-115-C



NAME RJW400-5-115
 EXPNO 5
 PROCNO 1
 Date_ 20140423
 Time 16.40
 INSTRUM spect
 PROBHD 5 mm CPPBBO BB
 PULPROG zgpg30
 TD 65536
 SOLVENT CDCl3
 NS 500
 DS 4
 SWH 24038.461 Hz
 FIDRES 0.366798 Hz
 AQ 1.3631988 sec
 RG 80.84
 DW 20.800 usec
 DE 18.00 usec
 TE 300.0 K
 D1 2.00000000 sec
 D11 0.03000000 sec
 TD0 1

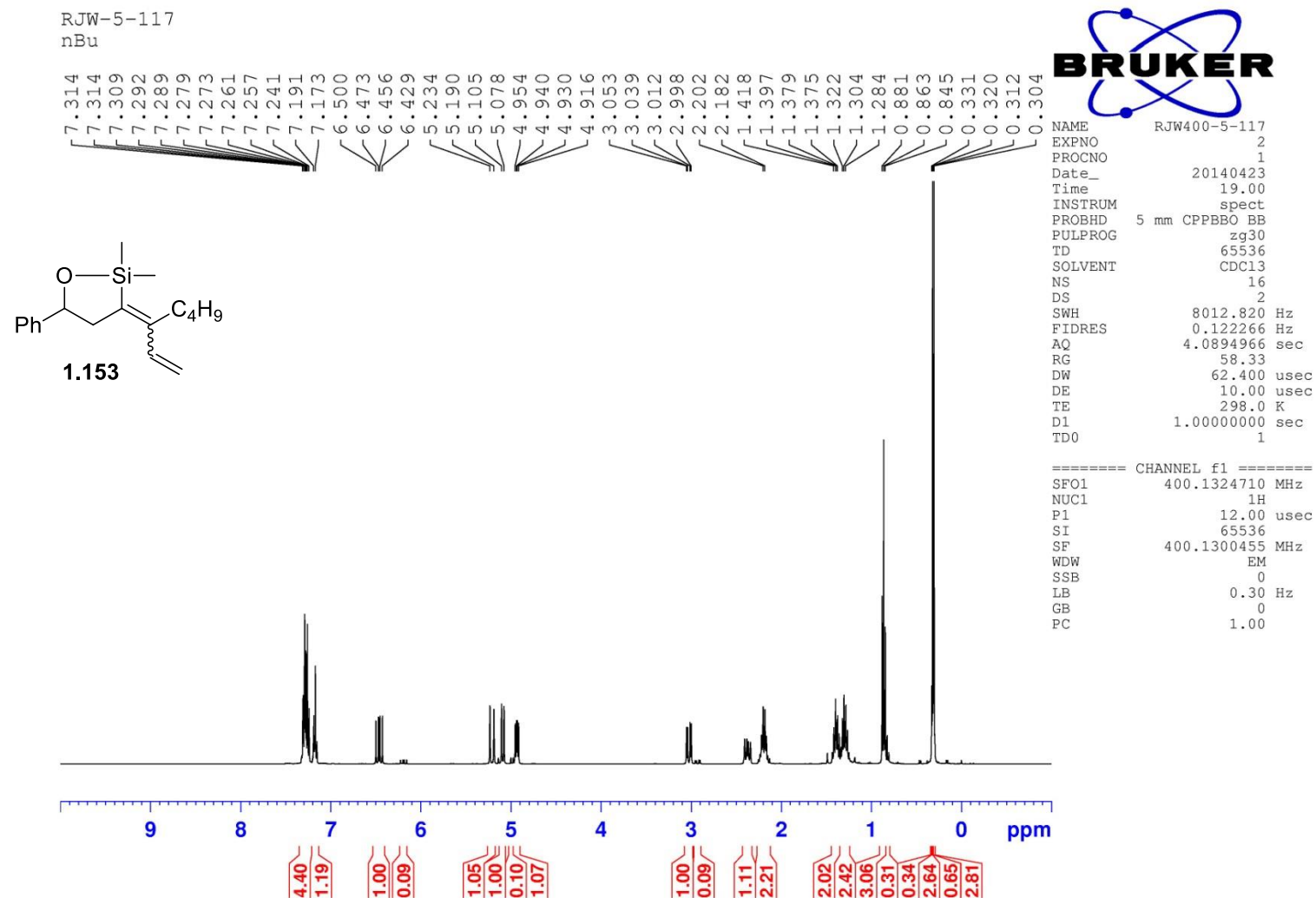
===== CHANNEL f1 =====
 SFO1 100.6228293 MHz
 NUC1 13C
 P1 10.00 usec
 SI 32768
 SF 100.6127600 MHz
 WDW EM
 SSB 0
 LB 1.00 Hz
 GB 0
 PC 1.40

RJW-5-115
NOESY

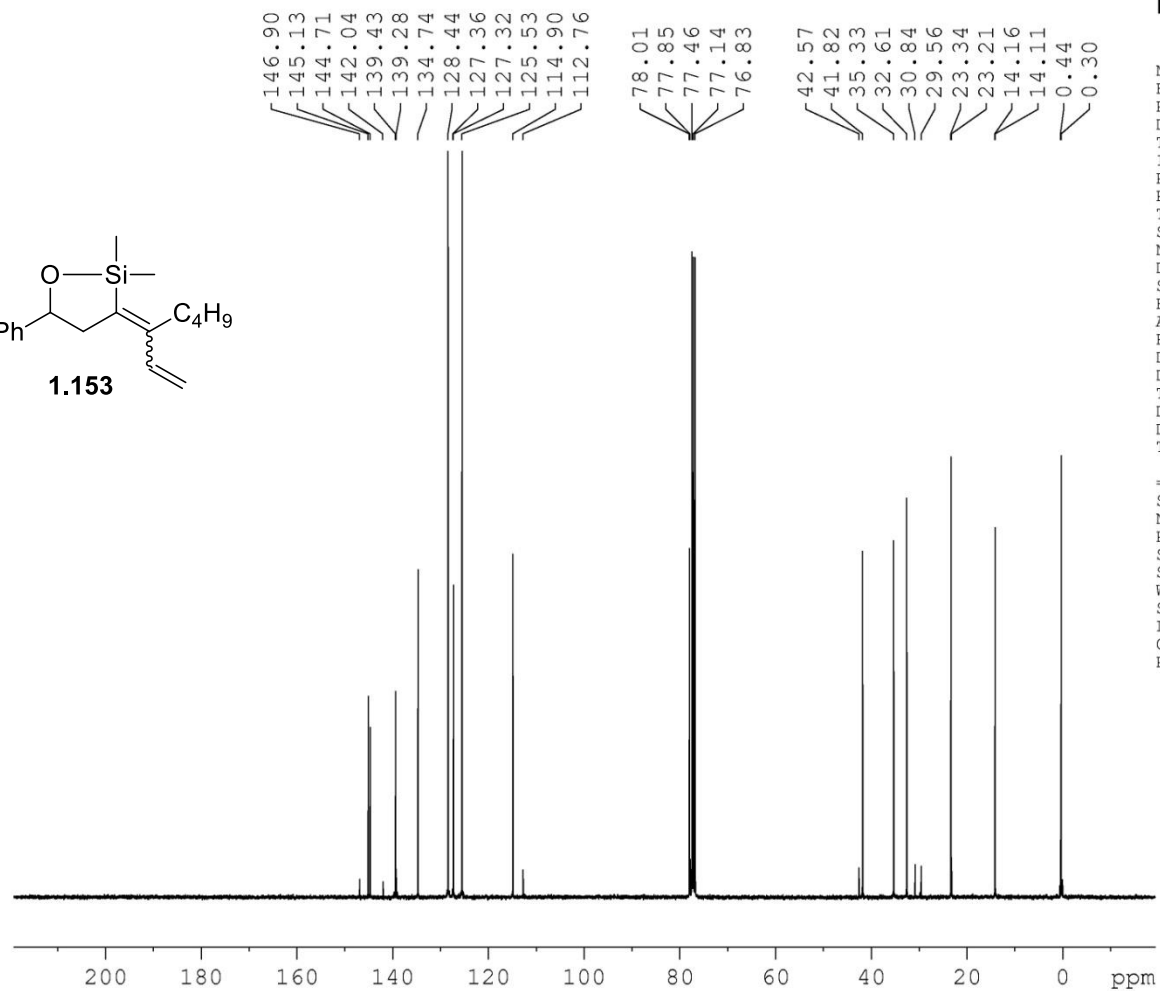
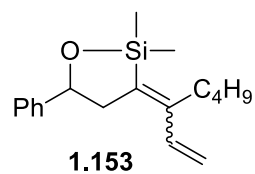


NAME RJW400-5-115
EXPNO 3
PROCNO 1
Date_ 20140423
Time 14.23
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG noesygpph
TD 2048
SOLVENT CDCl3
NS 4
DS 32
SWH 3472.222 Hz
FIDRES 1.695421 Hz
AQ 0.2949620 sec
RG 208.09
DW 144.000 usec
DE 10.00 usec
TE 298.0 K
D0 0.00012872 sec
D1 0.96108758 sec
D8 0.30000001 sec
D11 0.03000000 sec
D12 0.00002000 sec
D16 0.00020000 sec
IN0 0.00028800 sec

===== CHANNEL f1 =====
SFO1 400.1315261 MHz
NUC1 1H
P1 12.00 usec
P2 24.00 usec
P17 2500.00 usec
ND0 1
TD 256
SFO1 400.1315 MHz
FIDRES 13.563368 Hz
SW 8.678 ppm
FnMODE States-TPPI
SI 1024
SF 400.1300392 MHz
WDW QSINE
SSB 2
LB 0.00 Hz
GB 0
PC 1.00
SI 1024
MC2 States-TPPI
SF 400.1300392 MHz
WDW QSINE
SSB 2
LB 0.00 Hz
GB 0



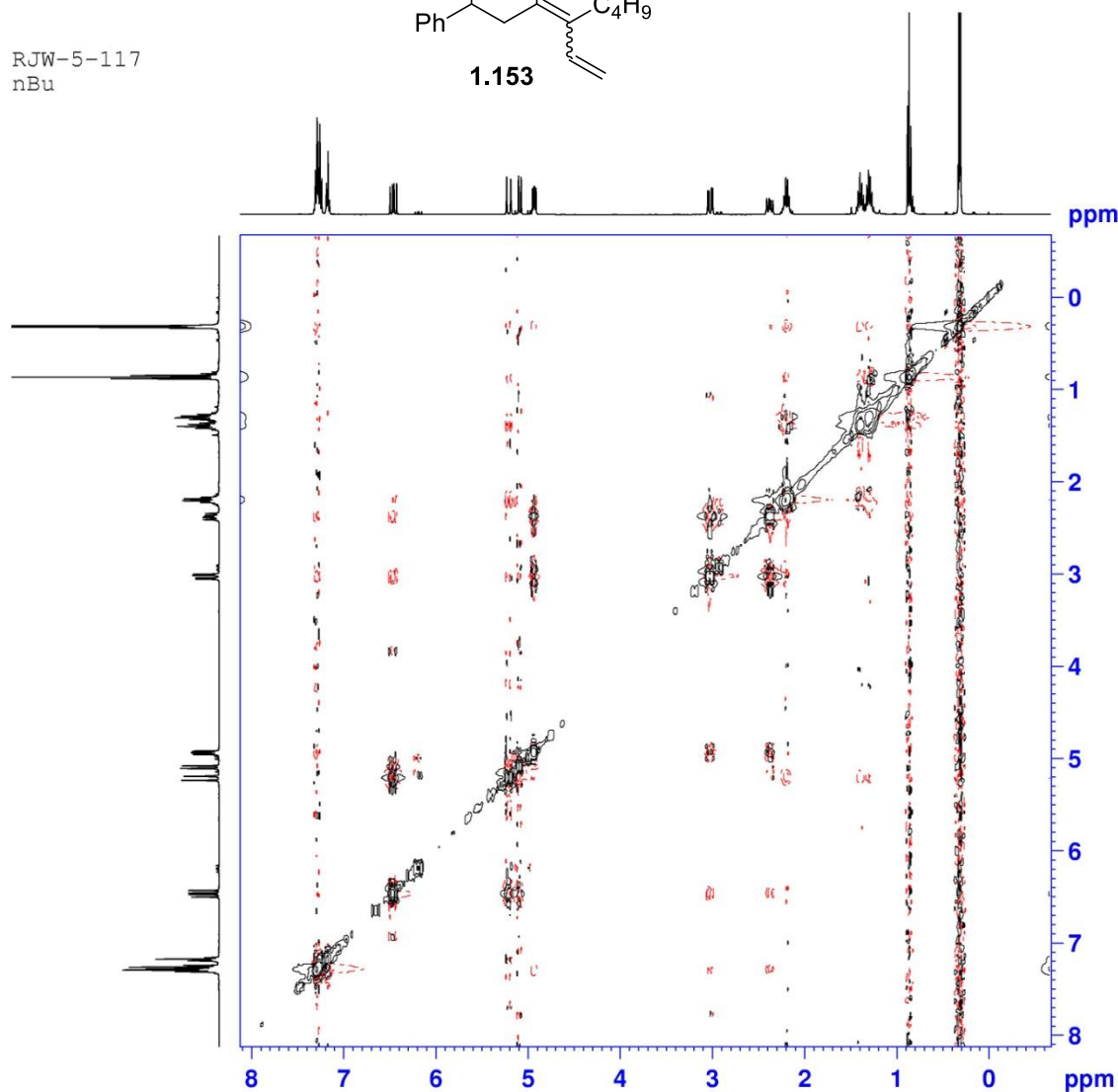
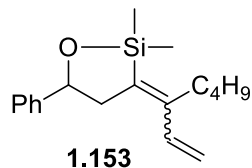
RJW-5-117
nBu



NAME RJW400-5-117
EXPNO 3
PROCNO 1
Date_ 20140423
Time 19.32
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDCl3
NS 540
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 50.16
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

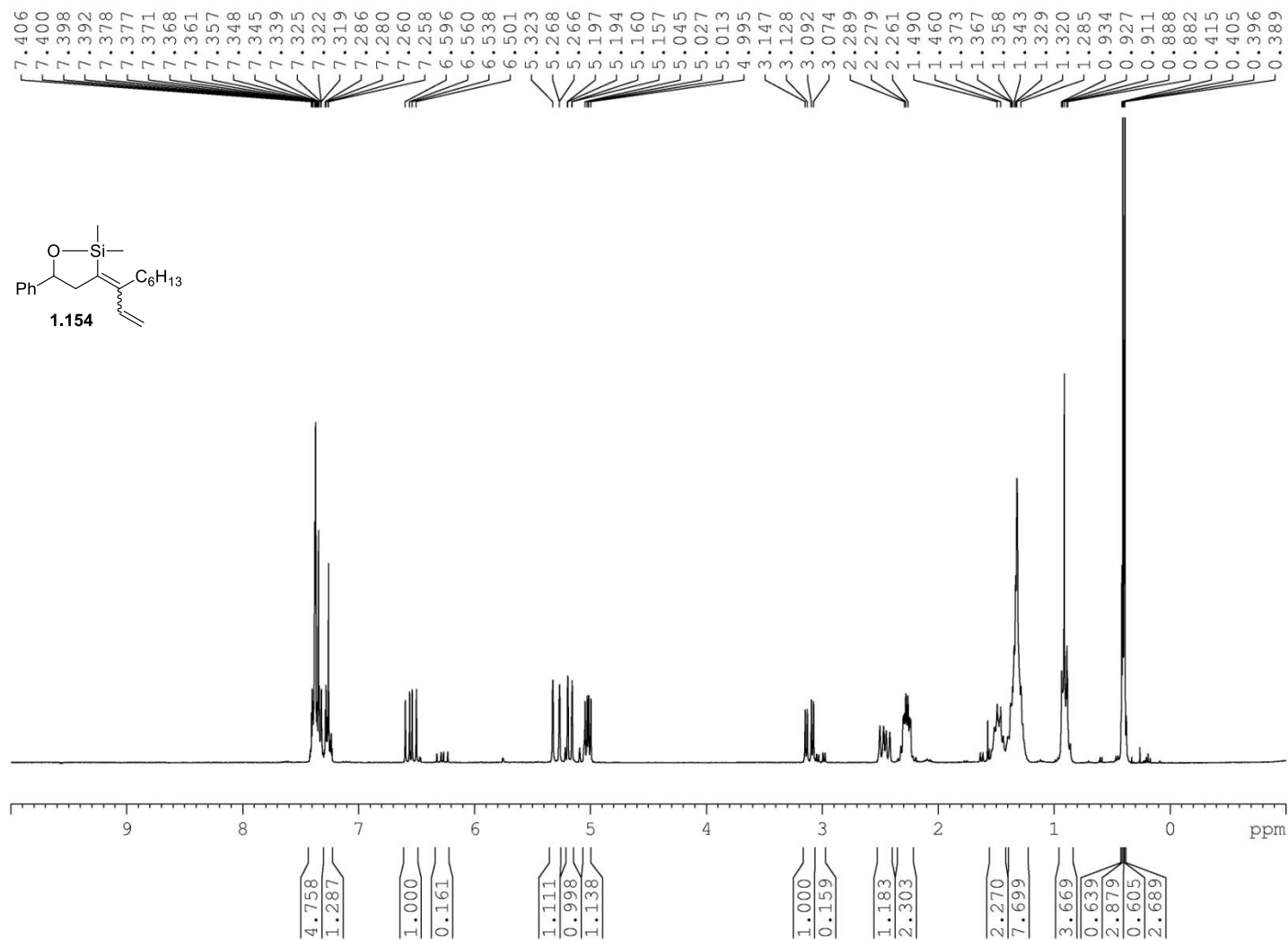
===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127589 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

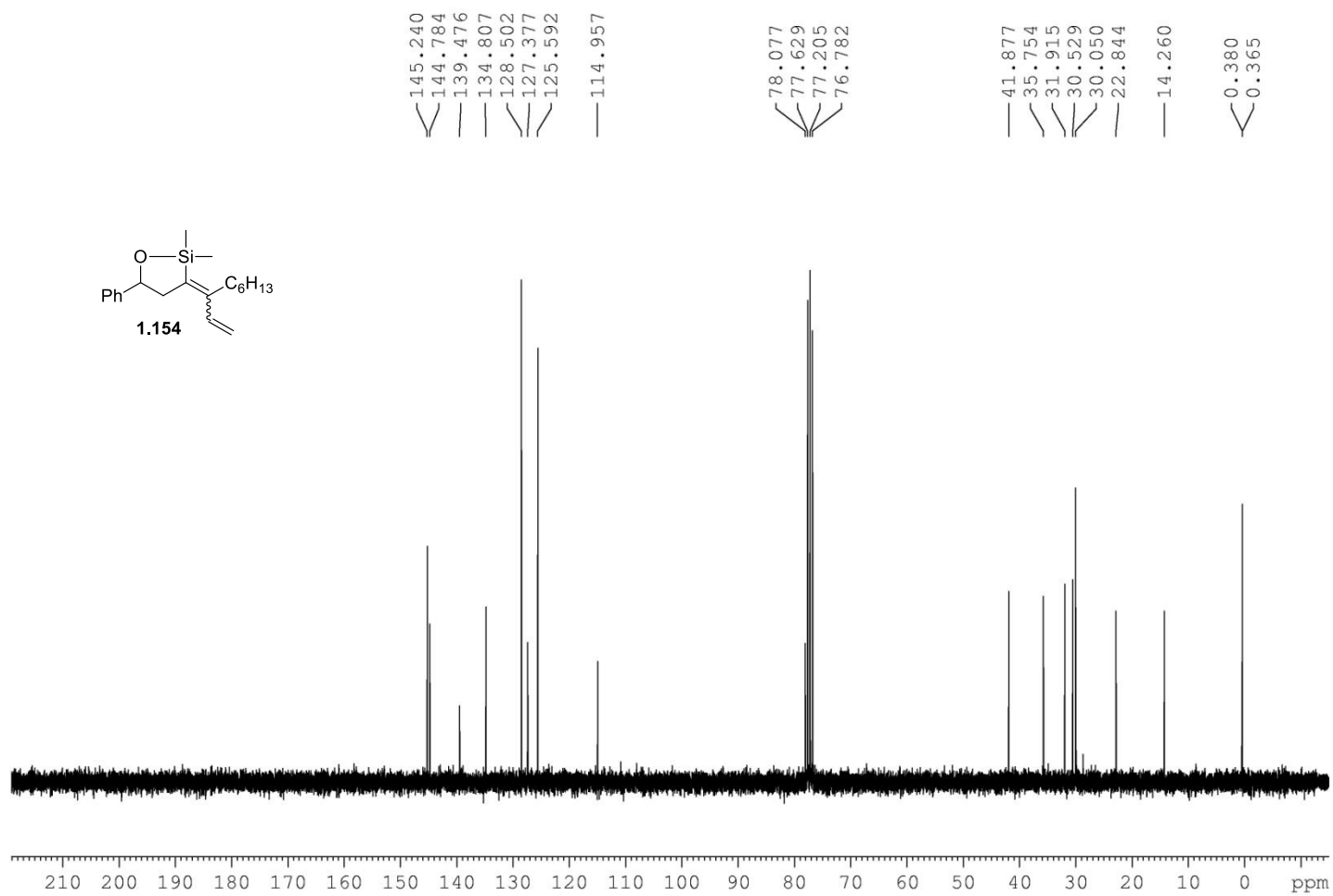
RJW-5-117
nBu

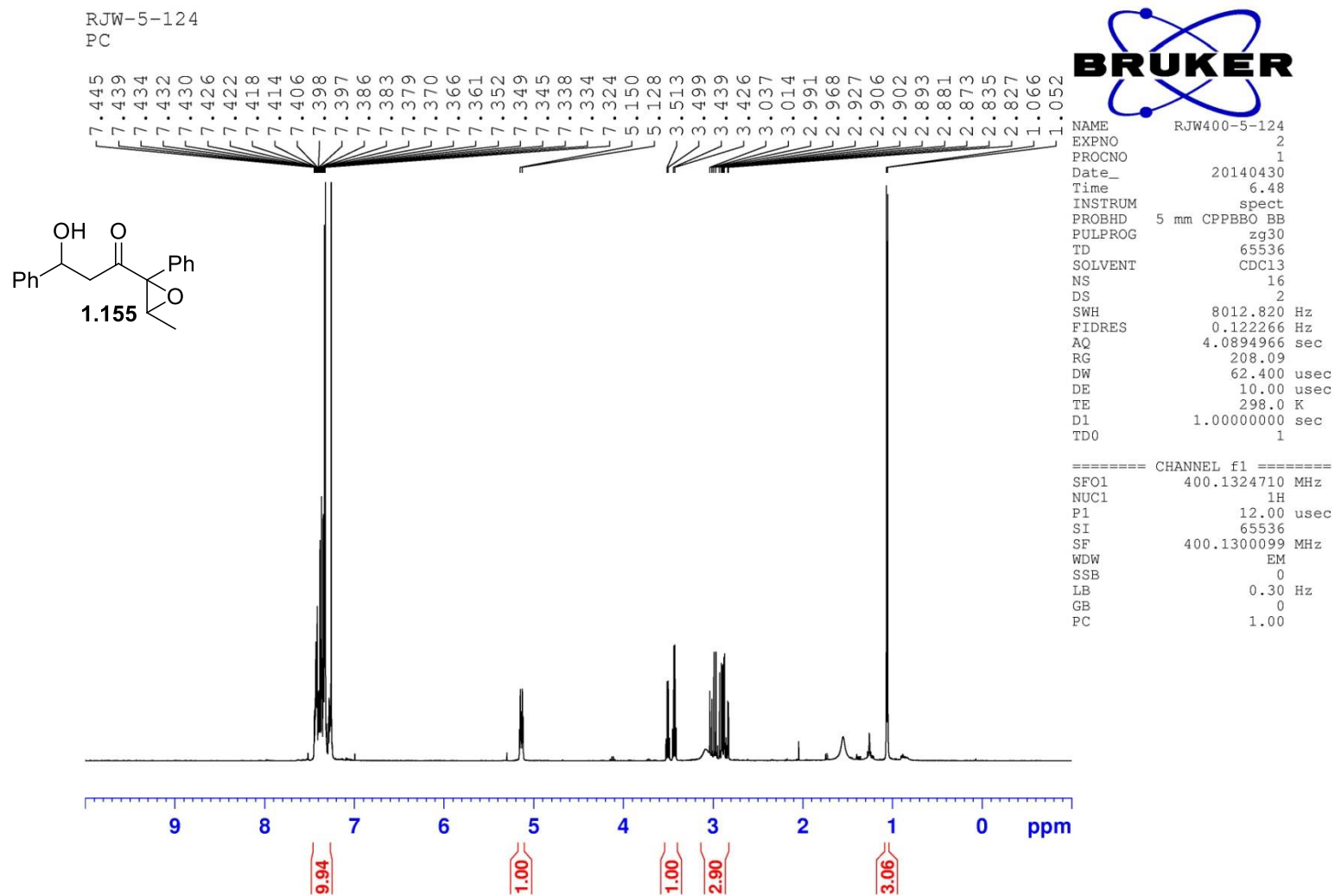


NAME RJW400-5-117
EXPNO 5
PROCNO 1
Date_ 20140423
Time 20.48
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG noesygpphph
TD 2048
SOLVENT CDCl3
NS 4
DS 32
SWH 3521.127 Hz
FIDRES 1.719300 Hz
AQ 0.2908660 sec
RG 50.16
DW 142.000 usec
DE 10.00 usec
TE 298.0 K
D0 0.00012672 sec
D1 0.96518362 sec
D8 0.30000001 sec
D11 0.03000000 sec
D12 0.00002000 sec
D16 0.00020000 sec
IN0 0.00028400 sec

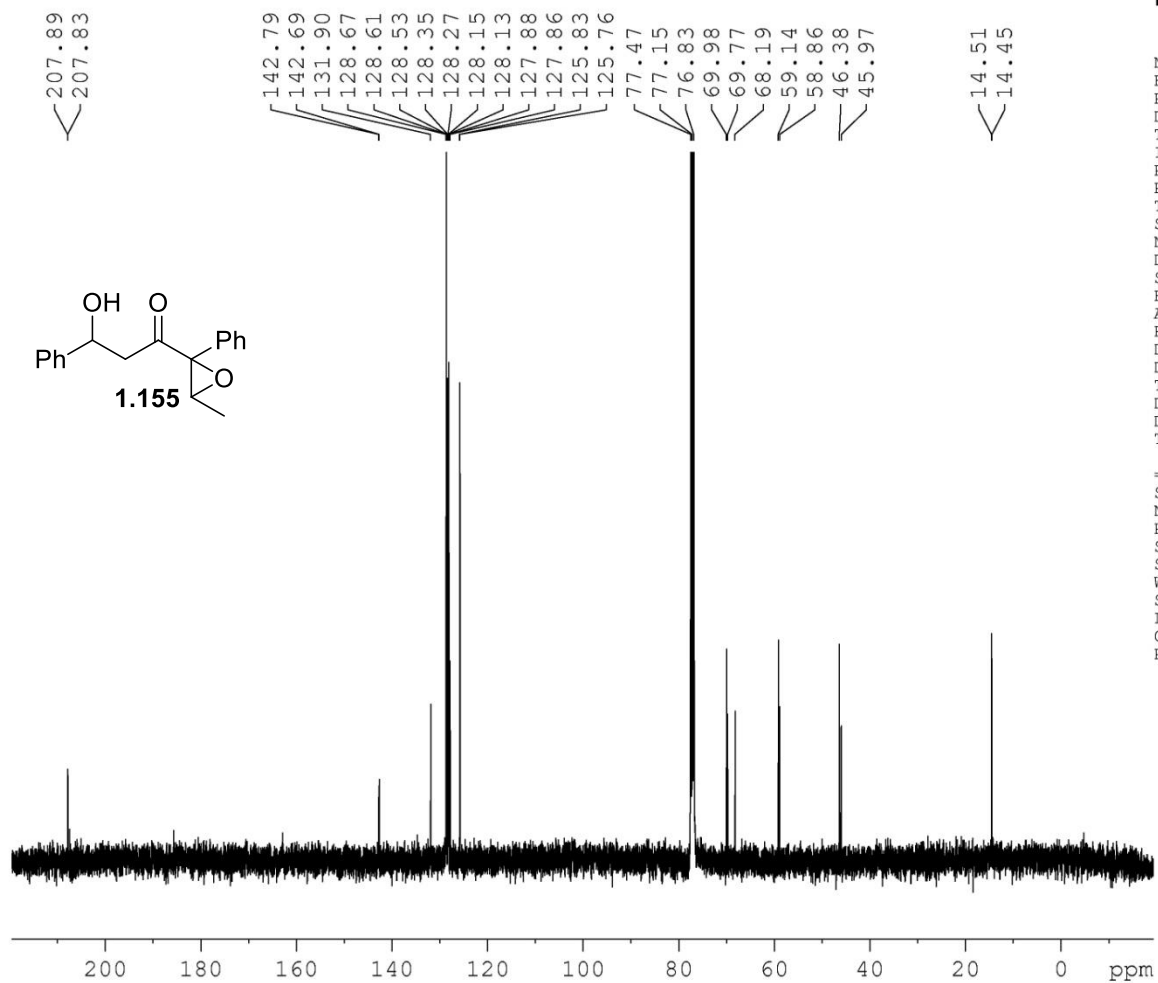
===== CHANNEL f1 =====
SFO1 400.1315367 MHz
NUC1 1H
P1 12.00 usec
P2 24.00 usec
P17 2500.00 usec
ND0 1
TD 256
SFO1 400.1315 MHz
FIDRES 13.754401 Hz
SW 8.800 ppm
FnMODE States-TPPI
SI 1024
SF 400.1300461 MHz
WDW QSINE
SSB 2
LB 0.00 Hz
GB 0
PC 1.00
SI 1024
MC2 States-TPPI
SF 400.1300461 MHz
WDW QSINE
SSB 2
LB 0.00 Hz
GB 0





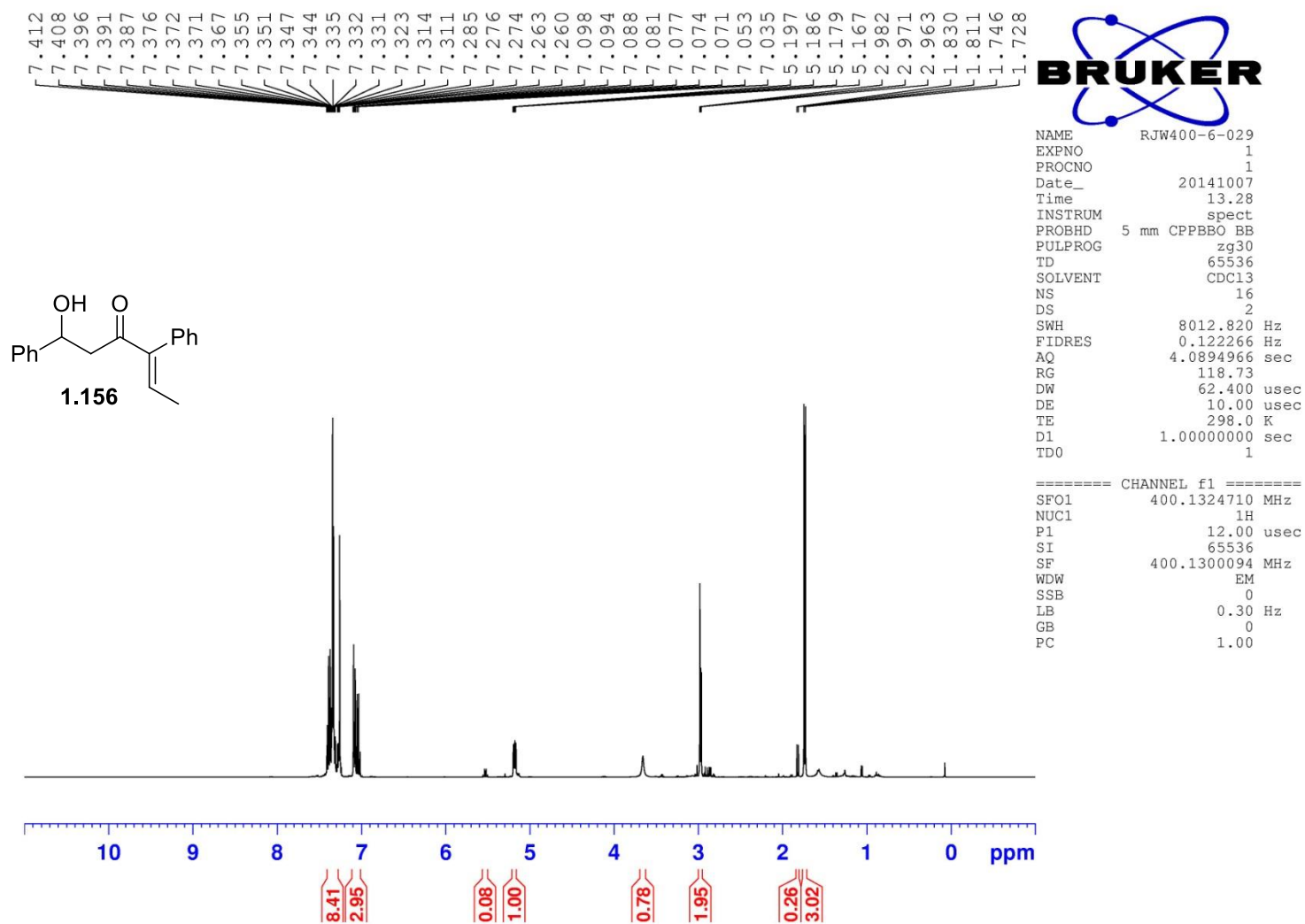


RJW-5-124
PC

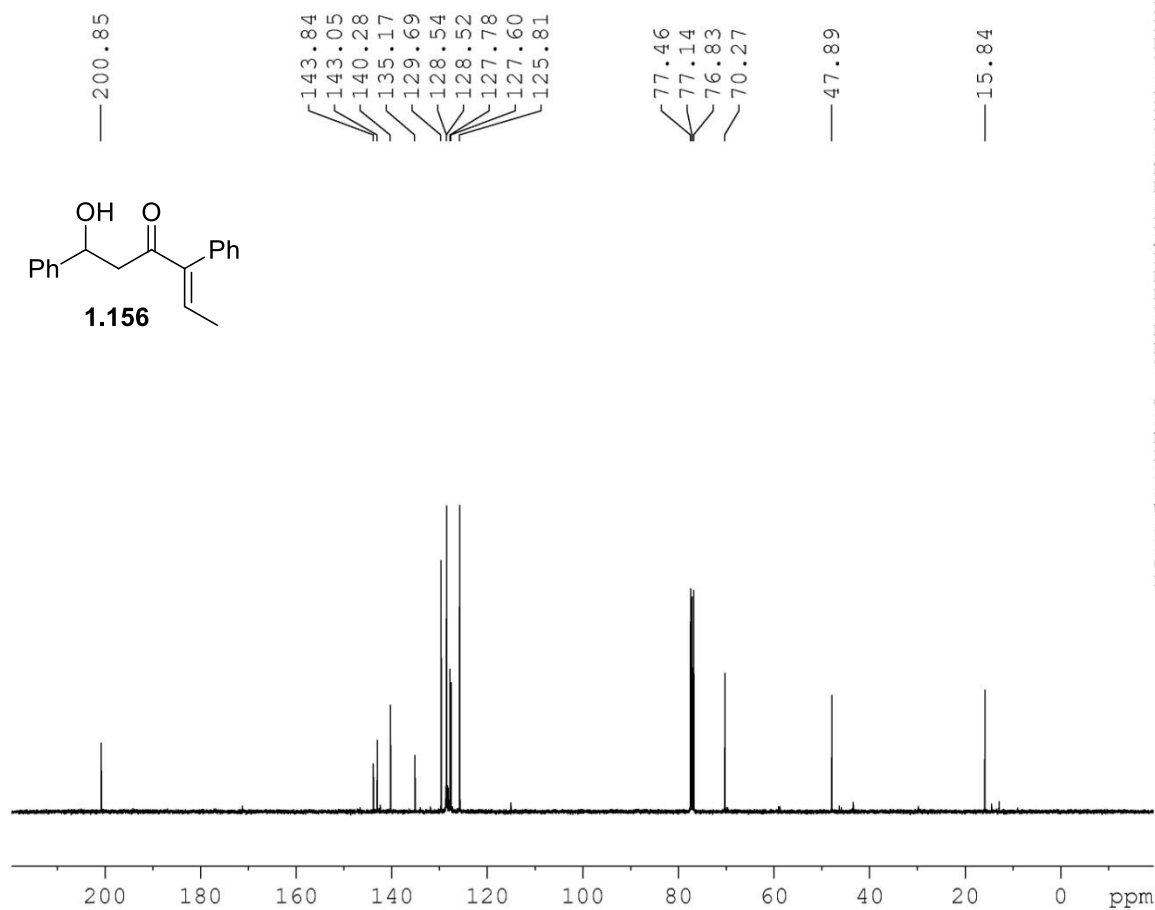


NAME RJW400-5-124
EXPNO 3
PROCNO 1
Date_ 20140430
Time 7.20
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDCl3
NS 540
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 80.84
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127561 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40



RJW-6-029



```

NAME      RJW400-6-029
EXPNO      3
PROCNO     1
Date_      20141007
Time       15.46
INSTRUM    spect
PROBHD     5 mm CPPBBO BB
PULPROG    zgpg30
TD         65536
SOLVENT    CDC13
NS         50
DS         4
SWH        24038.461 Hz
FIDRES     0.366798 Hz
AQ         1.3631988 sec
RG         91.52
DW         20.800 usec
DE         18.00 usec
TE         300.0 K
D1         2.00000000 sec
D11        0.03000000 sec
TD0        1

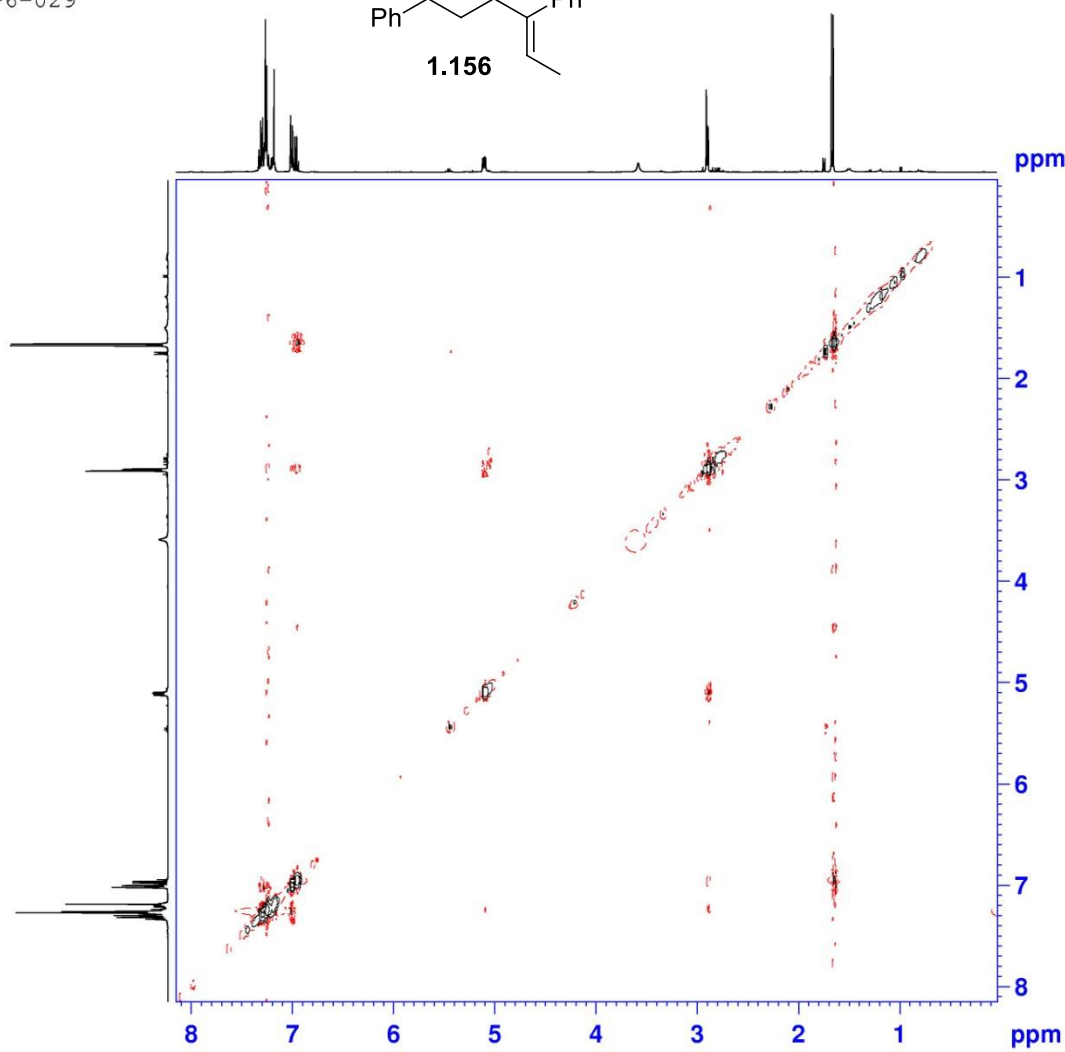
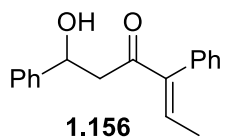
```

```

===== CHANNEL f1 =====
SFO1      100.6228293 MHz
NUC1      13C
P1        10.00 usec
SI        32768
SF        100.6127620 MHz
WDW       EM
SSB       0
LB        1.00 Hz
GB        0
PC        1.40

```

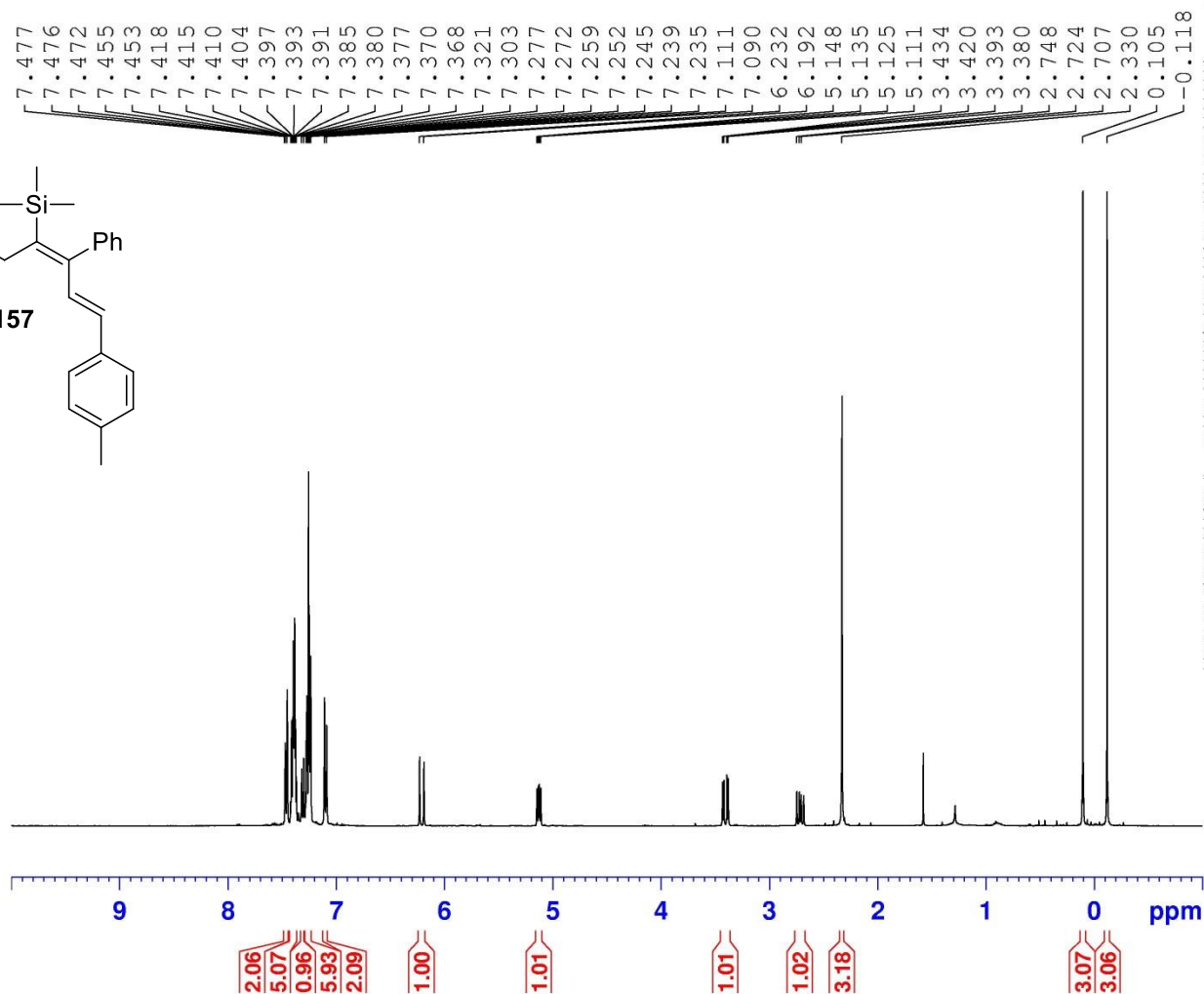
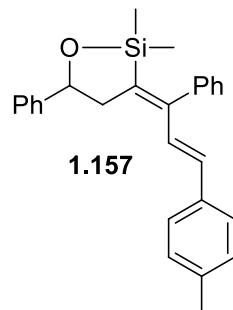
RJW-6-029



NAME RJW400-6-029
 EXPNO 5
 PROCNO 1
 Date_ 20141007
 Time 15.56
 INSTRUM spect
 PROBHD 5 mm CPPBBO BB
 PULPROG noesygpph
 TD 2048
 SOLVENT CDCl3
 NS 4
 DS 32
 SWH 3246.753 Hz
 FIDRES 1.585329 Hz
 AQ 0.3154420 sec
 RG 66.01
 DW 154.000 usec
 DE 10.00 usec
 TE 300.0 K
 D0 0.00013872 sec
 D1 1.04060805 sec
 D8 0.30000001 sec
 D11 0.03000000 sec
 D12 0.00002000 sec
 D16 0.00020000 sec
 IN0 0.00030800 sec

===== CHANNEL f1 =====
 SFO1 400.1316851 MHz
 NUC1 1H
 P1 12.00 usec
 P2 24.00 usec
 P17 2500.00 usec
 ND0 1
 TD 256
 SFO1 400.1317 MHz
 FIDRES 12.682630 Hz
 SW 8.114 ppm
 FMODE States-TPPI
 SI 1024
 SF 400.1300473 MHz
 WDW QSINE
 SSB 2
 LB 0.00 Hz
 GB 0
 PC 1.00
 SI 1024
 MC2 States-TPPI
 SF 400.1300473 MHz
 WDW QSINE
 SSB 2
 LB 0.00 Hz
 GB 0

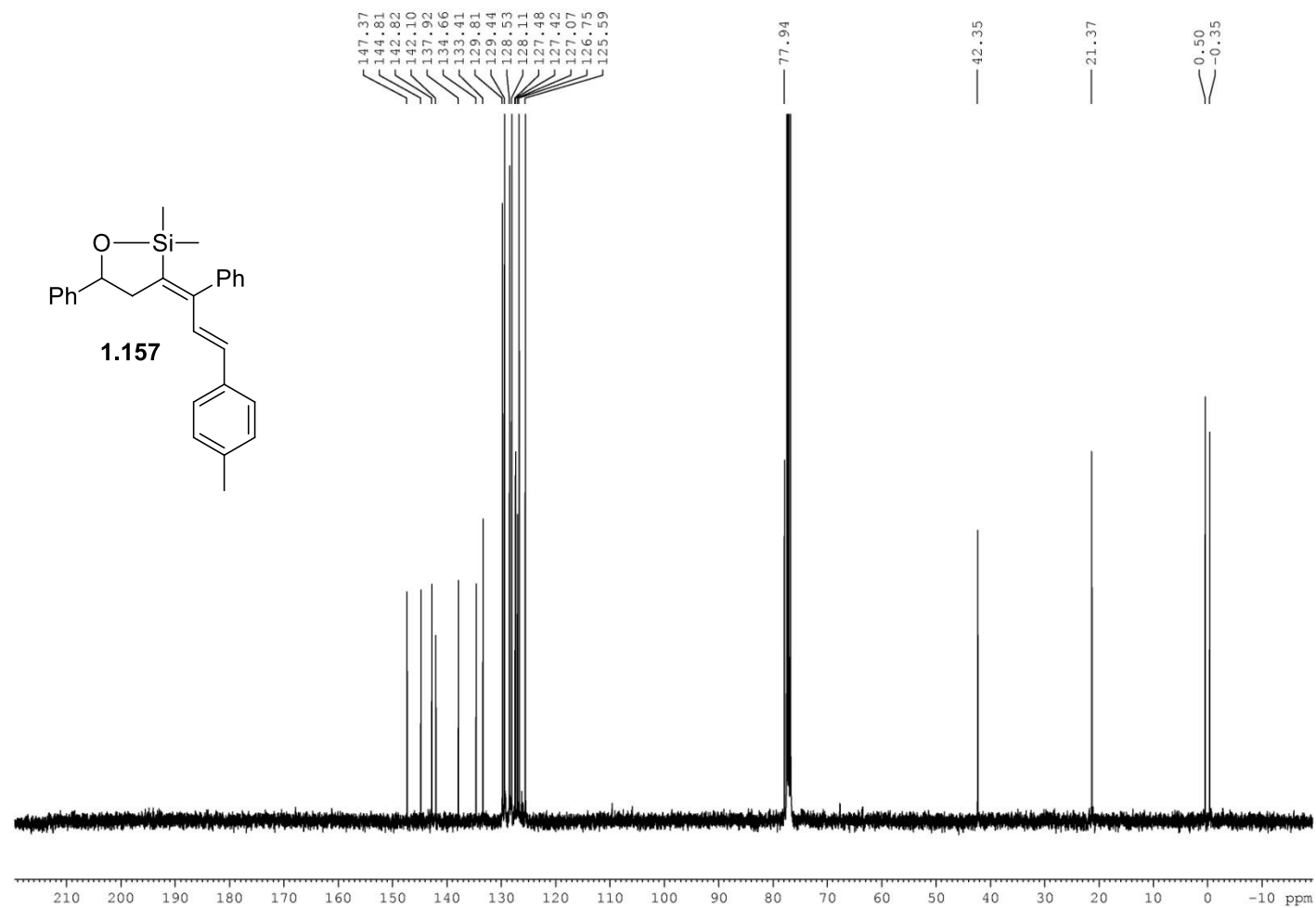
RJW-6-051
PC

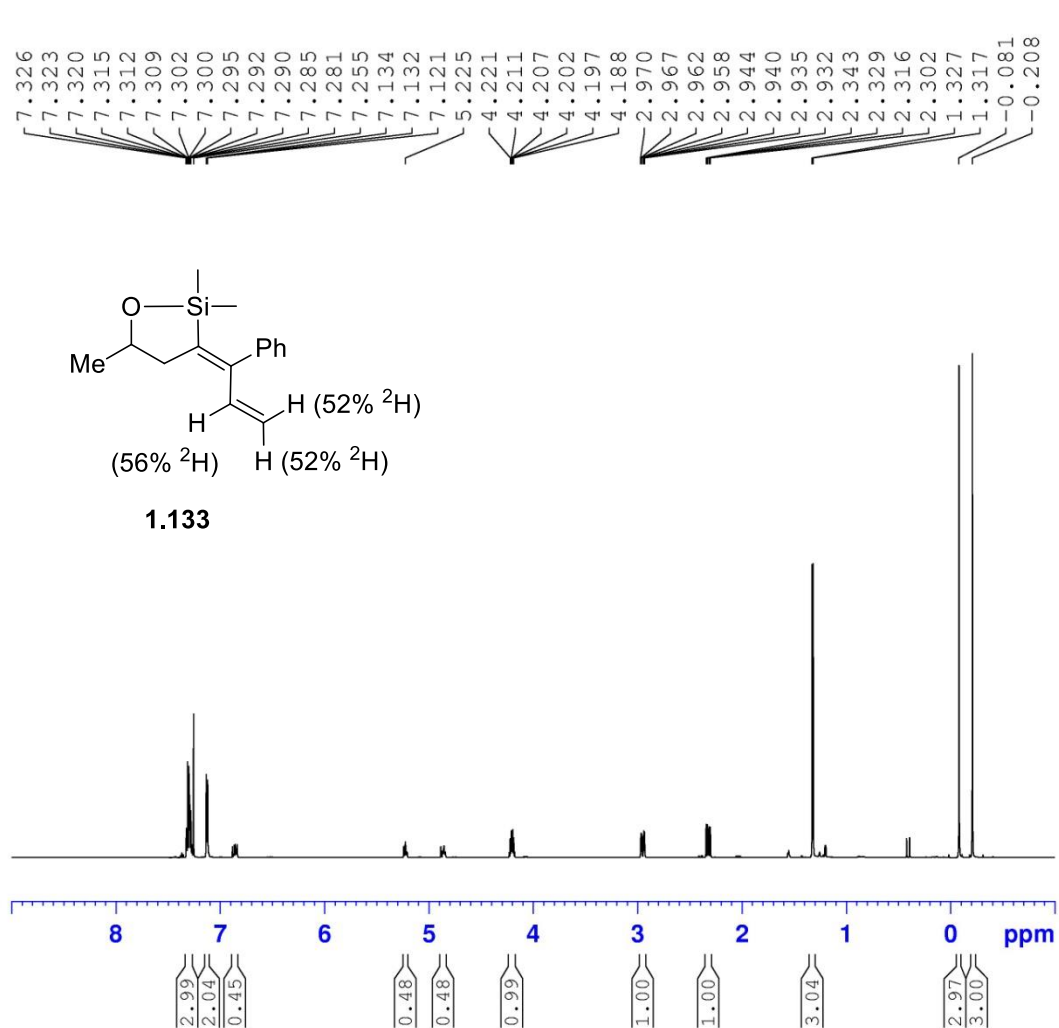


NAME RJW400-6-051
EXPNO 2
PROCNO 1
Date_ 20141028
Time 18.11
INSTRUM spect
PROBHD 5 mm CPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl3
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 50.16
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SF01 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300102 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

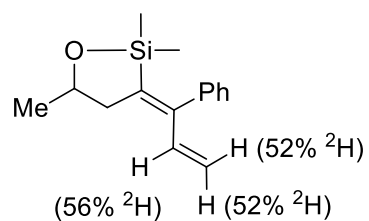
RJW-6-038
PC



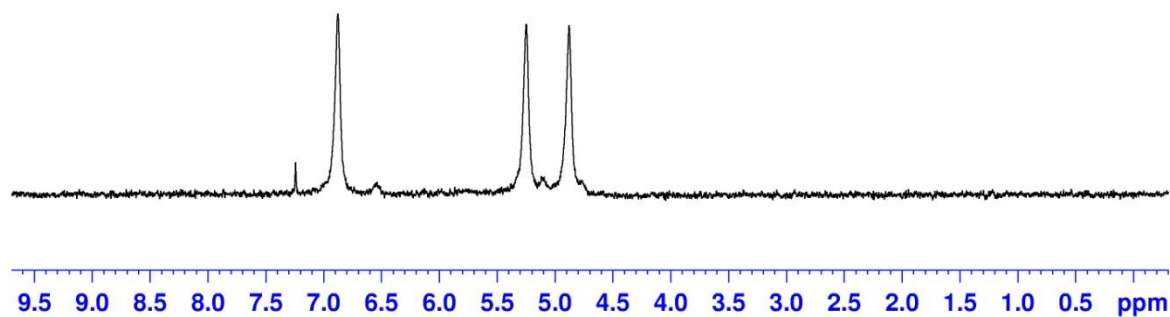


NAME RJW20150414
 EXPNO 1
 PROCNO 1
 Date_ 20150414
 Time 14.11
 INSTRUM spect
 PROBHD 5 mm CPPBBO BB
 PULPROG zg30
 TD 65536
 SOLVENT CDCl₃
 NS 16
 DS 0
 SWH 12335.526 Hz
 FIDRES 0.188225 Hz
 AQ 2.6564426 sec
 RG 45.19
 DW 40.533 use
 DE 10.00 use
 TE 303.1 K
 D1 4.00000000 sec
 TD0 1

===== CHANNEL f1 =====
 SFO1 600.1807061 MHz
 NUC1 1H
 P1 11.80 use
 SI 131072
 SF 600.1770178 MHz
 WDW EM
 SSB 0
 LB 0.30 Hz
 GB 0
 PC 1.00



1.133
 ^{2}H NMR



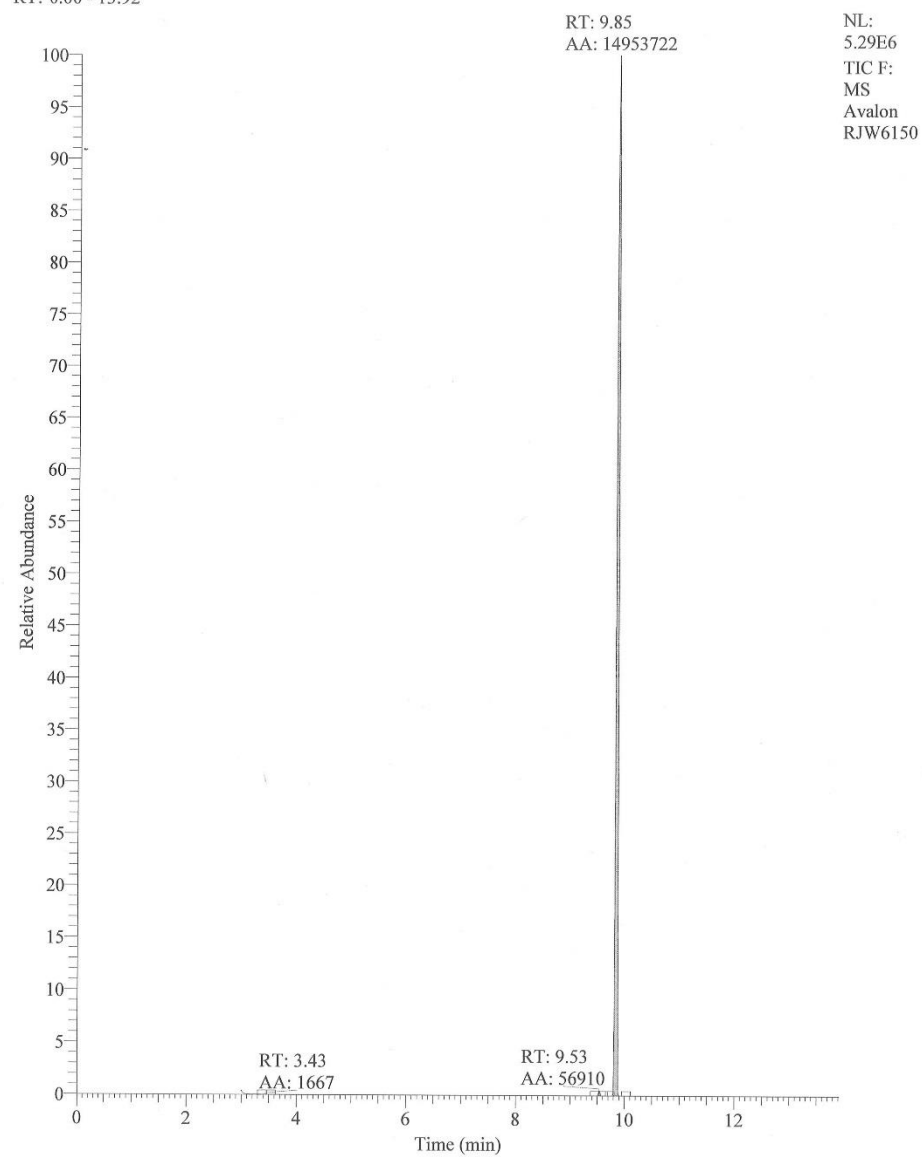
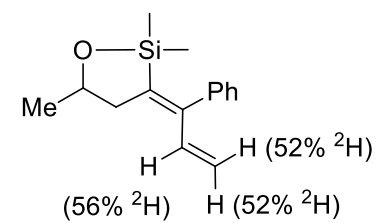
NAME RJW20150414
EXPNO 4
PROCNO 1
Date_ 20150414
Time 14.43
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg2h
TD 4096
SOLVENT CDC13
NS 32
DS 0
SWH 921.150 Hz
FIDRES 0.224890 Hz
AQ 2.2233589 se
RG 185.65
DW 542.800 us
DE 18.00 us
TE 315.0 K
D1 6.00000000 se
D11 0.03000000 se
TD0 1

===== CHANNEL f1 =====
SFO1 92.1312568 MH
NUC1 ^{2}H
P1 290.00 us
SI 32768
SF 92.1308240 MH
WDW EM
SSB 0
LB 0.20 Hz
GB 0
PC 1.00

C:\Xcalibur\Data\Clark\RJW6150

4/14/2015 2:52:02 PM

RT: 0.00 - 13.92

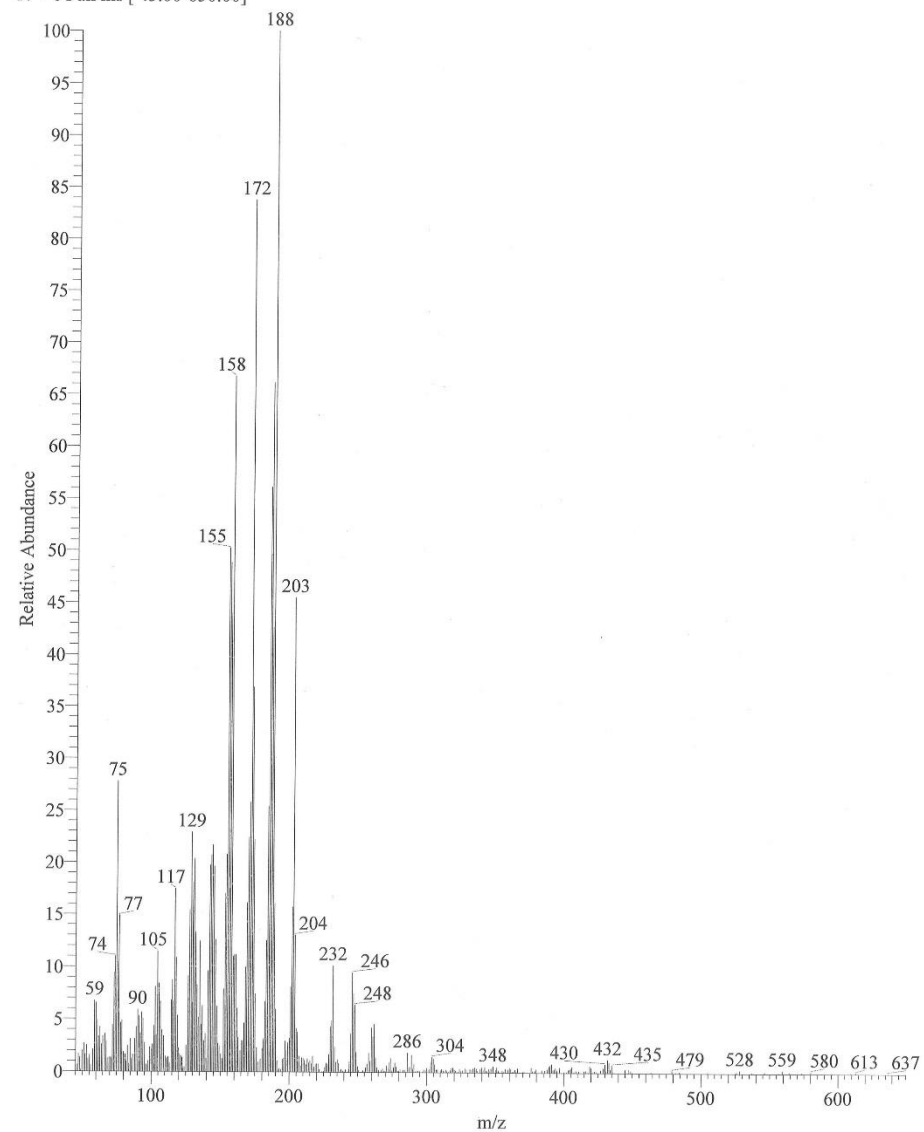
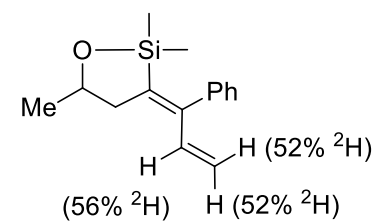
**GC-MS of 2b*****1.133**

C:\Xcalibur\Data\Clark\RJW6150

4/14/2015 2:52:02 PM

RJW6150 #690 RT: 9.82 AV: 1 NL: 2.17E5

T: + c Full ms [45.00-650.00]

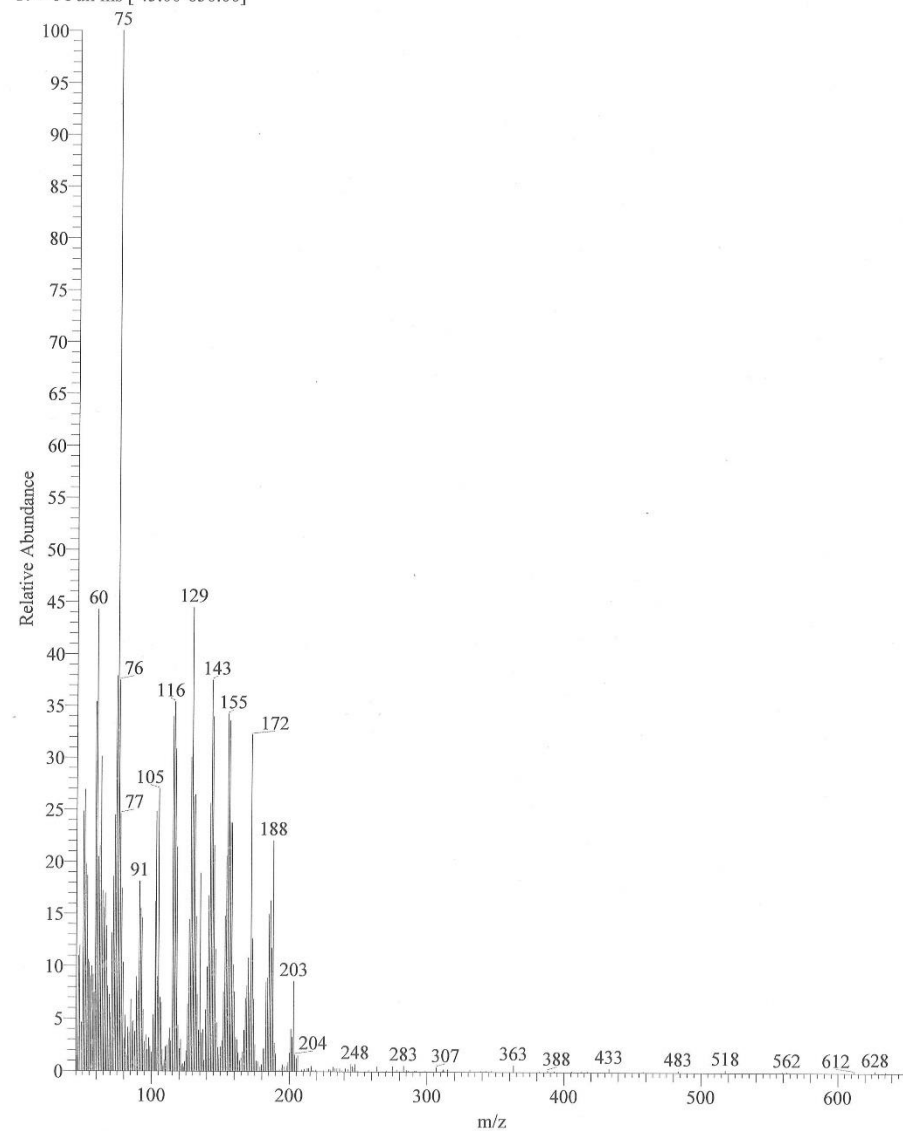
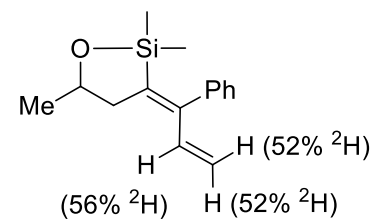
**GC-MS of 2b*****1.133**

C:\Xcalibur\Data\Clark\RJW6150

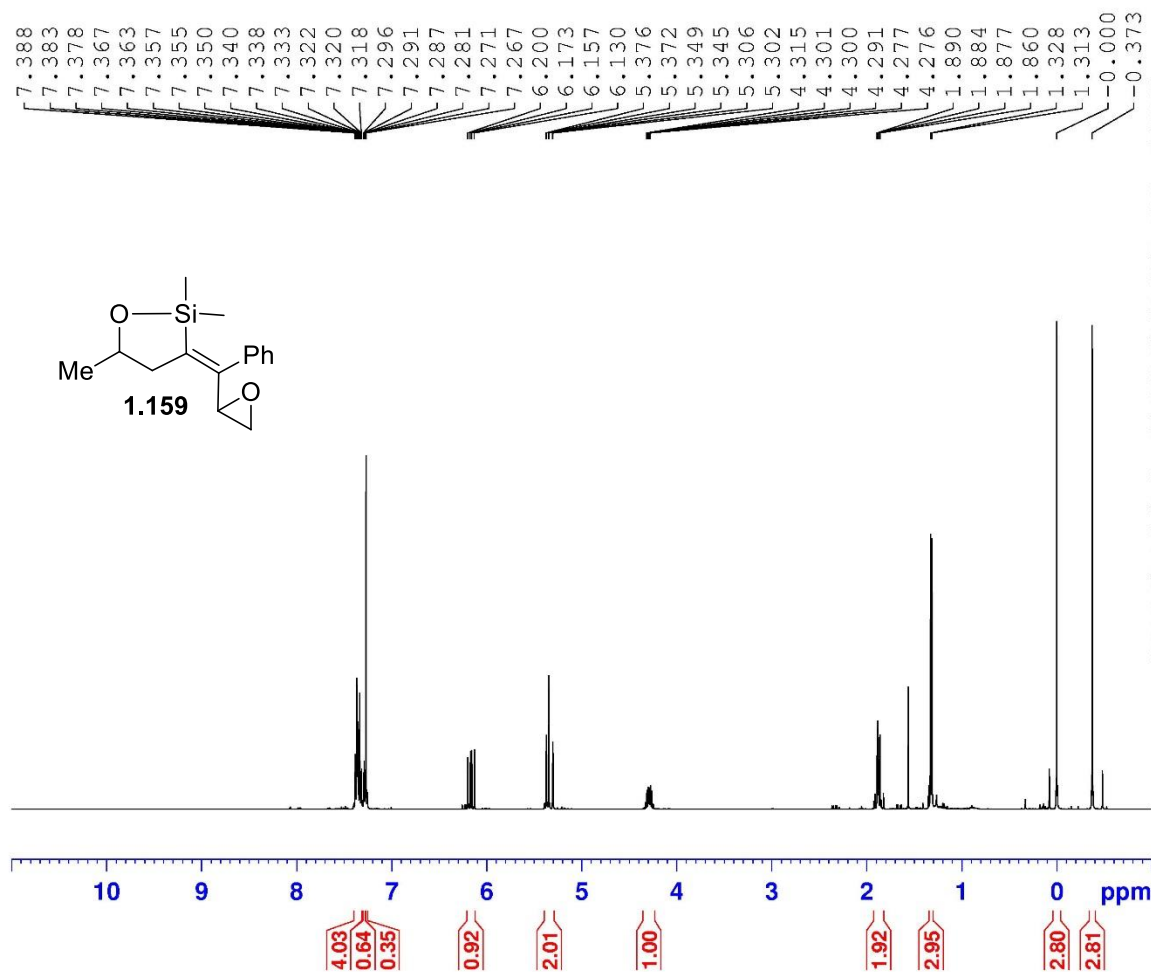
4/14/2015 2:52:02 PM

RJW6150 #661 RT: 9.53 AV: 1 NL: 1.48E3

T: + c Full ms [45.00-650.00]

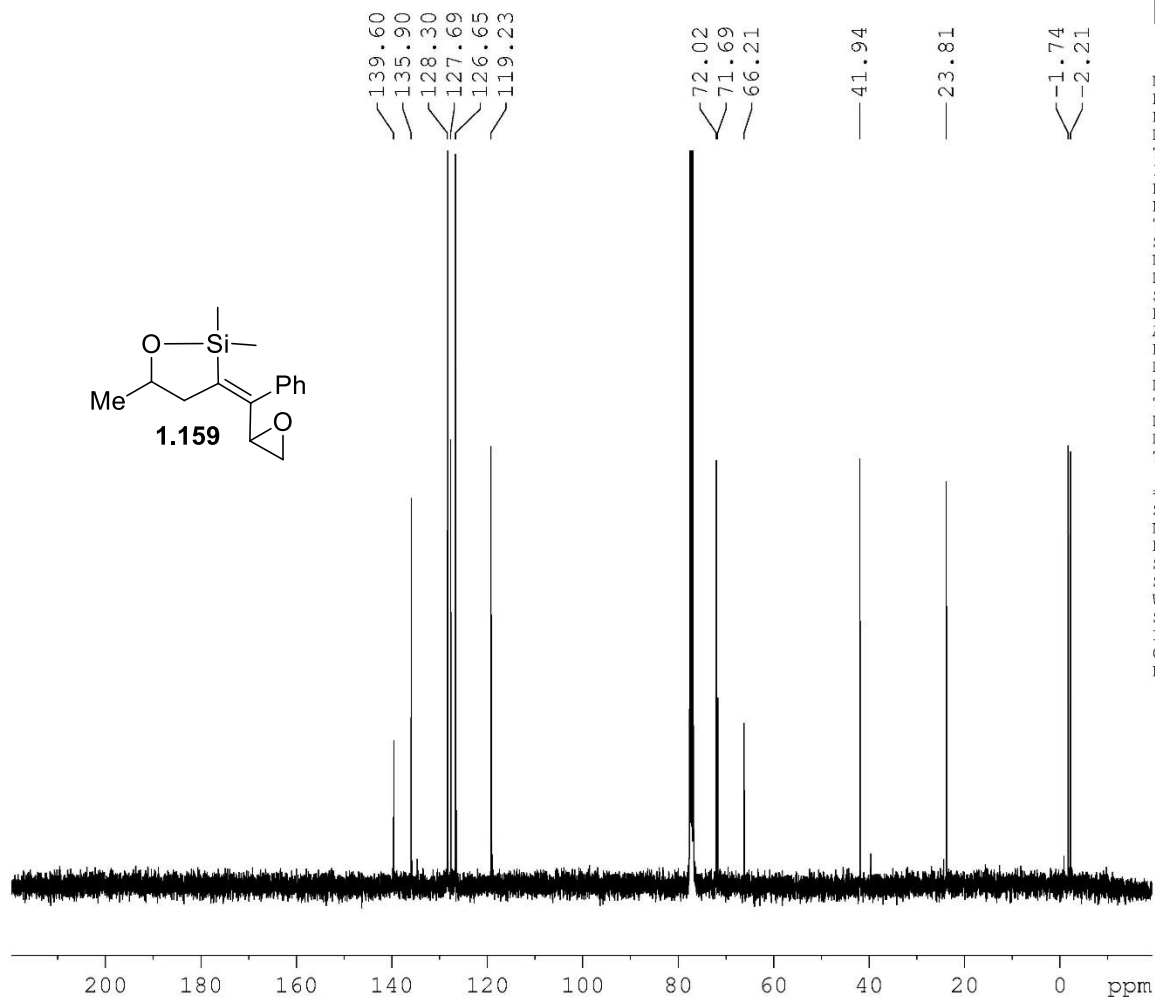
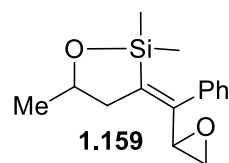
**GC-MS of 2b*****1.133**

RJW-5-069
PC



NAME RJW400-5-069
EXPNO 2
PROCNO 1
Date_ 20140319
Time 17.24
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl3
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 208.09
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1
===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300054 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

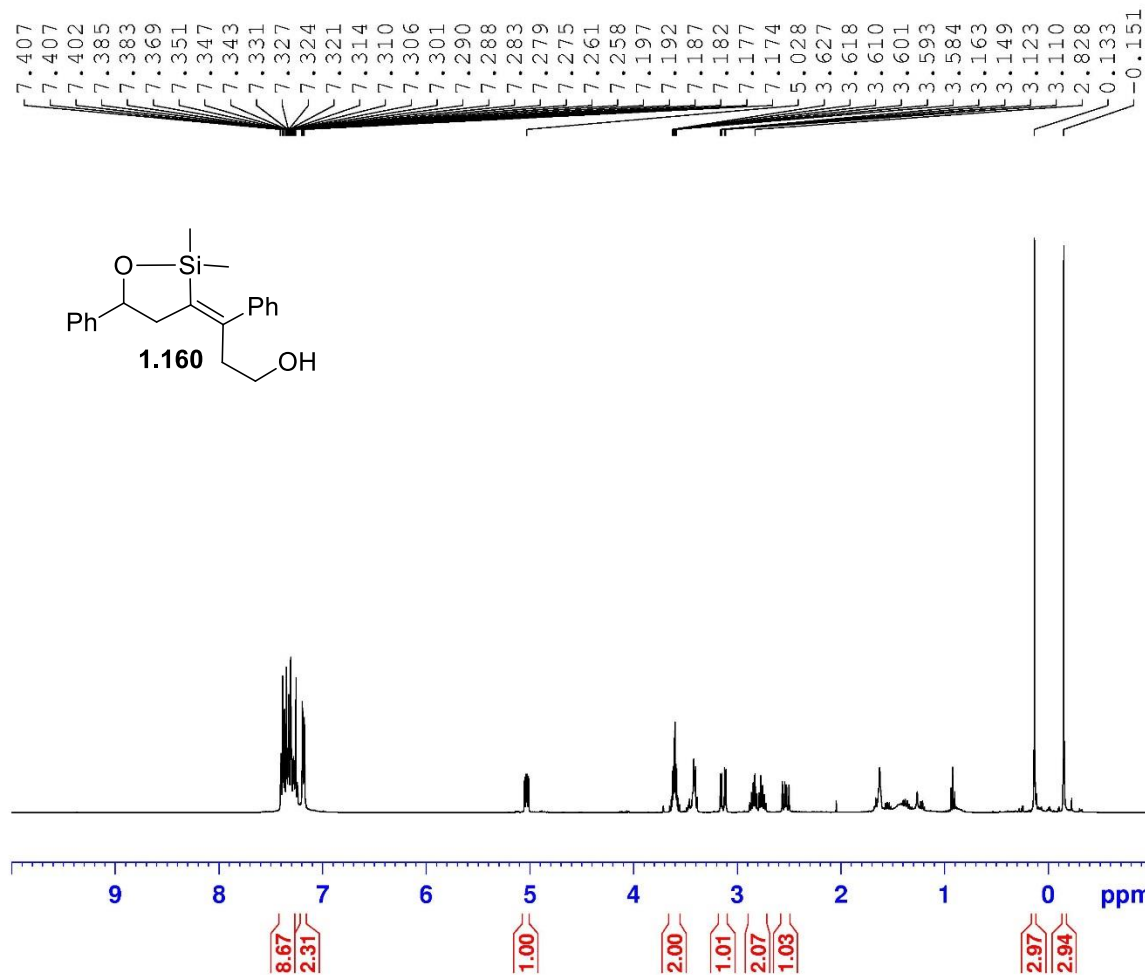
RJW-5-069
PC



NAME RJW400-5-069
EXPNO 3
PROCNO 1
Date_ 20140319
Time 17.57
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDCl3
NS 540
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 91.52
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127477 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

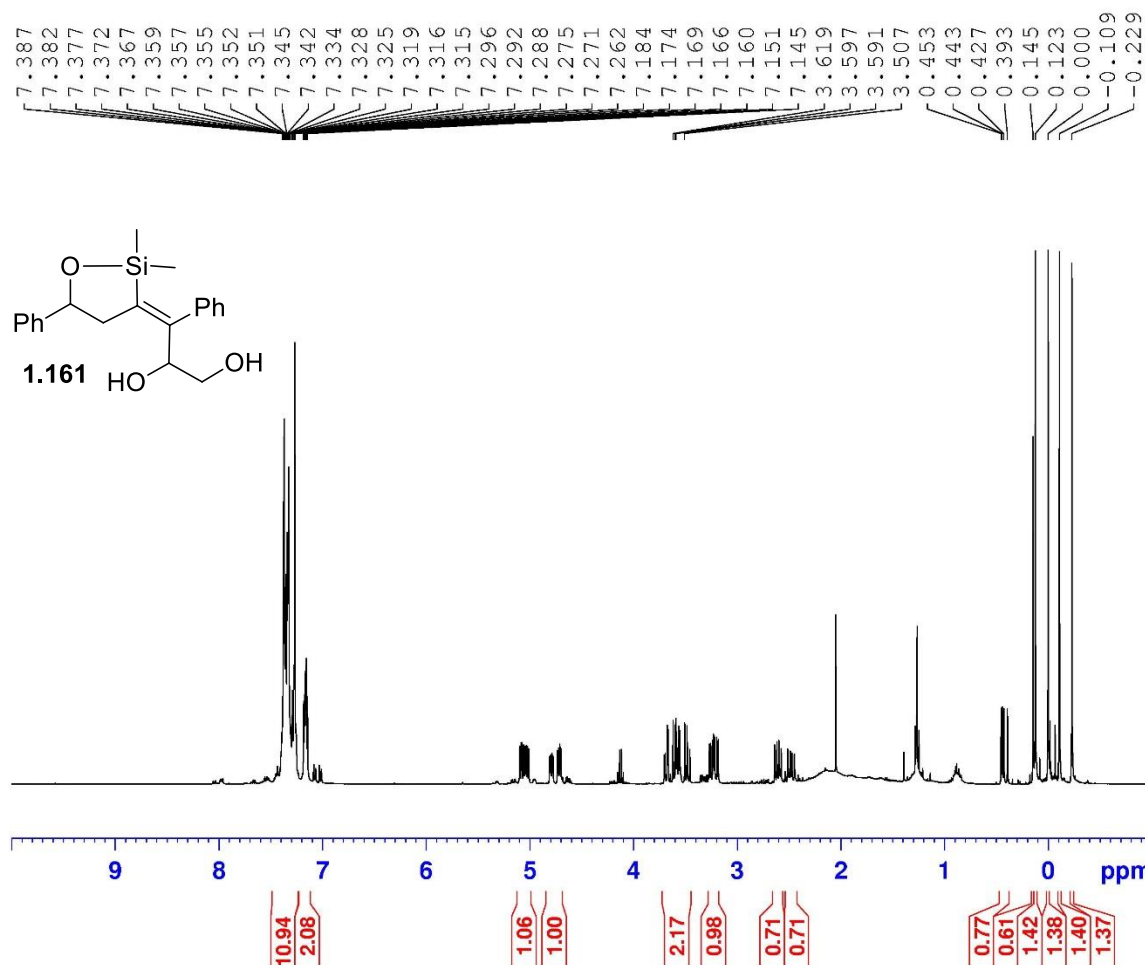
RJW-5-090
PC



NAME RJW400-5-090
EXPNO 2
PROCNO 1
Date_ 20140404
Time 1.40
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl3
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 74.16
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300107 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

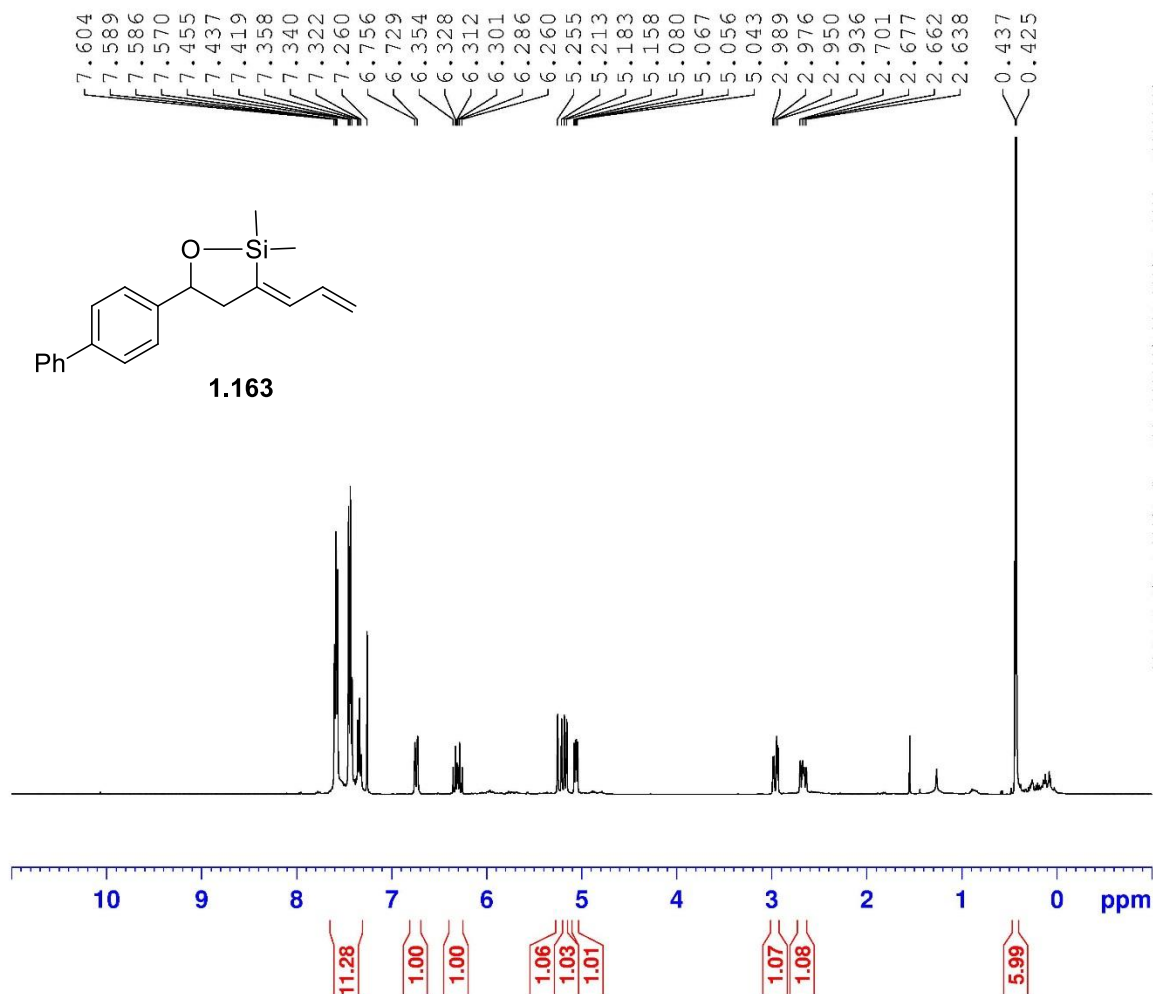
RJW-5-275
PC diol



NAME RJW400-5-275
EXPNO 2
PROCNO 1
Date_ 20140904
Time 8.55
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl3
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 118.73
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300063 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

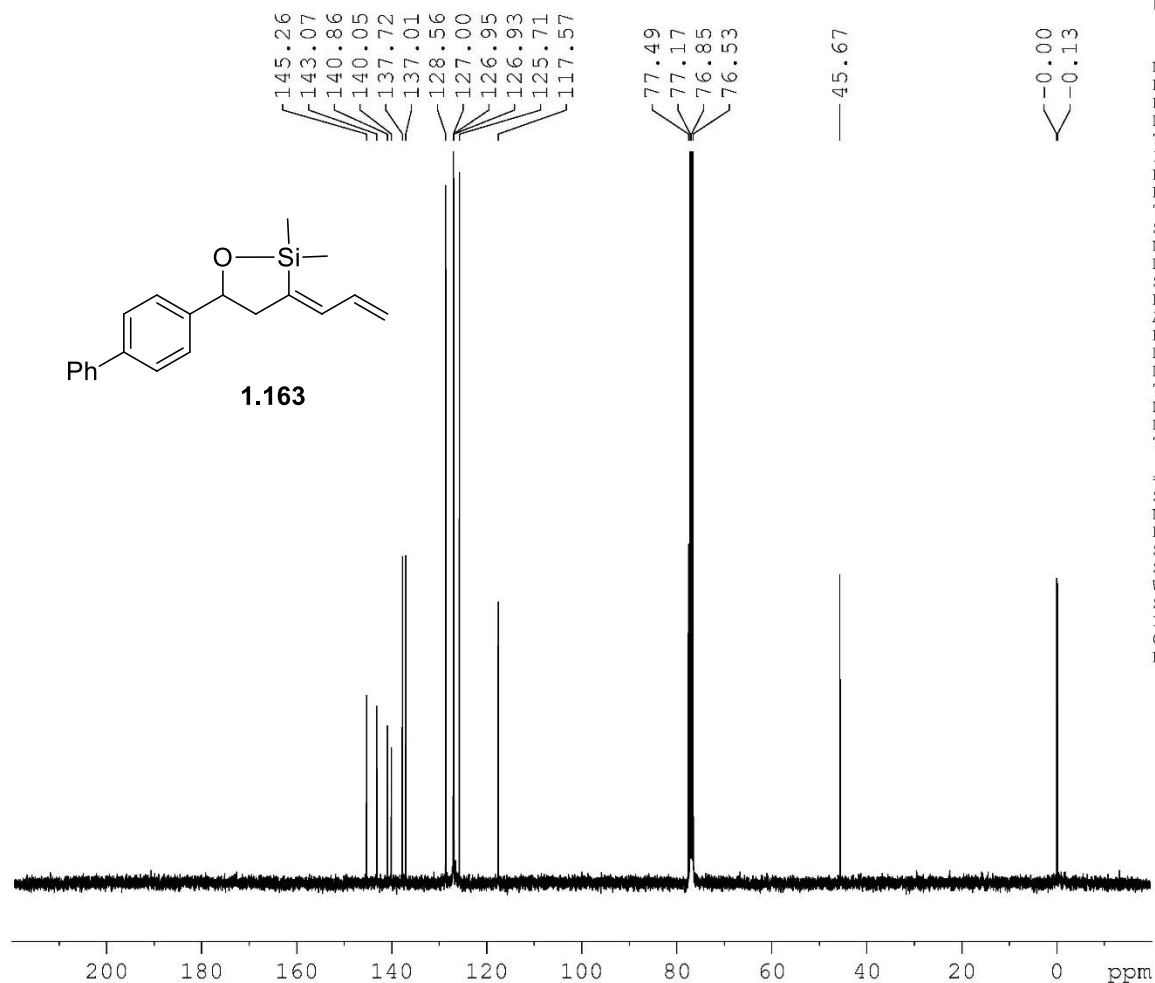
RJW-5-044



NAME RJW400-5-044
EXPNO 3
PROCNO 1
Date_ 20140219
Time 16.43
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl₃
NS 8
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 150.82
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300098 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

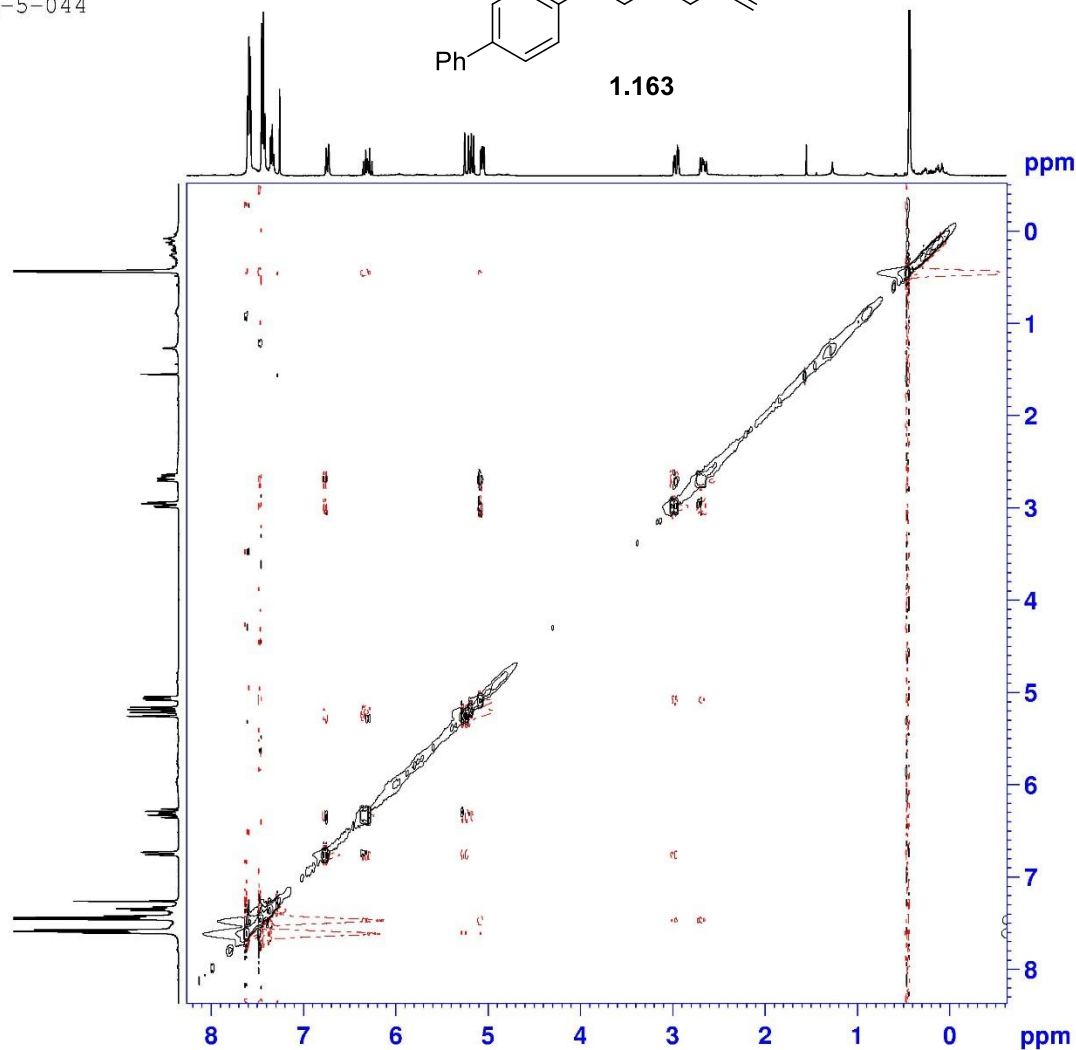
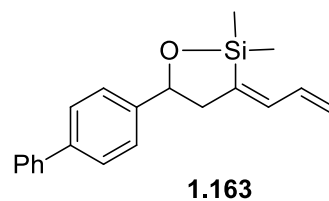
RJW-5-044



NAME RJW400-5-044
EXPNO 5
PROCNO 1
Date_ 20140219
Time 17.37
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDCl3
NS 500
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 45.77
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127870 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

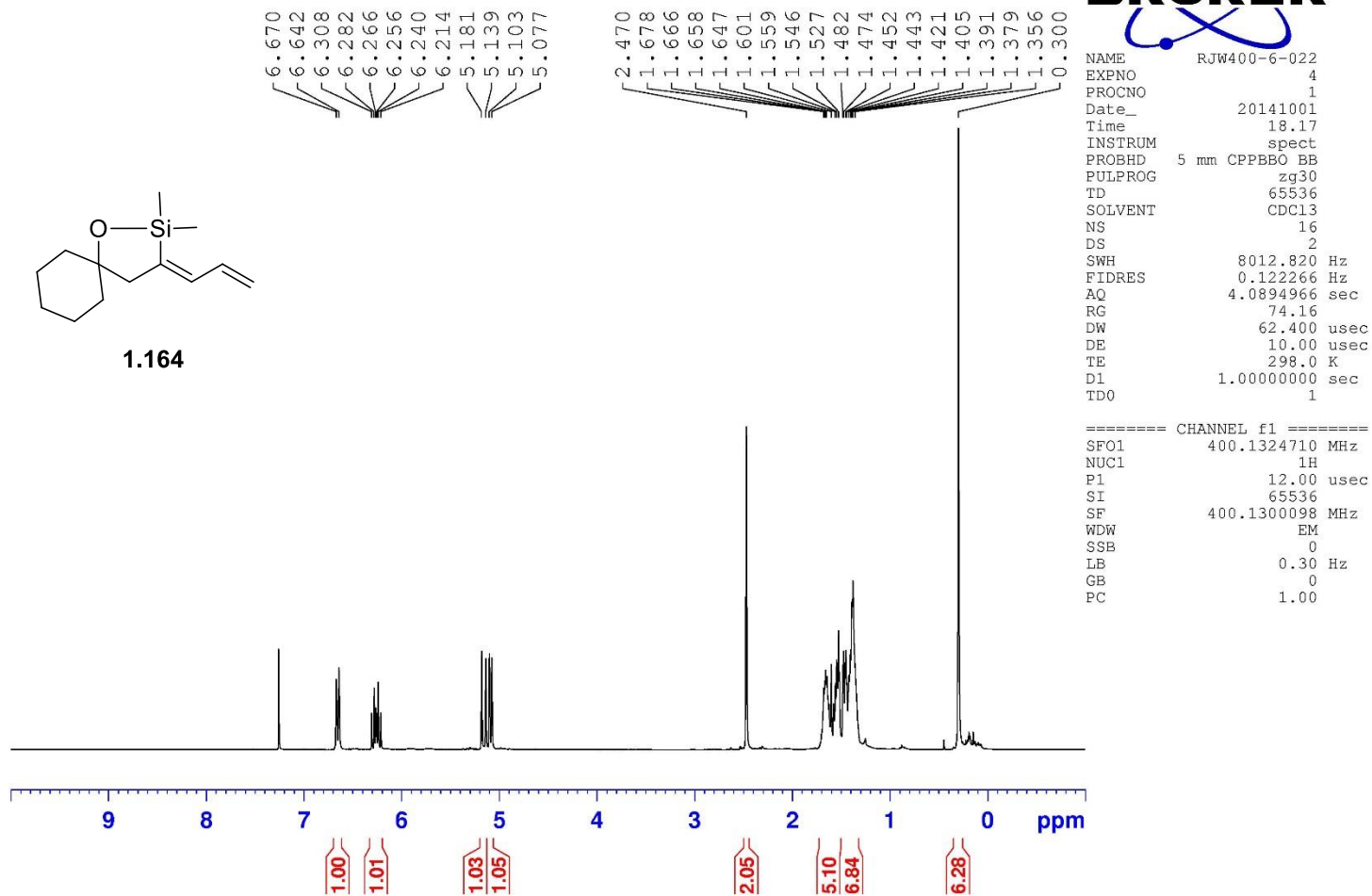
RJW-5-044



NAME RJW400-5-044
 EXPNO 4
 PROCNO 1
 Date_ 20140219
 Time 16.45
 INSTRUM spect
 PROBHD 5 mm CPPBBO BB
 PULPROG noesygpphpp
 TD 2048
 SOLVENT CDCl3
 NS 2
 DS 32
 SWH 3597.122 Hz
 FIDRES 1.756407 Hz
 AQ 0.2847220 sec
 RG 66.01
 DW 139.000 usec
 DE 10.00 usec
 TE 298.0 K
 D0 0.00012372 sec
 D1 1.97132802 sec
 D8 0.30000001 sec
 D11 0.03000000 sec
 D12 0.00002000 sec
 D16 0.00020000 sec
 IN0 0.00027800 sec

===== CHANNEL f1 =====
 SFO1 400.131502 MHz
 NUC1 1H
 P1 12.00 usec
 P2 24.00 usec
 P17 2500.00 usec
 ND0 1
 TD 256
 SFO1 400.1316 MHz
 FIDRES 14.051259 Hz
 SW 8.990 ppm
 FMODE States-TPPI
 SI 1024
 SF 400.130000 MHz
 WDW QSINE
 SSB 2
 LB 0.00 Hz
 GB 0
 PC 1.00
 SI 1024
 MC2 States-TPPI
 SF 400.130000 MHz
 WDW QSINE
 SSB 2
 LB 0.00 Hz
 GB 0

RJW-6-022
PC

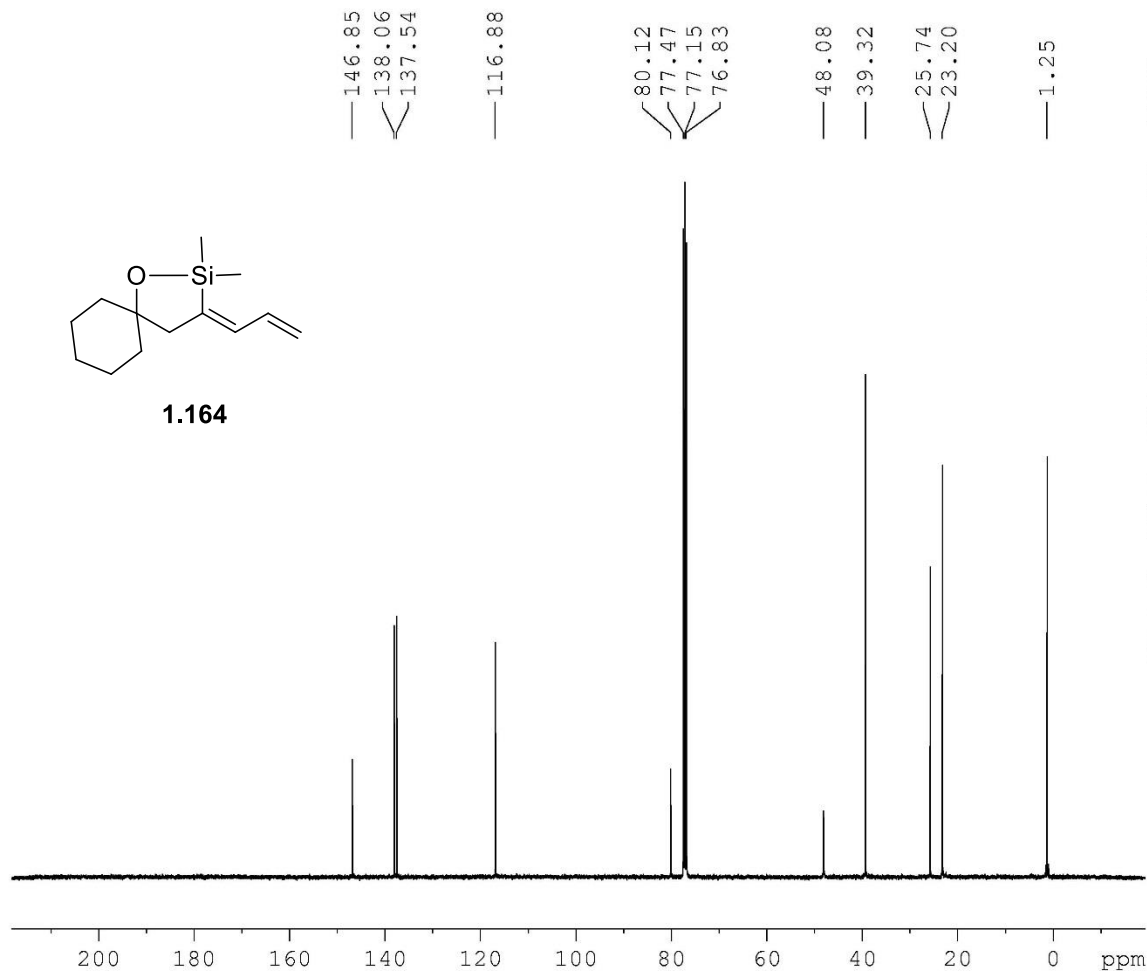


RJW-6-022
PC

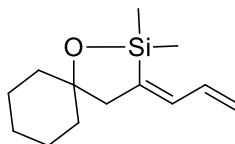


NAME RJW400-6-022
EXPNO 3
PROCNO 1
Date_ 20141001
Time 16.34
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDCl3
NS 500
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 50.16
DW 20.800 usec
DE 18.00 usec
TE 300.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

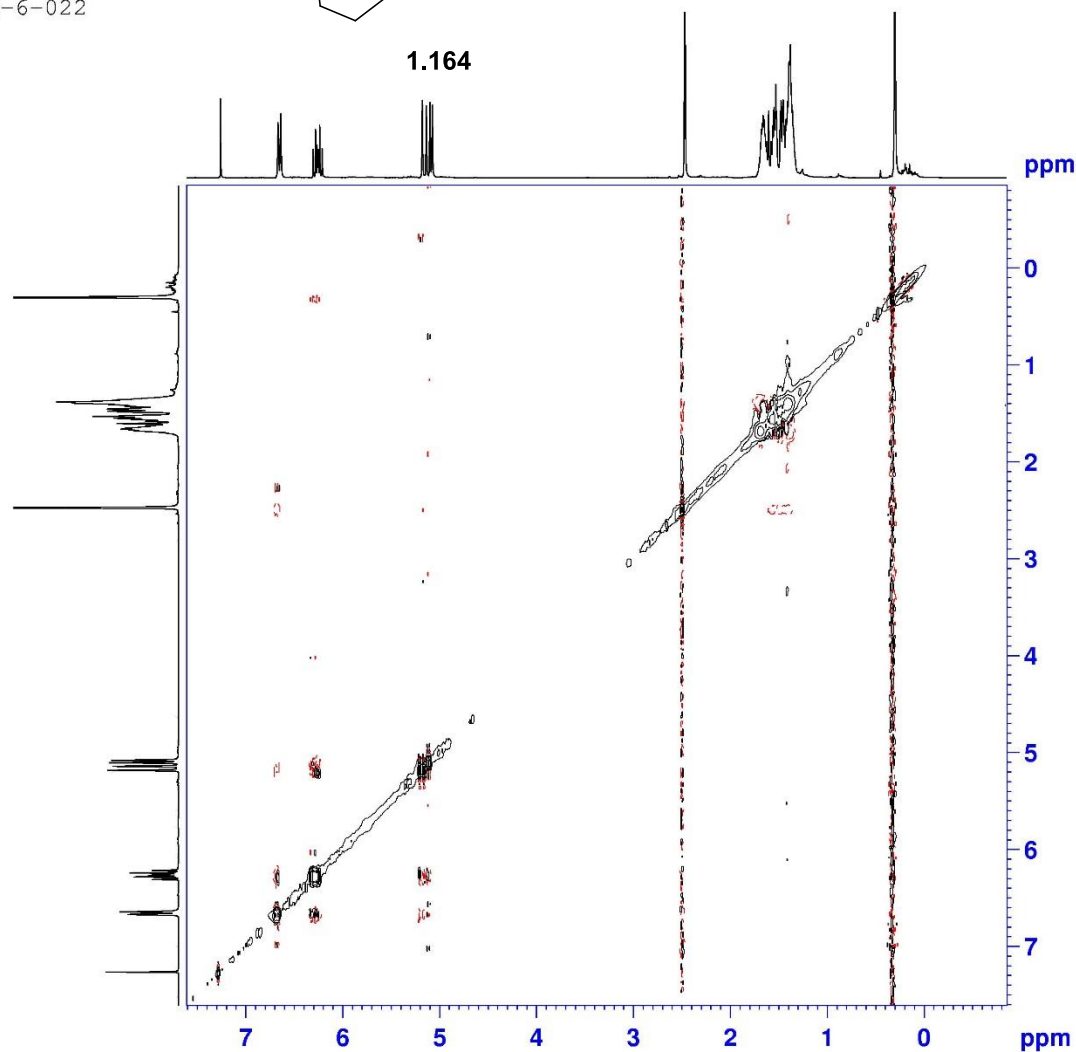
===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127549 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40



RJW-6-022
PC



1.164



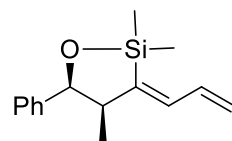
NAME RJW400-6-022
EXPNO 5
PROCNO 1
Date_ 20141001
Time 18.19
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG noesygpphpb
TD 2048
SOLVENT CDCl3
NS 4
DS 32
SWH 3472.222 Hz
FIDRES 1.695421 Hz
AQ 0.2949620 sec
RG 80.84
DW 144.000 usec
DE 10.00 usec
TE 298.0 K
D0 0.00012872 sec
D1 0.96108758 sec
D8 0.30000001 sec
D11 0.03000000 sec
D12 0.00002000 sec
D16 0.00020000 sec
IN0 0.00028800 sec

===== CHANNEL f1 =====
SFO1 400.1313944 MHz
NUC1 1H
P1 12.00 usec
P2 24.00 usec
P17 2500.00 usec
ND0 1
TD 256
SFO1 400.1314 MHz
FIDRES 13.563368 Hz
SW 8.678 ppm
FnMODE States-TPPI
SI 1024
SF 400.1300000 MHz
WDW QSINE
SSB 2
LB 0.00 Hz
GB 0
PC 1.00
SI 1024
MC2 States-TPPI
SF 400.1300000 MHz
WDW QSINE
SSB 2
LB 0.00 Hz
GB 0

RJW-6-025
PC



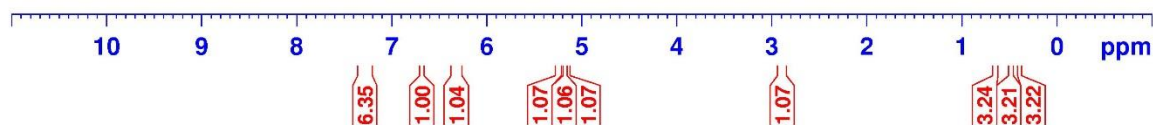
7.346
7.331
7.328
7.316
7.311
7.303
7.302
7.298
7.282
7.281
7.259
7.251
7.247
7.230
6.695
6.694
6.693
6.668
6.667
6.666
6.664
6.639
6.638
6.623
6.612
6.628
6.296
6.271
5.263
5.260
5.221
5.218
5.184
5.183
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5.156
5.148
5.136
0.653
0.635
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0.389

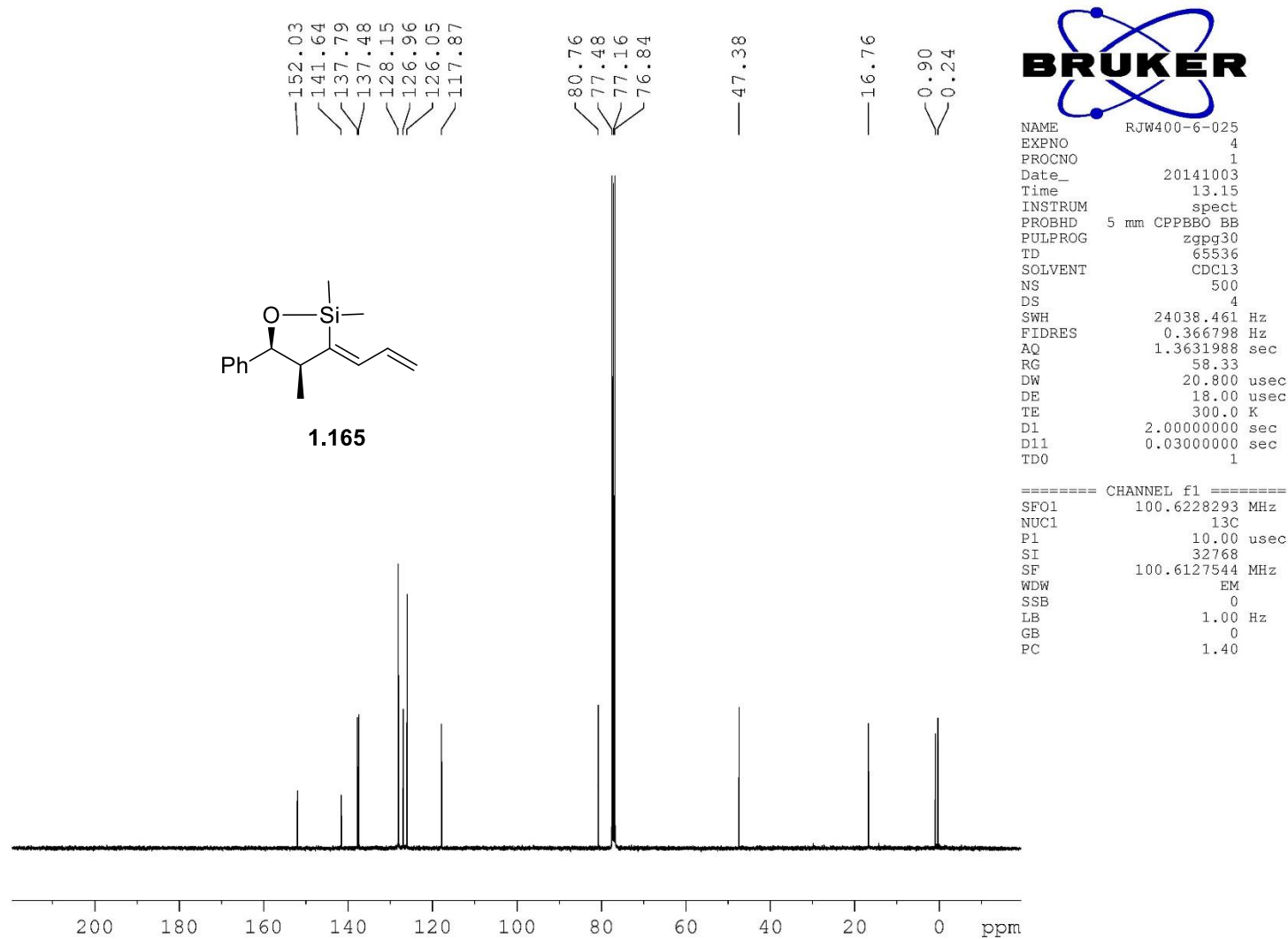


1.165

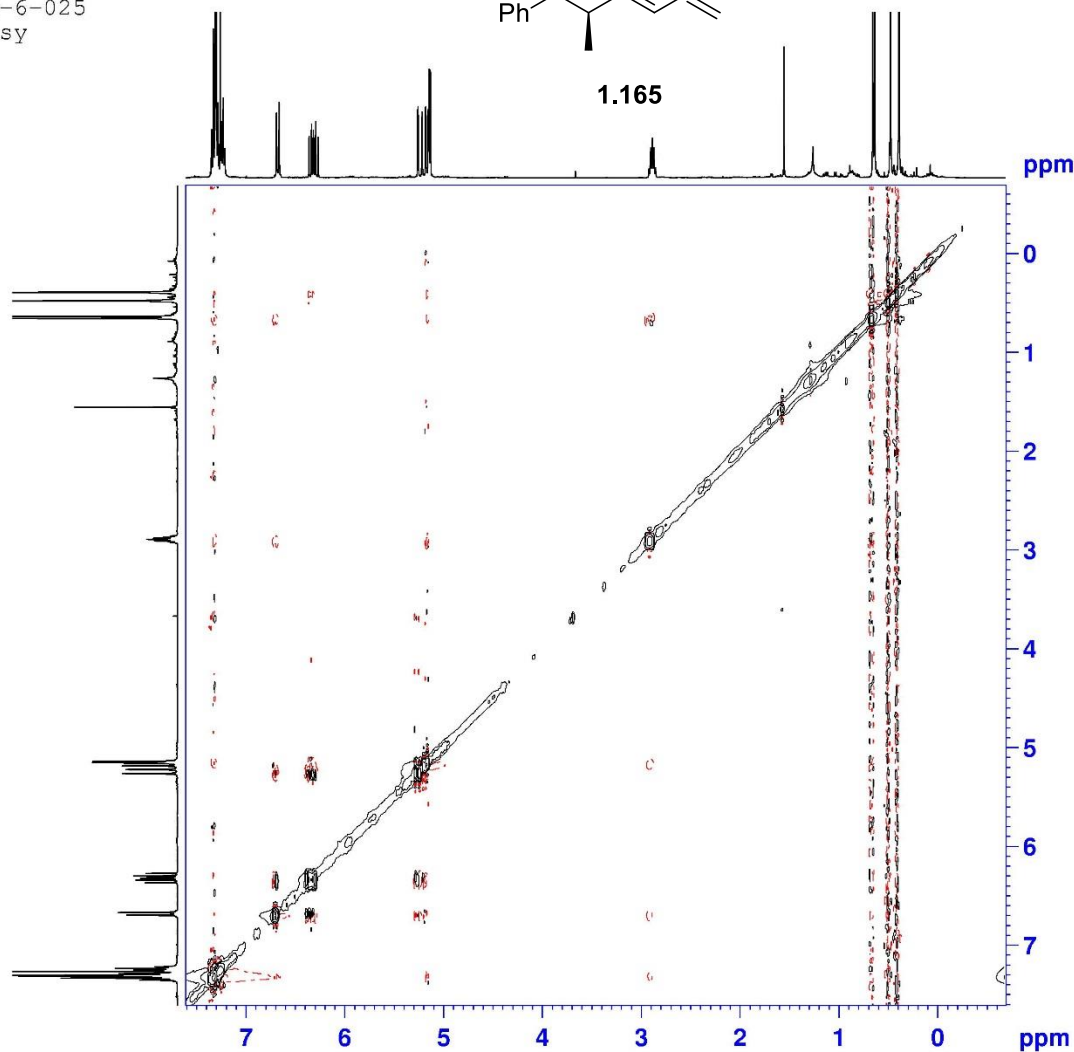
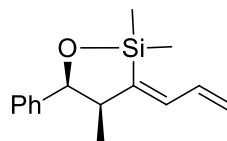
NAME RJW400-6-025
EXPNO 1
PROCNO 1
Date_ 20141003
Time 12.27
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl3
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 134.49
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300099 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00





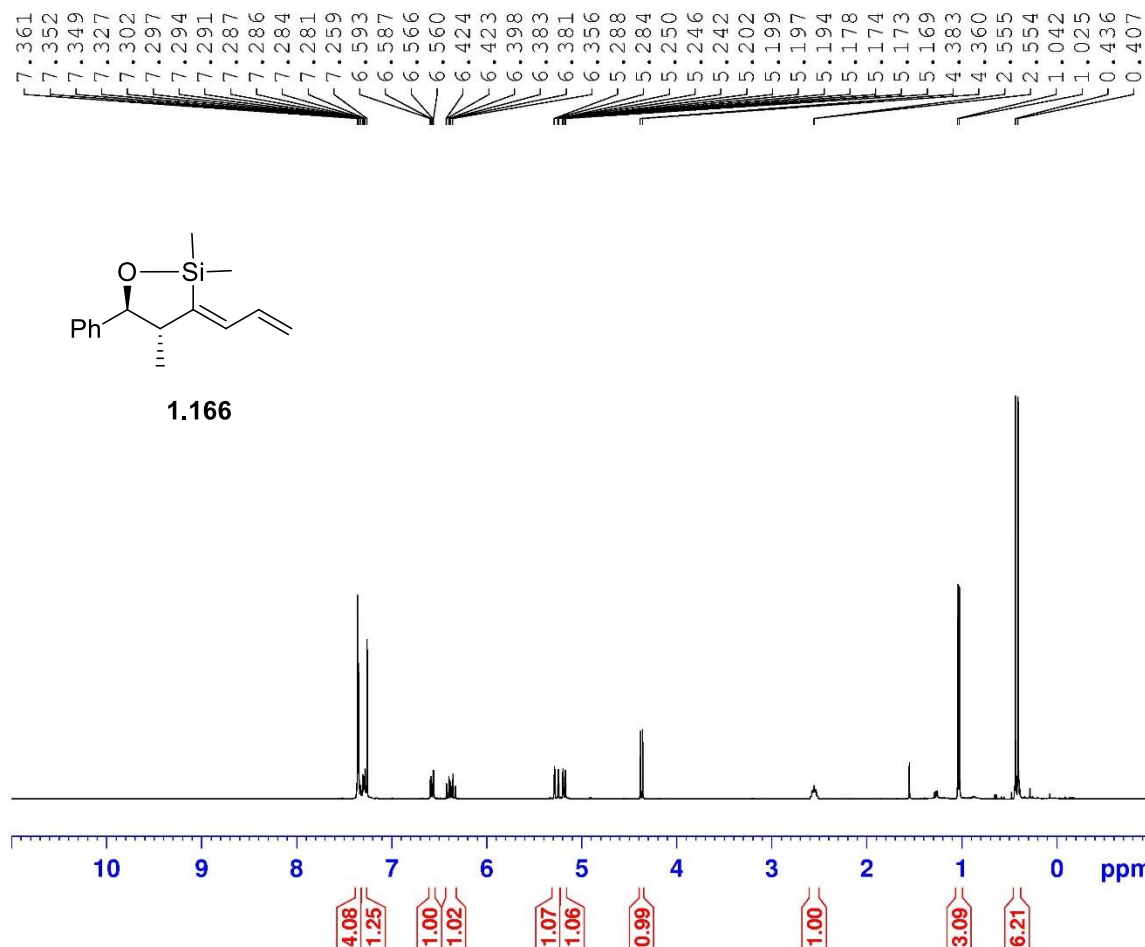
RJW-6-025
noesy



NAME RJW400-6-025
EXPNO 5
PROCNO 1
Date_ 20141003
Time 17.22
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG noesygpphpp
TD 2048
SOLVENT CDC13
NS 4
DS 32
SWH 3521.127 Hz
FIDRES 1.719300 Hz
AQ 0.2908660 sec
RG 66.01
DW 142.000 usec
DE 10.00 usec
TE 300.0 K
D0 0.00012672 sec
D1 1.96518397 sec
D8 0.30000001 sec
D11 0.03000000 sec
D12 0.00002000 sec
D16 0.00020000 sec
IN0 0.00028400 sec

===== CHANNEL f1 =====
SFO1 400.1314845 MHz
NUC1 1H
P1 12.00 usec
P2 24.00 usec
P17 2500.00 usec
ND0 1
TD 256
SFO1 400.1315 MHz
FIDRES 13.754401 Hz
SW 8.800 ppm
FnMODE States-TPPI
SI 1024
SF 400.1300000 MHz
WDW QSINE
SSB 2
LB 0.00 Hz
GB 0
PC 1.00
SI 1024
MC2 States-TPPI
SF 400.1300000 MHz
WDW QSINE
SSB 2
LB 0.00 Hz
GB 0

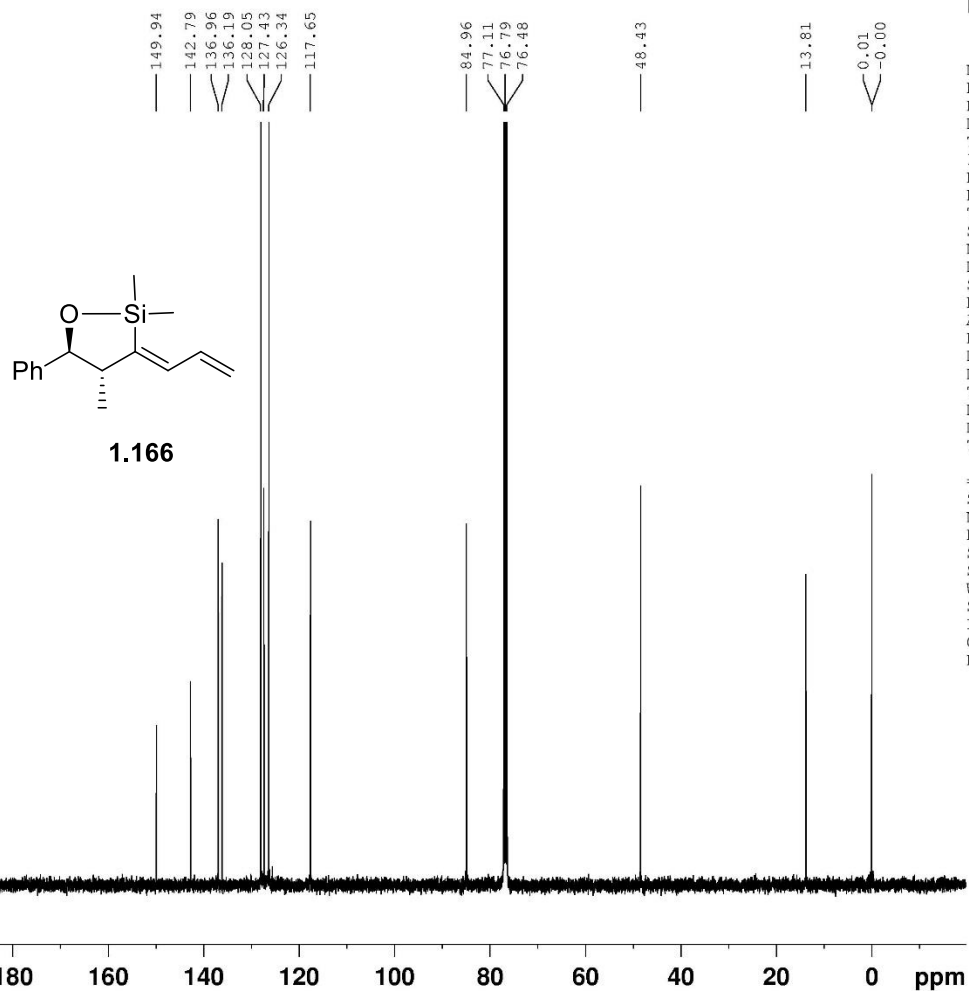
RJW-6-101
PC



NAME RJW400-6-101
EXPNO 1
PROCNO 1
Date_ 20150204
Time 14.10
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl₃
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 104.13
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300102 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

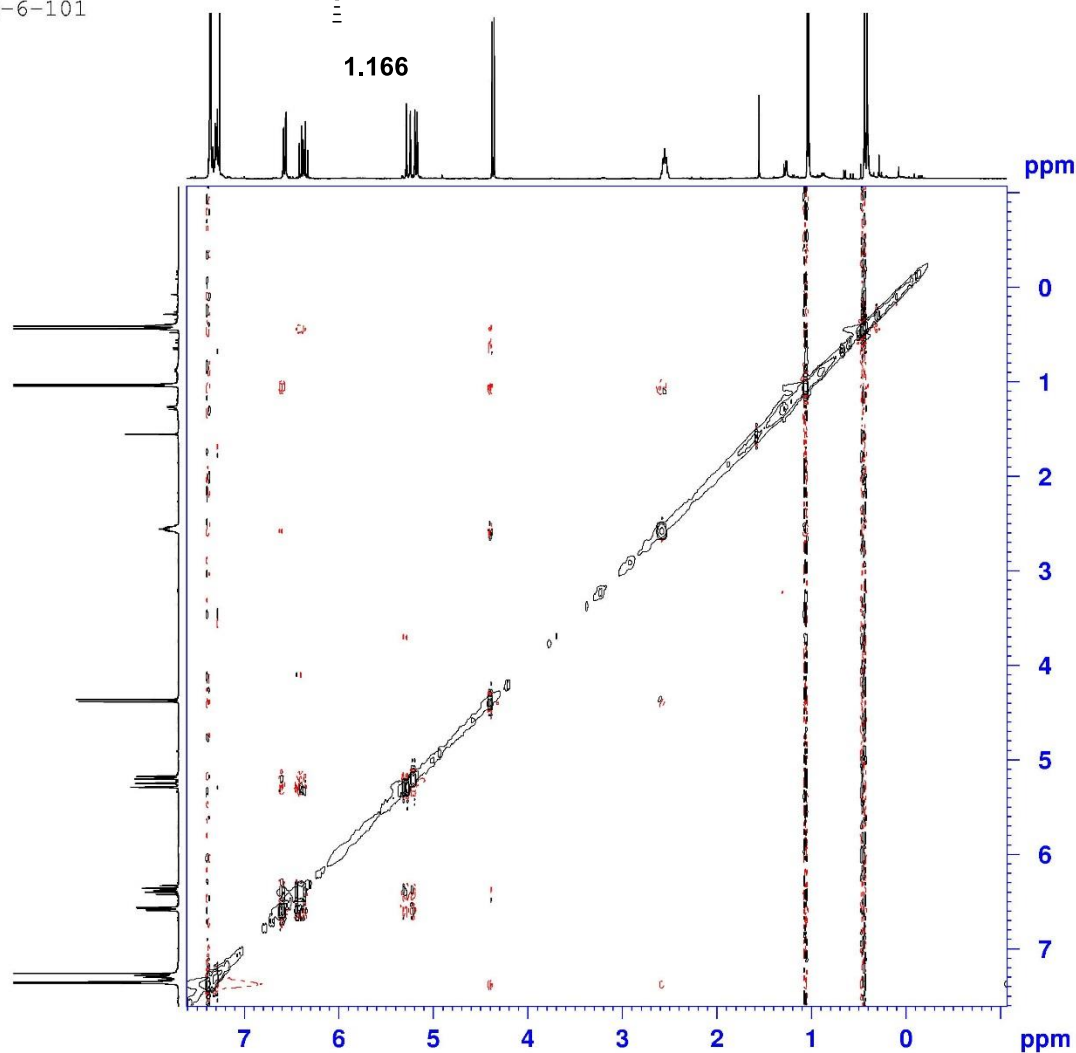
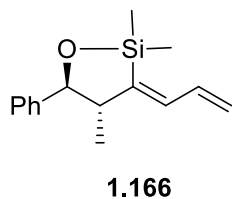
RJW-6-101
PC



NAME RJW400-6-101
EXPNO 2
PROCNO 1
Date_ 20150204
Time 14.40
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDCl3
NS 500
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 74.16
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127923 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

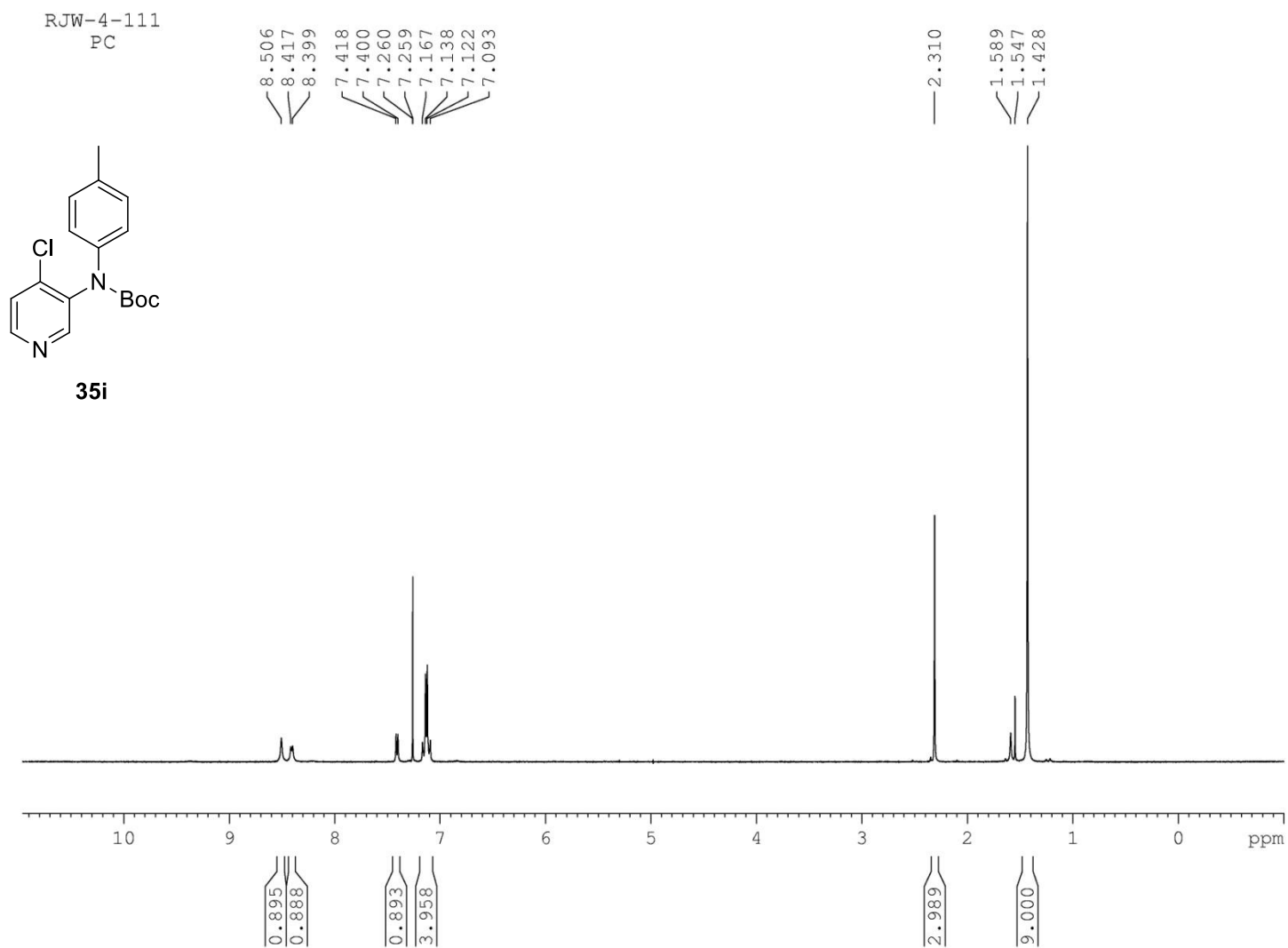
RJW-6-101
PC



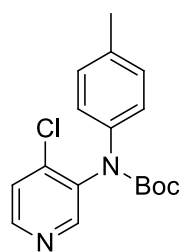
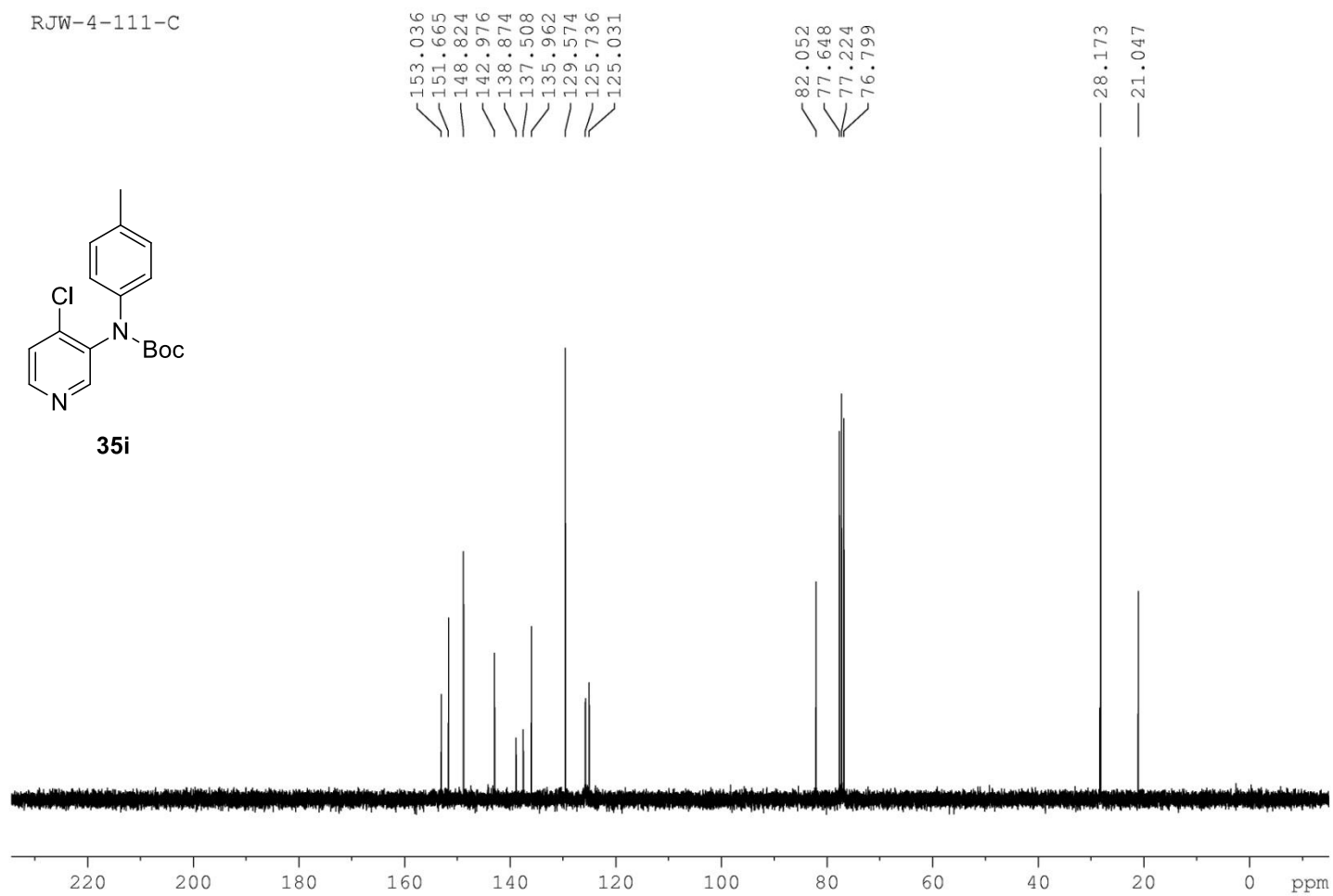
NAME RJW400-6-101
EXPNO 3
PROCNO 1
Date_ 20150204
Time 14.42
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG noesygpphpp
TD 2048
SOLVENT CDCl3
NS 4
DS 32
SWH 3731.343 Hz
FIDRES 1.821945 Hz
AQ 0.2744820 sec
RG 66.01
DW 134.000 usec
DE 10.00 usec
TE 298.0 K
D0 0.00011872 sec
D1 0.98156762 sec
D8 0.30000001 sec
D11 0.03000000 sec
D12 0.00002000 sec
D16 0.00020000 sec
IN0 0.00026800 sec

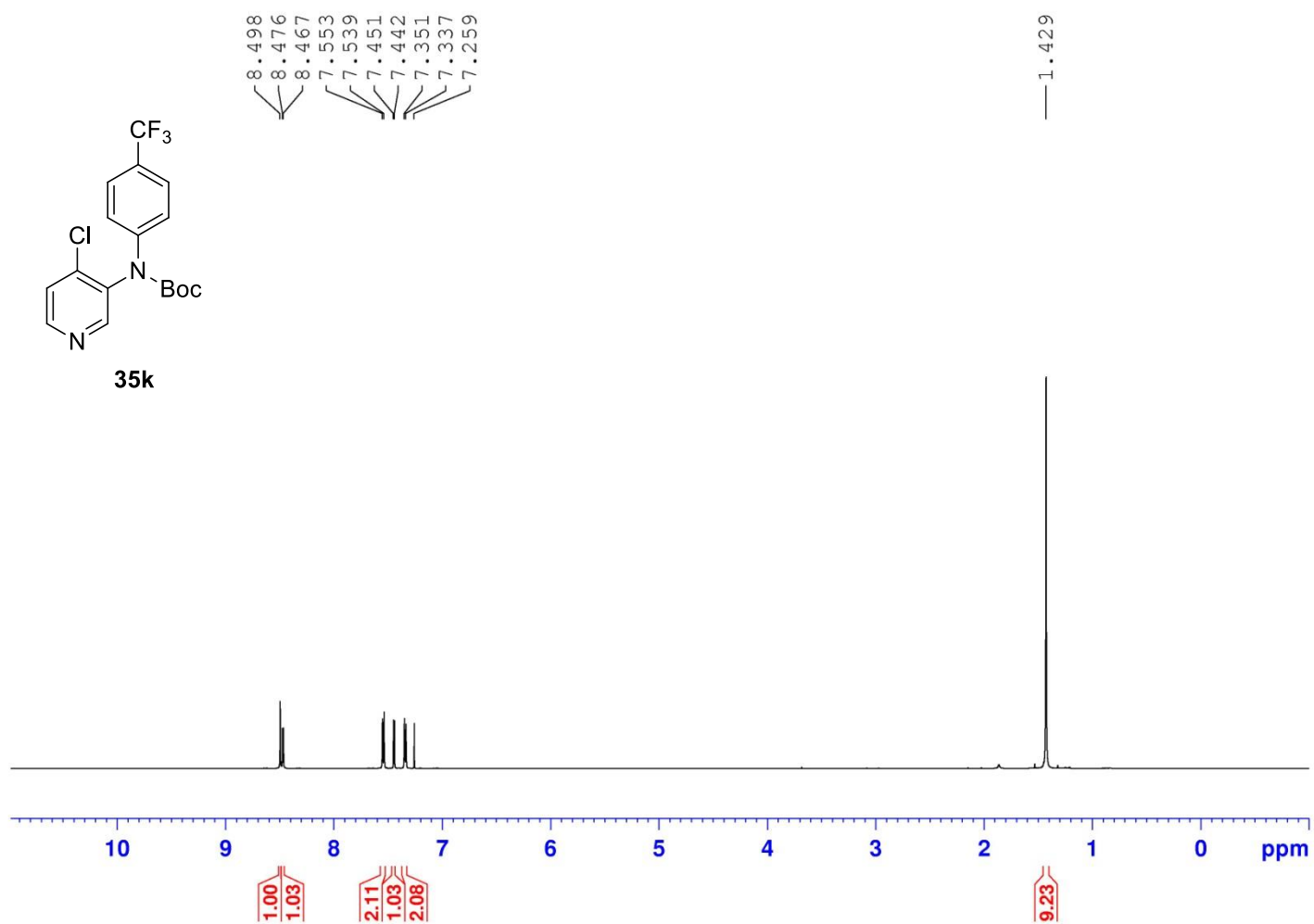
===== CHANNEL f1 =====
SFO1 400.1314092 MHz
NUC1 1H
P1 12.00 usec
P2 24.00 usec
P17 2500.00 usec
ND0 1
TD 256
SFO1 400.1314 MHz
FIDRES 14.575560 Hz
SW 9.325 ppm
FnMODE States-TPPI
SI 1024
SF 400.1300000 MHz
WDW QSINE
SSB 2
LB 0.00 Hz
GB 0
PC 1.00
SI 1024
MC2 States-TPPI
SF 400.1300000 MHz
WDW QSINE
SSB 2
LB 0.00 Hz
GB 0

5.5 IMIDAZOPYRIDINE SPECTRA

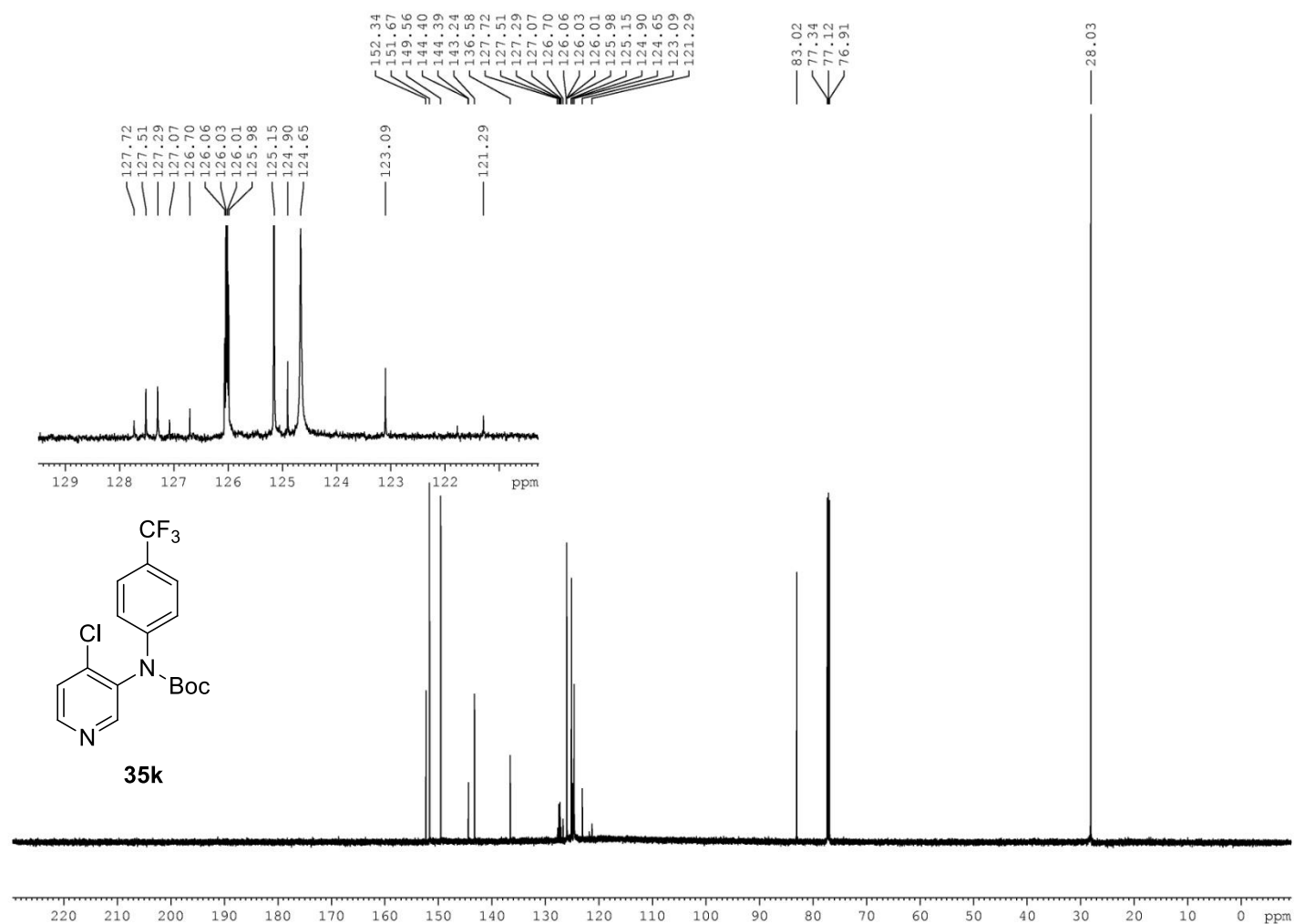


RJW-4-111-C

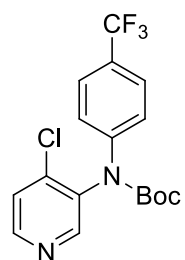
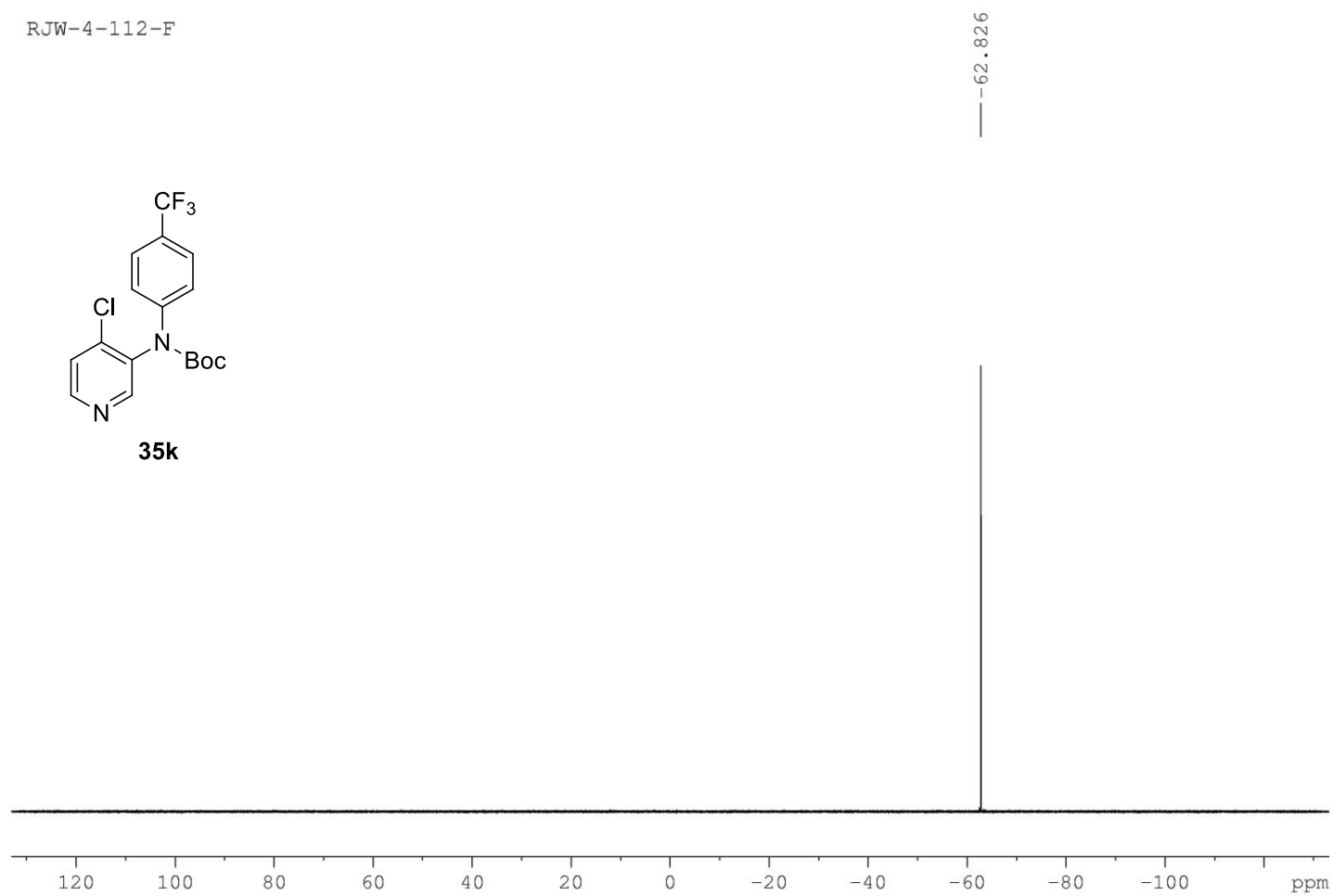
**35i**

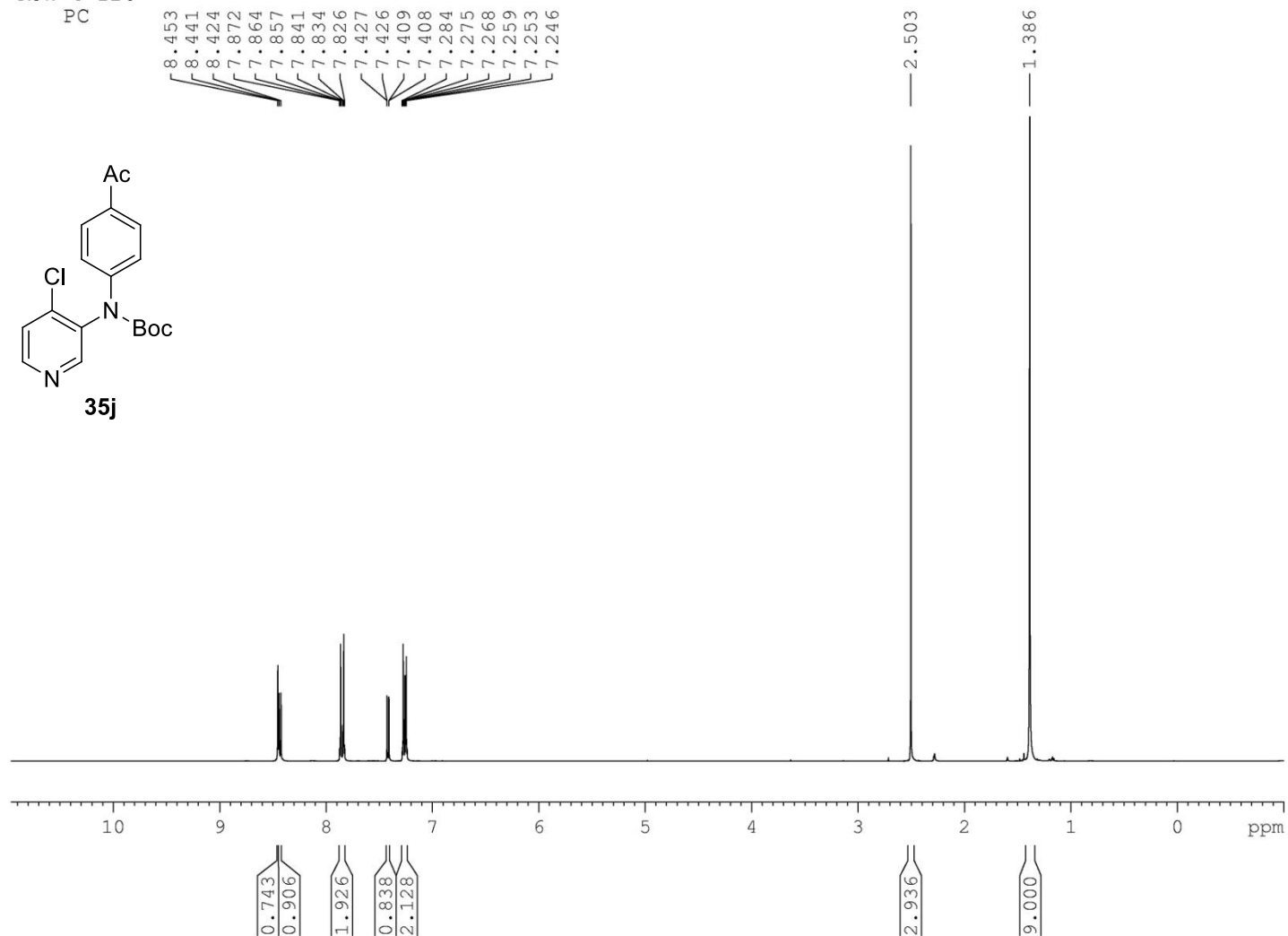
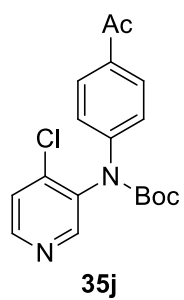


4112

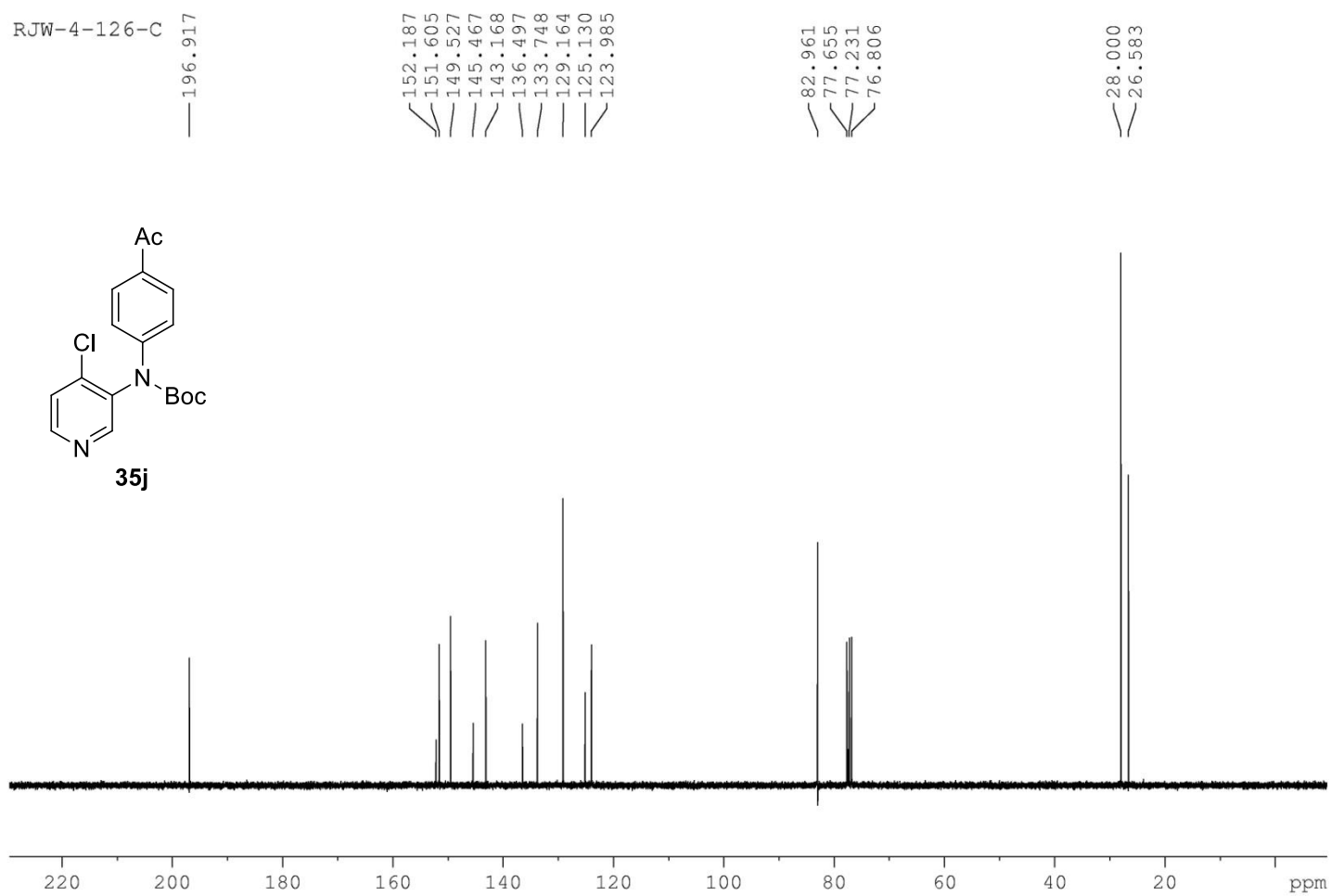


RJW-4-112-F

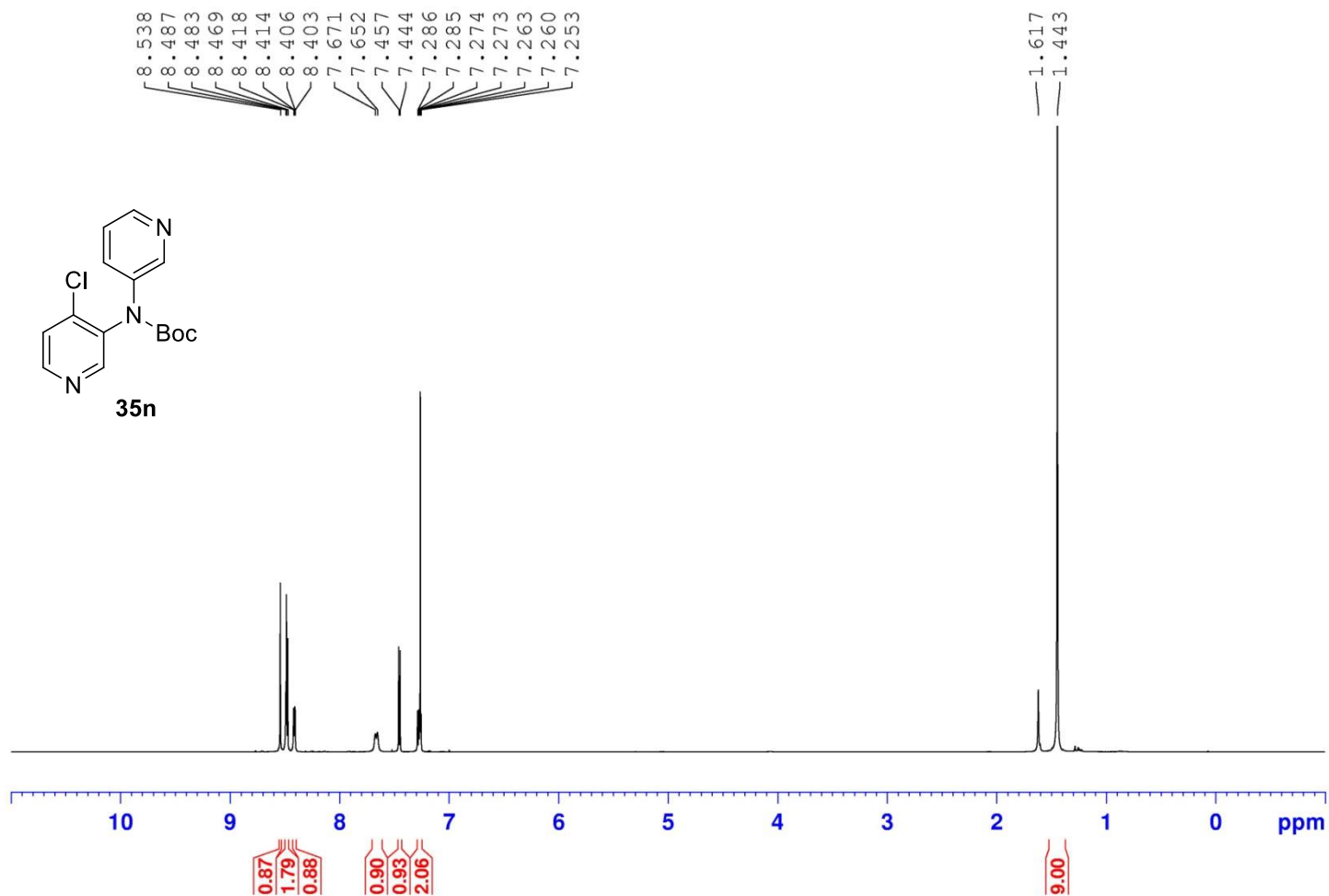
**35k**

RJW-4-126
PC

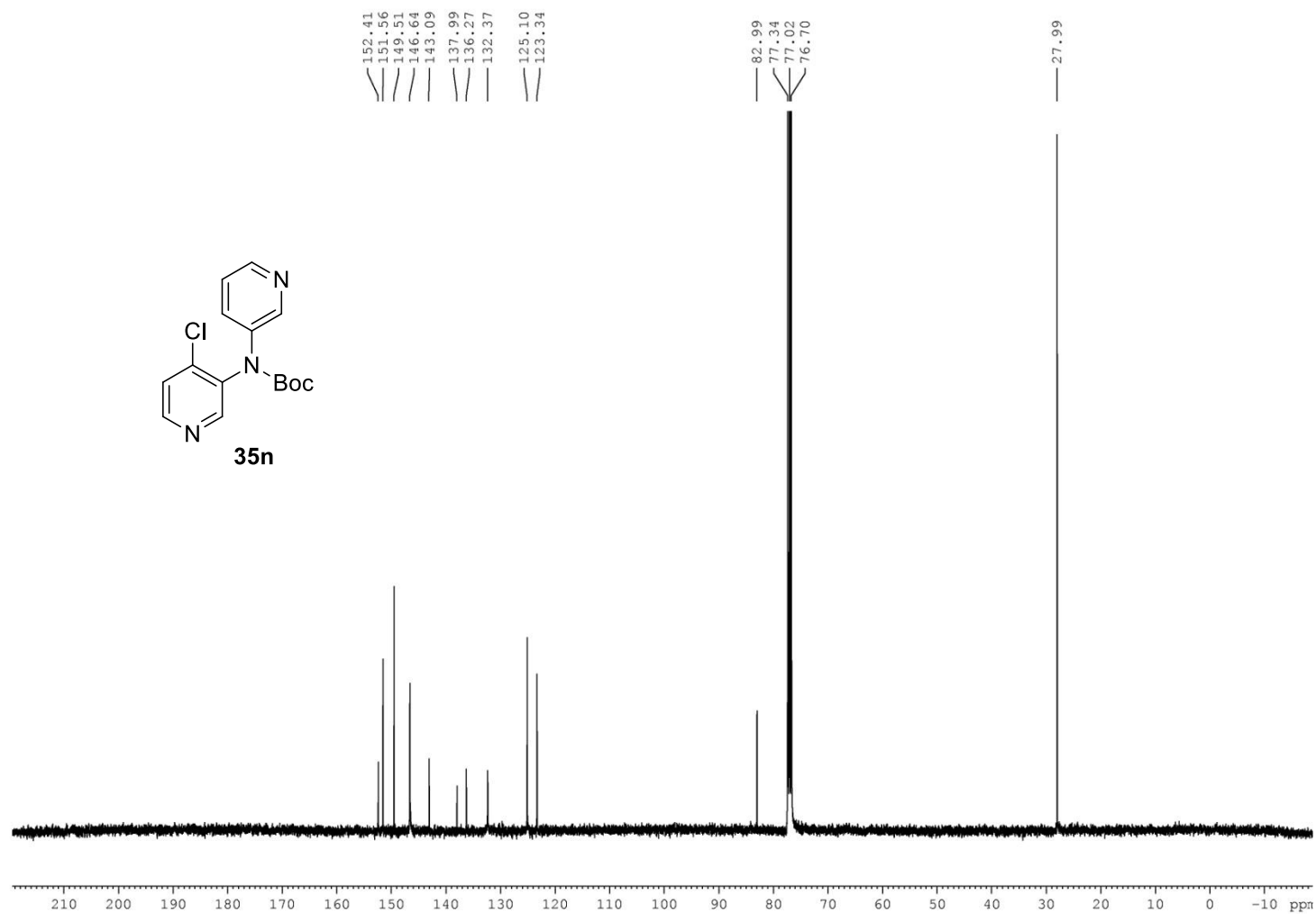
RJW-4-126-C



RJW-4-134
PC

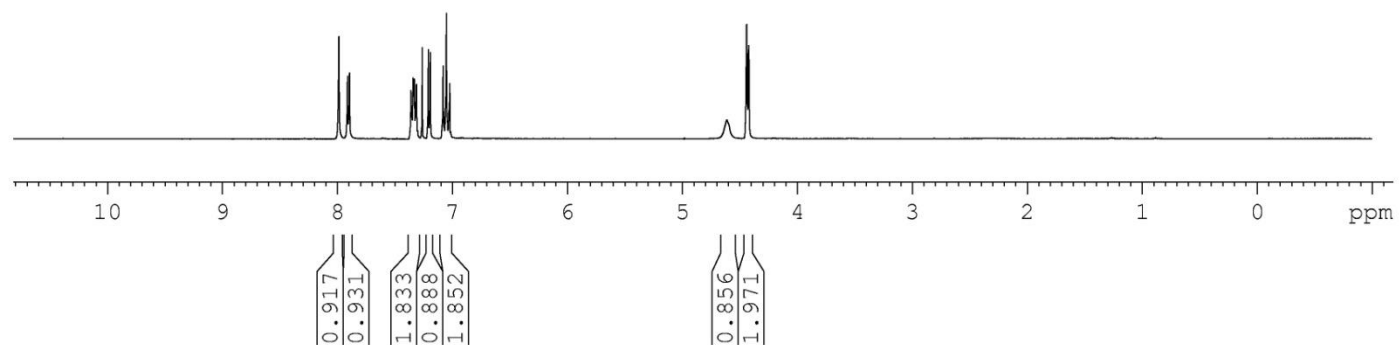
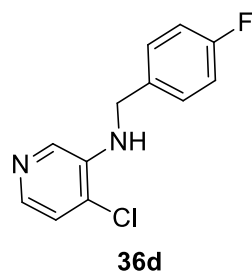


RJW-4-134-C

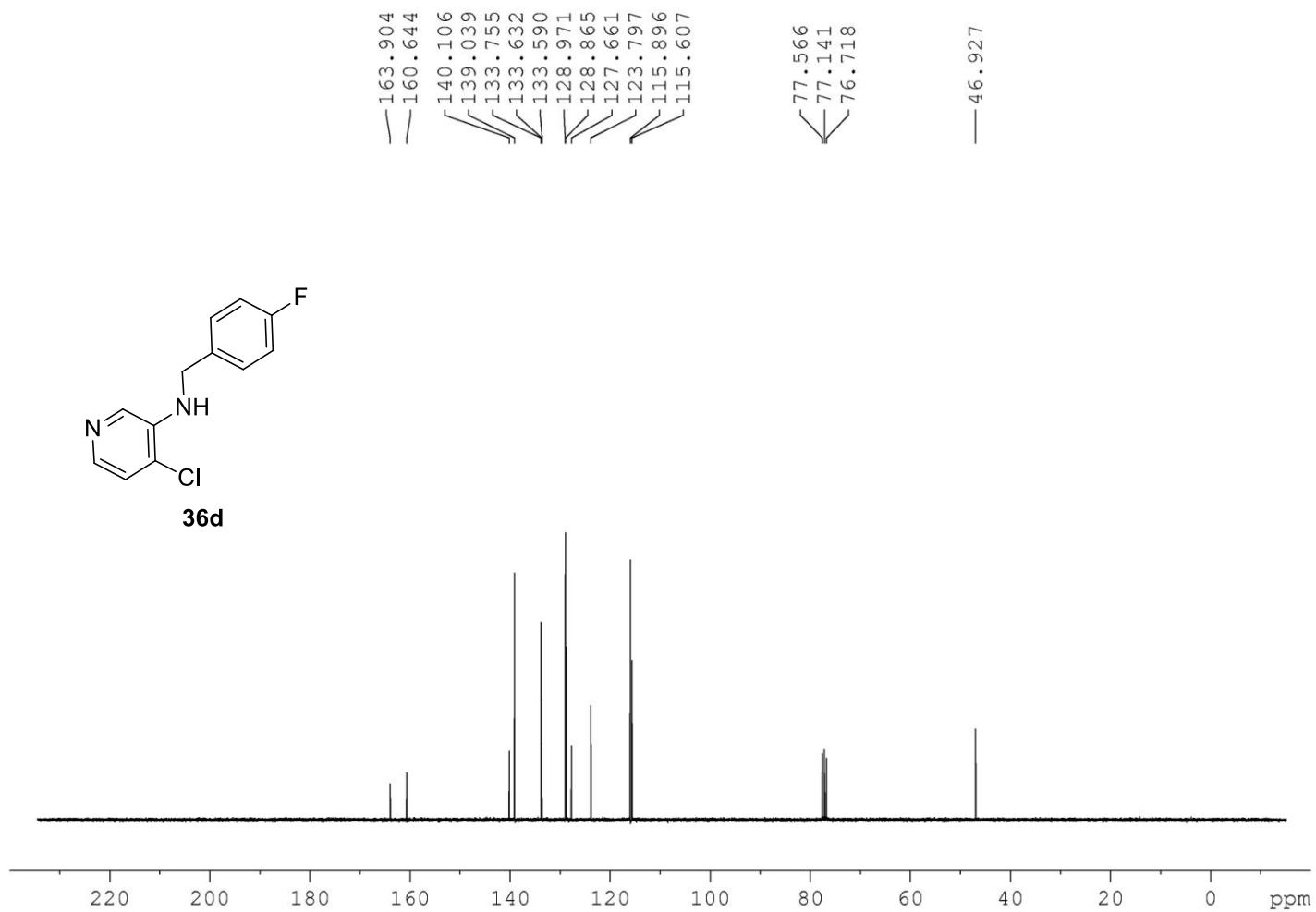


RJW-3-253
PC

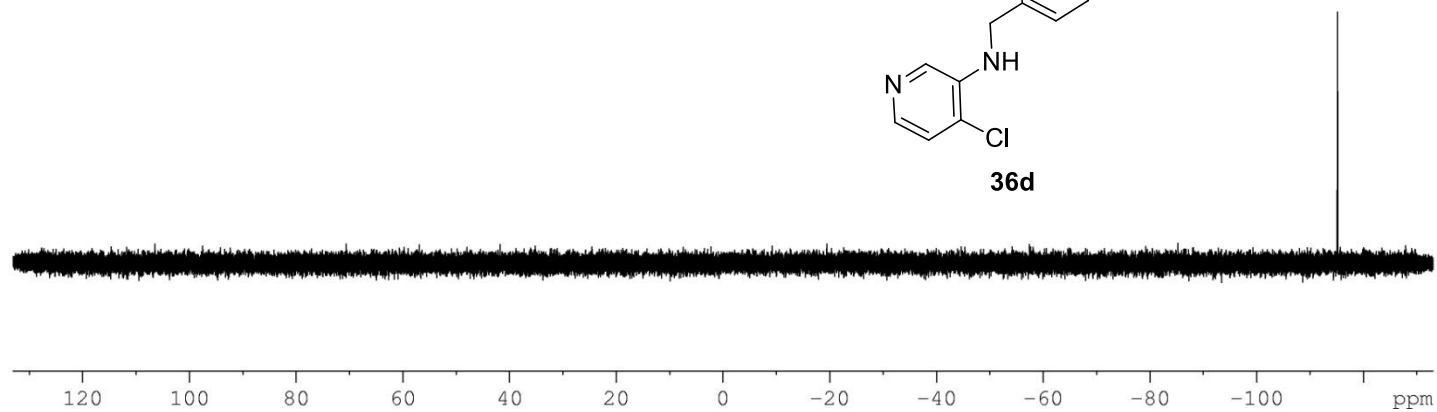
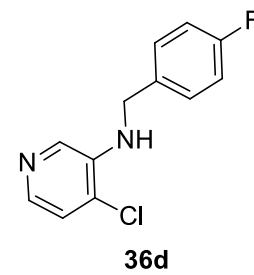
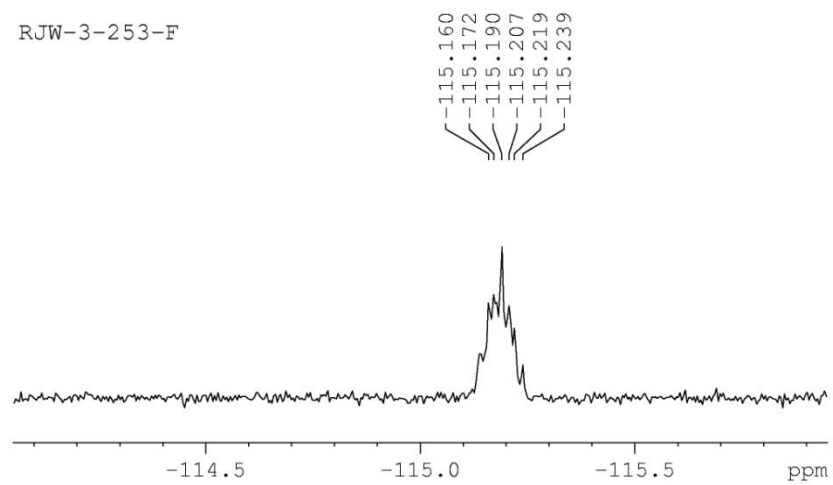
7.987
7.911
7.894
7.358
7.351
7.341
7.339
7.336
7.331
7.329
7.319
7.313
7.311
7.260
7.208
7.191
7.080
7.073
7.058
7.051
7.044
7.029
7.022
4.612
4.439
4.420

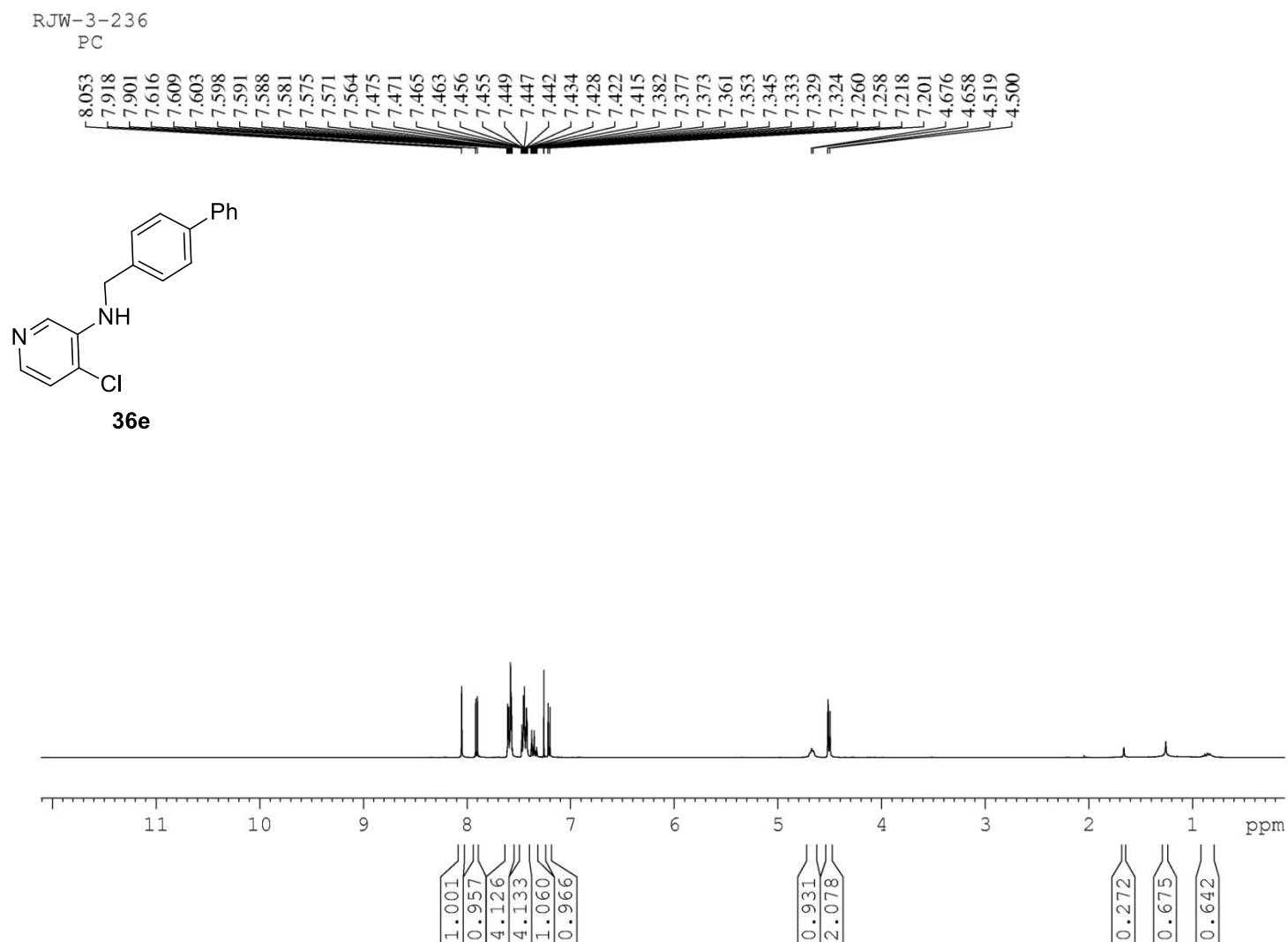


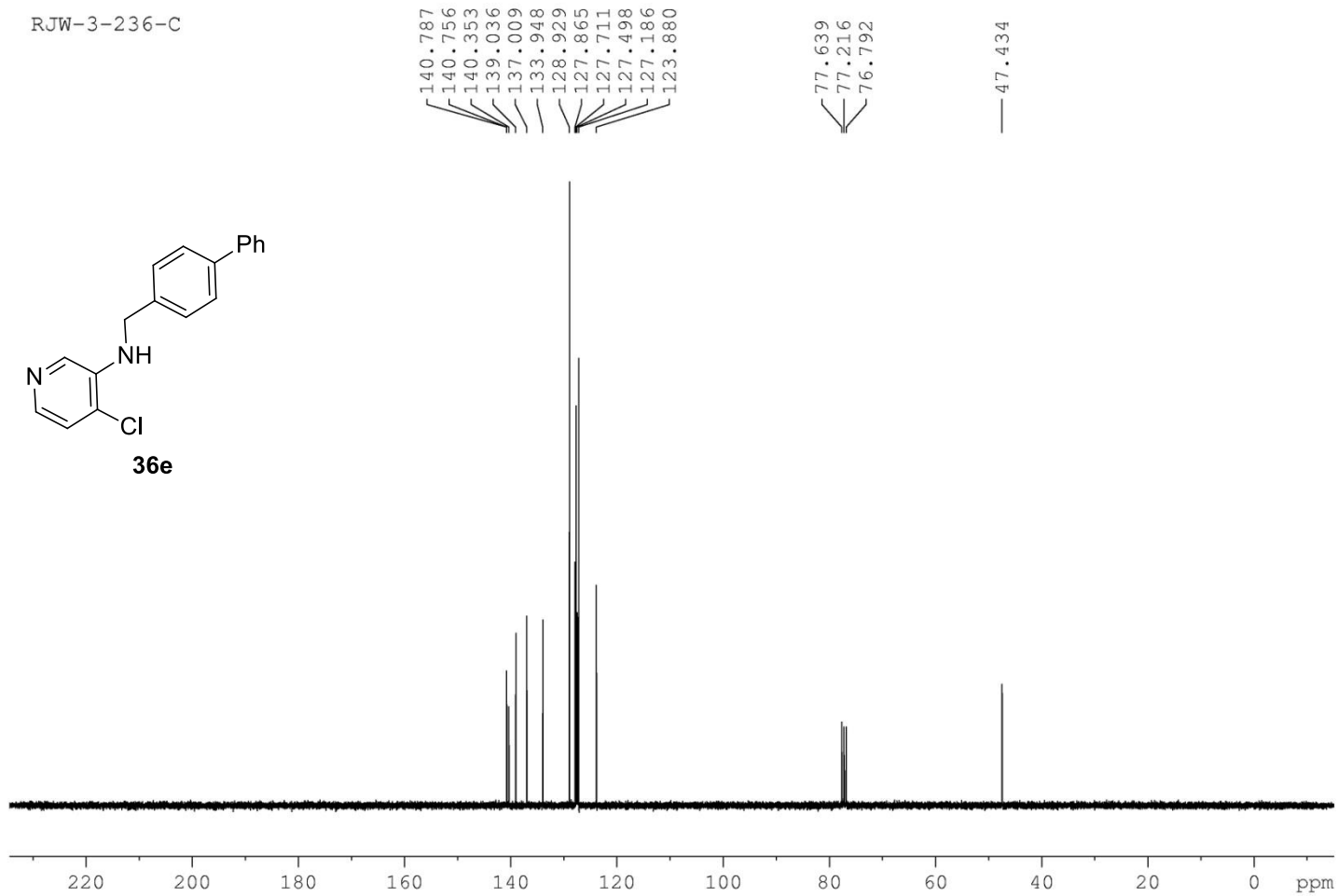
RJW-3-253-C



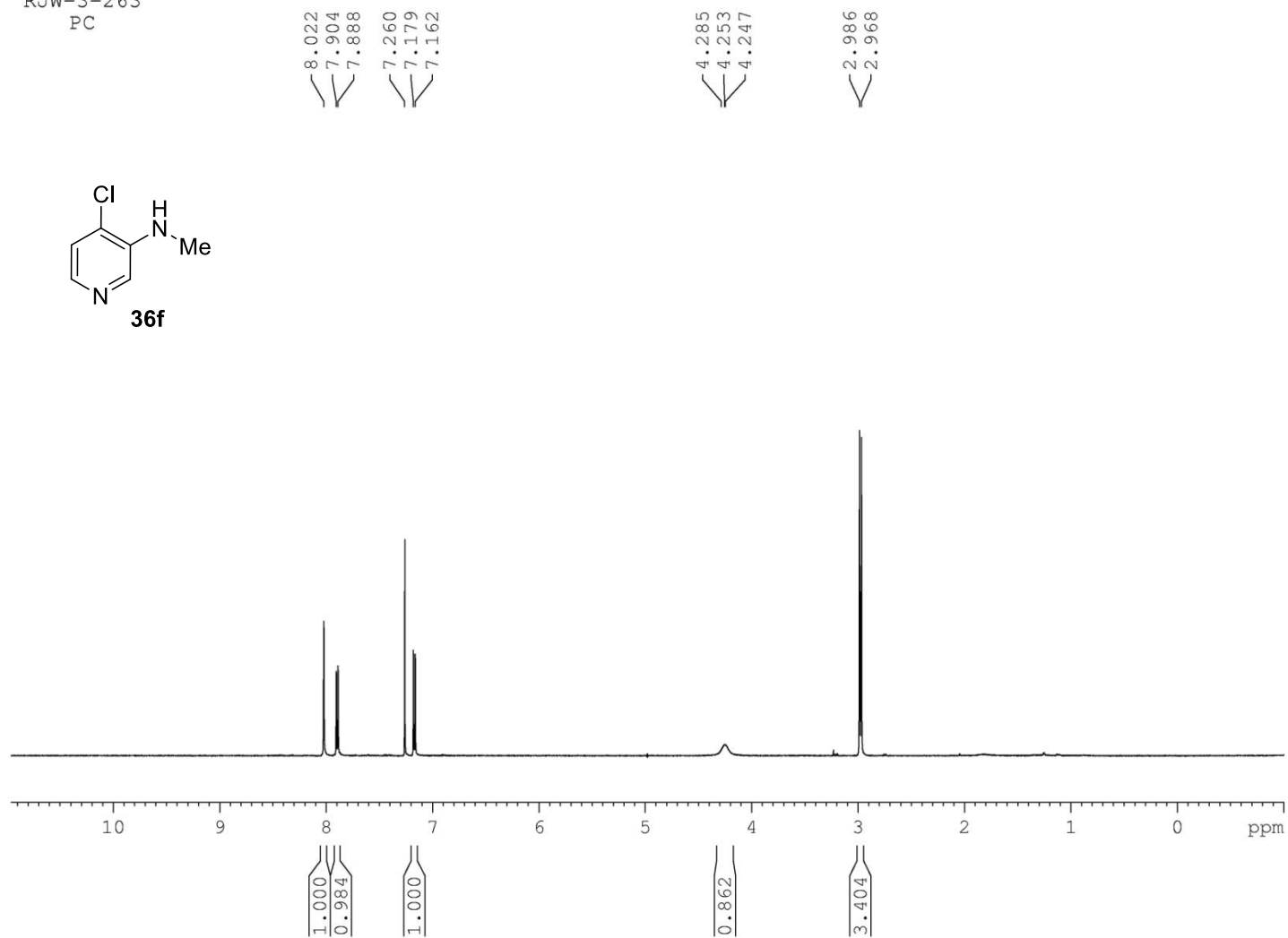
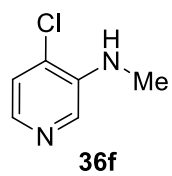
RJW-3-253-F







RJW-3-263
PC

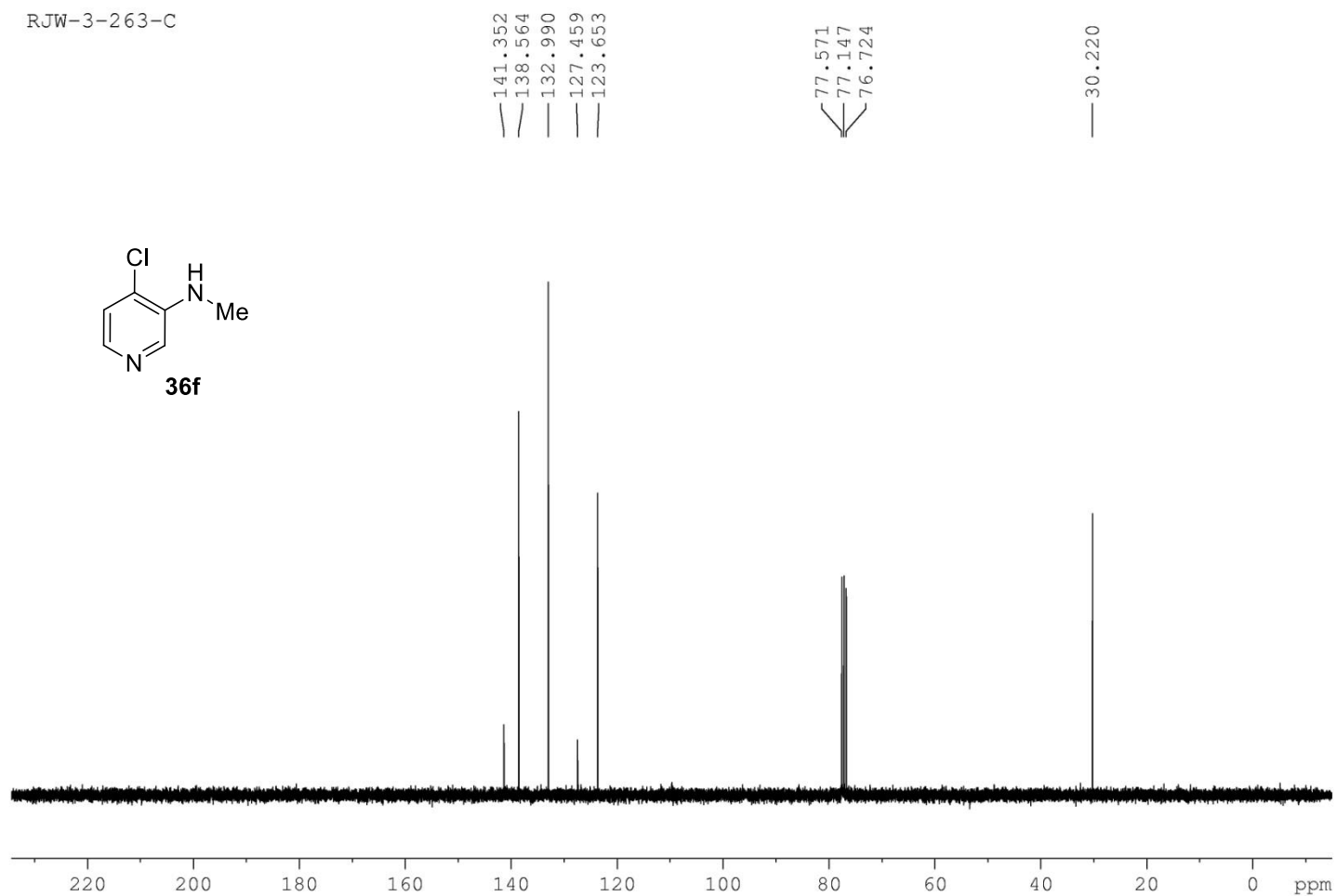
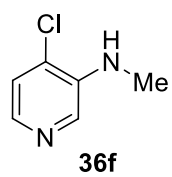


RJW-3-263-C

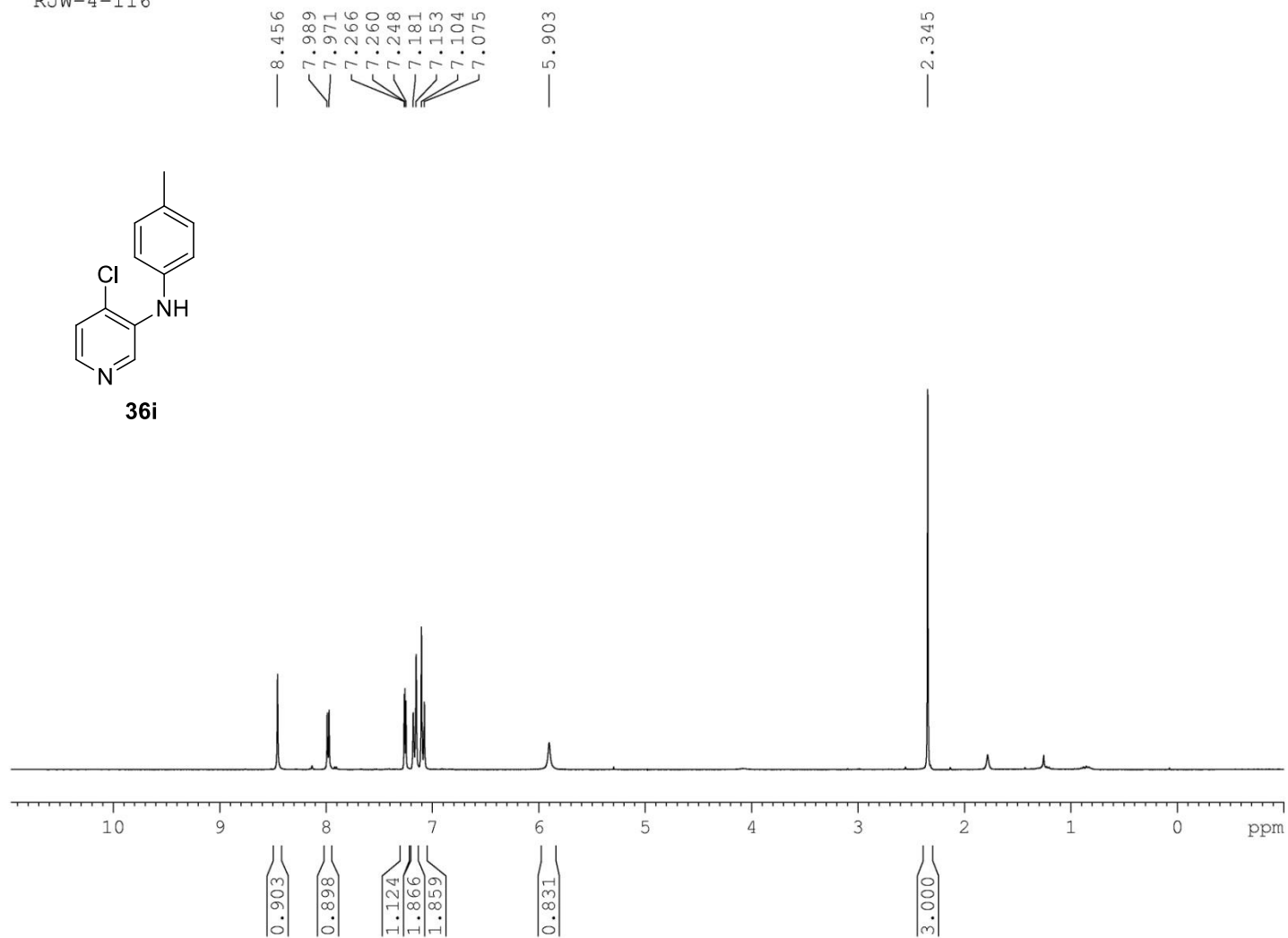
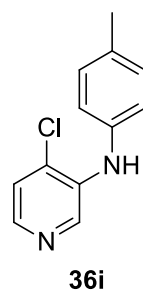
141.352
138.564
132.990
127.459
123.653

77.571
77.147
76.724

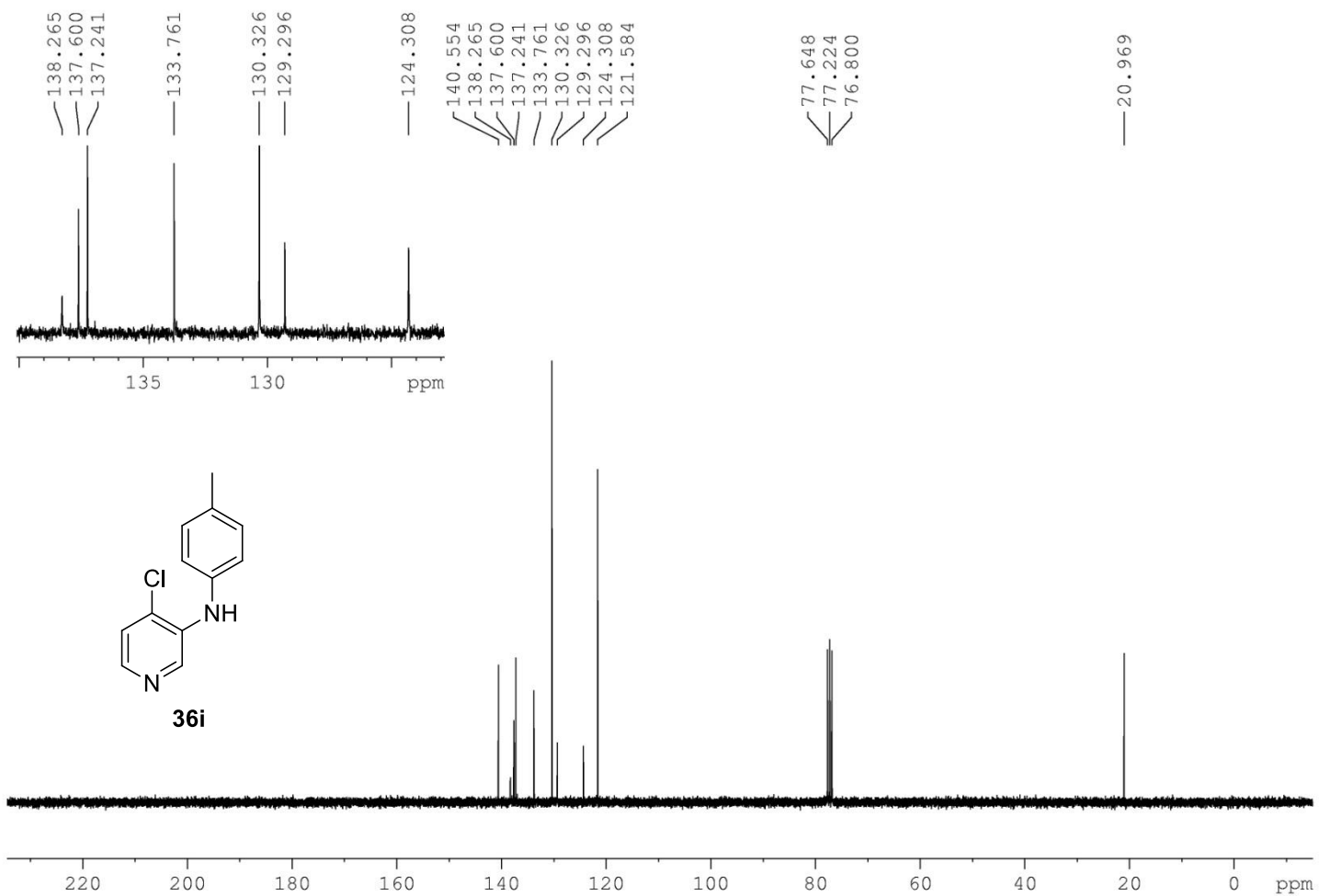
30.220



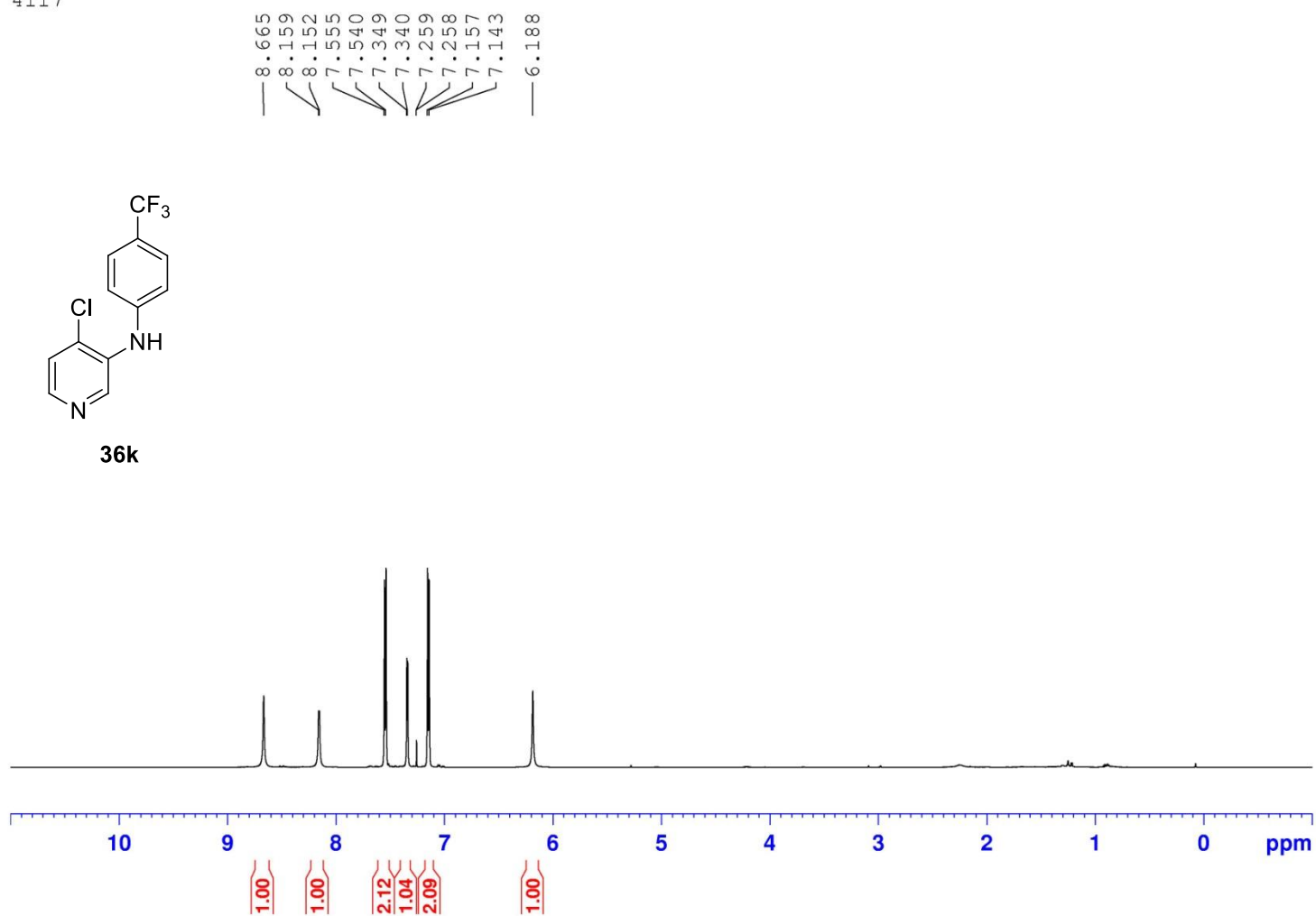
RJW-4-116



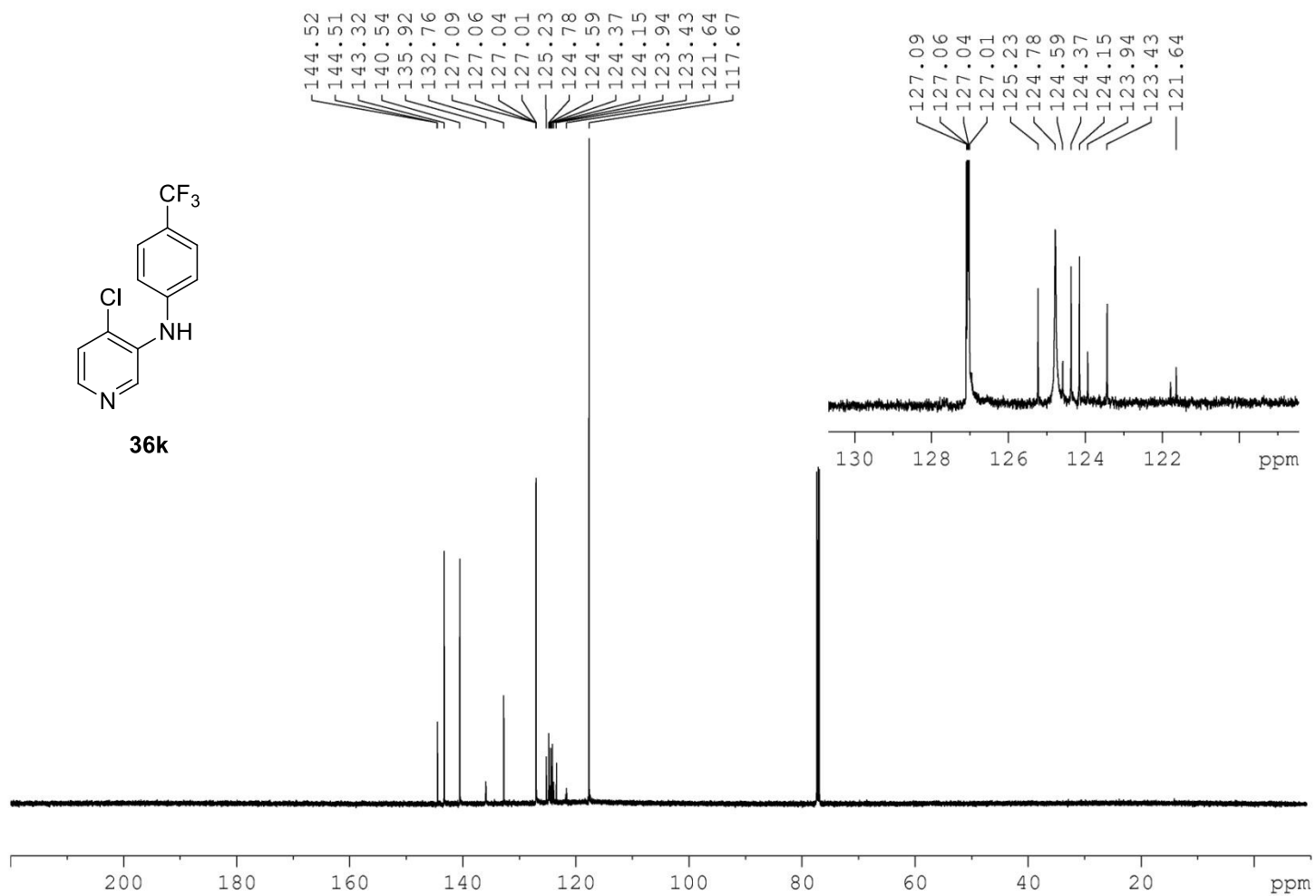
RJW-4-116-C



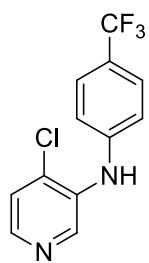
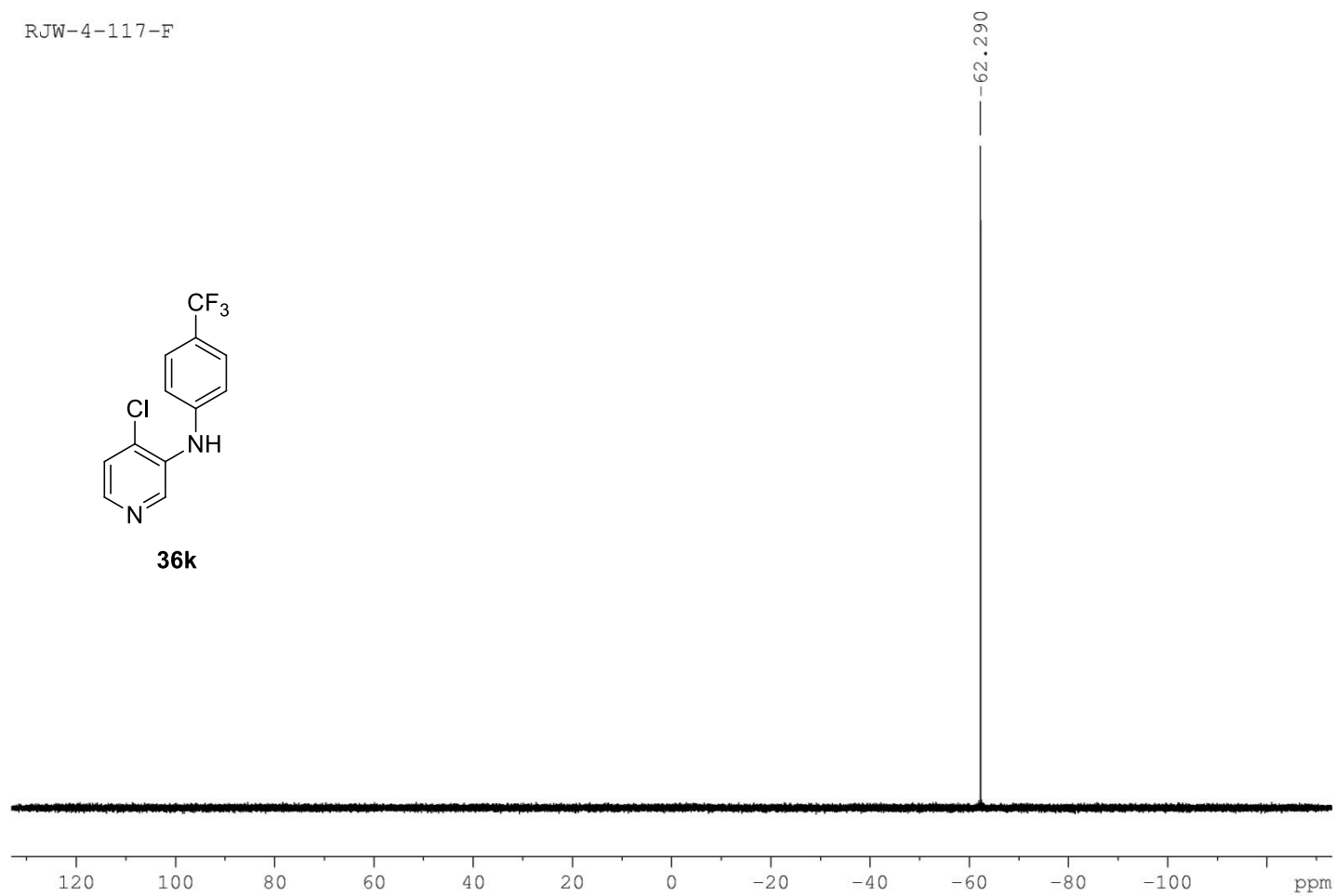
4117

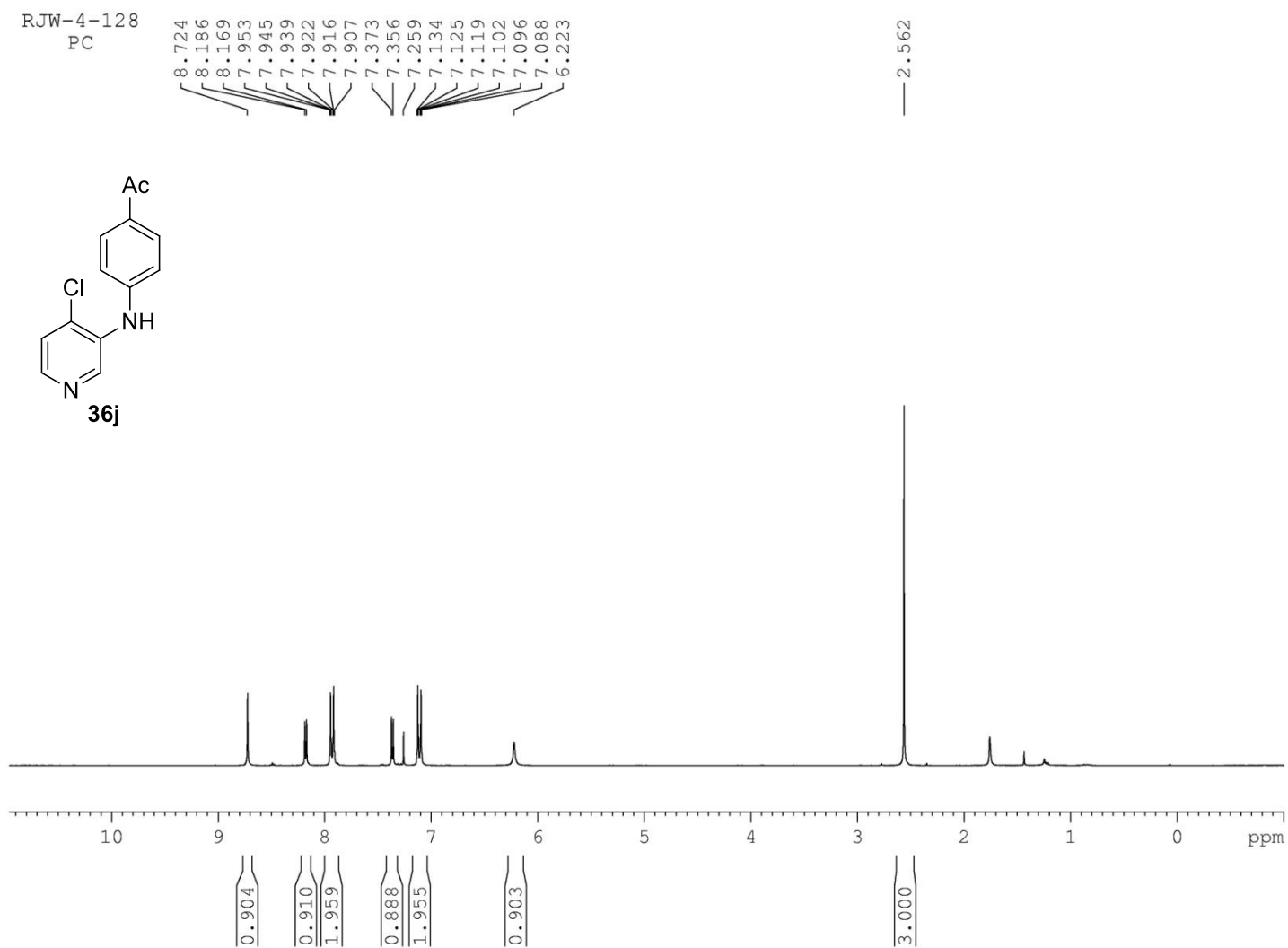


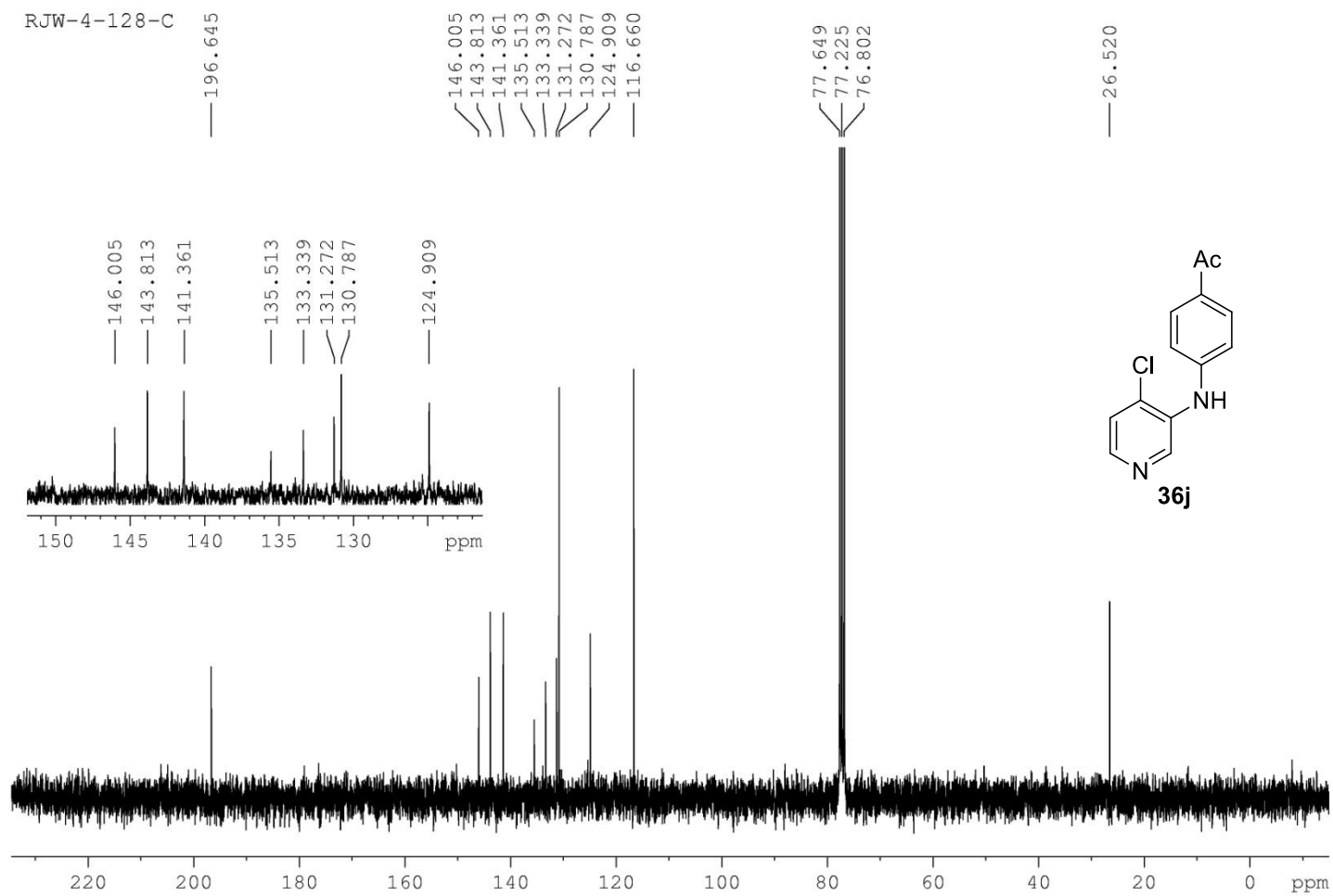
4117

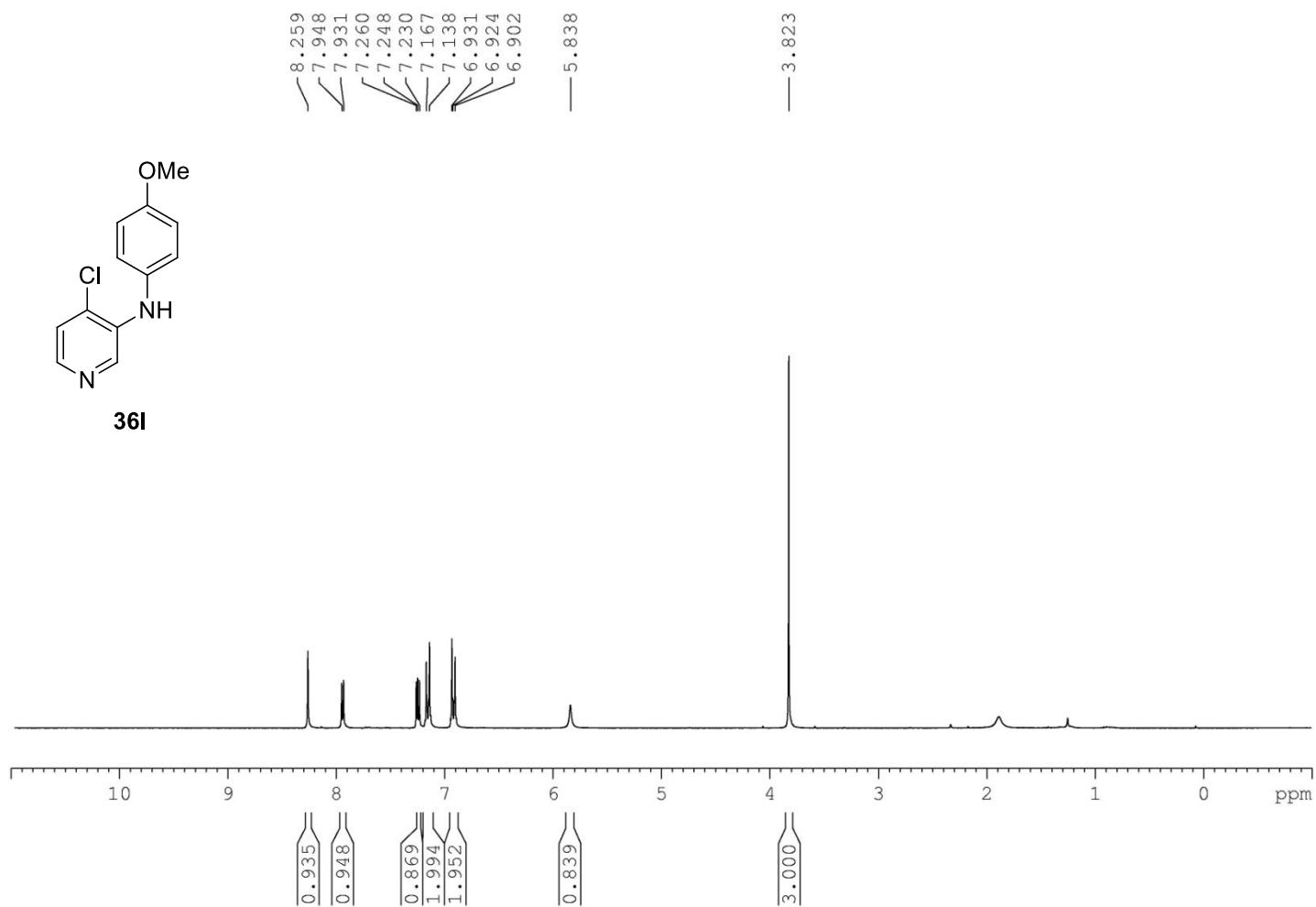


RJW-4-117-F

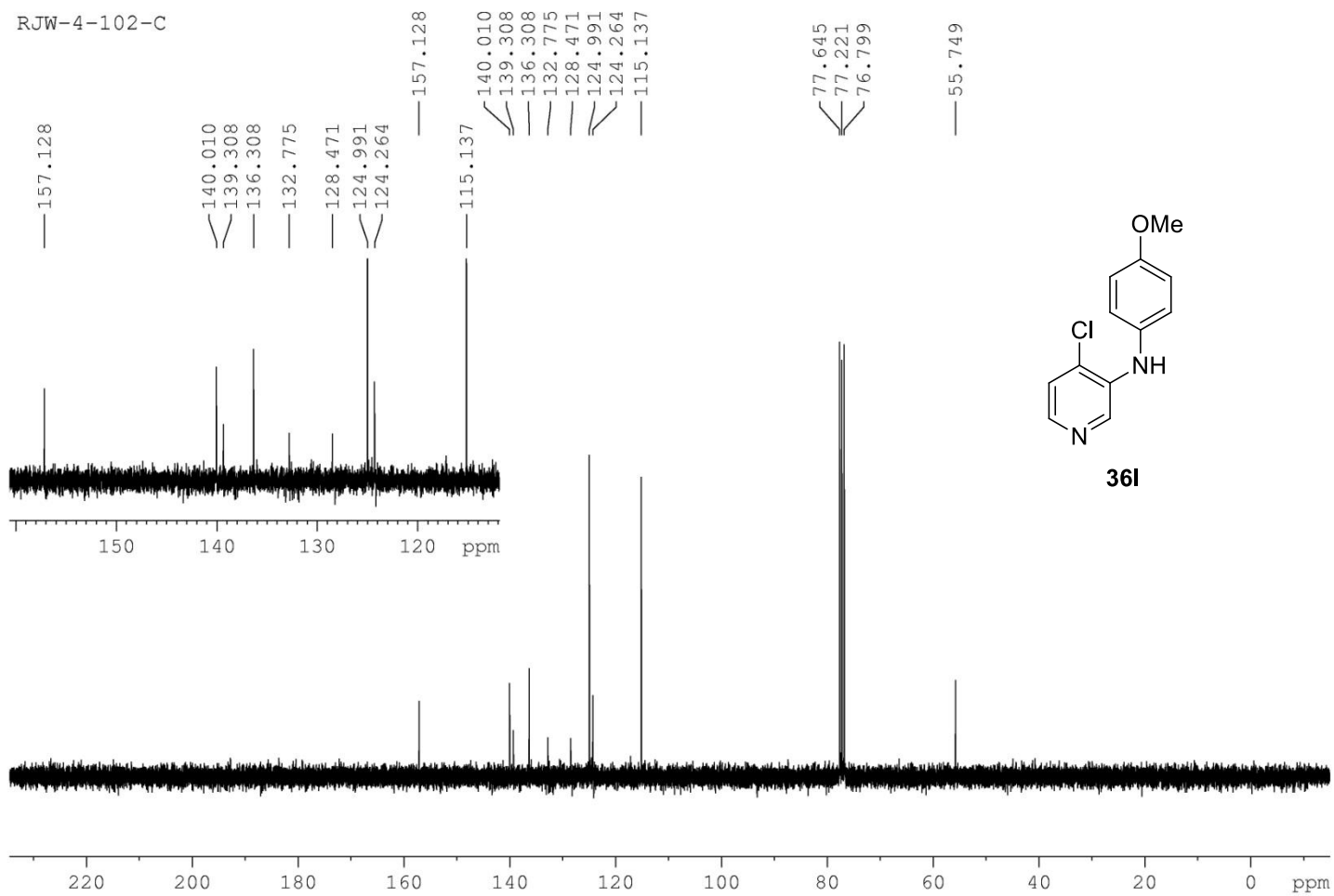
**36k**



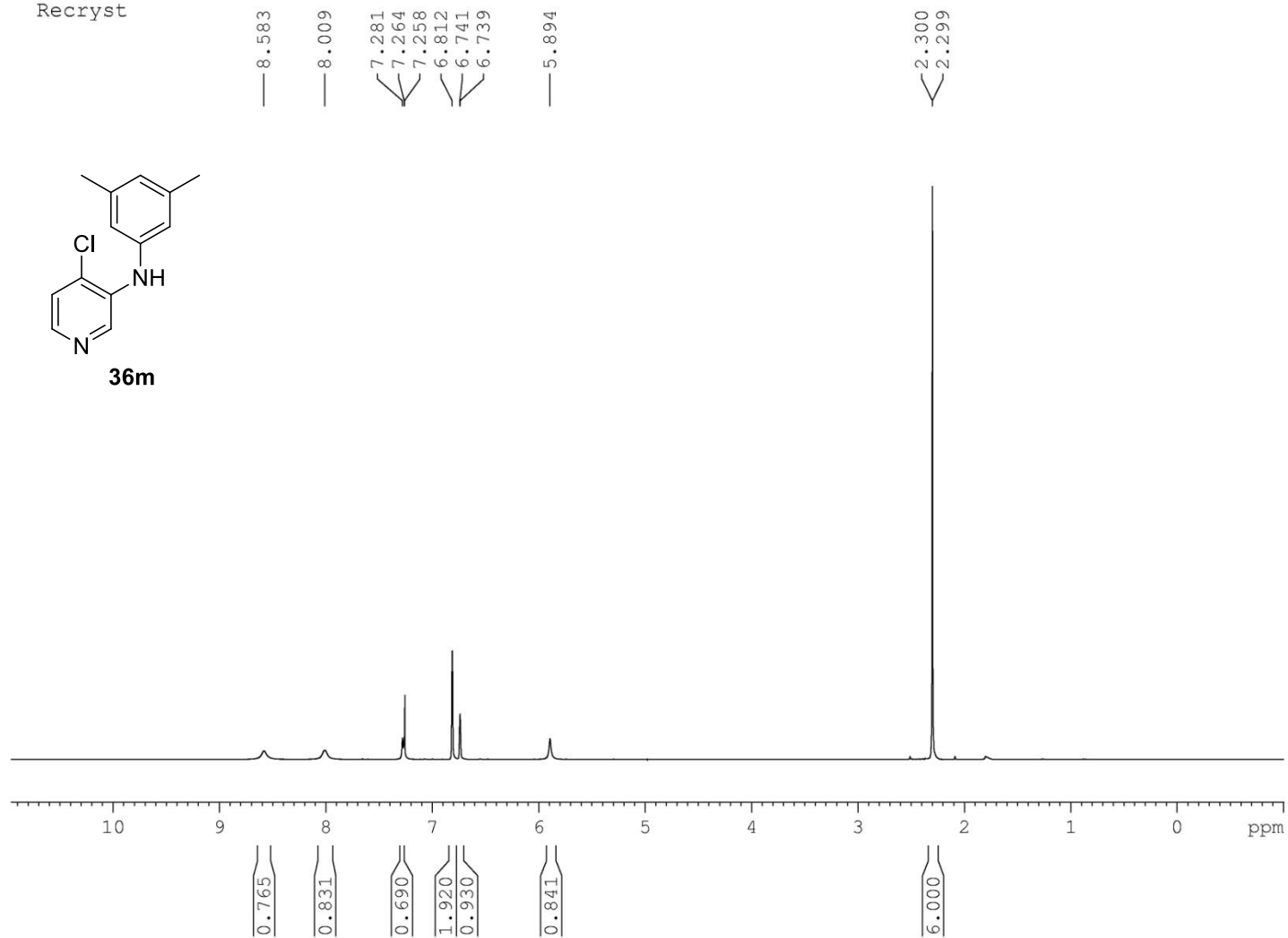


RJW-4-102
2

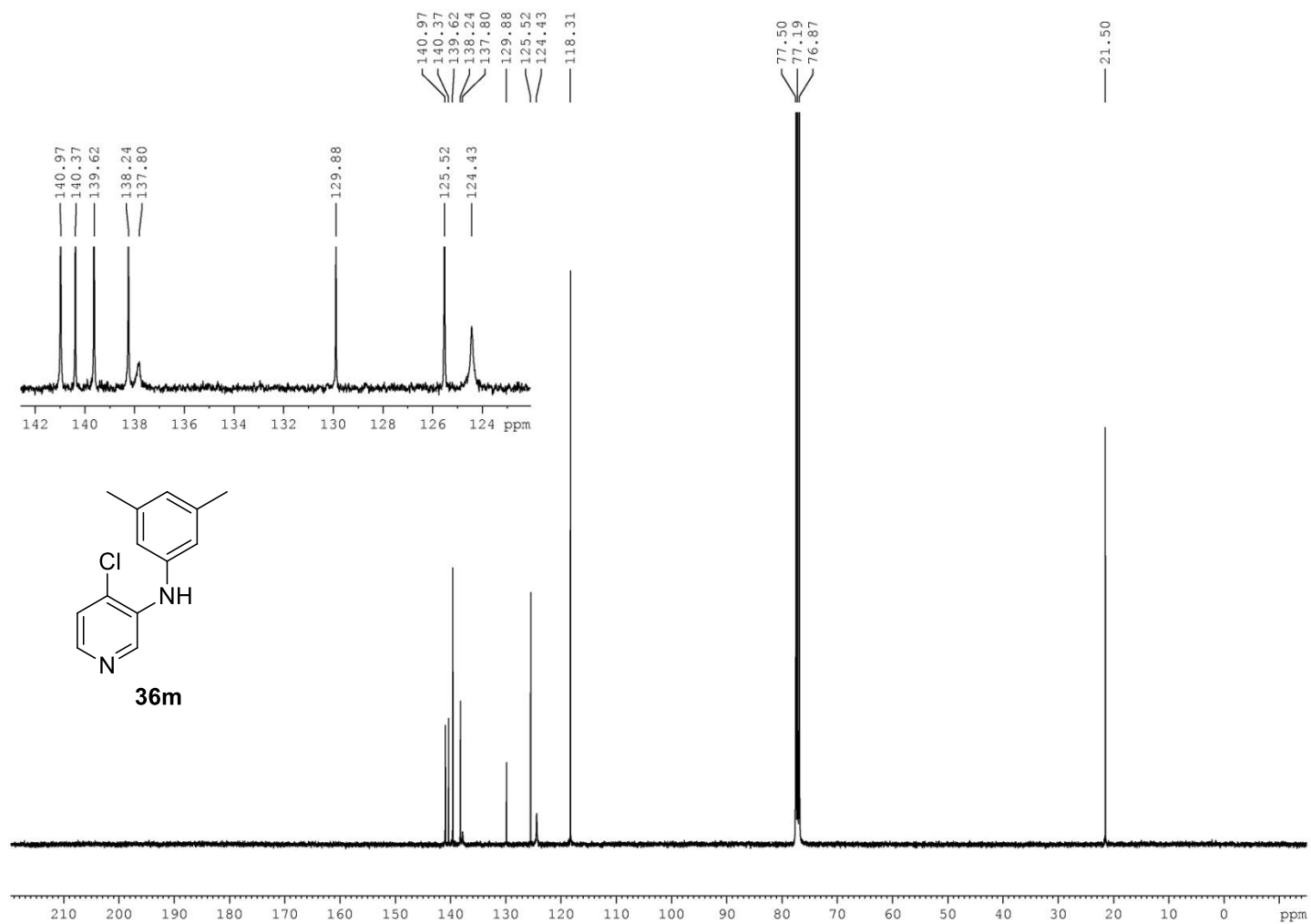
RJW-4-102-C



RJW-4-150
Recryst

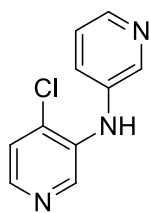


LIMS Container ID RJW-4-150

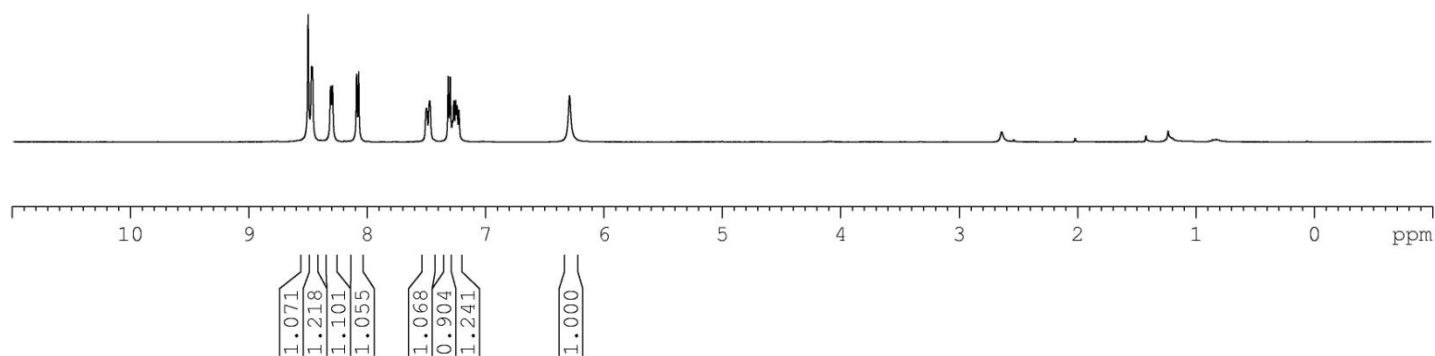


RJW-4-132
PC

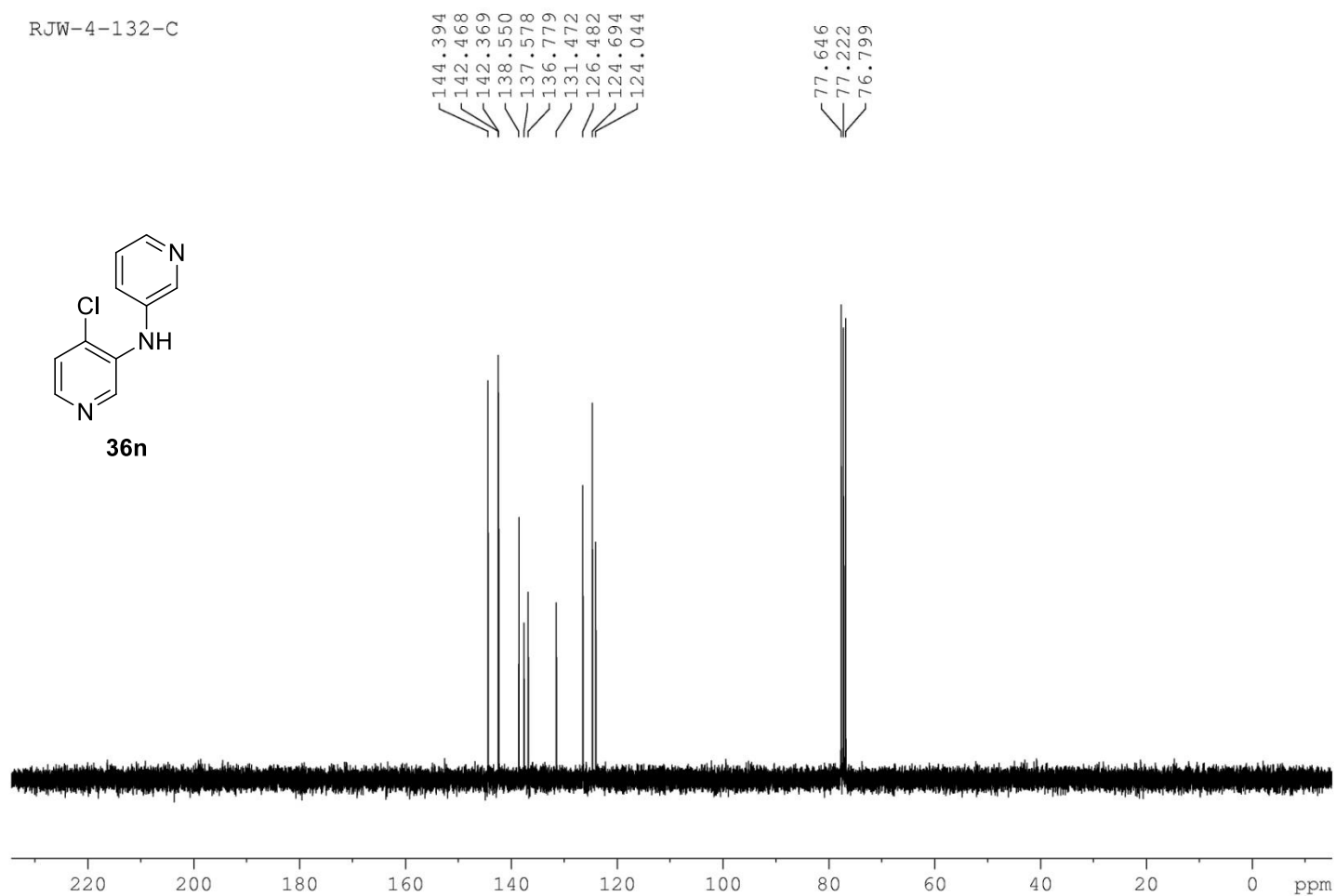
8.496
8.467
8.459
8.306
8.291
8.086
8.069
7.496
7.469
7.312
7.295
7.276
7.265
7.249
7.237
7.222
6.287



36n

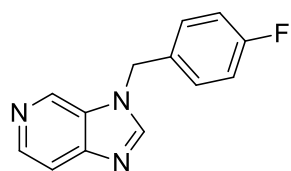


RJW-4-132-C

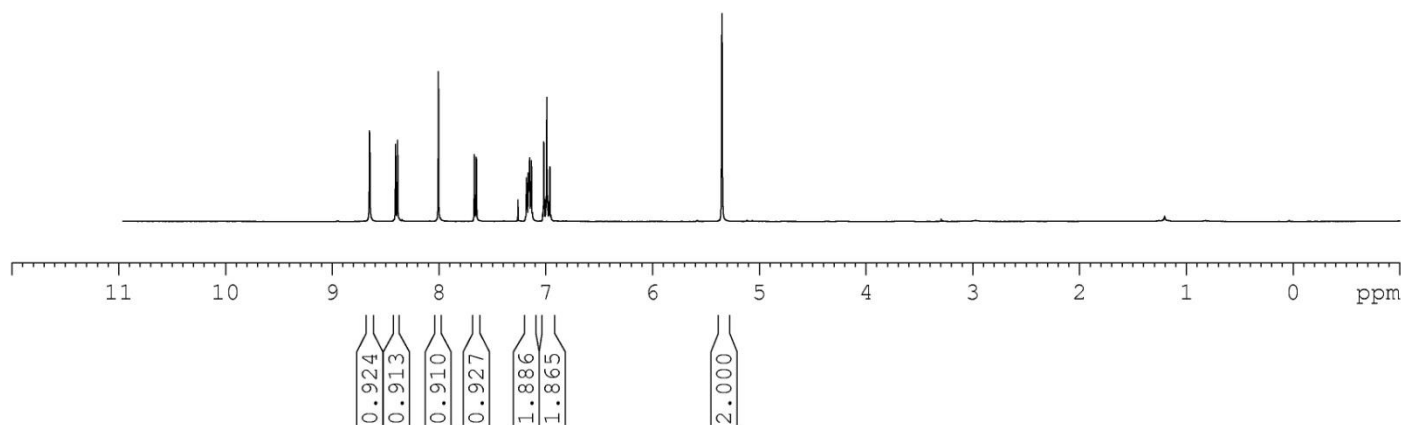


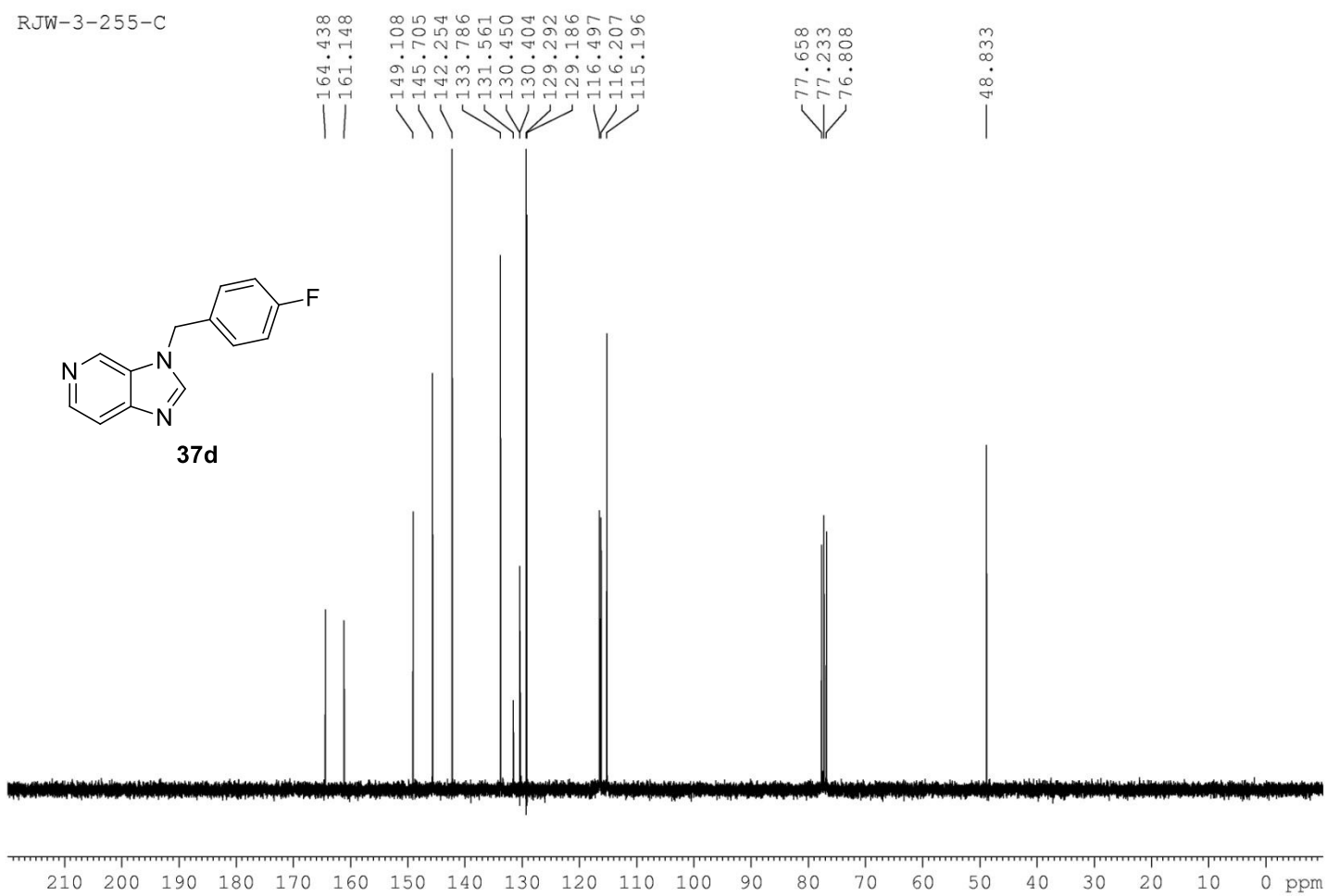
RJW-3-255
PC

8.651
8.648
8.407
8.388
8.005
7.670
7.666
7.651
7.647
7.260
7.180
7.173
7.163
7.158
7.151
7.141
7.133
7.018
7.011
6.999
6.995
6.989
6.982
6.968
6.961
5.349

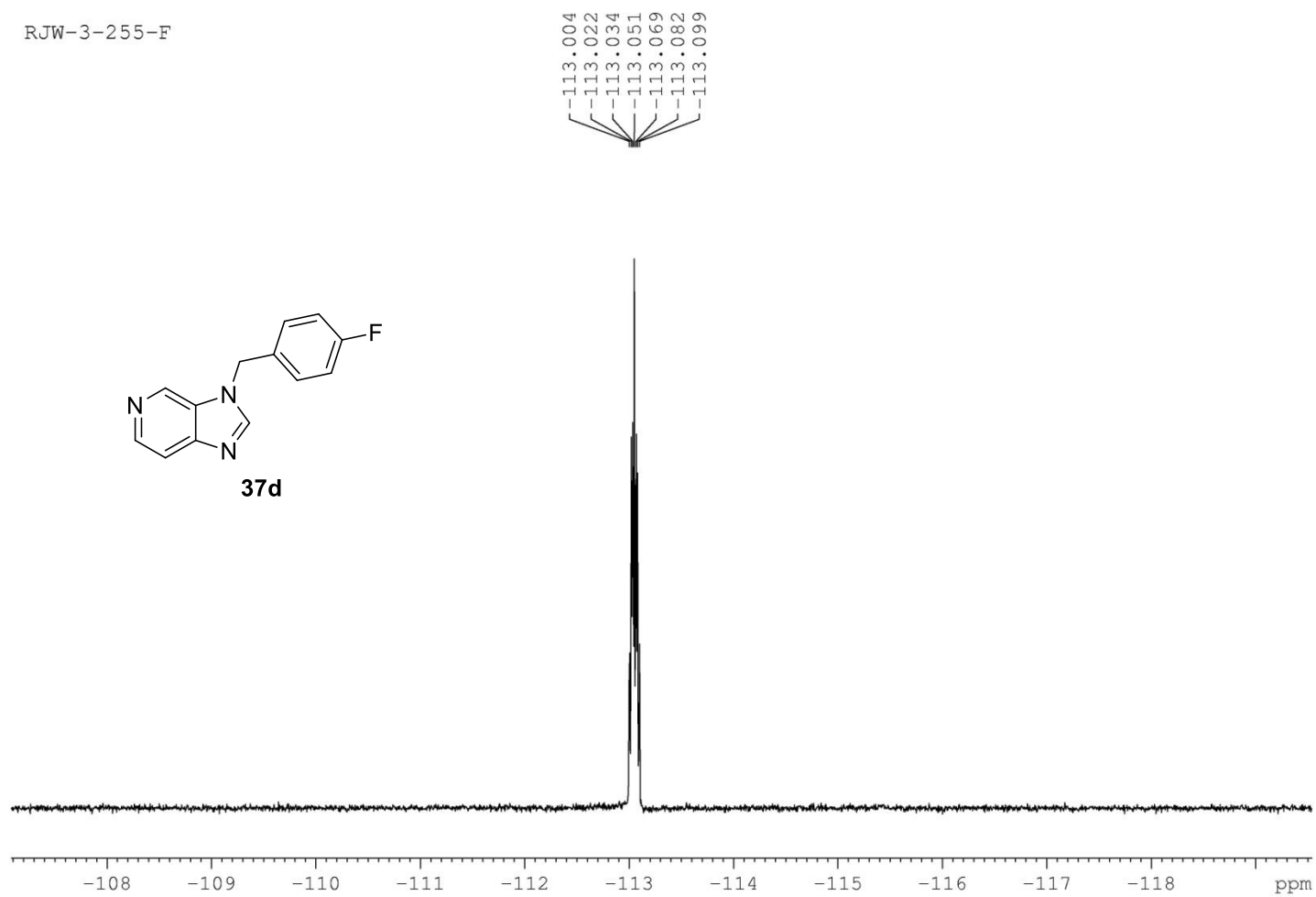


37d

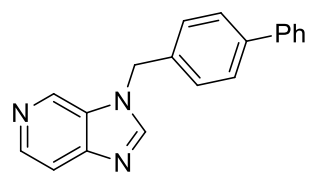
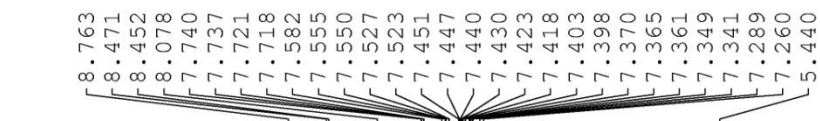




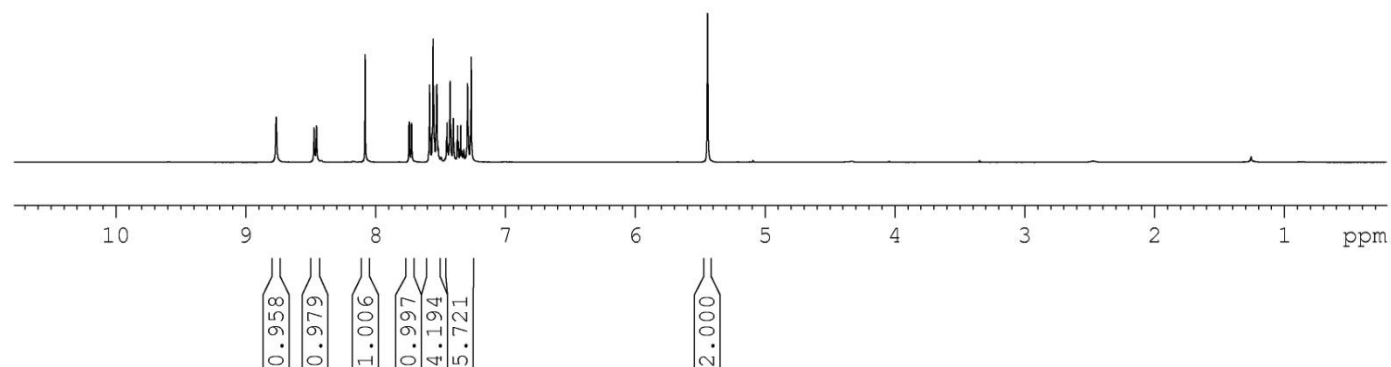
RJW-3-255-F

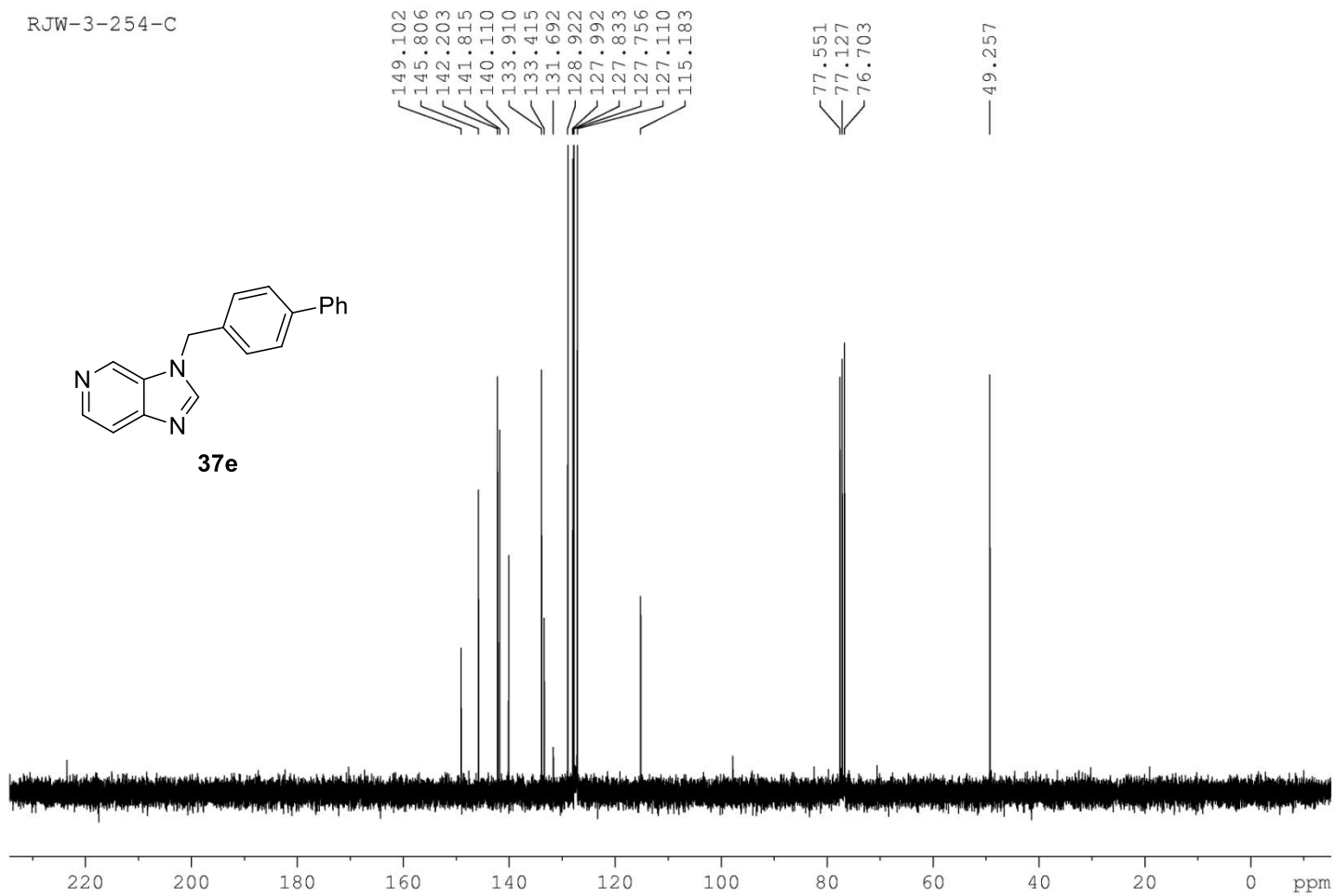


RJW-3-254
PC NaOH wash



37e

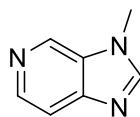




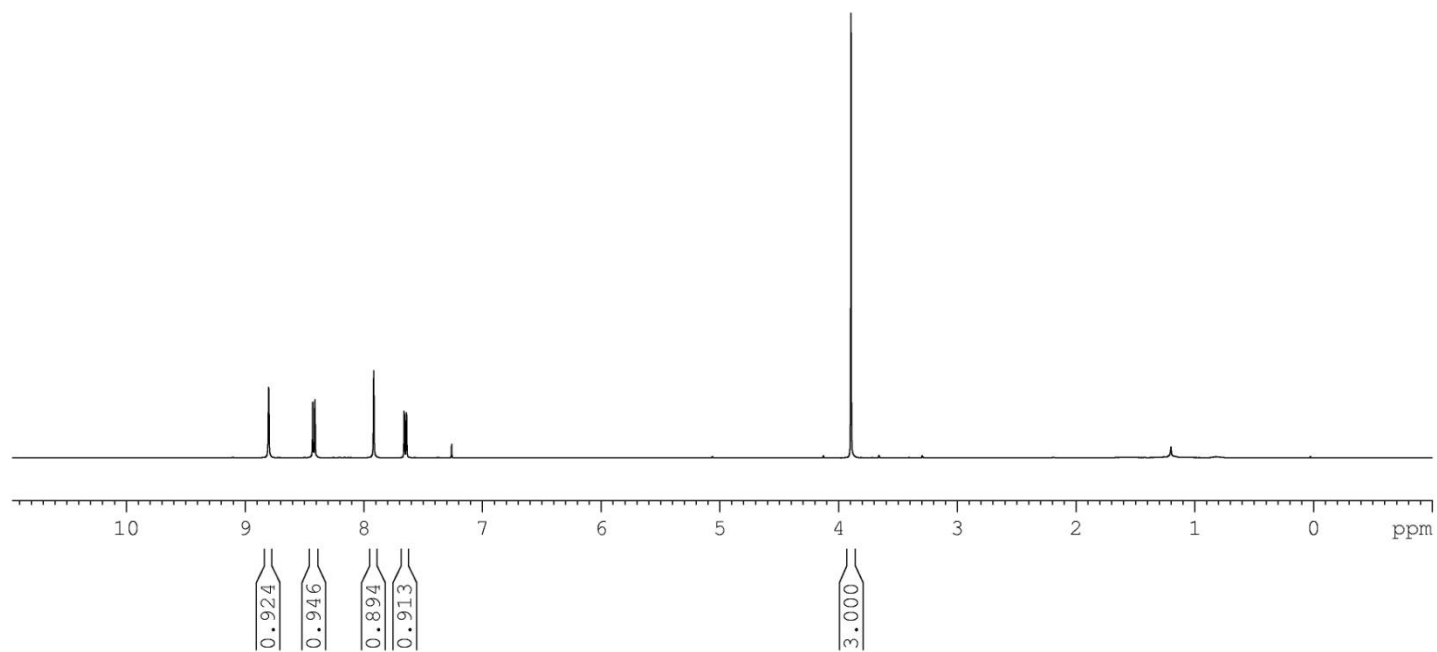
RJW-3-267
PC

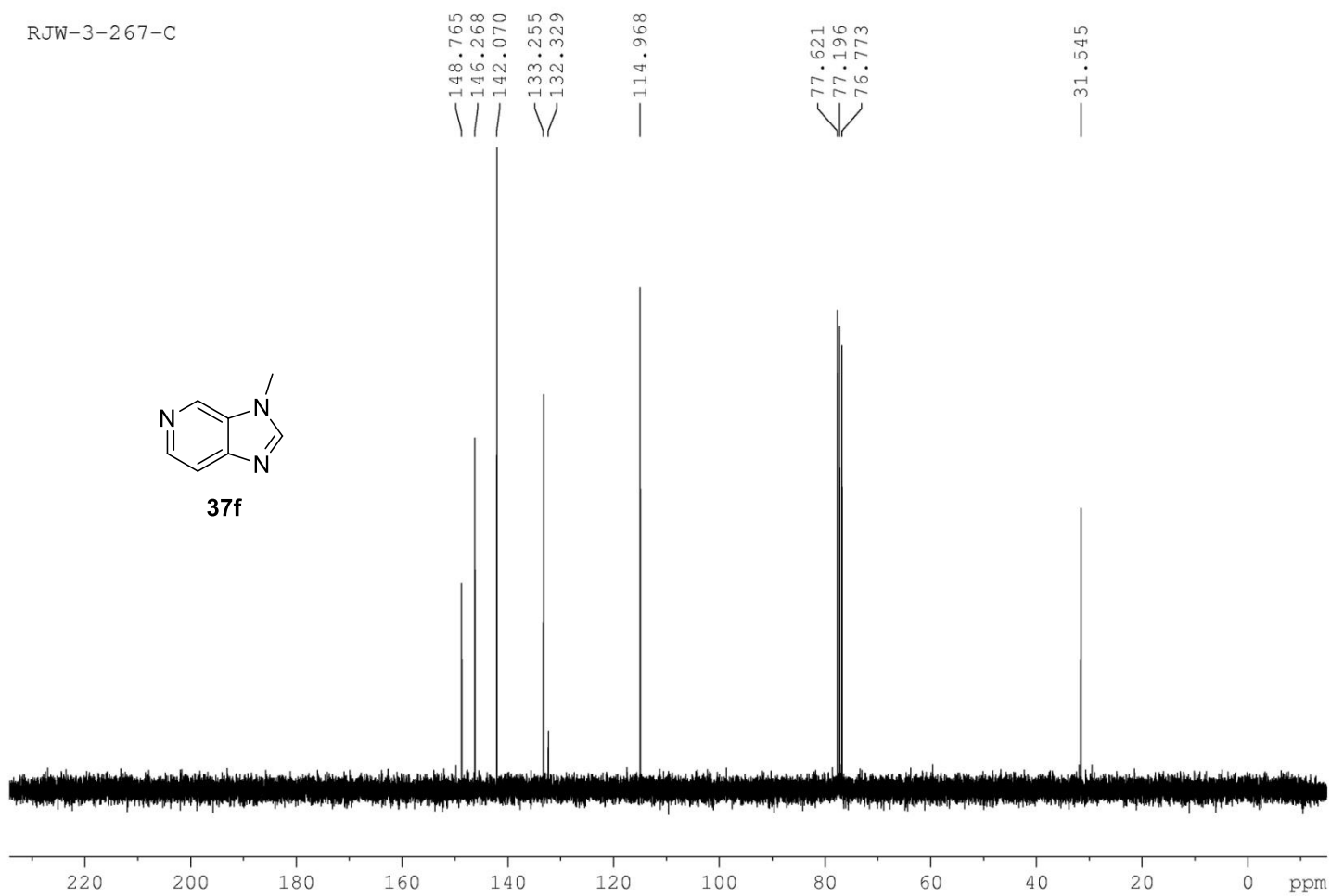
8.802
8.800
8.430
8.411
7.916
7.660
7.657
7.641
7.638

— 3.896

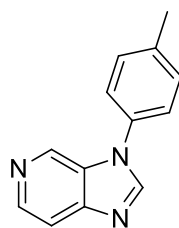
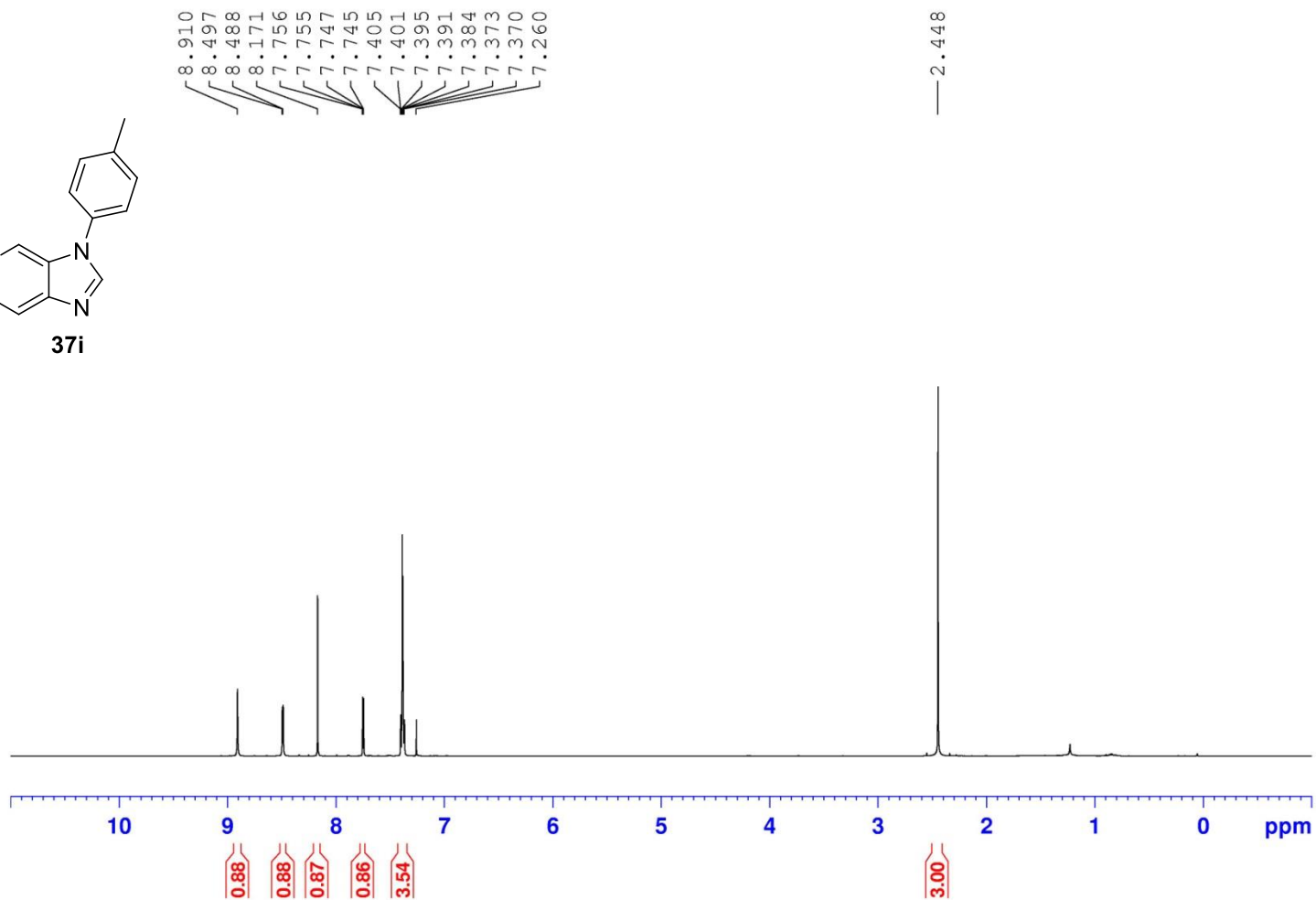


37f

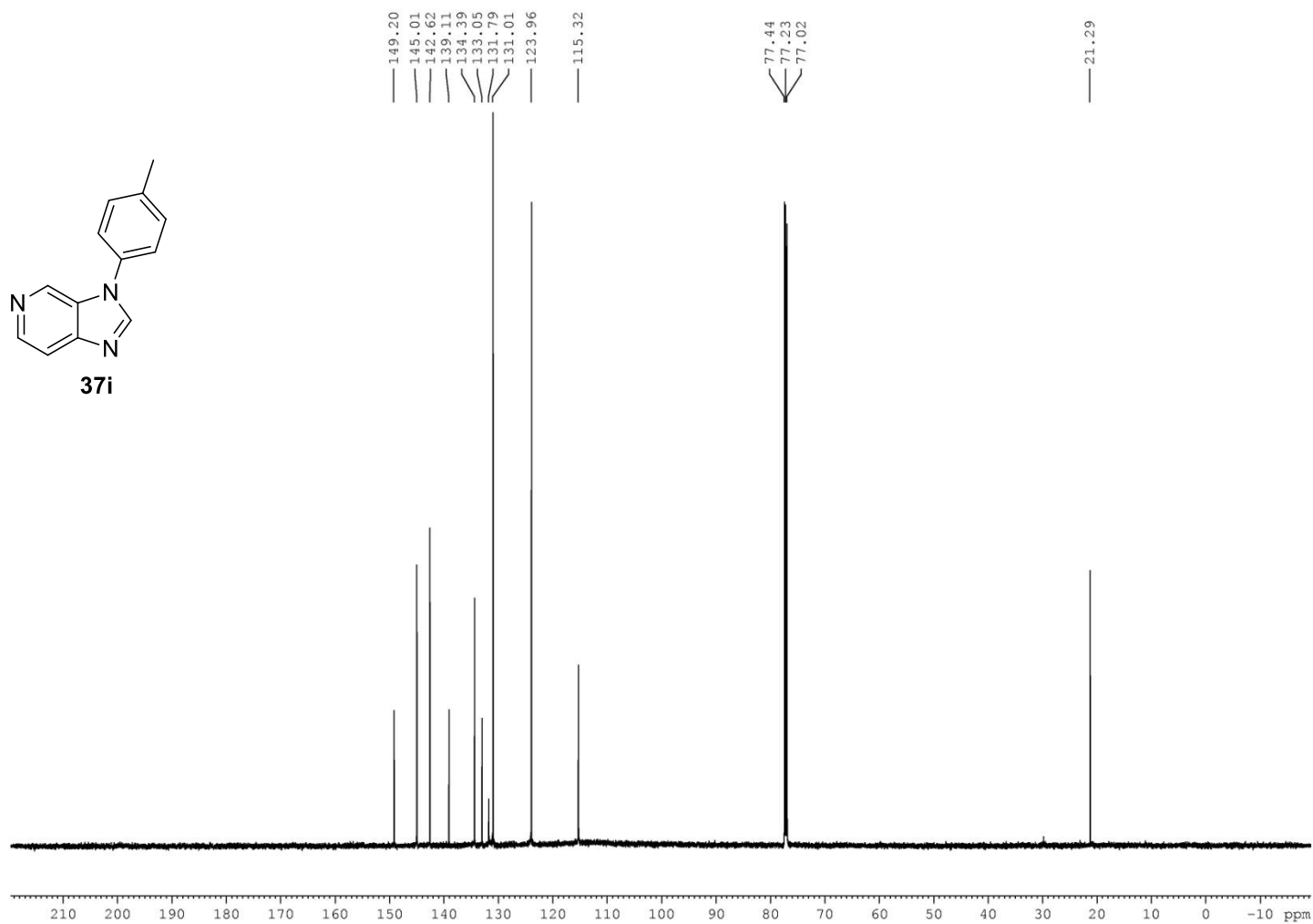
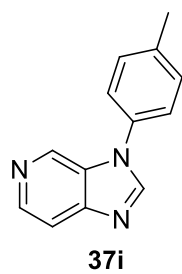


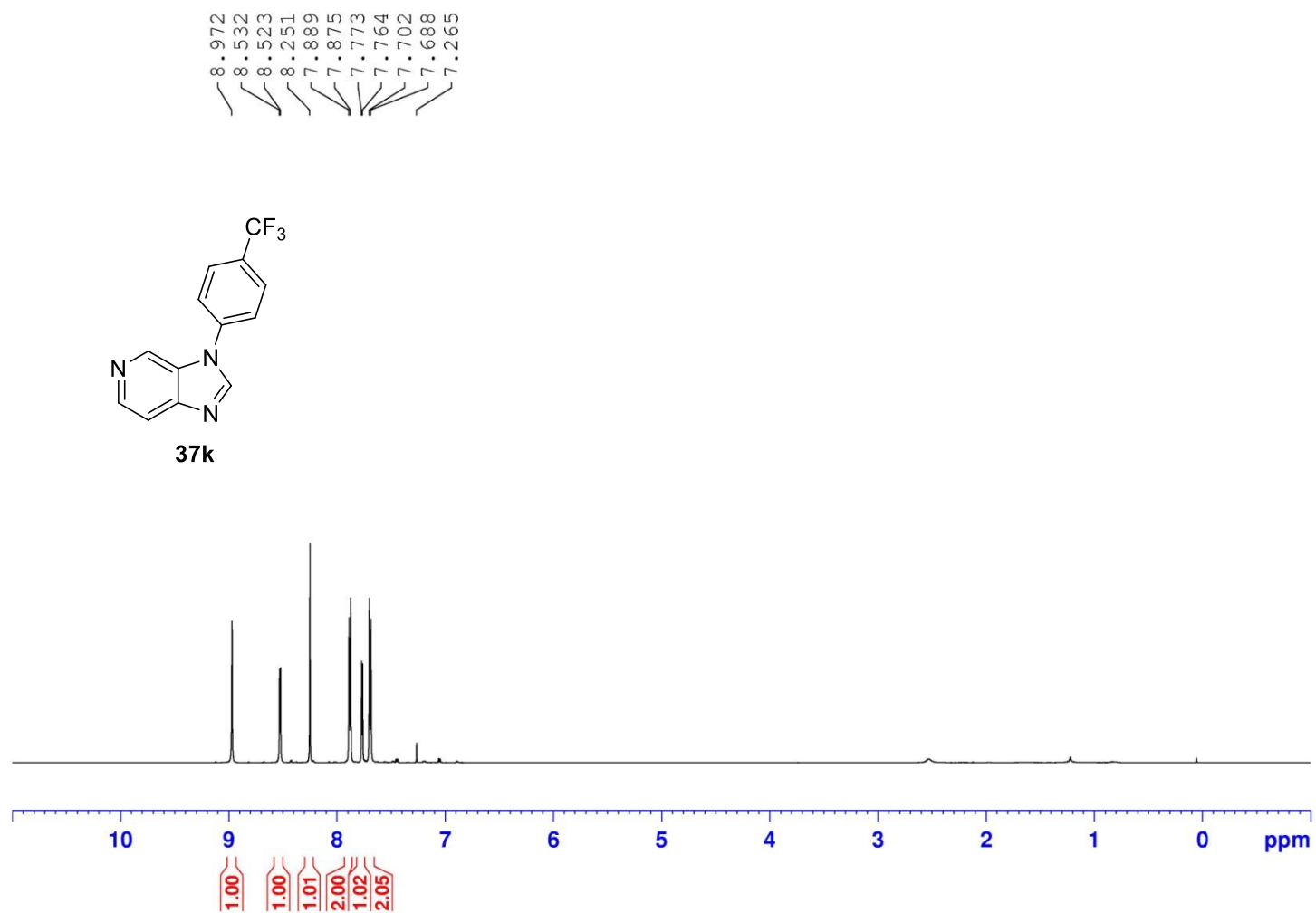


RJW-4-120

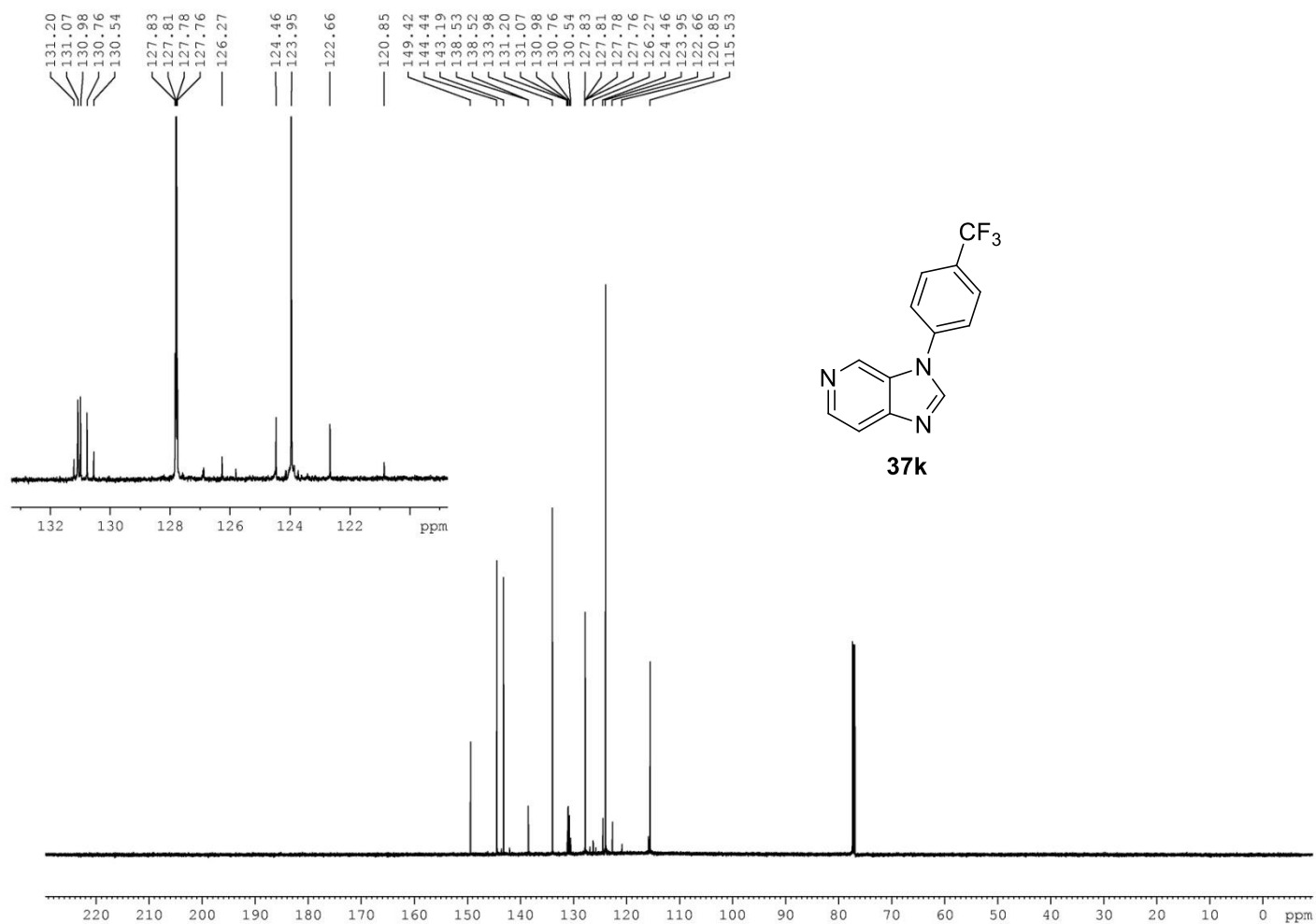
**37i**

RJW-4-120



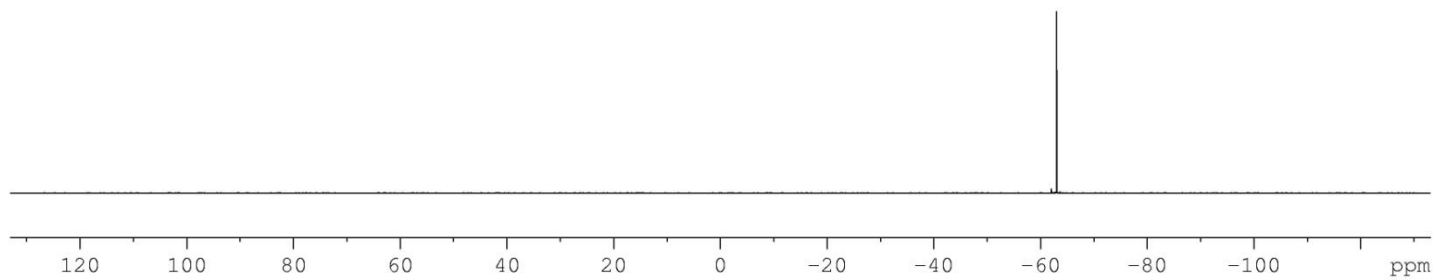
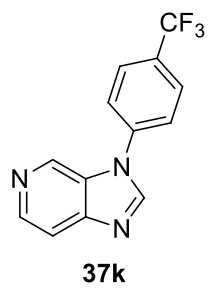


4119

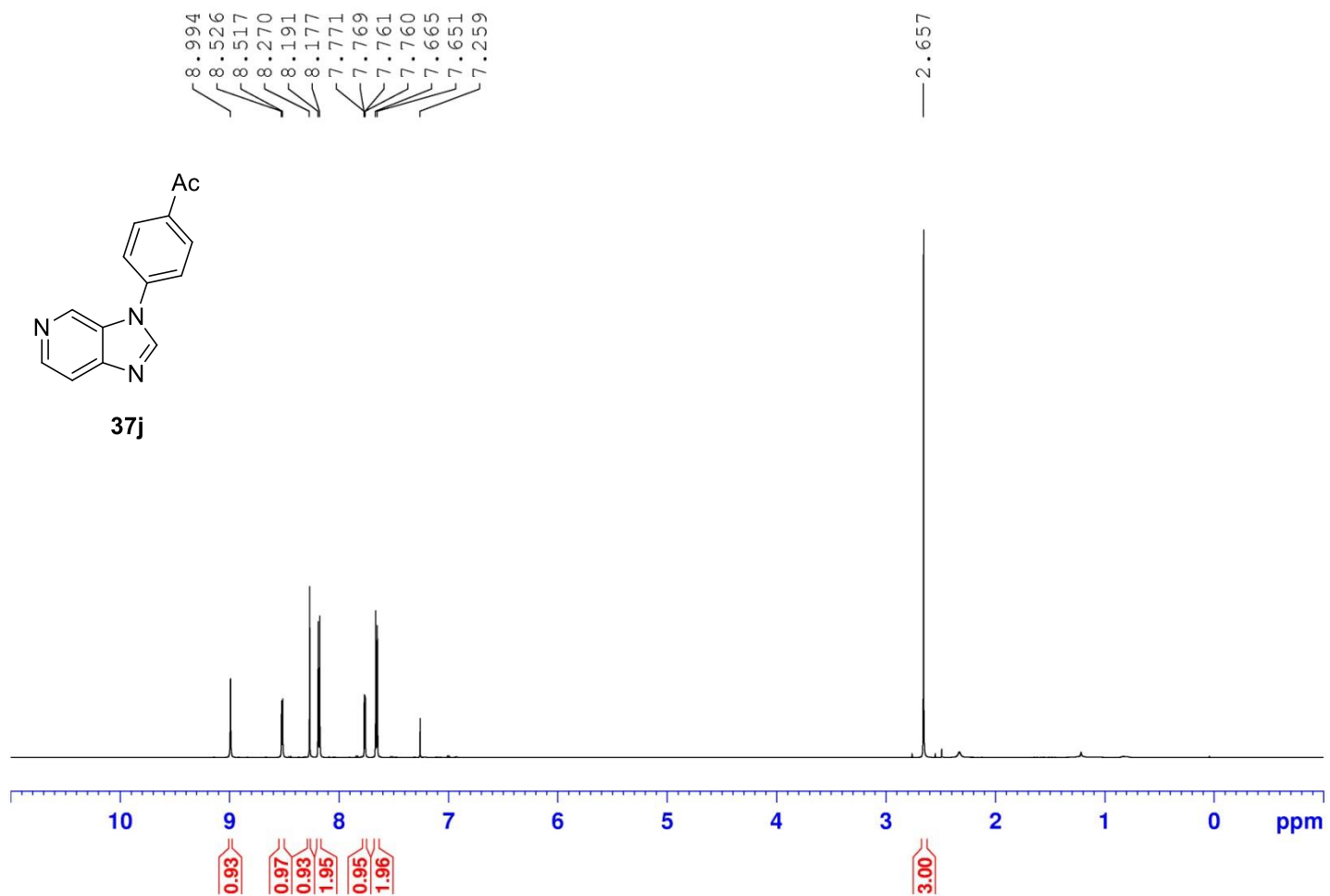


RJW-4-119-F

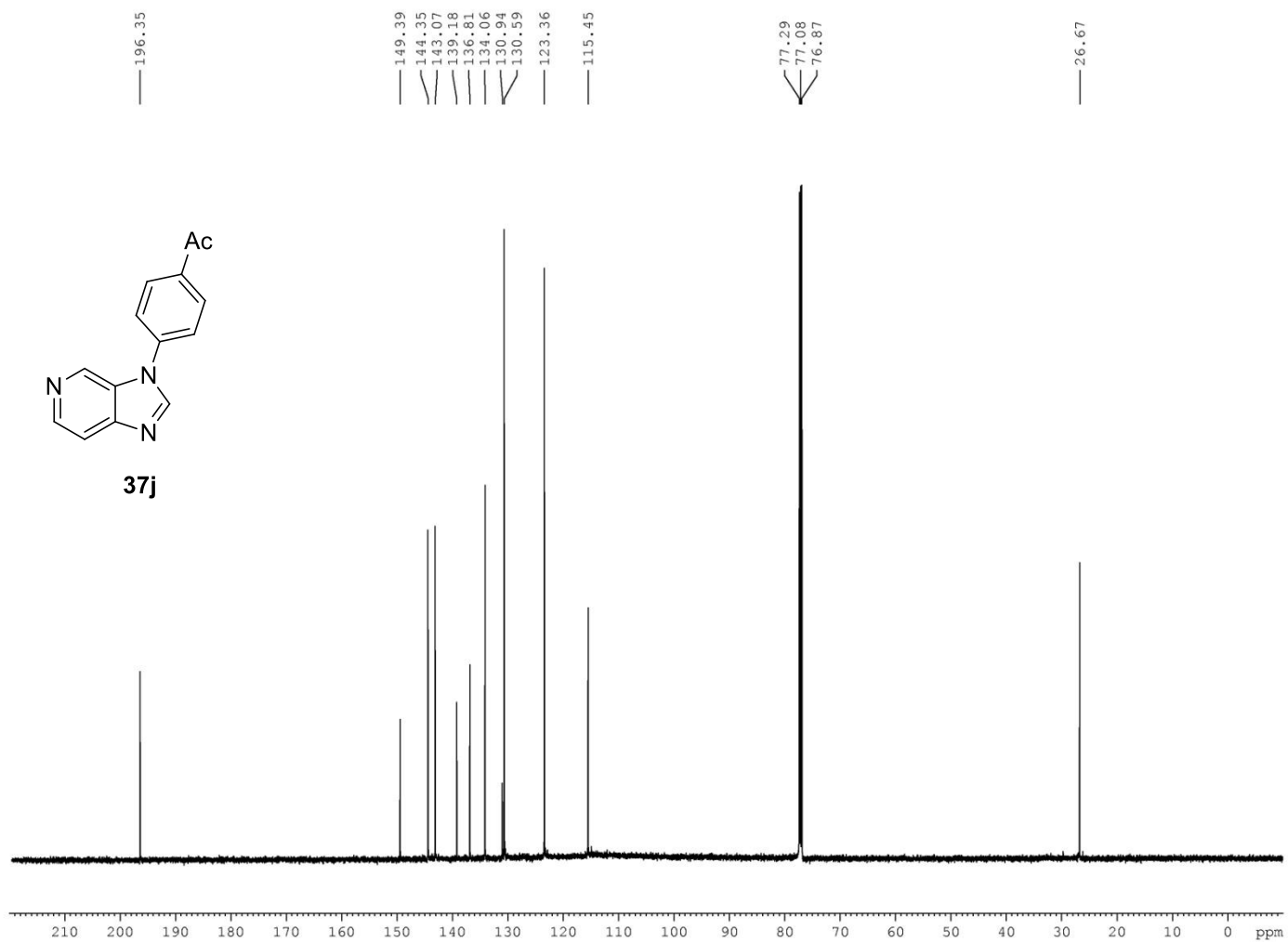
— -63.057

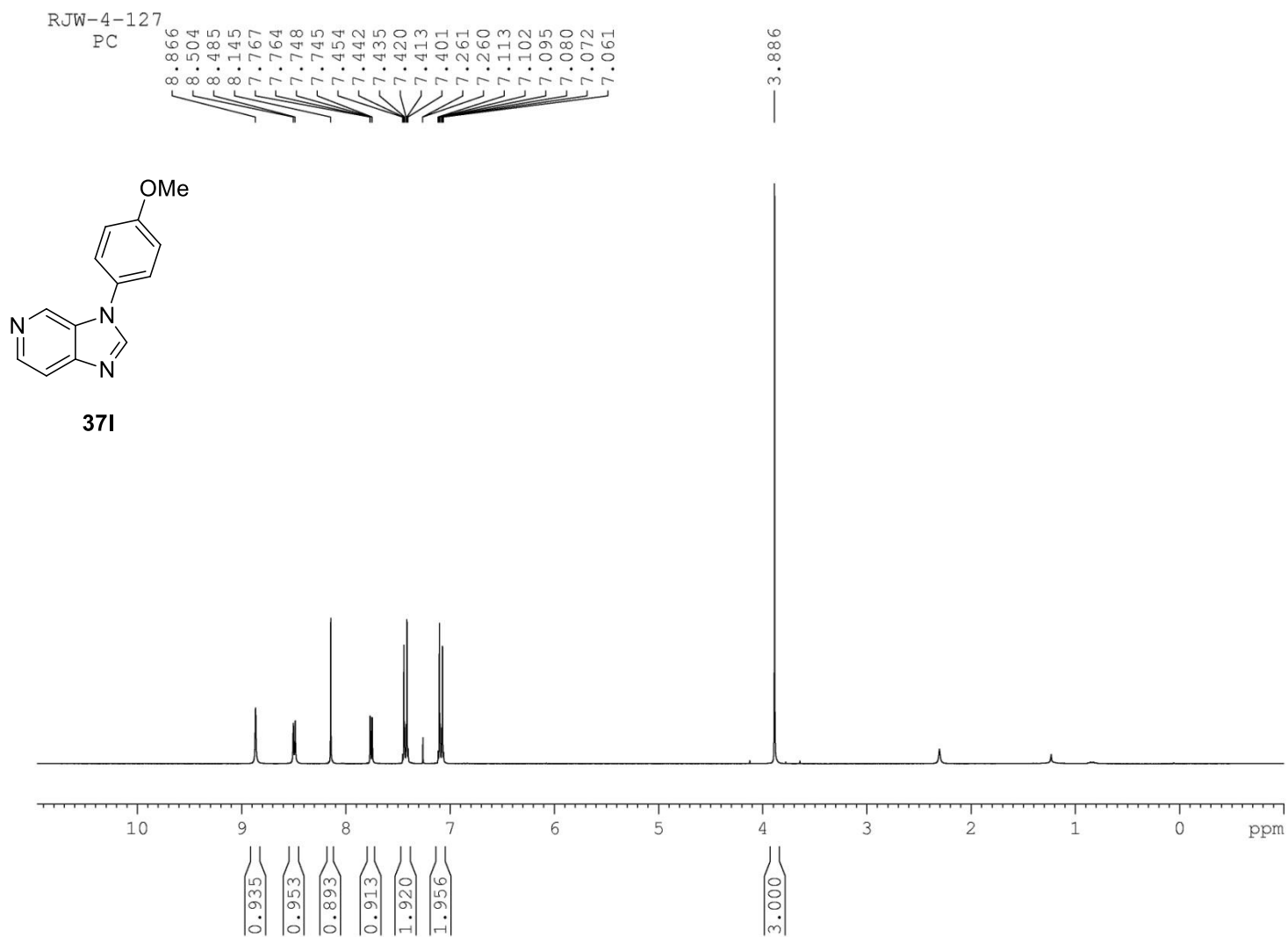


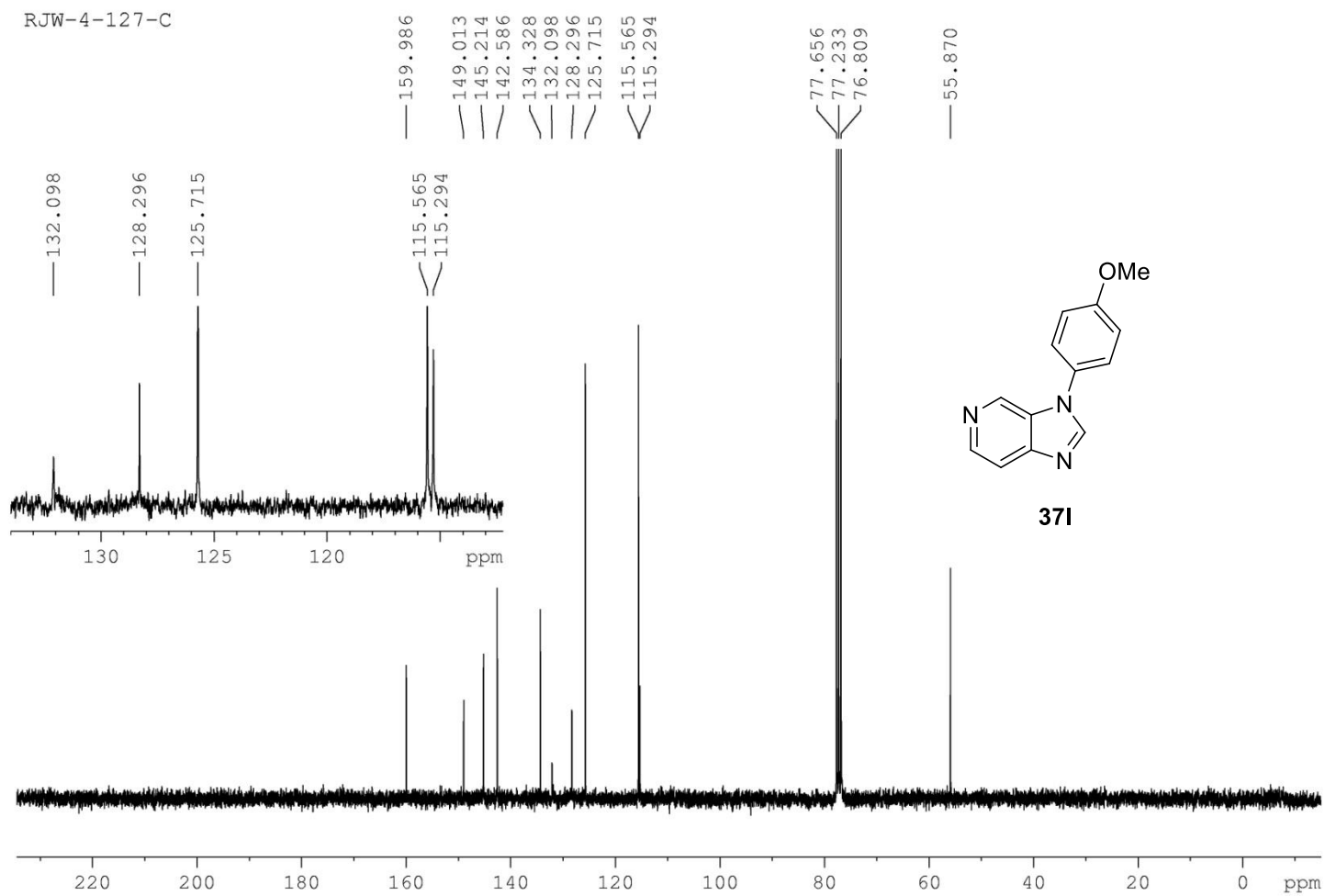
RJW-4-129

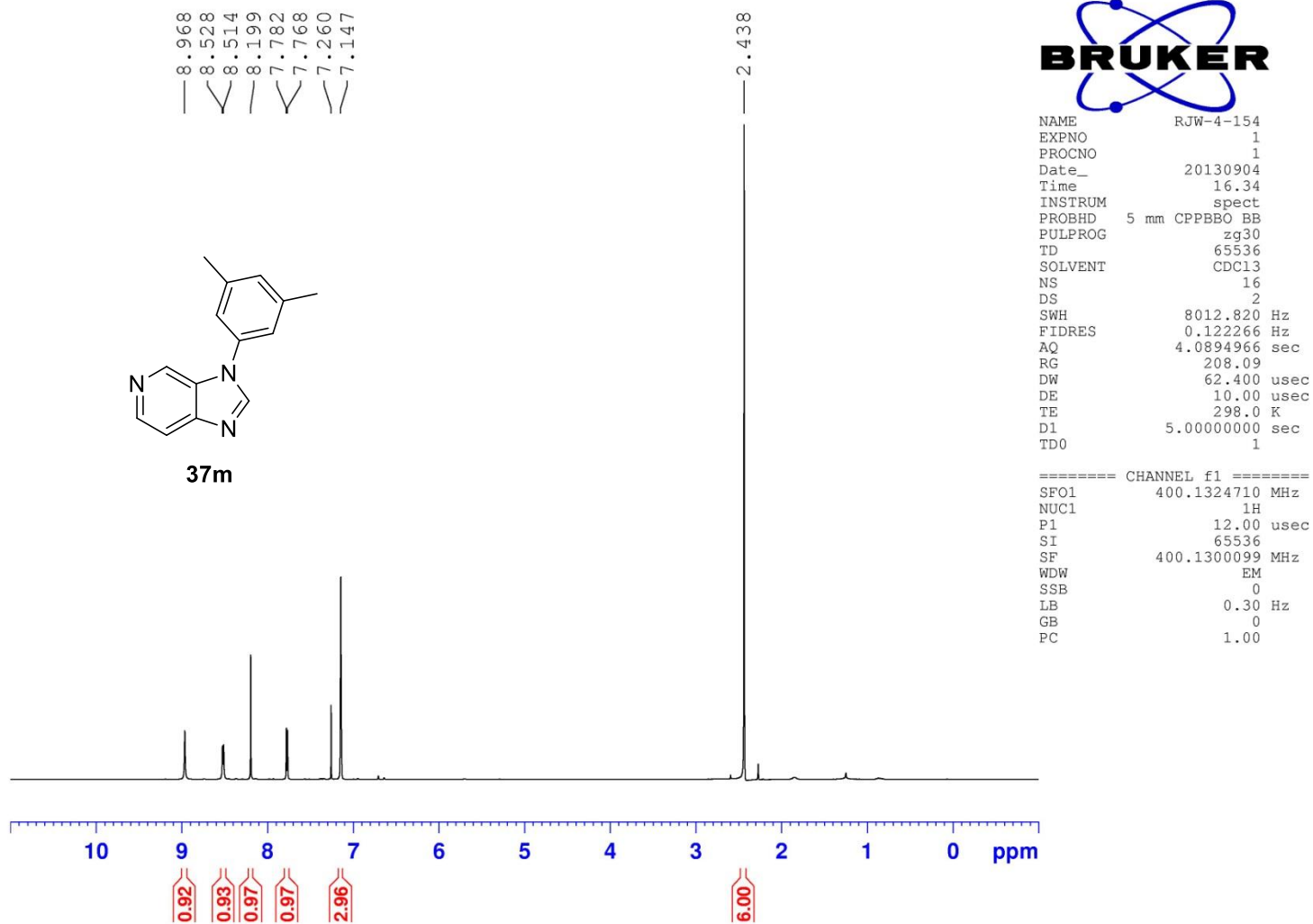


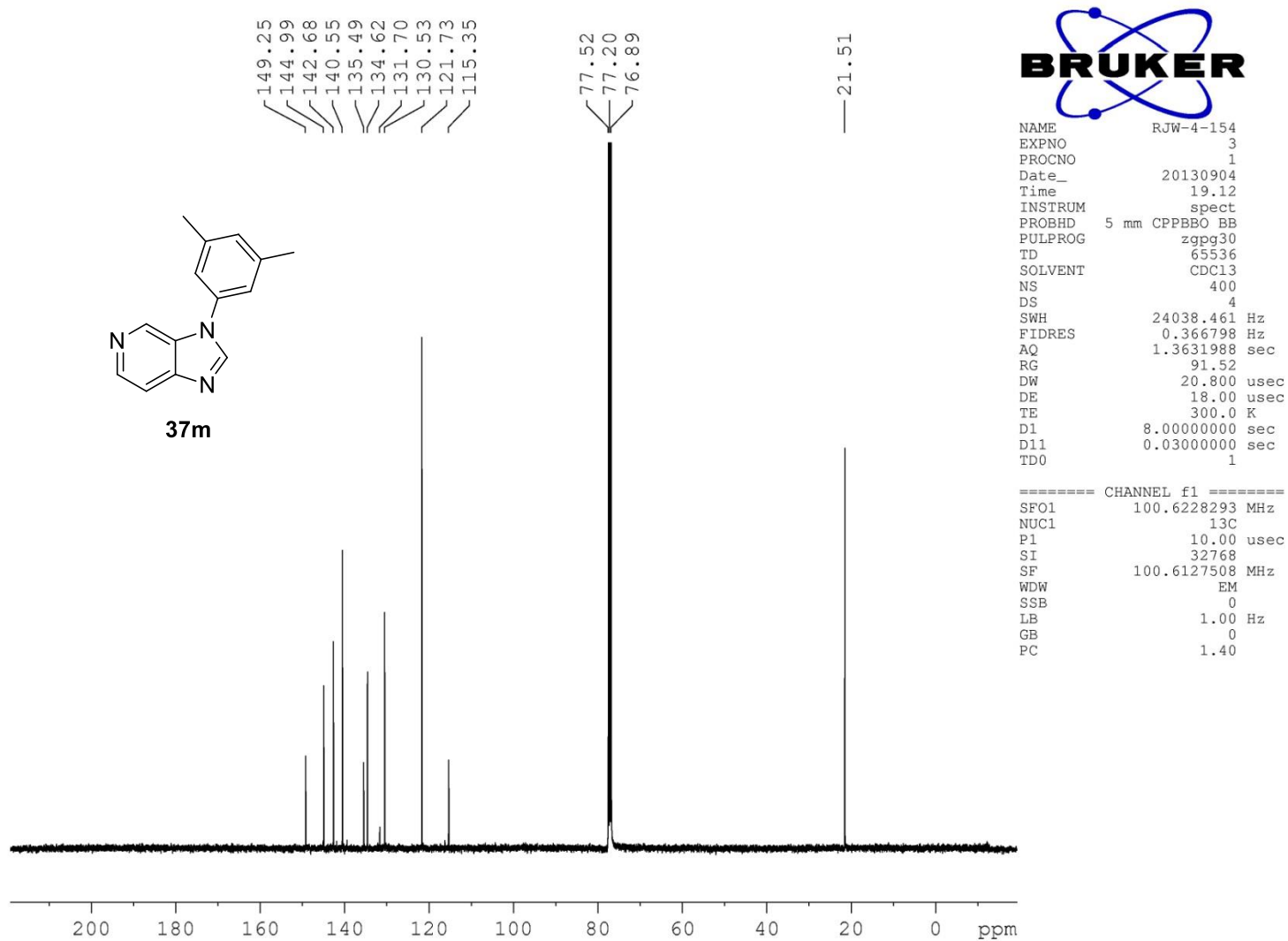
RJW-4-129





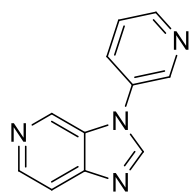
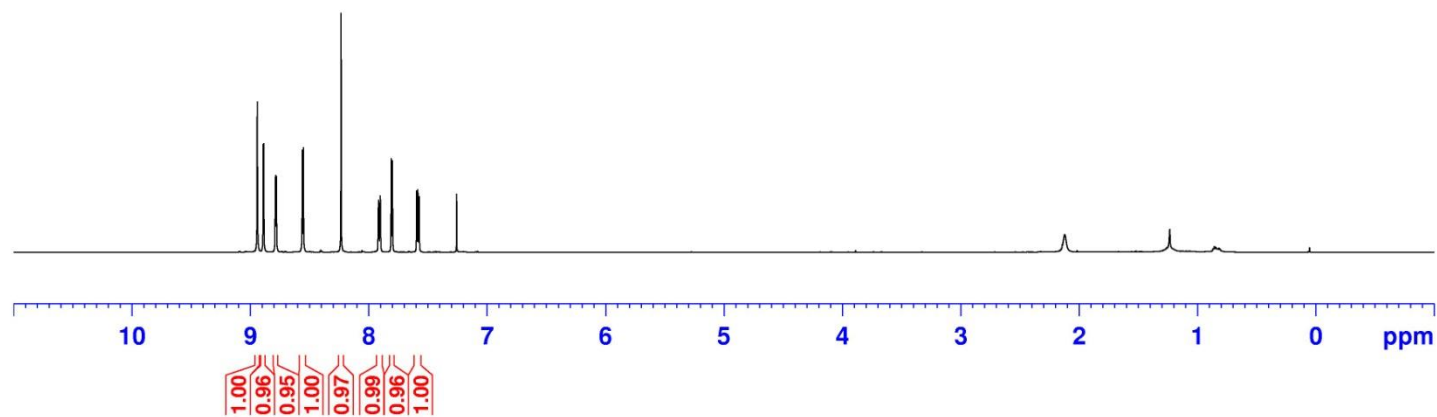




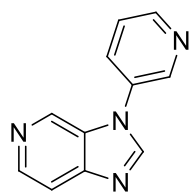
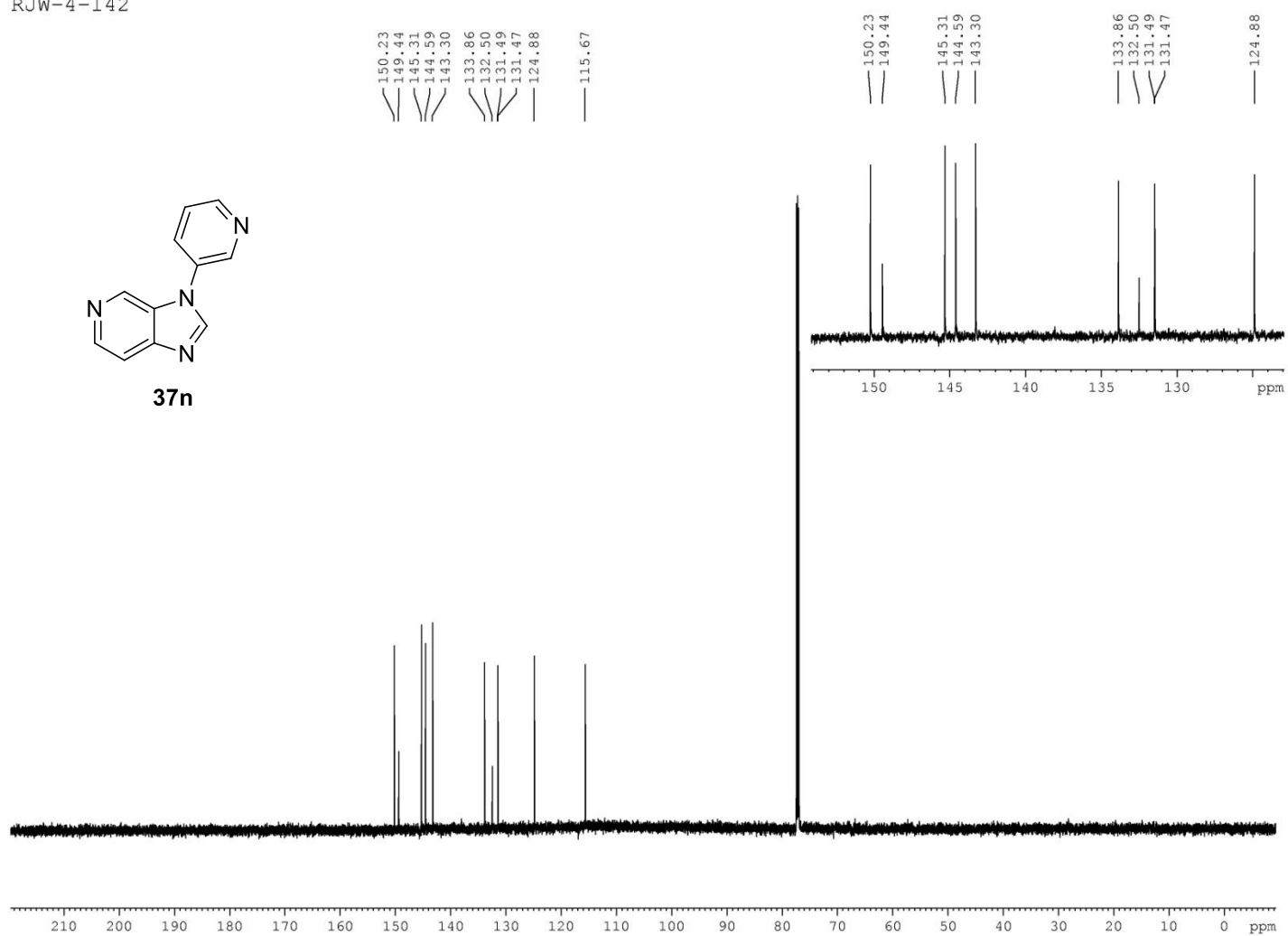


RJW-4-142

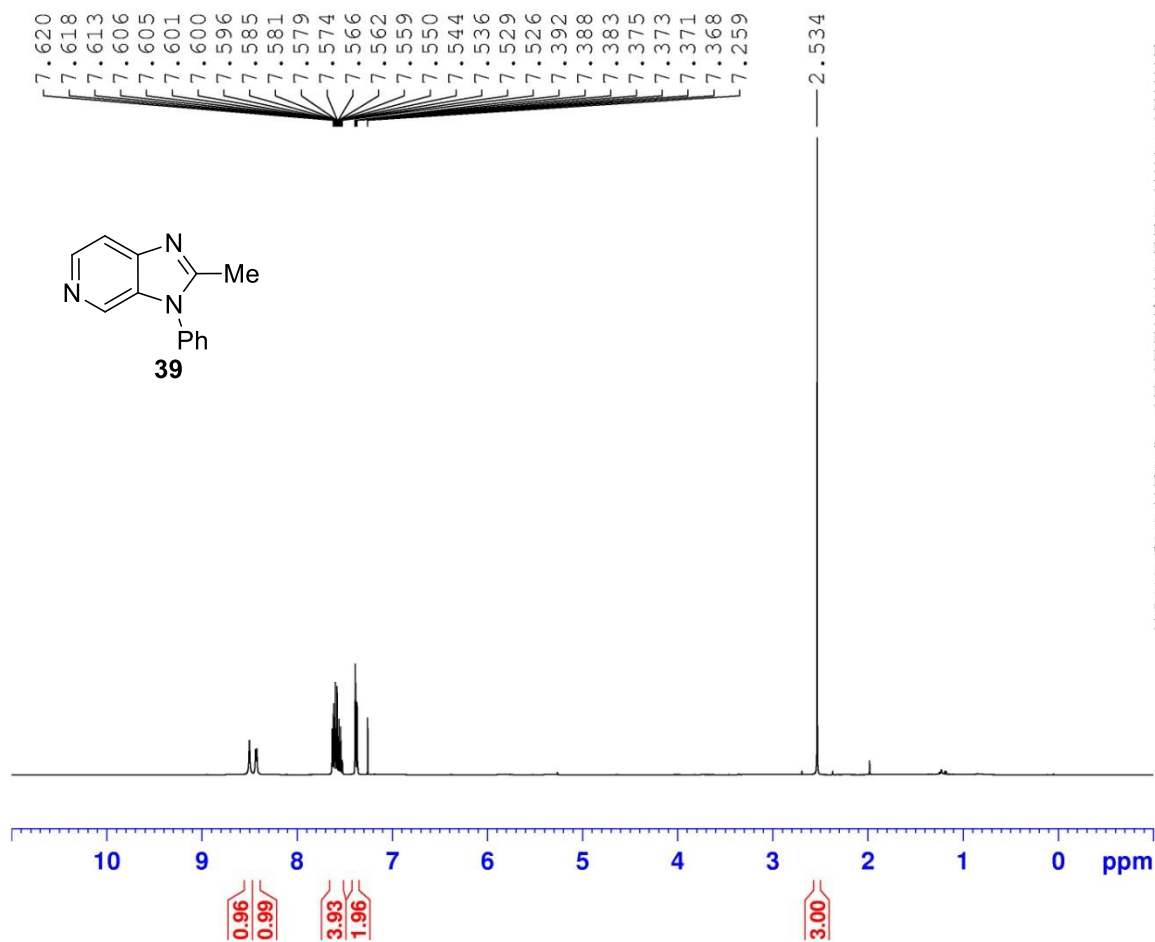
8.941
8.890
8.886
8.789
8.787
8.781
8.779
8.561
8.551
8.233
7.920
7.917
7.915
7.913
7.906
7.904
7.902
7.899
7.808
7.799
7.598
7.590
7.584
7.576
7.260

**37n**

RJW-4-142

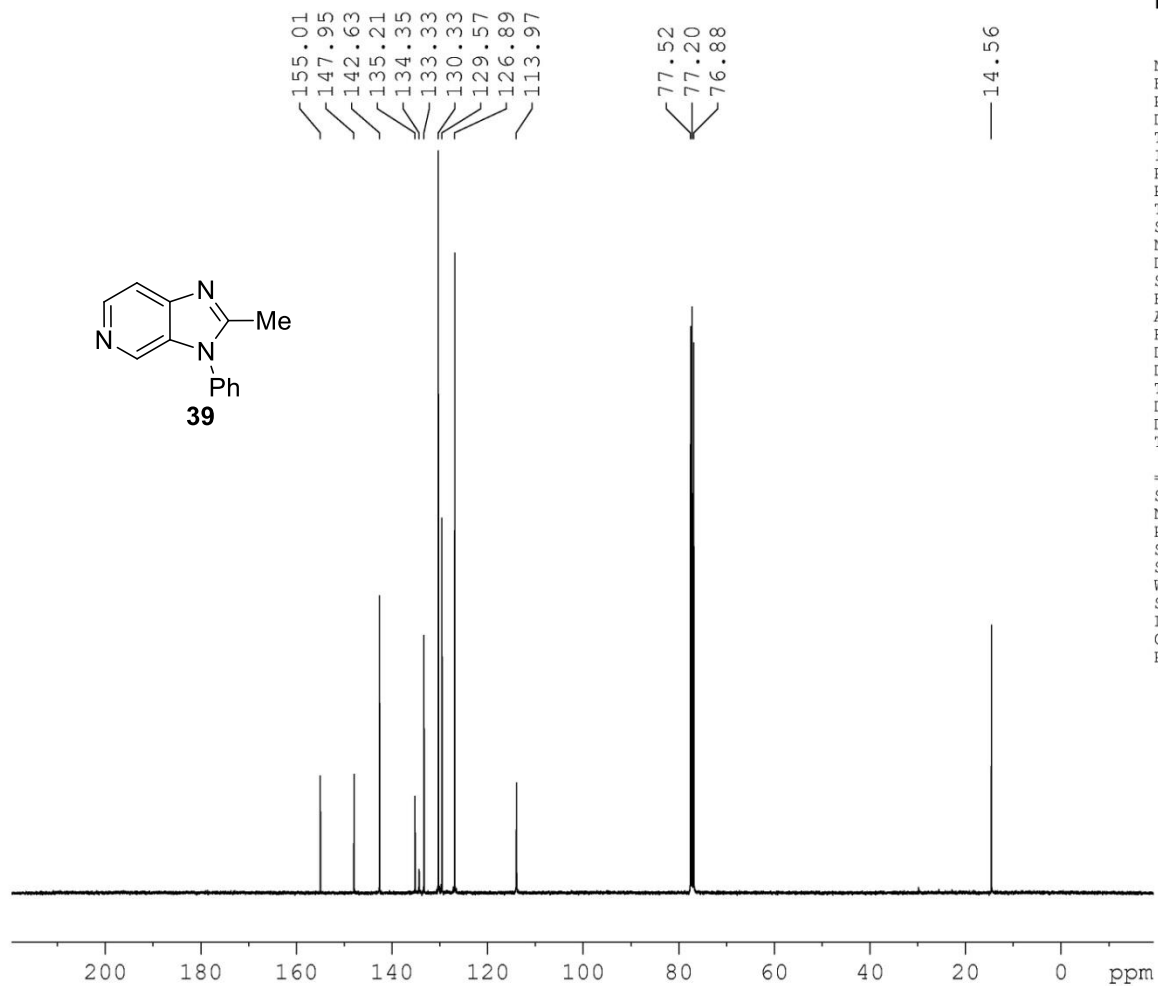
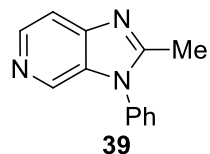
**37n**

RJW-4-239
PC



NAME RJW400-4-239
EXPNO 2
PROCNO 1
Date_ 20131114
Time 21.50
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl₃
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 104.13
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1
===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300100 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

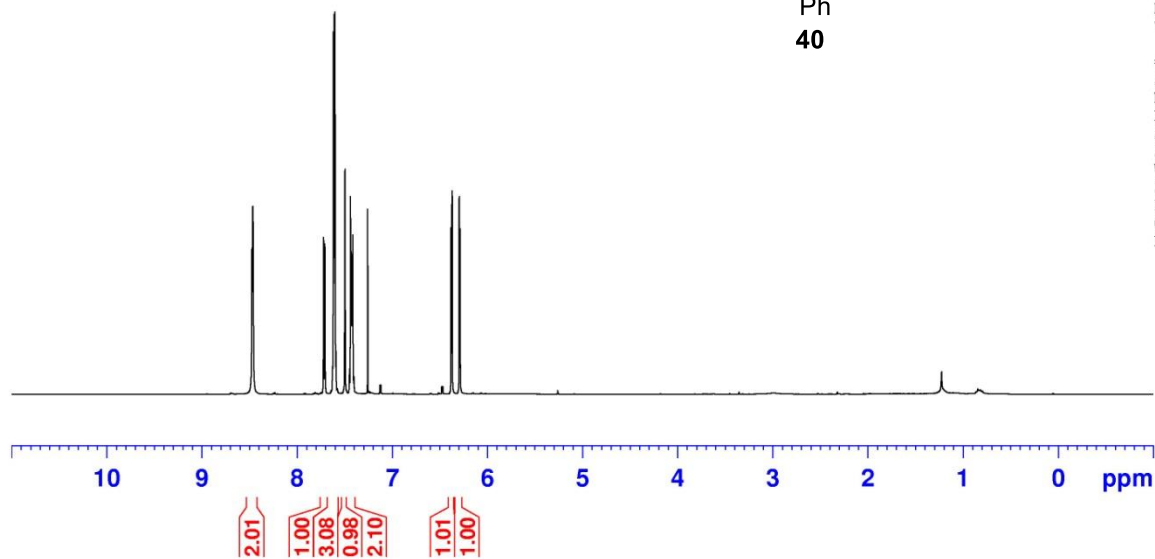
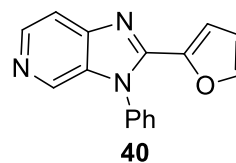
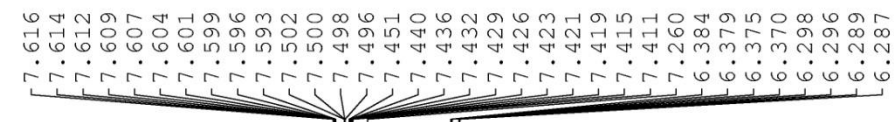
RJW-4-239
PC



NAME RJW400-4-239
EXPNO 3
PROCNO 1
Date_ 20131114
Time 22.17
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDCl₃
NS 440
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 80.84
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127560 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

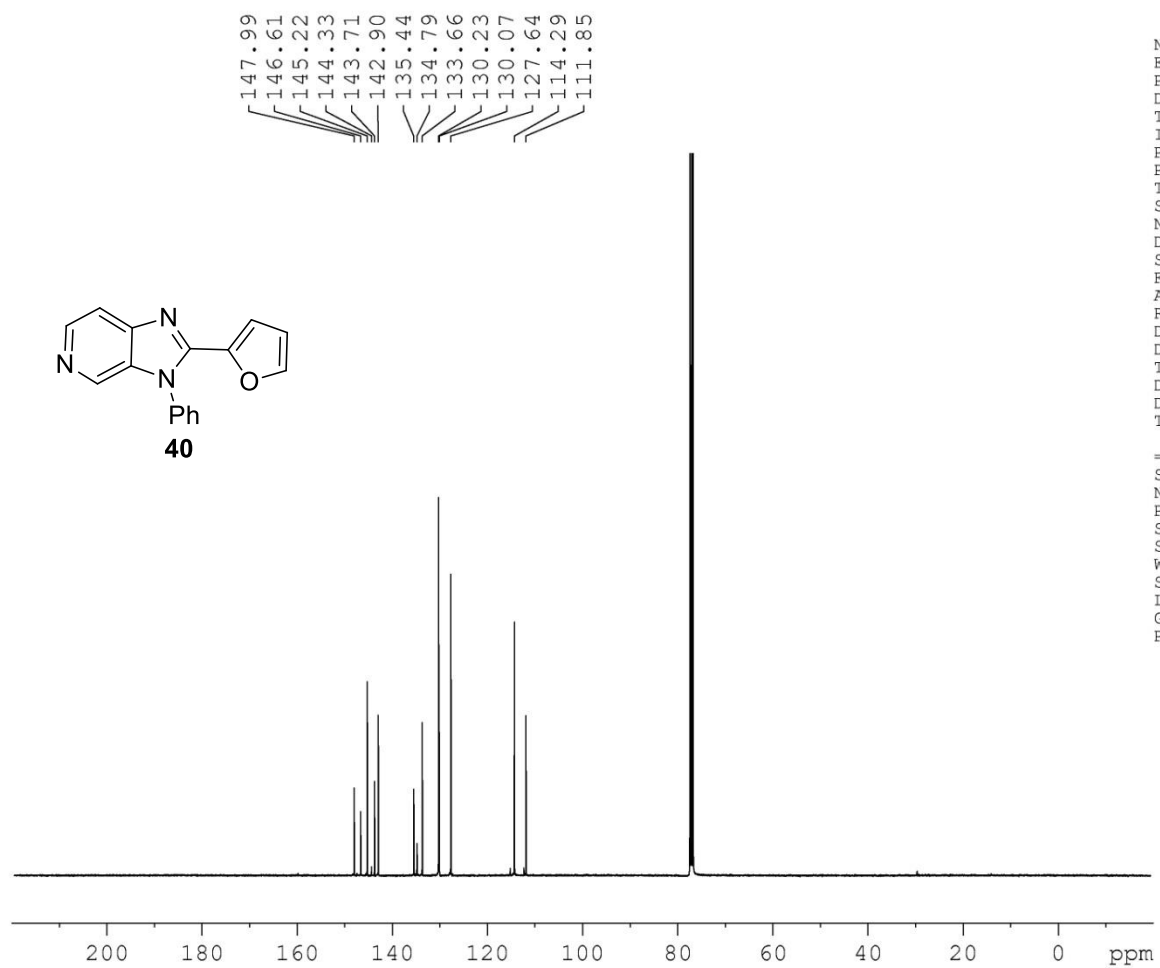
RJW-4-240
PC



NAME RJW400-4-240
EXPNO 1
PROCNO 1
Date_ 20131115
Time 19.47
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl3
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 91.52
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300099 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

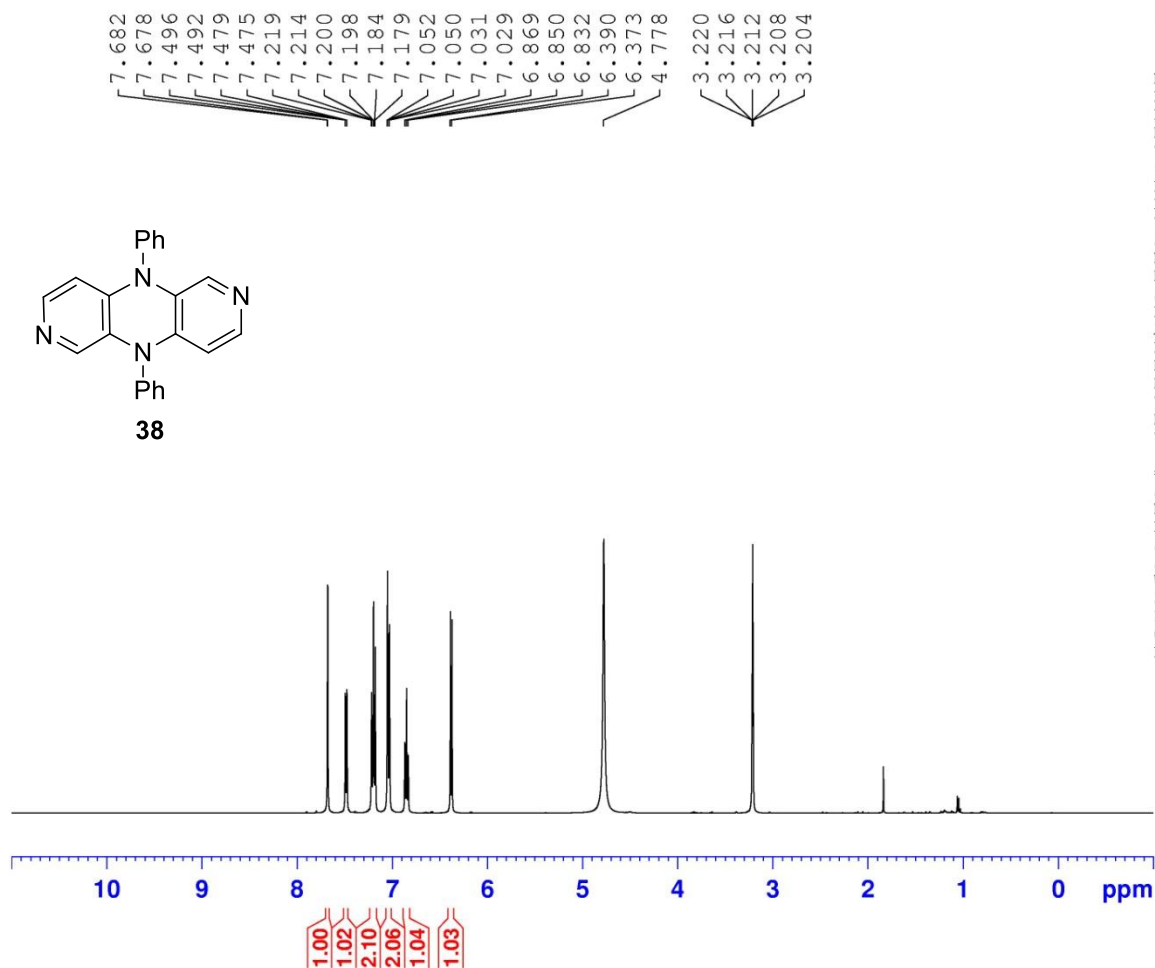
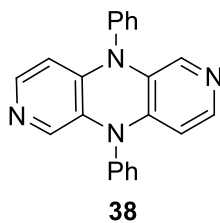
RJW-4-240-C



NAME RJW400-4-240
EXPNO 3
PROCNO 1
Date_ 20131116
Time 1.10
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDC13
NS 1200
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 104.13
DW 20.800 usec
DE 18.00 usec
TE 300.0 K
D1 8.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127690 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

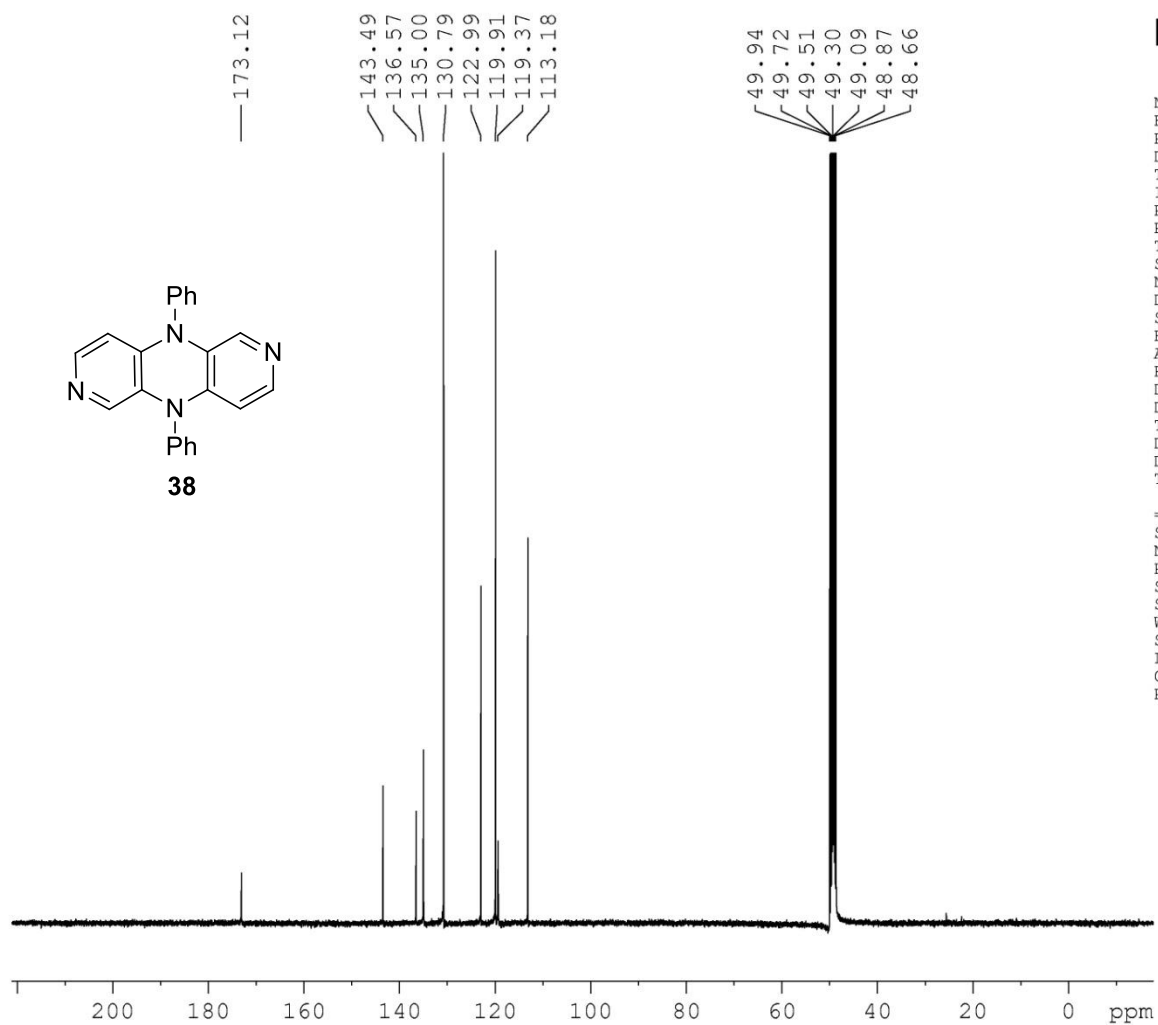
RJW-4-188
PC



NAME RJW400-4-188
EXPNO 5
PROCNO 1
Date_ 20131007
Time 16.56
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT MeOD
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 164.26
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300474 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

RJW-4-188-C

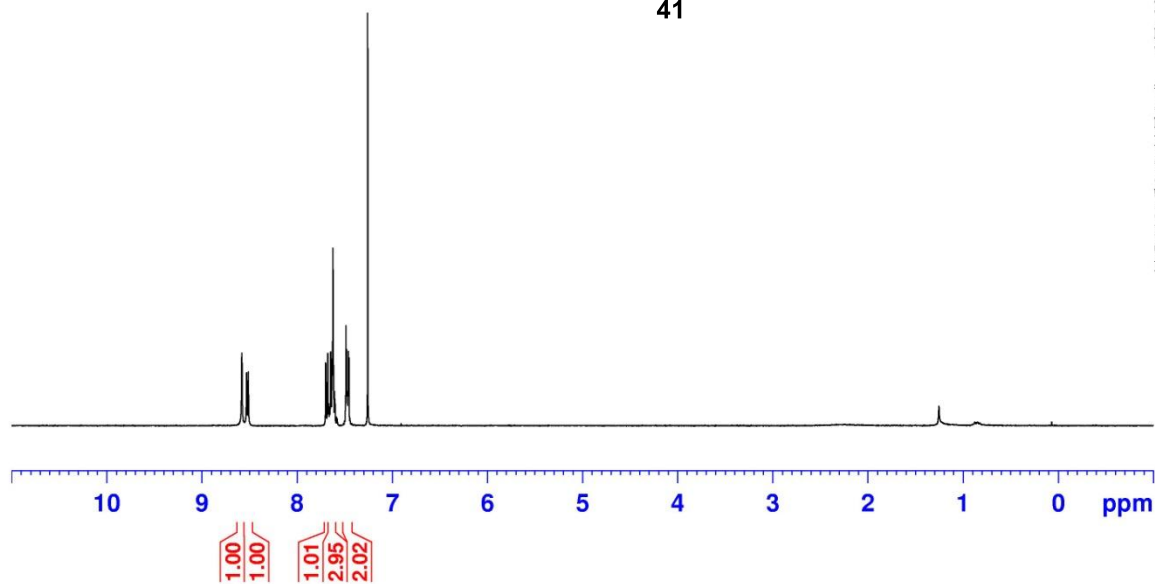
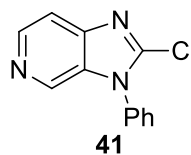


NAME RJW400-4-188
EXPNO 6
PROCNO 1
Date_ 20131007
Time 20.47
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT MeOD
NS 1024
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 50.16
DW 20.800 usec
DE 18.00 usec
TE 300.0 K
D1 8.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6125979 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

RJW-4-217
PC

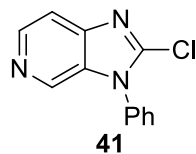
8.583
8.533
8.514
7.701
7.698
7.683
7.679
7.668
7.662
7.649
7.644
7.636
7.632
7.625
7.620
7.608
7.603
7.493
7.489
7.481
7.474
7.470
7.461
7.456



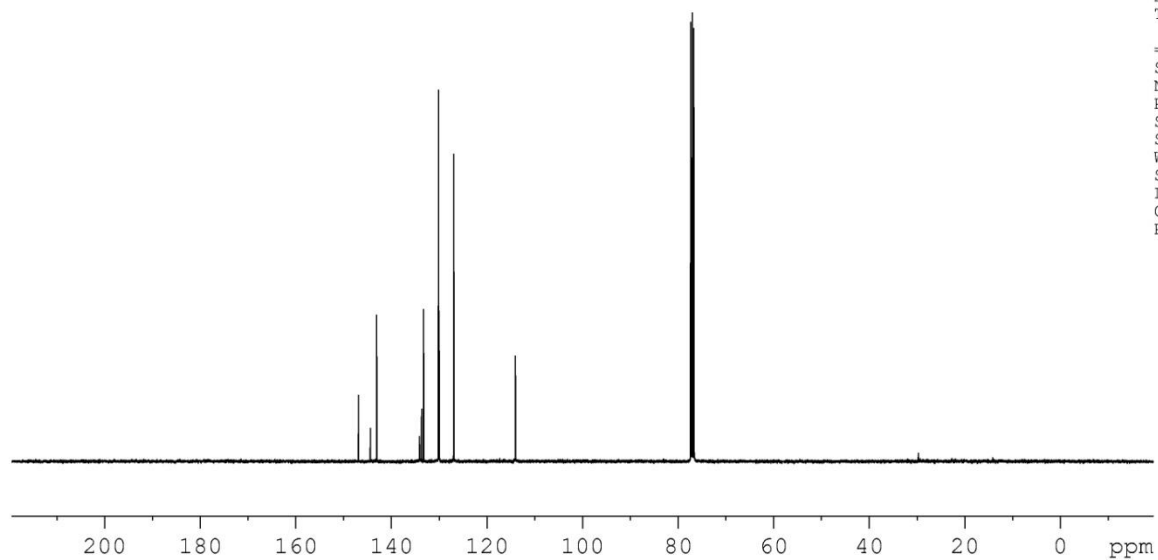
NAME RJW300-4-217
EXPNO 2
PROCNO 1
Date_ 20131031
Time 17.16
INSTRUM FOURIER300
PROBHD 5 mm DUL 13C-1
PULPROG zg30
TD 65536
SOLVENT CDCl3
NS 16
DS 2
SWH 6103.516 Hz
FIDRES 0.093132 Hz
AQ 5.3687592 sec
RG 202.563
DW 81.920 usec
DE 6.50 usec
TE 300.0 K
D1 5.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 300.1969109 MHz
NUC1 1H
P1 12.63 usec
SI 65536
SF 300.1955095 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

RJW-4-217-C



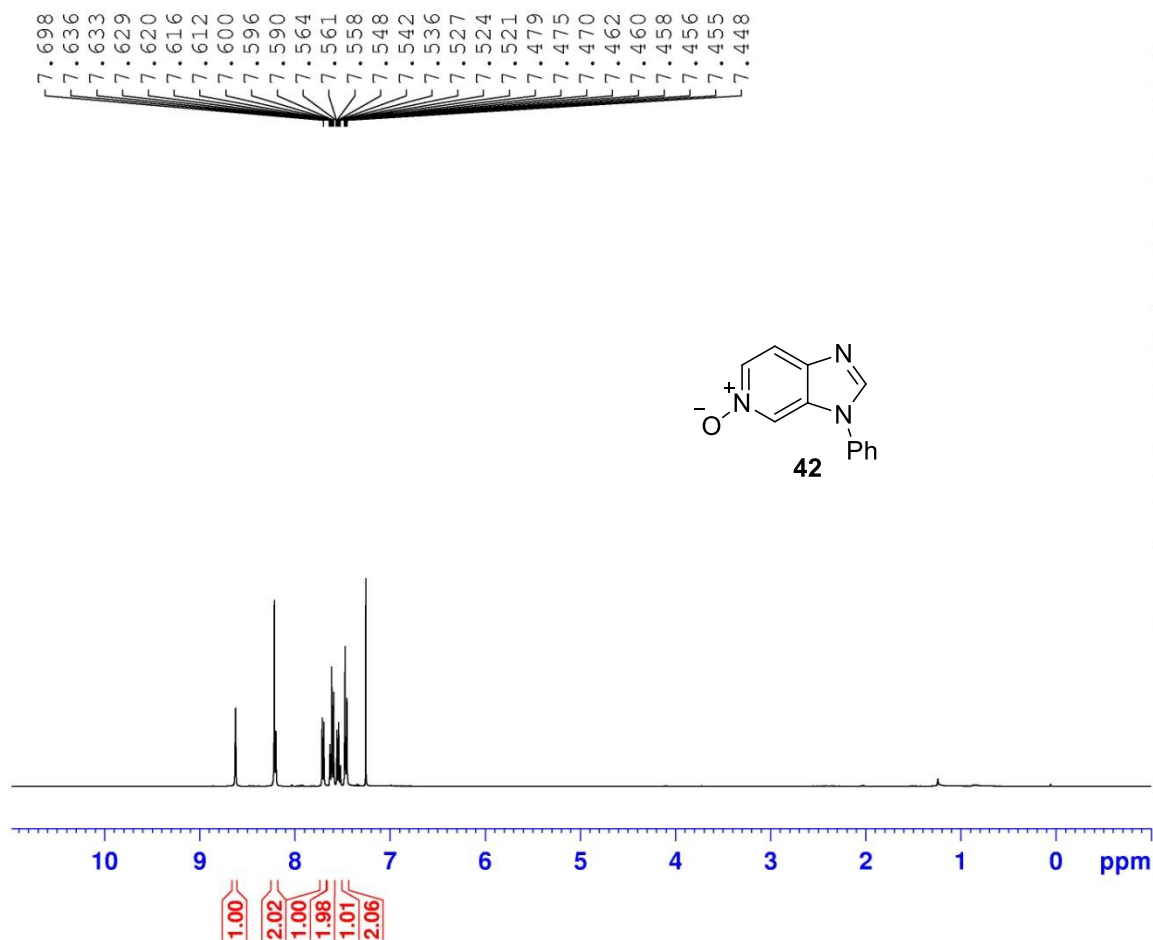
146.88
144.41
143.09
134.14
133.69
133.27
130.14
130.02
126.97
114.05



NAME RJW400-4-217
EXPNO 4
PROCNO 1
Date_ 20131108
Time 17.41
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDC13
NS 320
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 66.01
DW 20.800 usec
DE 18.00 usec
TE 300.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127690 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

RJW-4-201
PC



NAME RJW400-4-201
EXPNO 1
PROCNO 1
Date_ 20131018
Time 14.33
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDC13
NS 12
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 208.09
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

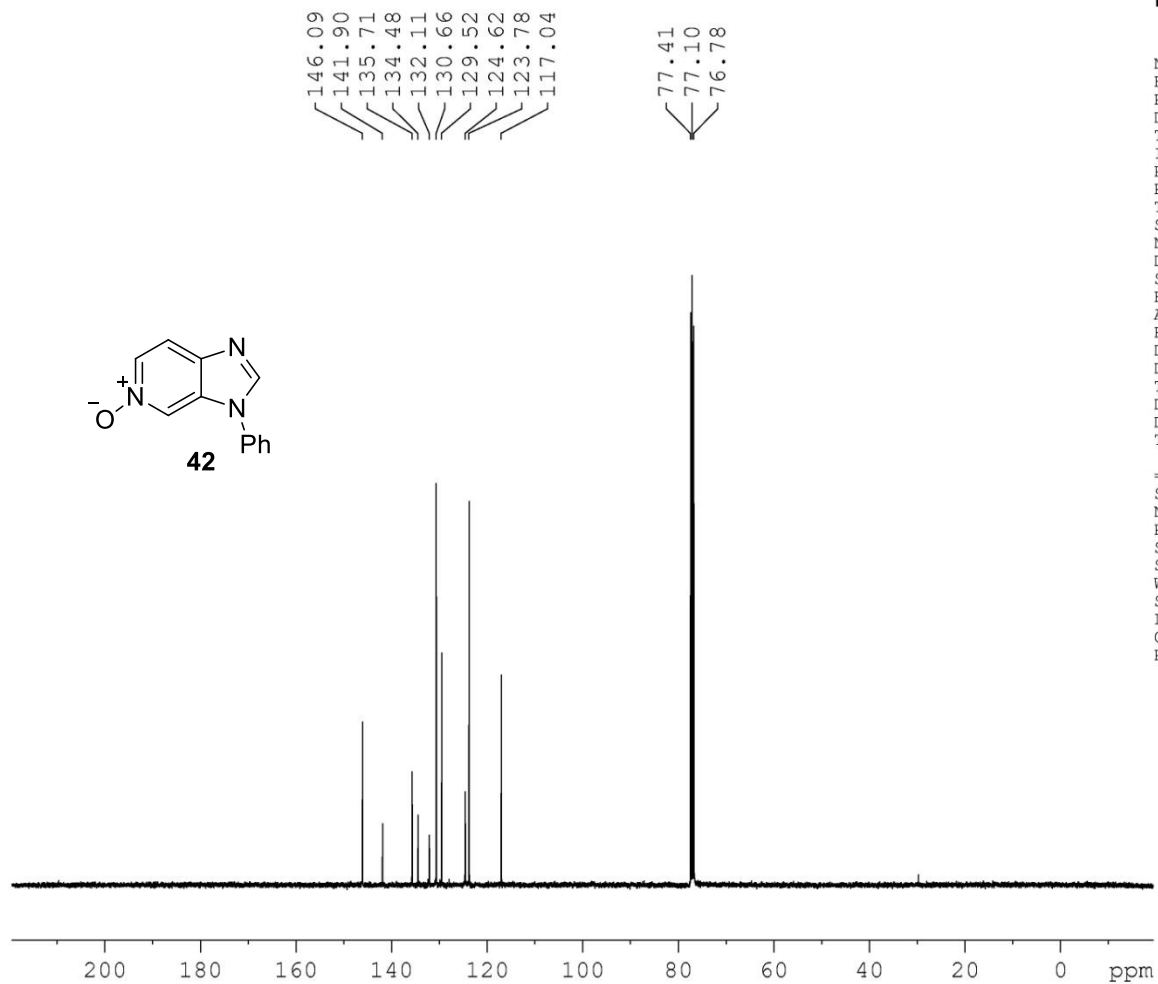
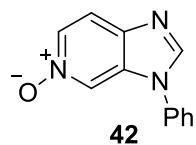
===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300109 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

RJW-4-199



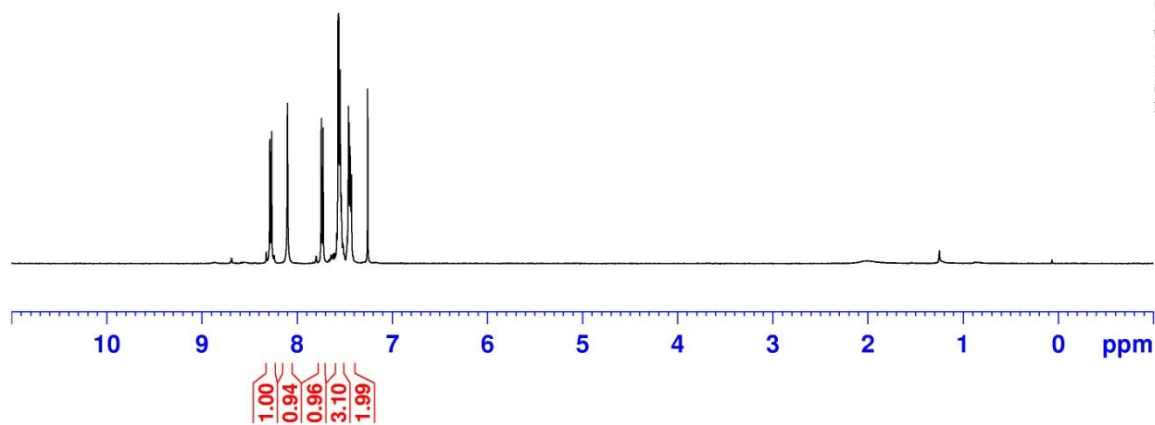
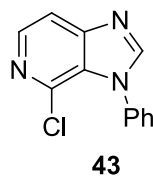
NAME RJW400-4-199
EXPNO 2
PROCNO 1
Date_ 20131015
Time 17.49
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDC13
NS 240
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 66.01
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 1.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127650 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40



RJW-4-207

8.289
8.270
8.103
7.747
7.729
7.572
7.564
7.556
7.553
7.549
7.542
7.537
7.463
7.456
7.450
7.446
7.442
7.438
7.433
7.430
7.260



NAME RJW300-4-207
EXPNO 1
PROCNO 1
Date_ 20131031
Time 17.10
INSTRUM FOURIER300
PROBHD 5 mm DUL 13C-1
PULPROG zg30
TD 65536
SOLVENT CDCl3
NS 16
DS 2
SWH 6103.516 Hz
FIDRES 0.093132 Hz
AQ 5.3687592 sec
RG 74.3843
DW 81.920 usec
DE 6.50 usec
TE 300.2 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 300.1969109 MHz
NUC1 1H
P1 12.63 usec
SI 65536
SF 300.1955094 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

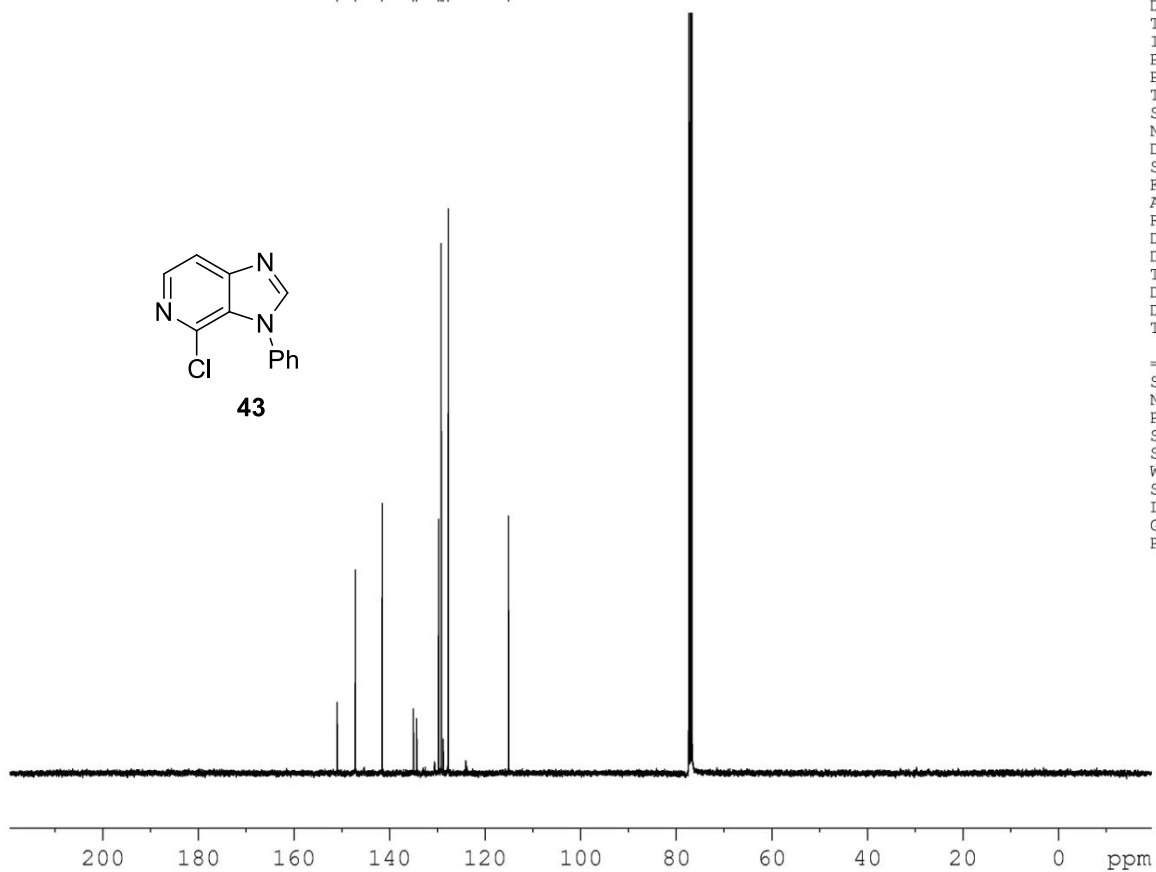
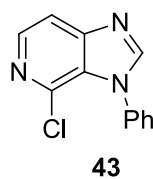
RJW-4-207-C



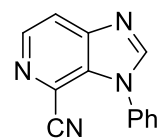
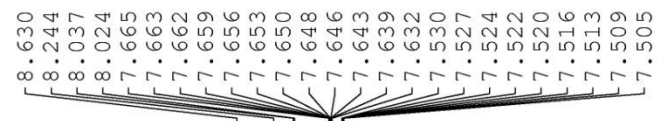
NAME RJW400-4-207
EXPNO 7
PROCNO 1
Date_ 20131108
Time 17.18
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDC13
NS 320
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 74.16
DW 20.800 usec
DE 18.00 usec
TE 300.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127690 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

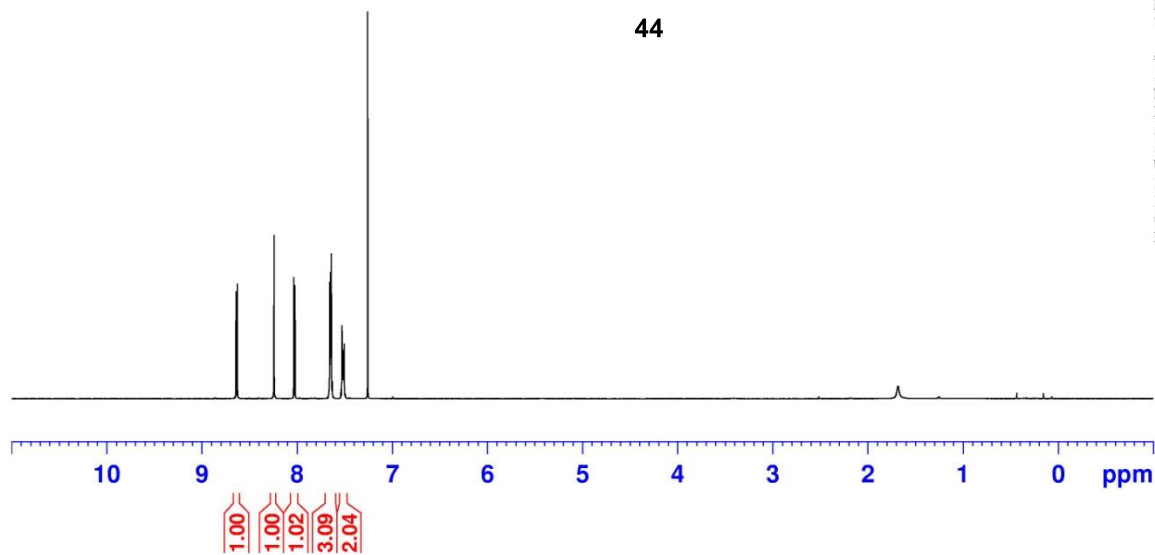
150.95
147.15
141.55
135.00
134.32
129.75
129.17
128.76
127.71
115.09



RJW-4-231
PC



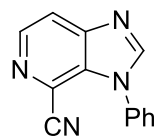
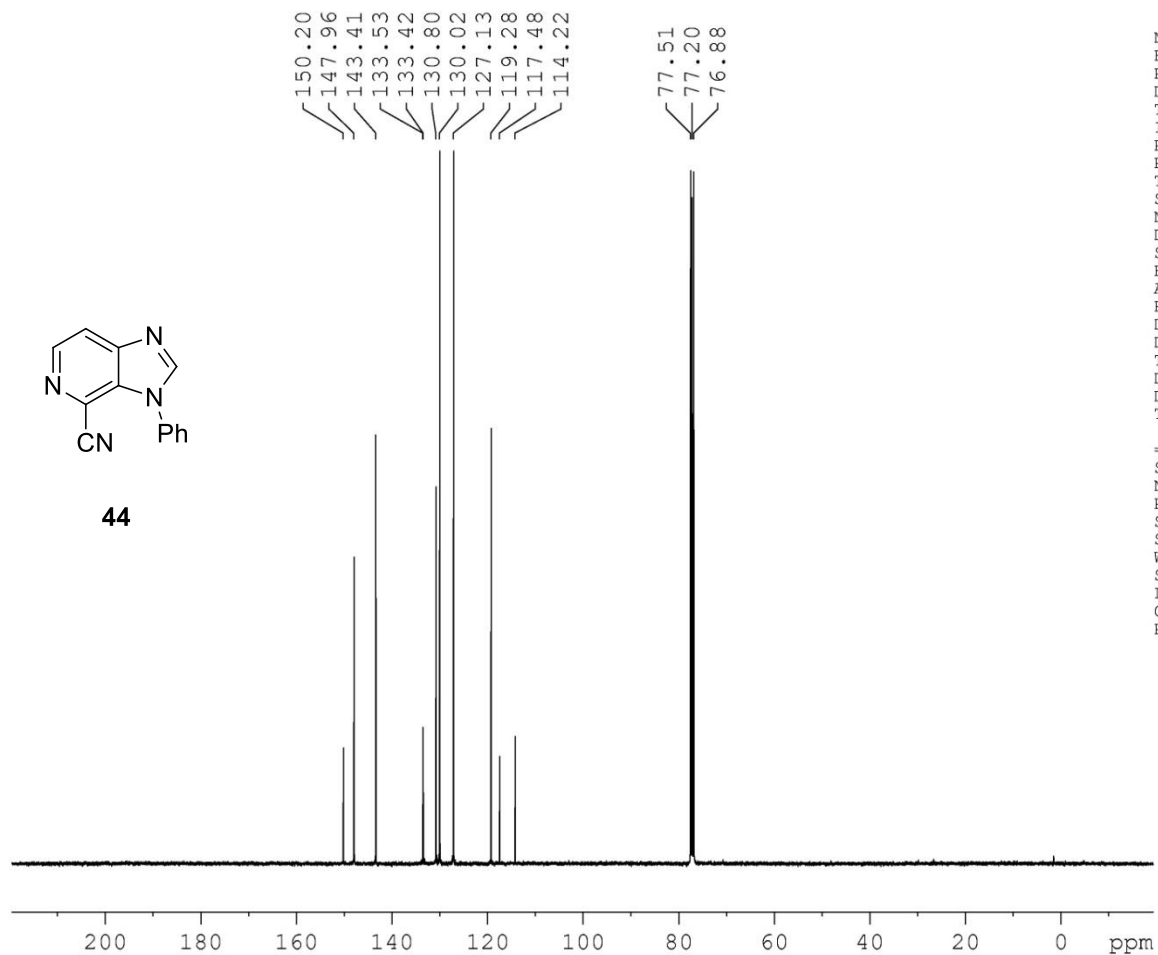
44



NAME RJW400-4-231
EXPNO 2
PROCNO 1
Date_ 20131109
Time 12.41
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl3
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 208.09
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300099 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

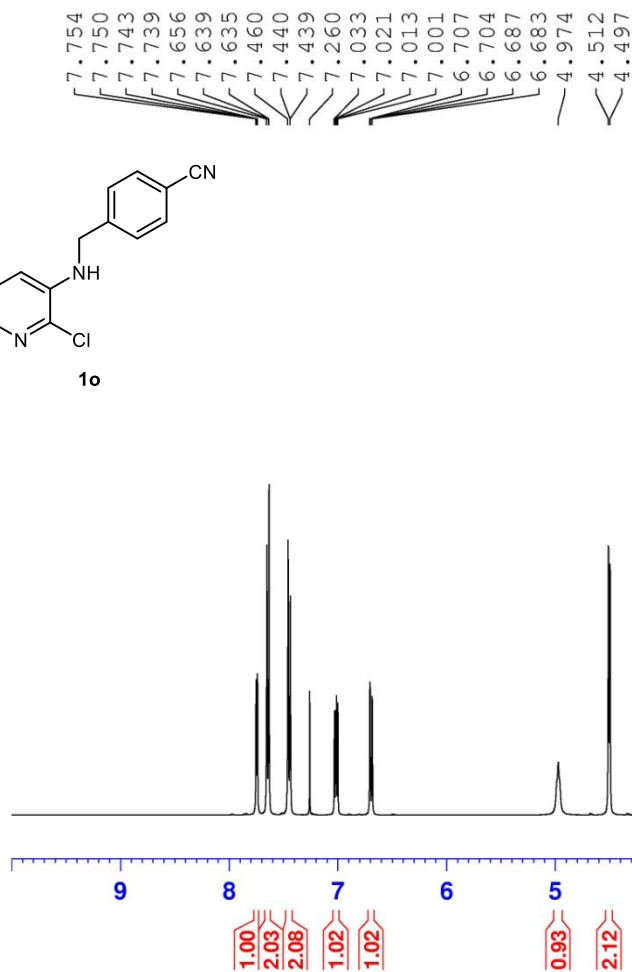
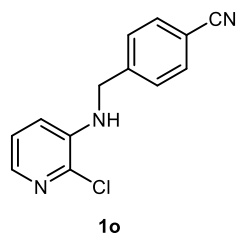
RJW-4-231-C

**44**

NAME RJW400-4-231
EXPNO 4
PROCNO 1
Date_ 20131109
Time 14.49
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDCl3
NS 320
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 66.01
DW 20.800 usec
DE 18.00 usec
TE 300.0 K
D1 4.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127566 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

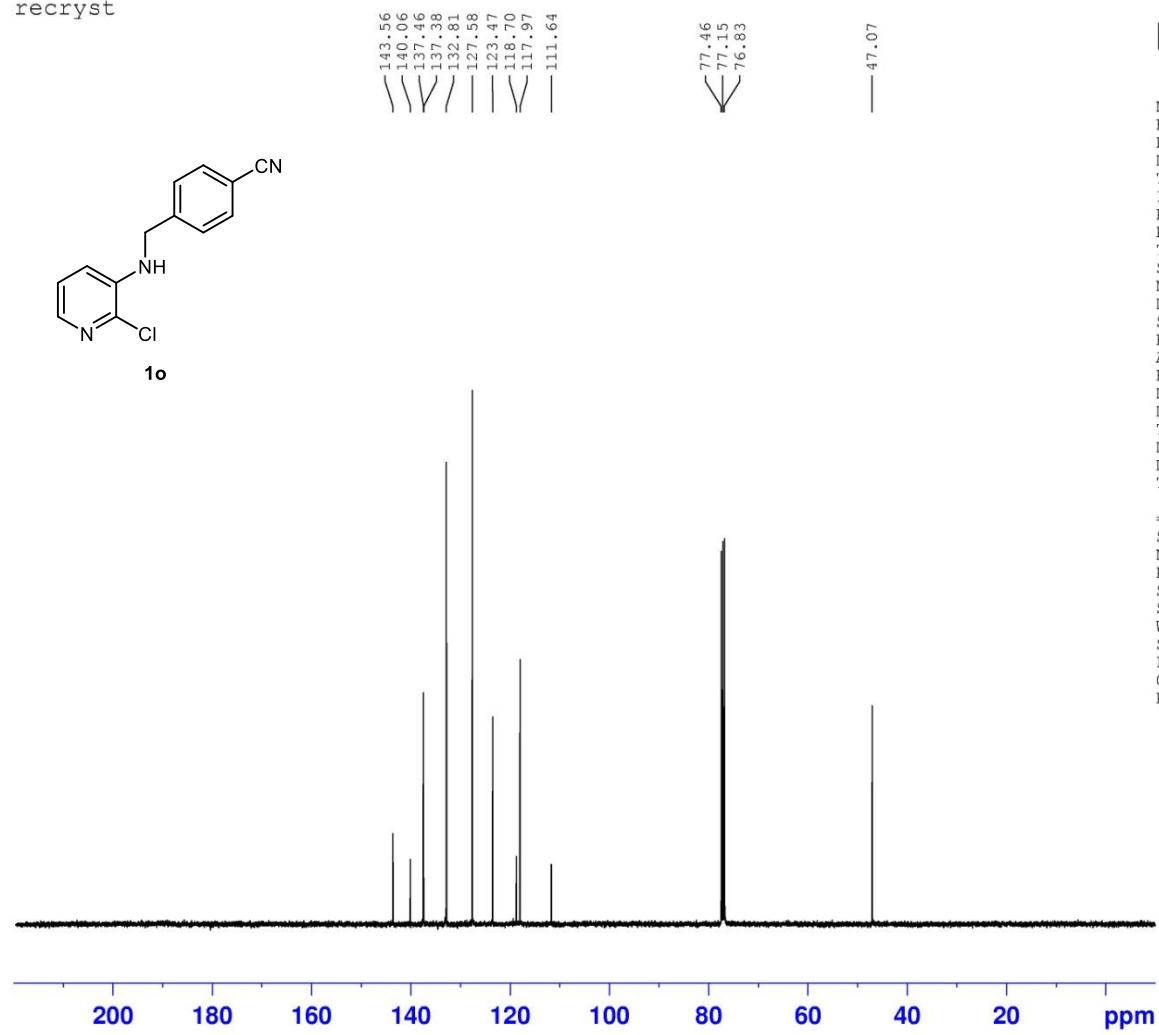
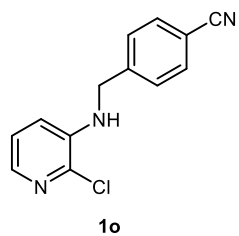
RJW-4-186
recryst



NAME RJW-4-186
EXPNO 1
PROCNO 1
Date_ 20131002
Time 7.55
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl3
NS 8
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 150.82
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300098 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

RJW-4-186-C
recryst

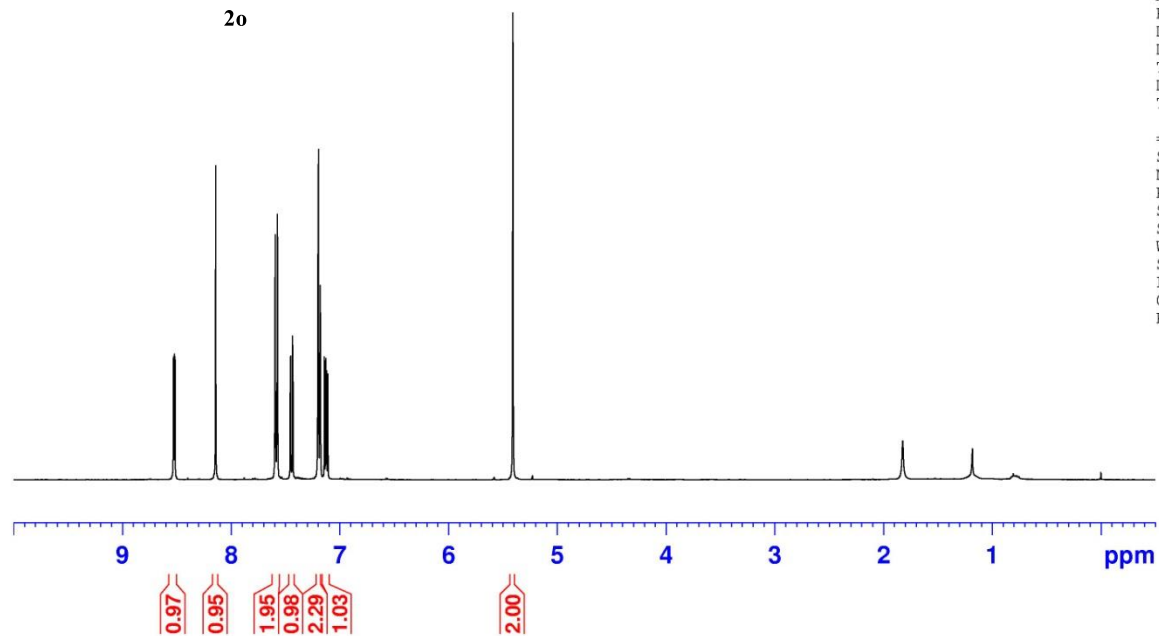
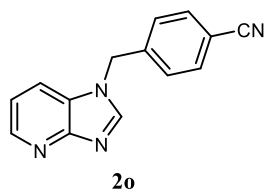


NAME RJW-4-186
EXPNO 2
PROCNO 1
Date_ 20131002
Time 8.02
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDC13
NS 200
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 58.33
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 0.40000001 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127596 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

RJW-4-191
PC

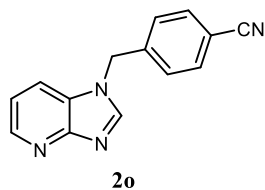
8.521
8.517
8.144
7.597
7.592
7.580
7.576
7.572
7.458
7.454
7.437
7.434
7.203
7.202
7.200
7.183
7.182
7.144
7.132
7.123
7.112
5.410



NAME RJW400-4-191
EXPNO 3
PROCNO 1
Date_ 20131009
Time 15.25
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDC13
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 208.09
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300340 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

RJW-4-191
PC

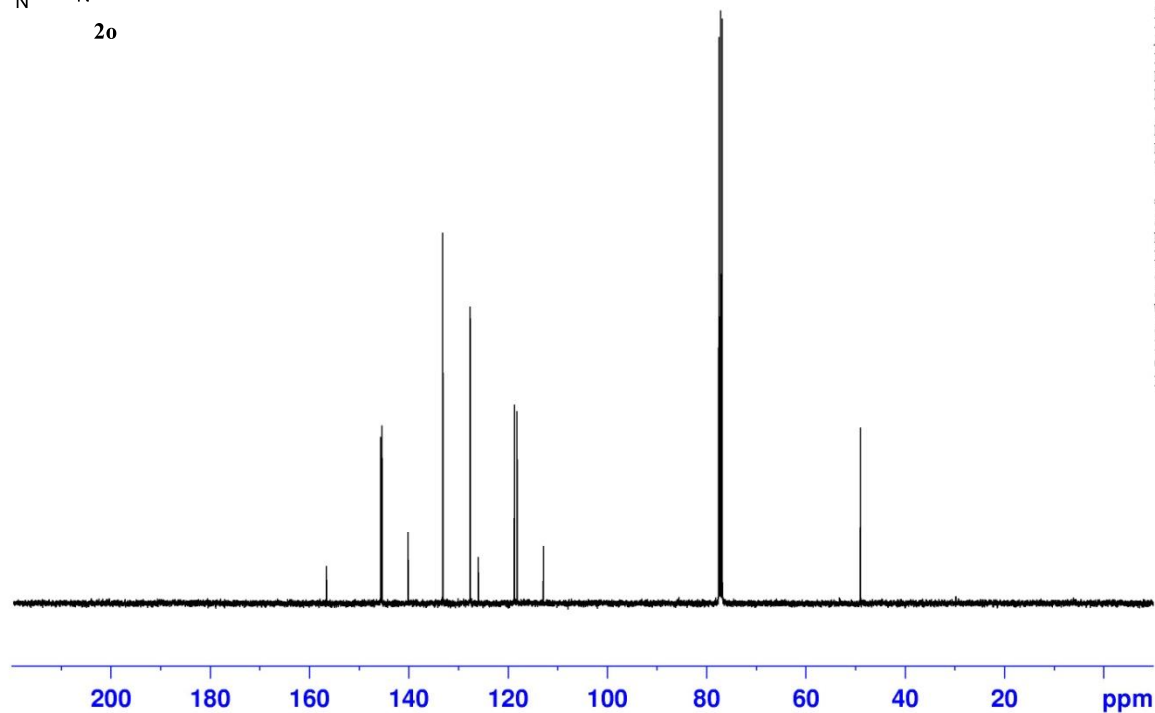


156.57
145.65
145.37
140.13
133.14
127.60
125.98
118.69
118.17
118.14
112.85
77.47
77.15
76.83
48.94

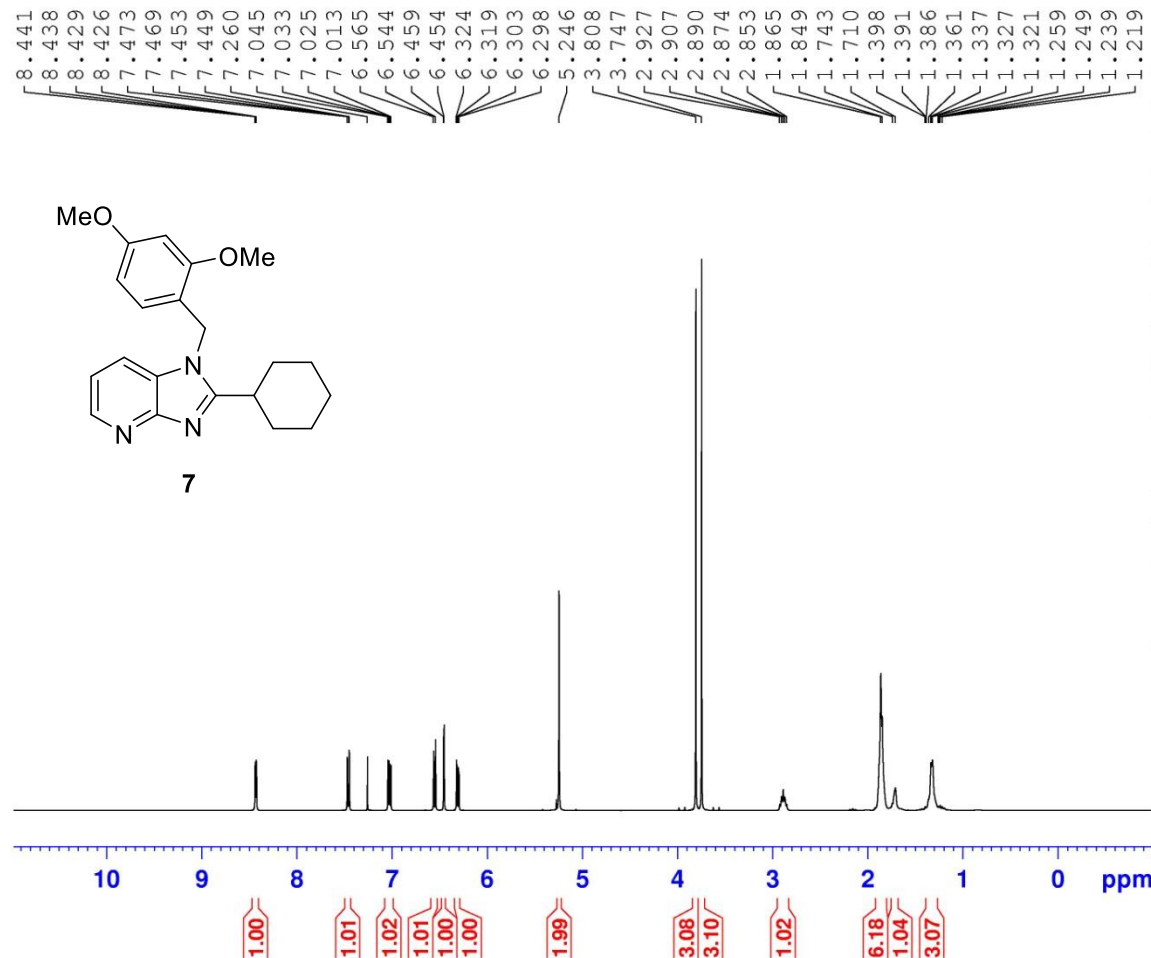


NAME RJW400-4-191
EXPNO 4
PROCNO 1
Date_ 20131009
Time 15.36
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDC13
NS 240
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 66.01
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 1.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127584 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40



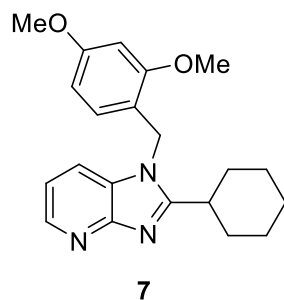
RJW-4-244
PC



NAME RJW400-4-244
EXPNO 3
PROCNO 1
Date_ 20131123
Time 16.47
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zg30
TD 65536
SOLVENT CDCl3
NS 16
DS 2
SWH 8012.820 Hz
FIDRES 0.122266 Hz
AQ 4.0894966 sec
RG 58.33
DW 62.400 usec
DE 10.00 usec
TE 298.0 K
D1 1.00000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 400.1324710 MHz
NUC1 1H
P1 12.00 usec
SI 65536
SF 400.1300098 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

RJW-4-244
PC

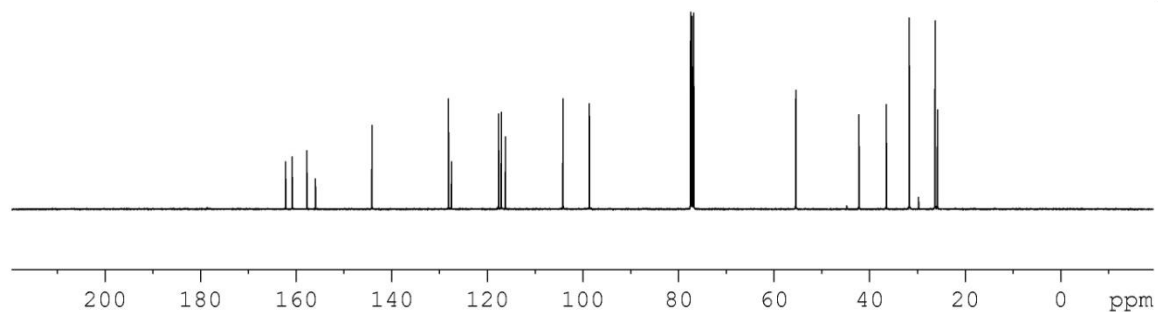


162.23
160.88
157.79
155.98
144.17
128.14
127.52
117.65
117.09
116.25
104.17
98.67
77.47
77.15
76.84
55.47
55.44
42.22
36.50
31.70
29.76
26.30
25.79



NAME RJW400-4-244
EXPNO 4
PROCNO 1
Date_ 20131123
Time 17.14
INSTRUM spect
PROBHD 5 mm CPPBBO BB
PULPROG zgpg30
TD 65536
SOLVENT CDC13
NS 440
DS 4
SWH 24038.461 Hz
FIDRES 0.366798 Hz
AQ 1.3631988 sec
RG 66.01
DW 20.800 usec
DE 18.00 usec
TE 298.0 K
D1 2.00000000 sec
D11 0.03000000 sec
TD0 1

===== CHANNEL f1 =====
SFO1 100.6228293 MHz
NUC1 13C
P1 10.00 usec
SI 32768
SF 100.6127616 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40



6.0 VITAE

Current Address:
10 Grampian Rd. Apt.79
Liverpool, NY 13090
(c):518-708-1742

Robert J Wilson
Rjwils02@syr.edu

Permanent Address:
499 Colebrook Rd.
Gansevoort, NY 12831
r.wilson.j@gmail.com

Professional Interests	Synthetic Organic and Medicinal Chemistry Total Synthesis of Natural Products Organometallic Chemistry and Catalysis
Education	<p>PhD in Organic Chemistry, August 2015 Syracuse University, Syracuse, NY <i>Thesis:</i> "Ruthenium Hydride Catalyzed Silylvinylation of Alkynes" <i>Advisor:</i> Dr. Daniel A. Clark</p> <p>B.S. in Medicinal Chemistry May 2007 University at Buffalo, Amherst, NY <i>Advisor:</i> Dr. Steven T. Diver</p> <p>A.A.S Liberal Arts and Science May 2004 Hudson Valley Community College, Troy, NY</p>
Research Experience	<p>Graduate Research Assistant, Department of Chemistry Syracuse University, August 2010 – Present <i>Advisor:</i> Dr. Daniel A. Clark</p> <p>Research Focus: <u>Methodology</u> -Developed ruthenium hydride catalyzed silylvinylation of internal alkynes -Synthesis of heterocyclic compounds using palladium and copper catalyzed amide coupling reactions -Implementation of these methods toward the synthesis of natural products</p> <p>Undergraduate Research, University at Buffalo, 2006-2007 <i>Advisor:</i> Dr. Steven T. Diver</p> <p>Research Focus: -Multi step chemical synthesis -Inter- and intramolecular enyne metathesis -Development of a tandem enyne metathesis approach for the synthesis of 4-substituted cyclohexa-3,5-diene-1,2-diols</p>
Teaching Experience	<p>Teaching Assistant, Syracuse University 2010-Present -Laboratory instructor for undergraduate organic chemistry with 35 students -Recitation instructor for undergraduate organic chemistry with 30 students</p>
Professional Associations	American Chemical Society, Organic and Medicinal chemistry divisions
Leadership Skills	Supervised and trained twelve students in advanced techniques and instrumental analysis

Research Skills	<ul style="list-style-type: none"> -Experienced in organometallic chemistry and organic synthesis -Maintaining laboratory notebooks in good laboratory practices -Experienced with small (mmol) and large (1 mol) scale multi-step organic synthesis -Skilled with air and moisture sensitive reactions, utilizing glove box and Schlenk techniques -Analytical techniques: TLC, HPLC, LC/MS, GC/MS, NMR, IR, Elemental Analysis. -Purification techniques: TLC, HPLC, flash chromatography, distillation, recrystallization. -Qualified in maintaining laboratory instrumentation including: Glove Box, Solvent purification systems and Elemental Analysis. -Responsible for maintaining chemical inventory. -Proficient with Chemdraw, Microsoft Office, and Citation Manager, Scifinder Scholar, Reaxys, and Web of Science.
Publications	<p>6) Wilson, R.J., Clark, D.A.; Silylvinilation and Hydrovinilation of Terminal Alkynes in the Presence Ethylene Gas at Elevated Pressures. Manuscript in preparation</p> <p>5) Wilson, R.J., Ahmed, I., Kaminsky, L., Clark, D.A.; Ruthenium Hydride Catalyzed <i>trans</i>-Silylvinilation of Internal Alkynes Using Ethylene as an Additive. <i>The Journal of Organic Chemistry</i> 2015 Just accepted</p> <p>4) Wilson, R.J., Kaminsky, L., Clark, D.A.; Regio and Stereoselective Synthesis of Silyl-dienyl Boronates. <i>Organic Letters</i> 2015, 17, (12), 3126-3129.</p> <p>3) Rosenberg, A. J.; Ahmed, I., Wilson, R. J., Williams, T.M., Kaminsky, L., Clark, D.A.; An Improved Synthesis of Imidazo[4,5-b]Pyridines and Imidazo[4,5-b]Pyrazines by Palladium Catalyzed Amidation Using Xantphos in a 1,4-Dioxane:tert-Amyl Alcohol Solvent System. <i>Advanced Synthesis & Catalysis</i> 2014, 356, 3465-3470</p> <p>2) Liu, S., Zhao, J., Kaminsky, L., Wilson, R.J., Marino, N., Clark, D.A.; Ethylene Transposition: Ruthenium Hydride Catalyzed Intramolecular <i>trans</i>-Silylvinilation of Internal Alkynes. <i>Organic Letters</i> 2014, 16, 4456</p> <p>1) Wilson, R. J., Rosenberg, A. J., Kaminsky, L., Clark, D. A.; Copper- and Palladium-Catalyzed Amidation Reactions for the Synthesis of Substituted Imidazo[4,5-c]pyridines. <i>The Journal of Organic Chemistry</i> 2014, 79 (5), 2203-2212. <i>Highlighted in Synfacts</i> 2014, 10(6), 0568</p>
Presentations	<p>2) Wilson, R.J., Clark, D.A.; "Ruthenium Hydride Catalyzed Silylvinilation of Internal Alkynes Using Ethylene as an Additive." Presented: 32nd annual Graduate Student Symposium, University at Buffalo, 2014</p> <p>1) Wilson, R.J., Clark, D.A.; "Ruthenium Hydride Catalyzed Intramolecular Silylvinilation of Internal Alkynes." Presented 38th Northeast Regional Meeting of the American Chemical Society, Rochester, N.Y. 2012</p>