New Advances in the Synthesis of Siloles and *N*-Heterocycles

BY

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THESIS

Submitted as partial fulfillment of the requirements
for the degree of Doctor of Philosophy of Chemistry
in the Graduate College of the
University of Illinois at Chicago, 2014

Chicago, Illinois

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ACKNOWELEDGEMENT

I would like to express my greatest appreciation to my advisor, Distinguished Professor Vladimir Gevorgyan, for his guidance, constant encouragement, and support throughout the years of my study (2008-2014). I am endlessly thankful for the given opportunity to work and learn in his fantastic research group. I would also like to thank the members of my thesis committee, Professor Daesung Lee, Professor Justin Mohr, Professor Duncan Wardrop, and Professor Karol Bruzik for their help, criticism, and constructive suggestions.

I am grateful to the teachers during my high school years: Mars N. Vahidov (1998-2001) and Vladimir V. Menshikov (1999-2001) for introducing me to the exciting subject of chemistry. I also thank my former research advisors at the Chemistry Department of Moscow State University, Professor Alexander Z. Voskoboynikov (2001-2002), Aleksandr N. Bumagin (2002-2003), and Professor Eugene V. Babaev (2004-2008) for training me in the area of synthetic organic chemistry. I would also like to thank all current and former members of Professor Gevorgyan group I worked with. It was my pleasure to collaborate with these talented young scientists on a daily basis in the inspiring environment.

I would like to thank my family, especially my mother and my sister as well as my friends Olesja, Anton, and Ferdinand for their love, support, and friendship throughout the years.

I would also like to extend my gratitude to the entire staff of the Chemistry Department, especially to Ms. Rhonda Staudohar and Dr. Randy Puchalski.

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Å	angstrom
Ac	acetyl
Alk	alkyl
Ar	aryl
Ar^F	perfluoroaryl
atm	atmosphere
ATPase	adenosine triphosphate hydrolase
(*R*)-binap	(R)-(+)-2,2′-bis(diphenylphosphino)-1,1′-binaphthyl
B	base
Bn	benzyl
Boc	*tert*-butoxycarbonyl
Bz	benzoyl
n-Bu	butyl
t-Bu	*tert*-butyl
Calcd	calculated
cat.	catalytic amount/catalyst
Cbz	carboxybenzyl
cod	1,5-cyclooctadiene
Cp^*	1,2,3,4,5-pentamethylcyclopentadienyl
m-CPBA	*meta*-chloroperoxybenzoic acid
Cy	cyclohexyl

LIST OF ABBREVIATIONS (continued)

δ	chemical shifts in parts per million downfield from tetramethylsilane (NMR)
d	doublet (NMR)
dba	dibenzylidene acetone
DBU	1,8-Diazabicyclo[5.4.0]undec-7-ene
DCM	dichloromethane
DCE	1,2-dichloroethane
dd	doublet of doublets (NMR)
DDQ	2,3-dichloro-5,6-dicyanobenzoquinone
DG	directing group
DIAD	diisopropyl azodicarboxylate
DIPEA	diisopropylethylamine
DMAP	4-dimethylaminopyridine
DME	dimethoxyethane
DMF	dimethylformamide
S-DOSP	1-[[4-alkyl(C_{11}-C_{13})phenyl]sulfonyl]-(2*S*)-pyrrolidinecarboxylate
dppbe	1,2-bis(diphenylphosphino)benzene
dppe	1,2-bis(diphenylphosphino)ethane
dppf	1,2-bis(diphenyl-phosphino)ferrocene
dppp	1,1'-bis(diphenylphosphino)propane
dt	doublet of triplets (NMR)
dtbpy	4,4′-Di-tert-butyl-2,2′-dipyridyl

LIST OF ABBREVIATIONS (continued)

EI	electron impact ionization (in mass spectrometry)
Et	ethyl
equiv	molar equivalent
EWG	electron-withdrawing group
G	group
g	gram
GC-MS	gas chromatography – mass spectrometer
h	hour(s)
Het	heteroaromatic
HRMS	high resolution mass spectrometry
Hz	hertz
IC_{50}	minimal (50%) inhibitory concentration (IC) of a substance
IMes	1,3-bis(2,4,6-trimethyl-phenyl)-1,3-dihydro-2H-imidazol-2-ylidene
IPr	1,3-bis(2,6-diisopropylphenyl)-1,3-dihydro-2H-imidazol-2-ylidene
J	spin-spin coupling constant (NMR)
k_H/k_D	kinetic isotope effect for $^1H/^2H$ substitution
L	ligand
LAH	lithium alumohydride
LDA	lithium diisopropyl amide
LiHMDS	lithium bis(trimethylsilyl)amide
LiNp	lithium naphthalenide
LRMS	low resolution mass spectra

LIST OF ABBREVIATIONS (continued)

LUMO	lowest unoccupied molecular orbital
m	multiplet (NMR)
μ	micro
M	molar, metal
$[M]^+$	molecular ion
MS	molecular sieves
Me	methyl
mg	milligram
MHz	megahertz
min	minute
mL	milliliter
mmol	millimole
mol	mole
MW	molecular weight
Na•naphth	sodium naphthalenide
NaBARF	sodium tetrakis[3,5-bis(trifluoromethyl)phenyl]boranuide
nb	norbornene
NCS	*N*-chlorosuccinimide
NIS	*N*-iodosuccinimide
nm	nanomolar
NMR	nuclear magnetic resonance
NXS	*N*-halosuccinimide

LIST OF ABBREVIATIONS (continued)

PCC	pyridinium chlorochromate
Ph	phenyl
phen	1,10-phenantroline
Phth	phthalyl
Piv	pivalyl, trimethylacetyl
ppm	parts per million
Pr	propyl
i-Pr	isopropyl
n-Pr	propyl
Py	pyridine
Pza	2-pyrazol-5-ylaniline
q	quartet (NMR)
quint	quintet (NMR)
R_f	retention factor
rt	room temperature
s	singlet (NMR)
s_{br}	broad singlet (NMR)
SIPr	1,3-Bis(2,6-di-i-propylphenyl)imidazolidin-2-ylidene
SPhos	2-dicyclohexylphosphino-2′,6′-dimethoxybiphenyl
t	triplet (NMR)
tbphen	2-*tert*-butyl-1,10-phenanthroline
Tf	trifluoromethanesulfonyl

LIST OF ABBREVIATIONS (continued)

TBAF	tetrabutylammonium fluoride
td	triplet of doublets (NMR)
TEA	triethylamine
THF	tetrahydrofuran
TIPS	triisopropylsilyl
TLC	thin layer chromatography
TMEDA	*N*-*N*-*N*′-*N*′-tetramethylethylenediamine
TMS	trimethylsilyl
Tol, tol	tolyl
tp	2,2′:6′,2″-terpyridine
Tp^{Me2}	hydrotris(3,5dimethylpyrazolyl)borate
Ts	*para*-toluenesulfonyl
TTBP	2,4,6-tris-*tert*-butylpyrimidine

SUMMARY

This thesis describes the development of novel transition metal-catalyzed processes toward dihydrobenzosiloles and fused heteroaromatic dihydrosiloles. It also includes development of a Brønsted acid-catalyzed protocol for the synthesis of indoles, as well as development of a new reactivity mode of diazocompounds towards triazolines.

In the first part, the nickel-catalyzed hydrosilylation/iridium-catalyzed dehydrogenative coupling of aromatic- and heteroaromatic styrenes allowing for the facile synthesis of fused aromatic- and heteroaromatic dihydrosiloles is disclosed. The introductory part of Chapter 1 briefly highlights the importance of silole, its aromatic- and heteroaromatic analogues in material sciences, as well as importance of dihydrobenzosilole as a pharmaceutically relevant motif. A description of the traditional methods of the synthesis of silole, its analogues, and dihydrobenzosilole is provided next. A major focus of the Chapter 1 lies in subsequent section describing development of the predominantly transition metal-catalyzed inter- and intramolecular C–H silylation reactions. Chapters 2 and 3 describe the development of novel transition-metal-catalyzed hydrosilylation and C–H/Si–H coupling reactions for the synthesis of fused aromatic and heteroaromatic dihydrobenzosiloles. It is shown that this approach exhibits great functional group tolerance and excellent regioselectivity. The performed mechanistic studies for the C–H/Si–H dehydrogenative coupling of aromatic substrates suggest the C–H activation mechanism rather than electrophilic metalation path for this step. Chapter 4 provides experimental details for the synthesis of fused aromatic and heteroaromatic

dihydrosiloles as well as further transformations of the obtained molecules, which were disclosed in Chapters 2 and 3.

The second part describes Brønsted acid-catalyzed one-pot synthesis of indoles from *ortho*-aminobenzyl alcohols and furans. The introductory part of Chapter 5 briefly describes importance of recyclization reactions of furan in the synthesis of some biologically important targets. An overview of the developed transition-metal-catalyzed and Brønsted acid-mediated processes for recyclization reactions of furans into different carbo- and heterocycles is provided next in details. Chapter 6 discloses development of a new protocol for recyclization reaction of furan into indoles starting from *ortho*-aminobenzyl alcohols. The presented method proved to exhibit wider scope and greater functional group tolerance than the previously reported proceedure. It's also shown that the formed indoles can be further transformed into valuable 1,2- and 1,3-fused indoles. Chapter 7 provides experimental details for the synthesis of indoles, as well as their further transformations, described in Chapter 6.

The part three is devoted to the discovery of a new reactivity mode of diazocompounds in a diastereoselective synthesis of triazolines via 1,3-aminoalkylation reaction of *β*-amino-*α*-diazoesters. The introductory part of Chapter 8 briefly highlights different reactivity modes of diazocompounds. A description of the reactions, which undergo with preservation of the diazo-group is described next in more details. Subsequently, Chapter 9 discloses novel 1,3-addition mode of nucleophile and electrophile at the diazo-group of *β*-amino-*α*-diazoesters with the formation of 1,2,3-triazolines. This reaction proceeds exclusively in a *trans*-manner with respect to the aryl substituent at the *β*-position of the diazoesters, providing the triazoline product as a single

diastereomer. The first gold-catalyzed intramolecular denitrogenative transannulation reaction of the propargyl triazolines into tetrasubstituted pyrroles is described next. Finally, Chapter 10 provides experimental details of the aminoalkylation and transannulation reactions described in Chapter 9.

PART ONE

DEVELOPMENT OF NOVEL C–H/Si–H COUPLING REACTIONS TOWARDS FUSED AROMATIC AND HETEROAROMATIC DIHYDROSILOLES

1. INTRODUCTION

1.1. Importance of Siloles and Dihydrobenzosiloles

Silole and its benzo analogues due to their low lying LUMO energy levels are promising scaffolds for material sciences as electron transporters and emitters.[1] Thus, Nakamura showed that simple 2-arylbenzosilole **1** is an efficient material for organic light-emitting diode (OLED) devices (Figure 1).[2] Other silole derivatives, such as π–extended ladder-type aromatic[3] (**2**) and heteroaromatic[4] (**3**) silafluorenes, as well as spiro-type[5] (**4**) silafluorenes, proved to have high fluorescence quantum yield and high glass-transition temperatures. An interesting example of the replacement of carbon atom with silicon atom is silasumanene **5**. It is the analogue of a bowl-shaped sumanene, which is a model compound for study of fullerenes and a possible intermediate for the newly designed macrocyclic fullerene-type systems (Figure 1).[6]

Recently, silicon-containing molecules and particularly dihydrobenzosiloles have also attracted attention as pharmaceutically important motifs.[7] Replacement of carbon by silicon (the C/Si switch) results in some important changes of the physicochemical properties of the silicon-containing molecules compared to their carbon-analogues, including increased lipophilicity and molecular size, hydrogen-bonding ability, and acidity.[8] Hence, it was shown that 1,4-silaspiro[indane-1,4-piperidine] derivatives **6** are

high-affinity selective central nerve system sigma-receptor ligands with IC_{50} values in the single nM range (Figure 1).[9] Other examples of pharmaceutically important molecules include gamma-secretase modulator **7**[10] for treatment of Alzheimer disease and Gonadotropin-Releasing Hormone (GnRH) antagonist **8**.[11]

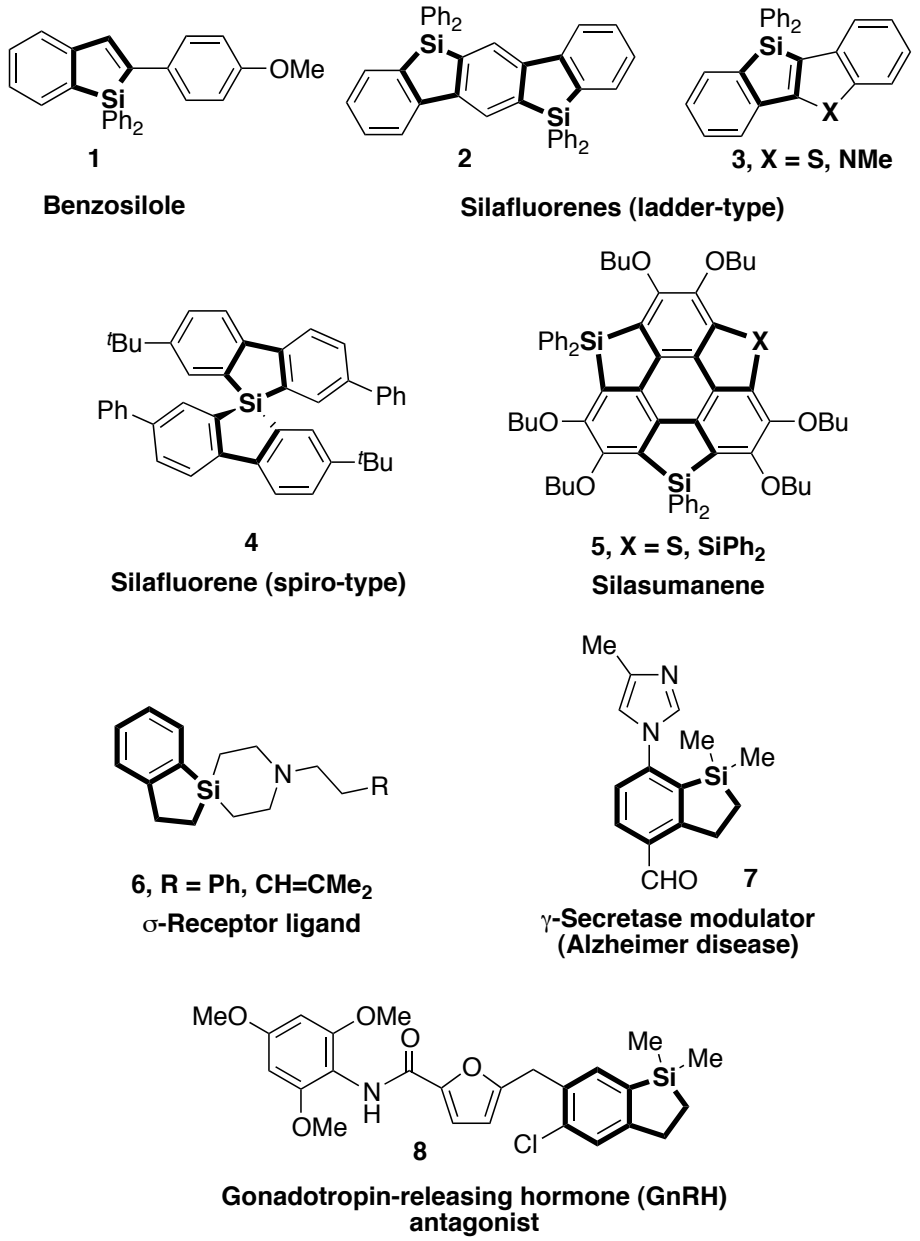


Figure 1. **Examples of important siloles and dihydrobenzosiloles for material and biological sciences**

Given the importance of silole and its benzo analogous in material sciences, a considerable attention has been paid to their synthesis. But, methodologies reported for the synthesis of dihydrobenzosiloles, which are promising scaffolds in medicinal chemistry, are much more scarce. In the following chapter, a summary of conventional methods for the synthesis of siloles, benzosiloles, and dihydrobenzosiloles is given. The following part will be devoted to the direct C–H silylation reactions. The development of inter- and intramolecular C–H silylation reactions lately led to the discovery of efficient methodologies for synthesis of silafluorenes, one of the important classes of silole molecules.

1.2. Methods for Synthesis of Siloles and Benzo Analogous of Silole

1.2.1. Traditional Methods for Synthesis of Siloles

One of the first methods developed for the synthesis of siloles **9** utilizes intermolecular coupling reaction between 1,4-dilithiobutadiene-1,3 **10** and dichlorosilanes (Figure 2). The 1,4-dilithiobutadiene specie can be generated by either reductive dimerization reaction of bisarylalkynes **11** with lithium[12,13] or by double metal-halogen exchange in 1,4-dihalobutadiene **12**.[14] Alternatively, siloles can be obtained via intramolecular cyclization of bisalkynylsilanes **13** in the presence of lithium naphthalenide[15,16] or organoboron compounds.[17] Another method involves cyclization of alkynes **11** or diynes **14** with dihydrosilane in the presence of transition metals, such as

Ni,[18] Pd,[19] and Ru.[20] It is also possible to exchange Zr in zirconocycle **15** with Si using different dichloro- and dihydrosilanes.[21] An interesting example includes utilization of silylene **16** (Si analogue of carbene)[22] in the reaction with butadiene **17**. In this case, the initially formed 2,5-dihydrosilole intermediate undergoes thermal[23] or oxidative[19c] dehydrogenation with the formation of silole.

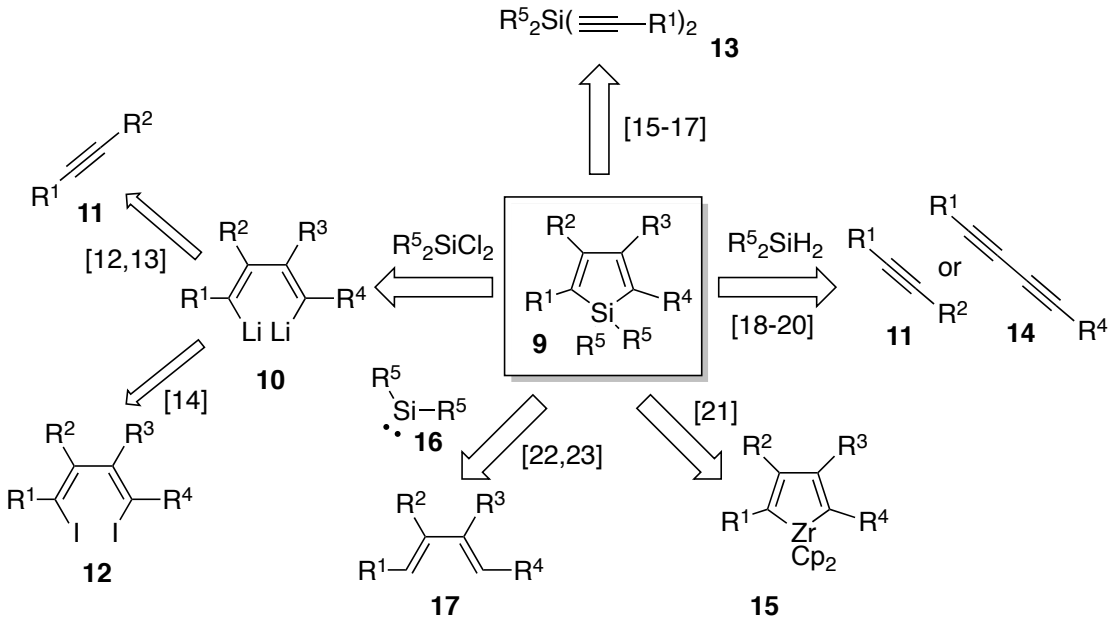


Figure 2. Traditional methods for synthesis of siloles

1.2.2. Traditional Methods for Synthesis of Benzosiloles, Dibenzosiloles and their Hetero Analogues

Similar to the synthesis of siloles, one of the first methods described for the synthesis of benzosiloles **18** utilizes reaction of dilithium intermediate **19** with

dichlorosilane (Figure 3). These dilithio intermediates can be generated by the reaction of *β*-bromostyrene **20**,[24] alkynes **21**,[25] or benzometalloles **22** (Zr[26] and Te[27]) with butyllithium. Alternatively, several methods for the synthesis of benzosiloles via intramolecular cyclization of *ortho*-silylsubstituted phenylalkynes **23** in the presence of $AlCl_3$,[28] lithium naphthalenide,[29] Me_3SnLi,[30] ruthenium catalyst,[20a] or KH[2a] have been developed. Benzosilole **18** can be also obtained by ring closing metathesis of diene **24**.[31] Recently, an elegant method has been described for the synthesis of benzosiloles via the palladium-catalyzed intramolecular Mizoroki-Heck reaction of bromovinylsilanes **25**.[32] Dibenzosilole and its heteroaromatic derivatives, by analogy with other silole systems, can be obtained from *ortho,ortho'*-dibromobiaryl derivatives **26** by reaction with butyllithium followed by trapping of the formed dilithio intermediate with dichlorosilane (Figure 3).[33,34] The same dihalobiaryl derivatives **26** can be converted into the corresponding dibenzosiloles via a direct palladium-catalyzed coupling reaction with hydrosilanes.[35] In addition, a C–H arylation process was also developed for the direct intramolecular cyclization of aryl- and heteroaryltriflates **27**.[36,37]

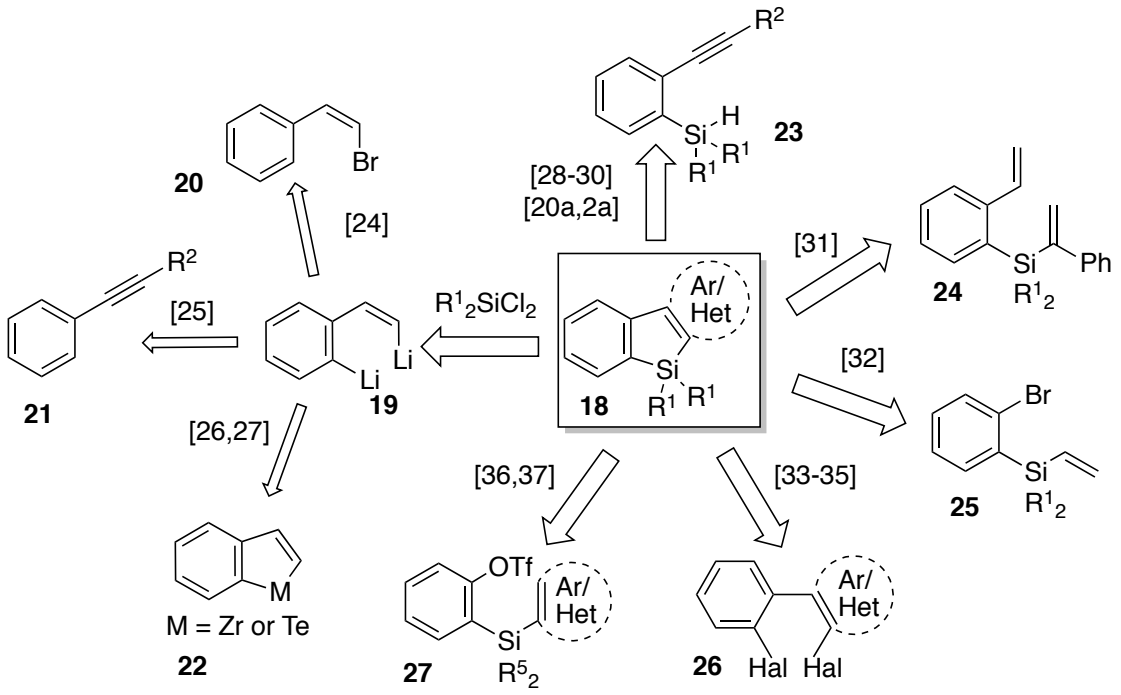


Figure 3. Conventional methods for synthesis of benzosiloles and dibenzosiloles

The methods for synthesis of dihydrobenzosiloles **28** are mainly limited to the use of Grignard reagent obtained from *ortho*-bromophenetylbromide or chloride **29** under Barbier reaction conditions. In this case, the initially formed organomagnesium derivative subsequently reacts with dichloro- or trichlorosilane to produce dihydrobenzosilole **28** (Figure 4).[9,38] Other examples include intramolecular cyclization reaction of *ortho*-chlorophenylsilane **30** with sodium metal,[39] low efficiency intermolecular cyclization of cyclotrisilane **31** with styrene **32**,[40] as well as pyrolysis of trimethylsilyl alcohol **33**[41] (Figure 4).

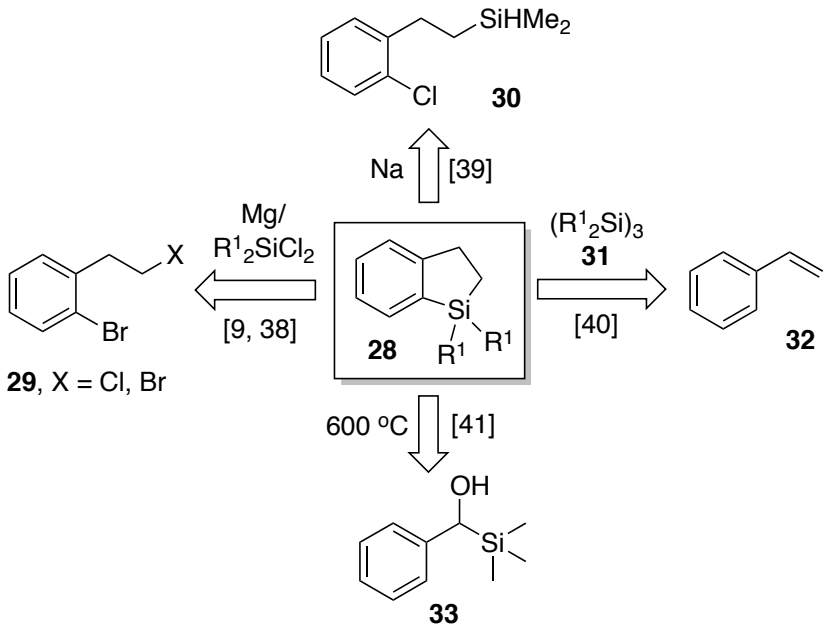


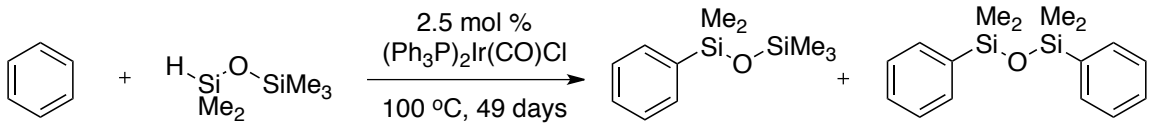
Figure 4. Methods for synthesis of dihydrobenzosiloles

1.2.3. Direct C–H Silylation Reactions

This part will be dedicated to the development of methods for direct C–H silylation reactions. First, discovery and further exploration of intermolecular C–H silylation reactions will be discussed. Next part is devoted to the recent advances in intramolecular C–H silylation. Some of these recent methodologies represent a new facile way for synthesis of silafluorenes, one of the important classes of siloles for material sciences (*vide supra*).

1.2.3.1 Intermolecular C–H Silylation Reactions

The first example of intermolecular dehydrogenative silylation reaction of arenes was reported by Curtis in 1982.[42] In this report, pentamethyldisiloxane **34** reacts with benzene in the presence of Vaska's complex (Scheme 1). In obtained mixture of products, along with a series of methylsiloxane oligomers, trace to low amounts of pentamethyl-(phenyl)disiloxane **35** and tetramethyl(diphenyl) disiloxane **36** have been formed as a result of C–H/Si–H dehydrogenative coupling.



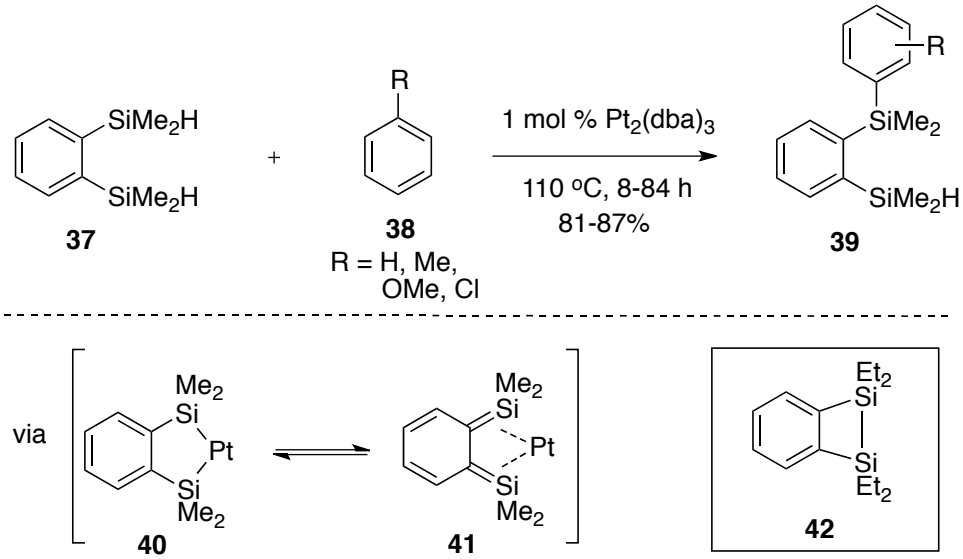
34 **35**, 17% **36**, 2.5%

Scheme 1.

Subsequently, Tanaka showed that Vaska-type rhodium complex promoted similar dehydrogenative coupling of benzene and toluene with triethylsilane under photolytic reaction conditions.[43]

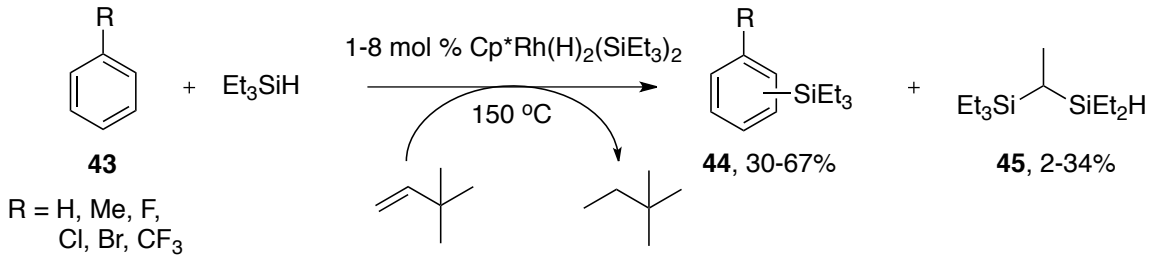
In 1993, the same group reported selective platinum-catalyzed arylation of *ortho*-bis(dimethylsilyl)benzene **37** (Scheme 2).[44] This interesting transformation gives high yields of silylated products **39** for a variety of arenes **38**, but limited to the particular disilane **37**. It was proposed that bis(silyl)platinum species **40**/**41** function as an active catalyst for oxidative addition into the aromatic C–H bond. The Ishikawa group disclosed similar transformations of simple arenes with highly reactive disilacyclobutene

derivative **42** (Scheme 2). These reactions were catalyzed by nickel,[45] platinum,[46] and palladium[47] complexes.



Scheme 2.

In 1998, Berry reported rhodium- and ruthenium-catalyzed dehydrogenative coupling of benzene derivatives **43** with triethylsilane to give arylsilanes **44** (Scheme 3).[48] Addition of *tert*-butylethylene as a hydrogen acceptor was essential for this reaction to proceed. This represents the first example of using external hydrogen acceptor in C–H silylation reaction. Competitive dimerization of triethylsilane with the formation of carbosilane **45** has also been observed (Scheme 3).[49]

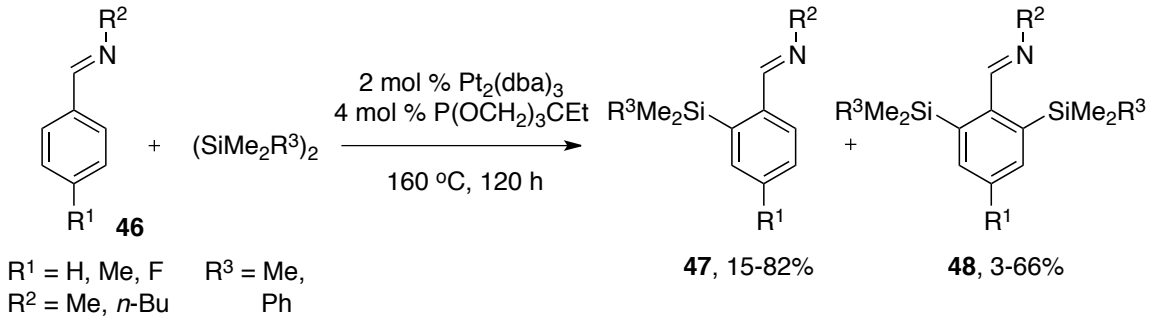


Scheme 3

It is worth mentioning that silylation reaction of monosubstituted arenes described in all these pioneering reports proceeds with low regioselectivity, providing a mixture of *ortho*/*meta*/*para*-isomers. In some cases,[44-47] specific silane coupling partner was used, which reduced the generality of the described methods.

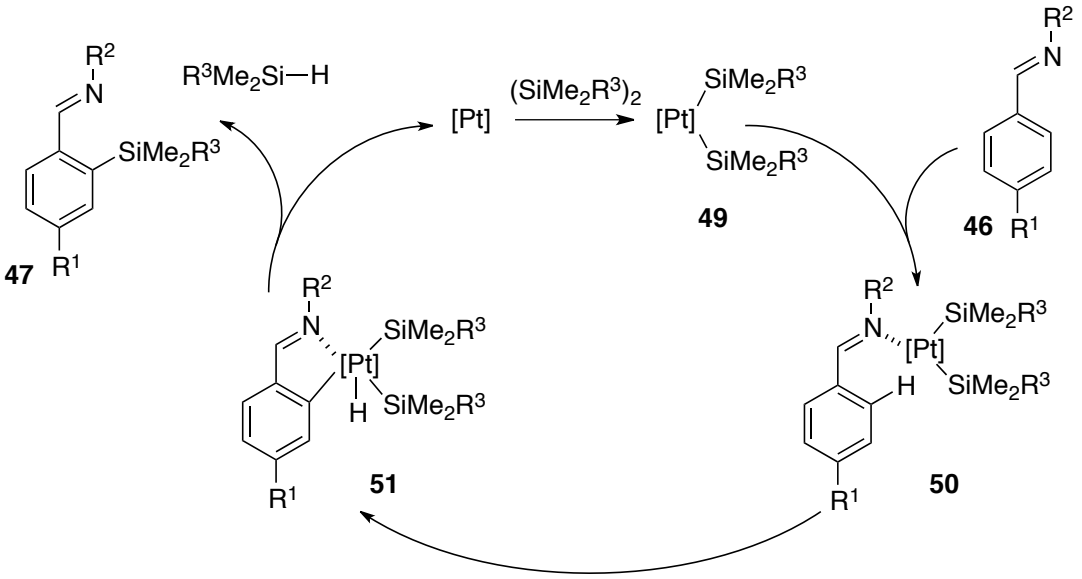
One of the ways of overcoming low regioselectivity in the C–H functionalization of arenes is to use a directing group. Consequently, during the past two decades, a number of methodologies have been developed for the directed C–H/Si–H coupling, which rely on the directing effect of heteroatoms for transition metal catalyst.

The first example of the directed *ortho*-C–H silylation reaction of arenes was reported by Tanaka in 1995.[50] It was found that platinum-catalyzed silylation of benzylidene-amines **46** with disilanes leads to the formation of mono- (**47**) and disilylated (**48**) products (Scheme 4).



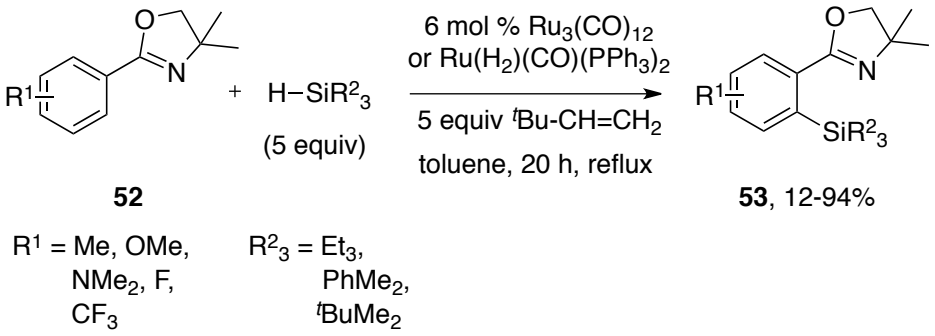
Scheme 4

The proposed mechanism for this transformation includes oxidative addition of disilane to platinum(0) yielding bis(silyl)platinum(II) species **49** (Scheme 5). The following coordination of the catalyst to imine **46** results in complex **50**, in which oxidative addition of the *ortho*-C–H bond at metal center furnishes platinum(IV) intermediate **51**. Two consecutive reductive eliminations to produce silylated imine **47** and hydrosilane complete the catalytic cycle.



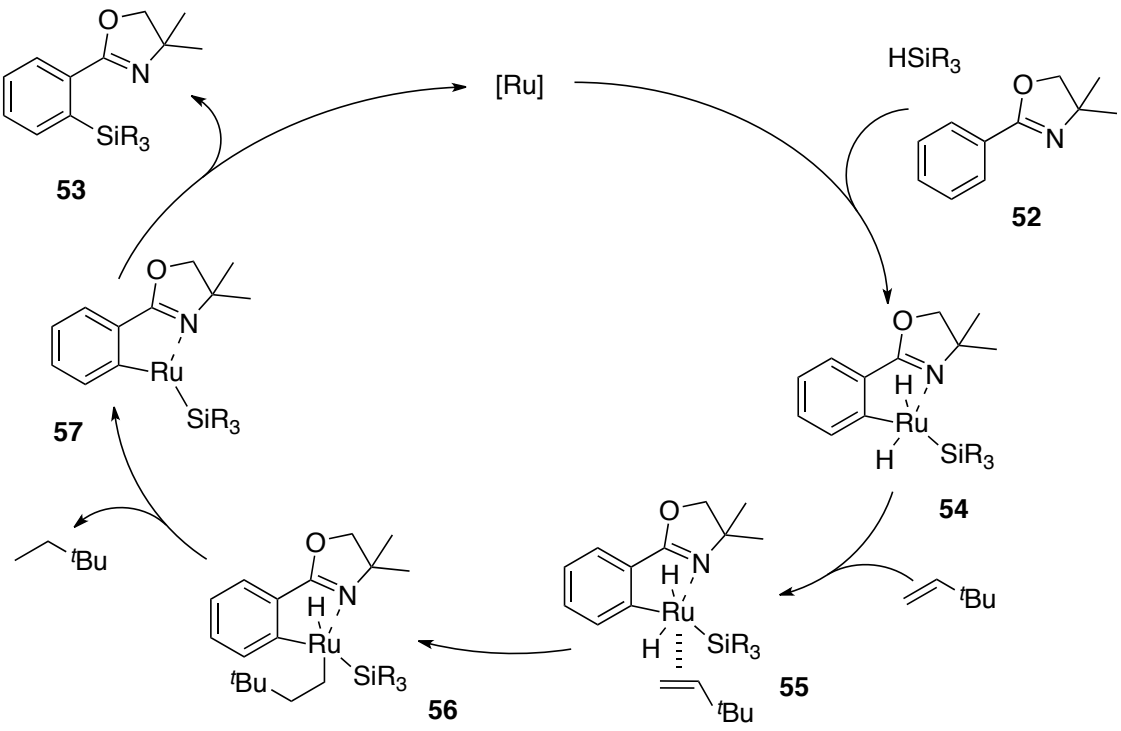
Scheme 5.

The idea of using a directing group was further explored by Kakiuchi. Thus, he reported the first example of the directed C–H silylation using hydrosilane as the source of the silyl group.[51] In this report, the reaction of aryloxazolines **52** with trialkylsilane in the presence of ruthenium catalyst results in mono *ortho*-silylation products **53** in low to excellent yields (Scheme 6). Similarly to the Berry reports,[48,49] addition of *tert*-butylethylene as a hydrogen acceptor was necessary for this reaction.



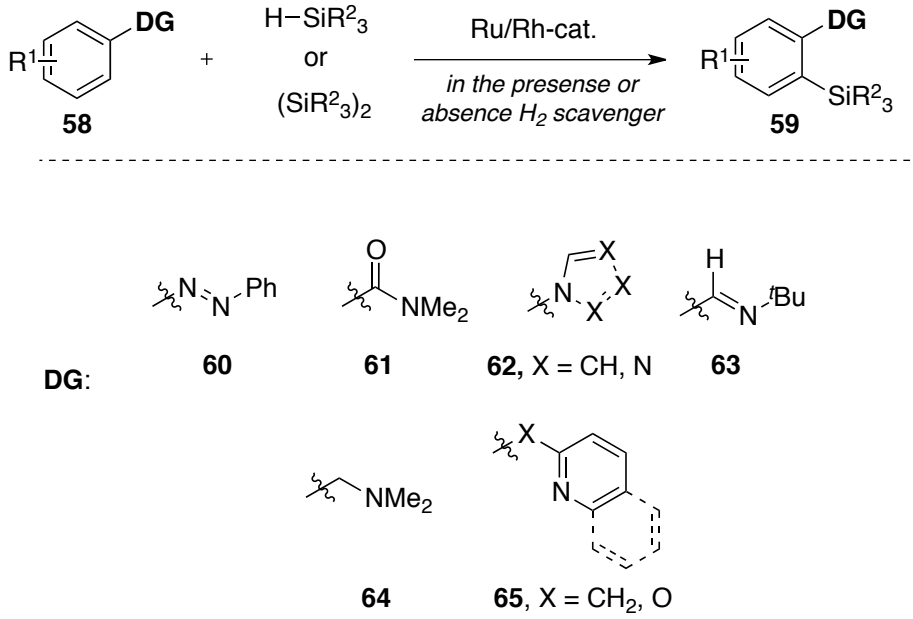
Scheme 6.

Substituents at the *ortho*-position of the arene decrease the reactivity compared to unsubstituted phenyloxazoline **52**. The proposed reaction pathway is depicted in Scheme 7. First, the oxidative addition of the hydrosilane at the Ru(0) center gives sila-ruthenium(II) hydride specie, which then undergoes an oxidative addition at the aromatic C–H bond, resulting in the formation of the Ru(IV) intermediate **54**. Alternatively, the oxidative addition of the C–H bond at the Ru(0) prior to the oxidative addition at the Si–H bond might also take place. The following coordination of the alkene at the metal center and a subsequent migratory insertion in the resulting complex **55** furnishes intermediate **56**. The latter, upon sequential reductive eliminations forms (silyl)(aryl)ruthenium intermediate **57**, and then the silylation product **53**.



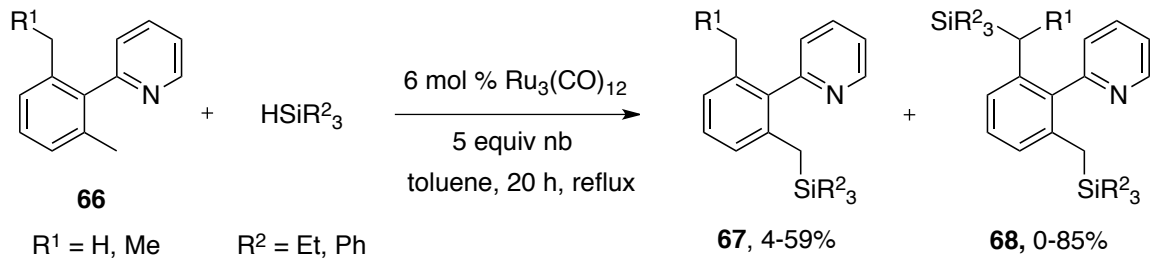
Scheme 7.

In the following years, a number of arene π-conjugated and non-π-conjugated directing groups for the ruthenium- or rhodium-catalyzed *ortho*-C–H silylation of arenes **58** with hydrosilanes or disilanes have been developed by Kakiuchi, Murai, and Chatani (Scheme 8).[52] The examples of π-conjugated directing groups for the preparation of *ortho*-silylated arenes **59** include diazophenyl **60**, amide **61**, azoles **62**, and aldimines **63**. The examples of non-π-conjugated directing groups include *N*,*N*-dimethylaminomethyl group **64**, 2-picolyl, 2-pyridyl ether and the corresponding quinoline derivatives **65** (Scheme 8).



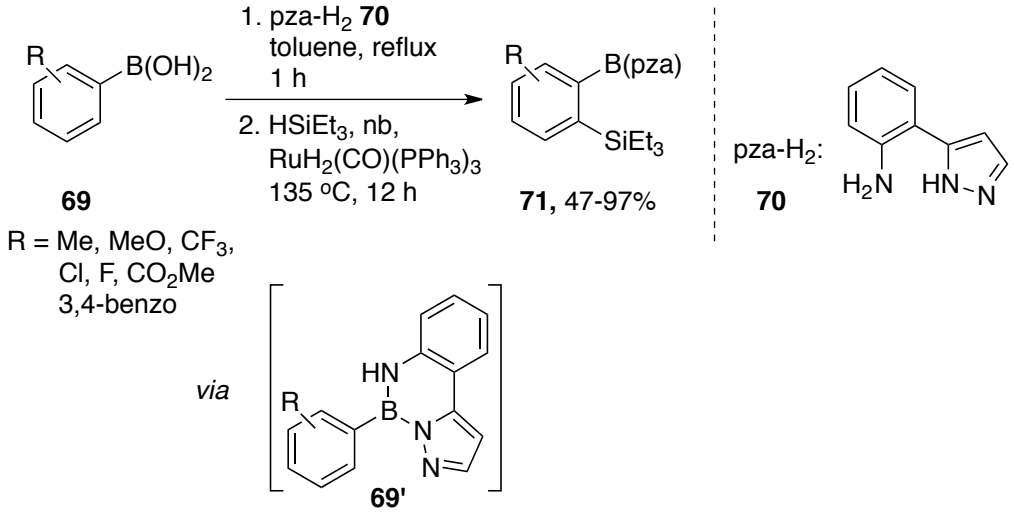
Scheme 8.

The same directing group strategy was utilized in the *ortho*-benzylic C(sp^3)–H silylation. For instance, the reaction of 2-(2,6-dimethylphenyl)pyridine **66** with hydrosilanes, using $Ru_3(CO)_{12}$ catalyst, produced the corresponding mono- **67** and disilylated **68** products in moderate yields (Scheme 9).[53] In 2012, Sato reported similar protocol for the iridium- or ruthenium-catalyzed *ortho*-benzylic C(sp^3)–H silylation of arenes.[54]



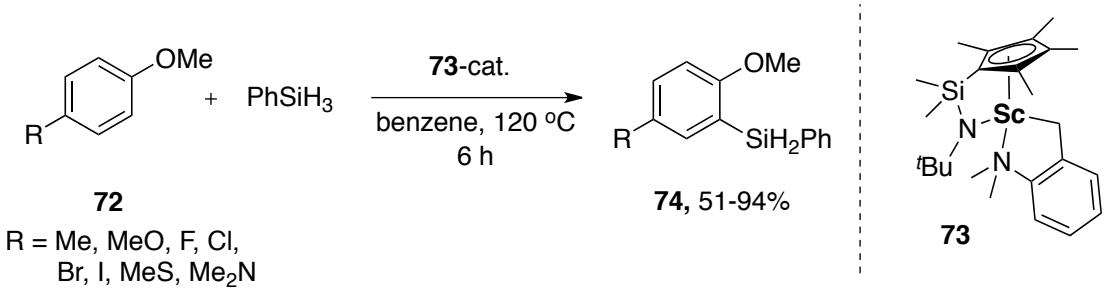
Scheme 9.

In 2009, Suginome reported the first example of an easily installable and removable directing group for the *ortho*-C–H silylation of arylboronic acids.[55] Thus, reaction of boronic acid **69** with 2-pyrazol-5-ylaniline (pza-H_2) **70** results in pza derivative **69′** (Scheme 10). The latter undergoes ruthenium-catalyzed *ortho*-C–H silylation with the formation of silane **71**. The obtained products can be subsequently converted to either boronic acids or boronic acid derivatives. Later, the same group disclosed a similar transformation for α-C–H silylation of methylboronic acid.[56]



Scheme 10.

Very recently, Hou reported *ortho*-C–H silylation of anisoles **72** with phenylsilane with the formation of phenylsilylanisoles **74** (Scheme 11).[57] This transformation was catalyzed by half-sandwich scandium alkyl complex **73**. Although this reaction proceeds in good yields, it is mostly limited to unsubstituted and *para*-substituted anisoles. In the case of *meta*-substituents, a mixture of products was formed; whereas *ortho*-substituted anisoles were not reactive.



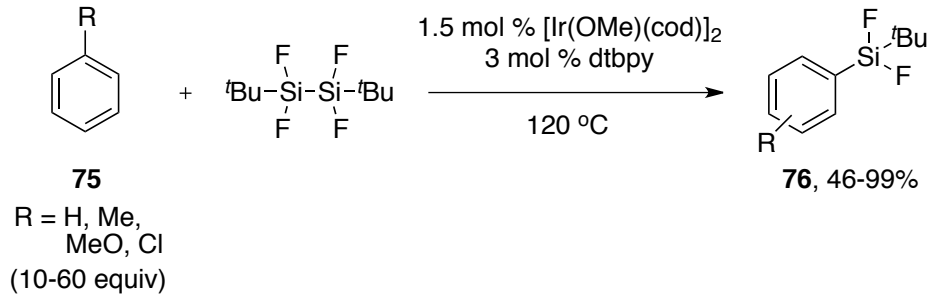
72
R = Me, MeO, F, Cl, Br, I, MeS, Me_2N

74, 51-94%

73

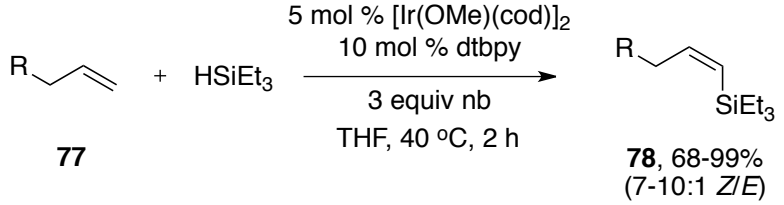
Scheme 11.

Ishiyama and Miyaura developed an efficient directing group-free procedure for C–H silylation of arenes.[58] In this work, aryl difluorosilanes **76** were obtained via iridium-catalyzed silylation of arenes **75** with tetrafluorodisilane (Scheme 12). Although this method requires large excess of arene (10-60 equiv), the corresponding arylfluorosilanes **76** were obtained in high yields and regioselectivity with silylation occurring at the less sterically hindered C–H bond.



Scheme 12.

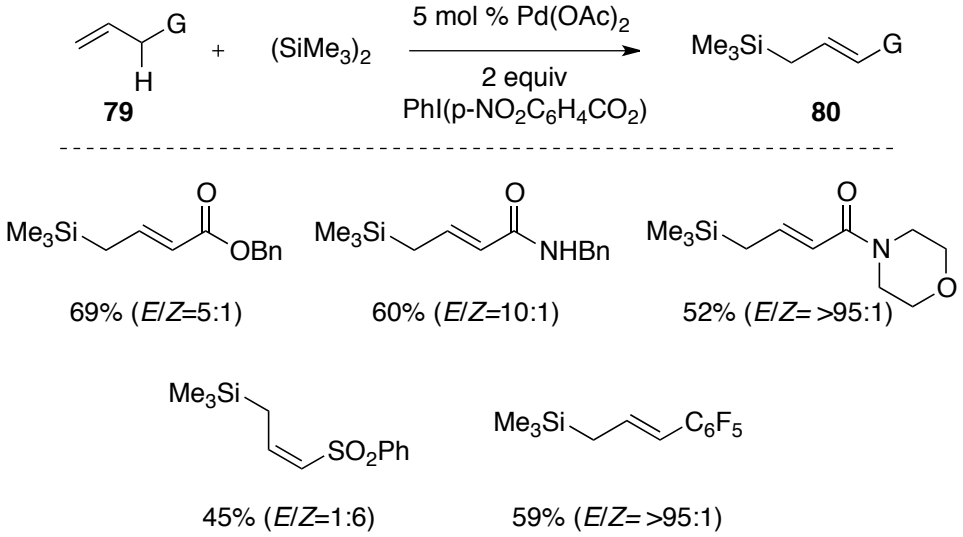
In 2010, Falck reported *Z*-selective iridium-catalyzed dehydrogenative silylation reaction of terminal olefins **77** with triethylsilane leading to vinylsilanes **78** (Scheme 13).[59] This reaction is compatible with many functional groups including epoxides, ketones, amides, alcohols, and esters. It was proposed that the reaction proceeds via a Heck-type mechanism. *E*-selective silylation of terminal olefins has also been reported for rhenium-[60] and palladium[61] complexes.



Scheme 13.

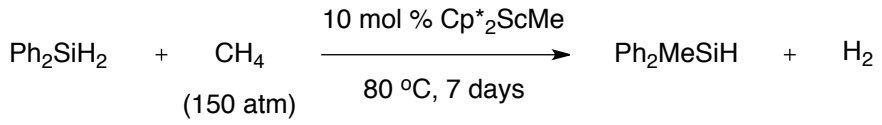
In 2011, Szabó showed the first example of the oxidative allylic C–H silylation of activated alkenes **79** using palladium catalyst and hexamethyldisilane as a source of the

silyl group (Scheme 14).[62] The reaction requires the presence of hypervalent iodine oxidant and provides only linear allylic product **80**. The observed regioselectivity for this reaction is consistent with the formation of allylpalladium intermediate, in which unsymmetrically substituted allyl moiety undergoes attack at the less sterically hindered terminus.[63]



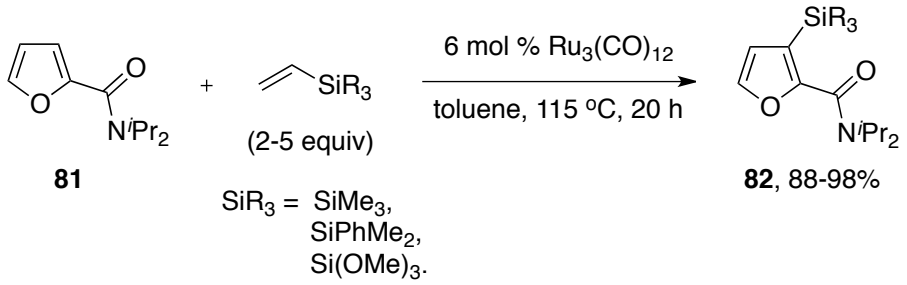
Scheme 14.

Only few examples for the intermolecular silylation of unactivated C(sp^3)–H bonds have been disclosed. Thus, in 2003 Tilly reported a possibility of the scandium-catalyzed σ-bond metathesis of methane with diphenylsilane leading to the formation of diphenylmethylsilane and dihydrogen (Scheme 15).[64] A similar approach for the σ-bond metathesis of methane was earlier reported earlier employing hafnium complex.[65]



Scheme 15.

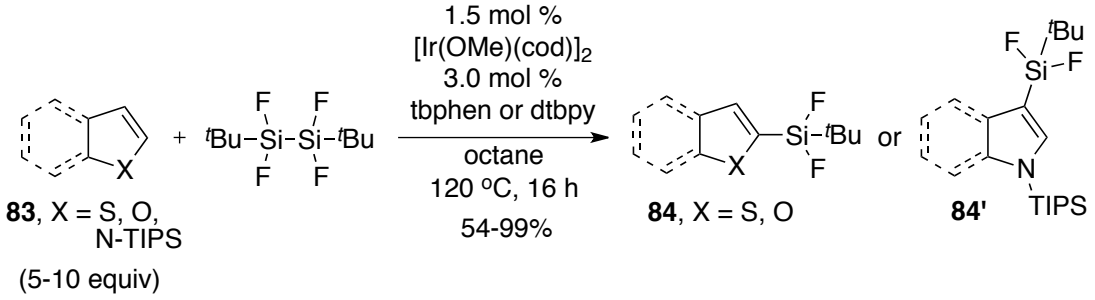
Although a number of methodologies have been developed for the silylation of aromatic C–H bonds, the analogous heteroaromatic C–H bond coupling reactions are still rare. For instance, in 2000, Murai reported the first ruthenium-catalyzed directed synthesis of furylsilanes **82** from furan-2-carboxylic acid, diisopropylamide **81**, and vinylsilanes (Scheme 16).[66] Thiophenes and pyrroles were also capable substrates for this transformation, however the yields of the corresponding products were significantly lower.



Scheme 16.

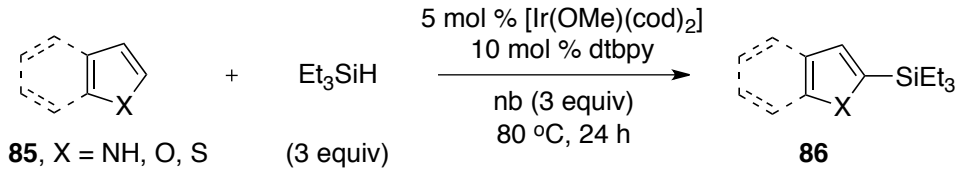
In 2005, Miyaura disclosed the iridium-catalyzed regioselective C–H silylation reaction of electron rich heterocycles **83** with tetrafluorodisilane (Scheme 17).[67] The reaction of furans and thiophenes predominantly gives the C2 silylation product **84**,

whereas silylation of *N*-triisopropylsilylpyrrole and –indole proceeds exclusively at C3 position to give **84′** due to the large steric effect of the TIPS group.



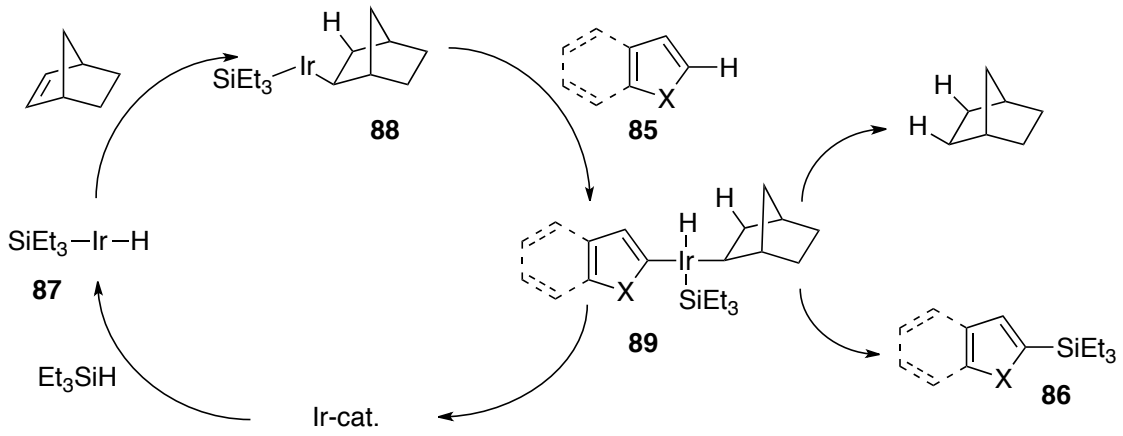
Scheme 17.

Later, Falck group developed a milder iridium-catalyzed norbornene-promoted intermolecular C2 silylation of electron-rich heterocycles such as indoles, furans, and thiophenes **85** with triethylsilane (Scheme 18).[68] The reaction of unsubstituted thiophenes and furans results in 2,5-disilyl derivatives, whereas 2-substituted substrates produce C5 monosilylated products **86**.



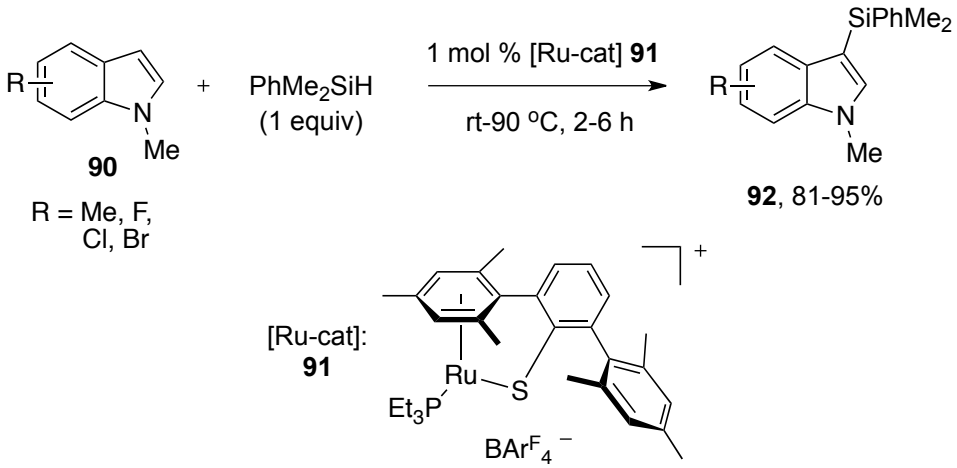
Scheme 18.

The following mechanism was proposed for this transformation (Scheme 19). First, iridium(I) catalyst undergoes oxidative addition with the Si–H bond to form iridium(III) hydride **87**. Hydrometalation of the double bond of norbornene with iridium(III) hydride **87** results in intermediate **88**, which then undergoes insertion into the aromatic C–H bond of **85** to give **89**. The following consecutive reductive elimination of norbornane and product **86** complete the catalytic cycle.



Scheme 19.

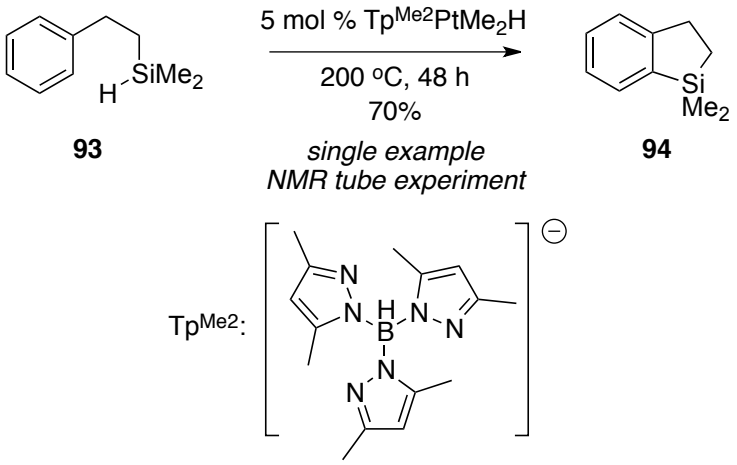
In 2011, Ohki and Tatsumi described the C–H silylation reaction of indoles **90** using base-, hydrogen acceptor-, and solvent-free conditions.[69] In this report, the authors used polar Ru–S bond of the catalyst **91** to activate Si–H bond for the regioselective synthesis of C3 silylated indoles **92** (Scheme 20). It was proposed that this reaction proceeds via a Friedel–Crafts-type mechanism.



Scheme 20.

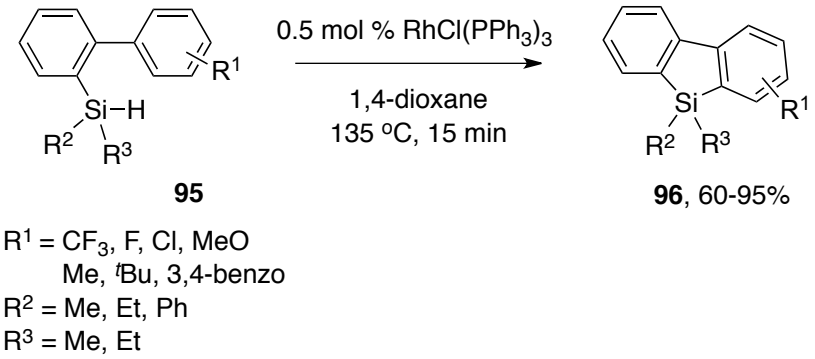
1.2.3.2 Intramolecular C–H Silylation Reactions

In 2005, Hartwig reported a single example of the intramolecular platinum-catalyzed C–H/Si–H dehydrogenative coupling reaction of dimethylphenethylsilane **93** to produce dihydrobenzosilole **94** (Scheme 21).[70] Although, this work sets a precedent for the synthesis of dihydrobenzosiloles via C–H/Si–H dehydrogenative coupling, the synthetic utility of this method is limited by the harsh reaction conditions.



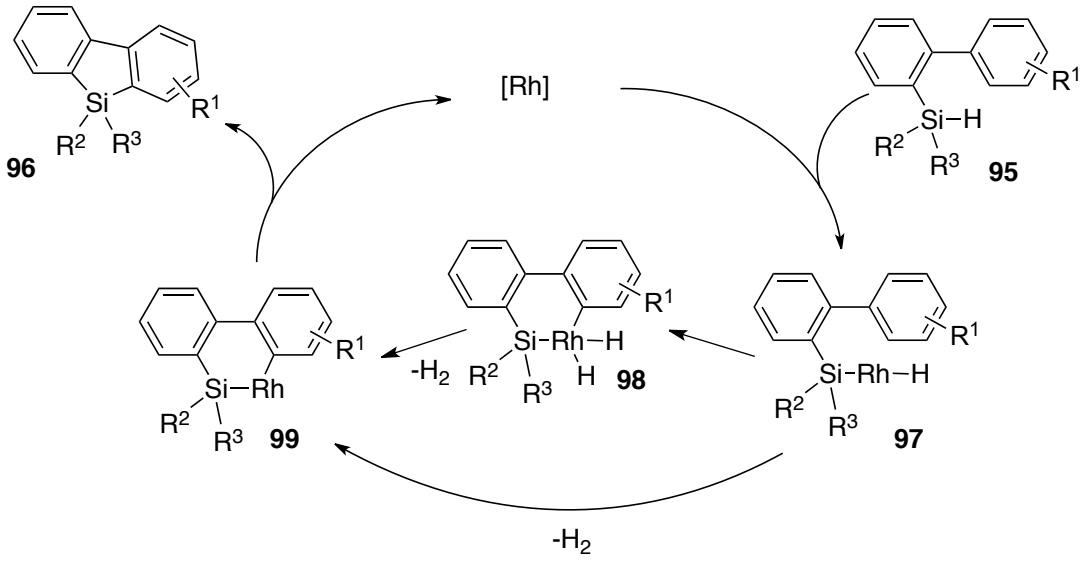
Scheme 21.

In 2010, Takai reported the rhodium-catalyzed hydrogen acceptor-free synthesis of dibenzosilole **96** from biarylhydrosilane **95** (Scheme 22).[71] It was shown, that biarylhydrosilanes bearing electron-withdrawing groups provide the corresponding cyclized products in higher yields and shorter reactions times than biarylhydrosilanes bearing electron-donating groups. Based on this observation, it was proposed that the reaction proceed via the oxidative addition mechanism rather than electrophilic path.



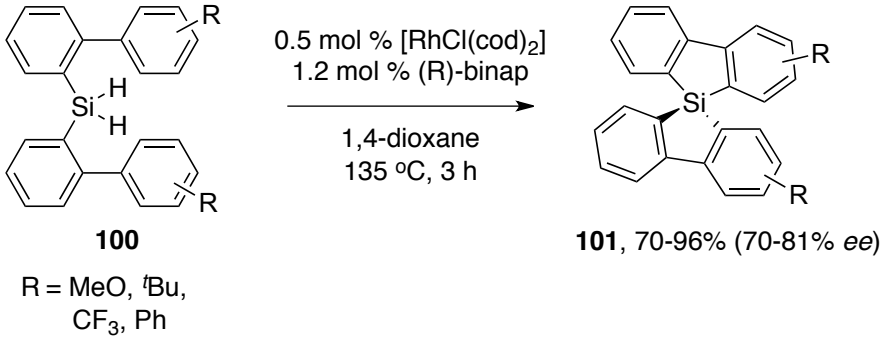
Scheme 22.

The suggested mechanistic pathway for this reaction includes oxidative addition of the Si–H bond of hydrosilane **95** at the rhodium(I) center with the formation of rhodium(III) hydride specie **97** (Scheme 23). The sequential oxidative addition of the aromatic C–H bond at the metal center of **97** results in rhodium(V) intermediate **98**. The latter, upon consequtive reductive eliminations produces **99**, and then silafluorene **96** and regenerates the catalyst. Reductive elimination of silafluorene **96** from intermediate **98** prior to the reductive elimination of dihydrogen might also take place. Alternatively, intermediate **99** can be formed directly from rhodium(III) hydride **97** via the σ-bond metathesis.



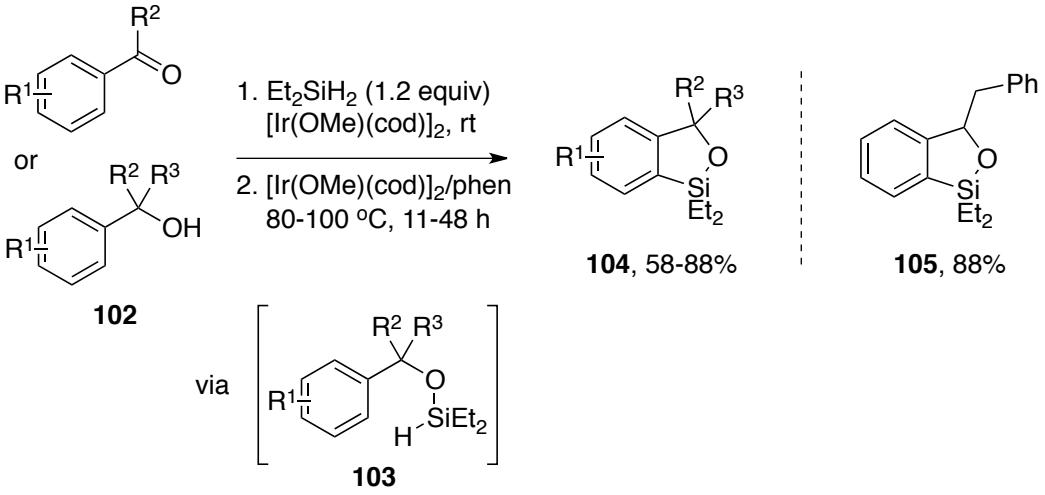
Scheme 23.

The same group also reported asymmetric synthesis of the chiral spirosilabifluorene derivatives **101** from bis(biphenyl)silanes **100** using a combination of rhodium catalyst with chiral phosphine ligand (Scheme 24).



Scheme 24.

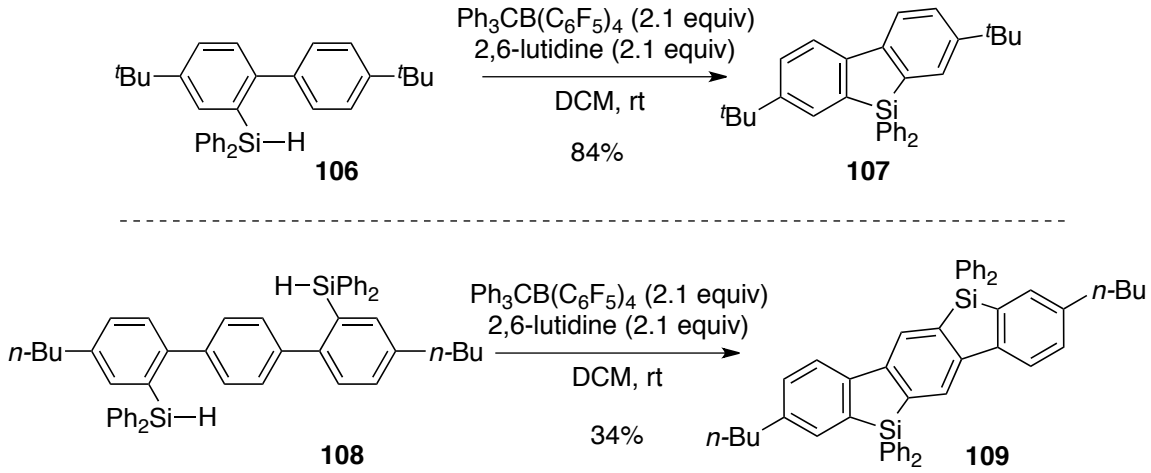
In 2010, Hartwig showed[72] that Falck's conditions[68] can be effectively used for the *ortho*-C–H silylation of benzyl alcohol derivatives **102** through the initial formation of (hydrido)silyl ether **103**, followed by a catalytic intramolecular dehydrogenative cyclization with the formation of benzoxasiloles **104** (Scheme 25). Formation of the five-membered ring was more favorable than formation of the six-membered ring upon cyclization, as shown by exclusive formation of benzyl-substituted benzoxasilole **105**. In the case of *meta*-substituted substrates, silylation occurred at the less sterically hindered C–H bond. Similarly to the Takai report,[71] the C–H bond cleavage is suggested to proceed via the oxidative addition mechanism, rather than by electrophilic metalation path.



Scheme 25.

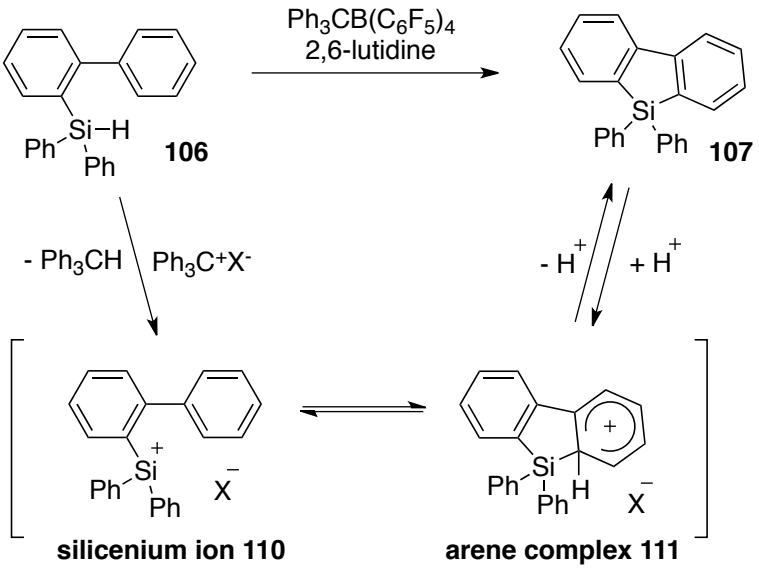
In 2009, Kawashima reported the Lewis-acid mediated intramolecular *sila*-Friedel–Crafts reaction of biarylhydrosilane **106** leading to dibenzosilole **107** (Scheme

26).[73] It was shown that this method is applicable for double C–H silylation of aryl bisilane **108** with the formation of a ladder-type disilafluorene **109**.



Scheme 26.

In this transformation, hydrosilane **106** first reacts with a trityl cation with the formation of silicenium ion **110** (Scheme 27). Subsequent nucleophilic attack of the aromatic ring at the silicenium cation leads to the arene complex **111**. The following deprotonation from the complex **111** results in the formation of the dibenzosilole product **107**. The presence of a base is necessary in this process to prevent a reverse protonation of the dibenzosilole product **107**.



Scheme 27.

1.3. Conclusions

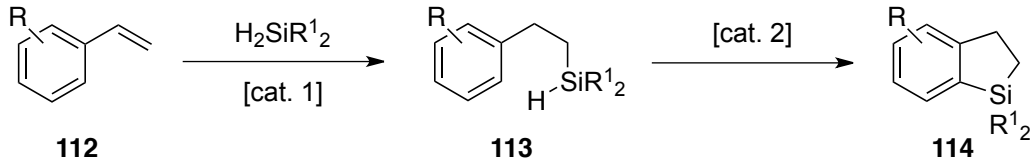
Siloles and their benzoanalogous attract a constant interest from the synthetic community and material sciences. Among the methods for synthesis of silicon-containing molecules, the ones that utilize direct C–H/Si–H coupling are the most attractive since they enable to reduce the amount of synthetic steps and reduce waste. Hence, the area of the direct C–H/Si–H dehydrogenative coupling reactions has been significantly developed over the last thirty years mainly due to discovery of various transition-metal-catalyzed processes. Existing synthetic methodologies for the intermolecular C–H/Si–H coupling are quite diverse, yet the C(sp^3)–H silylation reactions, as well as heteroaromatic C–H silylation reactions are still rare. Intramolecular methods for C–H/Si–H dehydrogenative coupling are much less developed with only a

few examples reported on dibenzosilole synthesis and a single example on dihydrobenzosilole synthesis. Dihydrobenzosiloles hold promise in becoming potentially important molecules in drug discovery (*vide supra*). Additionally, they could also serve as useful synthons in organic chemistry, for example in the synthesis of benzosiloles. However, to date, there are no efficient methods for their synthesis exist. Therefore, development of novel methods for the synthesis of dihydrobenzosiloles via C–H/Si–H dehydrogenative coupling is highly warranted.

2. SYNTHESIS OF DIHYDROBENZOSILOLES FROM STYRENES: NICKEL-CATALYZED HYDROSILYLATION/IRIDIUM-CATALYZED DEHYDROGENATIVE COUPLING OF THE Si–H BOND WITH THE AROMATIC C–H BOND

2.1. Optimization of Reaction Conditions, Scope and Limitations

We aimed at developing a method for the synthesis of dihydrobenzosiloles **114** via *β*-hydrosilylation of styrenes **112** with dihydrosilane, followed by dehydrogenative cyclization of the formed product **113** (Scheme 28).



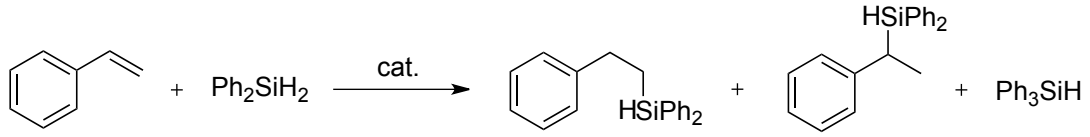
112 **113** **114**

Scheme 28.

First, we turned our attention to the hydrosilylation of styrene **112**, as the first step of the proposed path. There are several methods reported for the hydrosilylation of styrene with diphenylsilane using Au,[74] Zr,[75] Yb,[76] and Rh[77] catalysts, yet the methods utilizing cheap and readily available complexes are still in need. On the other hand, it is known that nickel(II) salts with phosphine ligands are effective catalysts for hydrosilylation of olefins.[78] Since there are no reports on nickel-catalyzed *β*-hydrosilylation of styrene **112a** with dihydrosilanes, we explored the possibility of using

readily available nickel catalysts in the hydrosilylation of styrene **112a** with diphenylsilane (Table 1). Thus, using 5 mol % $NiCl_2$•$(PCy_3)_2$, only triphenylsilane, a product of disproportionation reaction of diphenylsilane,[79] was formed in 34% yield (entry 1). When 5 mol % $NiCl_2$•dppe was employed, the desired *β*-silylated product **113a** was obtained in 6% yield along with 13% of undesired *α*-silylated product **115a** (entry 2). Other nickel(II) catalysts, such as $NiCl_2$•dppf and $NiCl_2$•dppp, provided **113a** in 10% and 55% yields, respectively together with **115a** (entries 3, 4). We were happy to find that $NiCl_2$•$(PPh_3)_2$ and $NiBr_2$•$(PPh_3)_2$ gave **113a** in high yield and regioselectivity (entries 5, 6). When $NiBr_2$ without triphenylphosphine was used, no reaction occured between styrene **112a** and diphenylsilane (entry 7). Employment of phosphine free $Ni(cod)_2$ resulted in the mixture of regioisomers **113a** and **115a** (entry 8). However, a combination of triphenylphosphine with $Ni(cod)_2$ gave the desired *β*-hydrosilylated product **113a** in high yield and regioselectivity (entry 9).

Table 1. Optimization of the reaction conditions for the Ni-catalyzed hydrosilylation of styrene with diphenylsilane[a]



112a *β*-**113a** *α*-**115a**

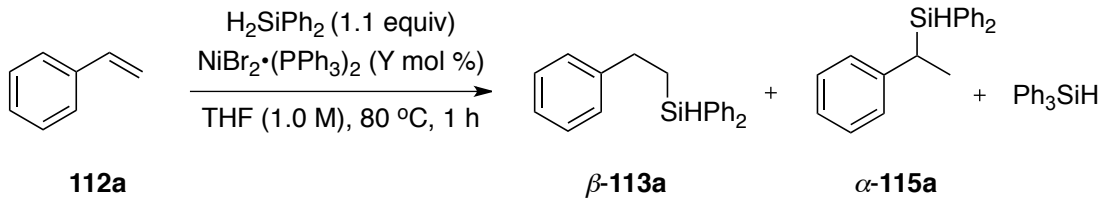
entry	cat.	GC yield, (%) *β*-**113a**	*α*-**115a**	Ph_3SiH
1	$NiCl_2$•$(PCy_3)_2$	--	--	34
2	$NiCl_2$•dppe	6	13	8
3	$NiCl_2$•dppf	10	3	3
4	$NiCl_2$•dppp	55	37	11
5	$NiCl_2$•$(PPh_3)_2$	87	<2	<2
6	**$NiBr_2$•$(PPh_3)_2$**	**90**	**<2**	**<1**
7	$NiBr_2$	--	--	--
8	$Ni(cod)_2$	53	30	6
9[b]	$Ni(cod)_2$/PPh_3	89	<2	<1

[a] Conditions: 5 mol % cat., 0.2 mmol of styrene, 0.22 mmol Ph_2SiH_2 in 0.2 mL THF were stirred at 80 °C for 6 h under N_2 atmosphere. The reaction was monitored by GC-MS analysis.

[b] 5 mol % cat. and 20 mol % PPh_3 were used.

After effective catalyst for *β*-hydrosilylation of styrene **112a** with diphenylsilane were identified (Table 1, entries 6,9) we next turned our attention to the optimization of the catalyst loading. For this purpose we chose $NiBr_2•(PPh_3)_2$ as more stable and readily available catalyst. Thus, employment of 0.5-1.5 mol % of the nickel catalyst led to the desired *β*-hydrosilylated product **113a** along with significant amounts of the *α*-hydrosilylated product **115a** and triphenylsilane (Table 2, entries 1-3). On the other hand, when 2.0-10.0 mol % of catalyst was used, the *β*-hydrosilylated product **113a** was obtained in excellent yield and regioselectivity (entries 4-6).

Table 2. Optimization of the catalyst loading[a]



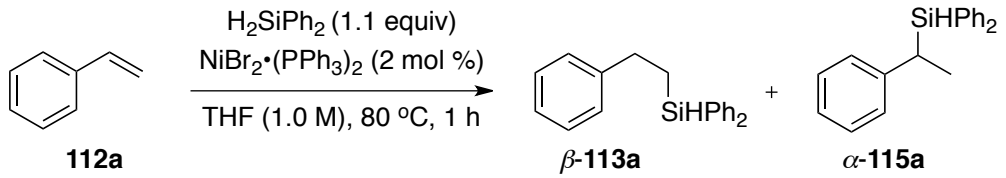
112a *β*-**113a** *α*-**115a**

Entry	Y	GC yield, (%)		
		β-**113a**	*α*-**115a**	Ph_3SiH
1	0.5	76	11	4
2	1.0	83	5	3
3	1.5	87	3	1
4[b]	**2.0**	**93**	**<1**	**<1**
5	5.0	89	<1	<1
6	10.0	91	<1	<1

[a] Conditions: 0.5-10 mol % $NiBr_2(PPh_3)_2$, 0.2 mmol of styrene, 0.22 mmol Ph_2SiH_2 in 0.2 mL THF were stirred at 80 °C for 1 h under N_2 atmosphere. The reaction was analyzed by GC-MS analysis.

[b] 1.05 equiv of diphenylsilane was used

We also found that hydrosilylation reaction of styrene **112a** under air proceeds with reduced regioselectivity and yield compared to the same reaction under nitrogen atmosphere (Scheme 29).



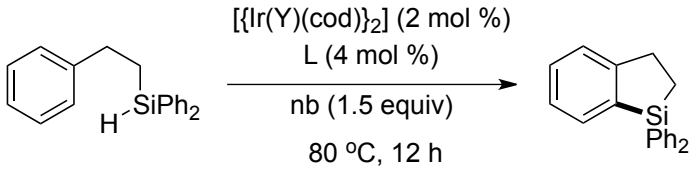
112a → *β*-**113a** + *α*-**115a**

	β-**113a**	*α*-**115a**
on air	43%	22%
under nitrogen	90%	<1%

Scheme 29.

After we developed a suitable method for *β*-hydrosilylation of styrene **112a** with diphenylsilane, we searched for efficient conditions for intramolecular dehydrogenative cyclization of phenetylsilane **113a** (Table 3). To this end, we found that under Falck's conditions[68] (entry 3), the hydrosilane **113a** underwent smooth dehydrogenative cyclization into dihydrobenzosilole **114a**. In the absence of the iridium catalyst, no dihydrobenzosilole **114a** was formed. When the reaction was run in the absence of either ligand or norbornene only trace amounts of **114a** were produced. We also found that the second dehydrocondensation step can be performed in a *one-pot* manner after completion of the first hydrosilylation reaction to give dihydrobenzosilole **114a** in 86% overall yield.

Table 3. Optimization of the dehydrogenative cyclization[a]



113a **114a**

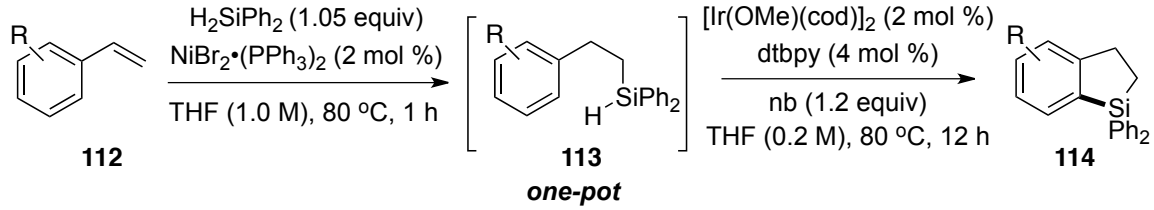
Entry	Y	L	Yield **114a**, (%)[b]
1	OMe	phen	63
2	Cl	phen	59
3	OMe	dtbpy	89
4	Cl	dtbpy	74

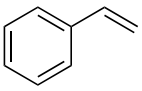
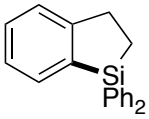
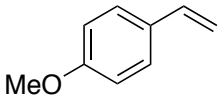
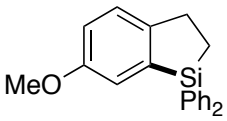
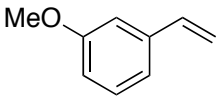
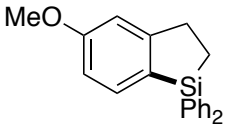
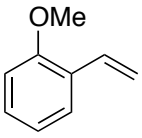
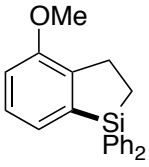
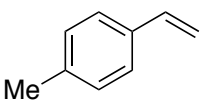
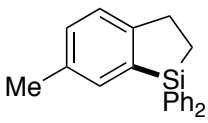
[a] Conditions: 2 mol % Ir cat., 4 mol % ligand, 0.24 mmol of norbornene, 0.2 mmol **113a** and 2.0 mL of THF were stirred at 80 °C for 12 h.

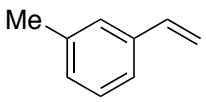
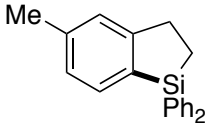
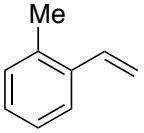
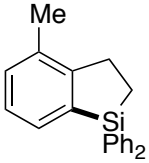
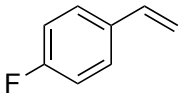
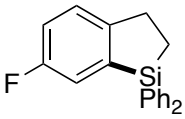
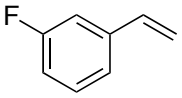
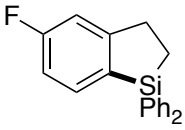
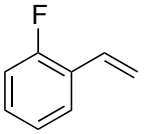
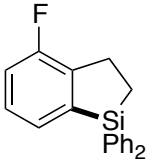
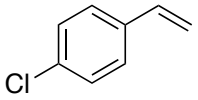
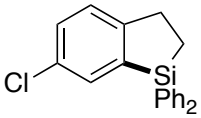
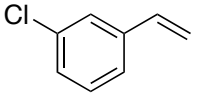
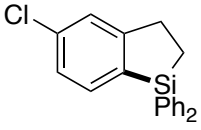
[b] NMR yield.

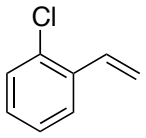
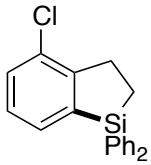
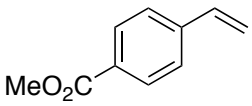
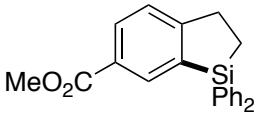
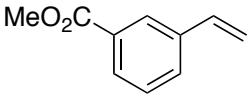
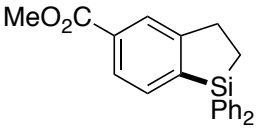
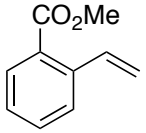
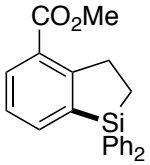
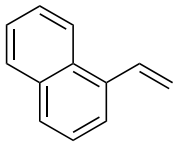
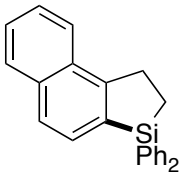
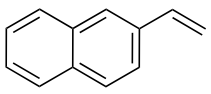
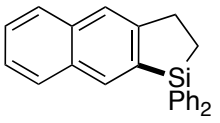
With the optimized conditions in hand, we evaluated the scope of this *one-pot* hydrosilylation/dehydrogenative coupling reaction (Table 4). Thus, we found that diverse styrenes, possessing MeO- (entries 2-4), Me- (entries 5-7), F- (entries 8-10), Cl- (entries 11-13), and MeO_2C- (entries 14-16) groups in *ortho*-, *meta*-, and *para*- positions were well tolerated under the reaction conditions to produce the corresponding dihydrobenzosiloles **114** in good yields over the two steps. When *meta*-substituted styrenes were used, C–H/Si–H dehydrogenative coupling generally occurred at the least sterically hindered *para*-position to the substituent. Only when a small fluorine group was employed, a 2:1 mixture of *para*- and *ortho*-cyclized products **114i** was isolated.

Table 4. Scope of the one-pot hydrosilylation/dehydrocyclization reaction[a]



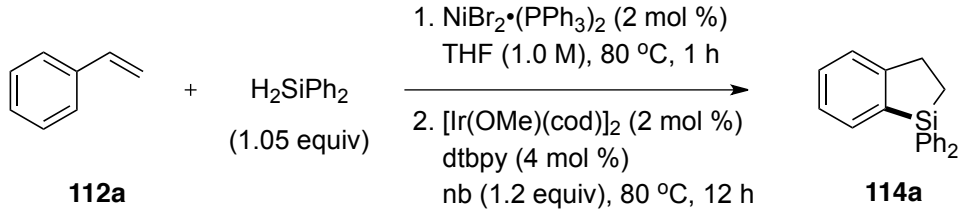
Entry	Substrate		Product		Yield (%)
1		**112a**		**114a**	86
2		**112b**		**114b**	81
3		**112c**		**114c**	79
4		**112d**		**114d**	80
5		**112e**		**114e**	73

Entry	Substrate		Product		Yield (%)
6		**112f**		**114f**	76
7		**112g**		**114g**	72
8		**112h**		**114h**	67
9		**112i**		**114i**	63 (2:1)
10		**112j**		**114j**	71
11		**112k**		**114k**	66
12		**112l**		**114l**	67

Entry	Substrate		Product		Yield (%)
13		**112m**		**114m**	64
14		**112n**		**114n**	57
15		**112o**		**114o**	56
16		**112p**		**114p**	60
17		**112q**		**114q**	49
18		**112r**		**114r**	54

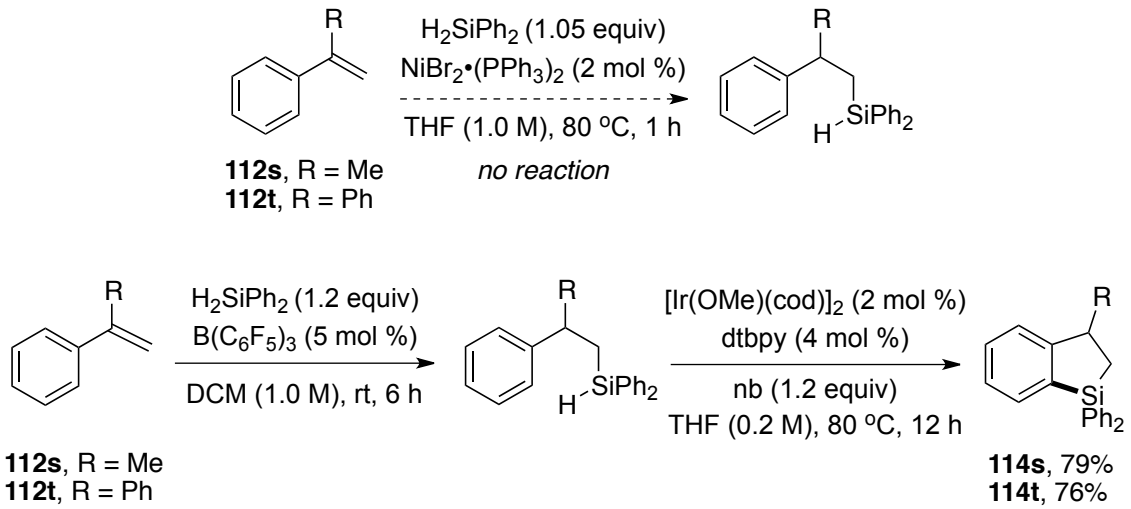
[a] Conditions: 2 mol % Ni cat., 0.50 mmol of styrene, 0.53 mmol of Ph_2SiH_2 in 0.5 mL of THF were stirred at 80 °C for 1 h under a N_2 atmosphere. Then, 2 mol % Ir cat., 4 mol % dtbpy, 0.6 mmol of norbornene, and 2.0 mL of THF were added. Reaction was stirred at 80 °C for 12 h.

We also showed that this reaction could be easily scaled up to a multi-gram synthesis of dihydrobenzosilole **114a** (Scheme 30). It's worth mentioning that the reaction on 2 and 10 mmol scale proceeded with nearly the same efficiency providing up to 2 grams of dihydrobenzosilole **114a**.



Scheme 30.

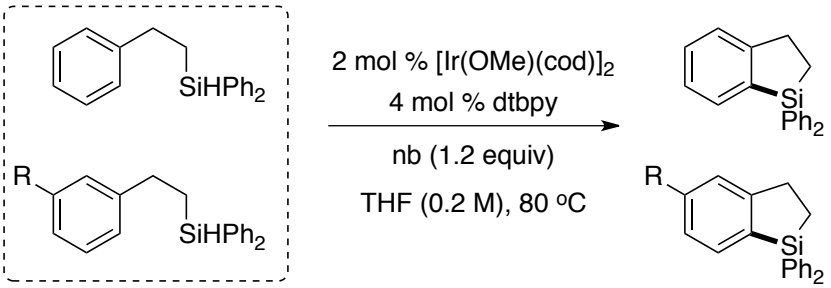
Next, the possibility of applying this *one-pot* procedure for the synthesis of substituted dihydrobenzosiloles was examined (Scheme 31). Hence, the hydrosilylation reaction of α-substituted styrenes has been explored. Unfortunately, hydrosilylation of α-methyl- **112s** and α-phenyl styrene **112t** with diphenylsilane in the presence of $NiBr_2•(PPh_3)_2$ catalyst was not effective. However, the corresponding hydrosilylated products were obtained in high yields and regioselectivity when the Lewis-acid catalyst $B(C_6F_5)_3$ was used.[80] Subsequently, after removing $B(C_6F_5)_3$ and the solvent, the following cyclization was performed using the standard dehydrogenative coupling conditions. As a result, 3-methylbenzosilole **114s** and 3-phenyldehydrobenzosilole **114t** were obtained using this formal semi one-pot procedure in 79% and 76% yields, respectively (Scheme 31).



Scheme 31.

2.2. Mechanistic Investigations

In order to get some information about the mechanism of the dehydrogenative cyclization step, we first performed intermolecular competitive cyclization study of different *meta*-substituted phenetylhydrosilanes **113** (Figure 5). It was found that the substrates possessing electron-withdrawing groups at the aromatic ring cyclized faster than substrates possessing electron-donating groups. Accordingly, the following reactivity trend was established for the rates of cyclization of *meta*-substituted phenetylsilanes **113**: MeO<Me<H<Cl<CO_2Me (Figure 5). This results suggest that dehydrogenative cyclization step does not proceed via electrophilic metalation path.



113 **114**

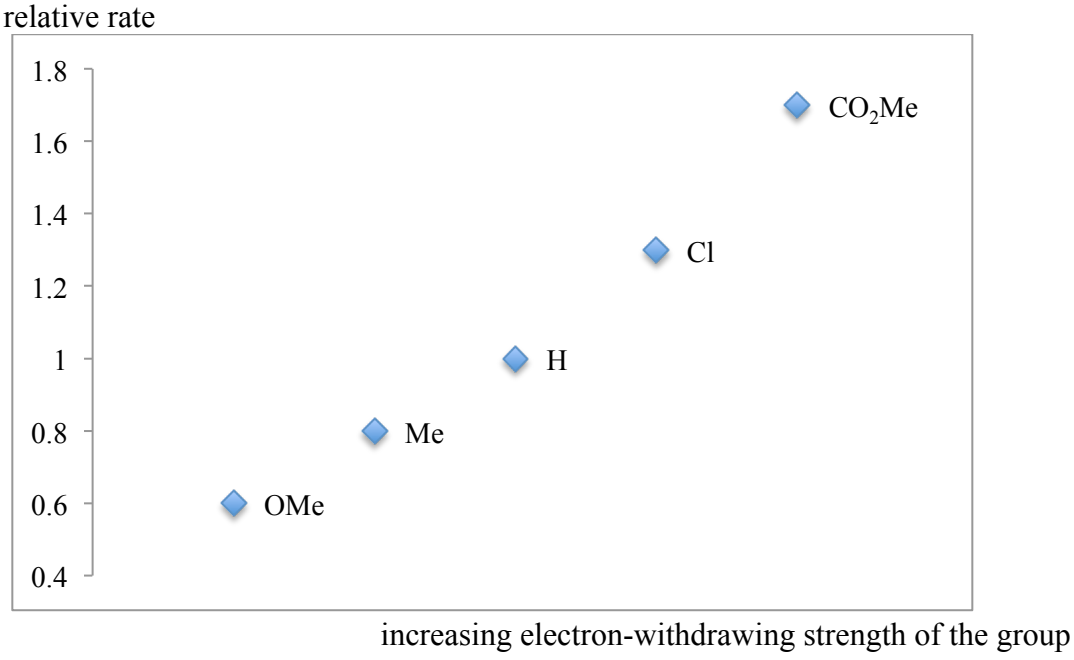
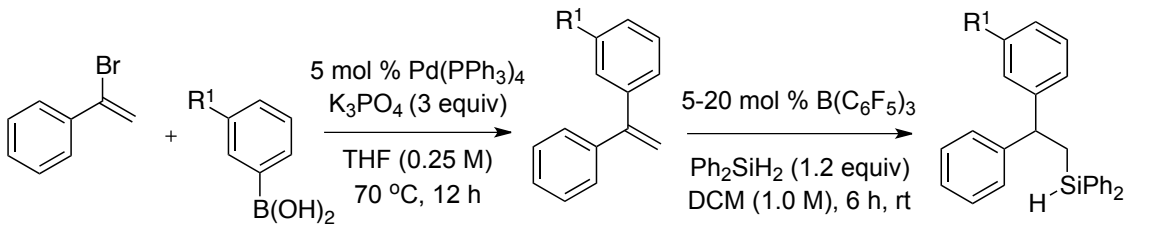


Figure 5. Relative cyclization rates

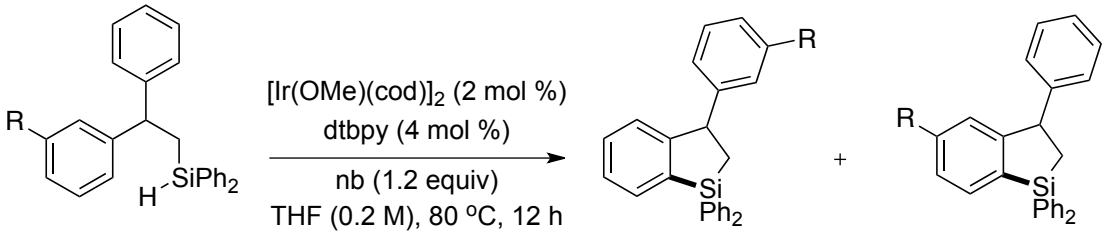
We also performed intramolecular competitive cyclization experiments. For this purpose, we synthesized *meta*-methyl and *meta*-chlorine substituted silanes **113u** and **113v** via the palladium-catalyzed coupling reaction of *α*-bromostyrene **116** with boronic acids **117u** and **117v** (Scheme 32). The initially formed *α*-arylstyrenes **112u** and **112v** underwent hydrosilylation reaction with diphenylsilane in the presence of Lewis-acid catalyst $B(C_6F_5)_3$.



116 **117u**, R^1 = Me; **117v**, R^1 = Cl; **112u**, R^1 = Me, 83%; **112v,** R^1 = Cl, 82%; **113u**, R^1 = Me, 88%; **113v**, R^1 = Cl, 83%

Scheme 32.

The following cyclization study of the hydrosilanes **113u** and **113v** indicated reactivity trend similar to the intermolecular cyclization study experiments. Thus, cyclization of **113u**, possessing Me group in one of the aromatic rings, preferentially occurred at the unsubstituted phenyl ring, whereas there was a slight preference of cyclization into Cl-substituted aromatic ring in **113v** (Scheme 33).



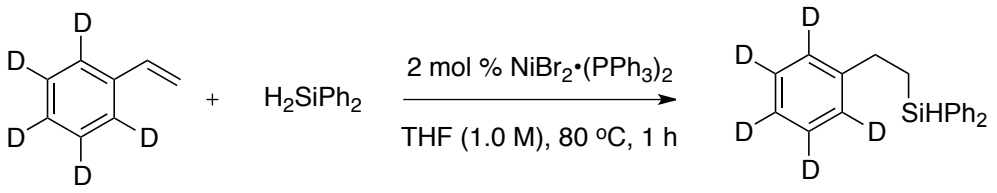
113u, R^1 = Me
113u, R^1 = Cl

114u, R = Me, 1 : 0.4
114v, R = Cl, 1 : 1.1

Scheme 33.

Consequently, all our experiments showed that dehydrogenative cyclization preferably occurs at the less electron-rich aromatic ring, and thus supporting the C–H activation mechanism rather than electrophilic metalation path.[71,72]

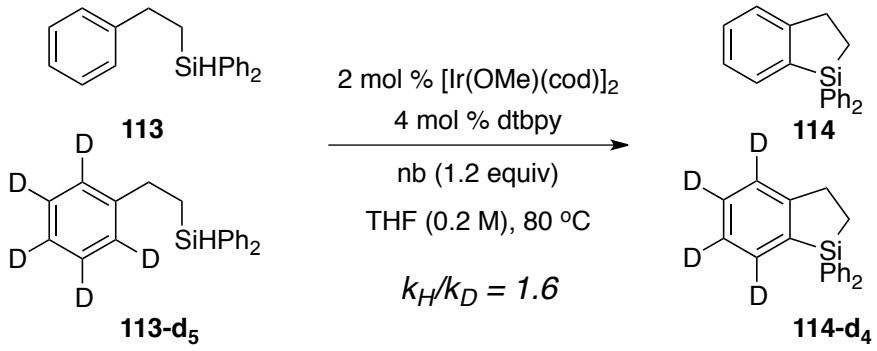
We also performed intramolecular kinetic isotope effect studies. To this end, we synthesized *d*$_5$-phenetylsilane **113-d$_5$** from *d*$_5$-styrene **112-d$_5$** using our standard nickel-catalyzed reaction conditions (Scheme 34).



112-d$_5$ **113-d$_5$**, 89% (D ~ 99%)

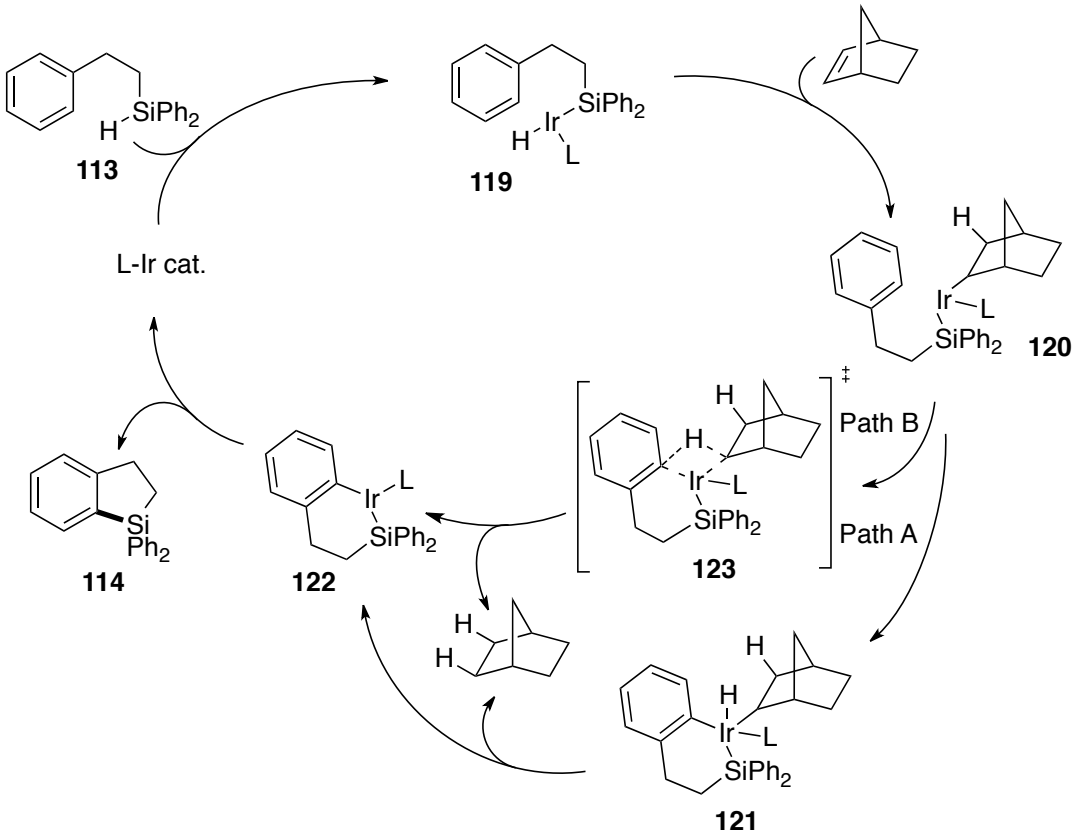
Scheme 34.

The following cyclization of **113** and **113-d$_5$** performed in separate vials revealed k_H/k_D to be equal to 1.6 (average of three runs). This result suggests that the cleavage of the aromatic C–H bond might occur at the rate-limiting step (Scheme 35).[81]



Scheme 35.

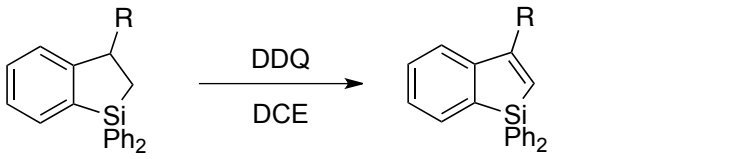
Based on the above mentioned observations, the following mechanistic pathways were proposed for the C–H/Si–H dehydrogenative coupling reaction (Scheme 3). First, the iridium(I) undergoes oxidative addition at the Si–H bond of hydrosilane **113** with the formation of iridium(III) hydride specie **119**. Hydrometallation of the double bond of norbornene produces intermediate **120**, in which iridium center further undergoes oxidative addition at the aromatic C–H bond to give intermediate **121** (**Path A**, similar to the Falck's mechanism[68]). The following reductive elimination of norbornane gives intermediate **122**. Alternatively (**Path B**), the concerted metalation-deprotonation of the intermediate **120** through the transition state **123**[82] can occur to produce the same intermediate **122** upon elimination of the norbornane. The reductive elimination from **122** leads to the cyclized product **114** and regeneratation of the iridium catalyst.



Scheme 36.

2.3. Further Transformations of Dihydrobenzosiloles

After we developed a general method for the synthesis of dihydrobenzosiloles from styrenes, we performed initial studies on their synthetic utility. Thus, we found that compounds **114a**, **114s**, and **114t** in the presence of DDQ can be efficiently oxidized into valuable benzosiloles **124**[83] (Scheme 37). Oxidation of 3-phenyl derivative **114t** is more facile then that of 3-methyl derivative **114s**, which in turn is more reactive than the unsubstituted dihydrobenzosilole **114a**.

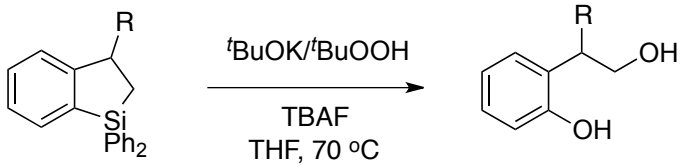


114a, R = H
114s, R = Me
114t, R = Ph

124a, R = H, 81% (100 °C, 12h)
124s, R = Me, 73% (80 °C, 12h)
124t, R = Ph, 77% (50 °C, 6h)

Scheme 37.

We also showed that dihydrobenzosiloles **114a**, **114s**, and **114t** can be readily transformed into the 2-hydroxyphenethyl alcohols **118** in excellent yields when treated with *tert*-butylperoxide, potassium *tert*-butoxide, and TBAF (Scheme 38).

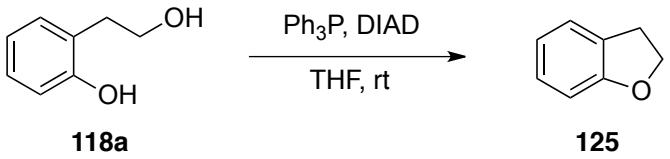


114a, R = H
114s, R = Me
114t, R = Ph

118a, R = H, 83%
118s, R = Me, 92%
118t, R = Ph, 79%

Scheme 38.

Subsequently, the resulting 2-hydroxyphenethyl alcohol **118a** can be smoothly converted into dihydrobenzofuran **125** by applying standard Mitsunobu-type reaction conditions (Scheme 39).



118a **125**

Scheme 39.

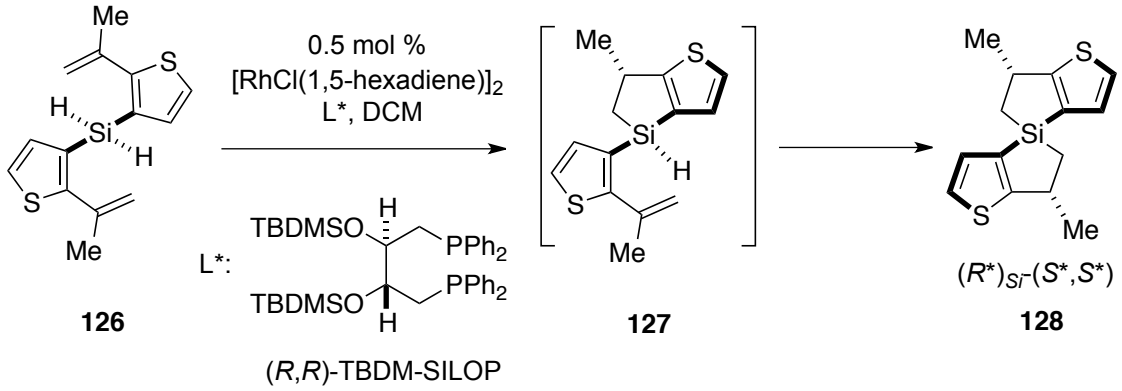
2.4. Summary

In summary, we have developed a new one-pot procedure for the synthesis of dihydrobenzosiloles from styrenes. This process involves the nickel-catalyzed hydrosilylation of styrene with diphenylsilane, followed by the iridium-catalyzed dehydrogenative cyclization. Our method proved to be effective for both electron-deficient and electron-rich styrenes. It also exhibits great functional group tolerance, as well as excellent regioselectivity. The resulting dihydrobenzosiloles can be easily converted into valuable benzosiloles or 2-hydroxyphenethyl alcohols.

3. FUSED HETEROAROMATIC DIHYDROSILOLES: NICKEL-CATALYZED HYDROSILYLATION/IRIDIUM-CATALYZED DE-HYDROGENATIVE COUPLING OF THE Si–H BOND WITH HETEROAROMATIC C–H BOND

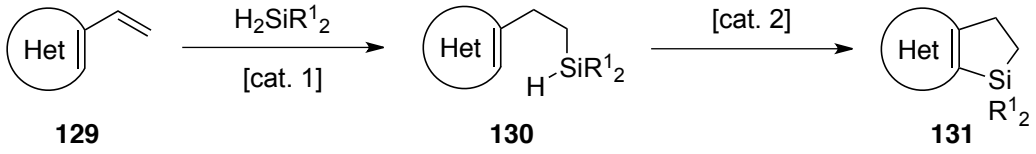
3.1. Introduction

After we developed the new method for the synthesis of dihydrobenzosiloles from styrenes via the nickel-catalyzed hydrosilylation of styrenes with diphenylsilane, followed by the iridium-catalyzed silylation of aromatic C–H bond, given the importance of heteroaromatic molecules in different fields, we turned our attention to the synthesis of fused heteroaromatic dihydrosiloles. To the best of our knowledge, there was no reports on C–H silylation of electron-deficient heterocycles. Moreover, fused heteroaromatic dihydrosiloles are almost unknown with the only example found in literature describing formation of chiral thiophene-containing spirosilane **128** from divinylhydrosilane **126** via intermediate **127** (Scheme 40).[84]



Scheme 40.

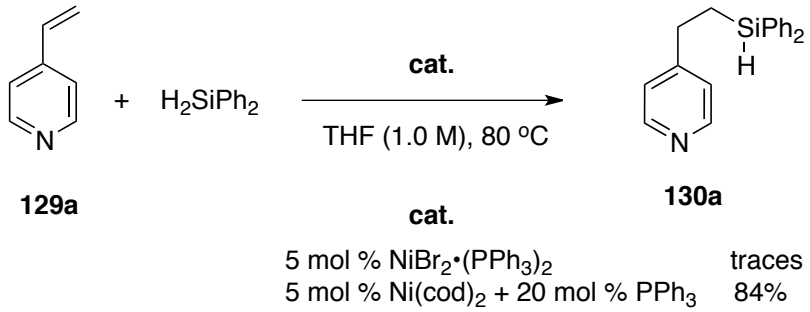
We aimed at developing a method for the synthesis of fused heteroaromatic siloles **131**. This approach would involve hydrosilylation of heteroaromatic styrenes **129** with dihydrosilane, followed by intramolecular dehydrogenative C–H/Si–H coupling reaction of the formed product **130** (Scheme 41).



Scheme 41.

3.2. Optimization of Reaction Conditions, Scope and Limitations

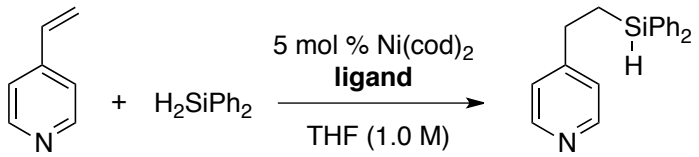
First, we attempted to apply our previously developed conditions for the synthesis of hydrosilane **130a** from 4-vinylpyridine **129a** (Scheme 42). However, hydrosilylation reaction of 4-vinylpyridine **129a** with diphenylsilane in the presence of $NiBr_2•(PPh_3)_2$ produced only trace amounts of hydrosilylated product **130a**. The use of combination $Ni(cod)_2$ with triphenylphosphine was more effective in this reaction to give the desired product in 84% yield (Scheme 42).



Scheme 42.

Optimization of the ligand for $Ni(cod)_2$ revealed that $Ni(cod)_2/PPh_3$ combination worked best in the β-hydrosilylation of 4-vinylpyridine with diphenylsilane (**Table 5**).

Table 5. Optimization of hydrosilylation reaction of 4-vinylpyridine



129a **130a**

entry	ligand[a]	(mol %)	**130a** yield, (%)[b]
1	dppe	10	-
2	dppf	10	-
3	dppbe	10	47
4	TMEDA	10	32
5	SIPr	20	<5
6	IPr	20	-
7	IMes	20	-
8	dtbpy	10	34
9	tp	10	29
10	PCy_3	20	-
11	PPh_3	20	76
12[c]	**PPh_3**	**20**	**89 (83)[d]**
13[e]	PPh_3	20	65

[a] mol %

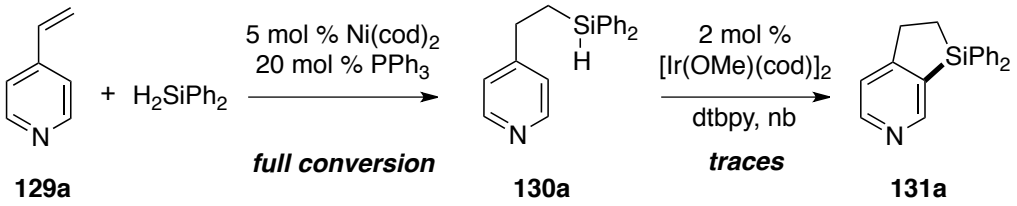
[b] GC Yield.

[c] Reaction was carried out at 90 ^{o}C during 1 h.

[d] Isolated yield is given in parenthesis.

[e] Reaction was carried out at room temperature for 24 h.

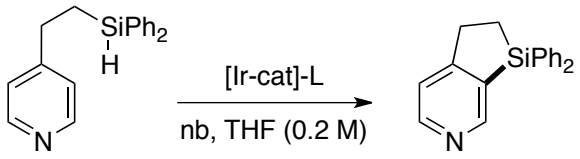
After the nickel-catalyzed hydrosilylation of 4-vinylpyridine with diphenylsilane was complete, the reaction mixture was subjected to the standard[68] C–H/Si–H dehydrogenative conditions with $[Ir(cod)(OMe)]_2$, dtbpy, and norbornene. However, no sufficient amounts of dihydropyridinosilole **131a** have been produced under these conditions (Scheme 43).



Scheme 43.

Consequently, we turned our attention to the optimization of dehydrogenative coupling step (Table 6). Thus, we were pleased to find that employment of 5 mol % [Ir(OMe)(cod)] and 10 mol % dtbpy, allowed for conversion of hydrosilane **130a** into dihydopyridinosilole **131a** in 47% yield (entry 1). The prolonged reaction time led to reduced yield of the product under the same reaction conditions (entry 2). Switching the ligand from dtbpy to 1,10-phenantroline improved the yield of the reaction (entries 3,4). Further modification of catalyst, ligand, and addition of triphenylphosphine resulted in lower or no product formation (entries 5-10). Subsequent optimization of the iridium catalyst and 1,10-phenantroline loading revealed the optimal conditions (entry 13).

Table 6. Optimization of dehydrogenative cyclization



130a **131a**

Entry	[Ir-cat]/L[a]	time, (h)	**131a** yield, (%)[b]
1	5% $[Ir(OMe)(cod)]_2$/10% dtbpy	6	47
2	5% $[Ir(OMe)(cod)]_2$/10% dtbpy	24	15
3	5% $[Ir(OMe)(cod)]_2$/10% phen	6	63
4[c]	5% $[Ir(OMe)(cod)]_2$/10% phen	6	67
5	5% $[Ir(OMe)(cod)]_2$/10% phen + 20% PPh_3	6	traces
6	5% $[Ir(OMe)(cod)]_2$/ --	6	<5
7	-- /10% phen	6	NR
8	5% $[Ir(OMe)(cod)]_2$/20% PPh_3	24	NR
9	5% $[IrCl(cod)]_2$/10% phen	12	51
10	5% $RhCl(PPh_3)_3$/10% phen	4	41
11[c]	4% $[Ir(OMe)(cod)]_2$/8% phen	6	72
12[c]	3% $[Ir(OMe)(cod)]_2$/6% phen	8	78
13[c]	**2% $[Ir(OMe)(cod)]_2$/4% phen**	**12**	**83 (79)[d]**
14[c]	1% $[Ir(OMe)(cod)]_2$/2% phen	24	81

[a] mol %

[b] GC Yield.

[c] 0.5 M concentration was used.

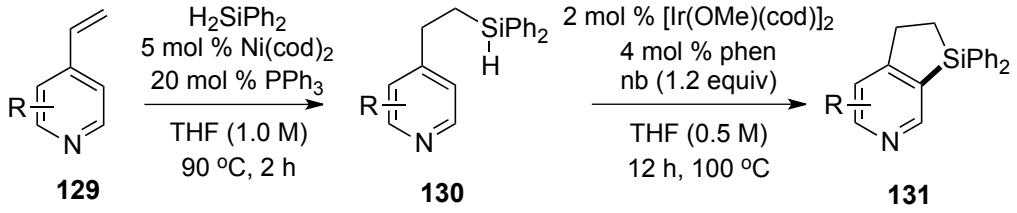
[d] Isolated yield is given in parenthesis.

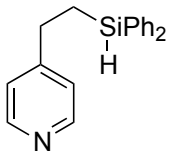
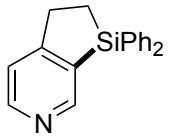
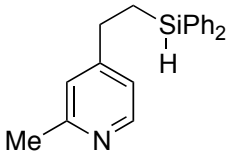
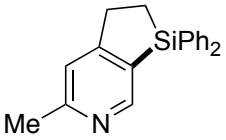
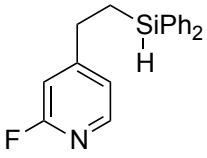
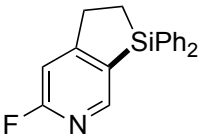
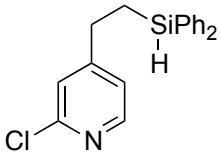
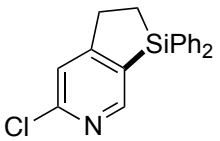
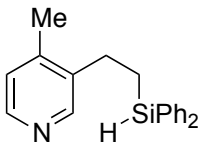
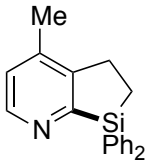
We found that, the presence of triphenylphosphine, which was required for hydrosilylation reaction, inhibited the dehydrogenative cyclization (Table 6, entry 5). Therefore, hydrosilylation/dehydrogenative coupling sequence was performed using two-step procedure.

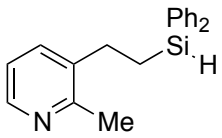
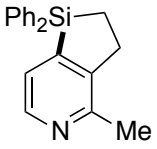
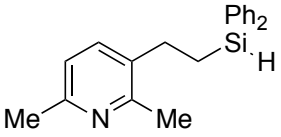
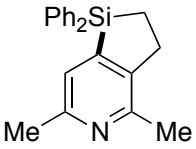
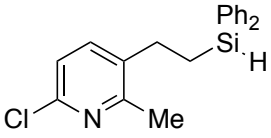
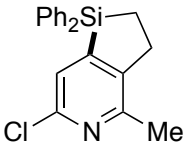
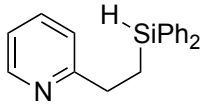
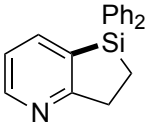
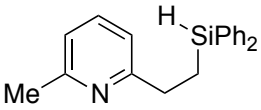
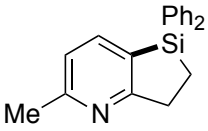
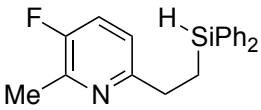
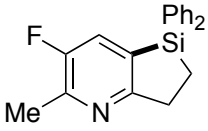
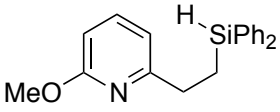
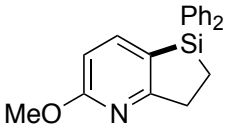
Accordingly, we examined the scope of the hydrosilylation/dehydrogenative cyclization reaction of different heterocyclic substrates starting from 4-vinylpyridines **129** bearing a substituent at the second position of the pyridine ring (Table 7, entries 2-4). Thus, it was found that both electron-donating and electron-withdrawing groups at this position were well tolerated leading to the dehydrogenative C–H/Si–H coupling reaction at the less sterically hindered site. Hydrosilylation reaction of 4-methyl-3-vinylpyridine **129e** worked well (entry 5), however, attempts on cyclization of **130e** resulted only in trace amounts of the product **131e** formed. On the other hand, 2-methyl-3-vinylpyridine **129f** and its derivatives were converted into the cyclized products in good yield (entries 6-8). 2-vinylpyridine **129i** underwent smooth hydrosilylation reaction, as determined by GC-MS analysis of the crude reaction mixture, however it decomposed upon purification into 2-ethylpyridine (entry 9). This result can be explained by intramolecular pyridine nitrogen-assisted hydrolysis of the formed hydrosilylation product **130i**. Consequently, we examined reactions of more sterically hindered substrates possessing a substituent at the sixth position of the pyridine ring. Thus, the hydrosilylation of 6-methyl-2-vinylpyridine **129j** lead to the corresponding hydrosilylation product **130j** in moderate yield (entry 10). Subsequent dehydrogenative cyclization reaction of **130j** produced **131j** in low yield. Introduction of fluorine substituent at the fifth position of 6-methyl-2-vinylpyridine, gave improved results (entry 11). Employment of substrates possessing

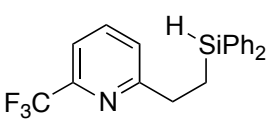
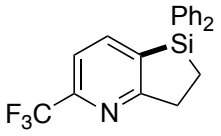
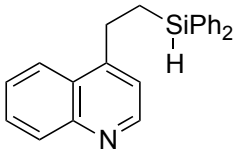
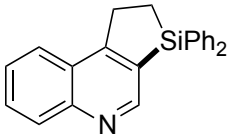
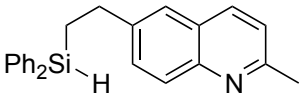
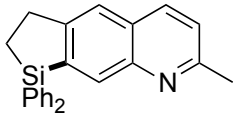
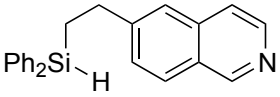
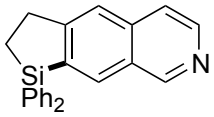
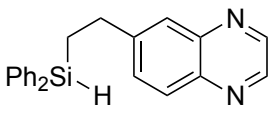
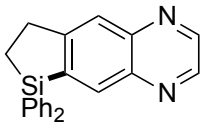
MeO- and CF_3- groups at the sixth position of 2-vinylpyridine resulted in comparable good yields for both steps (entries 12-13). Having explored dehydrogenative cyclization of pyridine substrates with silicon-tether at different positions, we turned our attention to other electron-defficient heterocycles. To this end, we found that quinolines **129n**,**o**, isoquinoline **129p**, and quinoxaline **129q** provided high yields of hydrosilylation products and good yields of a subsequent cyclization step (entries 14-17).

Table 7. Scope of electron-deficient heterocycles in hydrosilylation/dehydrogenative cyclization[a]



Entry	Intermediate	Yield (%)	Product	Yield (%)
1		**130a** 84		**131a** 83
2		**130b** 86		**131b** 87
3		**130c** 86		**131c** 68 (5:1)
4		**130d** 61		**131d** 64
5		**130e** 95		**131e** traces

Entry	Intermediate		Yield (%)	Product		Yield (%)
6		**130f**	93		**131f**	79
7		**130g**	90		**131g**	86
8		**130h**	83		**131h**	75
9		**130i**	dec.		**131i**	N/A
10		**130j**	48		**131j**	36
11		**130k**	76		**131k**	73
12		**130l**	67[b]		**131l**	72

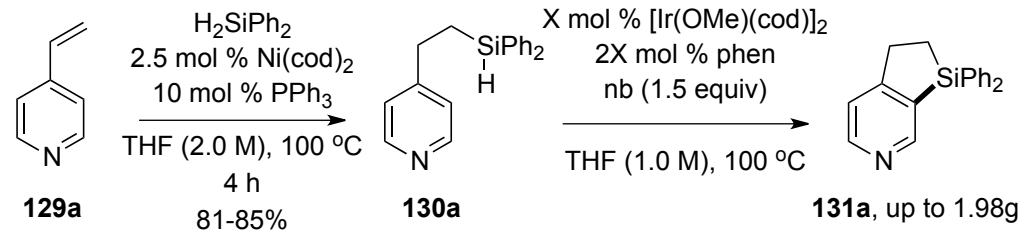
Entry	Intermediate	Yield (%)	Product	Yield (%)
13		**130m** 76		**131m** 77
14		**130n** 97		**131n** 74
15		**130o** 96		**131o** 78
16		**130p** 90		**131p** 74[c]
17		**130q** 94		**131q** 56[c]

[a] Hydrosilylation reaction conditions: **129** (1.0 mmol), H_2SiPh_2 (1.02 mmol), $Ni(cod)_2$ (5 mol %), PPh_3 (20 mol %), and THF (1.0 mL) were stirred at 90 ºC for 2 h under nitrogen. Dehydrogenative coupling reaction conditions: **130** (0.5 mmol), $[Ir(cod)OMe]_2$ (2 mol %) and 1,10-phenantroline (4 mol %), norbornene (1.2 equiv), and THF (1.0 mL) were stirred at 100 ºC for 12 h under nitrogen.

[b] 10 mol % $Ni(cod)_2$ was used.

[c] 48 h at 100 ºC.

We also showed that hydrosilylation and dehydrogenative cyclization reactions can be easily scaled up to a multi-gram synthesis of dehydropyridinoosilole **131** using reduced amounts of nickel- and iridium catalysts (Scheme 44).



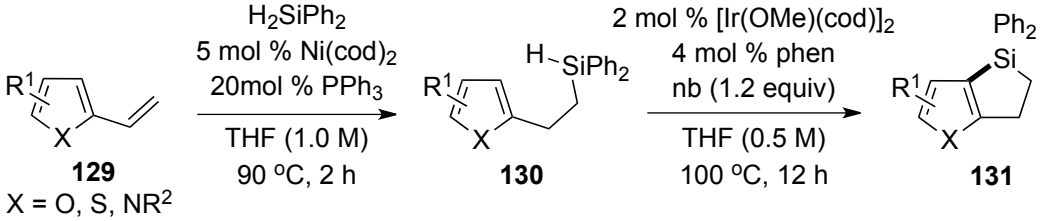
X	time, d	**131a**, yield
0.5	2	82%
0.25	6	74%

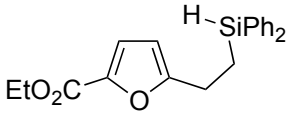
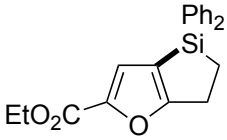
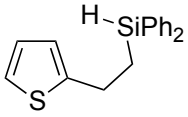
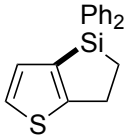
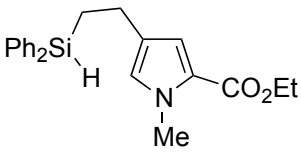
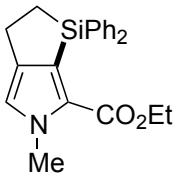
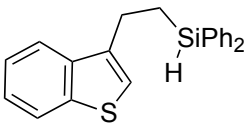
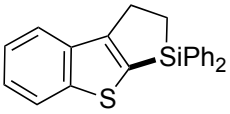
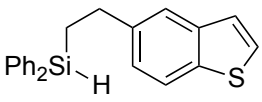
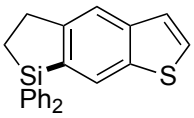
Scheme 44.

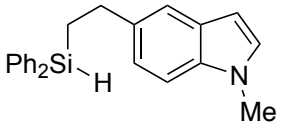
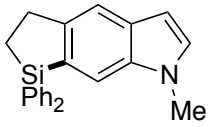
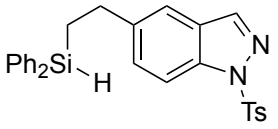
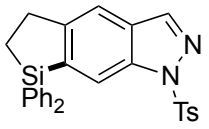
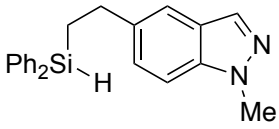
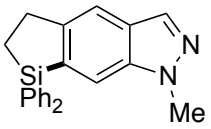
Next, we examined the possibility of using substrates possessing electron-rich heterocycles in this hydrosilylation/dehydrogenative cyclization reaction sequence (Table 8). We were pleased to find that furan **129aa**, thiophene **129bb**, and pyrrole **129cc** worked well in both reactions producing the corresponding cyclization products in good yields (entries 1-3). In the case of pyrrole **130cc** with silicon-tether at the fourth position, the cyclization selectively occured at the third position (entry 3). Expectedly, benzothiophene **130dd** with tether at the third position cyclized at C2 site (entry 4). Cyclization of fused benzo heteroaromatic systems at phenyl ring was efficient, as well. Thus, employment of benzothiophene **130ee** with the silicon tether at the C5 resulted in cyclization product **131ee** at the sixth position as a major regioisomer (entry 5). Similarly, indole **130ff** and *N*-Ts indazole **130gg** with alkylsilyl tether at C5 gave the C6

cyclization products as major regioisomers (entries 6-7). On the other hand, *N*-Me indazole with Si-tether at C5 **130hh** cyclized at the sixth position exclusively (entry 8).

Table 8. Scope of electron-rich heterocycles in hydrosilylation/dehydrogenative cyclization[a]



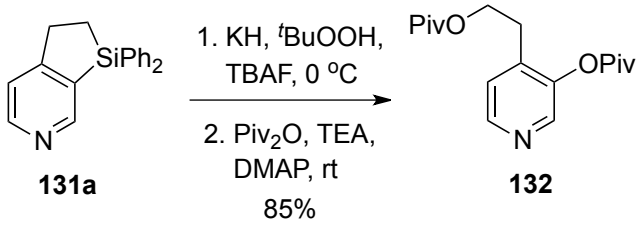
Entry	Intermediate	Yield (%)	Product	Yield (%)
1		**130aa** 93		**131aa** 88
2		**130bb** 70		**131bb** 67
3		**130cc** 91		**131cc** 84
4		**130dd** 94		**131dd** 63
5		**130ee** 92		**131ee** 61 (10:1)

Entry	Intermediate	Yield (%)	Product	Yield (%)
6	 **130ff**	89	 **131ff**	94 (10:1)
7	 **130gg**	85	 **131gg**	52 (7:1)
8	 **130hh**	84	 **131hh**	59

[a] Hydrosilylation reaction conditions: **129** (1.0 mmol), H_2SiPh_2 (1.02 mmol), $Ni(cod)_2$ (5 mol %), PPh_3 (20 mol %), and THF (1.0 mL) were stirred at 90 ºC for 2 h under nitrogen. Dehydrogenative coupling reaction conditions: **130** (0.5 mmol), $[Ir(cod)OMe]_2$ (2 mol %) and 1,10-phenantroline (4 mol %), norbornene (1.2 equiv), and THF (1.0 mL) were stirred at 100 ºC for 12 h under nitrogen.

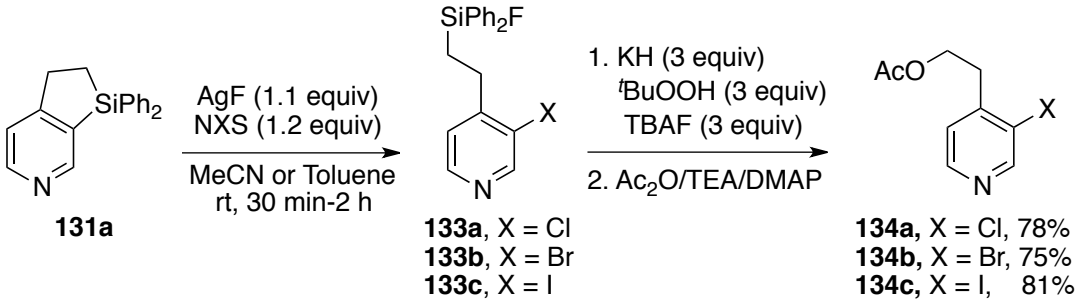
3.3. Further Transformations: Two-Fold Modification of Fused Heteroaromatic Dihydrosiloles

We also explored a synthetic utility of the newly obtained fused heteroaromatic dihydrosiloles by transforming them into the valuable heterocylic scaffolds. Thus, dihydropyridinosilole **131a** upon treatment with ^{t}BuOOH/KH and TBAF,[85,86] was oxidized into 4-(2-hydroxyethyl)pyridin-3-ol derivative **132** in excellent yield (Scheme 45).



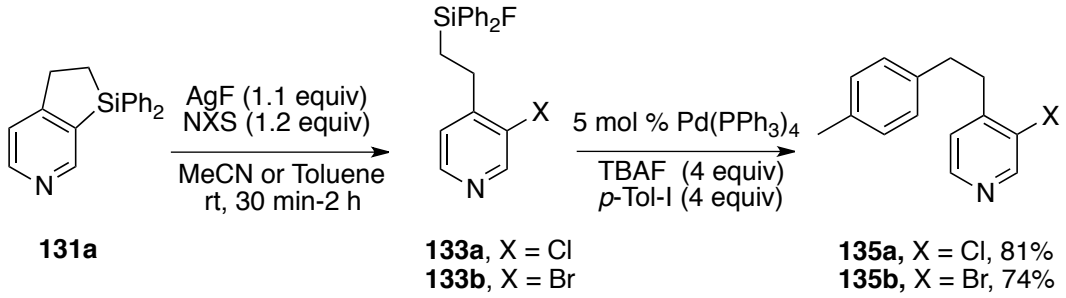
Scheme 45.

We also found that upon reaction with *N*-halosuccinimides and AgF, C(Het)-Si bond of dihydropyridinosilole **131a** can be cleaved selectively over the C(Ph)-Si bond to produce 3-halopyridinefluorosilanes **133a**, **133b**, and **133c** in good yields. The diphenylfluorosilyl group in **133a**/**c** can be further oxidized with ^{t}BuOOH/KH and TBAF to produce **134a**/**c** in excellent yields (Scheme 46).



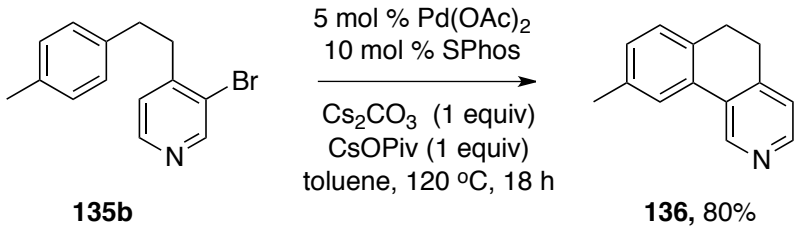
Scheme 46.

Alternatively, the silyl group in **133a** and **133b** can be replaced with an aryl-[87] group to form the arylation products **135a** and **135b** in 81% and 74% yields respectively (Scheme 47).



Scheme 47.

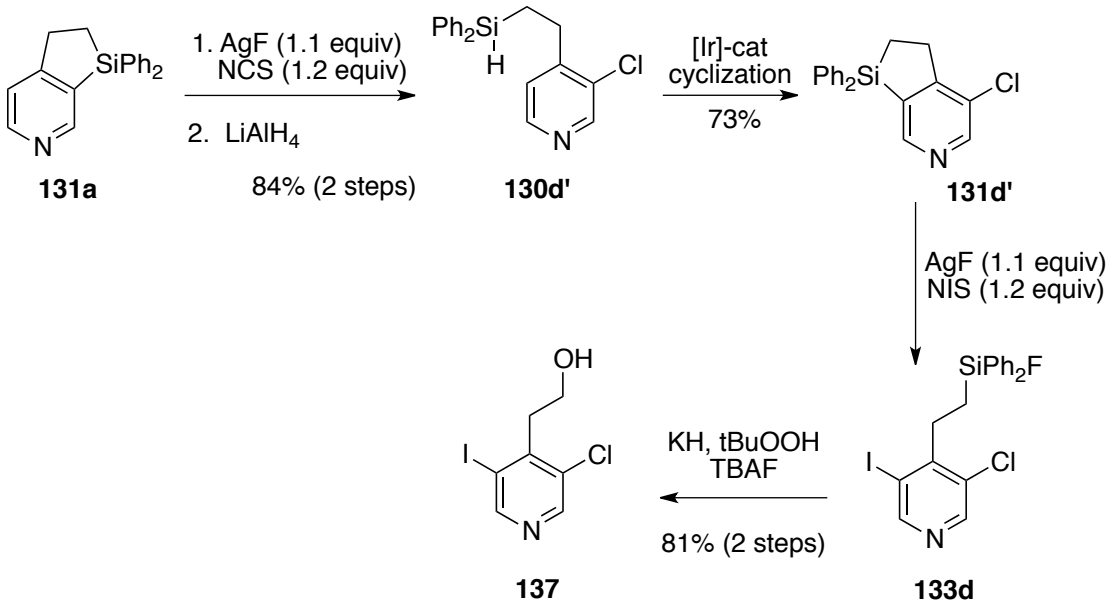
Compound **135b** can further undergo intramolecular direct arylation with the formation of tricyclic dihydrobenzoquinoline **136** (Scheme 48).



135b **136,** 80%

Scheme 48.

Furthermore, upon reaction with $LiAlH_4$,[88] 3-chloropyridinefluorosilane **133a** was converted to hydrosilane **130d'**, which then was cyclized into **131d'** under the iridium-catalyzed dehydrogenative coupling reaction conditions. Subsequent dihydrosilole ring opening with NIS and AgF, and oxidation of the silyl-group in the resulted 3-chloro-5-iodopyridinefluorosilane **133d** using ^{t}BuOOH/KH and TBAF, led to the highly functionalized pyridine derivative **137** (Scheme 49).



131a 84% (2 steps) **130d'** **131d'**

137 **133d**

Scheme 49.

3.4. Summary

In summary, we have developed an efficient method for the synthesis of fused heteroaromatic dihydrosiloles via the nickel-catalyzed hydrosilylation of heteroaromatic styrenes, followed by the iridium-catalyzed dehydrogenative Si-H/C-H coupling reaction. This method is very effective for both electron-deficient and electron-rich heterocycles. The newly formed fused heteroaromatic dihydrosiloles can be further transformed into valuable heterocyclic building blocks, possessing halogen-, hydroxyl-, and aryl-functionalities.

4. EXPERIMENTAL SECTION

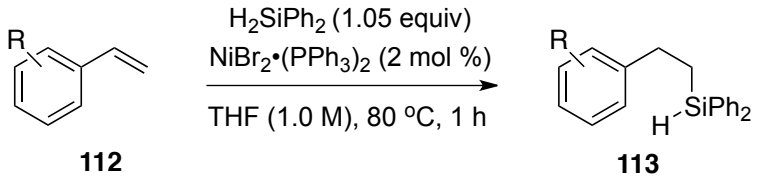
4.1. General Information

NMR spectra were recorded on Bruker Avance DRX-500 (500 MHz) or DPX-400 (400 MHz) instruments. GC-MS analysis was performed on a Hewlett Packard Model 6890 GC interfaced to a Hewlett Packard Model 5973 mass selective detector (15 m x 0.25 mm capillary column, HP-5MS). Column chromatography was carried out employing Silicycle Silica-P Flash silica gel (40-63 μm). Precoated silica gel plates F-254 were used for thin-layer analytical chromatography. All manipulations with transition metal catalysts were conducted under inert atmosphere using a combination of glovebox and standard Schlenk techniques. Anhydrous toluene, tetrahydrofuran, ether, and dichloromethane purchased from Aldrich were additionally purified on PureSolv PS-400-4 by Innovative Technology, Inc. purification system. Anhydrous solvents other than listed above were purchased from Aldrich and stored over calcium hydride. All starting materials were purchased from Aldrich, Strem Chemicals Inc., Alfa Aesar or AK Scientific, or synthesized using known procedures. Reactions were typically run in oven-dried glassware under inert atmosphere.

4.2. One-Pot Synthesis of Dihydrobenzosiloles from Styrenes

4.2.1. Synthesis of Starting Materials

General procedure for the hydrosilylation reaction of styrenes 112 with diphenylsilane:



112 **113**

Scheme 50.

In a glovebox, 1 mL Wheaton microreactor was charged with $NiBr_2$•$(PPh_3)_2$ (7.4 mg, 2 mol %) and THF (0.5 mL, 1.0 M). To the resulting solution, styrene **112** (0.5 mmol, 1 equiv) and Ph_2SiH_2 (0.53 mmol, 1.05 equiv, 97.0 μL) were added (**Scheme 50**). The microreactor was capped with a Teflon pressure cap, taken out of the glovebox, and placed into pre-heated (80 °C) aluminum block. The reaction mixture was stirred for 1 h at this temperature. After completion of the reaction (as judged by GC-MS analysis), microreactor, containing hydrosilylation product **113**, was cooled down and the solvent was evaporated. The product was purified using flash silica gel column chromatography.

113a: (89%, eluent: Hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.63-7.62 (m, 4H), 7.46-7.40 (m, 6H), 7.32-7.29 (m, 2H), 7.23-7.19 (m, 3H), 4.95 (m, 1H), 2.83-2.80 (m, 2H), 1.58-1.54 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 144.4, 135.2, 134.1, 129.7, 128.4, 128.1, 127.9, 125.7, 30.5, 14.3. HRMS (EI) calcd for $C_{20}H_{20}Si$ $[M]^+$: 288.1334, found: 288.1325.

113c: (95%, eluent: Hexanes/EtOAc = 100/4). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.62-7.61 (m, 4H), 7.46-7.39 (m, 6H), 7.22 (t, J = 8.1 Hz, 1H), 6.82 (d, J = 7.0 Hz, 1H), 6.76-6.74 (m, 2H), 4.94 (t, J = 3.7 Hz, 1H), 3.81 (s, 3H), 2.80-2.77 (m, 2H), 1.57-1.53 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.7, 146.1, 135.2, 134.1, 129.7, 129.3, 128.1, 120.3, 113.6, 111.1, 55.2, 30.5, 14.2. HRMS (EI) calcd for $C_{21}H_{22}SiO$ $[M]^+$: 318.1440, found: 318.1448.

113f: (87%, eluent: Hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.63-7.61 (m, 4H), 7.44-7.39 (m, 6H), 7.20 (m, 1H), 7.03 (m, 3H), 4.94 (m, 1H), 2.79-2.76 (m, 2H), 2.35 (s, 3H), 1.57-1.53 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 144.3, 137.9, 135.2, 134.2, 129.7, 128.7, 128.3, 128.1, 126.5, 124.9, 30.4, 21.4, 14.3. HRMS (EI) calcd for $C_{21}H_{22}Si$ $[M]^+$: 302.1491, found: 302.1489.

113l: (82%, eluent: Hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.64-7.61 (m, 4H), 7.48-7.40 (m, 6H), 7.23-7.17 (m, 3H), 7.08 (d, J = 7.0 Hz, 1H), 4.95 (m, 1H), 2.81-2.78 (m, 2H), 1.57-1.51 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 146.4, 135.9, 135.2, 134.1, 133.8, 129.8, 129.6, 128.1, 126.1, 125.9, 30.2, 14.1. HRMS (EI) calcd for

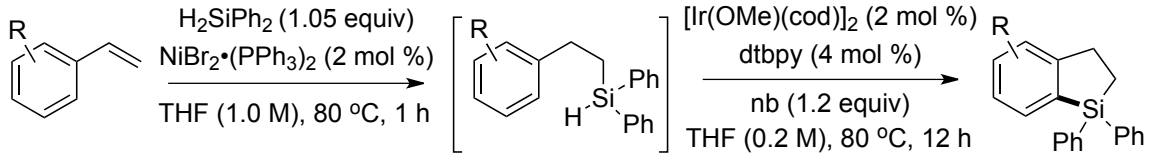
$C_{20}H_{19}SiCl$ $[M]^+$: 322.0945, found: 322.0948.

113o: (74%, eluent: Hexanes/EtOAc = 100/4). ^1H NMR (500 MHz, $CDCl_3$) δ 7.93 (m, 1H), 7.89 (dt, *J* = 7.7, 1.8 Hz, 1H), 7.63-7.62 (m, 4H), 7.47-7.39 (m, 7H), 7.36 (t, *J* = 7.7 Hz, 1H), 4.96 (t, *J* = 3.7 Hz, 1H), 3.34 (s, 3H), 2.87-2.84 (m, 2H), 1.59-1.55 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.3, 144.6, 135.2, 133.9, 132.6, 130.2, 129.8, 129.0, 128.4, 128.2, 127.1, 109.6, 52.1, 30.4, 14.3. HRMS (EI) calcd for $C_{22}H_{22}SiO_2$ $[M]^+$: 346.1395, found: 346.1389.

113-*d*$_5$: (83%, eluent: Hexanes/EtOAc = 100/1) ^1H NMR (500 MHz, $CDCl_3$) δ 7.62-7.61 (m, 4H), 7.45-7.39 (m, 6H), 4.93 (m, 1H), 2.82-2.79 (m, 2H), 1.57-1.53 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 144.2, 135.2, 134.1, 129.7, 128.1, 30.3, 14.3. HRMS (EI) calcd for $C_{20}H_{15}Si^2H_5$ $[M]^+$: 293.1648, found: 293.1643.

4.2.2. Synthesis of Dihydrobenzosiloles 114 from Styrenes 112

General procedure for the one-pot synthesis of dihydrobenzosiloles 114 from styrenes 112:



112 **113** **114**

one-pot

Scheme 51.

In a glovebox, 3 mL Wheaton microreactor was charged with $NiBr_2•(PPh_3)_2$ (7.4 mg, 2 mol %) and THF (0.5 mL, 1.0 M). To the resulting solution, styrene **112** (0.5 mmol, 1 equiv) and Ph_2SiH_2 (0.53 mmol, 1.06 equiv, 98.0 μL) were added. The microreactor was capped with a Teflon pressure cap, taken out of the glovebox, and placed into pre-heated (80 °C) aluminum block. The reaction mixture was stirred for 1 h at this temperature. After completion of the reaction (as judged by GC-MS analysis), microreactor, containing hydrosilylation product **113**, was cooled down and transferred into the glovebox, where it was charged with $[Ir(cod)OMe]_2$ (6.6 mg, 2 mol %), 4,4'-di-*tert*-butyl-2,2'-bipyridine (5.4 mg, 4 mol %), 2-norbornene (50.4 mg, 1.2 equiv), and THF (2.0 mL, 0.2M). The reaction vial was taken out of the glovebox and stirred at 80 °C for 12 h. After completion of the reaction (as judged by GC-MS analysis), microreactor,

containing dihydrobenzosilole **114**, was cooled down, and the solvent was evaporated. The product was purified using flash silica gel column chromatography (Scheme 51).

114a: (86%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.69 (d, *J* = 7.6 Hz, 1H), 7.60-7.58 (m, 4H), 7.42-7.32 (m, 8H), 7.27 (m, 1H), 3.26-3.22 (m, 2H), 1.55-1.51 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 154.3, 136.3, 135.3, 135.1, 133.3, 129.8, 129.6, 127.9, 126.0, 125.9, 31.8, 10.5. HRMS (EI) calcd for $C_{20}H_{18}Si$ $[M]^+$: 286.1178, found: 286.1188.

114b: (81%, eluent: hexanes/EtOAc = 100/4). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.62-7.61 (m, 4H), 7.44-7.37 (m, 6H), 7.27 (d, *J* = 7.7 Hz, 1H), 7.20 (m, 1H), 6.96 (dt, *J* = 8.4, 2.2 Hz, 1H), 3.21-3.18 (m, 2H), 1.57-1.54 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.1, 146.4, 137.7, 135.2, 135.2, 129.6, 128.0, 126.7, 117.0, 116.7, 55.5, 30.9, 11.2. HRMS (EI) calcd for $C_{21}H_{20}SiO$ $[M]^+$: 316.1284, found: 316.1290.

114c: (79%, eluent: hexanes/EtOAc = 100/4). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.65-7.63 (m, 5H), 7.45-7.39 (m, 6H), 6.92 (s, 1H), 6.89 (dd, *J* = 8.1, 2.2 Hz, 1H), 3.87 (s, 3H), 3.27-3.24 (m, 2H), 1.59-1.56 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 161.7, 156.8, 135.7, 135.1, 134.4, 129.6, 128.0, 127.3, 113.2, 110.7, 31.8, 21.7, 10.9. HRMS (EI) calcd for $C_{21}H_{20}SiO$ $[M]^+$: 316.1284, found: 316.1293.

114d: (81%, eluent hexanes/EtOAc = 100/4). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.68-7.66 (m, 4H), 7.48-7.40 (m, 6H), 7.37-7.32 (m, 2H), 6.94 (dd, *J* = 7.3, 1.5 Hz, 1H), 3.91 (s,

3H), 3.28-3.25 (m, 2H), 1.59-1.57 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 156.5, 142.5, 138.3, 135.5, 135.2, 129.6, 128.0, 127.7, 125.0, 111.0, 55.1, 27.3, 9.5. HRMS (EI) calcd for $C_{21}H_{20}SiO$ $[M]^+$: 316.1284, found: 316.1292.

114e: (73%, eluent hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.62-7.61 (m, 4H), 7.51 (s, 1H), 7.44-7.37 (m, 6H), 6.25 (d, *J* = 8.1 Hz, 1H), 7.20 (d, *J* = 8.1 Hz, 1H), 3.23-3.20 (m, 2H), 2.37 (s, 3H), 1.56-1.53 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 151.4, 136.3, 135.4, 135.3, 135.1, 133.6, 131.0, 129.6, 127.9, 125.6, 31.4, 21.2, 10.8. HRMS (EI) calcd for $C_{21}H_{20}Si$ $[M]^+$: 300.1334, found: 300.1342.

114f: (76%, eluent hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.69-7.67 (m, 5H), 7.48-7.42 (m, 6H), 7.25 (s, 1H), 7.18 (d, *J* = 7.3 Hz, 1H), 7.07 (dt, *J* = 8.8, 2.6 Hz, 1H), 3.30-3.27 (m, 2H), 2.45 (s, 3H), 1.62-1.59 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 154.9, 140.0, 135.6, 135.2, 133.3, 132.9, 129.6, 128.0, 127.3, 126.7, 31.8, 21.7, 10.9. HRMS (EI) calcd for $C_{21}H_{20}Si$ $[M]^+$: 300.1334, found: 300.1340.

114g: (72%, 36 h at 80 °C for the dehydrogenative cyclization reaction, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.70-7.67 (m, 4H), 7.64 (m, 1H), 7.49-7.42 (m, 6H), 7.30-7.28 (m, 2H), 3.25-3.22 (m, 2H), 2.39 (s, 3H), 1.63-1.60 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 152.8, 136.2, 135.6, 135.2, 134.7, 131.2, 130.9, 129.6, 128.0, 126.4, 30.1, 19.7, 9.7. HRMS (EI) calcd for $C_{21}H_{20}Si$ $[M]^+$: 300.1334, found: 300.1327.

114h: (66%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.61-7.60 (m, 4H), 7.46-7.39 (m, 6H), 7.35 (dd, *J* = 8.1, 2.9 Hz, 1H), 7.30 (dd, *J* = 8.4, 4.8 Hz, 1H), 7.07 (dt, *J* = 8.8, 2.6 Hz, 1H), 3.24-3.21 (m, 2H), 1.61-1.58 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.7, 149.5, 139.0, 135.1, 134.6, 129.8, 128.1, 127.2, 118.9, 117.2, 31.1, 11.2. HRMS (EI) calcd for $C_{20}H_{17}SiF$ $[M]^+$: 304.1084, found: 304.1094.

114i: (63%, 2:1 mixture *para-* : *ortho-* cyclized products formed, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.71-7.70 (m, 1.37H), 7.68-7.67 (m, 0.68H), 7.64-7.62 (m, 3H), 7.48-7.37 (m, 6H), 7.16 (d, *J* = 7.7 Hz, 0.30H), 7.16 (dd, *J* = 9.9 Hz, 2.2 Hz, 0.68H), 7.16 (dt, *J* = 9.2 Hz, 2.2 Hz, 0.74H), 7.16 (t, *J* = 7.0 Hz, 0.34H), 3.32-3.29 (m, 0.68H), 3.28-3.25 (m, 1.59H), 1.64-1.60 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.8, 163.8, 140.2, 135.1, 135.1, 135.0, 134.9, 134.8, 134.5, 131.8, 129.9, 129.8, 128.1, 128.1, 121.9, 113.9, 113.7, 112.7, 112.4, 32.0, 31.9, 11.1, 10.3. HRMS (EI) calcd for $C_{20}H_{17}SiF$ $[M]^+$: 304.1084, found: 304.1092.

114j: (71%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.70-7.68 (m, 4H), 7.56 (d, *J* = 7.0 Hz, 1H), 7.56-7.45 (m, 6H), 7.35 (m, 1H), 7.15 (t, *J* = 8.8 Hz, 1H), 3.37-3.34 (m, 2H), 1.67-1.64 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 161.2, 159.2, 140.6, 140.3, 135.2, 134.7, 129.9, 128.8, 128.2, 116.4, 26.2, 9.8. HRMS (EI) calcd for $C_{20}H_{17}SiF$ $[M]^+$: 304.1084, found: 304.1078.

114k: (66%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.62 (d, *J* = 1.8 Hz, 1H), 7.60-7.58 (m, 4H), 7.42-7.32 (m, 6H), 7.33 (dd, *J* = 8.4, 2.2 Hz, 1H), 7.26

(m, 1H), 3.22-3.19 (m, 2H), 1.59-1.56 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 152.5, 139.1, 135.1, 134.4, 132.7, 132.2, 130.0, 129.9, 128.1, 127.2, 31.3, 10.9. HRMS (EI) calcd for $C_{20}H_{17}SiCl$ $[M]^+$: 320.0788, found: 320.0775.

114l: (67%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.62-7.58 (m, 5H), 7.46-7.38 (m, 6H), 7.35 (s, 1H), 7.26 (dd, *J* = 7.7, 1.8 Hz, 1H, 3.25-3.22 (m, 2H), 1.59-1.56 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 156.4, 136.4, 135.1, 134.8, 134.7, 134.4, 129.8, 128.1, 126.5, 126.1, 31.8, 10.8. HRMS (EI) calcd for $C_{20}H_{17}SiCl$ $[M]^+$: 320.0788, found: 320.0798.

114m: (64%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.64-7.59 (m, 5H), 7.46-7.39 (m, 6H), 6.89 (t, *J* = 7.3 Hz, 1H), 3.34-3.31 (m, 2H), 1.60-1.57 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 139.6, 135.9, 135.1, 134.7, 132.7, 131.5, 130.3, 129.9, 128.1, 127.9, 30.7, 9.3. HRMS (EI) calcd for $C_{20}H_{17}SiCl$ $[M]^+$: 320.079, found: 320.078.

114n: (57%, eluent: hexanes/EtOAc = 100/4). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.41 (d, *J* = 1.5 Hz, 1H), 8.08 (dd, *J* = 8.1, 1.8 Hz, 1H), 7.63-7.61 (m, 4H), 7.47-7.39 (m, 7H), 3.92 (s, 3H), 3.32-3.29 (m, 2H), 1.63-1.60 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.4, 159.8, 137.1, 135.1, 134.7, 134.5, 131.3, 129.9, 128.1, 125.9, 52.0, 32.1, 10.6. HRMS (EI) calcd for $C_{22}H_{20}SiO_2$ $[M]^+$: 344.1233, found: 344.1239.

114o: (56%, eluent: hexanes/EtOAc = 100/4). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.01 (s,

1H), 7.92 (d, *J* = 7.7 Hz, 1H), 7.77 (d, *J* = 7.7 Hz, 1H), 7.59-7.58 (m, 4H), 7.45-7.37 (m, 6H), 3.94 (s, 3H), 3.31-3.28 (m, 2H), 1.61-1.58 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.5, 154.5, 142.8, 135.1, 134.4, 133.3, 131.5, 129.9, 128.1, 127.0, 126.6, 52.1 31.7, 10.7. HRMS (EI) calcd for $C_{22}H_{20}SiO_2$ $[M]^+$: 344.1233, found: 344.1223.

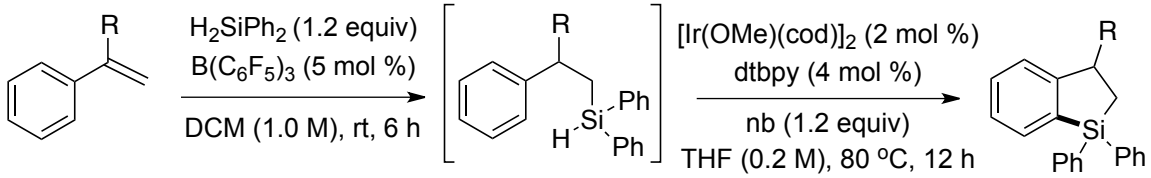
114p: (60%, eluent: hexanes/EtOAc = 100/4). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.06 (dd, *J* = 7.7, 1.1 Hz, 1H), 8.06 (d, *J* = 7.0 Hz, 1H), 7.61-7.59 (m, 4H), 7.45-7.34 (m, 7H), 3.93 (s, 3H), 3.68-3.65 (m, 2H), 1.59-1.56 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 168.0, 155.8, 139.0, 137.5, 135.1, 134.7, 132.3, 129.8, 128.1, 127.7, 126.1, 51.8, 31.9, 9.9. HRMS (EI) calcd for $C_{22}H_{20}SiO_2$ $[M]^+$: 344.1233, found: 344.1242.

114q: (49%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.06 (m, 1H), 7.85 (d, *J* = 8.1 Hz, 1H), 7.82 (d, *J* = 8.4 Hz, 1H), 7.79 (s, 1H), -7.74 (m, 2H), 7.64-7.62 (m, 4H), 7.58-7.54 (m, 2H), 7.45-7.37 (m, 6H), 3.70-3.67 (m, 2H), 1.69-1.66 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 152.0, 135.5, 135.1, 134.5, 133.7, 131.0, 129.6, 129.0, 128.5, 128.0, 126.7, 126.4, 126.0, 124.3, 29.6, 9.3. HRMS (EI) calcd for $C_{24}H_{20}Si$ $[M]^+$: 336.1334, found: 336.1333.

114r: (54%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.23 (s, 1H), 7.85 (d, *J* = 8.1 Hz, 1H), 7.82 (d, *J* = 8.4 Hz, 1H), 7.79 (s, 1H), 7.67-7.65 (m, 4H), 7.49 (m, 1H), 7.45-7.38 (m, 7H), 3.42-3.39 (m, 2H), 1.66-1.63 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 150.2, 135.7, 125.3, 134.8, 134.2, 129.7, 128.3, 128.0, 127.6, 126.5, 125.0, 123.2, 31.6, 11.8. HRMS (EI) calcd for $C_{24}H_{20}Si$ $[M]^+$: 336.1334, found: 336.1326.

114-d_4: (83%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.63-7.62 (m, 4H), 7.43-7.38 (m, 6H), 3.29-3.26 (m, 2H), 1.58-1.55 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 154.4, 135.3, 135.2, 129.6, 128.0, 125.8, 31.9, 10.6. HRMS (EI) calcd for $C_{20}H_{14}Si^2H_4$ $[M]^+$: 290.1429, found: 290.1421.

General procedure for the semi one-pot synthesis of dihydrobenzosiloles 114 from styrenes 112:



Scheme 52.

To a stirred solution of $B(C_6F_5)_3$ (13.1 mg, 5 mol %) in anhydrous CH_2Cl_2 (0.5 mL) H_2SiPh_2 (0.6 mmol, 110 mg, 111 μL) was added, followed by the addition of styrene **112** (0.5 mmol). The reaction mixture was stirred at room temperature for 6 h and filtered through a short column (silica gel, CH_2Cl_2 as an eluent). After evaporation of the solvent, the hydrosilylated product **113** was transferred to a 3 mL Wheaton microreactor and additionally dried on high vacuum. To the crude mixture, $[Ir(cod)OMe]_2$ (6.6 mg, 2 mol %), 4,4'-di-*tert*-butyl-2,2'-bipyridine (5.4 mg, 4 mol %), 2-norbornene (50.4 mg, 1.2

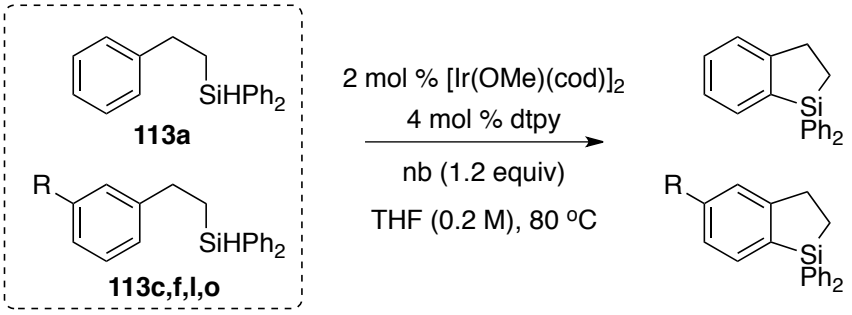
equiv), and THF (2.5 mL, 0.2 M) were added. The microreactor was capped with a Teflon pressure cap, taken out of the glovebox, and placed into pre-heated (80 °C) aluminum block. The reaction mixture was stirred at this temperature for 12 h. After completion of the reaction (as judged by GC-MS analysis), microreactor, containing dihydrobenzosilole **114**, was cooled down, and the solvent was evaporated. The product was purified using flash silica gel column chromatography (Scheme 52).

114s: (79%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.73 (d, *J* = 6.3 Hz, 1H), 7.68-7.66 (m, 2H), 7.61-7.60 (m, 2H), 7.47-7.37 (m, 8H), 7.31 (t, *J* = 7.7 Hz, 1H), 3.50 (m, 1H), 1.86 (dd, *J* = 15.0, 7.7 Hz, H), 1.45-1.43 (d, 3H), 1.23 (dd, *J* = 15.0, 6.2 Hz, H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.0, 135.7, 135.4, 135.3, 135.2, 133.3, 130.1, 129.6, 128.0, 126.2, 125.0, 38.5, 25.0, 20.7. HRMS (EI) calcd for $C_{21}H_{18}Si$ $[M]^+$: 298.1178, found: 298.1173.

114t: (76%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.82 (dd, *J* = 6.2, 2.2 Hz, 1H), 7.73-7.68 (m, 4H), 7.51-7.43 (m, 6H), 7.39-7.34 (m, 4H), 7.30-7.25 (m, 3H), 7.05 (d, *J* = 7.3 Hz, 1H), 4.61 (t, *J* = 8.4 Hz, 1H), 2.19 (dd, *J* = 15.0, 8.1 Hz, H), 1.68 (dd, *J* = 15.0, 8.1 Hz, H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 157.0, 148.3, 136.8, 135.4, 135.3, 135.1, 135.9, 133.1, 130.2, 129.9, 129.8, 128.6, 128.3, 128.1, 127.0, 126.5, 126.2, 50.3, 23.0. HRMS (EI) calcd for $C_{26}H_{22}Si$ $[M]^+$: 362.1491, found: 362.1488.

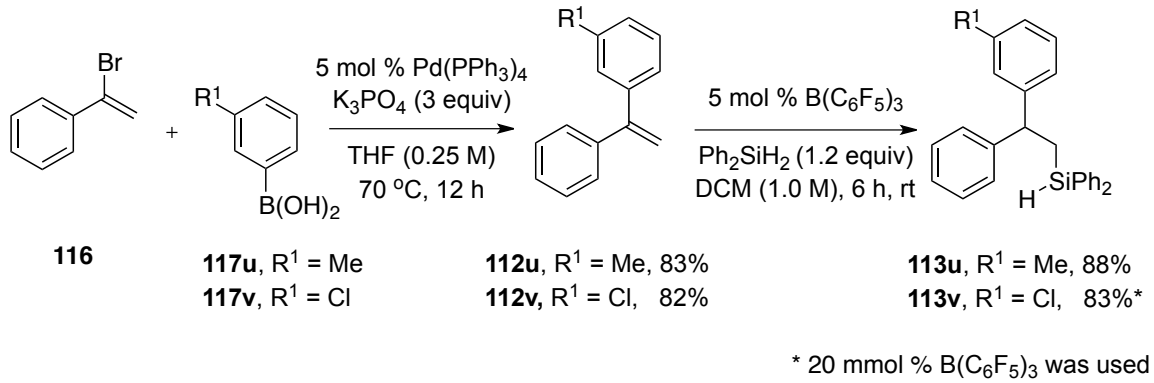
4.2.3. Mechanistic Studies

Intermolecular cyclization rate study. In a glovebox, a 1 mL Wheaton microreactor containing two hydrosilylated products **113a** and **113c/f/l/o** (0.1 mmol each), was charged with $[Ir(cod)OMe]_2$ (2.6 mg, 2 mol %), 4,4'-di-*tert*-butyl-2,2'-bipyridine (2.2 mg, 4 mol %), 2-norbornene (20.2 mg, 1.2 equiv), and THF (0.5 mL, 0.2 M). The microreactor was capped with a Teflon pressure cap, taken out of the glovebox, and placed into pre-heated (80 °C) aluminum block. The reaction progress was analyzed by GC-MS analysis every 30 min using *n*-pentadecane as an internal standard (Scheme 53). The relative rates of cyclization were determined by analyzing the corresponding initial rate plots.



Scheme 53.

Intramolecular cyclization study. Synthesis of unsymmetrically substituted phenetylsilanes **113u** and **113v** was accomplished as follows (Scheme 54).



116

117u, R^1 = Me
117v, R^1 = Cl

112u, R^1 = Me, 83%
112v, R^1 = Cl, 82%

113u, R^1 = Me, 88%
113v, R^1 = Cl, 83%*

* 20 mmol % $B(C_6F_5)_3$ was used

Scheme 54.

General procedure for the synthesis of 1-phenyl-1-arylethylene 112: A 10 mL Wheaton microreactor charged with α-bromostyrene (0.377 g, 268 μL, 2.0 mmol), 3-arylboronic acid (2.6 mmol, 1.3 equiv), potassium phosphate (1.27 g, 6.0 mmol, 3 equiv), $Pd(PPh_3)_4$ (0.116 g, 5 mol %), and THF (10 mL) was heated at 80 °C for 12 h (Scheme 54). After completion (as judged by GC-MS analysis) the reaction mixture was cooled down, filtered, and the solvent was evaporated. The product was purified by flash silica gel column chromatography.

112u (83%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40-7.34 (m, 5H), 7.31 (t, *J* = 7.3 Hz, 1H), 7.20 (m, 1H), 7.20-7.17 (m, 2H), 5.48 (s, 2H), 2.38 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 150.2, 141.6, 141.5, 137.8, 129.0, 128.5, 128.3, 128.2, 127.7, 125.5, 114.2, 109.6, 21.5.

112v (82%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.37-7.29 (m, 7H), 7.27 (m, 1H), 7.22 (m, 1H), 5.51-5.48 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ

148.9, 143.4, 140.8, 134.1, 129.4, 128.3, 128.2, 128.0, 127.8, 127.3, 126.5, 115.3.

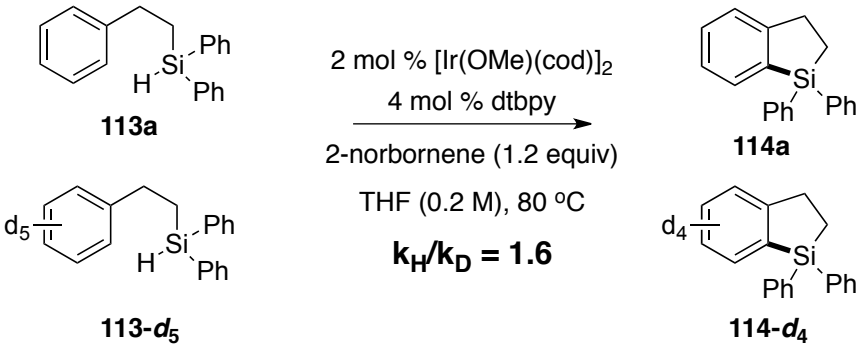
General procedure for the synthesis of (2-phenyl-2-arylethyl)diphenylsilanes 113: To a stirred solution of $B(C_6F_5)_3$ (26.2 mg, 5 mol %) in anhydrous CH_2Cl_2 (1.0 mL) H_2SiPh_2 (1.2 mmol, 184 mg, 185 μL) was added, followed by addition of 1-phenyl-1-arylethylene (1.0 mmol) (Scheme 54). The reaction mixture was stirred at room temperature until completion (12-24 h) as monitored by GC-MS analysis, filtered through a short column (silica gel, CH_2Cl_2 as an eluent) and concentrated. The product was purified by flash column chromatography.

113u: (88%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.50-7.48 (m, 4H), 7.41-7.38 (m, 2H), 7.36-7.34 (m, 4H), 7.27-7.23 (m, 4H), 7.18-7.13 (m, 2H), 7.05 (d, *J* = 7.7 Hz, 1H), 7.01 (s, 1H), 6.98 (d, *J* = 7.3 Hz, 1H), 4.60 (m, 1H), 4.11 (t, *J* = 8.1 Hz, 1H), 2.28 (s, 3H), 2.02-2.00 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 146.2, 137.8, 135.1, 134.3, 134.2, 129.5, 128.5, 128.3, 128.2, 127.9, 127.7, 126.9, 126.1, 124.7, 47.0, 21.5, 20.2. HRMS (EI) calcd for $C_{27}H_{26}Si$ $[M]^+$: 378.1804, found: 378.1806.

113v: (78%, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.48-7.46 (m, 4H), 7.41-7.38 (m, 2H), 7.35-7.32 (m, 4H), 7.27-7.24 (m, 2H), 7.20-7.07 (m, 7H), 4.59 (m, 1H), 4.09 (t, *J* = 8.1 Hz, 1H), 1.99-1.96 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 148.2, 145.3, 135.1, 134.1, 133.8, 129.7, 129.6, 128.5, 128.0, 127.8, 127.6, 126.5, 126.4, 125.9, 46.9, 20.0. HRMS (EI) calcd for $C_{26}H_{23}ClSi$ $[M]^+$: 398.1258, found: 398.1275.

Consequently, (2-phenyl-2-arylethyl)diphenylsilanes **113u** and **113v** were subjected to the cyclization reaction under standard conditions. The ratios of the corresponding cyclization products were determined by ^{1}H NMR analysis.

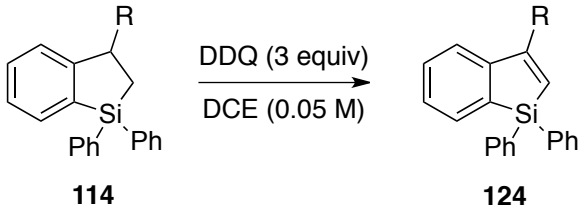
Kinetic isotope effect study. In a glovebox, two 1 mL Wheaton microreactors, one containing hydrosilylated product **113a**, the other hydrosilylated product **113-*d*$_5$** (0.1 mmol each), were charged with $[Ir(cod)OMe]_2$ (2.6 mg, 2 mol %), 4,4'-di-tert-butyl-2,2'-dipyridine (2.2 mg, 4 mol %), 2-norbornene (20.2 mg, 1.2 equiv), and THF (0.5 mL, 0.2M) (Scheme 55). The microreactors were capped with Teflon pressure caps, taken out of the glovebox, and placed into pre-heated (80 °C) aluminum block. The reaction progress was analyzed by GC-MS analysis every 30 min using *n*-pentadecane as an internal standard. The relative rates of cyclization towards **114a** and **114-*d*$_4$** were determined by the analysis the corresponding initial rate plots.



Scheme 55.

4.3. Further Transformations of Dihydrobenzosiloles 114

4.3.1. Dehydrogenation of Dihydrobenzosiloles 114 into Benzosiloles 124



114 **124**

Scheme 56.

General procedure for the synthesis of benzosiloles 124 from dihydrobenzosiloles 114: To a solution of dihydrobenzosilole **114** (0.3 mmol) in 6.0 mL DCE (0.05M), DDQ (204 mg, 3.0 equiv) was added. The resulting mixture was stirred at 50-100 °C. After completion of the reaction (as judged by GC-MS analysis), the reaction mixture, containing benzosilole **124**, was cooled down, diluted with hexanes, and filtered through silica gel. The silica gel was additionally washed with hexanes. The combined solutions were concentrated. The product was purified by flash silica gel column chromatography (Scheme 56).

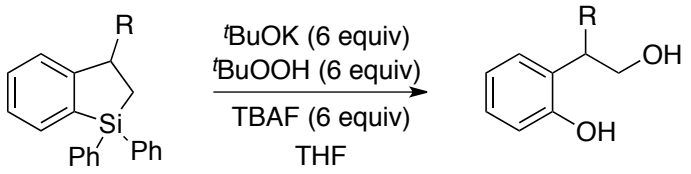
124a: (81%, 12h at 100 °C, eluent: hexanes/EtOAc = 100/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.70 (dd, *J* = 6.6, 0.7 Hz, 1H), 7.65-7.63 (m, 4H), 7.56 (d, *J* = 10.4 Hz, 1H), 7.45-7.41 (m, 2H), 7.40-7.32 (m, 6H), 7.27 (dt, *J* = 7.3, 1.1 Hz, 1H), 6.56 (d, *J* = 10.3 Hz,

1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 151.6, 150.1, 135.4, 132.9, 132.4, 130.3, 130.1, 129.4, 128.1, 127.4, 124.6. HRMS (EI) calcd for $C_{20}H_{16}Si$ $[M]^+$: 284.1021, found: 284.1012.

124s: (73%, 12h at 80 °C, eluent: hexanes/EtOAc = 100/1). ^1H NMR (500 MHz, $CDCl_3$) δ 7.70 (td, *J* = 7.0, 0.7 Hz, 1H), 7.66-7.63 (m, 4H), 7.45-7.40 (m, 4H), 7.37-7.34 (m, 4H), 7.29 (dt, *J* = 7.0, 1.8 Hz, 1H), 6.24 (m, 1H), 2.34 (d, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.0, 150.8, 136.8, 135.4, 132.9, 132.6, 130.1, 129.9, 128.0, 127.1, 124.7, 121.8, 19.9. HRMS (EI) calcd for $C_{21}H_{18}Si$ $[M]^+$: 298.1178, found: 298.1173.

124t: (77%, 6h at 50 °C, eluent: hexanes/EtOAc = 100/1). ^1H NMR (500 MHz, $CDCl_3$) δ 7.77 (td, *J* = 7.0, 1.1 Hz, 1H), 7.71-7.69 (m, 4H), 7.53-7.51 (m, 2H), 7.47-7.43 (m, 4H), 7.42-7.35 (m, 7H), 7.31 (dt, *J* = 7.0, 2.2 Hz, 1H), 6.46 (s, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.4, 149.6, 140.0, 137.0, 135.5, 133.2, 132.5, 130.1, 129.9, 128.3, 128.1, 128.0, 127.8, 127.3, 124.0. HRMS (EI) calcd for $C_{26}H_{20}Si$ $[M]^+$: 360.1334, found: 360.1344.

4.3.2. Oxidation of Dihydrobenzosiloles 114 into 2-hydroxyphenethyl Alcohols 118



114 **118**

Scheme 57.

General procedure for the synthesis of 2-hydroxyphenethyl alcohols 118 from dihydrobenzosiloles 114: To an ice-cooled (0 °C) stirred solution of ^{t}BuOK (202 mg, 1.8 mmol, 6 equiv) in 2.0 mL of THF, under the N_2 atmosphere, *tert*-butyl hydroperoxide (0.33 mL, 5.5 M in decane over MS, 6 equiv) was added. After 10 min, a solution of **114** (0.3 mmol) in 1.0 mL of THF was added to the resulted mixture. To the resulted solution TBAF (1.8 mL, 1.0 M solution in THF, 6 equiv) was added. The mixture was stirred overnight at 70 °C (Scheme 57). Then, the reaction mixture was cooled down and 1.0 g of $Na_2S_2O_3$•$5H_2O$ in 5.0 mL of water was added. The mixture was stirred for 30 min and 25 mL of saturated NH_4Cl was added. The resulted solution was extracted with diethyl ether (3 x 20 mL). The combined organic fractions were washed with 5% citric acid, $NaHCO_3$ (sat.), brine, dried (Na_2SO_4), and concentrated. The product **118** was purified by flash silica gel column chromatography.

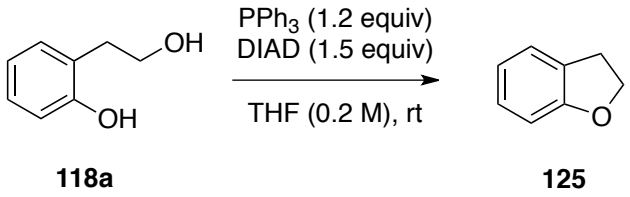
118a: (83%, eluent: hexanes/EtOAc = 4/1 then 2/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.04 (broad, 1H), 7.13 (t, J = 8.1 Hz, 1H), 7.06 (d, J = 7.3 Hz, 1H), 6.89 (d, J = 8.1 Hz, 1H),

6.84 (t, J = 7.3 Hz, 1H), 3.95-3.93 (m, 2H), 3.00 (broad, 1H) 2.90-2.87 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 155.1, 131.0, 128.3, 126.6, 120.6, 116.9, 64.5, 34.5.

118s: (87% eluent: hexanes/EtOAc = 4/1 then 2/1)**.** ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55 (broad, 1H), 7.16-7.12 (m, 2H), 6.92-6.88 (m, 2H), 3.95 (dd, J = 9.9, 3.7 Hz, 1H), 3.75 (m, 1H), 3.25 (m, 1H), 2.40 (broad, 1H), 1.33-1.32 (d, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 154.8, 130.6, 127.9, 127.8, 120.7, 117.1, 69.5, 36.8, 15.6. HRMS (EI) calcd for $C_9H_{12}O_2$ $[M]^+$: 152.0837, found: 152.0829.

118t: (79% eluent: hexanes/EtOAc = 4/1 then 2/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.35-7.32 (m, 2H), 7.27-7.24 (m, 3H), 7.15 (dt, J = 7.7, 1.8 Hz, 1H), 7.09 (broad, 1H), 7.04 (dd, J = 7.7, 1.5 Hz, 1H), 6.89-6.85 (m, 2H), 4.47 (dd, J = 7.3, 4.8 Hz, 1H), 4.33-4.23 (m, 2H), 2.29 (broad, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 154.6, 140.1, 129.8, 128.8, 128.4, 128.3, 128.2, 127.0, 120.7, 117.2, 66.5, 48.5. HRMS (EI) calcd for $C_{14}H_{14}O_2$ $[M]^+$: 214.0994, found: 214.1004.

4.3.3. Cyclization of 2-hydroxyphenethyl Alcohol 118a into Dihydrobenzofuran 125



118a **125**

Scheme 58.

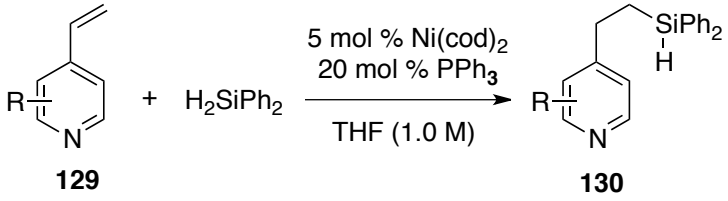
To a solution of **118a** (56 mg, 0.4 mmol) in 2.0 mL THF (0.2M), triphenylphosphine (0.48 mmol, 1.2 equiv. 126 mg) and diethyl azodicarboxylate (0.6 mmol, 1.5 equiv, 116 μL) were added. The reaction mixture was stirred at room temperature for 2 h. Then, the solvent was evaporated. The product **125** was purified using flash silica gel column chromatography (Scheme 58).

125: (80%, eluent, hexanes/EtOAc = 100/4). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.21 (dd, J = 7.3, 0.7 Hz, 1H), 7.12 (dt, J = 8.1, 0.7 Hz, 1H), 6.85 (dt, J = 7.3, 0.7 Hz, 1H), 6.81 (d, J = 8.1 Hz, 1H), 4.59-4.55 (m, 2H), 3.24-3.20 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.0, 127.9, 126.9, 124.9, 120.3, 109.4, 71.0, 29.8.

4.4. Fused Heteroaromatic Dihydrosiloles

4.4.1. Hydrosilylation of Heteroaromatic Styrenes 129

General procedure for the hydrosilylation reaction of heteroaromatic styrenes 129 with diphenylsilane:



Scheme 59.

In a glovebox, a 3 mL Wheaton microreactor vial was charged with $Ni(cod)_2$ (27.5 mg, 5 mol %), PPh_3 (52.4 mg, 20 mol %), and THF (1.0 mL, 1.0M). To the resulting solution, Ph_2SiH_2 (1.02 mmol, 1.02 equiv, 189 μL) was added, followed by heteroaromatic styrene[89] **129** (1.0 mmol, 1 equiv). The microreactor was capped with a Teflon pressure cap, taken out of the glovebox, and placed into pre-heated (90 °C) aluminum block. The reaction mixture was stirred for 1 h at this temperature (Scheme 59). After completion of the reaction (as judged by GC-MS analysis), microreactor, containing hydrosilylation product **130**, was cooled down and the solvent was evaporated. The product was purified using flash silica gel column chromatography.

130a: (84%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.48 (d, *J* = 5.9 Hz, 2H), 7.59-7.58 (m, 4H), 7.46-7.39 (m, 6H), 7.11 (d, *J* = 5.7 Hz, 2H), 4.92 (t, *J* = 3.7 Hz, 1H), 2.77-2.74 (m, 2H), 1.53-1.49 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 152.9, 149.7, 135.0, 133.4, 129.8, 128.1, 123.2, 29.8, 13.0. HRMS (EI+) calcd for $C_{20}H_{20}Si$: 289.1287, found: 289.1277.

130b: (86%, eluent: Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.34 (d, *J* = 5.3 Hz, 1H), 7.58-7.56 (m, 4H), 7.43-7.37 (m, 6H), 6.95 (s, 1H), 6.91 (d, *J* = 5.3 Hz, 1H), 4.90 (t, *J* = 3.5 Hz, 1H), 2.72-2.68 (m, 2H), 2.50 (s, 3H), 1.51-1.46 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.3, 153.2, 149.0, 135.1, 133.6, 129.8, 128.1, 122.8, 120.4, 29.8, 24.4, 13.1. HRMS (EI+) calcd for $C_{20}H_{21}SiN$: 303.1443, found: 303.1451.

130c: (86%, eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.08 (d, *J* = 5.3 Hz, 1H), 7.59-7.57 (m, 4H), 7.46-7.38 (m, 6H), 6.98 (d, *J* = 5.3 Hz, 1H), 6.74 (s, 1H), 4.92 (t, *J* = 3.5 Hz, 1H), 2.80-2.76 (m, 2H), 1.52-1.48 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.2 (d, $J_{C\text{-}F}$ = 237.7 Hz), 159.1 (d, $J_{C\text{-}F}$ = 8.3 Hz), 147.3 (d, *J* = 14.8 Hz), 135.1, 133.3, 130.0, 128.2, 121.1, 108.5 (d, $J_{C\text{-}F}$ = 37.0 Hz), 29.8, 13.0. HRMS (ES+) calcd for $C_{19}H_{19}SiNF$: 308.1271, found: 308.1266.

130d: (61%, eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.24 (d, *J* = 5.1 Hz, 1H), 7.59-7.58 (m, 4H), 7.47-7.39 (m, 6H), 7.15 (s, 1H), 7.02 (d, *J* = 5.1 Hz, 1H), 4.93 (t, *J* = 3.7 Hz, 1H), 2.76-2.73 (m, 2H), 1.52-1.48 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 156.3, 151.5, 149.3, 135.0, 133.1, 129.1, 128.1, 123.5, 122.1, 29.6, 12.9.

HRMS (EI+) calcd for $C_{19}H_{19}SiNCl$: 323.0897, found: 323.0892.

130e: (95%, eluent: Hexanes/EtOAc = 7/1) ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.32 (s, 1H), 8.28 (d, *J* = 5.3 Hz, 1H), 7.59-7.57 (m, 4H), 7.44-7.36 (m, 6H), 6.99 (d, *J* = 4.7 Hz, 1H), 4.95 (t, *J* = 3.5 Hz, 1H), 2.75-2.70 (m, 2H), 2.22 (s, 3H), 1.46-1.41 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 149.4, 147.3, 144.5, 135.1, 133.6, 129.8, 128.1, 125.1, 25.2, 18.5, 13.0. HRMS (EI+) calcd for $C_{20}H_{21}SiN$: 303.1443, found: 303.1444.

130f: (93%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.33 (d, *J* = 4.8 Hz, 1H), 7.61-7.59 (m, 4H), 7.46-7.39 (m, 7H), 7.05 (dd, *J* = 7.7, 4.9 Hz, 1H), 4.95 (m, 1H), 2.76-2.73 (m, 2H), 2.48 (s, 3H), 1.48-1.44 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 156.2, 146.5, 137.5, 135.5, 135.0, 133.6, 129.8, 128.1, 121.3, 27.3, 22.0, 12.5. HRMS (EI+) calcd for $C_{20}H_{20}SiN$: 302.1365, found: 302.1362.

130g: (90%, eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.61-7.59 (m, 4H), 7.45-7.39 (m, 6H), 7.31 (d, *J* = 8.1 Hz, 1H), 6.91 (d, *J* = 7.7 Hz, 1H), 4.95 (t, *J* = 3.7 Hz, 1H), 2.74-2.70 (m, 2H), 2.50 (s, 3H), 2.46 (s, 3H), 1.46-1.43 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 155.3, 154.8, 136.0, 135.0, 134.0, 133.7, 129.7, 128.1, 120.7, 27.0, 24.0, 22.0, 12.7. HRMS (EI+) calcd for $C_{21}H_{22}SiN$: 316.1522, found: 316.1524.

130h: (83%, eluent: Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.61-7.59 (m, 4H), 7.47-7.40 (m, 6H), 7.37 (d, *J* = 8.1 Hz, 1H), 7.07 (d, *J* = 7.7 Hz, 1H), 4.96 (t, *J* = 3.7 Hz, 1H), 2.75-2.71 (m, 2H), 2.45 (s, 3H), 1.47-1.43 (m, 2H). ^{13}C NMR (125 MHz,

$CDCl_3$) δ 159.6, 147.5, 138.5, 136.1, 135.0, 133.3, 129.8, 128.1, 121.4, 26.6, 21.7, 12.6. HRMS (EI+) calcd for $C_{20}H_{19}SiNCl$: 336.0975, found: 336.0971.

130j: (48%, eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.59-7.58 (m, 4H), 7.44-7.34 (m, 7H), 6.93 (d, J = 7.6 Hz, 2H), 4.94 (t, J = 4.1 Hz, 1H), 2.93-2.89 (m, 2H), 2.51 (s, 3H), 1.62-1.57 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.8, 157.7, 136.5, 135.4, 129.6, 128.0, 120.4, 118.8, 33.0, 24.5, 12.6. HRMS (EI+) calcd for $C_{20}H_{22}SiN$: 304.1522, found: 304.1527.

130k: (76%, eluent: Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.57-7.56 (m, 4H), 7.40-7.38 (m, 6H), 7.15 (t, J = 8.8 Hz, 1H), 6.91 (dd, J = 8.2, 3.5 Hz, 1H), 4.90 (t, J = 4.1 Hz, 1H), 2.91-2.87 (m, 2H), 2.45 (d, J = 2.9 Hz, 3H), 1.59-1.55 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.2 (d, $J_{C\text{-}F}$ = 5.2 Hz), 156.2 (d, $J_{C\text{-}F}$ = 252.3 Hz), 146.0 (d, $J_{C\text{-}F}$ = 17.0 Hz), 135.2, 134.0, 129.6, 128.0, 122.4, (d, $J_{C\text{-}F}$ = 19.6 Hz), 120.5 (d, $J_{C\text{-}F}$ = 3.7 Hz), 32.3, 17.9, 12.7. HRMS (EI+) calcd for $C_{20}H_{20}SiNF$: 321.1349, found: 321.1341.

130l: (67%, eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.62-7.60 (m, 4H), 7.44-7.35 (m, 7H), 6.69 (d, J = 7.0 Hz, 1H), 6.54 (d, J = 8.2 Hz, 1H), 4.94 (t, J = 3.5 Hz, 1H), 3.93 (s, 3H), 2.89-2.85 (m, 2H), 1.68-1.62 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 161.1, 138.7, 135.2, 134.5, 129.6, 128.0, 127.8, 114.5, 107.4, 53.2, 32.4, 11.8. HRMS (ES+) calcd for $C_{20}H_{22}SiNO$: 320.1471, found: 320.1462.

130m: (76%, eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.61-7.59

(m, 4H), 7.47-7.40 (m, 6H), 7.37 (d, J = 8.1 Hz, 1H), 7.07 (d, J = 7.7 Hz, 1H), 4.96 (t, J = 3.7 Hz, 1H), 2.75-2.71 (m, 2H), 2.45 (s, 3H), 1.47-1.43 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.3, 147.6 (q, J_{C-F} = 33.2 Hz), 137.4, 135.2, 133.7, 129.7, 128.0, 125.0, 121.6 (q, J_{C-F} = 273.7 Hz), 117.6, 32.8, 12.1. HRMS (EI+) calcd for $C_{20}H_{17}SiNF_3$: 356.1082, found: 356.1091.

130n: (97%, eluent: Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.78 (d, J = 4.7 Hz, 1H), 8.10 (d, J = 8.8 Hz, 1H), 7.68 (t, J = 7.0 Hz, 1H), 7.62-7.60 (m, 4H), 7.51 (t, J = 8.2 Hz, 1H), 7.44-7.38 (m, 6H), 7.23 (d, J = 4.7 Hz, 1H), 5.00 (t, J = 3.5 Hz, 1H), 3.22-3.18 (m, 2H), 1.65-1.60 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 150.3, 150.0, 148.3, 135.1, 133.5, 130.0, 129.9, 129.0, 128.2, 127.1, 126.3, 123.3, 120.0, 26.8, 13.1. HRMS (EI+) calcd for $C_{23}H_{20}SiN$: 338.1365, found: 338.1373.

130o: (96%, eluent: Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.93 (t, J = 8.8 Hz, 2H), 7.60-7.58 (m, 4H), 7.54-7.51 (m, 2H), 7.42-7.35 (m, 6H), 7.24 (d, J = 8.2 Hz, 1H), 4.92 (t, J = 3.5 Hz, 1H), 2.96-2.91 (m, 2H), 2.73 (s, 3H), 1.63-1.57 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.1, 146.7, 141.6, 135.7, 135.2, 134.0, 130.5, 129.8, 128.6, 128.1, 126.5, 125.2, 122.0, 30.4, 25.3, 14.1. HRMS (EI+) calcd for $C_{24}H_{23}SiN$: 353.1600, found: 353.1603.

130p: (90%, eluent: Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.26 (s, 1H), 8.53 (d, J = 5.8 Hz, 1H), 7.81 (d, J = 8.1 Hz, 1H), 7.67-7.63 (m, 5H), 7.55-7.50 (m, 2H), 7.46-7.40 (m, 6H), 5.02 (t, J = 3.7 Hz, 1H), 3.22-3.18 (m, 2H), 1.66-1.61 (m, 2H). ^{13}C

NMR (125 MHz, $CDCl_3$) δ 153.2, 143.0, 139.6, 135.1, 134.1, 133.7, 129.8, 129.1, 128.1, 126.9, 125.9, 116.5, 26.9, 13.7. HRMS (ES+) calcd for $C_{23}H_{22}SiN$: 340.1522, found: 340.1509.

130q: (94%, eluent: Hexanes/EtOAc = 4/1). ^1H NMR (500 MHz, $CDCl_3$) δ 8.81-8.79 (m, 2H), 8.01 (d, *J* = 8.4 Hz, 1H), 7.91 (s, 1H), 7.64-7.61 (m, 5H), 7.44-7.38 (m, 6H), 4.98 (t, *J* = 3.7 Hz, 1H), 3.05-3.01 (m, 2H), 1.68-1.63 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 146.7, 144.9, 144.1, 143.1, 141.7, 135.1, 133.6, 131.3, 129.7, 129.2, 128.1, 127.0, 30.6, 13.9. HRMS (ES+) calcd for $C_{22}H_{21}SiN_2$: 341.1474, found: 341.1476.

130aa: (93%, eluent: Hexanes/EtOAc = 10/1) ^1H NMR (500 MHz, $CDCl_3$) δ 7.59-7.58 (m, 4H), 7.43-7.37 (m, 6H), 7.06 (d, *J* = 3.5 Hz, 1H), 6.11 (d, *J* = 3.5 Hz, 1H), 4.92 (t, *J* = 3.5 Hz, 1H), 4.36 (q, *J* = 7.0 Hz, 2H), 2.87-2.83 (m, 2H), 1.60-1.55 (m, 2H), 1.39 (t, *J* = 7.0 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.2, 158.9, 143.2, 135.1, 133.3, 129.8, 128.1, 119.0, 107.2, 60.7, 23.3, 14.4, 10.5. HRMS (EI+) calcd for $C_{21}H_{22}SiO_3$: 350.1338, found: 350.1348.

1301bb: (70%, eluent: Hexanes/EtOAc = 200/1). ^1H NMR (500 MHz, $CDCl_3$) δ 7.62-7.60 (m, 4H), 7.46-7.37 (m, 6H), 7.12 (d, *J* = 5.1 Hz, 1H), 6.93-6.91 (m, 1H), 6.81-6.80 (m, 1H), 4.94 (t, *J* = 3.7 Hz, 1H), 3.02-2.99 (m, 2H), 1.66-1.62 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 147.8, 135.1, 133.7, 129.7, 128.1, 126.6, 123.4, 122.8, 24.8, 14.8. HRMS (EI+) calcd for $C_{18}H_{18}SiS$: 294.0899, found: 294.0905.

130cc: (91%, eluent: Hexanes/EtOAc = 25/1) ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.60-7.58 (m, 4H), 7.43-7.38 (m, 6H), 6.82 (d, *J* = 2.0 Hz, 1H), 6.54 (d, *J* = 1.8 Hz, 1H), 4.91 (t, *J* = 3.7 Hz, 1H), 4.29 (q, *J* = 7.0 Hz, 2H), 3.86 (s, 3H), 2.64-2.61 (m, 2H), 1.51-1.47 (m, 2H), 1.37 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 161.3, 135.1, 134.2, 129.5, 127.9, 127.1, 125.6, 122.1, 116.7, 59.6, 36.5, 21.3, 14.4, 13.8. HRMS (EI+) calcd for $C_{22}H_{25}SiNO_2$: 363.1655, found: 363.1662.

130dd: (94%, eluent: Hexanes/EtOAc = 200/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.89-7.87 (m, 1H), 7.71-7.69 (m, 1H), 7.66-7.64 (m, 4H), 7.48-7.42 (m, 6H), 7.38-7.35 (m, 2H), 7.13 (s, 1H), 5.02 (t, *J* = 3.3 Hz, 1H), 3.05-3.02 (m, 2H), 1.72-1.68 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 140.6, 138.6, 135.1, 133.9, 129.7, 128.5, 128.1, 124.1, 123.7, 122.9, 121.6, 120.7, 23.4, 11.9. HRMS (EI+) calcd for $C_{22}H_{20}SiS$: 344.1055, found: 344.1064.

130ee: (92%, eluent: Hexanes/EtOAc = 200/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.80 (d, *J* = 8.1 Hz, 1H), 7.65-7.62 (m, 5H), 7.47-7.38 (m, 7H), 7.30-7.29 (m, 1H), 7.22 (d, *J* = 8.1 Hz, 1H), 4.98-4.96 (m, 1H), 2.95-2.92 (m, 2H), 1.64-1.60 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 140.5, 139.9, 137.2, 135.1, 134.2, 129.6, 128.0, 126.4, 124.9, 123.6, 122.3, 122.2, 30.4, 14.7. HRMS (EI+) calcd for $C_{22}H_{20}SiS$: 344.1055, found: 344.1058.

130ff: (89%, eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.60-7.58 (m, 4H), 7.42-7.36 (m, 7H), 7.22 (d, *J* = 8.2 Hz, 1H), 7.06 (d, *J* = 8.8 Hz, 1H), 7.02 (d, *J* = 2.9 Hz, 1H), 6.40 (d, *J* = 2.9 Hz, 1H), 4.91 (t, *J* = 3.5 Hz, 1H), 2.89-2.85 (m, 2H), 1.60-1.56 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 135.4, 135.2, 134.4, 129.6, 128.9, 128.7,

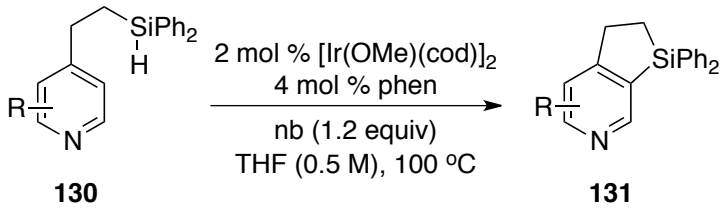
128.0, 122.1, 119.4, 109.0, 100.5, 32.9, 30.5, 15.2. HRMS (EI+) calcd for $C_{23}H_{23}SiN$: 341.1600, found: 341.1601.

130gg: (85%, eluent: Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.10 (d, *J* = 9.2 Hz, 1H), 8.09 (s, 1H), 7.87 (d, *J* = 8.4 Hz, 2H), 7.59-7.57 (m, 4H), 7.43-7.35 (m, 8H), 7.24 (d, *J* = 8.1 Hz, 1H), 4.92 (t, *J* = 3.7 Hz, 1H), 4.07 (s, 3H), 2.91-2.88 (m, 2H), 2.35 (s, 3H), 1.57-1.53 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 145.2, 141.0, 140.4, 138.9, 135.0, 134.6, 133.7, 130.0, 129.72, 129.67, 128.0, 127.4, 126.1, 119.4, 123.9, 30.1, 21.5, 14.4. HRMS (ES+) calcd for $C_{28}H_{27}SiN_2O_2S$: 483.1563, found: 483.1561.

130hh: (84%, eluent: Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.92 (s, 1H), 7.63-7.61 (m, 4H), 7.51 (s, 1H), 7.46-7.39 (m, 6H), 7.31 (d, *J* = 8.4 Hz, 1H), 7.26 (dd, *J* = 8.8, 1.5 Hz, 1H), 4.95 (t, *J* = 3.7 Hz, 1H), 4.07 (s, 3H), 2.94-2.90 (m, 2H), 1.62-1.59 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 138.7, 136.4, 135.1, 134.1, 132.1, 129.6, 128.0 127.3, 124.2, 118.8, 108.7, 35.5, 30.3, 14.8. HRMS (ES+) calcd for $C_{22}H_{23}SiN_2$: 343.1631, found: 343.1628.

4.4.2. Dehydrogenative Coupling of Heteroaromatic Diphenylsilanes 130

General procedure for dehydrogenative cyclization reaction of heteroaromatic diphenylsilanes 130:



130 **131**

Scheme 60.

In a 3 mL Wheaton microreactor vial, to a solution of $[Ir(cod)OMe]_2$ (0.01 mmol, 2 mol %, 6.6 mg,), 1,10-phenantroline (0.02 mmol, 4 mol %, 3.6 mg), nb (0.6 mmol, 1.2 equiv, 50.4 mg,), and THF (1.0 mL, 0.5M), heteroaromatic dihydrosilole **130** (0.5 mmol, 1.0 equiv) was added (Scheme 60). The microreactor was capped with a Teflon pressure cap, taken out of the glovebox, and placed into pre-heated (100 °C) aluminum block. The reaction mixture was stirred for 12 h at this temperature. After completion of the reaction (as judged by GC-MS analysis), microreactor containing cyclization product **131**, was cooled down and the solvent was evaporated. The product was purified using flash silica gel column chromatography.

131a: (83%, eluent hexanes/EtOAc = 7/1) ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.88 (s, 1H), 8.54 (d, *J* = 5.1 Hz, 1H), 7.60-7.59 (m, 4H), 7.46-7.38 (m, 6H), 7.26 (d, *J* = 5.1 Hz, 1H),

3.24-3.21 (m, 2H), 1.57-1.54 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.4, 154.2, 150.1, 135.0, 134.2, 132.2, 130.0, 128.2, 121.6, 31.7, 10.0. HRMS (EI) calcd. for $C_{20}H_{18}Si$ [M]+: 287.1130, found: 287.1135.

131b: (87%, eluent: Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.75 (s, 1H), 7.58-7.57 (m, 4H), 7.44-7.36 (m, 6H), 7.13 (s, 1H), 3.18-3.14 (m, 2H), 2.56 (s, 3H), 1.54-1.50 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.2, 159.0, 153.8, 135.0, 134.2, 129.8, 128.6, 128.1, 121.0, 31.5, 24.5, 10.3. HRMS (EI+) calcd. for $C_{20}H_{19}SiN$: 301.1287, found: 301.1281.

131c: (68% (5:1), eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.47 (s, 1H), 7.60-7.58 (m, 4H), 7.48-7.40 (m, 6H), 6.89 (s, 1H), 3.25-3.23 (m, 2H), 1.64-1.61 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.5 (d, $J_{C\text{-}F}$ = 7.4 Hz), 165.6 (d, $J_{C\text{-}F}$ = 238.6 Hz), 152.1 (d, $J_{C\text{-}F}$ = 14.8 Hz), 135.0, 133.5, 130.2, 129.9 (d, $J_{C\text{-}F}$ = 3.7 Hz), 128.2, 106.7 ($J_{C\text{-}F}$, J = 35.1 Hz), 31.6, 10.9. HRMS (EI+) calcd. for $C_{19}H_{16}SiNF$: 305.1036, found: 305.1038.

131d: (64%, eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.60 (s, 1H), 7.58-7.56 (m, 4H), 7.46-7.38 (m, 6H), 7.30 (s, 1H), 3.21-3.18 (m, 2H), 1.60-1.57 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.8, 153.8, 153.0, 135.0, 133.3, 131.4, 130.2, 128.3, 121.8, 31.4, 10.5. HRMS (EI+) calcd. for $C_{19}H_{16}SiNCl$: 321.0741, found: 321.0748.

131f: (79%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.39 (d, *J* = 4.8 Hz, 1H), 7.57-7.55 (m, 4H), 7.45-7.37 (m, 7H), 3.20-3.17 (m, 2H), 2.55 (s, 3H), 1.57-1.54 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 155.0, 146.7, 146.0, 145.9, 134.9, 133.7, 129.9, 128.1, 125.2, 29.6, 22.4, 9.0. HRMS (EI+) calcd. for $C_{20}H_{19}SiN$: 301.1287, found: 301.1291.

131g: (86%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.58-7.57 (m, 4H), 7.45-7.38 (m, 6H), 7.29 (s, 1H), 3.16-3.14 (m, 2H), 2.54 (s, 3H), 2.53 (s, 3H), 1.57-1.54 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 154.1, 154.0, 146.5, 143.5, 134.9, 133.9, 129.9, 128.0, 124.4, 29.1, 24.0, 22.3, 9.2. HRMS (EI+) calcd. for $C_{21}H_{21}SiN$: 315.1443, found: 315.1434.

131h: (75%, eluent: Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.56-7.54 (m, 4H), 7.48-7.45 (m, 2H), 7.42-7.39 (m, 5H), 3.15-3.13 (m, 2H), 2.52 (s, 3H), 1.62-1.59 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 155.9, 150.8, 147.9, 145.4, 135.0, 132.9, 130.3, 128.3, 125.0, 28.9, 22.1, 9.5. HRMS (EI+) calcd. for $C_{20}H_{18}SiNCl$: 335.0897, found: 335.0894.

131j: (36%, eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.86 (d, *J* = 7.3 Hz, 1H), 7.57-7.55 (m, 4H), 7.44-7.36 (m, 6H), 7.04 (d, *J* = 7.3 Hz, 1H), 3.34-3.31 (m, 2H), 2.57 (s, 3H), 1.58-1.55 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 172.8, 160.1, 141.8, 135.0, 134.6, 129.8, 128.1, 125.9, 121.0, 34.2, 24.7, 8.6. HRMS (EI+) calcd. for $C_{20}H_{20}SiN$: 302.1365, found: 302.1361.

131k: (73%, eluent: Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.56-7.51 (m, 5H), 7.46-7.37 (m, 6H), 3.30-3.27 (m, 2H), 2.54 (d, J = 2.9 Hz, 3H), 1.63-1.59 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.5 (d, $J_{C\text{-}F}$ = 5.2 Hz), 157.2 (d, $J_{C\text{-}F}$ = 253.6 Hz), 148.4 (d, $J_{C\text{-}F}$ = 17.7 Hz), 134.9, 133.9, 130.1, 129.0, 128.2, 126.5 (d, $J_{C\text{-}F}$ = 17.7 Hz), 33.3, 18.3, 9.4. HRMS (EI+) calcd. for $C_{20}H_{18}SiNF$: 319.1193, found: 319.1186.

131l: (72%, eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.84 (d, J = 8.1 Hz, 1H), 7.58-7.57 (m, 4H), 7.44-7.37 (m, 6H), 6.65 (d, J = 8.1 Hz, 1H), 3.99 (s, 3H), 3.28-3.25 (m, 2H), 1.58-1.55 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 172.3, 165.9, 143.4, 135.1, 134.9, 129.7, 128.0, 120.3, 108.9, 53.3, 34.0, 8.6. HRMS (ES+) calcd. for $C_{20}H_{20}SiNO$: 318.1314, found: 318.1313.

131m: (77%, eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.14 (d, J = 7.7 Hz, 1H), 7.57-7.53 (m, 5H), 7.48-7.39 (m, 6H), 3.46-3.43 (m, 2H), 1.68-1.65 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 173.7, 149.4 (q, $J_{C\text{-}F}$ = 33.3 Hz), 143.1, 135.0, 134.3, 133.1, 130.3, 128.3, 121.7 (q, $J_{C\text{-}F}$ = 274.7 Hz), 117.7, 34.0, 8.7. HRMS (EI+) calcd. for $C_{20}H_{16}SiNF_3$: 355.1004, found: 355.1002.

131n: (74%, eluent: Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.12 (s, 1H), 8.16 (d, J = 8.2 Hz, 1H), 8.01 (t, J = 8.2 Hz, 1H), 7.76 (t, J = 8.2 Hz, 1H), 7.63-7.58 (m, 5H), 7.45-7.37 (m, 6H), 3.69-3.65 (m, 2H), 1.70-1.67 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.3, 153.4, 148.4, 135.1, 134.3, 130.0, 129.9, 129.4, 128.2, 126.7, 126.5,

124.0, 29.4, 9.2. HRMS (EI+) calcd. for $C_{23}H_{19}SiN$: 337.1287, found: 337.1280.

131o: (78%, eluent: Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.39 (s, 1H), 8.00 (d, *J* = 8.1 Hz, 1H), 7.68 (s, 1H), 7.65-7.63 (m, 4H), 7.42-7.34 (m, 6H), 7.27-7.26 (m, 1H), 3.39-3.36 (m, 2H), 2.73 (s, 1H), 1.67-1.64 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.2, 149.9, 146.7, 140.1, 135.9, 1351, 134.43, 134.40, 129.8, 128.0, 127.6, 122.8, 122.4, 31.4, 25.3, 11.4. HRMS (EI+) calcd. for $C_{24}H_{21}SiN$: 351.1443, found: 351.1449.

131p: (74%, eluent: Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.30 (s, 1H), 8.64 (d, *J* = 5.9 Hz, 1H), 7.88 (s, 2H), 7.79 (d, *J* = 5.9 Hz, 1H), 7.63-7.61 (m, 4H), 7.46-7.38 (m, 6H), 3.66-3.62 (m, 2H), 1.72-1.69 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 152.9, 150.8, 143.5, 135.0, 134.5, 133.2, 130.3, 129.8, 129.4, 128.1, 128.0, 125.7, 117.0, 29.0, 9.1. HRMS (ES+) calcd. For $C_{23}H_{20}SiN$: 338.1365, found: 338.1361.

131q: (56%, eluent: Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.82 (d, *J* = 13.6 Hz, 2H), 8.48 (s, H), 8.04 (s, 1H), 7.67-7.65 (m, 4H), 7.46-7.38 (m, 6H), 3.50-3.47 (m, 2H), 1.73-1.70 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 154.9, 145.3, 144.2, 143.9, 141.8, 141.7, 135.2, 135.1, 133.7, 130.0, 128.1, 124.7, 31.7, 11.5. HRMS (ES+) calcd. for $C_{22}H_{19}SiN_2$: 339.1318, found: 339.1313.

131aa: (88%, eluent: Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.59-7.57 (m, 4H), 7.46-7.39 (m, 6H), 7.34 (s, 1H), 4.40 (q, *J* = 7.0 Hz, 2H), 3.09-3.06 (m, 2H),

1.83-1.80 (m, 2H), 1.41-1.39 (t, J = 7.0 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 176.3, 158.9, 148.6, 134.7, 134.6, 129.9, 128.0, 120.7, 117.0, 60.8, 23.8, 14.3, 12.0. HRMS (ES+) calcd. for $C_{21}H_{21}SiO_3$: 349.1260, found: 349.1262.

131bb: (67%, eluent: Hexanes/EtOAc = 200/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.63-7.61 (m, 4H), 7.46-7.38 (m, 6H), 7.20 (d, J = 4.8 Hz, 1H), 3.31-3.28 (m, 2H), 1.90-1.87 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 161.8, 137.6, 135.6, 134.9, 129.6, 128.3, 127.9, 27.0, 14.7. HRMS (EI+) calcd. for $C_{18}H_{16}SiS$: 292.0742, found: 292.0748.

131cc: (84%, eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.63-7.61 (m, 4H), 7.48-7.41 (m, 6H), 6.87 (s, 1H), 4.31 (q, J = 7.3 Hz, 2H), 3.90 (s, 3H), 2.93-2.91 (m, 2H), 1.78-1.75 (m, 2H), 1.38 (t, J = 7.0 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 161.5, 143.1, 141.6, 135.1, 134.2, 130.1, 129.9, 128.1, 113.4, 59.8, 37.9, 22.4, 14.4. HRMS (EI+) calcd. for $C_{22}H_{23}SiNO_2$: 361.1498, found: 361.1505.

131dd: (63%, eluent: Hexanes/EtOAc = 200/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.91 (d, J = 7.3 Hz, 1H), 7.79 (d, J = 7.0 Hz, 1H), 7.67-7.65 (m, 4H), 7.46-7.38 (m, 8H), 3.33-3.30 (m, 2H), 1.93-1.91 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 156.8, 149.2, 137.2, 135.0, 134.7, 133.9, 129.9, 124.8, 123.9, 123.2, 122.3, 25.7, 13.1. HRMS (EI+) calcd. for $C_{22}H_{18}SiS$: 342.0899, found: 342.0890.

131ee: (61% (10:1), eluent: Hexanes/EtOAc = 200/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.18 (s, 1H), 7.79 (s, 1H), 7.64-7.62 (m, 4H), 7.48 (d, J = 5.1 Hz, 1H), 7.44-7.37 (m, 6H),

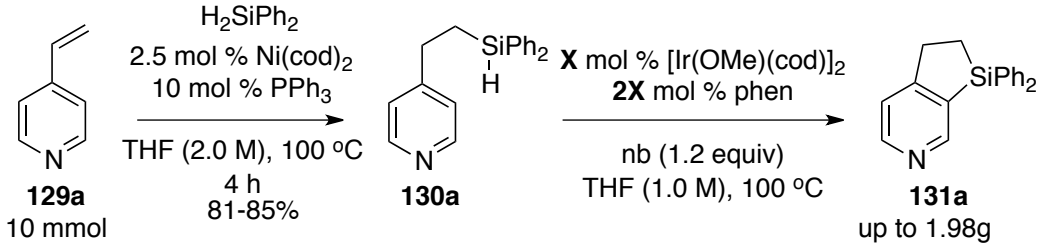
7.31 (d, *J* = 5.5 Hz, 1H), 3.37-3.34 (m, 2H), 1.65-1.62 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 149.8, 141.5, 138.3, 135.2, 133.2, 129.7, 128.0, 127.5, 127.3, 123.5, 120.2, 31.4, 11.7. HRMS (EI+) calcd. for $C_{22}H_{18}SiS$: 342.0899, found: 342.0906.

131ff: (94% (10:1), eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.68-7.66 (m, 4H), 7.61 (d, *J* = 9.9 Hz, 2H), 7.44-7.38 (m, 6H), 7.08 (d, *J* = 3.1 Hz, 1H), 6.46 (d, *J* = 3.1 Hz, 1H), 3.79 (s, 3H), 3.37-3.34 (m, 2H), 1.63-1.60 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 144.4, 136.6, 135.9, 135.3, 131.0, 129.9, 129.4, 129.0, 127.8, 117.0, 113.6, 100.3, 32.9, 31.2, 12.1. HRMS (EI+) calcd. for $C_{23}H_{21}SiN$: 339.1443, found: 339.1448.

131gg: (52% (7:1), eluent: Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.46 (s, 1H), 8.14 (s, 1H), 7.82 (d, *J* = 8.1 Hz, 2H), 7.63-7.60 (m, 4H), 7.58 (s, 1H), 7.47-7.39 (m, 6H), 7.20 (d, *J* = 8.1 Hz, 2H), 3.31-3.28 (m, 2H), 2.36 (s, 3H), 1.66-1.63 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 149.2, 145.2, 141.4, 140.2, 135.2, 134.6, 134.0, 130.0, 129.8, 129.7, 128.1, 128.0, 127.5, 117.5, 117.3, 31.2, 21.6, 11.8. HRMS (ES+) calcd. for $C_{28}H_{25}SiN_2O_2S$: 481.1406, found: 481.1414.

131hh: (59%, eluent: Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.94 (s, 1H), 7.68 (s, 1H), 7.65-7.63 (m, 5H), 7.45-7.38 (m, 6H), 4.08 (s, 3H), 3.35-3.31 (m, 2H), 1.67-1.63 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 145.0, 139.8, 136.1, 135.2, 134.7, 132.0, 129.8, 128.0, 126.2, 116.5, 113.5, 35.6, 31.0, 12.2. HRMS (ES+) calcd. for $C_{22}H_{21}SiN_2$: 341.1474, found: 341.1479.

Gram-scale synthesis of dihydropyridinosilole 131a from 4-vinylpyridine 129a



X	time, d	yield
0.5	2	82%
0.25	6	74%

Scheme 61.

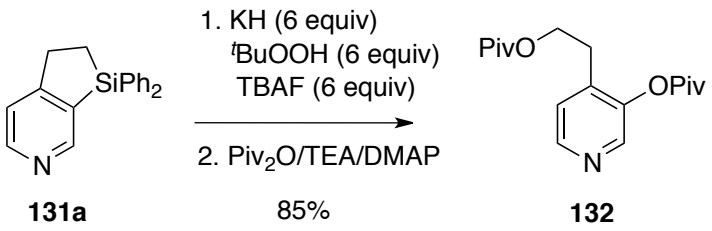
Hydrosilylation. A 10 mL Wheaton microreactor vial was charged with $Ni(cod)_2$ (68.8 mg, 2.5 mol %), PPh_3 (262.0 mg, 10 mol %), and THF (5.0 mL, 2.0 M) and stirred for 5 min. To the resulting solution, Ph_2SiH_2 (10.2 mmol, 1.02 equiv, 1.89 mL) was added, followed by 4-vinylpyridine (**129a**, 10 mmol, 1.05 g, 1.08 mL). The microreactor was capped with a Teflon pressure cap, taken out of the glovebox, and placed into pre-heated (100 °C) aluminum block. The reaction mixture was stirred for 4 h at this temperature (Scheme 61). After completion of the reaction (as judged by GC-MS analysis), microreactor, containing hydrosilylation product **130a**, was cooled down and the solvent was evaporated. The product was purified using flash silica gel column chromatography (2.33-2.45g, 81-85%, eluent Hexanes/EtOAc = 7/1).

Dehydrogenative cyclization. In a 10 mL Wheaton microreactor, to a solution of $[Ir(cod)OMe]_2$ (0.25-0.5 mol %), 1,10-phenantroline (0.5-1.0 mol %), 2-norbornene (1.2 equiv), and THF (1.0 M), was added pyridinosilane **130a**. The microreactor, capped with

a Teflon pressure cap was placed into pre-heated (100 °C) aluminum block. The reaction mixture was stirred at this temperature for 2-6 days (Scheme 61). After completion of the reaction (as judged by GC-MS analysis), microreactor, containing dihydropyridinosilole **131a**, was cooled down, and the solvent was evaporated. The product was purified using flash silica gel column chromatography (1.71-1.98 g, 74-82%, eluent Hexanes/EtOAc = 7/1).

4.5. Further Transformations. Two-Fold Modification of Dihydropyridinosilole 131

4.5.1. Oxidation of Dihydropyridinosilole



131a 85% **132**

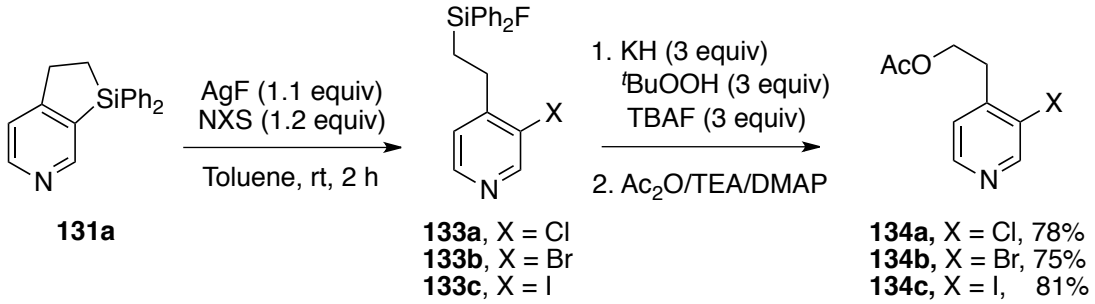
Scheme 62.

To an ice-cooled stirred suspension of KH (2.4 mmol, 6 equiv, 96.0 mg) in THF (4 mL), *tert*-butyl hydroperoxide (2.4 mmol, 6 equiv, 0.44 mL 5.5 M in decane) was added. After 10 min, a solution of **131a** (0.4 mmol, 114.8 mg) in THF (0.5 mL) was added to the obtained slurry. To the resulted clear solution, TBAF (2.4 mmol, 6 equiv,

2.4 mL 1.0 M solution in THF) was added and the reaction mixture was allowed warm up to room temperature and stirred for 3 h (Scheme 62). After that, the reaction mixture was cooled down (ice bath) and 1.0 g of $Na_2S_2O_3 \bullet 5H_2O$ in water (5.0 mL) was added. The mixture was stirred for 30 min and 50 mL of saturated NH_4Cl was added. The resulted solution was extracted with diethyl ether (3 x 10 mL), and the combined organic layers were dried (Na_2SO_4) and concentrated. To the crude, DCM (3mL), Piv_2O (2 mmol, 5 equiv, 189 μL) Et_3N (2 mmol, 5 equiv, 278 μL), and DMAP (0.02 mmol, 0.1 equiv, 4.9 mg) were added and reaction mixture was stirred at room temperature for 2h (Scheme 62). Then, a saturated NH_4Cl solution was added and the organic layer was separated. The aqueous solution was extracted with diethyl ether (3 x 10 mL), and the combined organic layers were dried (Na_2SO_4) and concentrated. The product was purified using flash silica gel column chromatography.

132: (85%, eluent Hexanes/EtOAc = 3/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.40 (d, *J* = 5.0 Hz, 1H), 8.30 (s, 1H), 7.22 (d, *J* = 5.0 Hz, 1H), 4.27-4.25 (t, *J* = 6.6 Hz, 2H), 2.86-2.83 (t, *J* = 6.6 Hz, 2H), 1.39 (s, 9H), 1.13 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$): δ ppm 178.1, 176.4, 146.9, 146.5, 144.1, 139.1, 125.0, 62.2, 39.3, 38.7, 28.8, 27.1, 27.0. HRMS (ES+) calcd. for $C_{17}H_{25}NO_4$: 307.1784, found: 307.1791.

4.5.2. Two-Fold Modification of Dihydropyridinosilole (Halogenation/ Oxygenation)



Scheme 63.

Halogenation. To a 3mL Wheaton vial containing NXS (X = Cl, Br, I) (1.2 equiv), AgF (1.1 equiv), and dihydropyridinosilole (**131a**, 0.4 mmol, 114.8 mg), was added toluene (2 mL, 0.2 M). The reaction mixture was vigorously stirred in dark for 2 h (Scheme 63). After completion of the reaction (as judged by GC-MS analysis), the reaction mixture was filtered through small silica gel column (140 mm x 15 mm) using Hexanes/EtOAc = 4/1 as eluent. Evaporation of the solvent gave **133a**/**c** as colorless oil.

Oxidation. To an ice-cooled (0 °C) stirred suspension of KH (1.2 mmol, 3 equiv, 48 mg) in THF (2 mL), *tert*-butyl hydroperoxide (1.2 mmol, 3 equiv, 0.22 mL 5.5 M in decane over MS) was added. After 10 min, a solution of **133a/c** in THF (0.5 mL) was added to the obtained slurry mixture. To the resulted clear yellowish solution, TBAF (1.2 mmol, 3 equiv, 1.2 mL 1.0 M solution in THF) was added and the reaction mixture was allowed warmed up to room temperature and stirred for 3 h (Scheme 63). Then, the reaction mixture was cooled down (ice bath) and 1.0 g of $Na_2S_2O_3 \cdot 5H_2O$ in water (5.0

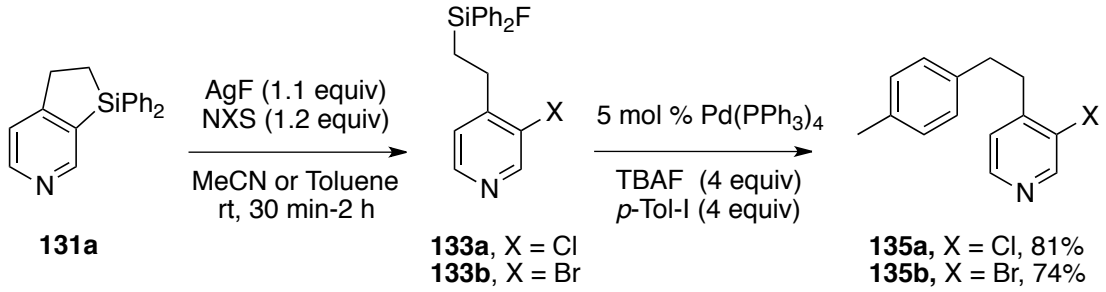
mL) was added. The mixture was stirred for 30 min and 50 mL of saturated NH_4Cl was added. The resulted solution was extracted with diethyl ether (3 x 10 mL), and the combined organic layers were dried (Na_2SO_4) and concentrated. To the crude, DCM (3mL), Ac_2O (2 mmol, 5 equiv, 189 μL) Et_3N (2 mmol, 5 equiv, 278 μL), and DMAP (0.02 mmol, 0.1 equiv, 4.9 mg) were added and the reaction mixture was stirred at room temperature for 2h. Next, a saturated NH_4Cl was added and organic layer was separated. The aqueous solution was extracted with diethyl ether (3 x 10 mL), and the combined organic layers were dried (Na_2SO_4) and concentrated. The product was purified using flash silica gel column chromatography.

134a: (78%, eluent Hexanes/EtOAc = 3/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.56 (s, 1H), 8.42 (d, *J* = 4.8 Hz, 1H), 7.19 (d, *J* = 4.8 Hz, 1H), 4.35-4.32 (t, *J* = 6.6 Hz, 2H), 3.09-3.06 (t, *J* = 6.6 Hz, 2H), 2.02 (s, 3H).^{13}C NMR (125 MHz, $CDCl_3$): δ ppm 170.7, 149.4, 147.7, 144.5, 132.3, 125.2, 62.0, 32.0, 20.8. HRMS (EI+) calcd. for $C_9H_{10}ClNO_2$: 199.0400, found: 199.0395.

134b: (75%, eluent Hexanes/EtOAc = 3/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.70 (s, 1H), 8.45 (d, *J* = 4.9 Hz, 1H), 7.19 (dd, *J* = 4.9, 0.4 Hz, 1H), 4.36-4.32 (t, *J* = 6.7 Hz, 2H), 3.10-3.07 (t, *J* = 6.7 Hz, 2H), 2.04 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): δ ppm 170.7, 152.1, 148.2, 146.2, 125.5, 123.2, 62.1, 34.5, 20.8. HRMS (EI+) calcd. for $C_9H_{10}BrNO_2$: 242.9895, found: 242.9903.

134c: (81%, eluent Hexanes/EtOAc = 3/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.90 (s, 1H), 8.43 (d, *J* = 4.8 Hz, 1H), 7.19 (d, *J* = 4.9 Hz, 1H), 4.32-4.29 (t, *J* = 6.6 Hz, 2H), 3.06-3.03 (t, *J* = 6.8 Hz, 2H), 2.04 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): δ ppm 170.7, 157.6, 149.5, 148.9, 125.2, 100.2, 62.2, 38.9, 20.8. HRMS (EI+) calcd. for $C_9H_{10}INO_2$: 290.9757, found: 290.9762.

4.5.3. Two-Fold Modification of Dihydropyridinosilole (Halogenation/Arylation)



Scheme 64.

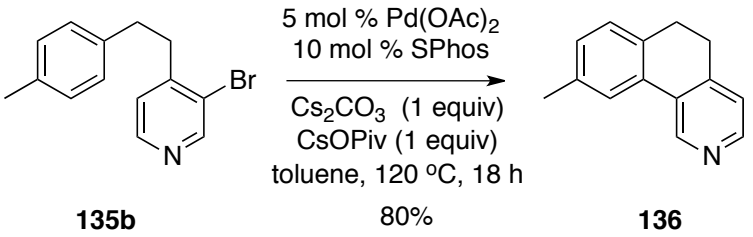
Halogenation. To a 3 mL Wheaton vial containing NXS (X = Cl, Br, I) (1.2 equiv), AgF (0.44 mmol, 1.1 equiv, 55.9 mg), and dihydropyridinosilole (**131a**, 0.4 mmol, 114.8 mg), was added toluene (2 mL, 0.2 M). The reaction mixture was vigorously stirred in dark for 2 h (Scheme 64). After completion of the reaction (as judged by GC-MS analysis), the reaction mixture was filtered through small silica gel column (140 mm x 15 mm) with Hexanes/EtOAc = 4/1 as eluent. Evaporation of the solvent gave **133a**/**b** as colorless oil.

Arylation. To a solution of $Pd(PPh_3)_4$ (0.02 mmol, 5 mol %, 23.1 mg) in THF (0.5 mL), *p*-tolyliodide (1.6 mmol, 4 equiv, 349 mg) was added. After 10 min, a solution of **133a**/**b** in 0.5 mL of THF, followed by TBAF (1.6 mmol, 4 equiv, 1.6 mL, 1.0 M solution in THF) was added. The reaction mixture was stirred at 90 °C for 24 h (Scheme 64), and then cooled down. The solvent was evaporated and the product was purified using flash silica gel column chromatography.

135a: (79%, eluent Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.56 (s, 1H), 8.35 (d, *J* = 4.8 Hz, 1H), 7.13-7.06 (m, 5H), 3.04-3.01 (m, 2H), 2.92-2.89 (m, 2H), 2.34 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): δ ppm 149.3, 127.9, 147.6, 137.3, 135.8, 132.0, 129.1, 128.2, 124.9, 34.9, 34.3, 21.0. HRMS (EI+) calcd. for $C_{14}H_{15}ClN$: 232.0893, found: 232.0891.

135b: (74%, eluent Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.68 (s, 1H), 8.38 (d, *J* = 5.0 Hz, 1H), 7.12-7.06 (m, 5H), 3.02-2.99 (m, 2H), 2.90-2.87 (m, 2H), 2.34 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): δ ppm 151.9, 149.6, 148.2, 137.3, 135.8, 129.2, 128.2, 125.2, 123.0, 37.5, 34.5, 21.0. HRMS (EI+) calcd. for $C_{14}H_{14}BrN$: 275.0309, found: 275.0304.

Intramolecular direct arylation of 3-bromo-4-(4-methylphenethyl)pyridine



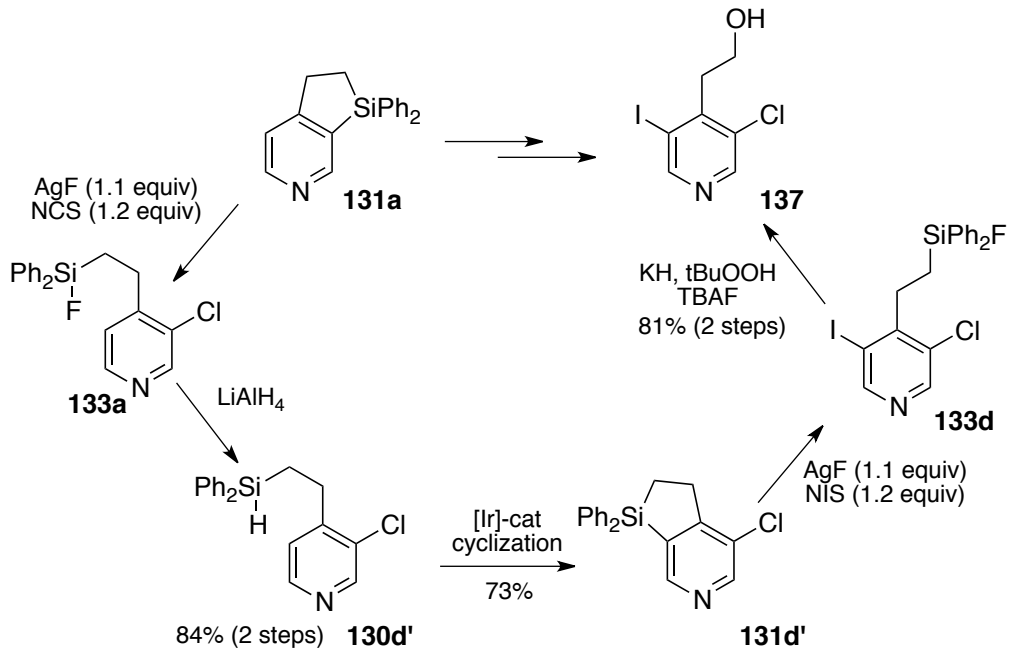
135b **136**

Scheme 65.

A suspension of $Pd(OAc)_2$ (0.01 mmol, 5 mol %, 2.2 mg), 2-dicyclohexyl-phosphino-2′,6′-dimethoxybiphenyl (SPhos, 0.02 mmol, 10 mol %, 8.2 mg), Cs_2CO_3 (0.2 mmol, 1 equiv, 32.6 mg), CsOPiv (0.2 mmol, 1 equiv, 23.4 mg), **135b** (0.2 mmol, 55 mg), and toluene (1.0 mL) was heated at 120 °C for 18 h (Scheme 65). After completion of the reaction (as judged by GC-MS analysis), the reaction mixture was cooled down, filtered through Celite and the product was purified using flash silica gel column chromatography.

136: (80%, eluent Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.96 (s, 1H), 8.43 (d, J = 4.8 Hz, 1H), 7.63 (s, 1H), 7.15-7.13 (m, 2H), 7.10 (d, J = 7.7 Hz, 1H), 2.84 (s, 4H), 2.42 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): δ ppm 148.3, 145.7, 144.9, 136.8, 134.2, 131.5, 130.5, 129.0, 128.2, 124.0, 122.9, 28.4, 27.6, 21.3. HRMS (EI+) calcd. for $C_{14}H_{13}N$: 195.1048, found: 195.1041.

4.5.4. Synthesis of Highly Functionalized Pyridine 137 through Two-Fold Modification/C–H Activation Sequence of Dihydropyridinosilole 131a



Scheme 66.

Halogenation (131a–>133a). To a 5 mL Wheaton vial containing NCS (1.2 mmol, 1.2 equiv, 160.2 mg), AgF (1.1 mmol, 1.1 equiv, 139.7 mg), and dihydropyridinosilole (**131a**, 1.0 mmol, 287.4 mg), was added toluene (5.0 mL, 0.2 M). The reaction mixture was vigorously stirred in dark for 2 h (Scheme 66). After completion of the reaction (as judged by GC-MS analysis), the reaction mixture was filtered through small silica gel column (150 mm x 18 mm) using Hexanes/EtOAc = 4/1 as an eluent. Evaporation of the solvent gave **133a** (318.2 mg, 0.93 mmol, 93%) as colorless oil.

Reduction (133a–>130d'). To an ice-cooled (0 °C) stirred suspension of $LiAlH_4$ (0.65 mmol, 0.6 equiv, 24.7 mg) in Et_2O (5.0 mL), a solution of **133a** (0.93 mmol, 317.2 mg) in Et_2O (1.0 mL) was added. The reaction mixture was allowed to warm up and stirred at room temperature for 2 h (Scheme 66). After completion of the reaction (as judged by GC-MS analysis), the reaction mixture was cooled down (ice bath) and EtOH (0.1 mL) was added. The resulting mixture was filtered through Celite and concentrated. The product was purified using flash silica gel column chromatography.

130d': (84% (2 steps), eluent Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.50 (s, 1H), 8.36 (d, *J* = 5.0 Hz, 1H), 7.62-7.60 (m, 4H), 7.46-7.38(m, 6H), 7.14 (d, *J* = 5.0 Hz, 1H), 4.97 (t, *J* = 3.7 Hz, 1H), 2.87-2.84 (m, 2H), 1.52-1.48 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 150.4, 149.2, 147.8, 135.1, 133.3, 131.6, 129.9, 128.1, 124.2, 27.9, 11.7. HRMS (EI+) calcd. for $C_{19}H_{18}ClNSi$: 323.0897, found: 323.0901.

Dehydrogenative cyclization (130d'–>131d'). In a 5 mL Wheaton microreactor, to a solution of $[Ir(cod)OMe]_2$ (4 mol %), 1,10-phenantroline (8 mol %), 2-norbornene (1.2 equiv), and THF (1.0 mL), was added 3-chloropyridinosilane **130d'** (161.8 mg, 0.5 mmol) under inert atmosphere. The microreactor capped with a Teflon pressure cap was placed into pre-heated (100 °C) aluminum block. The reaction mixture was stirred at this temperature for 3 h (Scheme 66). After completion of the reaction (as judged by GC-MS analysis), microreactor, containing dihydropyridinosilole **131d'**, was cooled down, and the solvent was evaporated. The product was purified using flash silica gel column chromatography.

131d': (73%, eluent Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.72 (s, 1H), 8.54 (s, 1H), 7.59-7.58 (m, 4H), 7.48-7.39(m, 6H), 3.31-3.28 (m, 2H), 1.61-1.58 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.2, 151.7, 149.2, 134.9, 134.5, 133.3, 130.8, 130.2, 128.2, 30.4, 8.8. HRMS (ES+) calcd. for $C_{19}H_{17}ClNSi$: 322.0819, found: 322.0819.

Halogenation (131d'–>133d). To a 3 mL Wheaton vial containing NIS (0.24 mmol, 1.2 equiv, 54.0 mg), AgF (0.22 mmol, 1.1 equiv, 27.9 mg), and 3-chlorodihydropyridinosilole (**131d'**, 0.2 mmol, 64.3mg), was added CH_3CN (1.0 mL, 0.2 M). The reaction mixture was vigorously stirred in dark for 1 h (Scheme 66). After completion of the reaction (as judged by GC-MS analysis), the reaction mixture was diluted with acetone, filtered through Celite and concentrated. The product **133d** was purified using flash silica gel column chromatography (80.3 mg, 87%, eluent Hexanes/EtOAc = 7/1).

Oxidation (133d–>137). To an ice-cooled (0°C) stirred suspension of KH (0.6 mmol, 3 equiv, 24.0 mg) in THF (1 mL), *tert*-butyl hydroperoxide (0.6 mmol, 3 equiv, 0.11 mL 5.5 M in decane) was added. After 10 min, a solution of **133d** in THF (0.5 mL) was added to the obtained slurry. To the resulted clear yellowish solution, TBAF (1.2 mmol, 3 equiv, 1.2 mL 1.0 M solution in THF) was added and the reaction mixture was allowed to warmed up to room temperature and stirred for 3 h (Scheme 66). Then, the reaction mixture was cooled down (ice bath) and 1.0 g of $Na_2S_2O_3•5H_2O$ in water (5.0 mL) was added. The mixture was stirred for 30 min and 50 mL of saturated NH_4Cl was added. The resulted solution was extracted with diethyl ether (3 x 10 mL),

and the combined organic layers were dried (Na_2SO_4) and concentrated. The product was purified using flash silica gel column chromatography.

137: (81% (2 steps), eluent Hexanes/EtOAc = 2/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.76 (s, 1H), 8.43 (s, 1H), 3.91-3.87 (m, 2H), 3.31-3.26 (m, 2H), 1.94 (broad, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 155.7, 148.7, 147.6, 132.4, 100.7, 60.2, 41.1. HRMS (EI+) calcd. for C_7H_7ClINO $[M]^+$: 282.9261, found: 282.9256.

PART TWO

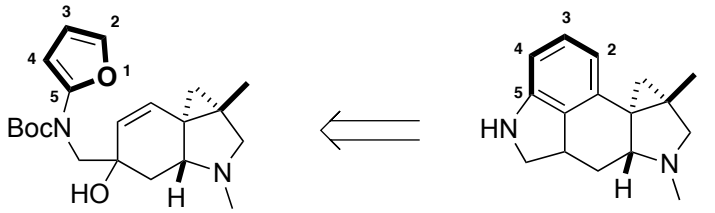
BRØNSTED ACID-CATALYZED ONE-POT SYNTHESIS OF INDOLES FROM *O*-AMINOBENZYLALCOHOLS AND FURANS

5. INTRODUCTION

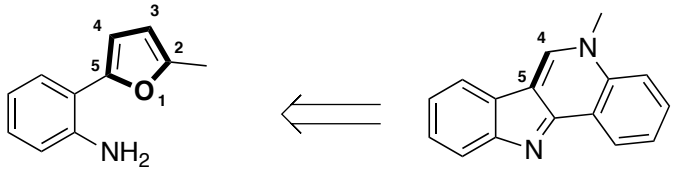
5.1. Recyclization Reaction of Furans

Low resonance energy of the furan ring[90] allows for its facile recyclization reactions into different carbo- and heterocycles. These reactions were successfully used in the synthesis of some biologically important targets. For example, furan/alkyne cycloisomerization reaction was recently applied for the construction of the phenyl ring of (±)-cycloclavine **138**[91] (Figure 6), a member of the ergot alkaloids family. These alkaloids are clinically used for the treatment of vasoconstriction and migraines.[92] Butin and co-workers has showed that the synthesis of antimalarial alkaloid isocryptolepine **139** can also be accomplished via recyclization reaction.[93] The pyrimidine ring of swainsonine **140** can be synthesized via *aza*-Achmatowicz furan recyclization reaction.[94] It was shown that this naturally occurring indolizidine alkaloid **140**, isolated from *Rhizoctonia leguminicola,* possesses a considerable antimetastatic,[95] anticancer,[96] and immunomodu-lating activity.[97] It is worth mentioning that all five atoms of the furan core remained in the target molecule. The other example is the synthesis of basiliolide B **141**,[98] a selective, potent, and irreversible inhibitor of sacroendoplasmic reticulum Ca^{2+}-

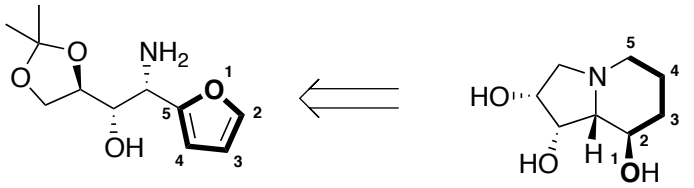
ATPase (SERCA),[99] which is also able to induce apoptosis through endoplasmic reticulum stress.[100]



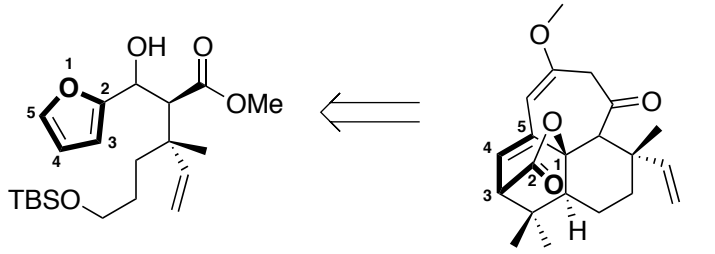
Cycloclavine, **138**



Isocryptolepine, **139**



Swainsonine, **140**



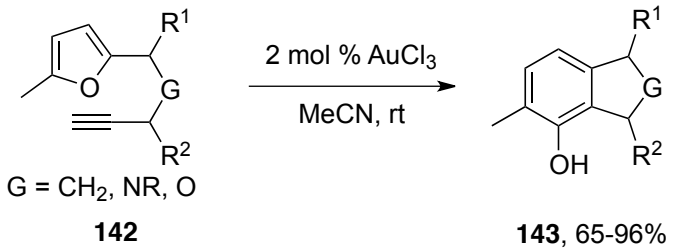
Basiliolide B, **141**

Figure 6. Examples of biologically important targets obtained via recyclization reaction of furan

Given unique low resonance energy of the furan, a considerable attention has been given to the development of different transition-metal-catalyzed and Brønsted acid-mediated processes for its recyclization into valuable carbo- and heterocycles. Accordingly, in the following chapter, a summary of methods for the recyclization reaction of furan is given. The processes, which utilize well-known [4+2] cycloaddition reaction of furan with dienophiles, were omitted from the consideration.

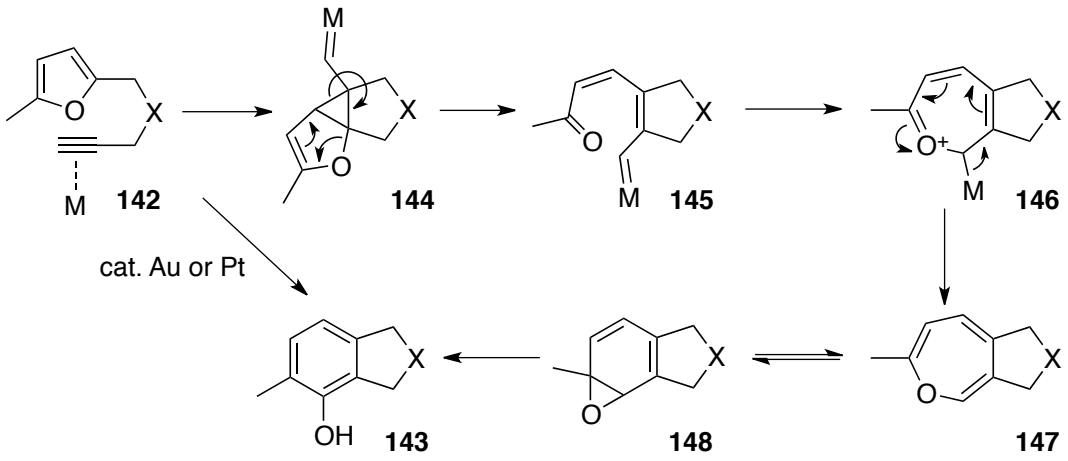
5.2. Recyclization Reaction of Furans into Carbocycles

In 2000, Hashmi reported the first gold-catalyzed synthesis of phenols **143** from furylalkynes **142** based on the intramolecular furane/alkyne cycloisomerization reaction (Scheme 67).[101] Using this approach, different phenol fused carbo- and heterocyclic systems have been obtained in good to excellent yields. Later, it was shown that other catalytic systems including platinum(II),[102] cationic Au (I)[103] and heterogeneous gold[104] can be also efficiently used in this transformation.



Scheme 67.

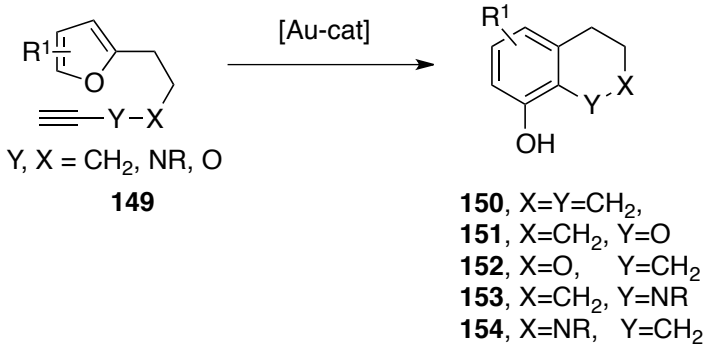
It was initially proposed that this cycloisomerization reaction proceeds via [4+2] cycloaddition reaction of the furan at the alkyne moiety followed by the furan ring opening and rearomatization. However, the subsequent investigation of the reaction mechanism accomplished by Hashmi[105] and Echavarren[102a] groups established the correct mechanism for this transformation (Scheme 68). First, nucleophilic attack of the furan **142** at the alkynyl metal complex produces cyclopropyl metal carbene **144**, which then undergoes cyclopropane and furane ring opening with the formation of conjugated keto metal carbene specie **145**. The following nucleophilic attack of oxygen at the carbene and subsequent demetalation from oxonium **146** produces oxepin **147**. Formation of the arene oxide **148** from oxepin **147** and epoxide ring opening leads to the phenol **143**.



Scheme 68.

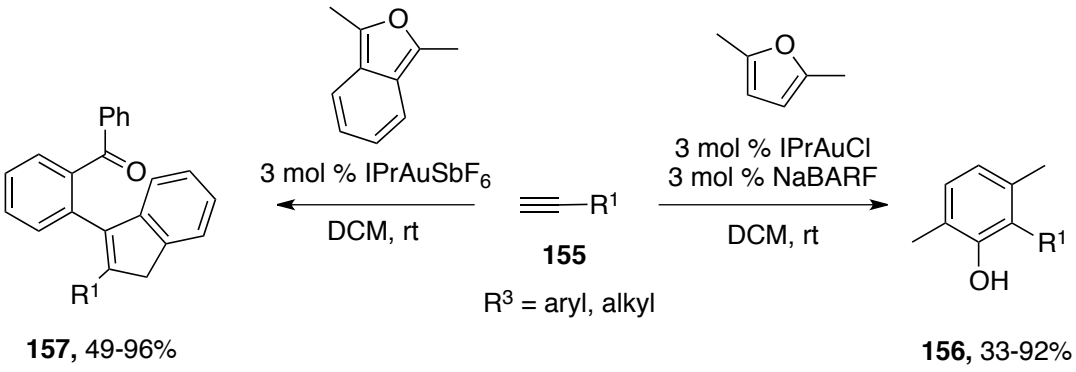
Later, Hashmi group extended this furan/alkyne cycloisomerization reaction to the synthesis of tetrahydronaphthalines **150**,[106] chromans **151**[107] isochromans **152**,[108] tetra-

hydroquinolines **153**,[107] –isoquinolines **154**,[109] and other systems[107,110] starting from alkynyl furans **149** (Scheme 69).



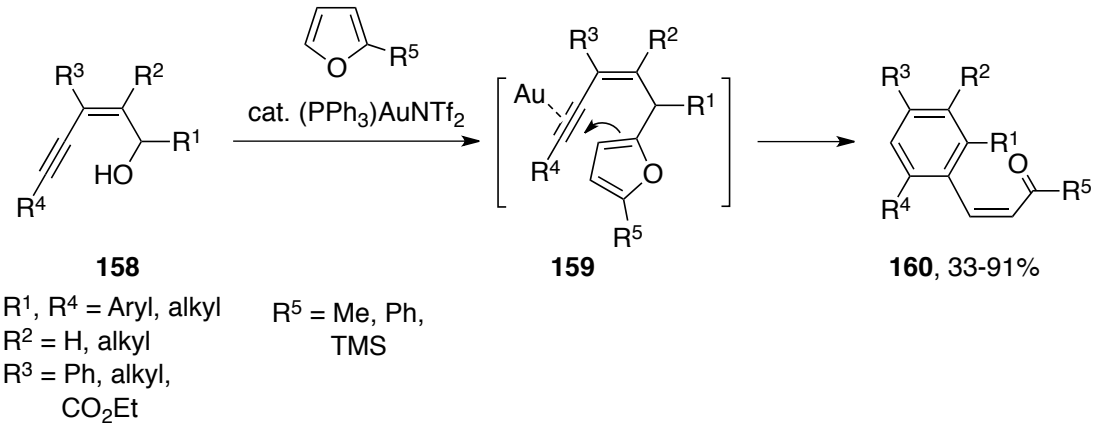
Scheme 69.

Very recently, Echavarren reported an efficient gold(I)-catalyzed intermolecular reaction of furans and isobenzofurans with alkynes **155** (Scheme 70).[111] Using this procedure, various phenols **156** and indenes **157** were obtained in moderate to high yields.



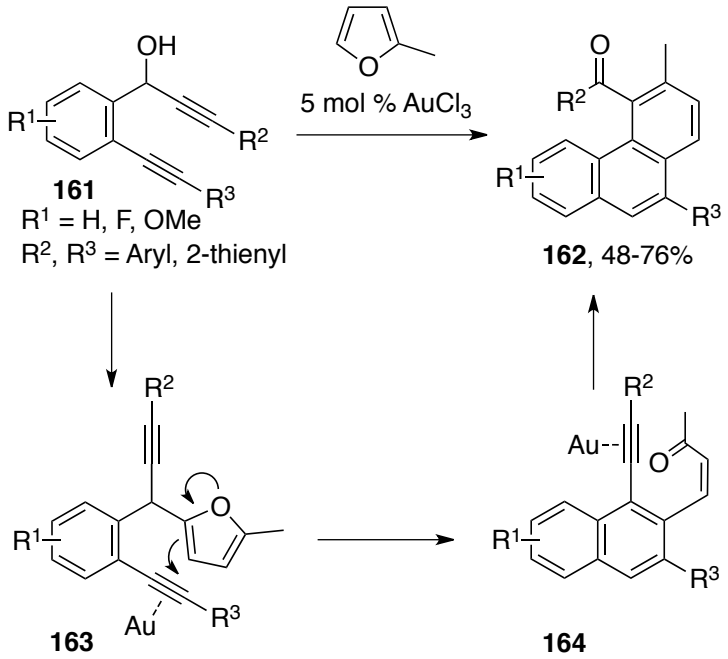
Scheme 70.

In 2009, Liu reported the gold(I)-catalyzed synthesis of arylated (*Z*)-enones or -enals **160** from enynoles **158** and furans through initial Friedel–Crafts reaction, followed by a furan/alkyne cyclization of the formed furyl intermediates **159** to give the product (Scheme 71).[112] Later, an analogues transformation has also been revealed for the synthesis of naphthalenes.[113]



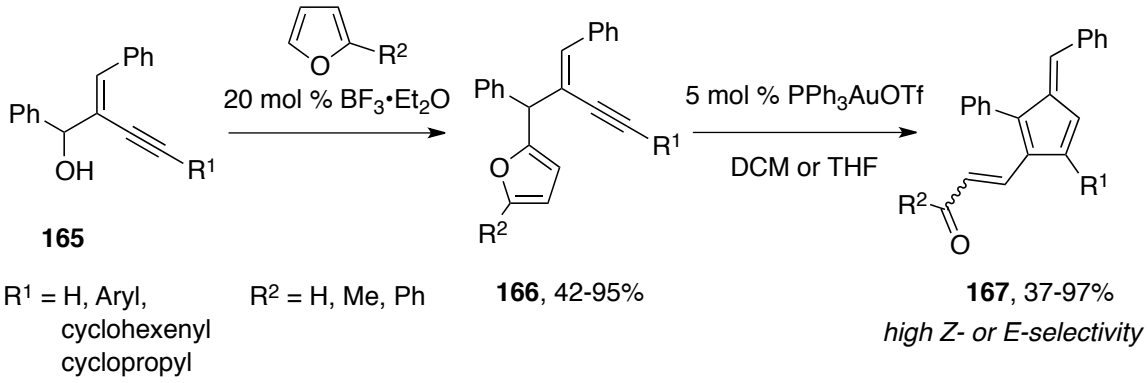
Scheme 71.

The same group also reported the gold(III)-catalyzed cycloisomerization reaction of diyne **161** and 2-methylfuran into phenanthrenyl ketone **162** (Scheme 72).[114] This reaction involves the initial formation of propargyl furan **163**, in which the first cycloizomerization reaction produces alkynyl (*Z*)-enone **164**. The subsequent alkyne-ketone metathesis generates the final product **162**.



Scheme 72.

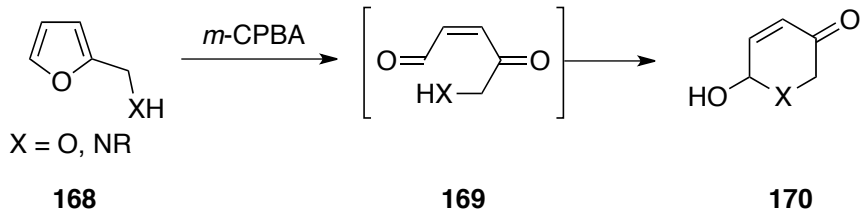
Liu group also revealed a similar strategy for the synthesis of fulvenes **167** from enynoles **165**, which also combines Friedel-Crafts and alkyne/furan cyclization reaction sequence (Scheme 73).[115] When recyclization reaction of alkynylfuran intermediate **166** was carried out using DCM as a solvent, the (*E*)-isomer of the product **167** was formed. Interestingly, recyclization reaction of **166** in the presence of a coordinating solvent, such as 1,4-dioxane or THF, produced the (*Z*)-isomer **167** in high selectivity.



Scheme 73.

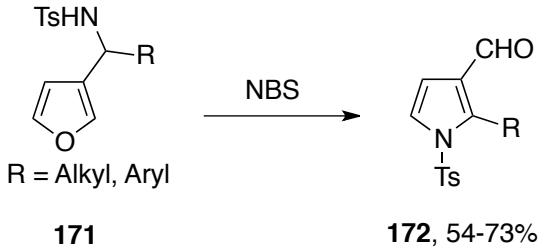
5.3. Recyclization Reaction of Furans into Heterocycles

One of the first methods developed for the recyclization reaction of furans into other heterocycles involves oxidative rearrangement of 2-furfuryl alcohols or –amines **168** into dihydropyranones or –pyridinones **170** (Scheme 74).[116,117] The reaction proceeds via formation of the acyclic 1,4-dicarbonyl compound **169**, which then undergoes intramolecular cyclization into the product in good yields.



Scheme 74.

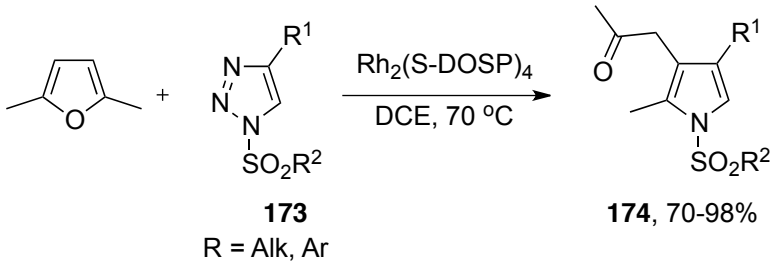
Similarly, *N*-tosyl protected 3-aminomethylfurans **171** can undergo oxidative recyclization reaction to produce pyrroles **172** (Scheme 75).[118]



171 **172**, 54-73%

Scheme 75.

Very recently, Davies group reported the rhodium-catalyzed reaction of 2,5-dimethylfuran with *N*-sulfonyltriazole **173** leading to the tetrasubstituted pyrroles **174** in good yields (Scheme 76).[119]



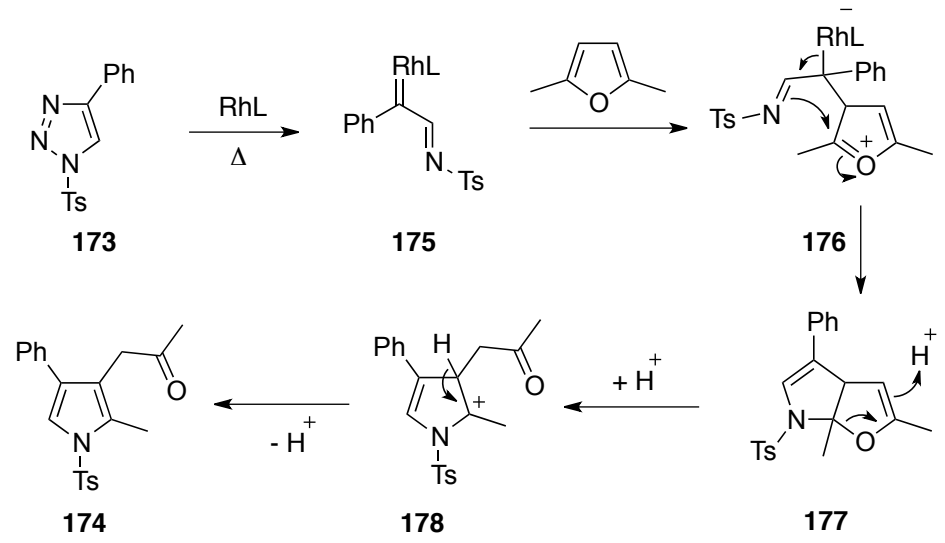
173
R = Alk, Ar

174, 70-98%

Scheme 76.

The mechanism for this reaction is shown in Scheme 77. First, triazole **173** in the presence of the rhodium catalyst undergoes thermal ring opening and dinitrogen extrusion with formation of the rhodium-imino carbene **175** intermediate. The following

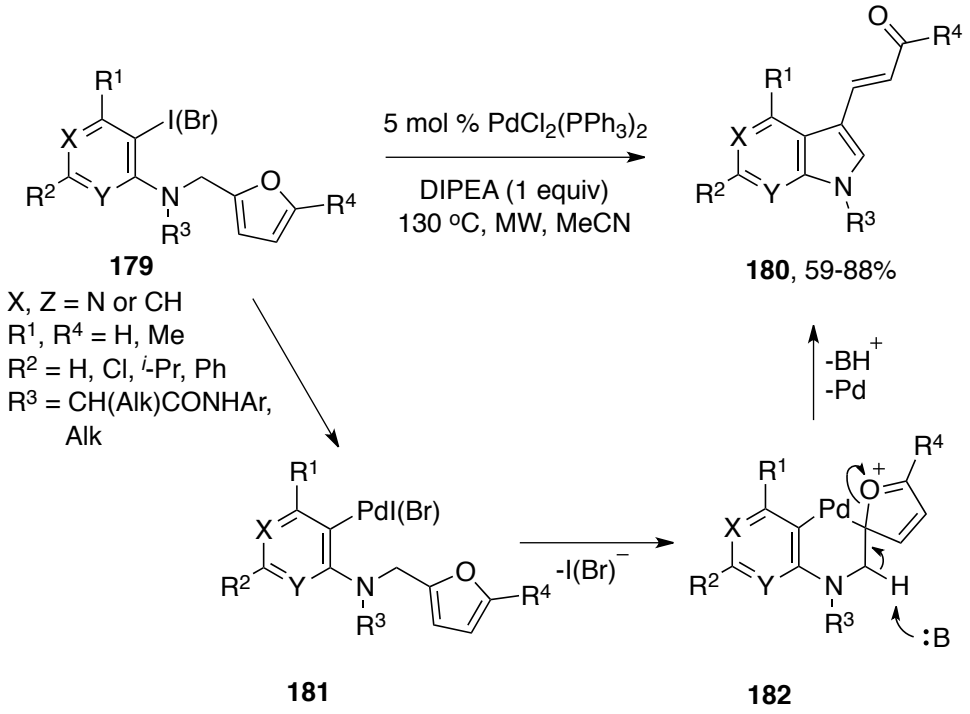
reaction of **175** with the furan at C3 position generates zwitterion **176**, which then closes to the hemiaminal **177**. The latter, upon furan ring opening under slightly acidic reaction conditions produces cation **178**, which further aromatizes to the pyrrole **174**.



Scheme 77.

In 2011, El Kaïm reported the palladium-catalyzed recyclization reaction of furan-containing aryl- or hetaryl halides **179** into pyrrolopyrimidines or indoles **180**, possessing *α,β*-unsaturated aldehyde or ketone moiety at C3 (Scheme 78).[120] It was suggested that the reaction proceeds via generation of the aryl palladium intermediate **181**, which further undergoes electrophilic attack at C2 position of the furan ring to give **182**. The subsequent base-induced deprotonation, accompanied by the double bond formation and furan ring opening, and the following reductive elimination of the palladium produces the final product. A similar approach to the synthesis of indoles and

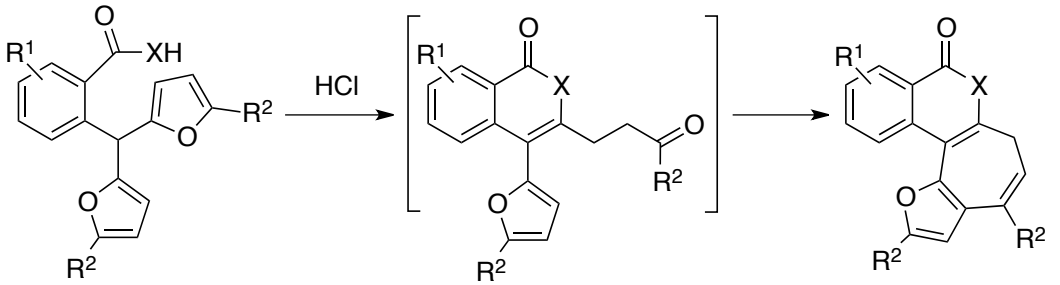
benzofurans starting from furan-tethered *ortho*-bromophenols and –anilines was recently reported by Yin.[121]



Scheme 78.

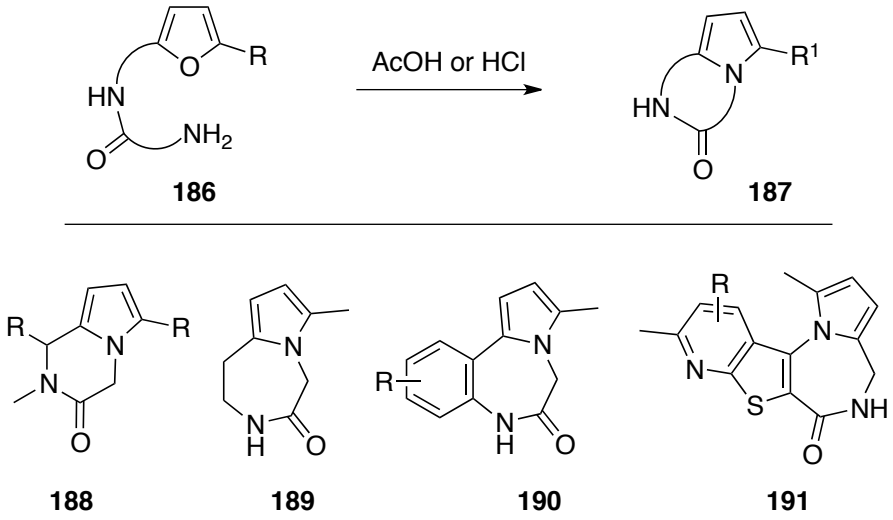
Butin and co-workers made a significant contribution to the area of recyclization reaction of furans. Thus, he showed that various furan-containing aromatic, -hetero-aromatic, and -acyclic molecules could be recyclized into a number of heterocycles under the Brønsted- or Lewis acid-mediated conditions. For example, when bisfuryl benzoic acid derivatives **183** (X=O) were subjected to a saturated methanolic HCl solution, isocoumarine-containing compounds **185** were isolated in high yields (Scheme 79).[122] The reaction proceeds via formation of the isocoumarin **184**, which then undergoes

further intramolecular condensation to produce a tetracyclic motif **185**. In the case of bisfuryl benzamide derivatives **183** (X=NR), the corresponding isoquinolone-containing compounds **185** were formed in moderate yields (Scheme 79).[123]



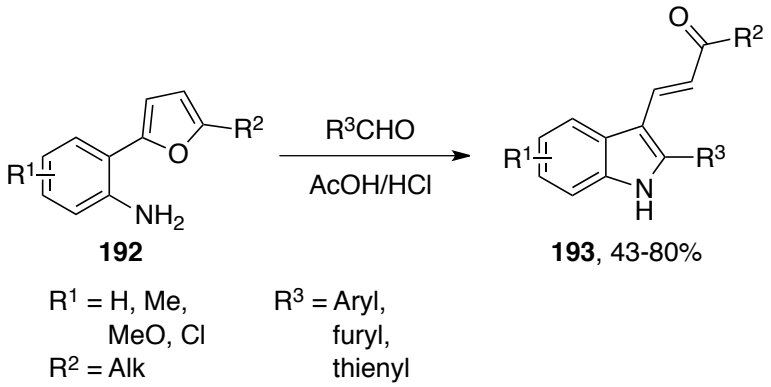
Scheme 79.

Recyclization of furan-containing amido-tethered amines **186** under acidic conditions produced different pyrrole-fused heterocyclic systems **187** as the result of the furan opening-Paal–Knorr cyclization reaction (Scheme 80). Thus, different pyrrolopyrazines **188**,[124] pyrrolediaze-pinone **189**[125] and its annulated aromatic **190**[126] or -heteroaromatic analogues **191**[127] were obtained using this approach.



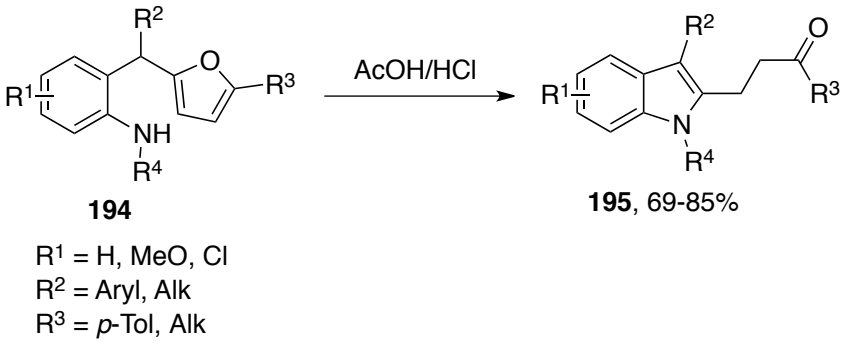
Scheme 80.

Another example includes furan ring opening/pyrrole ring closure in the synthesis of indoles. For instance, the reaction of *ortho*-(2-furyl)anilines **192** with aldehydes under the strong acidic conditions resulted in the synthesis of indoles **193** containing *α,β*-unsaturated ketone moiety at the C3 (Scheme 81).[93,128] A similar approach to the synthesis of *α,β*-unsaturated ketoindoles was reported for the recyclization of *ortho*-(2-furyl)nitrobenzene derivatives under reductive conditions.[129]



Scheme 81.

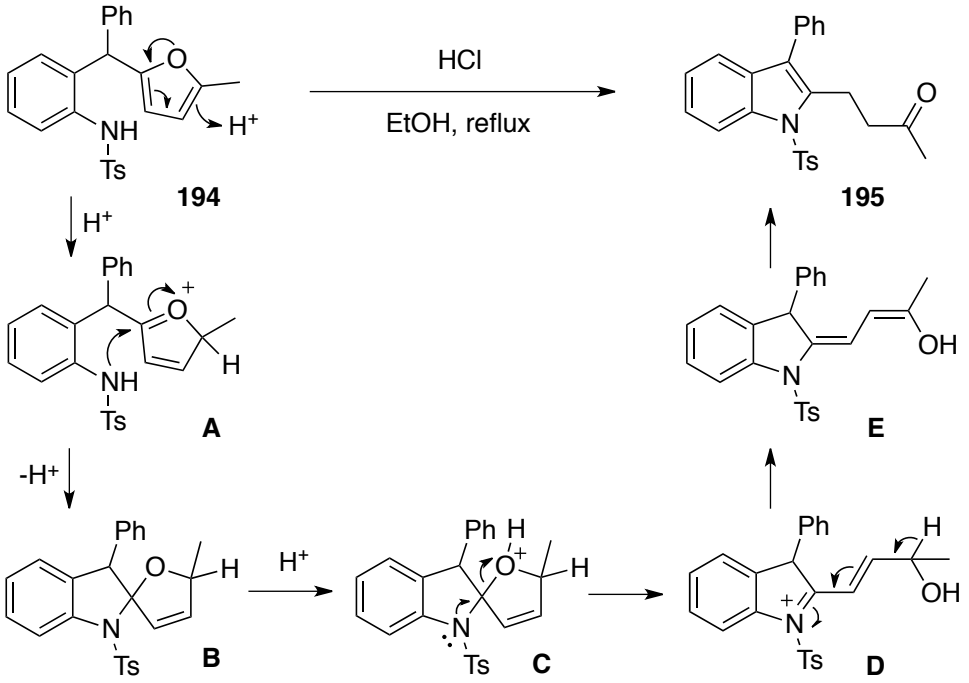
Another approach to the synthesis of indoles includes recyclization reaction of 2-aminobenzylfurans **194** into indoles **195**, possessing a saturated ketone moiety at C2 position (Scheme 82).[130]



Scheme 82.

The mechanism for this reaction is shown in Scheme 83. First, protonation of the furan ring of **194** results in intermediate **A**. The following nucleophilic attack of the

amino group at the furan ring and deprotonation from ammonium results in spirocyclic specie **B**. The latter, upon protonation and the following furan ring opening from **C** gives ammonium intermediate **D**. Deprotonation from **D** results in dienol **E**, which after aromatization and tautomerization produces indole **195**.



Scheme 83.

5.4. Conclusion

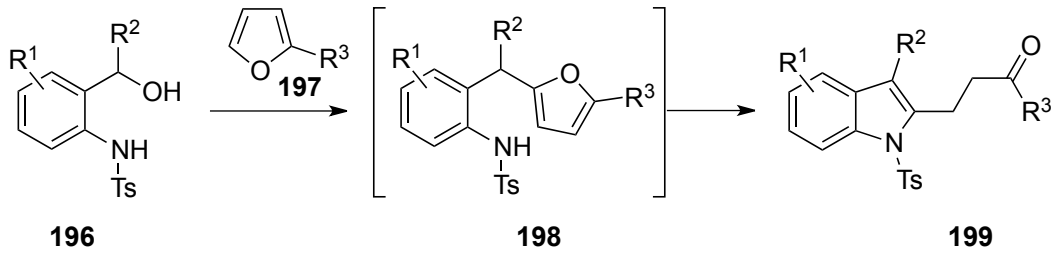
Recyclization reaction of furans into carbo- and heterocycles is a powerful method for construction of these molecules. Thus, the efficient gold- and platinum-catalyzed procedures have been developed for the synthesis of phenols via furan/alkyne

cycloisomerization reaction. Subsequently, this methodology was extended to the synthesis of other aromatic systems, including fulvene, naphthalene, and phenanthrene. Recyclization reaction of furan was also reported for the synthesis of various *N*-heterocycles, including pyrrole, pyridine, and indole. Of particular interest, is recyclization reaction of furan into indole, since valuable indole[131] fragments can be obtained from the readily available starting materials.[132] Among the methods for the synthesis of indoles via recyclization reaction of furans, two reports were published on the palladium-catalyzed arylative recyclization reaction of furan-containing aryl- or hetaryl halides (Scheme 78). Another method developed by Butin includes a Brønsted acid-mediated recyclization reaction of furylmethane derivatives (Scheme 82). The latter approach seems to have a potential to become a synthetically useful tool toward indole, however it requires initial preparation of the furylmethyl aniline derivative starting from benzyl alcohol and furan. Moreover, the use of harsh overstoichiometric acidic conditions in the recyclization step limits the scope of this transformation. Accordingly, we envisioned that the development of more environmentally benign and general catalytic method for the synthesis of indoles starting from benzyl alcohols and furans, which would provide a convenient one-pot procedure and exhibit better scope and higher functional group tolerance, is justified.

6. BRØNSTED ACID-CATALYZED ONE-POT SYNTHESIS OF INDOLES FROM *O*-AMINOBENZYLALCOHOLS AND FURANS

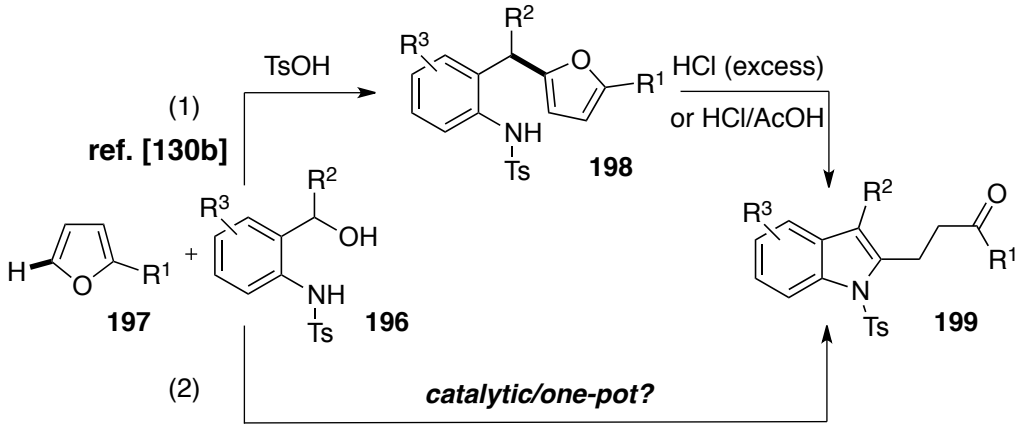
6.1. Optimization of Reaction Conditions, Scope and Limitations

We aimed at developing efficient conditions for the one-pot synthesis of indoles **199** starting from *ortho*-aminobenzyl alcohols **196** and furans **197** (Scheme 84). The reaction sequence would consist of the initial dehydrocondensation step to produce furyl intermediate **198**, followed by its recyclization to the indole **199**.



Scheme 84.

Recognizing that the both reactions in the procedure developed by Butin for the synthesis of indoles **199** from aminobenzyl alcohols **196** and 2-alkylfuran **197** proceed under electrophilic conditions (Scheme 85-1),[130b] we decided to explore the possibility of finding the efficient catalytic system for the formation of indole **199** without necessity of isolation of intermediate **198** (Scheme 85-2).

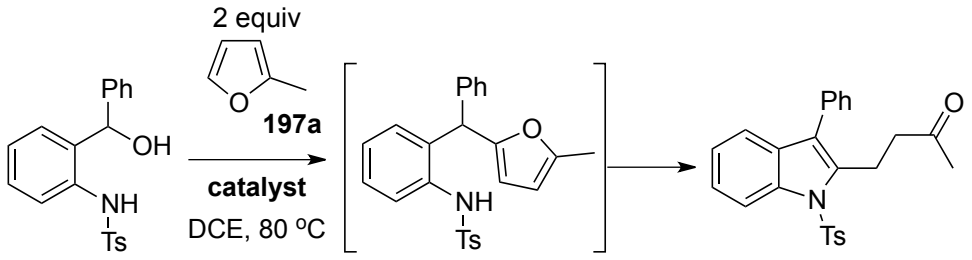


Scheme 85.

To this end, we first screened different Lewis acid catalysts in the recyclization reaction of *ortho*-aminobenzyl alcohol **196a** and 2-methylfuran **197a** to produce indole **199aa** (Table 9). Thus, employment of $FeCl_3$ resulted in the formation of intermediate **198aa** in 91% with only trace amounts of indole **199aa** detected (entry 1). Employment of Cu(II)-, In(III)- and Ag(I)-triflates (entries 2-5) was more efficient for the second recyclization step. The use of $Sc(OTf)_3$ resulted in nearly complete conversion of the starting materials into indole **199aa** (entry 5). In order to verify whether $Sc(OTf)_3$ is the true catalyst in this recyclization reaction, or if it is catalyzed by the Brønsted acid[133] (TfOH) produced by a hydrolysis of $Sc(OTf)_3$ during the first dehydrocondensation step, the following test experiments were performed. Thus, addition of activated molecular sieves, which scavenged the forming water and thus suppressed the hydrolysis of $Sc(OTf)_3$, resulted in a more sluggish recyclization reaction, producing intermediate **198aa** as a major product (entry 6). We observed a similar inhibition effect on the recyclization step upon addition of a proton scavenger 2,4,6-tritertbutylpyrimidine

(TTBP)[134] (entry 7). Finally, addition of both water- and proton scavengers completely shut down the recyclization step, thus producing furylmethyl aniline **198aa** as a single reaction product (entry 8). These results unambiguously demonstrate that TfOH is the true catalyst of the recyclization step (**198aa→199aa**). Subsequently, we examined several Brønsted acids in the recyclization reaction of **196a** and **197a** into **199aa** (entries 9-17). We were pleased to find that MsOH and TfOH furnished indole **3aa** in 87% and 95% yield, respectively (entries 16-17). The further optimization of the reaction conditions using TfOH as catalyst revealed the best conditions for the facile and complete conversion of the starting material into the indole (entry 19).

Table 9. Optimization of the one-pot synthesis of indole **199aa** from *ortho*-aminobenzyl alcohol **196a**[a]



entry	catalyst	(mol %)	time, (h)	yield **199** (**198**), (%)[b]
1	$FeCl_3$	10	12	<5 (91)
2	$Cu(OTf)_2$	10	12	53 (38)
3	$In(OTf)_3$	10	2	87 (10)
4	AgOTf	10	1	80 (13)
5	$Sc(OTf)_3$	10	12	92 (<1)
6[c]	$Sc(OTf)_3$	10	24	29 (61)
7[d]	$Sc(OTf)_3$	10	24	22 (70)
8[c,d]	$Sc(OTf)_3$	10	24	-- (94)
9	$HNTf_2$	10	12	-- (68)
10[e]	HCl	10	12	-- (38)
11[e]	HCl	100	12	-- (21)
12	AcOH	10	12	-- (<10)
13	CF_3COOH	10	12	-- (58)
14	H_2SO_4	10	12	39 (50)

entry	catalyst	(mol %)	time, (h)	yield **199** (**198**), (%)[b]
15	TsOH	10	12	41 (48)
16	MsOH	10	4	87 (0)
17	TfOH	10	1	95 (0)
18	TfOH	5	4	91 (0)
19[f]	**TfOH**	**10**	**1**	**94 (0)**
20[g]	TfOH	10	1	73 (0)

[a] Reaction conditions: *o*-Aminobenzyl alcohol **196a** (0.2 mmol), 2-methylfuran **197a** (2 equiv, 0.4 mmol, 35.8 μL), and catalyst were stirred in DCE (0.7 mL, 0.3 M) at 80 °C. The progress of the reaction was monitored by TLC.

[b] NMR Yield.

[c] In the presense of 50 mg molecular sieves 4Å.

[d] In the presence of 30 mol % 2,4,6-tritertbutylpyrimidine.

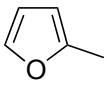
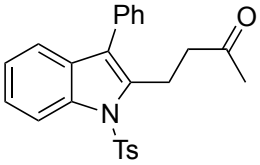
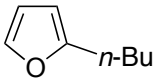
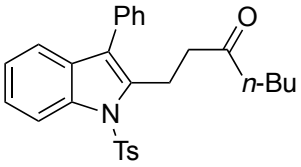
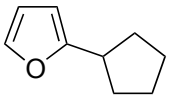
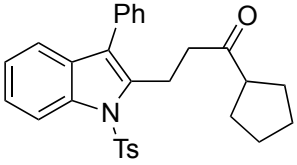
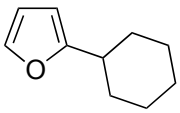
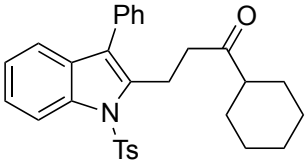
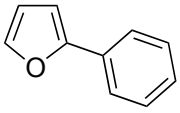
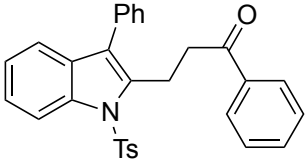
[e] 4M HCl in dioxane was used.

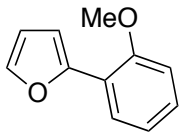
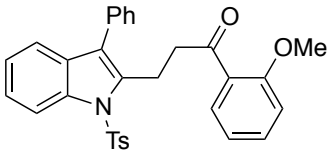
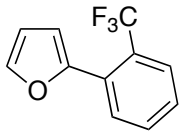
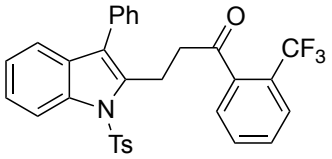
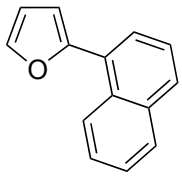
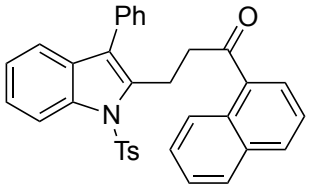
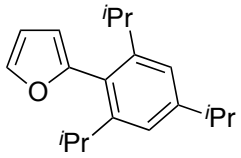
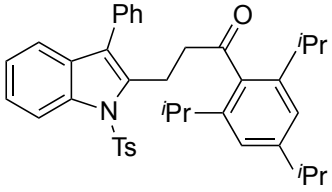
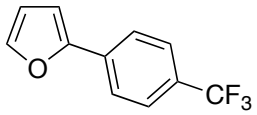
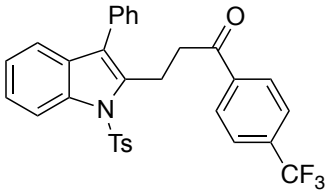
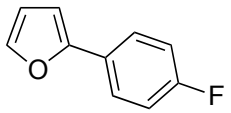
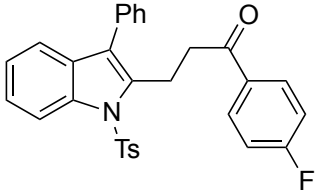
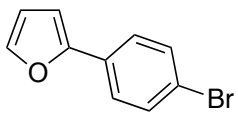
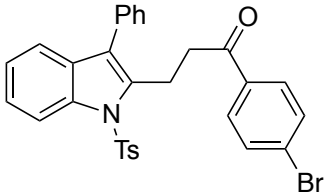
[f] 1.5 equiv of 2-methylfuran was used.

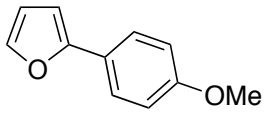
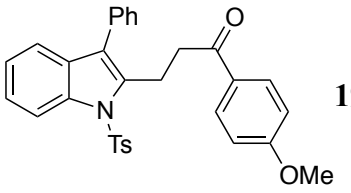
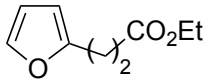
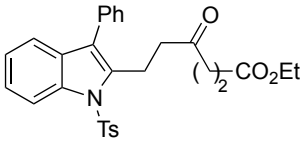
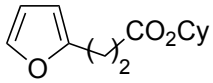
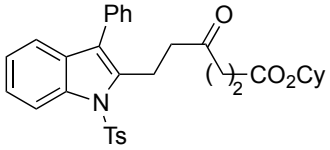
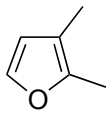
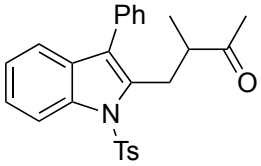
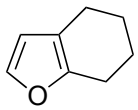
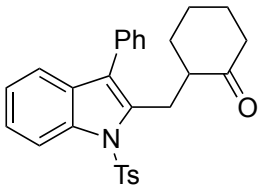
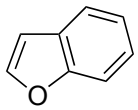
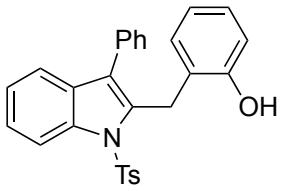
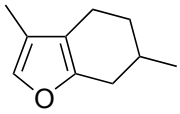
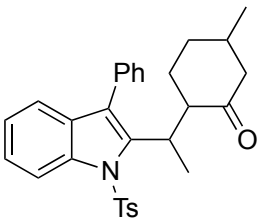
[g] 1.2 equiv of 2-methylfuran was used.

Next, under the optimized conditions, we examined the scope of this reaction. First, we explored the scope of furans **197** in the recyclization reaction with *ortho*-aminoalcohol **196a** (Table 2). Accordingly, 2-alkyl- and 2-cycloalkylfurans **197a-d** were easily converted into the corresponding indoles **199ab**-**ad** in good to excellent yields (entries 1-4). Different 2-arylfurans **197e-m**, possessing MeO-, Br-, F-, and CF_3- groups were also efficiently transformed into indoles **199ae**-**am** (entries 5-13). Noteworthy, even sterically bulky 2-arylfurans **197g-i** were also competent reaction partners in this transformation providing the corresponding indoles **199ag-ai** in moderate yields (entries 7-9). Furans **197n** and **197o**, possessing an ester group in a side chain, smoothly recyclized into indoles **199an** and **199ao** in 61% and 68% yield, respectively (entry 14,15). We found that 2,3-disubstituted furans, such as 2,3-dimethylfuran **197p** and 4,5,6,7-tetrahydrobenzofuran **197q**, produced the corresponding indoles **199ap** and **199aq** in 87% and 70% yields (entries 16,17). Benzofuran **197r** also underwent recyclization reaction to produce benzylphenoloindole derivative **199ar** in moderate yield (entry 18). Unfortunately, C-4 substituted menthofuran **197s** gave no recyclization product **199as** (entry 19).

Table 10. Scope of furans in the one-pot synthesis of indoles **199** from *ortho*-aminobenzyl alcohol **196a**[a]

entry	furan		indole		yield **199**, (%)
1		**197a**		**199aa**	90
2		**197b**		**199ab**	95
3		**197c**		**199ac**	93
4		**197d**		**199ad**	75
5[b]		**197e**		**199ae**	87

entry	furan		indole		yield **199**, (%)
6		**197f**		**199af**	85
7		**197g**		**199ag**	56
8		**197h**		**199ah**	53
9		**197i**		**199ai**	48
10		**197j**		**199aj**	60
11		**197k**		**199ak**	83
12		**197l**		**199al**	73

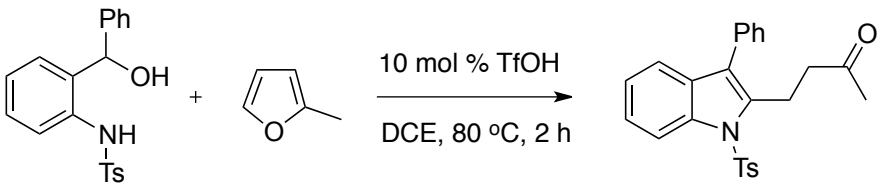
entry	furan		indole		yield **199**, (%)
13		**197m**		**199am**	56
14		**197n**		**199an**	61
15		**197o**		**199ao**	68
16		**197p**		**199ap**	87
17		**197q**		**199aq**	70
18		**197r**		**199ar**	45
19[c]		**197s**		**199as**	0

[a] Reaction conditions: *ortho*-Aminobenzyl alcohol **196a** (0.5 mmol), furan **197** (1.5 equiv, 0.75 mmol), and TfOH (10 mol %, 4.5 μL) were stirred in DCE (1.6 mL, 0.3 M) at 80 °C. The progress of the reaction was monitored by TLC.

[b] Reaction mixture (entries 5-13) was heated at 110 °C for 2h.

[c] Furylmethyl aniline intermediate **198ar** was isolated in 95% yield.

We have also demonstrated that the recyclization reaction of *ortho*-aminobenzyl alcohol **196a** and furan **197a** could be easily scaled up to a gram-scale synthesis of indole **199aa** using our standard conditions (Scheme 86).



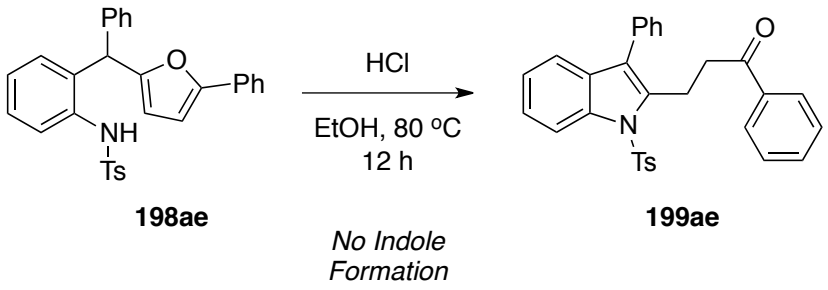
196a 4 mmol

197a 6 mmol

199aa 1.38 g (83%)

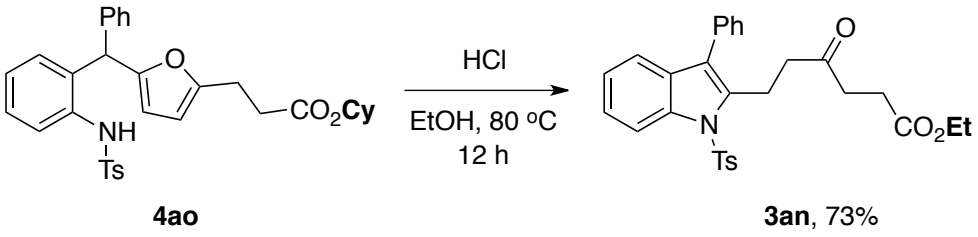
Scheme 86.

Noteworthy, our newly developed catalytic system exhibits wider scope and better functional group tolerance than the earlier published procedure by Butin.[130b] Thus, attempts on recyclization of intermediate **198ae** using previously developed conditions (HCl-EtOH) did not provide any amount of indole **199ae** (Scheme 87). On the other hand, the TfOH-catalyzed reaction of *ortho*-aminobenzyl alcohol **196a** and 2-phenylfuran **197e** produced indole **199ae** in 87% yield (Table 10, entry 5).



Scheme 87.

Moreover, recyclization reaction of furylmethyl aniline **199ao** using HCl-EtOH produced indole **198an** as a result of transesterification reaction (Scheme 88), whereas TfOH-catalyzed recyclization reaction of *ortho*-aminobenzyl alcohol **196a** and cyclohexyl 3-(furan-2-yl)propanoate **197o** produced the target indole **199ao** in 68% yield (Table 10, entry 15).



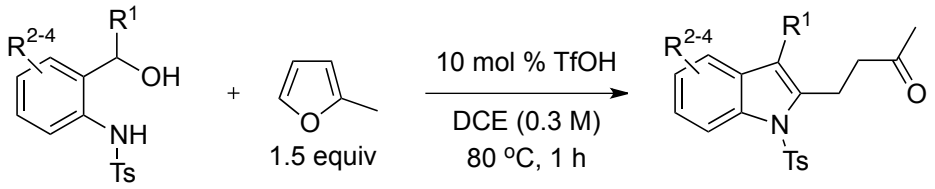
Scheme 88.

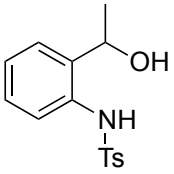
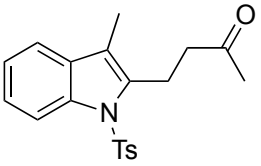
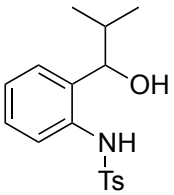
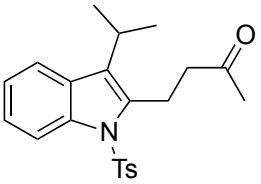
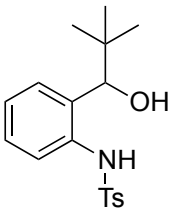
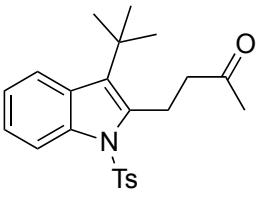
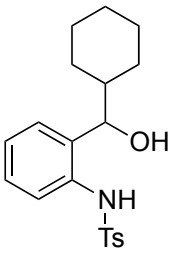
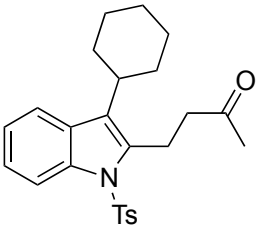
Next, the generality of our newly developed catalytic system was examined with *ortho*-aminobenzyl alcohol **196** possessing different substituents at the α-position to hydroxyl group (Table 11, entries 1-8). We were happy to find that alkyl-substituted

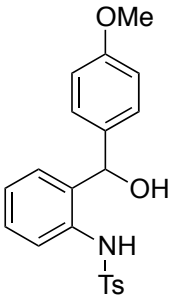
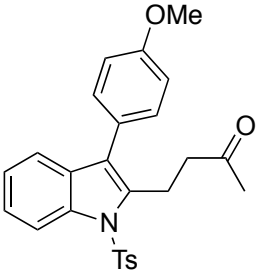
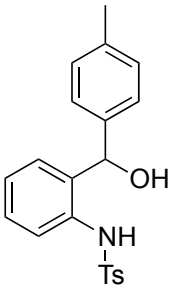
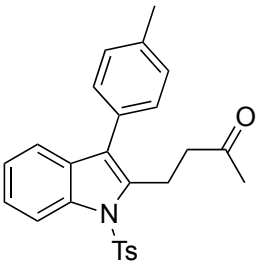
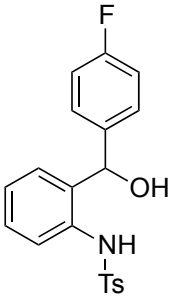
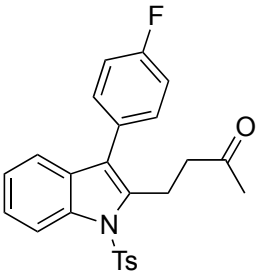
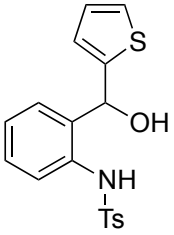
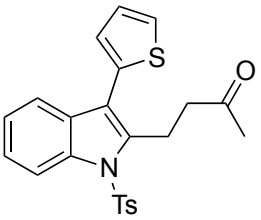
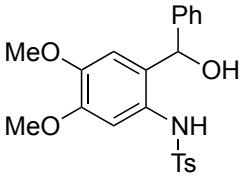
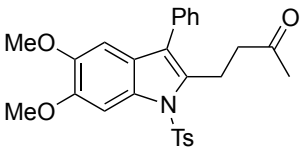
benzyl alcohols, such as methyl-, *iso*-propyl-, *tert*-butyl-, and cyclohexyl-, can be easily transformed into indoles **199ba-ea** in good to excellent yields (entries 1-4). Similarly, aryl-substituted aminoalcohols, possessing MeO, Me-, and F- groups efficiently recyclized into indoles **199fa-ha** (entries 5-7). Recyclization reaction of 2-thienyl-substituted benzyl alcohol **196i** produced the corresponding indole **199ia** in moderate yield (entry 8).

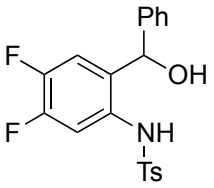
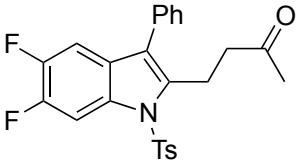
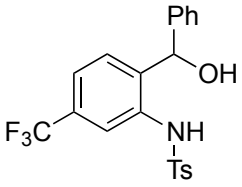
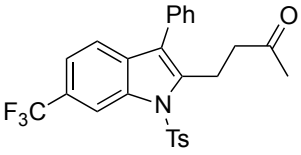
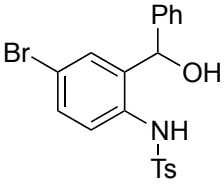
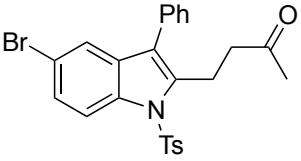
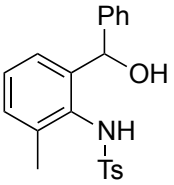
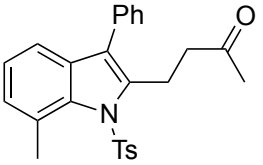
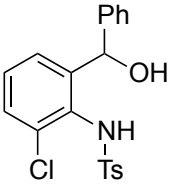
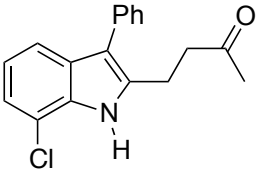
Finally, substrates possessing different substituents at the aniline ring of *ortho*-aminobenzyl alcohol **196** were tested in this recyclization reaction (Table 11, entries 9-14). Thus, reaction of 4,5-dimethoxy- and 4,5-difluorobenzyl alcohols **196j** and **196k** led to the formation of indoles **199ja** and **199ka** in good yields (entries 9-10). 5-Trifluoromethylbenzyl alcohol **196l** and 4-bromobenzyl alcohol **196m** provided the corresponding indoles **199la** and **199ma** in good yields, as well (entries 11-12). Surprisingly, 6-methyl aminoalcohol **196n** was not efficient reaction partner (entry 13), whereas 6-chloro aminoalcohol **196o** provided *N*-detosylated indole **199oa** in moderate yield (entry 14).

Table 11. Variation of substituents at α-position and at aniline phenyl ring of *ortho*-aminobenzyl alcohols[a]



entry	aminobenzyl alcohol		indole		yield **199**, %
1		**196b**		**199ba**	88
2		**196c**		**199ca**	76
3		**196d**		**199da**	63
4		**196e**		**199ea**	83

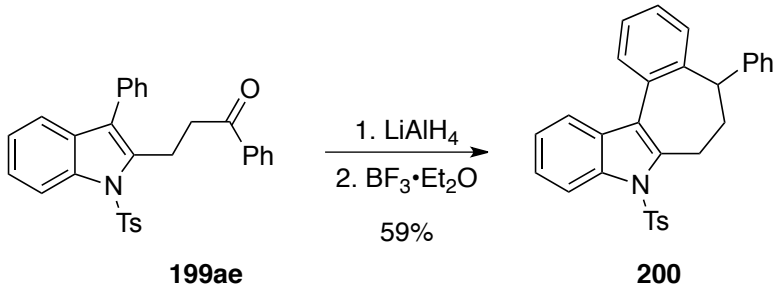
entry	aminobenzyl alcohol		indole		yield **199**, %
5		**196f**		**199fa**	71
6		**196g**		**199ga**	60
7		**196h**		**199ha**	72
8		**196i**		**199ia**	41
9		**196j**		**199ja**	60

entry	aminobenzyl alcohol		indole		yield **199**, %
10		**196k**		**199ka**	79
11		**196l**		**199la**	61
12		**196m**		**199ma**	63
13		**196n**		**199na**	traces
14		**196o**		**199oa**	59

[a] Reaction conditions: *o*-Aminobenzyl alcohol **196** (0.5 mmol), 2-methylfuran **197a** (1.5 equiv, 0.75 mmol, 67.1 μL), and TfOH (10 mol %, 4.5 μL) were stirred in DCE (1.6 mL, 0.3 M) at 80 °C. The progress of the reaction was monitored by TLC.

6.2. Further Modifications of the Obtained Indoles

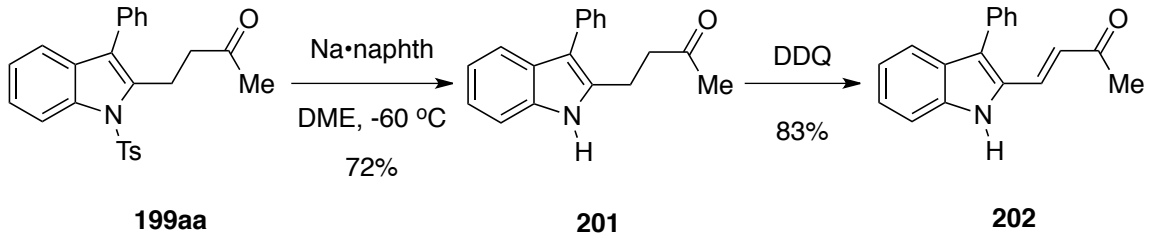
After the scope of this one-pot recyclization reaction was established, we turned our attention to the synthetic utility of the obtained indoles **199**. Accordingly, we found that upon reduction of the carbonyl group of indole **199ae** into the alcohol group, the subsequent Friedel–Crafts-type cyclization resulted in the formation of the tetracyclic cyclohepta[2,3]fused indole **200** (Scheme 89).[135]



199ae **200**

Scheme 89.

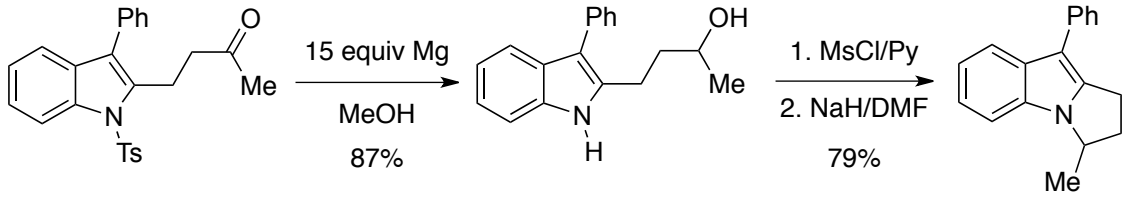
Removal of the tosyl group from indole **199aa** with sodium naphthalenide[136] gave *N*–H indole **201**, which upon oxidation with DDQ produced *α*,*β*-unsaturated ketone **202** (Scheme 90).



199aa **201** **202**

Scheme 90.

Alternatively, the tosyl group in the indole **199aa** can be removed with simultaneous reduction of the carbonyl- group when treated with excess of Mg in methanol,[137] to produce alcohol **203** (Scheme 91). The latter, upon mesylation and subsequent intramolecular *N*-alkylation,[138] was smoothly converted into dihydropyrrolo-indole **204**, an important motif found in a number of drug candidates and natural products.[139]



199aa **203** **204**

Scheme 91.

6.3. Conclusion

In conclusion, we developed efficient one-pot Brønsted acid-catalyzed method for the synthesis of indoles starting from *ortho*-aminobenzyl alcohols and furans. It includes the initial formation of aminobenzylfuran, which further undergoes recyclization reaction into indole possessing a saturated ketone moiety at C3 position. This newly developed two-component catalytic method proved to have a wider substrate scope and higher functional group tolerance than the previously reported procedure. The formed indoles can be further transformed into valuable 2,3- and 1,2-fused indoles, and into indoles possessing an α,β-unsaturated ketone moiety.

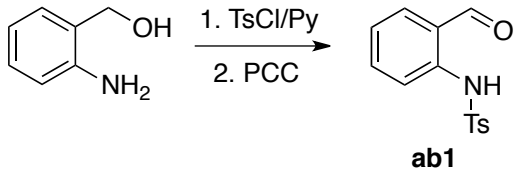
7. EXPERIMENTAL SECTION

7.1. Instrumentation

Column chromatography was carried out employing Silicycle Silica-P flash silica gel (40-63 μm). Precoated silica gel plates F-254 were used for thin-layer analytical chromatography (TLC). Chemical shifts for ^{1}H and ^{13}C nuclear magnetic resonance (NMR) spectra were reported in parts per million (ppm, δ). HRMS analyses were performed on either Micromass 70-VSE mass spectrometer by using electron ionization (EI) technique with Spector analyzer or by using electrospray ionization (ESI) with time-of-flight (TOF) analyzer. Anhydrous solvents purchased from suppliers were additionally purified on solvent purification system and/or stored over calcium hydride/molecular sieves. 2-Aryl/alkylfurans, if not commercially available, were synthesized from 2-bromofuran.[140]

7.2. Synthesis of Starting Materials

2-(N-tosylamino)benzaldehyde **ab1** was prepared as described.[141]



ab1

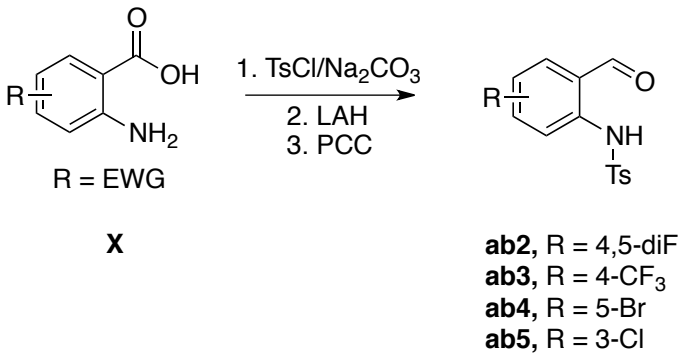
Scheme 92.

To a solution of 2-aminobenzyl alcohol (6.2 g, 50.0 mmol) and pyridine (1.2 equiv, 4.8 mL, 60.0 mmol) in $CHCl_3$ (165 mL), TsCl (0.98 equiv, 9.3 g, 49.0 mmol) in $CHCl_3$ (50 mL) was added dropwise at room temperature (Scheme 92). The reaction mixture was stirred for 3 h and then quenched with water (50 mL). The organic phase was separated, washed with water, dried over Na_2SO_4, and concentrated to give the 2-(*N*-tosylamino)benzyl alcohol (13.5 g, 48.6 mmol, 97%), which was used directly in the next step.

To a stirred suspension of PCC (1.5 equiv, 15.7 g, 72.9 mmol) in CH_2Cl_2 (240 mL), a solution of the 2-(*N*-tosylamino)benzyl alcohol in CH_2Cl_2 (360 mL) was added dropwise at room temperature. The mixture was stirred for 3 h. The liquid was decanted from the solid, and the remaining solid was washed several times with Et_2O (3x100 mL). The combined organic fractions were passed through a short pad of silica gel. The silica gel was additionally washed with CH_2Cl_2 (3x100 mL) and the combined organic

solutions were evaporated to give the crude product. The product was recrystallized from $CHCl_3$/EtOH (1/5, 100 ml) to yield aldehyde **ab1** as a white-yellow solid (11.2 g, 40.8 mmol, 84%), which was used directly in the synthesis of alcohols **196**.

General procedure for the synthesis of 2-(*N*-tosylamino)-4,5-difluoro-benzaldehyde ab2, 2-(*N*-tosylamino)-4-trifluoromethylbenzaldehyde ab3, 2-(*N*-tosyl-amino)-5-bromobenzaldehyde ab4, and 2-(*N*-tosylamino)-3-chlorobenzaldehyde ab5:[142]



Scheme 93.

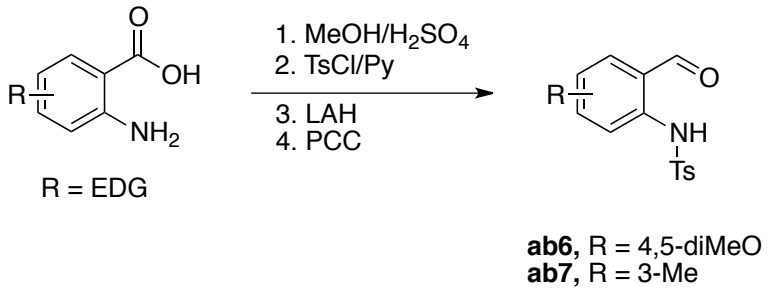
To a solution of a proper 2-aminobenzoic acid (5 mmol) and Na_2CO_3 (2.5 equiv) in distilled water (0.4 M) heated to 60 °C, TsCl (1.25 equiv) was added during the course of 15 min (Scheme 93). The mixture was then heated to 85 °C and stirred at this temperature for 3 h. The hot mixture was then cooled down and mixed with ice. HCl (6 N) was added dropwise to the resulted mixture until slightly acidic pH (*caution: CO_2 evolution!*). The resulted white suspension was extracted with EtOAc (3x10 mL), and

combined organic solutions were additionally washed with HCl (1 N), dried over Na_2SO_4, and evaporated to give the 2-(*N*-tosylamino)benzoic acid. The crude product was used directly in the next step.

Under a nitrogen atmosphere, to an ice-cooled stirred suspension of $LiAlH_4$ (2.0 equiv) in THF (0.2 M), a solution of 2-(*N*-tosylamino)benzoic acid in minimum amount of THF was added dropwise. The reaction mixture was allowed to warm up to room temperature and stirred for 3 h. After completion of the reaction (determined by TLC, eluent Hexanes/EtOAc = 2/1), the reaction mixture was cooled down (ice bath) and saturated aqueous NH_4Cl (2.0 mL) was added dropwise (*caution: H_2 evolution!*). The resulting sluggish mixture was filtered through Celite and concentrated. The crude product was used directly in the next step.

The resulted alcohol was oxidized to aldehyde using PCC as described earlier. The obtained aldehydes **ab2-ab5** were used directly in the synthesis of alcohols **196**.

General procedure for the synthesis of 2-(*N*-tosylamino)-4,5-dimethoxy-benzaldehyde ab6 and 2-(*N*-tosylamino)-3-methylbenzaldehyde ab7:[143]



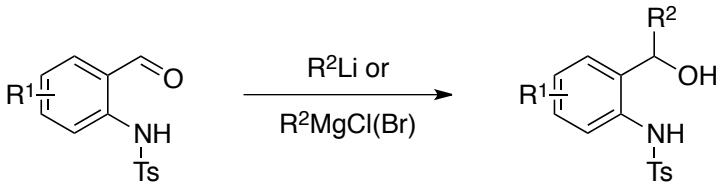
Scheme 94.

A solution of a proper 2-aminobenzoic acid (5 mmol), methanol (10 mL), and concentrated H_2SO_4 (2 mL) was heated under reflux for 24 h. The reaction mixture was cooled down, concentrated, poured into ice, neutralized with solid Na_2CO_3 (*caution: CO_2 evolution!*), and extracted with CH_2Cl_2 (3x10 mL). The combined organic layers were washed with water, saturated aqueous $NaHCO_3$, dried over Na_2SO_4, and concentrated to provide a crude methyl 2-aminobenzoate, which was used directly in the next step.

To a solution of crude methyl 2-aminobenzoate and pyridine (3 equiv) in CH_2Cl_2 (10 mL), a solution of TsCl (0.98 equiv) in CH_2Cl_2 (5 mL) was added dropwise at room temperature. The reaction mixture was stirred for 3 h and then quenched with water (10 mL). The organic layer was separated, washed with water, dried over Na_2SO_4, and concentrated. The crude product was used directly in the next step.

Reduction of methyl ester with $LiAlH_4$ and subsequent oxidation of the resulted alcohol to aldehyde with PCC was done as described earlier. The obtained aldehydes **ab6-ab7** were used directly in the synthesis of alcohols **196**.

General procedure for the synthesis of 2-(N-tosylamino)benzyl alcohols 196 from 2-(N-tosylamino)benzaldehydes ab:



ab **196**

Scheme 95.

An oven dried, argon flushed 25 mL flask was loaded with *2*-(*N*-tosylamino)benzaldehyde **ab** (1.0 mmol) and THF (8.0 mL, 0.125 M). The flask was cooled to -78 °C and a solution of $R^2Li/R^2MgCl(Br)$ (2.2 mmol, 2.2 equiv) was added dropwise (Scheme 95). The resulting mixture was allowed to warm up to 0 °C and saturated NH_4Cl (5 mL) was added. The organic layer was separated and the water layer was washed with ethyl acetate (2x5 mL). The combined organic solutions were dried over Na_2SO_4 and the solvents were evaporated. The resulted crude product was purified by recrystallization from ^{i}PrOH to give pure alcohol **1** as a white solid.

196a: obtained from aldehyde **ab1** and PhLi, 332 mg (94%), R_f = 0.09 (Hexanes/EtOAc = 4/1). The spectral data matched those of the previously synthesized material.[130b] ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.00 (s, 1H), 7.48-7.46 (m, 3H), 7.32-7.30 (m, 3H), 7.23 (t, *J* = 7.3 Hz, 1H), 7.17-7.14 (m, 4H), 7.02 (t, *J* = 7.7 Hz, 1H), 6.92 (d, *J* = 7.3 Hz, 1H), 5.67 (s, 1H), 2.69 (s_{br}, 1H), 2.36 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.6, 141.0, 136.6, 135.8, 133.1, 129.5, 129.0 (2C), 128.6, 127.9, 127.2, 126.3, 124.6, 122.1, 74.7, 21.5. HRMS (EI+) calcd. for $C_{20}H_{19}NO_3S$ $[M]^+$: 353.1086, found: 353.1087.

196b: obtained from aldehyde **ab1** and MeLi, 255 mg (88%), R_f = 0.18 (Hexanes/EtOAc = 4/1). The spectral data matched those of the previously synthesized material.[144] ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.51 (s_{br}, 1H), 7.68-7.67 (m, 2H), 7.41 (d, *J* = 8.1 Hz, 1H), 7.22-7.20 (m, 2H), 7.17 (dt, *J* = 7.3, 1.7 Hz, 1H), 7.09-7.02 (m, 2H), 4.84 (q, *J* = 6.6 Hz, 1H), 2.68 (s_{br}, 1H), 2.36 (s, 3H), 1.34 (d, *J* = 6.6 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ

143.7, 136.9, 135.7, 134.0, 129.6, 128.5, 127.1, 127.0, 124.6, 121.8, 69.8, 22.8, 21.5. HRMS (EI+) calcd. for $C_{15}H_{17}NO_3S$ $[M]^+$: 291.0929, found: 291.0935.

196c: obtained from aldehyde **ab1** and ^{i}PrMgCl, 213 mg (67%), R_f = 0.21 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.48 (s_{br}, 1H), 7.67-7.66 (m, 2H), 7.48 (d, *J* = 7.5 Hz, 1H), 7.21-7.15 (m, 3H), 7.00-6.95 (m, 2H), 4.23 (d, *J* = 9.0 Hz, 1H), 2.70 (s_{br}, 1H), 2.36 (s, 3H), 1.66 (m, 1H), 1.00 (d, *J* = 6.6 Hz, 3H), 0.43 (d, *J* = 6.8 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.7, 136.8, 135.8, 132.0, 129.5, 129.2, 128.3, 127.1, 123.9, 121.3, 81.3, 33.4, 21.5, 19.4, 19.2. HRMS (EI+) calcd. for $C_{17}H_{21}NO_3S$ $[M]^+$: 319.1242, found: 319.1245.

196d: obtained from aldehyde **ab1** and ^{t}BuMgCl, 209 mg (63%), R_f = 0.23 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.86 (s_{br}, 1H), 7.76-7.74 (m, 2H), 7.38 (d, *J* = 8.3 Hz, 1H), 7.24-7.23 (m, 2H), 7.14 (m, 1H), 6.99-6.93 (m, 2H), 4.51 (s, 1H), 2.53 (s_{br}, 1H), 2.38 (s, 3H), 0.98 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.6, 137.1, 136.6, 130.5, 129.6, 128.4, 128.1, 127.3, 122.6, 119.4, 84.0, 37.3, 26.3, 21.5. HRMS (EI+) calcd. for $C_{18}H_{23}NO_3S$ $[M]^+$: 333.1399, found: 333.1404.

196e: obtained from aldehyde **ab1** and CyMgBr, 305 mg (85%), R_f = 0.20 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.62 (s_{br}, 1H), 7.70-7.69 (m, 2H), 7.58 (d, *J* = 8.1 Hz, 1H), 7.23-7.17 (m, 3H), 7.00-6.97 (dt, J = 7.5, 1.1 Hz, 1H), 6.92 (dd, *J* = 7.7, 1.5 Hz, 1H), 4.29 (d, *J* = 9.0 Hz, 1H), 2.65 (s_{br}, 1H), 2.37 (s, 3H), 2.05 (m, 1H), 1.73 (m, 1H), 1.58 (m, 1H), 1.48 (m, 1H), 1.30 (m, 1H), 1.14-1.01 (m, 2H), 0.95-

0.89 (m, 2H), 0.79 (m, 1H), 0.67 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.7, 137.0, 135.9, 131.2, 129.6, 129.3, 128.3, 127.1, 123.6, 120.9, 80.7, 42.5, 29.6, 29.5, 26.1, 25.6, 25.4, 21.5. HRMS (EI+) calcd. for $C_{20}H_{25}NO_3S$ $[M]^+$: 359.1555, found: 333.1558.

196f: obtained from aldehyde **ab1** and 4-FC_6H_4MgBr, 248 mg (67%), R_f = 0.13 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.06 (s_{br}, 1H), 7.47 (d, J = 7.9 Hz, 1H), 7.44-7.43 (m, 2H), 7.21 (dt, J = 8.1, 1.5 Hz, 1H), 7.13-7.12 (m, 2H), 7.10-7.08 (m, 2H), 7.02 (dt, J = 7.5, 0.7 Hz, 1H), 6.94-6.90 (m, 3H), 5.72 (s, 1H), 3.10 (s_{br}, 1H), 2.38 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.2 (d, J_{C-F} = 246.0 Hz), 143.7, 136.9 (d, J_{C-F} = 2.8 Hz), 136.4, 135.7, 133.0, 129.5, 129.1 (d, J_{C-F} = 3.7 Hz), 127.9 (d, J_{C-F} = 8.3 Hz), 127.0, 124.7, 122.1, 115.3 (d, J_{C-F} = 22.2 Hz), 74.1, 21.5. HRMS (EI+) calcd. for $C_{20}H_{18}NO_3SF$ $[M]^+$: 371.0991, found: 371.0986.

196g: obtained from aldehyde **ab1** and 4-MeC_6H_4MgBr, 256 mg (70%), R_f = 0.12 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.08 (s_{br}, 1H), 7.49-7.47 (m, 3H), 7.22 (m, 1H), 7.15-7.10 (m, 4H), 7.04-7.00 (m, 3H), 6.93 (d, J = 7.7 Hz, 1H), 5.62 (d, J = 3.1 Hz, 1H), 2.81 (d, J = 3.5 Hz, 1H), 2.39 (s, 3H), 2.37 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.5, 138.0, 137.5, 136.5, 135.8, 133.1, 129.4, 129.3, 128.9, 128.8, 127.1, 126.2, 124.5, 121.9, 74.5, 21.5, 21.1. HRMS (EI+) calcd. for $C_{21}H_{21}NO_3S$ $[M]^+$: 367.1242, found: 367.1240.

196h: obtained from aldehyde **ab1** and 4-$MeOC_6H_4MgBr$, 321 mg (84%), R_f = 0.06 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.19 (s_{br}, 1H), 7.47-7.45 (m,

3H), 7.19 (m, 1H), 7.13-7.11 (m, 2H), 7.05-6.99 (m, 3H), 6.91 (d, J = 7.7 Hz, 1H), 6.80-6.78 (m, 2H), 5.59 (s_{br}, 1H), 3.79 (s, 3H), 3.11 (m, 1H), 2.37 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.1, 143.5, 136.5, 135.7, 133.2, 129.4, 128.9, 128.7, 127.6, 127.1, 124.4, 121.8, 113.9, 74.3, 55.2, 21.4. HRMS (EI+) calcd. for $C_{21}H_{21}NO_4S$ $[M]^+$: 383.1191, found: 383.1194.

196i: obtained from aldehyde **ab1** and thiophen-2-yl lithium (prepared by mixing 2-bromothiophene with 1.1 equiv of *n*-BuLi in THF at -78 °C), 341 mg (95%), R_f = 0.15 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.10 (s_{br}, 1H), 7.49-7.48 (m, 2H), 7.45 (d, J = 8.1 Hz, 1H), 7.26-7.21 (m, 2H), 7.15-7.13 (m, 2H), 7.10-7.03 (m, 2H), 6.87 (dd, J = 5.1, 3.5 Hz, 1H), 6.59 (m, 1H), 5.93 (m, 1H), 3.41 (m, 1H), 2.43 (s, 3H). ^{13}C NMR (125 MHz, acetone-d_6) δ 148.7, 144.9, 138.3, 137.4, 134.7, 130.8, 129.9 (2C), 128.4, 126.4, 125.6, 125.3, 121.9, 72.6, 21.8. HRMS (EI+) calcd. for $C_{18}H_{17}NO_3S_2$ $[M]^+$: 359.0650, found: 359.0648.

196j: obtained from aldehyde **ab2** and PhLi, 303 mg (78%), R_f = 0.19 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.46-7.45 (m, 2H), 7.30-7.26 (m, 4H), 7.18-7.16 (m, 2H), 7.09-7.08 (m, 2H), 6.66 (dd, J = 10.8, 8.6 Hz, 1H), 5.53 (s, 1H), 2.39 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 149.5 (dd, J_{C-F} = 249.7, 13.9 Hz), 147.1 (dd, J_{C-F} = 247.8, 12.9 Hz), 144.3, 140.4, 135.8, 131.8 (q, J_{C-F} = 6.5 Hz), 131.0, 129.8, 128.8, 128.2, 127.1, 126.3, 117.6 (q, J_{C-F} = 19.4 Hz), 112.2 (d, J_{C-F} = 21.3 Hz), 73.2, 21.5. HRMS (EI+) calcd. for $C_{20}H_{17}NO_3SF_2$ $[M]^+$: 389.0897, found: 389.0895.

196k: obtained from aldehyde **ab6** and PhLi, 313 mg (76%), R_f = 0.10 (Hexanes/EtOAc = 2/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.53-7.51 (m, 2H), 7.31-7.27 (m, 4H), 7.21-7.19 (m, 2H), 7.15-7.13 (m, 2H), 6.83 (s, 1H), 6.45 (s, 1H), 5.62 (d, *J* = 3.3 Hz, 1H), 3.75 (s, 3H), 3.68 (s, 3H), 2.73 (s_{br}, 1H), 2.41 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 148.7, 146.8, 143.8, 141.6, 136.3, 129.6, 128.7, 128.5, 127.7, 127.4, 126.3, 111.5, 108.6, 73.0, 55.9, 21.5. HRMS (EI+) calcd. for $C_{22}H_{23}NO_5S$ $[M]^+$: 413.1297, found: 413.1294.

196l: obtained from aldehyde **ab3** and PhLi, 341 mg (81%), R_f = 0.16 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.34 (s_{br}, 1H), 7.72 (s, 1H), 7.45-7.44 (m, 2H), 7.33-7.31 (m, 3H), 7.26-7.24 (d, *J* = 8.1 Hz, 1H), 7.18-7.14 (m, 4H), 7.07 (d, *J* = 8.1 Hz, 1H), 5.77 (s, 1H), 3.18 (s, 1H), 2.38 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 144.2, 140.3, 136.4, 136.0, 135.7, 131.1 (q, J_{C-F} = 32.4 Hz), 129.7, 129.5, 128.8, 128.2, 127.2, 126.2, 123.5 (q, J_{C-F} = 272.8 Hz), 120.8, 118.0, 74.5, 21.5. HRMS (EI+) calcd. for $C_{21}H_{18}NO_3SF_3$ $[M]^+$: 421.0960, found: 421.0940.

196m: obtained from aldehyde **ab4** and PhLi, 401 mg (93%), R_f = 0.12 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.02 (s_{br}, 1H), 7.45-7.43 (m, 2H), 7.33-7.32 (m, 5H), 7.16-7.14 (m, 4H), 7.07 (d, *J* = 1.8 Hz, 1H), 5.61 (s, 1H), 2.96 (s_{br}, 1H), 2.39 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.9, 140.2, 136.1, 135.1, 134.6, 131.8, 131.7, 129.7, 128.8, 128.2, 127.1, 126.3, 123.5, 117.7, 74.2, 21.5. HRMS (ES+) calcd. for $C_{20}H_{18}NO_3SBrNa$ $[M+Na]^+$: 454.0088, found: 454.0090.

196n: obtained from aldehyde **ab7** and PhLi, 235 mg (64%), R_f = 0.08 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.63-7.61 (m, 2H), 7.33-7.27 (m, 5H), 7.21-7.19 (m, 2H), 7.11-7.07 (m, 2H), 6.94 (d, *J* = 9.0 Hz, 1H), 6.73 (s, 1H), 5.96 (s, 1H), 3.11 (s_{br}, 1H), 2.45 (s, 3H), 1.94 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 144.1, 142.8, 142.5, 137.1, 137.0, 132.0, 130.7, 129.8, 128.3, 128.0, 127.3, 127.2, 127.1, 126.5, 71.3, 21.6, 18.4. HRMS (EI+) calcd. for $C_{21}H_{21}NO_3S$ $[M]^+$: 367.1242, found: 367.1241.

196o: obtained from aldehyde **ab5** and PhLi, 232 mg (60%), R_f = 0.10 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55-7.54 (m, 2H), 7.37-7.35 (m, 2H), 7.32-7.21 (m, 6H), 7.14-7.13 (m, 2H), 6.67 (s_{br}, 1H), 6.61 (s, 1H), 3.78 (s_{br}, 1H), 2.42 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 146.4, 144.5, 142.9, 135.6, 132.0, 130.2, 129.6, 129.2, 129.0, 128.6, 128.1, 127.6, 127.0, 126.1, 70.2, 21.6. HRMS (EI+) calcd. for $C_{20}H_{18}NO_3SCl$ $[M]^+$: 387.0696, found: 387.0697.

7.3. One-Pot Synthesis of Indoles 199 from *ortho*-Aminobenzyl Alcohols 196 and Furans 197

Optimization of the one-pot synthesis of indoles from *o*-aminobenzyl alcohols. In a 1 mL Wheaton microreactor vial, equipped with a Teflon pressure cap, a mixture of *o*-aminobenzyl alcohol **196a** (0.1 mmol, 35.3 mg), 2-methylfuran **197a** (0.2 mmol, 2 equiv, 18 μL), catalyst, and DCE (0.4 mL, 0.25M) was stirred at 80 °C. The progress of the reaction was monitored by TLC (eluent Hexane/EtOAc = 4/1). After

completion, the reaction mixture was filtered through Celite, the solvent was evaporated and crude product was analyzed by ^{1}H NMR.

General procedure for one-pot synthesis of indoles 199 from *o*-amino-benzylalcohols and furans: In a 3 mL Wheaton microreactor vial, to a stirred suspension of *ortho*-aminobenzylalcohol **196** (0.4 mmol) and furan **197** (0.6 mmol, 1.5 equiv) in DCE (1.3 mL, 0.3M), triflic acid (0.04 mmol, 10 mol%, 3.6 μL) was added. The microreactor was capped with a Teflon pressure cap and placed into pre-heated (80 °C) aluminum block. The resulted solution was stirred for 1-2 h at this temperature. After completion of the reaction (determined by TLC, eluent Hexanes/EtOAc = 4/1), microreactor, containing product **199**, was cooled down and the reaction mixture was diluted with 1.5 mL of Hexanes. The product was purified using flash silica gel column chromatography.

199aa: 150 mg (90%), yellow oil, eluent: Hexanes/EtOAc = 7/1; Rf = 0.42 (Hexanes/EtOAc = 4/1). The spectral data matched those of the previously synthesized material.[130b] ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.26 (d, J = 8.4 Hz, 1H), 7.65 (d, J = 8.1 Hz, 2H), 7.46-7.43 (m, 2H), 7.39-7.28 (m, 5H), 7.23-7.18 (m, 3H), 3.35 (t, J = 7.7 Hz, 2H), 2.94 (t, J = 7.7 Hz, 2H), 2.34 (s, 3H), 2.14 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.3, 144.9, 136.7, 136.3, 135.5, 132.6, 130.6, 129.9, 129.8, 128.7, 127.7, 126.4, 124.7, 124.4, 123.9, 119.5, 115.2, 44.7, 29.8, 21.6, 21.3. HRMS (EI+) calcd. for $C_{25}H_{23}NO_3S$ $[M]^+$: 417.1399, found: 417.1388.

199ab: 174 mg (95%), yellow oil, eluent: Hexanes/EtOAc = 7/1; Rf = 0.42 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.25 (d, *J* = 8.0 Hz, 1H), 7.65 (d, *J* = 8.4 Hz, 2H), 7.45-7.42 (m, 2H), 7.39-7.29 (m, 4H), 7.26-7.22 (m, 2H), 7.19 (d, *J* = 8.4 Hz, 2H), 3.22 (t, *J* = 7.7 Hz, 2H), 2.89 (t, *J* = 7.7 Hz, 2H), 2.37 (t, *J* = 7.3 Hz, 2H), 2.32 (s, 3H), 1.58-1.52 (m, 2H), 1.34-1.26 (m, 2H), 0.90 (t, *J* = 7.3 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 209.7, 144.9, 136.6, 136.5, 135.5, 132.7, 130.5, 129.8 (2C), 128.7, 127.6, 126.4, 124.7, 124.3, 123.9, 119.5, 115.2, 43.7, 42.4, 26.0, 22.3, 21.6, 21.3, 13.9. HRMS (EI+) calcd. for $C_{28}H_{29}NO_3S$ $[M]^+$: 459.1868, found: 459.1867.

199ac: 175 mg (93%), yellow oil, eluent: Hexanes/EtOAc = 7/1; Rf = 0.36 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.27 (d, *J* = 9.1 Hz, 1H), 7.65 (d, *J* = 8.1 Hz, 2H), 7.45-7.42 (m, 2H), 7.38-7.28 (m, 5H), 7.24-7.22 (m, 1H), 7.19 (d, *J* = 8.1 Hz, 2H), 3.24 (t, *J* = 7.7 Hz, 2H), 2.96 (t, *J* = 7.7 Hz, 2H), 2.85 (pent, *J* = 8.4 Hz, 1H), 2.34 (s, 3H), 1.84-1.70 (m, 4H), 1.68-1.54 (m, 4H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 211.6, 144.8, 136.7, 136.7, 135.7, 132.8, 130.6, 129.8, 129.8, 128.7, 127.6, 126.4, 124.6, 124.2, 123.8, 119.5, 115.2, 51.3, 42.8, 28.8, 26.0, 21.5, 21.4. HRMS (EI+) calcd. for $C_{29}H_{29}NO_3S$ $[M]^+$: 471.1868, found: 471.1877.

199ad: 146 mg (75%), yellow oil, eluent: Hexanes/EtOAc = 9/1; R_f = 0.41 (Hexanes/EtOAc = 9/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.27 (d, *J* = 8.4 Hz, 1H), 7.64 (d, *J* = 8.0 Hz, 2H), 7.45-7.42 (m, 2H), 7.38-7.27 (m, 5H), 7.26-7.21 (m, 1H), 7.19 (d, *J* = 8.0 Hz, 2H), 3.21 (t, *J* = 7.7 Hz, 2H), 2.94 (t, *J* = 7.7 Hz, 2H), 2.34 (s, 3H), 1.85-1.75 (m, 4H), 1.66-1.64 (m, 1H), 1.34-1.17 (m, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 212.5, 144.8,

136.8, 136.7, 135.6, 132.7, 130.6, 129.8, 129.7, 128.6, 127.6, 126.4, 124.6, 124.2, 123.8, 119.4, 115.2, 50.7, 41.7, 28.5, 25.9, 25.7, 21.5, 21.3. HRMS (ES+) calcd. for $C_{30}H_{32}NO_3S$ $[M+H]^+$: 486.2103, found 486.2081.

199ae: 166 mg (87%), yellow oil, eluent: Hexanes/EtOAc = 9/1; R_f = 0.38 (Hexanes/EtOAc = 9/1). ^1H NMR (400 MHz, $CDCl_3$) δ 8.30 (d, *J* = 9.7 Hz, 1H), 7.95-7.93 (m, 2H), 7.68 (d, *J* = 8.4 Hz, 2H), 7.56-7.53 (m, 1H), 7.45-7.42 (m, 4H), 7.38-7.31 (m, 5H), 7.25-7.19 (m, 3H), 3.49-3.42 (m, 4H), 2.34 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.6, 144.9, 136.8, 136.6, 136.5, 135.6, 133.0, 132.7, 130.6, 129.9, 129.8, 128.7, 128.5, 128.1, 127.7, 126.4, 124.7, 124.5, 123.9, 119.5, 115.2, 40.1, 21.8, 21.5. HRMS (ES+) calcd. for $C_{30}H_{25}NO_3S$ $[M+H]^+$: 480.1633, found: 480.1638.

199af: 173 mg (85%), colorless oil, eluent: Hexanes/EtOAc = 5/1; R_f = 0.24 (Hexanes/EtOAc = 5/1). ^1H NMR (500 MHz, $CDCl_3$) δ 8.30 (d, *J* = 8.4 Hz, 1H), 7.74-7.72 (m, 1H), 7.68 (d, *J* = 8.0 Hz, 2H), 7.44-7.42 (m, 3H), 7.36-7.32 (m, 5H), 7.24-7.22 (m, 1H), 7.19 (d, *J* = 8.0 Hz, 2H), 7.01-6.92 (m, 2H), 3.84 (s, 3H), 3.49 (t, *J* = 7.1 Hz, 2H), 3.41 (t, *J* = 7.1 Hz, 2H), 2.34 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 200.4, 158.8, 144.7, 137.2, 136.7, 135.8, 133.4, 132.9, 130.7, 130.4, 129.9 (2C), 129.7 (2C), 128.7 (2C), 127.8, 127.5, 126.4 (2C), 124.5, 124.1, 123.8, 120.5, 119.4, 115.2, 111.5, 55.5, 45.0, 21.8, 21.5. HRMS (EI+) calcd. for $C_{31}H_{27}NO_4S$ $[M]^+$: 509.1661, found: 509.1663.

199ag: 122 mg (56%), colorless oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.26 (Hexanes/EtOAc = 7/1). ^1H NMR (500 MHz, $CDCl_3$) δ 8.27 (d, *J* = 8.4 Hz, 1H), 7.71-

7.69 (m, 1H), 7.67 (d, J = 8.4 Hz, 2H), 7.61-7.58 (m, 1H), 7.56-7.50 (m, 2H), 7.47-7.44 (m, 2H), 7.41-7.29 (m, 5H), 7.24-7.20 (m, 3H), 3.43-3.36 (m, 4H), 2.35 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 202.7, 144.9, 139.9, 136.7, 135.8, 135.6, 132.5, 131.8, 130.5, 130.0, 129.9, 129.7, 128.7, 127.8, 127.1, 126.9 (q, J_{C-F} = 32.4 Hz), 126.6 (q, J_{C-F} = 4.4 Hz), 126.4, 124.8, 124.6, 123.9, 123.6 (q, J_{C-F} = 272.5 Hz), 119.6, 115.1, 44.4, 21.6, 21.4. HRMS (EI+) calcd. for $C_{31}H_{24}NO_3SF_3$ $[M]^+$: 547.1429, found: 547.1435.

199ah: 112 mg (53%), yellow oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.28 (Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.60 (d, J = 8.4 Hz, 1H), 8.29 (d, J = 8.8 Hz, 1H), 7.97 (d, J = 8.4 Hz, 1H), 7.90-7.86 (m, 2H), 7.69 (d, J = 8.0 Hz, 2H), 7.59-7.51 (m, 2H), 7.48-7.43 (m, 3H), 7.40-7.32 (m, 5H), 7.25-7.22 (m, 1H), 7.20 (d, J = 8.0 Hz, 2H), 3.53-3.49 (m, 4H), 2.34 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 202.8, 144.9, 136.8, 136.5, 135.7, 135.5, 133.9, 133.2, 132.9, 132.7, 132.6, 130.5, 130.1, 129.8, 128.8, 128.4, 127.8, 127.7, 126.4, 126.3, 125.8, 124.7, 124.5, 124.4, 123.9, 119.5, 115.2, 43.3, 22.1, 21.5. HRMS (ES+) calcd. for $C_{34}H_{27}NO_3S$ $[M+H]^+$: 530.1790, found: 530.1791.

199ai: 116 mg (48%), colorless oil, eluent: Hexanes/EtOAc = 9/1; R_f = 0.33 (Hexanes/EtOAc = 9/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.25 (d, J = 8.4 Hz, 1H), 7.71 (d, J = 8.4 Hz, 2H), 7.48-7.39 (m, 3H), 7.34-7.31 (m, 4H), 7.23-7.20 (m, 3H), 6.98 (s, 2H), 3.45 (t, J = 7.5 Hz, 2H), 3.25 (t, J = 7.5 Hz, 2H), 2.88 (sept, J = 6.6 Hz, 1H), 2.60 (sept, J = 6.6 Hz, 2H), 2.36 (s, 3H), 1.25 (d, J = 6.6 Hz, 6H), 1.20 (d, J = 6.6 Hz, 12H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 209.4, 149.4, 144.8, 143.6, 137.5, 136.6, 136.3, 135.8, 132.9, 130.5,

129.9, 129.8, 128.7, 127.7, 126.4, 124.6, 124.4, 123.8, 121.0, 119.4, 115.1, 47.7, 34.3, 30.9, 24.5, 24.0, 21.6, 21.1. HRMS (EI+) calcd. for $C_{39}H_{43}NO_3S$ $[M]^+$: 605.2964, found: 605.2958.

199aj: 131 mg (60%), colorless oil; eluent: Hexanes/EtOAc = 9/1; R_f = 0.23 (Hexanes/EtOAc = 9/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.29 (d, J = 8.4 Hz, 1H), 8.04 (d, J = 8.4 Hz, 2H), 7.70 (d, J = 8.0 Hz, 2H), 7.66 (d, J = 8.4 Hz, 2H) 7.45-7.42 (m, 2H), 7.39-7.30 (m, 5H), 7.25-7.22 (m, 1H), 7.20 (d, J = 8.4 Hz, 2H), 3.51-3.43 (m, 4H), 2.34 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.7, 145.0, 139.2, 136.8, 136.0, 135.5, 134.3 (q, $J_{C\text{-}F}$ = 32.4 Hz), 132.6, 130.5, 129.9, 129.8, 128.8, 128.4, 127.8, 126.4, 125.6 (q, $J_{C\text{-}F}$ = 3.0 Hz), 124.9, 124.8, 124.0, 123.7 (q, $J_{C\text{-}F}$ = 272.7 Hz), 119.6, 115.2, 40.4, 21.8, 21.5. HRMS (EI+) calcd. for $C_{31}H_{24}NO_3SF_3$ $[M]^+$: 547.1429, found: 547.1437.

199ak: 165 mg (83%), light blue oil; eluent: Hexanes/EtOAc = 7/1; R_f = 0.31 (Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.30 (d, J = 8.8 Hz, 1H), 7.98-7.95 (m, 2H), 7.67 (d, J = 7.7 Hz, 2H), 7.45-7.42 (m, 2H), 7.38-7.31 (m, 5H), 7.25-7.19 (m, 3H), 7.11-7.08 (m, 2H), 3.44 (s, 4H), 2.34 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.0, 165.7 (d, $J_{C\text{-}F}$ = 255 Hz), 144.9, 136.8, 136.4, 135.6, 133.1, 132.6, 130.7 (d, $J_{C\text{-}F}$ = 9.25 Hz), 130.5 , 129.9, 129.8, 128.8, 127.7, 126.4, 124.6, 124.4 (d, $J_{C\text{-}F}$ = 105 Hz), 119.6, 115.7, 115.5, 115.2, 40.0, 21.8, 21.5. HRMS (EI+) calcd. for $C_{30}H_{24}NO_3SF$ $[M]^+$: 497.1461, found: 497.1455.

199al: 156 mg (70%), colorless oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.28 (Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.29 (d, *J* = 8.0 Hz, 1H), 7.80 (d, *J* = 8.4 Hz, 2H), 7.67 (d, *J* = 8.0 Hz, 2H), 7.57 (d, *J* = 8.8 Hz, 2H), 7.45-7.45 (m, 2H), 7.39-7.30 (m, 5H), 7.25-7.19 (m, 3H), 3.43 (s, 4H), 2.34 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.6, 144.9, 136.8, 136.2, 135.5, 135.3, 132.6, 131.8, 130.5, 129.9, 129.8, 129.6, 128.8, 128.2, 127.7, 126.4, 124.8, 124.7, 123.9, 119.6, 115.2, 40.0, 21.8, 21.5. HRMS (ES+) calcd. for $C_{30}H_{24}NO_3SBr$ $[M+H]^+$: 558.0739, found: 558.0742.

199am: 114 mg (56%), colorless oil, eluent: Hexanes/EtOAc = 4/1; R_f = 0.33 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.29 (d, *J* = 9.1 Hz, 1H), 7.92 (d, *J* = 8.4 Hz, 2H), 7.68-7.66 (m, 2H), 7.44-7.41 (m, 2H), 7.37-7.29 (m, 5H), 7.24-7.21 (m, 1H), 7.19 (d, *J* = 8.4 Hz, 2H), 6.91-6.89 (m, 2H), 3.86 (s, 3H), 3.41 (s, 4H), 2.34 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.2, 163.4, 144.8, 136.8, 132.7, 130.6, 130.3, 129.9, 129.5, 128.9, 128.7, 128.0, 127.6, 126.4, 125.9, 124.7, 124.3, 123.9, 119.5, 115.2, 113.6, 55.4, 39.8, 21.9, 21.5. HRMS (ES+) calcd. for $C_{31}H_{28}NO_4S$ $[M+H]^+$: 510.1739, found: 510.1741.

199an: 123 mg (61%), yellow oil, eluent: Hexanes/EtOAc = 5/1; R_f = 0.20 (Hexanes/EtOAc = 5/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.26 (d, *J* = 9.7 Hz, 1H), 7.64 (d, *J* = 8.4 Hz, 2H), 7.45-7.42 (m, 2H), 7.38-7.27 (m, 5H), 7.23-7.18 (m, 3H), 4.12 (q, *J* = 7.0 Hz, 2H), 3.26 (t, *J* = 7.7 Hz, 2H), 2.96 (t, *J* = 7.7 Hz, 2H), 2.73 (t, *J* = 6.6 Hz, 2H), 2.58 (t, *J* = 6.6 Hz, 2H), 2.34 (s, 3H), 1.24 (t, *J* = 7.0 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.3, 172.6, 144.8, 136.7, 136.3, 135.6, 132.6, 130.5, 129.8, 129.7, 128.7,

127.7, 126.3, 124.7, 124.4, 123.9, 119.5, 115.2, 60.6, 43.7, 36.9, 28.0, 21.5, 21.5, 14.2. HRMS (EI+) calcd. for $C_{29}H_{29}NO_5S$ $[M]^+$: 503.1766, found: 503.1759.

199ao: 189 mg (68%), colorless oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.21 (Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.26 (d, *J* = 8.0 Hz, 1H), 7.65-7.63 (m, 2H), 7.45-7.42 (m, 2H), 7.39-7.36 (m, 1H), 7.34-7.26 (m, 4H), 7.23-7.17 (m, 3H), 4.74 (sept, *J* = 4.2 Hz, 1H), 3.28-3.24 (m, 2H), 2.98-2.94 (m, 2H), 2.73 (t, *J* = 6.7 Hz, 2H), 2.56 (t, *J* = 6.6 Hz, 2H), 2.33 (s, 3H), 1.83-1.80 (m, 2H), 1.73-1.68 (m, 2H), 1.55-1.50 (m, 1H), 1.44-1.22 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 207.3, 172.1, 144.9, 136.7, 136.3, 135.6, 132.6, 130.5, 129.8, 129.8, 128.7, 127.7, 126.4, 124.7, 124.4, 123.9, 119.5, 115.2, 72.9, 43.7, 37.1, 31.5, 28.4, 25.3, 23.7, 21.6, 21.3. HRMS (EI+) calcd. for $C_{30}H_{35}NO_5S$ $[M]^+$: 557.2236, found: 557.2243.

199ap: 150 mg (87%), yellow oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.31 (Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.25 (d, *J* = 8.0 Hz, 1H), 7.61 (d, *J* = 8.0 Hz, 2H), 7.45-7.42 (m, 2H), 7.39-7.27 (m, 5H),7.23-7.20 (m, 1H), 7.18 (d, *J* = 8.0 Hz, 2H), 3.47 (dd, *J* = 14.4, 4.4 Hz, 1H), 3.32-3.25 (m, 1H), 2.97 (dd, *J* = 14.4, 9.5 Hz, 1H), 2.33 (s, 3H), 2.13 (s, 3H), 0.82 (d, *J* = 7.3 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 211.8, 144.8, 137.0, 135.3, 135.1, 132.7, 130.8, 130.2, 129.7, 128.7, 127.7, 126.8, 126.3, 124.8, 124.1, 119.6, 115.5, 47.5, 29.4, 28.5, 21.5, 15.4. HRMS (EI+) calcd. for $C_{26}H_{25}NO_3S$ $[M]^+$: 431.1555, found: 431.1559.

199aq: 128 mg (70%), yellow oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.16 (Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.26 (d, *J* = 8.7 Hz, 1H), 7.62 (d, *J* = 8.2 Hz, 2H), 7.44-7.40 (m, 2H), 7.35-7.26 (m, 3H), 7.25-7.16 (m, 5H), 3.65 (dd, *J* = 14.6, 3.5 Hz, 1H), 3.08-3.00 (m, 1H), 2.89 (dd, *J* = 14.6, 9.9 Hz, 1H), 2.33 (s, 3H), 2.34-2.31 (m, 2H), 2.05-1.99 (m, 1H), 1.81-1.76 (m, 1H), 1.68-1.65 (m, 1H), 1.59-1.48 (m, 2H), 0.90-0.83 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 212.0, 144.8, 137.0, 135.6, 135.2, 133.0, 130.8, 130.2, 129.7, 128.6, 127.6, 126.6, 126.4, 124.6, 124.0, 119.4, 115.5, 51.2, 42.0, 32.7, 27.8, 26.7, 25.1, 21.5. HRMS (EI+) calcd. for $C_{28}H_{27}NO_3S$ $[M]^+$: 457.1712, found: 457.1716.

199ar: 82 mg (45%), colorless oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.39 (Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.19 (d, *J* = 8.4 Hz, 1H), 7.46-7.33 (m, 9H), 7.27-7.25 (m, 1H), 7.08-7.03 (m, 3H), 6.80-6.65 (m, 3H), 5.53 (s, 1H), 4.45 (s, 2H), 2.31 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 153.0, 144.6, 136.7, 135.6, 134.7, 132.7, 130.2, 129.8 129.6, 129.6, 126.4, 128.8, 127.7, 127.4, 126.5, 126.1, 124.8, 123.7, 120.9, 119.7, 116.2, 115.1, 26.0, 21.5. HRMS (EI+) calcd. for $C_{28}H_{23}NO_3S$ $[M]^+$: 453.1399, found: 453.1407.

198as: 184 mg (95%), colorless oil, eluent: Hexanes/EtOAc = 9/1; R_f = 0.39 (Hexanes/EtOAc = 9/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.58 (d, *J* = 8.1 Hz, 2H), 7.48 (d, *J* = 7.6 Hz, 1H), 7.27-7.25 (m, 1H), 7.24-7.20 (m, 3H), 7.06 (dd, *J* = 8.1, 7.0 Hz, 1H), 6.81-6.78 (m, 3H), 6.43 (d, *J* = 7.0 Hz, 1H), 4.88 (d, *J* = 4.0 Hz, 1H), 2.60-2.52 (m, 1H), 2.43 (s, 3H), 2.37-2.27 (m, 2H), 2.13-2.05 (m, 1H), 1.91-1.79 (m, 2H), 2.66 (d, *J* = 4.0

Hz, 3H), 1.38-1.26 (m, 2H), 1.05 (d, *J* = 7.0 Hz, 3H), 1.01-0.84 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 150.0, 145.4, 143.8, 140.1, 137.0, 135.4, 135.3, 134.4, 129.7, 128.7, 128.6, 127.7, 127.1, 126.9, 126.0, 124.9, 124.8, 118.2, 116.5, 44.7, 31.4, 31.2, 29.6, 21.5, 20.1, 7.9. HRMS (EI+) calcd. for $C_{30}H_{31}NO_3S$ $[M]^+$: 485.2025, found: 485.2015.

199ba: 125 mg (88%), colorless oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.31 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.19 (d, *J* = 8.4 Hz, 1H), 7.57-7.56 (m, 2H), 7.37 (d, *J* = 7.7 Hz, 1H), 7.31-7.23 (m, 2H), 7.15-7.14 (m, 2H), 3.23-3.20 (m, 2H), 2.94-2.91 (m, 2H), 2.31 (s, 3H), 2.17 (s, 3H), 2.15 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.7, 144.5, 136.6, 135.6, 135.4, 131.4, 129.7, 126.2, 124.3, 123.5, 118.5, 117.6, 115.0, 43.9, 29.9, 21.5, 20.7, 8.9. HRMS (ES+) calcd for $C_{20}H_{22}NO_3S$ $[M+H]^+$: 356.1320, found: 356.1323.

199ca: 117 mg (76%), colorless oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.35 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.21 (d, *J* = 8.3 Hz, 1H), 7.59 (d, *J* = 7.7 Hz, 1H), 7.55-7.53 (m, 2H), 7.26 (m, 1H), 7.21 (m, 1H), 7.16-7.14 (m, 2H), 3.24-3.20 (m, 2H), 3.14 (sept, *J* = 7.0 Hz, 1H), 2.90-2.87 (m, 2H), 2.32 (s, 3H), 2.18 (s, 3H), 1.32 (d, *J* = 7.2 Hz, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.7, 144.5, 137.2, 135.7, 134.2, 129.7, 129.2, 127.3, 126.2, 123.8, 123.0, 120.2, 115.4, 44.6, 30.0, 25.9, 22.1, 21.5, 20.8. HRMS (ES+) calcd for $C_{22}H_{26}NO_3S$ $[M+H]^+$: 384.1633, found: 384.1636.

199da: 100 mg (63%), colorless oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.33 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.28 (d, *J* = 8.4 Hz, 1H), 7.77 (d,

J = 8.1 Hz, 1H), 7.49-7.48 (m, 2H), 7.24 (m, 1H), 7.19 (m, 1H), 7.15-7.14 (m, 2H), 3.45-3.42 (m, 2H), 2.91 (s_{br}, 2H), 2.32 (s, 3H), 2.19 (s, 3H), 1.46 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.6, 144.5, 137.7, 135.7, 135.0, 130.3, 129.6, 129.0, 126.1, 123.7, 122.9, 122.3, 115.8, 45.4, 34.0, 31.6, 29.9, 21.6, 21.5. HRMS (ES+) calcd for $C_{23}H_{28}NO_3S$ $[M+H]^+$: 398.1790, found: 398.1797.

199ea: 141 mg (83%), colorless oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.36 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.21 (d, *J* = 8.3 Hz, 1H), 7.64 (d, *J* = 7.7 Hz, 1H), 7.54-7.52 (m, 2H), 7.24 (t, *J* = 8.3 Hz, 1H), 7.19 (t, *J* = 7.9 Hz, 1H), 7.15-7.13 (m, 2H), 3.25-3.22 (m, 2H), 2.90-2.87 (m, 2H), 2.72 (m, 1H), 2.31 (s, 3H), 2.18 (s, 3H), 1.90-1.77 (m, 5H), 1.61-1.59 (m, 2H), 1.42-1.26 (m, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.8, 144.5, 137.2, 135.7, 124.6, 129.7, 126.6, 126.2, 123.8, 123.0, 120.5, 115.3, 44.7, 36.7, 32.0, 30.0, 26.9, 26.1, 21.5, 20.8. HRMS (ES+) calcd for $C_{25}H_{30}NO_3S$ $[M+H]^+$: 424.1946, found: 424.1944.

199fa: 127 mg (71%), yellow oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.19 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.25 (d, *J* = 8.8 Hz, 1H), 7.65-7.63 (m, 2H), 7.33-7.30 (m, 2H), 7.21-7.17 (m, 5H), 6.99-6.97 (m, 2H), 3.85 (s, 3H), 3.26-3.23 (m, 2H), 2.95-2.92 (m, 2H), 2.33 (s, 3H), 2.13 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.3, 159.1, 144.8, 136.6, 136.0, 135.5, 130.9, 130.8, 129.8, 126.3, 124.7, 124.6, 124.1, 123.8, 119.4, 115.1, 114.2, 55.2, 44.6, 29.7, 21.5, 21.3. HRMS (EI+) calcd for $C_{26}H_{25}NO_4S$ $[M]^+$: 447.1504, found: 447.1509.

199ga: 103 mg (60%), yellow oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.25 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.26 (d, *J* = 9.0 Hz, 1H), 7.65-7.64 (m, 2H), 7.33-7.31 (m, 2H), 7.28-7.26 (m, 2H), 7.23 (m, 1H), 7.20-7.18 (m, 4H), 3.24-3.20 (m, 2H), 2.95-2.91 (m, 2H), 2.42 (s, 3H), 2.34 (s, 3H), 2.14 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.3, 144.8, 137.4, 136.6, 136.1, 135.5, 130.6, 129.8, 129.6, 129.5, 129.4, 126.3, 124.6, 124.4, 123.8, 119.5, 115.1, 44.7, 29.7, 21.5, 21.3, 21.2. HRMS (EI+) calcd for $C_{26}H_{25}NO_3S$ $[M]^+$: 431.1555, found: 431.1561.

199ha: 126 mg (72%), yellow oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.23 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.26 (d, *J* = 8.4 Hz, 1H), 7.65-7.64 (m, 2H), 7.33 (t, *J* = 8.3 Hz, 1H), 7.28-7.22 (m, 4H), 7.20-7.19 (m, 2H), 7.14 (d, *J* = 8.6 Hz, 2H), 3.24-3.20 (m, 2H), 2.95-2.91 (m, 2H), 2.34 (s, 3H), 2.14 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.1, 162.3 (d, J_{C-F} = 247.8 Hz), 145.0, 136.6, 136.5, 135.5, 131.5 (d, J_{C-F} = 7.4 Hz), 130.5, 129.9, 128.6 (d, J_{C-F} = 2.8 Hz), 126.4, 124.4 (d, J_{C-F} = 105.4 Hz), 123.4, 119.3, 115.9, 115.7, 115.2, 44.6, 29.7, 21.6, 21.2. HRMS (ES+) calcd for $C_{25}H_{23}FNO_3S$ $[M+H]^+$: 436.1383, found: 436.1376.

199ia: 69 mg (41%), yellow oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.22 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.25 (d, *J* = 8.4 Hz, 1H), 7.67-7.65 (m, 2H), 7.54 (d, *J* = 7.7 Hz, 1H), 7.39 (dd, *J* = 5.3, 0.7 Hz, 1H), 7.34 (m, 1H), 7.26 (m, 1H), 7.21-7.20 (m, 2H), 7.14 (m, 1H), 7.05 (dd, *J* = 3.5, 0.7 Hz, 1H), 3.36-3.33 (m, 2H), 3.00-2.97 (m, 2H), 2.34 (s, 3H), 2.18 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.1, 145.1, 137.6, 136.3, 135.6, 133.1, 130.1, 129.9, 127.5, 127.4, 126.4, 126.0, 124.9, 124.0,

119.6, 116.8, 115.0, 44.7, 29.8, 21.6, 21.4. HRMS (ES+) calcd for $C_{23}H_{22}NO_3S_2$ $[M+H]^+$: 424.1041, found: 424.1042.

199ja: 143 mg (79%), colorless solid, eluent: Hexanes/EtOAc = 7/1; R_f = 0.27 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.12 (dd, *J* = 11.4, 7.0 Hz, 1H), 7.64-7.62 (m, 2H), 7.46-7.43 (m, 2H), 7.38 (m, 1H), 7.25-7.22 (m, 4H), 7.12 (dd, *J* = 9.9, 7.9 Hz, 1H), 3.21-3.18 (m, 2H), 2.93-2.90 (m, 2H), 2.37 (s, 3H), 2.13 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 206.9, 148.8 (ddd, $J_{C\text{-}F}$ = 244.1, 19.4, 14.8 Hz), 145.4, 137.6 (d, $J_{C\text{-}F}$ = 4.6 Hz), 135.1, 131.9, 131.6, 131.6, 130.0, 129.5, 128.9, 128.0, 126.3, 123.8, 107.6 (d, $J_{C\text{-}F}$ = 19.4 Hz), 104.5 (d, $J_{C\text{-}F}$ = 24.0 Hz), 44.5, 29.7, 21.6, 21.3. HRMS (ES+) calcd for $C_{25}H_{22}NO_3SF_2$ $[M+H]^+$: 454.1288, found: 454.1291.

199ka: 114 mg (60%), yellow solid, eluent: Hexanes/EtOAc = 3/1; R_f = 0.19 (Hexanes/EtOAc = 3/1). The spectral data matched those of the previously synthesized material.[130b] ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.85 (s, 1H), 7.59-7.57 (m, 2H), 7.46-7.43 (m, 2H), 7.37 (m, 1H), 7.26-7.25 (m, 2H), 7.19-7.17 (m, 2H), 6.72 (s, 1H), 4.00 (s, 3H), 3.79 (s, 3H), 3.19-3.16 (m, 2H), 2.93-2.90 (m, 2H), 2.33 (s, 3H), 2.12 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.3, 147.8, 147.4, 144.7, 135.3, 134.8, 132.8, 130.7, 129.7, 129.6, 128.7, 127.6, 126.1, 124.7, 123.5, 100.8, 99.3, 56.4, 56.0, 44.7, 29.7, 21.5, 21.4. HRMS (ES+) calcd for $C_{27}H_{28}NO_5S$ $[M+H]^+$: 478.1688, found: 478.1679.

199la: 122 mg (63%), colorless solid, eluent: Hexanes/EtOAc = 7/1; R_f = 0.24 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.57 (d, *J* = 0.7 Hz, 1H), 7.67-

7.65 (m, 2H), 7.48-7.45 (m, 3H), 7.42-7.38 (m, 2H), 7.28-7.23 (m, 4H), 3.28-3.25 (m, 2H), 2.95-2.92 (m, 2H), 2.36 (s, 3H), 2.14 (d, J = 1.3 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 206.8, 145.4, 139.1, 135.8, 135.2, 132.9, 131.9, 130.0, 129.7, 128.9, 128.0, 126.7 (q, J_{C-F} = 31.4 Hz), 126.4, 124.6 (q, J_{C-F} = 271.9 Hz), 123.9, 120.6 (d, J_{C-F} = 2.8 Hz), 119.8, 112.5 (d, J_{C-F} = 3.7 Hz), 44.4, 29.7, 21.5, 21.2. HRMS (ES+) calcd for $C_{26}H_{23}NO_3SF_3$ $[M+H]^+$: 486.1351, found: 486.1350.

199ma: 121 mg (61%), yellowish solid, eluent: Hexanes/EtOAc = 7/1; R_f = 0.21 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.13 (d, J = 8.6 Hz, 1H), 7.63-7.62 (m, 2H), 7.46-7.38 (m, 5H), 7.26-7.21 (m, 4H), 3.24-3.20 (m, 2H), 2.94-2.91 (m, 2H), 2.35 (s, 3H), 2.13 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 206.9, 145.2, 137.7, 135.3, 135.2, 132.3, 131.9, 129.9, 129.7, 128.9, 128.0, 127.5, 126.3, 123.6, 122.2, 117.5, 116.6, 44.5, 29.7, 21.6, 21.2. HRMS (ES+) calcd for $C_{25}H_{23}BrNO_3S$ $[M+H]^+$: 496.0582, found: 496.0583.

199oa: 68 mg (58%), colorless solid, eluent: Hexanes/EtOAc = 7/1; R_f = 0.23 (Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.05 (s_{br}, 1H), 7.52-7.44 (m, 5H), 7.37 (m, 1H), 7.19 (d, J = 7.5 Hz, 1H), 7.04 (t, J = 7.7 Hz, 1H), 3.14-3.12 (m, 2H), 2.92-2.89 (m, 2H), 2.22 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 209.5, 135.8, 134.8, 132.4, 129.6, 129.0, 128.6, 126.3, 121.1, 120.5, 117.5, 116.2, 115.5, 43.8, 30.0, 19.6. HRMS (EI+) calcd for $C_{18}H_{16}ClNO$ $[M]^+$: 297.0920, found: 297.0923.

Procedure for a gram-scale synthesis of indole 199aa from aminobenzylalcohol 196a and furan 197a. In a 25 mL pressure tube, to a stirred suspension of aminobenzylalcohol **196a** (4.0 mmol, 1.41 g) and furan **197a** (6.0 mmol, 1.5 equiv, 537.0 μL) in DCE (13.3 mL, 0.3 M), triflic acid (0.4 mmol, 10 mol %, 36.0 μL) was added. The tube was capped with a Teflon pressure cap and placed into pre-heated (80 °C) oil bath. The resulted solution was stirred for 2 h at this temperature. After completion of the reaction (determined by TLC, eluent Hexanes/EtOAc = 4/1), the pressure tube, containing product **199aa**, was cooled down and the solvent was evaporated. The product was purified using silica gel column chromatography (eluent Hexanes/EtOAc = 7/1) to yield indole **199aa** (1.38 g, 83%) as a yellow oil, crystallizing upon staying.

7.4. Competitive Recyclization Studies

General Procedure for the Synthesis of Furylmethyl Aniline Derivatives 198:[130b] A mixture of alcohol **196a** (0.5 mmol), *p*-TsOH (4.3 mg, 5 mol %), and furan **197** (0.6 mmol, 1.2 equiv) in benzene (5 mL) was refluxed with azeotropic removal of water for 30 min (TLC monitoring, eluent: Hexanes/EtOAc = 4/1). After completion, the reaction flask was cooled down and the product **198** was purified using flash silica gel column chromatography.

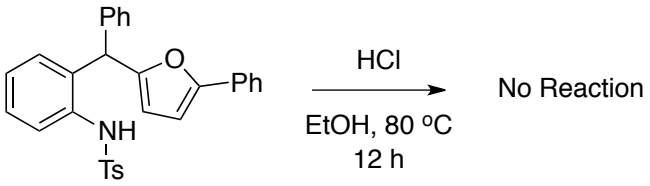
198ae: 179 mg (75%), yellowish solid, eluent: Hexanes/EtOAc = 7/1; R_f = 0.16 (Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61-7.58 (m, 2H), 7.57-7.54 (m,

2H), 7.47 (dd, *J* = 8.0, 1.2 Hz, 1H), 7.38-7.34 (m, 2H), 7.30-7.23 (m, 7H), 7.13 (dt, *J* = 7.7, 1.3 Hz, 1H), 6.94-6.92 (m, 2H), 7.86 (dd, *J* = 7.8, 1.2 Hz, 1H), 6.54 (d, *J* = 3.3 Hz, 1H), 6.28 (s, 1H), 5.80 (dd, *J* = 3.4, 0.8 Hz, 1H), 5.05 (s, 1H), 2.39 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.4, 143.9, 139.5, 136.8, 125.6, 134.1, 130.6, 129.8, 129.6, 129.0, 128.7, 128.6, 128.0, 127.5, 127.4, 127.1, 126.6, 125.9, 123.6, 111.3, 105.6, 46.1, 21.5. HRMS (EI+) calcd. for $C_{30}H_{25}NO_3S$ $[M]^+$: 479.1555, found: 479.1546.

198ao: 211 mg (76%), colorless oil, eluent: Hexanes/EtOAc = 7/1; R_f = 0.19 (Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.58-7.56 (m, 2H), 7.45 (dd, *J* = 8.0, 1.0 Hz, 1H), 7.27-7.21 (m, 6H), 7.10 (dt, *J* = 7.7, 1.2 Hz, 1H), 6.80-6.78 (m, 2H), 7.73 (dd, *J* = 7.8, 1.3 Hz, 1H), 6.28 (s, 1H), 5.90 (d, *J* = 3.1 Hz, 1H), 5.59 (d, *J* = 3.1 Hz, 1H), 4.91 (s, 1H), 4.75 (sept, *J* = 4.2 Hz, 1H), 2.91-2.87 (m, 2H), 2.59-2.56 (m, 2H), 2.43 (s, 3H), 1.82-1.79 (m, 2H), 1.73-1.69 (m, 2H), 1.56-1.51 (m, 1H), 1.42-1.22 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.8, 154.4, 152.8, 143.8, 139.6, 136.9, 135.6, 134.1, 129.8, 129.5, 128.8, 128.7, 127.9, 127.3, 127.1, 126.5, 125.7, 109.8, 105.9, 72.8, 45.9, 33.0, 31.6, 25.3, 23.7, 23.7, 21.5. HRMS (EI+) calcd. for $C_{33}H_{35}NO_5S$ $[M]^+$: 557.2236, found: 557.2231.

General Procedure for Recyclization Reaction of 198 into Indole 199:[130b] A solution of compound **198** (0.2 mmol) in 2 mL of HCl-EtOH (1.25 M) was stirred under reflux for 12h. After that time, the solvent was evaporated and the product was purified using flash silica gel column chromatography.

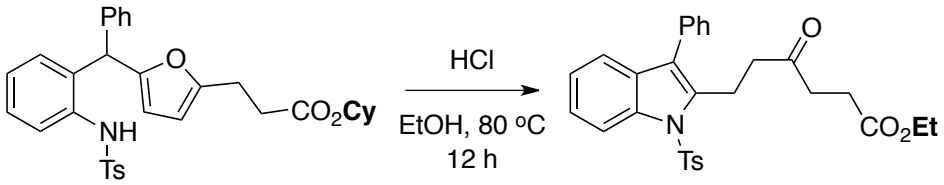
198ae→199ae: 94% of **198ae** was recovered (Scheme 96).



198ae

Scheme 96.

198ao→199ao: Conversion of **198ao** (>95%). Indole **199an** was isolated instead of indole **199ao** as a result of transesterification reaction (Scheme 97).

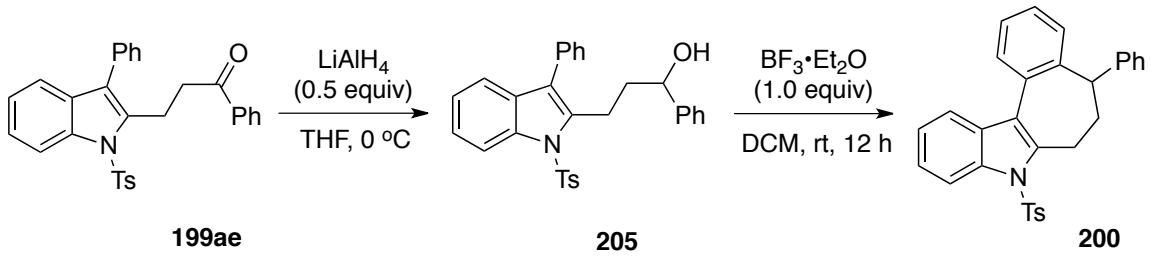


198ao **199an**, 73%

Scheme 97.

7.5. Further Transformations of the Formed Indoles 199

7.5.1. Synthesis of Tetrahydrobenzo[3,4]cyclohepta[1,2-b]indole 200 from Indole 199ae



199ae **205** **200**

Scheme 98.

Reduction of ketone (**199ae→205**). To an ice-cooled stirred suspension of $LiAlH_4$ (0.5 mmol, 0.5 equiv, 18.0 mg) in THF (5.0 mL), a solution of indole **199ae** (1.0 mmol, 417.0 mg) in THF (2.0 mL) was added (Scheme 98). The reaction mixture was allowed to warm up to room temperature and stirred for 30 min. After completion of the reaction (determined by TLC, eluent Hexanes/EtOAc = 4/1), reaction mixture was cooled down (ice bath) and aqueous sat. NH_4Cl (1.0 mL) was added dropwise (*caution: H_2 evolution!*). The resulting sluggish mixture was filtered through Celite and concentrated. The alcohol **205** was purified using flash silica gel column chromatography. 406 mg (97%), yellow-brown solid, eluent: Hexanes/EtOAc = 3/1; R_f = 0.13 (Hexanes/EtOAc = 3/1).

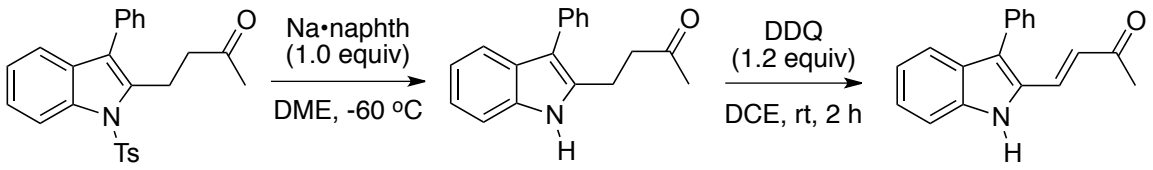
205: ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.27 (d, *J* = 8.4 Hz, 1H), 7.62-7.61 (m, 2H), 7.46-7.43 (m, 2H), 7.39 (s, 1H), 7.36-7.29 (m, 8H), 7.26-7.21 (m, 2H), 7.19-7.17 (m, 2H), 4.69 (m, 1H), 3.23-3.17 (m, 1H), 3.11-3.05 (m, 1H), 2.34 (s, 3H), 2.28-2.19 (m, 2H), 2.07 (s_{br}, 1H). ^{13}C NMR (125 MHz, $CDCl_3$): δ ppm 144.7, 144.0, 137.3, 136.7, 135.7, 132.9, 130.5, 129.7, 128.7, 128.3, 127.5, 127.3, 126.2, 125.8, 124.5, 124.0, 124.0, 123.8, 119.4, 115.2, 73.6, 40.1, 23.2, 21.5. HRMS (EI+) calcd. for $C_{30}H_{27}NO_3S$ $[M]^+$: 481.1712, found: 481.1712.

Cyclization (**205→200**). In a 3 mL Wheaton vial, to a stirred solution of alcohol **205** (0.2 mmol, 96.2 mg) in DCM (1.0 mL), a solution of BF_3•Et_2O (0.2 mmol, 1.0 equiv, 24.7 μL) was added (Scheme 98). The reaction mixture was stirred at room temperature for 12 h. After completion of the reaction (determined by TLC, eluent Hexanes/EtOAc = 4/1) the resulting mixture was diluted with hexanes (1.0 mL). The cyclized product **200** was purified using flash silica gel column chromatography. 56 mg (61%), colorless solid, eluent: Hexanes/EtOAc = 25/1; R_f = 0.45 (Hexanes/EtOAc = 4/1).

200: ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.35 (d, *J* = 8.5 Hz, 1H), 7.75 (d, *J* = 7.9 Hz, 1H), 7.69-7.67 (m, 2H), 7.64 (d, *J* = 7.5 Hz, 1H), 7.38 (t, *J* = 6.1 Hz, 1H), 7.35-7.30 (m, 4H), 7.27-7.26 (m, 1H), 7.18-7.14 (m, 5H), 6.88 (d, *J* = 7.9 Hz, 1H), 3.92-3.88 (m, 1H), 3.74-3.69 (m, 1H), 2.77-2.67 (m, 2H), 2.53-2.46 (m, 1H), 2.30 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): δ ppm 144.8, 143.5, 132.1, 137.9, 137.1, 136.1, 133.1, 129.8, 129.1, 128.6, 128.3, 128.2, 128.1, 126.9, 126.5, 126.3, 126.0, 124.2, 123.8, 121.3, 119.1, 115.2,

46.5, 39.1, 23.7, 21.5. HRMS (EI+) calcd. for $C_{30}H_{25}NO_2S$ $[M]^+$: 463.1606, found: 463.1599.

7.5.2. Synthesis of *α,β*-Unsaturated Ketone 202 from Indole 199aa



199aa **201** **202**

Scheme 99.

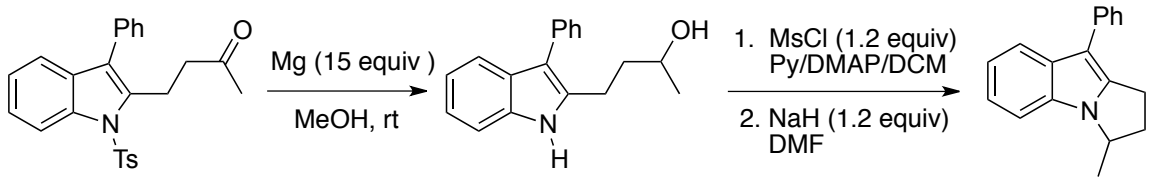
Tosyl- group deprotection (**199aa→201**). In a 25 mL round-bottom argon flushed flask, equipped with a stirring bar and septum, to a dry-ice cooled solution of indole **199aa** (1 mmol, 417 mg) in DME (10 mL), a solution of sodium naphthalenide in DME (1.0-1.1 equiv) was added dropwise (Scheme 99). Addition of sodium naphthalenide continues until the dark green color of its solution stops disappearing. It is important not to add excess of sodium naphthalenide. The resulting yellow-green solution was allowed to warm up to room temperature (turn yellow) and the solvent was evaporated. The mixture, containing product **201** and naphthalene was purified using flash silica gel column chromatography. 189 mg (72%), colorless solid, eluent: Hexanes/EtOAc = 7/1; R_f = 0.18 (Hexanes/EtOAc = 4/1).

201: ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.81 (s_{br}, 1H), 7.64 (d, J = 7.9 Hz, 1H), 7.49-7.47 (m, 4H), 7.38-7.33 (m, 2H), 7.20 (t, J = 7.2 Hz, 1H), 7.12 (t, J = 7.3 Hz, 1H), 3.13-3.10 (m, 2H), 2.91-2.88 (m, 2H), 2.21 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): δ ppm 210.0, 135.3, 135.0 (2C), 129.7, 128.5, 127.5, 126.0, 121.8, 119.8, 118.9, 114.4, 110.7, 44.1, 30.1, 19.5. HRMS (EI+) calcd. for $C_{18}H_{17}ON$ $[M]^+$: 263.1310, found: 263.1313.

Oxidation (**201→202**). In a 3 mL Wheaton vial, to a stirred solution of ketone **201** (0.2 mmol, 52.6 mg) in DCE (2.0 mL), DDQ (0.24 mmol, 1.2 equiv, 54.5 mg) was added (Scheme 99). The reaction mixture was stirred at room temperature for 2 h. After completion of the reaction (determined by TLC, eluent Hexanes/EtOAc = 4/1) the resulting mixture was diluted with hexanes (2.0 mL). The product **202** was purified using flash silica gel column chromatography. 43 mg (83%), deep yellow solid, eluent: Hexanes/EtOAc = 7/1; R_f = 0.15 (Hexanes/EtOAc = 4/1).

202: ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.81 (s_{br}, 1H), 7.71 (d, J = 8.1 Hz, 1H), 7.63 (d, J = 16.3 Hz, 1H), 7.55-7.53 (m, 4H), 7.47-7.43 (m, 2H), 7.35 (t, J = 7.3 Hz, 1H), 7.17 (t, J = 7.2 Hz, 1H), 7.61 (d, J = 16.3 Hz, 1H), 2.36 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): δ ppm 198.6, 137.6, 133.5, 132.8, 130.2, 129.8, 128.8, 127.7, 127.3, 125.6, 125.1, 124.8, 120.9, 120.7, 111.5, 26.8. HRMS (EI+) calcd. for $C_{18}H_{15}ON$ $[M]^+$: 261.1154, found: 261.1157.

7.6. Synthesis of Dihydropyrroloindole 204 from Indole 199aa



199aa **203** **204**

Scheme 100.

Tosyl- group deprotection/reduction of carbonyl group (**199aa→203**). To a 25 mL round-bottom argon flushed flask, indole **199aa** (1 mmol, 417 mg), Mg (15 mmol, 15 equiv, 360 mg), and methanol (15 mL) were added (Scheme 100). The flask was sonicated in the ultrasound bath until the start of the dihydrogen evolution from magnesium surface, and then reaction mixture was stirred at room temperature until all magnesium reacted (1-2 h). The resulting mixture was filtered through Celite and concentrated. The alcohol **203** was purified using flash silica gel column chromatography. 230 mg (87%), yellow oil, eluent: Hexanes/EtOAc = 4/1; R_f = 0.08 (Hexanes/EtOAc = 4/1).

203: ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 8.67 (s_{br}, 1H), 7.70 (d, *J* = 7.9 Hz, 1H), 7.56-7.49 (m, 4H), 7.37-7.34 (m, 2H), 7.22 (t, *J* = 7.0 Hz, 1H), 7.16 (d, *J* = 7.9 Hz, 1H), 3.86 (m, 1H), 3.05-2.96 (m, 2H), 1.88-1.78 (m, 3H), 1.22 (d, *J* = 5.7 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): δ ppm 135.6, 135.5, 135.3, 129.6, 128.6, 127.8, 126.0, 121.6, 119.8,

118.9, 114.4, 110.6, 67.6, 38.6, 23.8, 22.6. HRMS (EI+) calcd. for $C_{18}H_{19}ON$ $[M]^+$: 265.1467, found: 265.1468.

Cyclization (**203→204**). In a 10 mL round-bottom flask, to a solution of alcohol **203** (0.2 mmol, 53.0 mg), triethylamine (0.3 mmol, 1.5 equiv, 42.5 μL), and DMAP (0.02 mmol, 0.1 equiv, 2.4 mg) in DCM (1.0 mL), MsCl (0.24 mmol, 1.2 equiv, 19.0 μL) was added (Scheme 100). The reaction mixture was stirred at room temperature for 2 h and then filtered through Celite and concentrated. The crude product was dissolved in 0.2 mL of DMF and added to an ice-cooled suspension of NaH (0.24 mmol, 1.2 equiv, 5.8 mg) in DMF (0.8 mL) (Scheme 100). The resulting mixture was allowed to warm up to room temperature and stirred for 2 h. After, the reaction mixture was poured into water (10.0 mL) and the product **204** was extracted with diethyl ether (3x5 mL). The combined organic fractions were washed with brine, dried over Na_2SO_4, and concentrated. The crude dihydropyrroloindole **204** was purified using flash silica gel column chromatography. 39 mg (79%), colorless oil, eluent: Hexanes/EtOAc = 25/1; R_f = 0.50 (Hexanes/EtOAc = 4/1).

204: ^{1}H NMR (500 MHz, $CDCl_3$): δ ppm 7.94 (d, *J* = 7.2 Hz, 1H), 7.68-7.67 (m, 2H), 7.50-7.47 (t, *J* = 7.5 Hz, 2H), 7.40 (d, *J* = 6.1 Hz, 1H), 7.26 (m, 1H), 7.23-7.17 (m, 2H), 4.66 (m, 1H), 3.27 (m, 1H), 3.16 (m, 1H), 2.83 (m, 1H), 2.29 (m, 1H), 1.61 (d, *J* = 6.4 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): δ ppm 141.7, 136.2, 132.3, 130.8, 128.6, 127.4, 124.9, 120.6, 119.5, 109.6, 107.5, 52.6, 36.0, 23.7, 20.3. HRMS (EI+) calcd. for $C_{18}H_{17}N$ $[M]^+$: 247.1361, found: 247.1365.

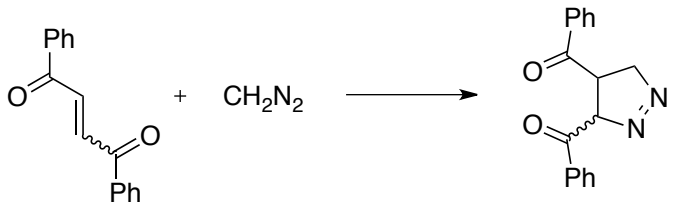
PART THREE

A NEW REACTIVITY MODE OF DIAZO-GROUP: DIASTEREOSELECTIVE 1,3-AMINOALKYLATION REACTION OF *β*-AMINO-*α*-DIAZOESTERS TOWARDS TRIAZOLINE

8. INTRODUCTION

8.1. Different Reactivity Modes of Diazo-group

Diazocompounds are important building blocks that have been extensively studied over the years.[145,146] They are widely used in organic chemistry due to the high energy and diverse reactivity of the diazo-group. Primarily, diazocompounds are utilized in the copper-,[147] palladium,[148] and rhodium-catalyzed[149] denitrogenative reactions to form metal carbene species. The latter can subsequently undergo insertion into the X–H bonds (X = C, N, O, S),[147] cyclopropanation,[150] 1,2-migration,[151] and ylide reactions.[152] On the other hand, reactions with preservation of the diazo-group are also known. Thus, one of the first such reactions presented was [3+2] cycloaddition of diazocompounds and alkenes. For example, back in 1943 Smith reported a reaction of *cis*/*trans*-dibenzoylethylene **206** with diazomethane producing pyrazoline **207** in high to quantitative yield (Scheme 101).[153]

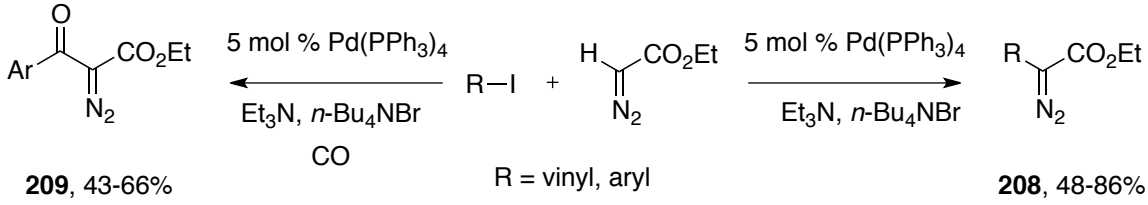


206 **207**, 80-100%

Scheme 101.

In the following years this methodology was expanded to the application of other diazocompounds and activated alkenes.[154] The analogues [3+2] cycloaddition reaction of diazocompounds with alkynes furnishing 3*H*-pyrazoles has also been reported.[155]

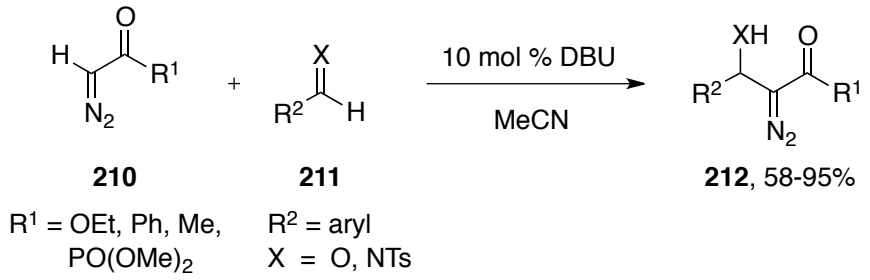
Wang group showed that diazocompounds can serve as nucleophiles in the cross-coupling reactions. Accordingly, the palladium-catalyzed reaction of ethydiazoacetate with vinyl- or aryliodides led to the formation of α-vinyl or -aryl diazocompounds **208** in moderate to high yields (Scheme 102).[156] When the reaction was carried out in the presence of carbon monoxide, the corresponding carbonylative arylation products *β*-keto-*α*-diazo esters **209** were obtained in moderate yields.



209, 43-66% R = vinyl, aryl **208**, 48-86%

Scheme 102.

In addition, Wang group also developed a mild base-catalyzed addition of diazocompounds **210** to aldehydes and imines **211** with the formation of keto- or aminoalcohols **212** (Scheme 103).[157] Subsequently, the asymmetric chiral Brønsted acid-catalyzed mode for this reaction has been developed by Terada,[158] Maruoka,[159] Trost,[160] and others.[161]

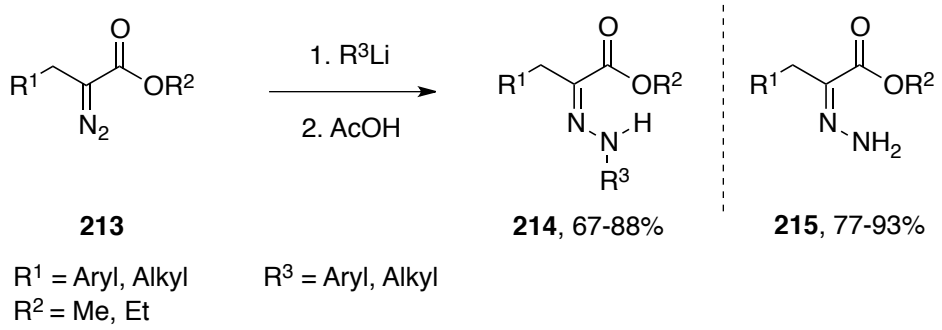


210 **211** **212**, 58-95%

R^1 = OEt, Ph, Me, $PO(OMe)_2$ R^2 = aryl X = O, NTs

Scheme 103.

There are also scattered reports on the reaction of a diazo-group with nucleophiles and electrophiles in a *1,1-fashion* when both, nucleophile and electrophile are added to the terminal nitrogen atom of the diazo-group. Thus, Takamura showed that organolithium reagents undergo addition at the terminal *N*-atom of the diazog-roup of **213** with the formation of hydrozones **214** in high yields after protonation (Scheme 104).[162] The same group also reported addition of a hydride ion at the *N*-terminus of a diazocompound and subsequent generation of hydrazones **215**.[163]



213 **214**, 67-88% **215**, 77-93%

R^1 = Aryl, Alkyl R^3 = Aryl, Alkyl
R^2 = Me, Et

Scheme 104.

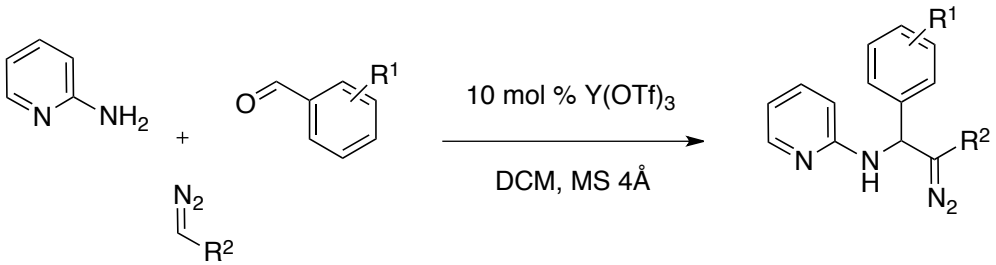
8.2. Conclusion

Diazocompounds are widely used in the synthetic organic chemistry. Primarily, they are utilized in denitrogenative formation of high-energy metal carbene species, which then undergo insertion or cycloaddition reactions. On the other hand, reactions of diazocompounds with preservation of the diazo-group are also known. Thus, [3+2] cycloaddition reactions of diazocompounds with alkenes or alkynes are used in the synthesis of pyrazoline and pyrazole derivatives. There are also reports on cross-coupling and addition reactions of imines and aldehydes at the *C*-atom of the diazo-group (serving as nucleophile). However, reports on the addition of both nucleophiles and electrophiles to the diazo-group are exceedingly rare. Thus, just a couple of examples have been reported on the addition of nucleophiles (RLi or hydride ion), followed by electrophile (H^+), to the diazo-group to give hydrazones in a *1,1-fashion*. Accordingly, the development of novel reactivity modes of diazocompounds, which potentially can lead to development of useful synthetic protocols is justified.

9. 1,3-AMINOALKYLATION REACTION OF *β*-AMINO-*α*-DIAZOESTERS TOWARDS TRIAZOLINE

9.1. Aminoalkylation Reaction: Scope and Limitation

Recently, our group have developed a method for synthesis of *β*-pyridylamino-*α*-diazoesters **216** via a three-component coupling reaction of 2-aminoazines, aldehydes, and diazocompounds (Scheme 105).[164]



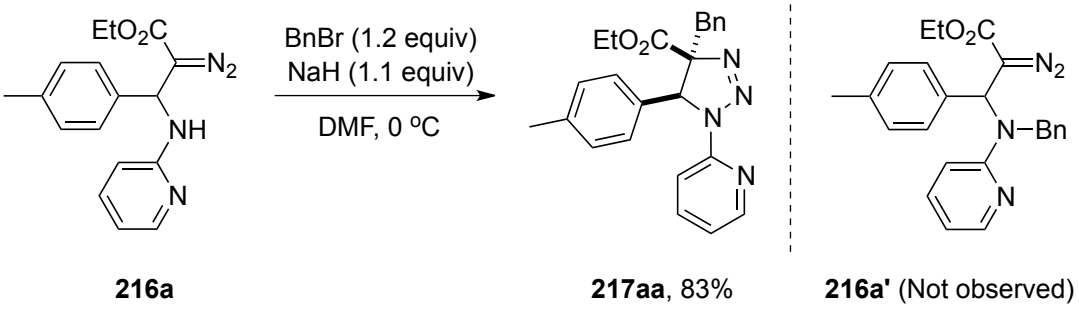
R^1 = Alk, Hal, MeO, OH, CF_3
R^2 = CO_2Cy or $PO(OEt)_2$

216, 41-76%

Scheme 105.

Upon investigation of the synthetic utility of the obtained products **216**, we found an unexpected reactivity of the diazo-group. Thus, an alkylation reaction of *N*-pyridyl diazocompound **216a** with benzyl bromide in the presence of NaH, produced 1,2,3-triazoline **217aa**, the product of amination of the terminal *N*-atom and alkylation of *C*-atom of the diazo-group (Scheme 106).[165] The expected *N*-alkylation product **216a'** was not observed. Notably, this reaction proceeds exclusively in a *trans*-manner with respect

to the aryl substituent at the *β*-position of the diazoesters **216a**, thus providing triazoline **217aa** as a single diastereomer.[166]



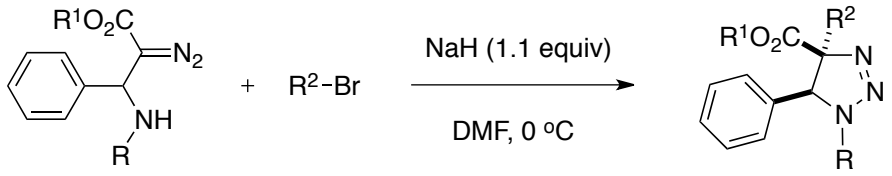
Scheme 106.

The observed aminoalkylation reaction is conceptually interesting as it represents the first example of intramolecular *1,3-addition* of nucleophile and electrophile to the diazo-group. This reaction also holds a synthetic promise in becoming a modular approach to the valuable 1,2,3-triazoline molecules.[167,168]

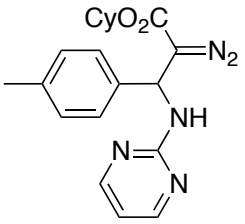
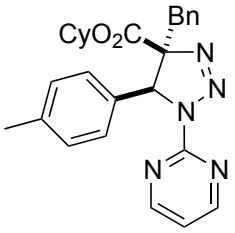
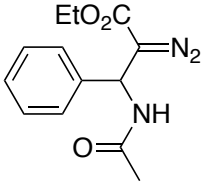
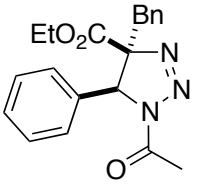
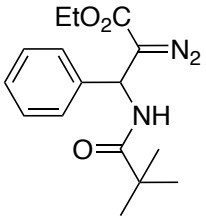
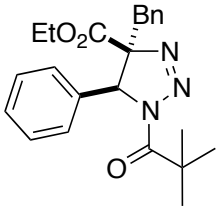
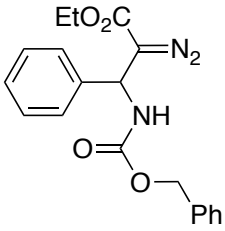
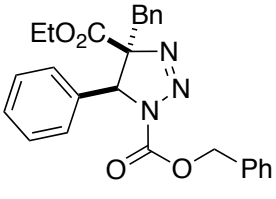
Accordingly, we turned our attention to the investigation of the scope of this new transformation (Table 12). We were delighted to find, that this aminoalkylation reaction is quite general with respect to the substituent at the *β*-*N*-atom of the diazoester **216**. Accordingly, upon reaction of **216** with benzyl bromide, triazolines bearing pyrimidyl (**217ab**), acetyl (**217ac**), pivaloyl (**217ad**), carboxybenzyl (**217ae**), and *tert*-butoxycarbonyl (**217af**) groups at *N*-atom were formed in high yields and diastereoselectivity (Table 2, entries 1-5). In the case of *N*-benzoyl diazoester **216g**, the product **217ag** was formed in lower yield and diastereoselectivity (entry 6), whereas *N*-tosyl amino- **216h** and *N*-diphenylphosphonyl diazoester **216i** produced the

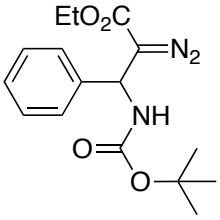
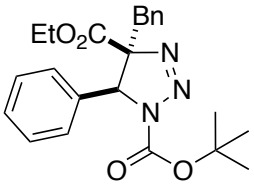
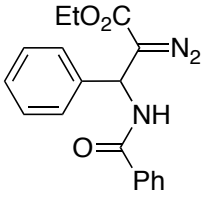
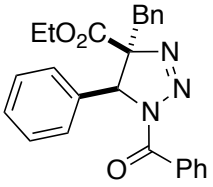
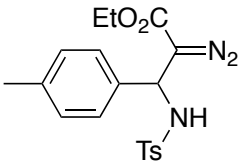
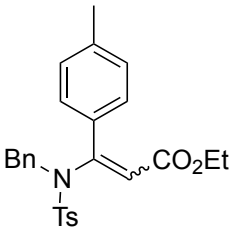
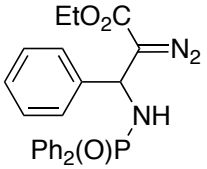
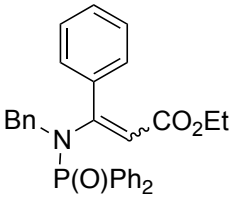
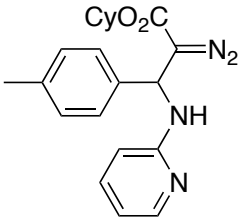
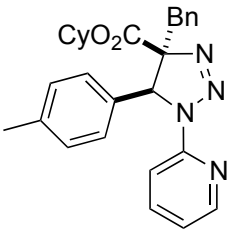
corresponding enamies **216h'** and **216i'** as major products (entries 7,8). Next, we examined the scope of alkylating agents in this transformation. We found that benzyl triflate is also a competitive reaction partner, however the prodict **217aj** was formed in a slightly lower yield than in the case of reaction with benzyl bromide (Table 1, entry 9). Benzyl bromides having electron-donating (entries 10-12) or electron-withdrawing groups (entries 13,14), as well as allyl bromide (entries 15-17), also underwent aminoalkylation reaction with different diazocompounds producing the desired products in high yields. The reaction also worked well with internal (entries 18-20) and terminal (entry 21) propargyl bromides, methyl bromoacetate (entry 22), and bromoacetonitrile (entry 23) as alkylating agents. Simple aliphatic alkylating agents, such as methyl iodide (entries 24-26), *n*-butyl iodide, as well as *n*-butyl bromide (entry 27), were also efficient in this reaction. Notably, even secondary alkyl halides (entries 28-30) produced the corresponding triazolines in good yields. The reaction also showed good compatibility with respect to the electronic nature of the aryl substituent and *N*-pyridyl group of *β*-amino-*α*-diazoesters (entries 31-34). Unfortunately, aminoalkylation reaction of diazomethylenephosphonate derivative **116o** was not efficient (entry 35).

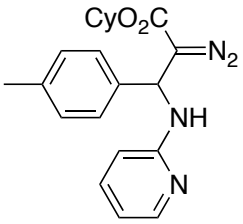
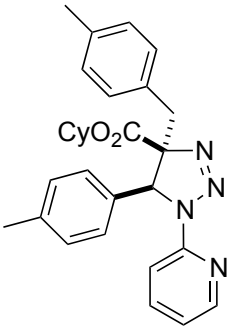
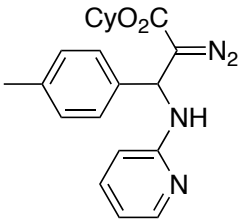
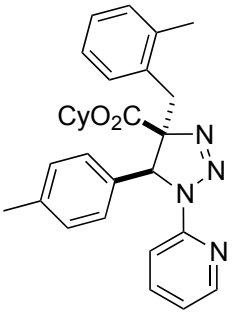
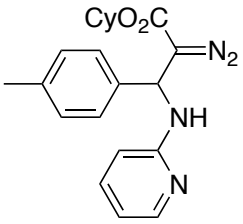
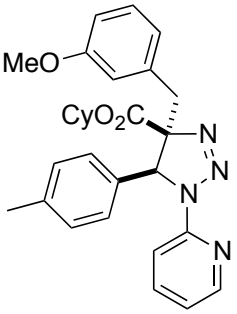
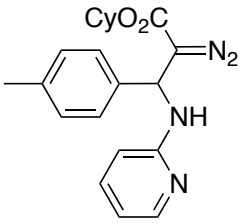
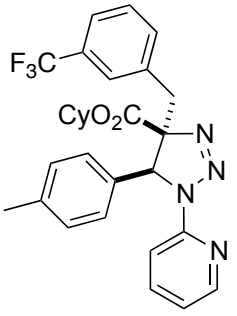
Table 12. Scope of the aminoalkylation reaction of β-amino-α-diazoesters **216**.

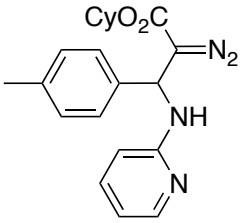
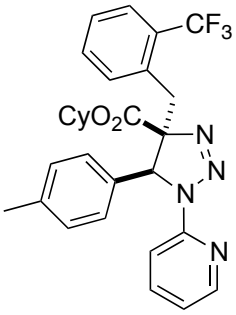
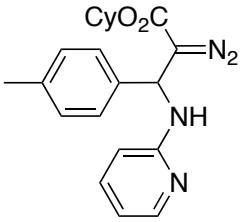
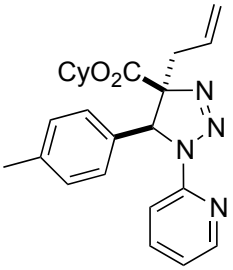
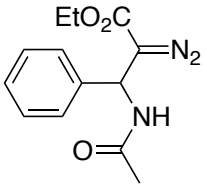
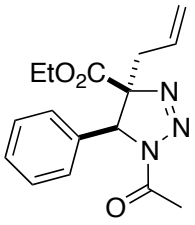
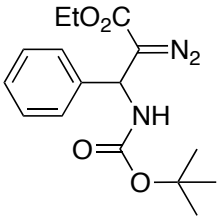
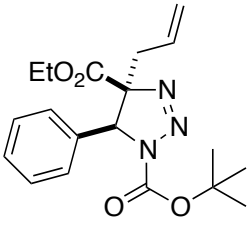
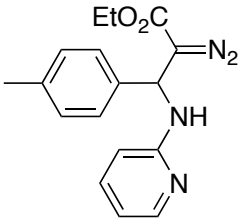
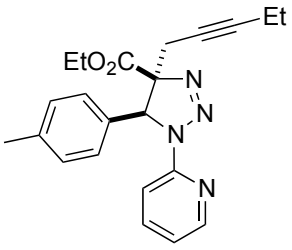


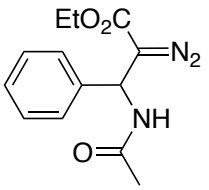
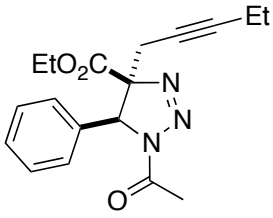
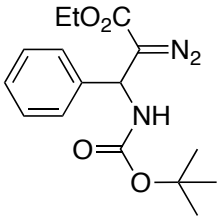
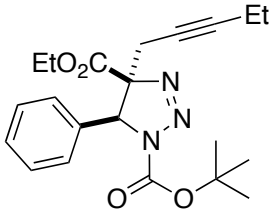
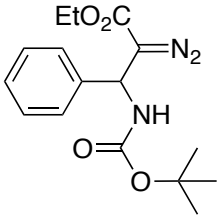
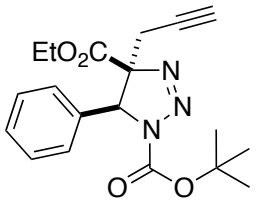
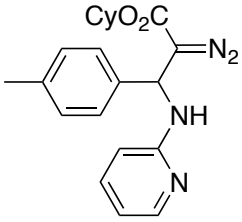
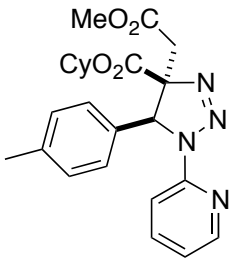
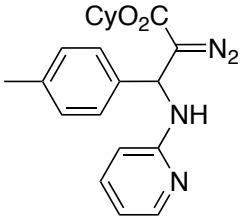
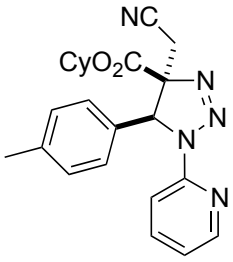
216 **218**

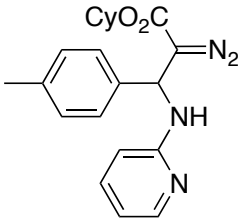
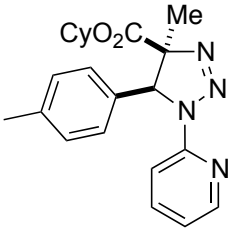
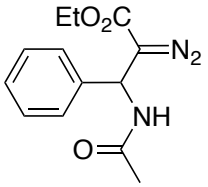
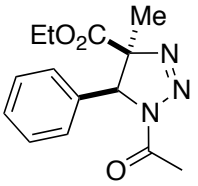
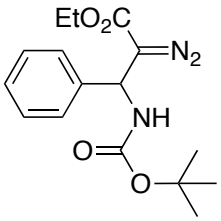
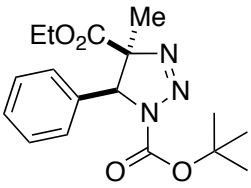
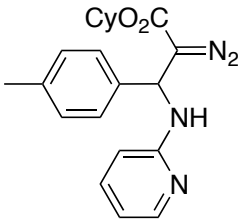
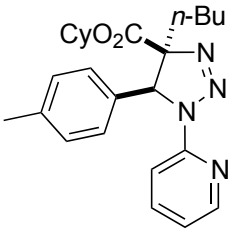
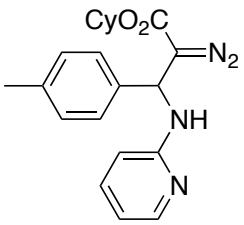
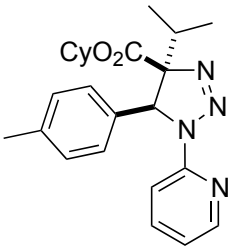
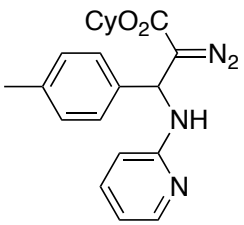
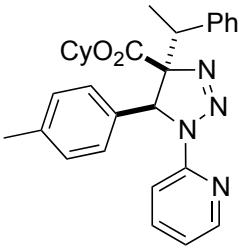
entry	diazocompound		triazoline		yield **217**, (%)[a]
1		**216b**		**217ab**	71
2		**216c**		**217ac**	81
3		**216d**		**217ad**	49
4		**216e**		**217ae**	58

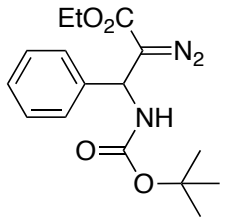
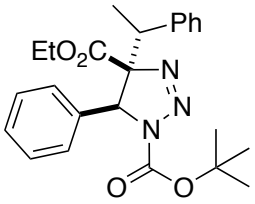
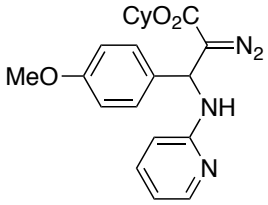
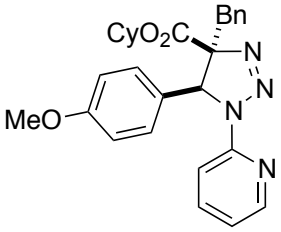
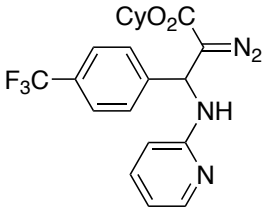
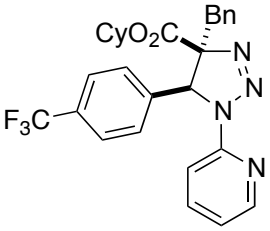
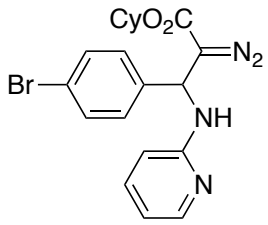
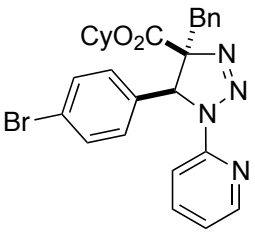
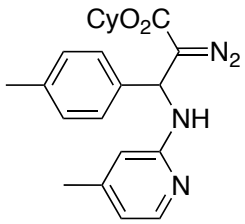
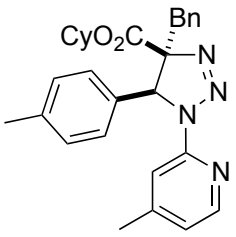
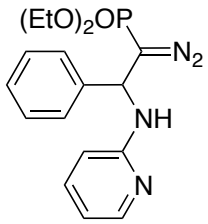
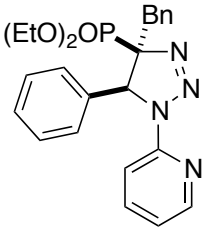
entry	diazocompound		triazoline		yield **217**, (%)[a]
5		**216f**		**217af**	85
6		**216g**		**217ag**	36[b]
7		**216h**		**217ah**	65
8		**216i**		**217ai**	61[c]
9		**216j**		**217aj**	87/64[d]

entry	diazocompound		triazoline		yield **217**, (%)[a]
10		**216j**		**217ak**	83
11		**216j**		**217al**	91
12		**216j**		**217am**	89
13		**216j**		**217an**	86

entry	diazocompound		triazoline		yield **217**, (%)[a]
14		**216j**		**217ao**	69
15		**216j**		**217ap**	78
16		**216c**		**217aq**	71
17		**216f**		**217ar**	75
18		**216a**		**217as**	69

entry	diazocompound		triazoline		yield **217**, (%)[a]
19		**216c**		**217at**	62
20		**216f**		**217au**	70
21		**216f**		**217av**	59
22		**216j**		**217aw**	41
23		**216j**		**217ax**	45

entry	diazocompound		triazoline		yield **217**, (%)[a]
24		**216j**		**217ay**	71[e]
25		**216c**		**217az**	79[e]
26		**216f**		**217ba**	56[e]
27		**216j**		**217bb**	47/66[f]
28		**216j**		**217bc**	49[g]
29		**216j**		**217bd**	67

entry	diazocompound		triazoline		yield **217**, (%)[a]
30		**216f**		**217be**	59
31		**216k**		**217bf**	70
32		**216l**		**217bg**	67
33		**216m**		**217bh**	54
34		**216n**		**217bi**	62
35		**216o**		**217bh**	--[h]

[a] Isolated yields, *d.r.* >99:1 in all cases unless otherwise noted.

[b] d.r. 97:3.

[c] NMR yield.

[d] BnOTf was used.

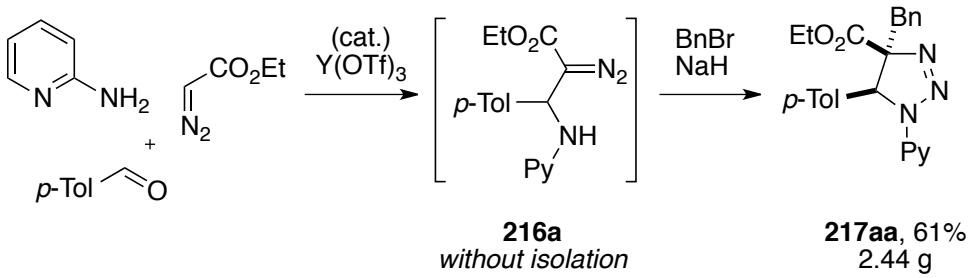
[e] MeI was used.

[f] *n*-BuI was used.

[g] *i*-PrI was used.

[h] Trace of product, the starting diazocompound was recovered.

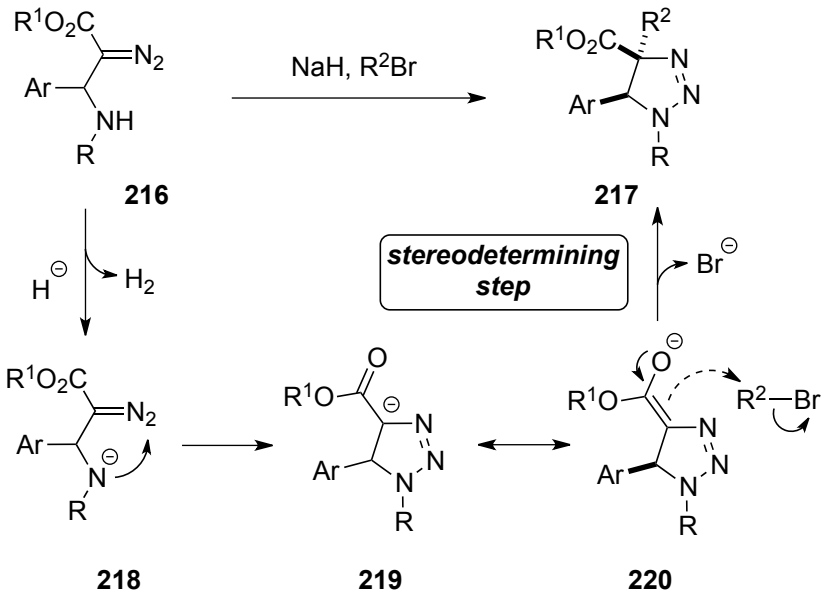
We also showed a possibility of a direct access to the relatively complex triazoline molecules **217** through our newly developed aminoalkylation reaction of **216** using simple commercially available reagents. Thus, the starting *β*-amino-*α*-diazoesters **216** could be easily obtained via previously reported base-[157,169] or acid-catalyzed[158-161] addition of diazoacetates to imines. Furthermore, *β*-pyridylamino-*α*-diazoesters **216** can be obtained through a three-component coupling reaction recently developed in our group (Scheme 105).[164] Accordingly, we demonstrated that triazoline **217aa** can be efficiently prepared on a gram-scale via a formal four-component coupling reaction of simple commercially available reagents: 2-aminopyridine, *p*-tolualdehyde, ethyldiazoacetate, and benzyl bromide (Scheme 107).



Scheme 107.

9.2. Mechanistic Proposal

The proposed mechanism for the aminoalkylation reaction of *β*-amino-*α*-diazoesters is depicted in Scheme 108. First, deprotonation of the amino-group of **216** with sodium hydride leads to the formation of anion **218**, which then undergoes cyclization to form enolate **219**/**220**. The following nucleophilic attack of the enolate at the electrophile which approaches from the less sterically hindered site produces the corresponding 1,2,3-triazoline **217** in a highly diastereoselective fashion.

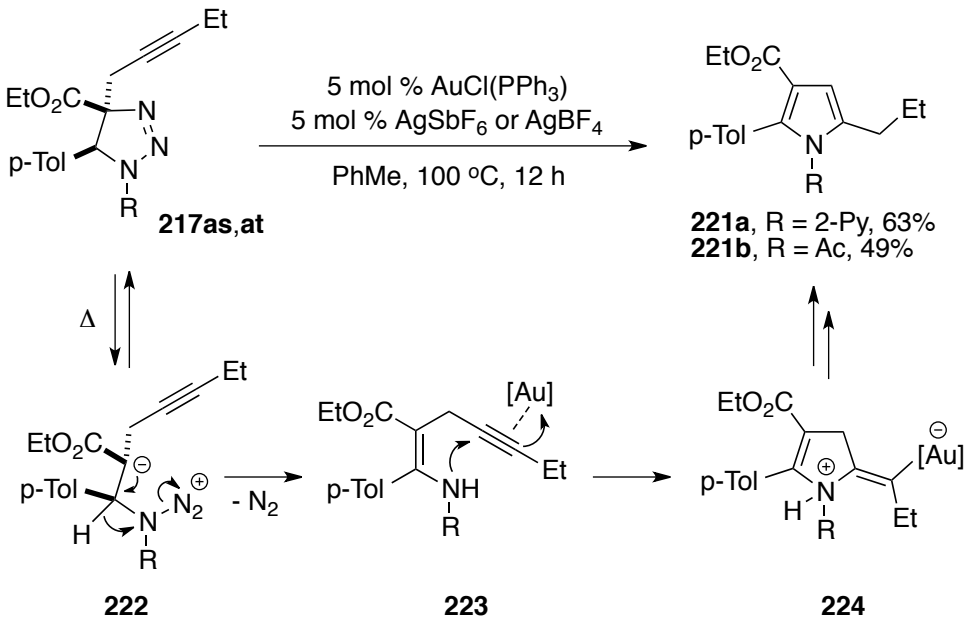


Scheme 108.

9.3. Cycloisomerization Reaction of Propargyl Triazolines

In continuation of our studies on the synthesis of heterocycles via transition metal-catalyzed cycloisomerization reactions of alkynes[170] and transannulation reactions of triazoles,[171] a potential heterocyclization reaction of propargyl triazolines **217as**,**at** was examined (Scheme 109). Accordingly, upon screening of different transition metal catalysts, we discovered that under the Au-catalyzed conditions, propargyl triazolines **217as**,**at** undergo denitrogenative cycloisomerization reaction with the formation of tetrasubstituted pyrroles **221** (Scheme 109). The following considerations can account for the mechanism of this reaction. First, triazoline **217** undergoes a thermal ring opening to give **222**, followed by denitrogenative rearrangement to produce enamine **223**.[172] A

subsequent aminoauration of the triple bond of enamine **223** results in the formation of a vinyl-gold dihydropyrollium intermediate **224**.[173] The latter, upon protiodemetalation and aromatization produces pyrrole **221**.[174] This cycloisomerization process represents the first example of denitrogenative transannulation reaction of *1,2,3-triazolines* with alkynes, that is complimentary to the denitrogenative transannulation of *1,2,3-triazoles*.[171,175]



Scheme 109.

9.4. CONCLUSION

In conclusion, we developed a highly diastereoselective intramolecular aminoalkylation reaction of *β*-amino-*α*-diazoesters with the formation of tetrasubstituted 1,2,3-triazolines. The reaction features a novel intramolecular aminoalkylation reaction, which proceeds via unprecedented addition of nucleophile and electrophile to the diazo-group of a diazocompound in a *1,3-fashion*. This reaction works with a variety of *C*-electrophiles and demonstrates a broad scope with respect to the substituent at the amino- and aryl group of *β*-amino-*α*-diazoesters. We also discovered the first gold-catalyzed intramolecular denitrogenative transannulation reaction of propargyl triazolines into pyrroles.

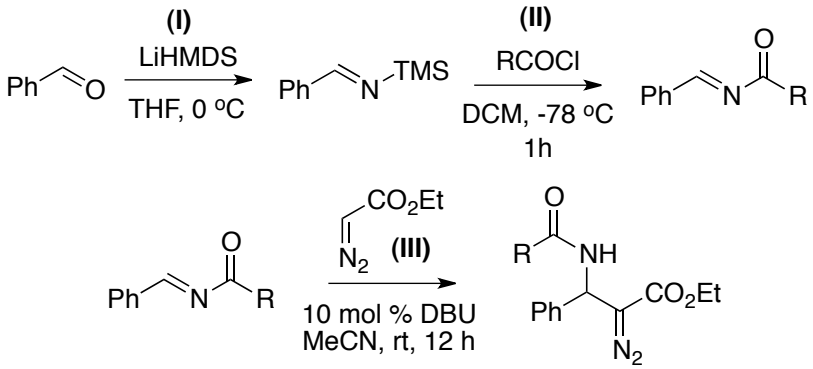
10. EXPERIMENTAL SECTION

10.1. General Information

GC-MS analysis was performed on a Hewlett Packard Model 6890 GC interfaced to a Hewlett Packard Model 5973 mass selective detector (15 m x 0.25 mm capillary column, HP-5MS). Column chromatography was carried out employing Silicycle Silica-P flash silica gel (40-63 μm). Precoated silica gel plates F-254 were used for thin-layer analytical chromatography. NMR spectra were recorded on Bruker Avance DRX-500 (500 MHz) or DPX-400 (400 MHz) instrument. LRMS and HRMS analyses were performed on Micromass 70 VSE mass spectrometer. All manipulations with transition metal catalysts were conducted in oven-dried glassware under inert atmosphere using a combination of glovebox and standard Schlenk techniques unless otherwise noted. Anhydrous solvents purchased from Sigma-Aldrich were additionally purified on PureSolv PS-400-4 by Innovative Technology, Inc. purification system and/or stored over calcium hydride. The starting materials were purchased from Sigma-Aldrich, Alfa Aesar, Strem Chemicals, and AK Scientific.

10.2. Synthesis of Starting Materials

Synthesis of *N*-Ac, *N*-Piv, *N*-Cbz, and *N*-Bz diazocompounds 216



Scheme 110.

(I) Synthesis of *N*-trimethylsilylbenzaldimine.[176] To an ice-bath cooled solution of benzaldehyde (50 mmol, 5.1 mL) in THF (25 mL), LiHMDS (50 mmol, 8.35 g) in THF (25 mL) was added over a period of 10 min under argon (Scheme 110). Direct fractional distillation of the resulting suspension gave 7.46 g (73%) of *N*-(trimethylsilyl)benzaldimine as a light yellow liquid: bp 45 ºC (0.15 mm), which was stored under argon at 0 ºC.

(II) General Procedure for the Synthesis of the *N*-Acylimines:[177] To a solution of *N*-trimethylsilylbenzaldimine (1 mmol) in CH_2Cl_2 (1 mL), acyl chloride (1 mmol) was

added dropwise at -78 ºC (Scheme 110). After stirring for 1 h at room temperature, the solvent and TMSCl were removed under reduced pressure to obtain *N*-acyl benzaldimine, which was used directly in the synthesis of diazocompounds **216**.

(III) General Procedure for the Synthesis of the Diazocompounds 216:[157] To a room temperature solution of ethyl diazoacetate (1.2 mmol) in anhydrous CH_3CN (5 mL) under argon, DBU (0.1 mmol) and freshly prepared *N*-acyl benzaldimine (1 mmol) in anhydrous CH_3CN (4 mL) were added dropwise (Scheme 110). After stirring at room temperature for 12 h, the volatiles were removed under reduced pressure and the crude product was purified by flash silica gel chromatography.

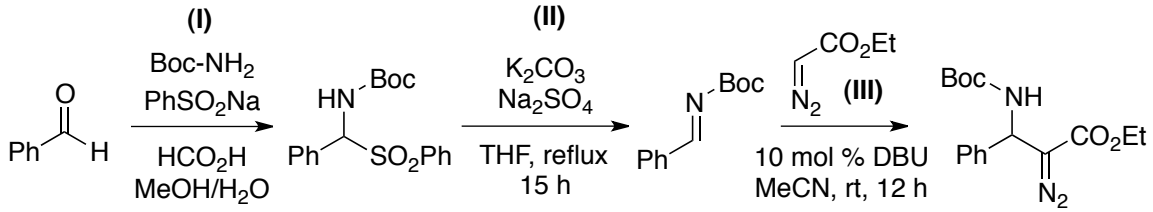
216c: 56% over 2 steps, eluent: Hexanes/EtOAc = 2/1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35-7.28 (m, 5H), 6.73 (s_{br}, 1H), 5.96 (d, J = 8.3 Hz, 1H), 4.21 (q, J = 7.2 Hz, 2H), 3.14 (s, 3H), 1.25 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.5, 166.2, 138.7, 128.9, 128.1, 126.3, 61.1, 49.6, 23.1, 14.4. HRMS (ES+) calcd. for $C_{13}H_{15}NO_3Na$ (M^++Na): 284.1011, found: 284.1014.

216d: 51% over 2 steps, eluent: Hexanes/EtOAc = 7/1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37-7.26 (m, 5H), 6.85 (s_{br}, 1H), 5.92 (d, J = 8.0 Hz, 1H), 4.21 (q, J = 7.2 Hz, 2H), 1.24 (t, J = 7.1 Hz, 3H), 1.23 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.8, 166.2, 139.1, 128.8, 127.9, 126.1, 61.0, 49.4, 38.8, 27.4, 14.3. HRMS (ES+) calcd. for $C_{16}H_{21}N_3O_3Na$ (M^+ + Na): 326.1481, found: 326.1487.

216e: 68% over 2 steps, eluent: Hexanes/EtOAc = 7/1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40-7.29 (m, 10H), 5.89 (s_{br}, 1H), 5.79 (d, J = 7.7 Hz, 1H), 5.16 (s, 2H), 4.26-4.19 (m, 2H), 1.25 (t, J = 7.1 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.8, 155.6, 138.4, 136.1, 128.8, 128.5, 128.1, 128.0, 126.1, 67.1, 61.0, 51.6, 14.3. HRMS (ES+) calcd. for $C_{19}H_{19}N_3O_4Na$ (M^++Na): 376.1273, found: 376.1271.

216g: 63% over 2 steps, eluent: Hexanes/EtOAc = 7/1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84-7.81 (m, 2H), 7.58 (s_{br}, 1H), 7.53-7.49 (m, 1H), 7.45-7.40 (m, 4H), 7.38-7.34 (m, 2H), 7.32-7.28 (m, 1H), 6.19 (d, J = 8.1 Hz, 1H), 4.23 (q, J = 7.2 Hz, 2H), 1.26 (t, J = 7.1 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.6, 166.3, 138.8, 133.6, 131.8, 128.9, 128.6, 128.0, 127.1, 126.3, 61.1, 50.0, 14.3. HRMS (ES+) calcd. for $C_{18}H_{17}N_3O_3Na$ (M^++Na): 346.1168, found: 346.1171.

Synthesis of *N*-Boc diazocompound 216f



216f

Scheme 111.

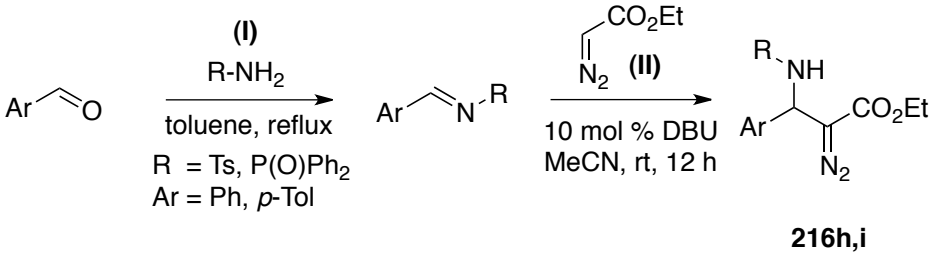
N-Boc diazocompound **216f** was prepared as follows:

(I) *N*-(*tert*-butoxycarbonyl)-*α*-(phenylsulfonyl)benzylamine.[178] A 500-mL flask was charged with *tert*-butyl carbamate (10.0 g, 85.5 mmol, 1.00 equiv) and benzenesulfinic acid sodium salt (28 g, 170 mmol, 2.0 equiv). The solids were suspended in a solution of methanol in water (1:2, 250 mL). Benzaldehyde (13.0 mL, 128 mmol, 1.50 equiv) was added in one portion to the resulted suspension, followed by formic acid (98%, 6.4 mL) (Scheme 111). The reaction was allowed to stir 48 h at room temperature. During this time the product precipitated as a white solid. The resulted precipitate was isolated via Buchner funnel filtration, washed with water and diethyl ether, and dried *in vacuo* overnight at 100 ºC.

(II) Benzaldehyde *N*-(*tert*-butoxycarbonyl)imine.[178] A 250-mL, 3-neck flask was charged with anhydrous potassium carbonate (12.4 g, 90.0 mmol, 6.0 equiv) and anhydrous sodium sulfate (15 g). The solids were placed under vacuum and flame-dried. Once cooled, *N*-Boc-*α*-(phenylsulfonyl)benzylamine (5.2 g, 15 mmol, 1.0 equiv) was added under a positive stream of nitrogen, followed by anhydrous tetrahydrofuran (140 mL) (Scheme 111). The flask was capped with a water-cooled reflux condenser under nitrogen atmosphere and heated to reflux with stirring. After 15 h, the reaction was cooled to ambient temperature and the solids were removed via filtration through a fine glass filter. The filtrate was concentrated *in vacuo* and dried under high vacuum to give imine benzaldehyde *N*-(*tert*-butoxycarbonyl)imine as a colorless oil.

(III) *N*-Boc diazocompound 216f. The freshly prepared benzaldehyde *N*-(*tert*-butoxycarbonyl)imine was immediately used for the synthesis of diazocompound using procedure described earlier (Scheme 111). The spectral data of the product matched those of the previously synthesized material.[179]

Synthesis of *N*-Ts and *N*-P(O)Ph$_2$ diazocompounds 216h and 216i



216h,i

Scheme 112.

N-Ts diazocompound **216h** was prepared as described:

(I) *N*-sulfonylimine. A solution of *p*-tolualdehyde (5 mmol, 589 μL), tosylamide (5 mmol, 856 mg), and *p*-toluenesulfonic acid (0.1 mmol, 17.2 mg) in toluene (5 mL) was refluxed with azeotropic removal of water (Scheme 112) until consumption of all starting materials (about 8 h). After that, the reaction mixture was cooled down and the resulted precipitate was filtered and washed with hexanes to obtain *N*-sulfonylimine, which was used in the next step without additional purification.

(II) Synthesis of *N*-Ts diazocompound 216h. The resulted *N*-sulfonylimine was used directly in the reaction with ethyldiazoacetate using procedure described earlier (Scheme 112). The spectral data of the product matched those of the previously synthesized material.[180]

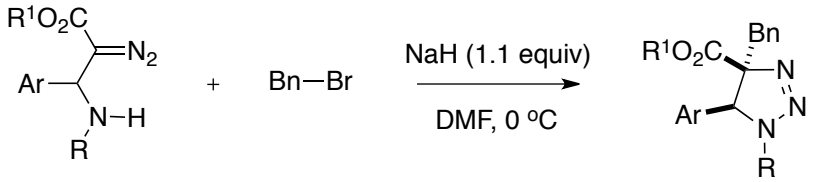
N-P(O)Ph_2 diazocompound **216i** was prepared using procedure similar to the *N*-Ts diazocompound starting from benzaldehyde (5 mmol, 589 μL) and diphenylphosphinamide (5 mmol, 1.09 g) (Scheme 112).

216i: 39%, eluent: Hexanes/EtOAc = 1/2. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93-7.86 (m, 4H), 7.53-7.39 (m, 8H), 7.37-7.33 (m, 2H), 7.30-7.26 (m, 1H), 5.25 (t, *J* = 9.9 Hz, 1H), 4.10 (s_{br}, 1H), 4.07 (q, *J* = 7.2 Hz, 2H), 1.16 (t, *J* = 6.9 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.7, 140.6, 140.6, 132.5, 132.2, 132.1, 132.1, 131.9, 131.8, 128.8, 128.6, 128.6, 128.53, 128.48, 128.0, 126.3, 60.8, 51.6, 14.30. HRMS (ES+) calcd. for $C_{23}H_{22}N_3O_3PNa$ (M^++Na): 442.1296, found: 442.1298.

Synthesis of *N*-Py and *N*-Pyrimidine diazocompounds 216.

N-pyridine and *N*-pyrimidine diazocompounds were synthesized using our previously developed procedure.[164]

10.3. Synthesis of Triazolines 217 from Diazocompounds 216



216 **217**

Scheme 113.

General procedure for the synthesis of Triazolines 217 from Diazocompounds 216: An oven dried 3 mL vial equipped with a rubber septum and a stirring bar was charged with NaH (0.44 mmol, 10.6 mg, 1.1 equiv) under an inert atmosphere (glove box). DMF (0.44 mL) was added to the vial, and the resulting suspension was cooled to 0 ºC (ice bath). A solution of diazoester **216** (0.4 mmol, 1 equiv) and alkyl halide (0.48 mmol, 1.2 equiv) in dry DMF (1 mL) was added to the suspension of NaH at 0 ºC dropwise (Scheme 113). The reaction mixture was stirred at this temperature for 15 min and then allowed to warm up to room temperature. After completion of gas evolution (15-30 min) the reaction mixture was quenched with saturated aqueous NH_4Cl. The product **217** was extracted with EtOAc, dried over $MgSO_4$, concentrated, and purified by flash silica gel column chromatography (eluent: Hexanes/EtOAc = 7/1).

217aa: (83%, eluent: Hexanes/EtOAc = 7/1) ^1H NMR (500 MHz, $CDCl_3$): 8.02 (d, J = 5.1 Hz, 1H), 7.56-7.50 (m, 2H), 7.33-7.22 (m, 2H), 7.23-7.15 (m, 2H), 7.15-7.10 (m, 1H),

7.10-6.80 (m, 4H), 6.80-6.70 (m, 1H), 5.2 (s, 1H), 3.70-3.60 (m, 2H), 3.55 (d, *J* = 13.9 Hz, 1H), 3.28 (d, *J* = 13.9 Hz, 1H), 2.25 (s, 3H), 0.87 (t, *J* = 7.0 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): 168.0, 151.8, 147.8, 137.7, 137.4, 134.1, 132.6, 130.6, 128.8, 128.1, 127.1, 127.0, 117.8, 110.7, 93.1, 64.1, 61.5, 43.4, 21.1, 13.5. HRMS (ES+) calcd. for $C_{24}H_{25}N_4O_2$ (M^++H): 401.1978, found: 401.1978.

217ab: (71%, eluent: Hexanes/EtOAc = 2/1). The product is decomposing upon storage at room temperature. ^{1}H NMR (500 MHz, $CDCl_3$): 8.35 (d, *J* = 4.8 Hz, 2H), 7.32-7.24 (m, 2H), 7.20-7.10 (m, 2H), 7.11-7.05 (m, 1H), 7.0 (s_{br}, 4H), 6.76 (t, *J* = 4.8 Hz, 1H), 5.18 (s, 1H), 4.35-4.25 (m, 1H), 3.53 (d, *J* = 13.9 Hz, 1H), 3.28 (d, *J* = 13.9 Hz, 1H), 2.23 (s, 3H), 1.55-0.99 (m, 10H). ^{13}C NMR (125 MHz, $CDCl_3$): 167.1, 158.1, 156.3, 140.0, 133.8, 132.5, 130.5, 128.9, 128.1, 127.9, 127.1, 115.3, 94.3, 74.5, 63.3, 43.4, 30.8, 25.2, 23.6, 21.1.

217ac: (81%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30-7.24 (m, 8H), 7.03-7.02 (m, 2H), 4.99 (s, 1H), 3.72-3.63 (m, 2H), 3.53 (d, *J* = 13.3 Hz, 1H), 3.30 (d, *J* = 13.3 Hz, 1H) 2.24 (s, 3H), 0.85 (t, *J* = 7.3 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.6, 167.1, 134.8, 132.9, 130.5, 128.6, 128.4, 128.4, 127.7, 126.7, 95.2, 61.9, 60.9, 42.7, 22.0, 13.4. HRMS (ES+) calcd. for $C_{20}H_{21}N_3O_3Na$ (M^++Na): 374.1481, found: 374.1477.

217ad: (49%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.26-7.24 (m, 8H), 7.02-7.01 (m, 2H), 5.05 (s, 1H), 3.72-3.63 (m, 2H), 3.53 (d, *J* = 14.1 Hz, 1H),

3.31 (d, J = 14.1 Hz, 1H) 1.13 (s, 9H), 0.86 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.9, 167.4, 135.6, 132.9, 130.6, 128.4, 127.5, 126.6, 92.3, 61.9, 42.7, 40.6, 26.7, 13.4. HRMS (ES+) calcd. for $C_{23}H_{28}N_3O_3$ (M^++H): 394.2131, found: 394.2136.

217ae: (58%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.28-7.20 (m, 11H), 7.10-7.02 (m, 4H), 5.14-5.02 (m, 2H), 4.88 (s, 1H), 3.73-3.59 (m, 2H), 3.55 (d, J = 14.1 Hz, 1H), 3.27 (d, J = 14.1 Hz, 1H), 0.84 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.9, 150.1, 135.1, 134.9, 133.1, 130.5, 128.7, 128.5, 128.4, 128.3, 128.0, 127.6, 126,8, 95.6, 68.3, 62.4, 61.9, 42.8, 13.4. HRMS (ES+) calcd. for $C_{26}H_{26}N_3O_4$ (M^++H): 444.1923, found: 444.1923.

217af: 85% (eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$): 7.36-7.21 (m, 8H), 7.10-7.00 (m, 2H), 4.80 (s, 1H), 3.71-3.57 (m, 2H), 3.53 (d, J = 14.1 Hz, 1H), 3.24 (d, J = 14.1 Hz, 1H), 1.26 (s, 9H), 0.82 (t, J = 7.0 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): 167.1, 148.9, 135.7, 133.4, 130.6, 128.5, 128.4, 128.3, 127.5, 94.9, 83.4, 62.9, 61.7, 43.0, 27.7, 13.4 (one signal of a benzene ring overlapped). HRMS (ES+) calcd. for $C_{23}H_{27}N_3O_4Na$ (M^++Na): 432.1899, found: 432.1883.

217ag: (36%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.65-7.63 (m, 2H), 7.53-7.49 (m, 1H), 7.42-7.38 (m, 2H), 7.33-7.22 (m, 8H), 7.16-7.14 (m, 2H) 5.23 (s, 1H), 3.74-3.66 (m, 2H), 3.64 (d, J = 14.3 Hz, 1H), 3.39 (d, J = 14.1 Hz, 1H), 0.90-0.86 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.0, 165.8, 134.9, 133.1, 132.1, 130.6, 129.9, 128.6, 128.5, 127.9, 127.7, 126.8, 94.4, 61.9, 61.7, 42.6, 13.4. HRMS (ES+)

calcd. for $C_{25}H_{23}N_3O_3Na$ (M^++Na): 436.1637, found: 436.1649.

217aj: (87%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03-8.02 (m, 1H), 7.56-7.52 (m, 2H), 7.33-7.31 (m, 2H), 7.21-7.18 (m, 2H), 7.13-7.12 (m, 1H), 7.04-6.98 (m, 4H), 6.78-6.75 (m, 1H), 5.28 (s, 1H), 4.34-4.29 (m, 1H), 3.55 (d, *J* = 13.9 Hz, 1H), 3.27 (d, *J* = 13.9 Hz, 1H), 2.24 (s, 3H), 1.55-1.52 (m, 2H), 1.41-1.34 (m, 3H), 1.17-1.13 (m, 3H), 1.04-1.02 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.4, 151.9, 147.7, 137.7, 137.4, 134.2, 132.7, 130.5, 128.8, 128.0, 127.2, 127.0, 117.7, 110.7, 93.0, 74.2, 64.2, 43.8, 30.8, 25.2, 23.54, 23.49, 21.0. HRMS (ES+) calcd. for $C_{28}H_{31}N_4O_2$ (M^++H): 455.2447, found: 455.2440.

217ak: (83%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03-8.02 (m, 1H), 7.55-7.50 (m, 2H), 7.20-7.18 (m, 2H), 7.02-6.98 (m, 6H), 6.78-6.75 (m, 1H), 5.26 (s, 1H), 4.35-4.29 (m, 1H), 3.51 (d, *J* = 13.9 Hz, 1H), 3.23 (d, *J* = 14.3 Hz, 1H), 2.24 (s, 3H), 2.20 (s, 3H), 1.55-1.53 (m, 2H), 1.42-1.35 (m, 3H), 1.20-1.12 (m, 3H), 1.07-1.01 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ.167.5, 152.0, 147.8, 137.7, 137.3, 136.6, 132.8, 131.1, 130.4, 128.8, 128.7, 127.3, 117.7, 110.8, 93.2, 74.2, 64.2, 43.4, 30.9, 25.2, 23.6, 23.5, 21.1, 21.0. HRMS (ES+) calcd. for $C_{29}H_{32}N_4O_2Na$ (M^++Na): 491.2423, found: 491.2419.

217al: (91%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04-8.03 (m, 1H), 7.59-7.57 (m, 1H), 7.55-7.51 (m, 1H), 7.45-7.43 (m, 1H), 7.10-7.08 (m, 1H), 7.03-7.01 (m, 6H), 6.79-6.76 (m, 1H), 5.31 (s, 1H), 4.35-4.30 (m, 1H), 3.56 (d, *J* = 14.7

Hz, 1H), 3.35 (d, J = 14.7 Hz, 1H), 2.39 (s, 3H), 2.25 (s, 3H), 1.56-1.49 (m, 2H), 1.42-1.40 (m, 2H), 1.34-1.32 (m, 1H), 1.18-1.13 (m, 3H), 1.09-0.99 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ.167.7, 152.0, 147.8, 137.7, 137.4, 137.2, 133.2, 132.8, 130.4, 128.8, 127.3, 127.0, 125.6, 117.7, 110.8, 93.5, 74.2, 64.6, 40.2, 30.84, 30.76, 25.2, 23.5, 21.0, 20.4. HRMS (ES+) calcd. for $C_{29}H_{32}N_4O_2Na$ (M^++Na): 491.2423, found: 491.2422.

217am: (89%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03-8.02 (m, 1H), 7.56-7.51 (m, 2H), 7.10 (t, J = 8.1 Hz, 1H), 7.02-7.00 (m, 4H), 6.90 (d, J = 7.7 Hz, 1H), 6.87 (s_{br}, 1H), 6.79-6.76 (m, 1H), 6.67-6.65 (m, 1H), 5.29 (s, 1H), 4.35-4.30 (m, 1H), 3.73 (s, 3H), 3.53 (d, J = 13.9 Hz, 1H), 3.25 (d, J = 13.9 Hz, 1H), 2.25 (s, 3H), 1.54-1.53 (m, 2H), 1.41-1.34 (m, 3H), 1.17-1.13 (m, 3H), 1.05-1.01 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.4, 159.2, 151.9, 147.8, 137.7, 137.4, 135.7, 132.7, 128.9, 128.8, 127.2, 122.9, 117.7, 115.8, 113.0, 110.7, 93.0, 74.2, 64.1, 55.1, 43.8, 30.8, 25.2, 23.5, 23.5, 21.0. HRMS (ES+) calcd. for $C_{29}H_{32}N_4O_3Na$ (M^++Na): 507.2372, found: 503.2368.

217an: (86%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04-8.03 (m, 1H), 7.58-7.52 (m, 4H), 7.39 (d, J = 8.1 Hz, 1H), 7.33 (t, J = 8.1 Hz, 1H), 7.03-6.98 (m, 4H), 6.81-6.78 (m, 1H), 5.28 (s, 1H), 4.33-4.27 (m, 1H), 3.58 (d, J = 14.3 Hz, 1H), 3.27 (d, J = 13.9 Hz, 1H), 2.25 (s, 3H), 1.54-1.50 (m, 2H), 1.41-1.31 (m, 3H), 1.18-1.11 (m, 3H), 1.05-0.97 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.0, 151.7, 147.8, 137.9, 137.5, 135.4, 134.0, 132.3, 130.3 (q, J_{C-F} = 31.4 Hz), 128.9, 128.5, 127.1 (J_{C-F} = 15.7 Hz), 124.0 (q, J_{C-F} = 271.9 Hz), 123.9, 118.0, 110.7, 92.5, 74.5, 64.7, 43.7, 30.8, 25.1, 23.5, 23.4, 21.0. HRMS (ES+) calcd. for $C_{29}H_{29}F_3N_4O_2Na$ (M^++Na): 545.2140, found:

545.2135.

217ao: (69%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.04-8.03 (m, 1H), 8.00 (d, *J* = 8.1 Hz, 1H), 7.67 (d, *J* = 8.4 Hz, 1H), 7.62-7.57 (m, 2H), 7.42 (t, *J* = 7.7 Hz, 1H), 7.26 (t, *J* = 8.1 Hz, 1H), 7.01 (s_{br}, 4H), 6.82-6.80 (m, 1H), 5.27 (s, 1H), 4.33-4.27 (m, 1H), 3.82 (d, *J* = 15.8 Hz, 1H), 3.53 (d, *J* = 16.1 Hz, 1H), 2.24 (s, 3H), 1.53-1.50 (m, 1H), 1.38-1.35 (m, 2H), 1.27-1.24 (m, 2H), 1.18-1.07 (m, 4H), 1.00-0.96 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.1, 151.9, 147.9, 137.8, 137.6, 134.5, 132.2, 131.8, 130.9, 129.2 (q, J_{C-F} = 28.7 Hz), 128.9, 127.3, 126.8, 126.0 (J_{C-F} = 5.6 Hz), 124.5 (q, J_{C-F} = 273.7 Hz), 118.0, 111.0, 92.5, 74.5, 65.5, 39.4, 30.6, 30.5, 25.1, 23.3, 23.2, 21.0. HRMS (ES+) calcd. for $C_{29}H_{29}F_3N_4O_2Na$ (M^++Na): 545.2140, found: 545.2139.

217ap: (78%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.09-8.08 (m, 1H), 7.71 (d, *J* = 8.4 Hz, 1H), 7.63-7.59 (m, 1H), 7.01-6.97 (m, 4H), 6.84-6.82 (m, 1H), 5.77-5.69 (m, 1H), 5.26 (d, *J* = 16.9 Hz, 1H), 5.20 (s, 1H), 5.16 (d, *J* = 9.9 Hz, 1H), 4.38-4.33 (m, 1H), 2.94 (dd, *J* = 13.4, 7.0 Hz, 1H), 2.74 (dd, *J* = 14.3, 7.7 Hz, 1H), 2.24 (s, 3H), 1.60-1.54 (m, 2H), 1.44-1.37 (m, 3H), 1.22-1.15 (m, 3H), 1.10-1.04 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.3, 152.0, 147.9, 137.63, 137.58, 132.0, 130.8, 128.8, 127.2, 120.4, 117.9, 110.0, 92.0, 74.0, 63.7, 42.0, 30.8, 25.2, 23.5, 21.0. HRMS (ES+) calcd. for $C_{24}H_{28}N_4O_2Na$ (M^++Na): 427.2110, found: 427.2110.

217aq: (71%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.28-7.25 (m, 3H), 7.02-7.01 (m, 2H), 5.66-5.59 (m, 1H), 5.31-5.27 (m, 1H), 5.26-5.24 (m, 1H),

4.91 (s, 1H), 3.69-3.62 (m, 2H), 2.93 (dd, J = 14.3, 6.8 Hz, 1H), 2.73 (dd, J = 14.3, 7.9 Hz, 1H), 2.57 (s, 3H), 0.85 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.2, 166.9, 134.7, 129.5, 128.6, 128.4, 126.6, 121.7, 94.4, 61.8, 61.3, 41.2, 22.6, 13.5. HRMS (ES+) calcd. for $C_{16}H_{19}N_3O_3Na$ (M^++Na): 324.1324, found: 324.1326.

217ar: (75% eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$): 7.30-7.20 (m, 3H), 7.07-7.00 (m, 2H), 5.75-5.60 (m, 1H), 5.30-5.20 (m, 2H), 4.71 (s, 1H), 3.75-3.59 (m, 2H), 2.90 (dd, J = 14.2, 6.8 Hz, 1H), 2.70 (dd, J = 14.2, 6.8 Hz, 1H), 1.33 (s, 9H), 0.85 (t, J = 7.2 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): 167.0, 149.2, 135.7, 130.0, 128.5, 128.3, 126.7, 121.2, 94.9, 83.6, 63.0, 61.7, 41.4, 27.8, 13.4. HRMS (ES+) calcd. for $C_{19}H_{26}N_3O_4$ (M^++H): 360.1923, found: 360.1924.

217as: (69%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.06-8.04 (m, 1H), 7.71 (d, J = 8.5 Hz, 1H), 7.60-7.55 (m, 1H), 6.99 (s_{br}, 4H), 6.81-6.78 (m, 1H), 5.46 (s, 1H), 3.69-3.64 (m, 1H), 3.58-3.54 (m, 1H), 3.08-2.93 (m, 2H), 2.21 (s, 3H), 1.84-1.80 (m, 2H), 0.83 (t, J = 7.1 Hz, 3H), 0.69 (t, J = 7.5 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.2, 151.8, 147.7, 137.4, 132.6, 128.6, 126.7, 117.7, 110.8, 91.3, 84.8, 71.9, 62.8, 61.4, 27.3, 20.8, 13.3, 13.2, 11.9. HRMS (ES+) calcd. for $C_{22}H_{24}N_4O_2Na$ (M^++Na): 399.1797, found: 399.1791.

217at: (62%, eluent: Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.29-7.23 (m, 3H), 7.06-7.05 (m, 2H), 5.19 (s, 1H), 3.69-3.55 (m, 2H), 3.11-2.98 (m, 2H), 2.59 (s, 3H), 2.13-2.08 (m, 2H), 1.06 (t, J = 7.5 Hz, 3H), 0.84 (t, J = 7.2 Hz, 3H). ^{13}C NMR (125

MHz, $CDCl_3$) δ 168.0, 166.3, 134.6, 128.5, 128.4, 126.6, 93.6, 85.7, 71.2, 62.0, 60.9, 27.2, 22.6, 13.9, 13.3, 12.2. HRMS (ES+) calcd. for $C_{18}H_{21}N_3O_3Na$ (M^++Na): 350.1481, found: 350.1479.

217au: (70%, eluent: Hexanes/EtOAc = 7/1). ^1H NMR (500 MHz, $CDCl_3$): 7.30-7.24 (m, 3H), 7.13-7.03 (m, 2H), 5.02 (s, 1H), 3.57-3.50 (m, 1H), 3.60-3.50 (m, 1H), 3.10-2.96 (m, 2H), 2.15-2.08 (m, 2H), 1.35 (s, 9H), 1.08 (t, *J* = 7.5 Hz, 3H), 0.84 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): 166.4, 149.0, 135.6, 128.4, 128.2, 126.6, 93.2, 85.7, 83.4, 71.5, 62.3, 61.9, 27.8, 27.1, 13.9, 13.3, 12.2. HRMS (ES+) calcd. for $C_{21}H_{28}N_3O_4$ (M^++H): 386.2080, found: 386.2079.

217av: (59%, eluent: Hexanes/EtOAc = 7/1). ^1H NMR (500 MHz, $CDCl_3$): 7.35-7.22 (m, 3H), 7.12-7.02 (m, 2H), 4.99 (s, 1H), 6.74-6.65 (m, 1H), 3.62-3.50 (m, 1H), 3.10-3.00 (m, 2H), 2.06 (t, *J* = 2.6 Hz, 1H), 1,35 (s, 9H), 0.85 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): 166.1, 149.1, 135.2, 128.6, 128.3, 126.7, 92.5, 83.7, 76.6, 72.1, 62.6, 62.1, 27.8, 26.8, 13.3. HRMS (ES+) calcd. for $C_{19}H_{24}N_3O_4$ (M^++H): 358.1767, found: 358.1768.

217aw: (41%, eluent: Hexanes/EtOAc = 4/1). ^1H NMR (500 MHz, $CDCl_3$) δ 8.08-8.07 (m, 1H), 7.75 (d, *J* = 8.4 Hz, 1H), 7.65-7.61 (m, 1H), 7.02-6.98 (m, 4H), 6.86-6.84 (m, 1H), 5.47 (s, 1H), 4.36-4.32 (m, 1H), 3.69 (s, 3H), 3.27 (d, *J* = 16.1 Hz, 1H), 2.87 (d, *J* = 16.1 Hz, 1H), 2.24 (s, 3H), 1.59-1.47 (m, 3H), 1.42-1.35 (m, 2H), 1.21-1.12 (m, 4H), 1.07-1.01 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.1, 166.6, 152.1, 148.0, 137.9,

137.7, 131.8, 128.9, 127.2, 118.2, 111.3, 89.1, 74.4, 64.4, 52.0, 41.1, 30.8, 30.7, 25.2, 23.5, 21.1. HRMS (ES+) calcd. for $C_{24}H_{28}N_4O_4Na$ (M^++Na): 459.2008, found: 459.2007.

217ax: (45%, eluent: Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.10-8.09 (m, 1H), 7.78 (d, *J* = 8.4 Hz, 1H), 7.69-7.66 (m, 1H), 7.05-7.00 (m, 4H), 6.92-6.90 (m, 1H), 5.46 (s, 1H), 4.41-4.36 (m, 1H), 3.17-3.08 (m, 2H), 2.26 (s, 3H), 1.60-1.56 (m, 2H), 1.48-1.37 (m, 3H), 1.21-1.04 (m, 5H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.2, 151.5, 148.0, 138.3, 137.9, 131.0, 129.1, 126.9, 118.8, 115.0, 111.6, 87.7, 75.6, 64.5, 30.8, 30.6, 25.9, 25.1, 23.40, 23.36, 21.1. HRMS (ES+) calcd. for $C_{23}H_{26}N_5O_2$ (M^++H): 404.2087, found: 404.2089.

217ay: (71%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.09-8.08 (m, 1H), 7.74 (d, *J* = 8.4 Hz, 1H), 7.64-7.60 (m, 1H), 7.01-6.96 (m, 4H), 6.85-6.83 (m, 1H), 5.16 (s, 1H), 4.38-4.32 (m, 1H), 2.24 (s, 3H), 1.70 (s, 3H), 1.57-1.52 (m, 2H), 1.42-1.36 (m, 3H), 1.19-1.16 (m, 3H), 1.12-1.03 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.9, 152.5, 147.9, 137.6, 132.5, 128.8, 127.0, 117.9, 111.2, 89.0, 74.0, 66.3, 30.84, 30.81, 25.2, 23.9, 23.5, 21.0. HRMS (ES+) calcd. for $C_{22}H_{27}N_4O_2$ (M^++H): 379.2134, found: 379.2131.

217az: (79%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.29-7.25 (m, 3H), 7.02-7.01 (m, 2H), 4.86 (s, 1H), 3.72-3.59 (m, 2H), 2.60 (s, 3H), 1.68 (s, 3H), 0.84 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 168.6, 167.4, 134.5, 128.6, 128.4, 126.4, 91.1, 64.1, 61.8, 23.5, 22.6, 13.4. HRMS (ES+) calcd. for $C_{14}H_{17}N_3O_3Na$

(M^++Na): 298.1168, found: 298.1169.

217ba: (56%, eluent: Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$): 7.30-7.20 (m, 3H), 7.11-7.00 (m, 2H), 4.67 (s, 1H), 3.75-3.55 (m, 2H), 1.67 (s, 3H), 1.33 (s, 9H), 0.83 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): 167.6, 149.5, 135.5, 128.5, 128.3, 126.5, 90.9, 83.6, 65.7, 61.7, 27.8, 23.4, 13.4. HRMS (ES+) calcd. for $C_{17}H_{24}N_3O_4$ (M^++H): 334.1767, found: 334.1770.

217bb: (66%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.09-8.07 (m, 1H), 7.74-7.72 (m, 1H), 7.63-7.59 (m, 1H), 7.00-6.96 (m, 4H), 6.84-6.81 (m, 1H), 5.15 (s, 1H), 4.39-4.34 (m, 1H), 2.23 (s, 3H), 1.91-1.85 (m, 1H), 1.61-1.55 (m, 3H), 1.46-1.04 (m, 12H), 0.89 (t, *J* = 7.0 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.7, 152.3, 147.9, 137.6, 132.9, 128.8, 127.2, 117.8, 111.1, 92.8, 73.8, 64.8, 38.6, 30.9, 30.8, 25.7, 25.2, 23.5, 22.9, 21.0, 13.8. HRMS (ES+) calcd. for $C_{25}H_{33}N_4O_2$ (M^++H): 421.2604, found 421.2608.

217bc: (49%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.07-8.06 (m, 1H), 7.72 (d, *J* = 8.4 Hz, 1H), 7.60-7.57 (m, 1H), 7.02-6.95 (m, 4H), 6.81-6.79 (m, 1H), 5.21 (s, 1H), 4.36-4.32 (m, 1H), 2.48-2.43 (m, 1H), 2.23 (s, 3H), 1.61-1.50 (m, 3H), 1.43-1.33 (m, 2H), 1.21-1.15 (m, 4H), 1.20 (d, *J* = 7.0 Hz, 3H), 1.05-1.00 (m, 1H), 0.86 (d, *J* = 6.6 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.9, 151.8, 148.0, 137.6, 133.7, 128.8, 127.4, 117.7, 110.9, 96.5, 73.6, 62.7, 36.8, 31.0, 30.8, 25.2, 23.6, 23.5, 21.1, 18.1, 15.7. HRMS (ES+) calcd. for $C_{24}H_{30}N_4O_2Na$ (M^++Na): 429.2266, found: 429.2260.

217bd: (67%, eluent: Hexanes/EtOAc = 7/1). Mixture of diastereomers 1:1. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.11-8.09 (m, 1H), 7.87-7.85 (m, 1H), 7.78-7.76 (m, 1H), 7.62-7.59 (m, 1H), 7.55-7.54 (m, 2H), 7.38-7.35 (m, 1H), 7.30-7.25 (m, 6H), 7.21-7.18 (m, 1H), 7.12-7.09 (m, 2H), 7.02-6.95 (m, 8H), 6.84-6.81 (m, 1H), 6.65-6.62 (m, 1H), 5.33 (s, 1H), 5.10 (s, 1H), 4.44-4.38 (m, 1H), 4.06-4.01 (m, 1H), 3.65-3.61 (m, 1H), 3.55-3.51 (m, 1H), 2.24-2.23 (m, 6H), 1.62-1.61 (m, 5H), 1.52-1.45 (m, 4H), 1.39-1.32 (m, 2H), 1.29-1.26 (m, 3H), 1.22-1.16 (m, 6H), 1.05-0.96 (m, 4H), 0.90-0.86 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.8, 167.1, 151.7, 151.2, 148.0, 147.4, 141.9, 139.1, 137.6, 137.5, 136.9, 133.6, 133.4, 129.1, 128.9, 128.7, 128.0, 127.9, 127.3, 127.2, 126.8, 117.8, 117.2, 111.0, 110.0, 96.7, 96.4, 74.1, 73.5, 64.1, 62.8, 49.4, 47.9, 30.92, 30.87, 30.6, 30.4, 25.2, 25.1, 23.6, 23.5, 23.42, 23.39, 21.0, 17.0, 16.1. HRMS (ES+) calcd. for $C_{29}H_{32}N_4O_2Na$ (M^++Na): 491.2423, found: 491.2429.

217be: (59% eluent: Hexanes/EtOAc = 7/1) Mixture of diastereomers ~ 0.55:0.45. ^{1}H NMR (500 MHz, $CDCl_3$): 7.45-7.20 (m, 10H), 4.81, 4.63 (s, 1H), 3.28-3.75 (m, 3H), 1.59, 1.23 (d, J = 6.8 Hz, 3H), 1.33, 1.16 (s, 9H), 0.91, 0.64 (t, J = 6.8 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): 167.6, 166.7, 149.1, 148.4, 140.9, 138.7, 136.8, 136.6, 129.1, 129.0, 128.4, 128.3, 128.2, 127.8, 127.2, 98.6, 83.6, 82.9, 63.4, 62.1, 61.8, 61.0, 49.0, 47.7, 27.8, 27.7, 17.1, 15.6, 13.5, 13.2. HRMS (ES+) calcd. for $C_{24}H_{30}N_3O_4$ (M^++H): 424.2236, found: 424.2237.

217bf: (70%, eluent: Hexanes/EtOAc = 4/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.05-8.03 (m, 1H), 7.58-7.51 (m, 2H), 7.33-7.31 (m, 2H), 7.22-7.18 (m, 2H), 7.15-7.11 (m, 1H), 7.04-7.02 (m, 2H), 6.80-6.78 (m, 1H), 6.75-6.73 (m, 2H), 5.28 (s, 1H), 4.39-4.32 (m, 1H), 3.72 (s, 3H), 3.53 (d, J = 13.9 Hz, 1H), 3.25 (d, J = 13.9 Hz, 1H), 1.59-1.52 (m, 2H), 1.44-1.37 (m, 2H), 1.20-1.03 (m, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.4, 159.3, 151.8, 147.8, 137.4, 134.2, 130.5, 128.5, 128.0, 127.7, 127.0, 117.7, 113.6, 110.7, 92.9, 74.2, 64.0, 55.2, 43.8, 30.9, 25.2, 23.55, 23.49. HRMS (ES+) calcd. for $C_{28}H_{31}N_4O_3$ (M^++H): 471.2396, found: 471.2394.

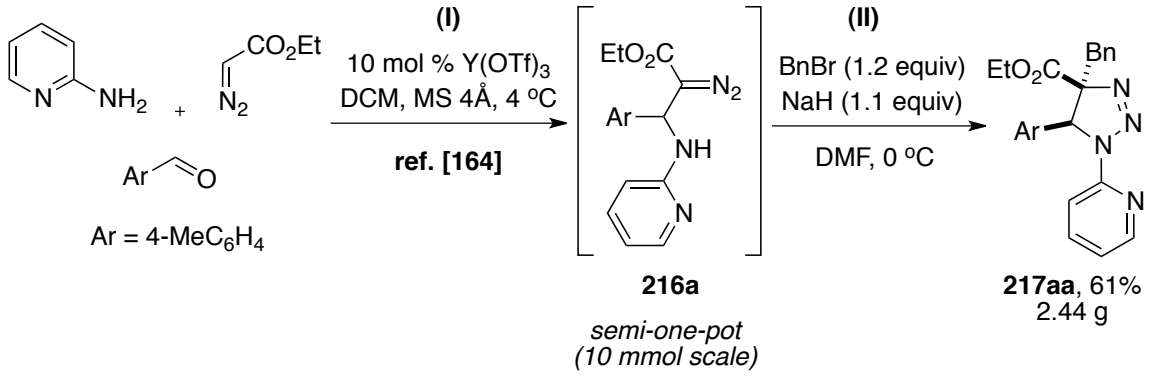
217bg: (67%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.99-7.98 (m, 1H), 7.60-7.56 (m, 2H), 7.54-7.48 (m, 2H), 7.33-7.31 (m, 2H), 7.23-7.19 (m, 4H), 7.16-7.12 (m, 1H), 6.83-6.79 (m, 1H), 5.35 (s, 1H), 4.35-4.28 (m, 1H), 3.57 (d, J = 14.0 Hz, 1H), 3.32 (d, J = 14.0 Hz, 1H), 1.54-1.51 (m, 2H), 1.43-1.38 (m, 1H), 1.33-1.26 (m, 2H), 1.19-1.08 (m, 3H), 1.00-0.89 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.1, 151.2, 147.7, 140.2, 137.6, 133.8, 130.5, 130.2 (q, $J_{C\text{-}F}$ = 32.4 Hz), 128.1, 127.8, 127.3, 125.21, 125.17, 121.1 (q, $J_{C\text{-}F}$ = 284.5 Hz), 119.8, 118.0, 110.7, 93.3, 74.7, 63.6, 43.6, 30.8, 25.1, 23.52, 23.49. HRMS (ES+) calcd. for $C_{28}H_{28}F_3N_4O_2$ (M^++H): 509.2164, found: 509.2162.

217bh: (54%, eluent: Hexanes/EtOAc = 7/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.01-7.99 (m, 1H), 7.57-7.53 (m, 2H), 7.35-7.33 (m, 2H), 7.31-7.29 (m, 2H), 7.21-7.18 (m, 2H), 7.14-7.11 (m, 1H), 7.00-6.98 (m, 2H), 6.81-6.78 (m, 1H), 5.26 (s, 1H), 4.39-4.34 (m, 1H), 3.53 (d, J = 14.1 Hz, 1H), 3.27 (d, J = 14.1 Hz, 1H), 1.57-1.54 (m, 2H), 1.43-1.37

(m, 3H), 1.19-1.16 (m, 3H), 1.06-1.02 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.2, 151.6, 147.7, 137.5, 135.0, 133.9, 131.3, 130.5, 129.0, 128.1, 127.2, 122.0, 117.9, 110.7, 93.0, 74.5, 63.6, 43.7, 30.8, 25.1, 23.55, 23.50. HRMS (ES+) calcd. for $C_{27}H_{28}N_4O_2Br$ (M^++H): 519.1396, found: 519.1398.

217bi: (62%, eluent: Hexanes/EtOAc = 25/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.88 (d, *J* = 5.1 Hz, 1H), 7.42-7.41 (m, 1H), 7.33-7.31 (m, 2H), 7.22-7.18 (m, 2H), 7.15-7.11 (m, 1H), 7.01-6.97 (m, 4H), 6.61-6.61 (m, 1H), 5.28 (s, 1H), 4.33-4.27 (m, 1H), 3.53 (d, *J* = 14.0 Hz, 1H), 3.24 (d, *J* = 14.0 Hz, 1H), 2.29 (s, 3H), 2.24 (s, 3H), 1.55-1.51 (m, 2H), 1.43-1.32 (m, 3H), 1.16-1.11 (m, 3H), 1.06-0.98 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.4, 152.0, 148.7, 147.4, 137.6, 134.4, 132.8, 130.6, 128.8, 128.0, 127.2, 127.0, 119.3, 111.2, 92.8, 74.2, 64.4, 43.9, 30.8, 25.2, 23.6, 23.5, 21.14, 21.08. HRMS (ES+) calcd. for $C_{29}H_{33}N_4O_2$ (M^++H): 469.2604, found: 469.2599.

10.4. Gram-Scale Synthesis of Triazoline 217aa Based on the Four-Component Coupling Reaction

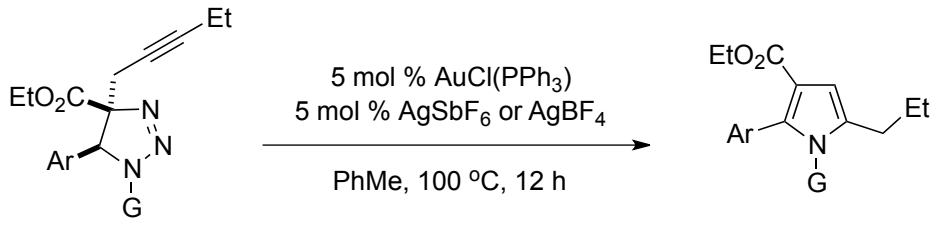


Scheme 114.

(I) An oven dried 50 mL round bottom flask, equipped with a rubber septum and a stirring bar, was charged with 2-aminopyridine (10.5 mmol, 987 mg, 1.05 equiv), *p*-tolualdehyde (10 mmol, 1178 μL, 1 equiv), activated MS 4Å (1.25 g), and $Y(OTf)_3$ (568 mg, 1 mmol, 0.1 equiv) under N_2 atmosphere (glovebox). Dry DCM (25 mL) was added, and the mixture was stirred 10 min at room temperature and then cooled to 10 ºC. Ethyldiazoacetate (12 mmol, 1.2 equiv) in DCM (5.0 mL) was added to the resulting mixture, and the reaction was stirred at this temperature for 12 h. After that, the reaction mixture was filtered (Celite/DCM), washed (aq. $NaHCO_3$), dried (Na_2SO_4), and concentrated under reduced pressure to give crude **216a**, which was used directly in the next step.

(II) An oven dried 50 mL round bottom flask equipped with a rubber septum and a stirring bar was charged with NaH (10 mmol, 240 mg, 1 equiv) under an inert atmosphere (glove box). Dry DMF (15 mL) was added to the flask and the resulting suspension was cooled to 0 ºC (ice bath). A solution of diazoester **216a** (ca. 10 mmol, 1 equiv) and benzyl bromide (12 mmol mmol, 1.2 equiv) in dry DMF (10 mL) was added to the suspension of NaH at 0 ºC dropwise. The reaction mixture was stirred at this temperature for 15 min and then allowed to warm up to room temperature. After completion of gas evolution (15-30 min) the reaction mixture was quenched with saturated aqueous NH_4Cl. The product was extracted with EtOAc, dried over $MgSO_4$, concentrated, and purified by flash silica gel column chromatography (eluent: Hexanes/EtOAc = 7/1) to give 2.44 g of triazoline **217aa** as a off yellow solid.

10.5. Cycloisomerization Reaction of Triazolines 217 into Pyrroles 221.



217as: G = 2-Py, Ar = *p*-Tol
217at: G = Ac, Ar = Ph

221a, G = 2-Py, Ar = *p*-Tol, 63%
221b, G = Ac, Ar = Ph, 49%

Scheme 115.

In a 1 mL Wheaton microreactor vial, to a solution of $AuCl(PPh_3)$ (5 mol %, 2.5 mg) and silver(I) salt (5 mol %) in toluene (0.5 mL), a solution of triazoline **217as/at** (0.1 mmol) in the same solvent (0.3 mL) was added under inert atmosphere. The microreactor was capped with a Teflon pressure cap and placed into pre-heated (100 ºC) aluminum block. The reaction mixture was stirred for 12 h at this temperature. After completion of the reaction (as judged by TLC analysis, eluent Hexanes/EtOAc = 7/1), microreactor, containing pyrrole **221**, was cooled down and the solvent was evaporated. The product was purified using flash silica gel column chromatography.

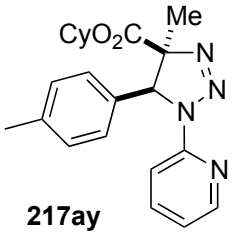
221a: (63%, $AgSbF_6$ was used, eluent: Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.54-8.53 (m, 1H), 7.54 (dt, *J* = 7.6, 2.0 Hz, 1H), 7.20 (ddd, *J* = 7.5, 4.9, 1.0 Hz, 1H), 7.08-7.06 (m, 2H), 6.98-6.96 (m, 2H), 6.80 (dt, *J* = 8.0, 1.0 Hz, 1H), 6.55-6.55 (m, 1H), 4.17 (q, J = 7.2 Hz, 2H), 2.50-2.46 (m, 2H), 2.26 (s, 3H), 1.52 (sext, *J* = 7.5 Hz, 2H), 1.21 (t, *J* = 7.1 Hz, 3H), 0.88 (t, *J* = 7.3 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.9, 151.5, 148.9, 138.0, 137.6, 137.2, 135.0, 130.9, 128.6, 128.0, 123.4, 122.8, 113.2, 108.3, 59.4, 28.9, 21.6, 21.2, 14.3, 13.9. HRMS (ES+) calcd. for $C_{22}H_{25}N_2O_2$ (M^++H): 349.1916, found: 349.1910.

221b: (49%, $AgBF_4$ was used, eluent: Hexanes/EtOAc = 10/1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41-7.40 (m, 5H), 6.46-6.45 (m, 1H), 6.80 (dt, J = 8.0, 1.0 Hz, 1H), 6.55-6.55 (m, 1H), 4.12 (q, J = 7.2 Hz, 2H), 2.74-2.70 (m, 2H), 1.85 (s, 3H), 1.52 (sext, *J* = 7.5 Hz, 2H), 1.15 (t, *J* = 7.2 Hz, 3H), 1.00 (t, *J* = 7.4 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.3, 164.2, 136.6, 136.4, 132.6, 130.5, 128.81, 128.76, 128.1, 116.0, 110.1, 59.8, 30.1,

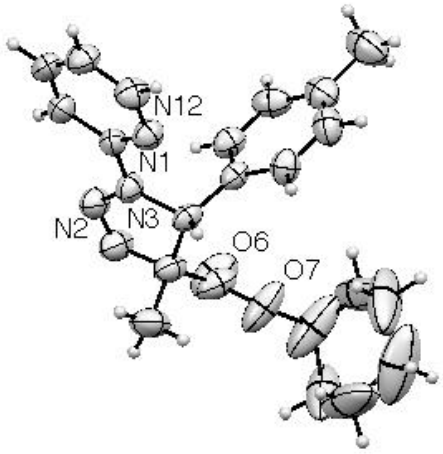
28.1, 22.1, 14.1, 13.9. HRMS (CI+) calcd. for $C_{18}H_{21}NO_3$ (M^+): 299.1521, found: 299.1522.

10.6. X-Ray Analysis of the Compound 217ay

Compound **217ay** was crystallized from chloroform at room temperature. CCDC-995385 contains the supplementary crystallographic data for this compound. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif



217ay



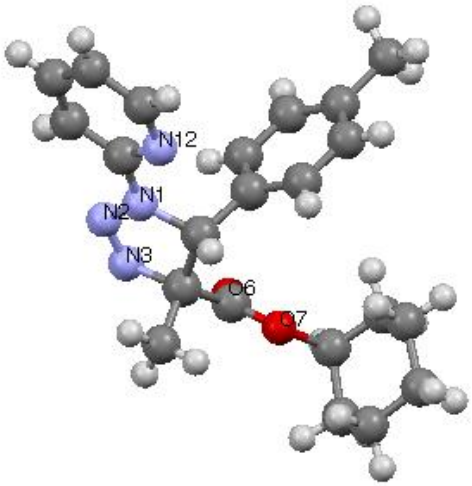


Figure 7. ORTEP-style drawing of molecule 217ay with thermal ellipsoids drawn at the 50% probability level. Drawing produced by Mercury 2.4 (Build RC5).

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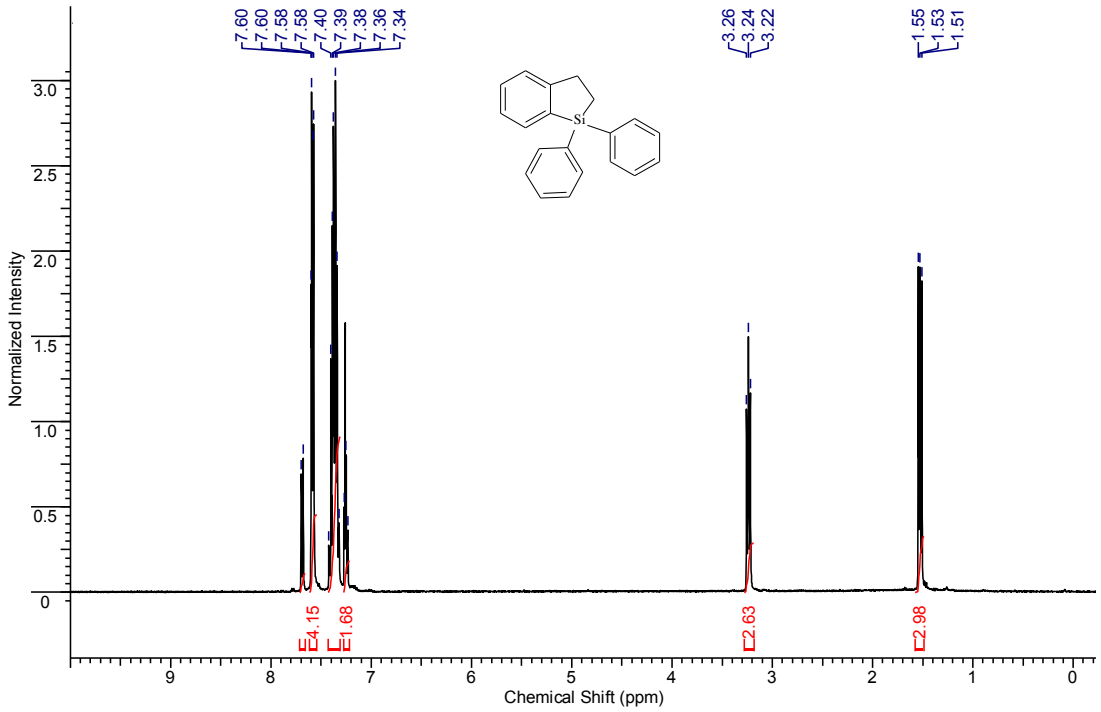
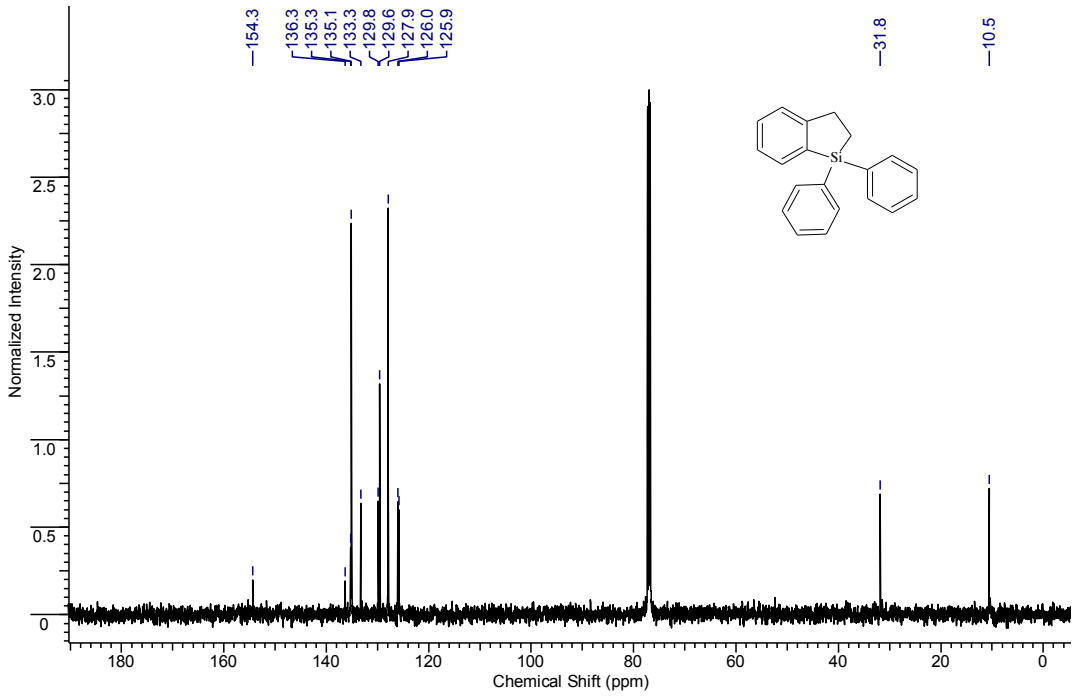
APPENDICES

APPENDIX A. ^{1}H and ^{13}C spectra of dihydrobenzosiloles **114** and the products of their further transformations

114a:





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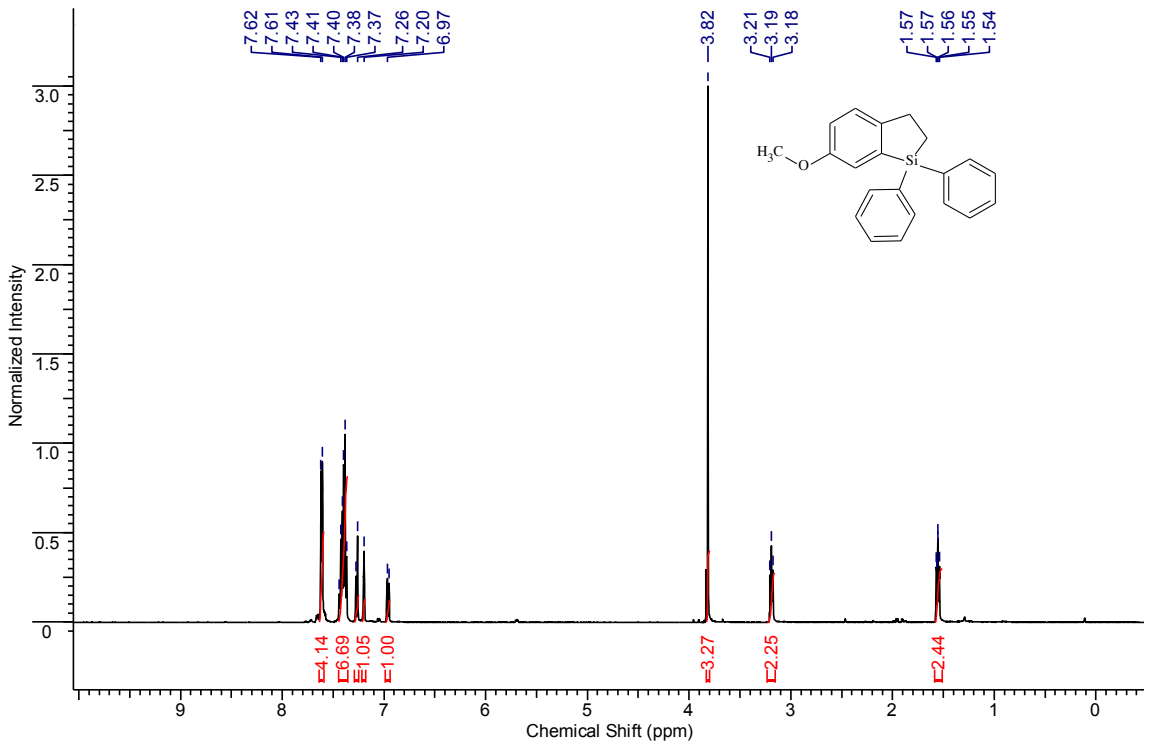
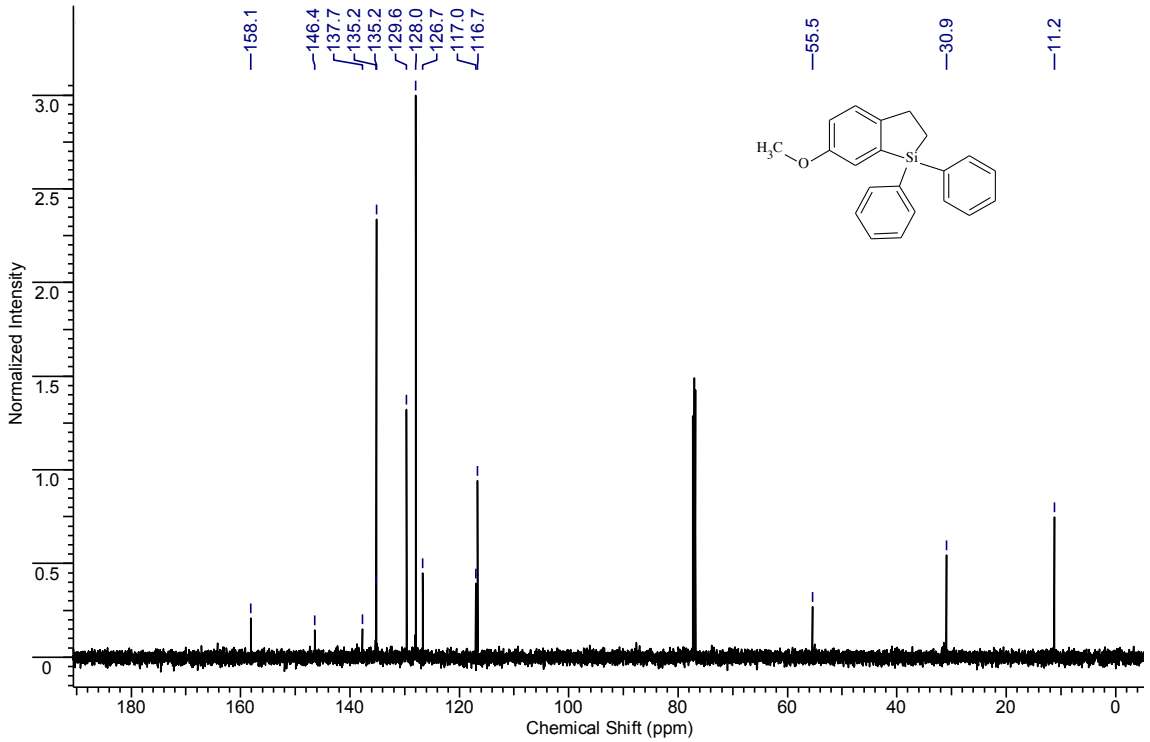
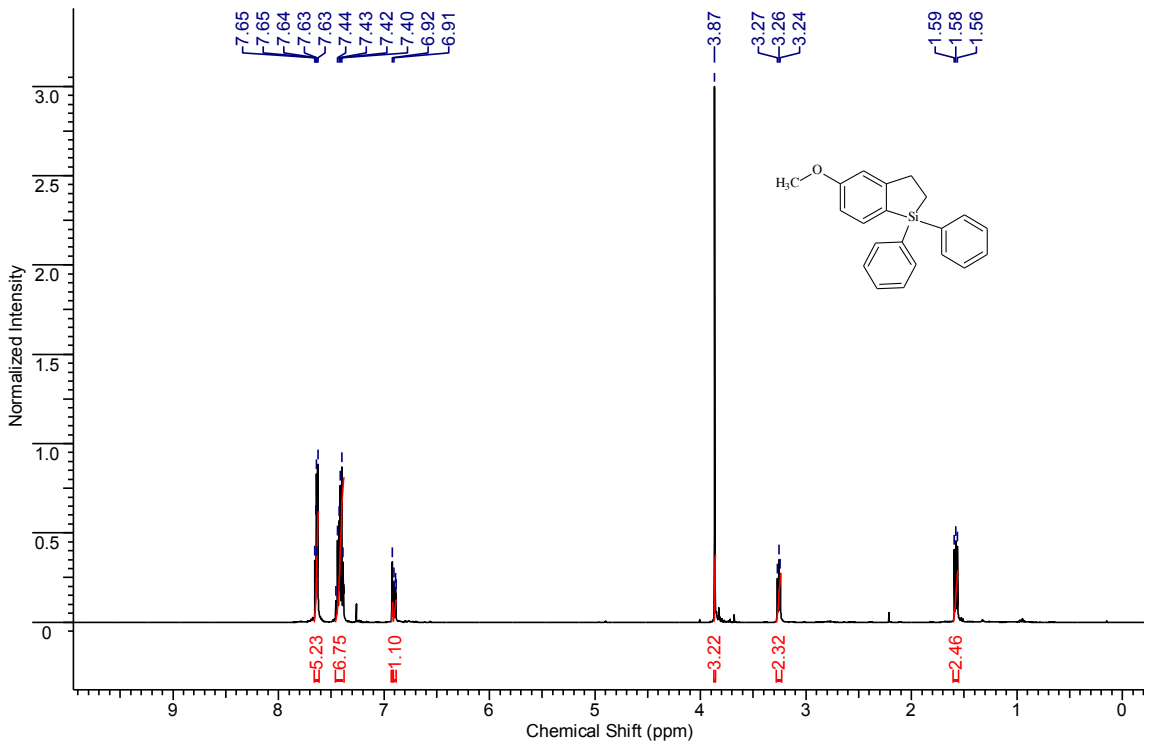
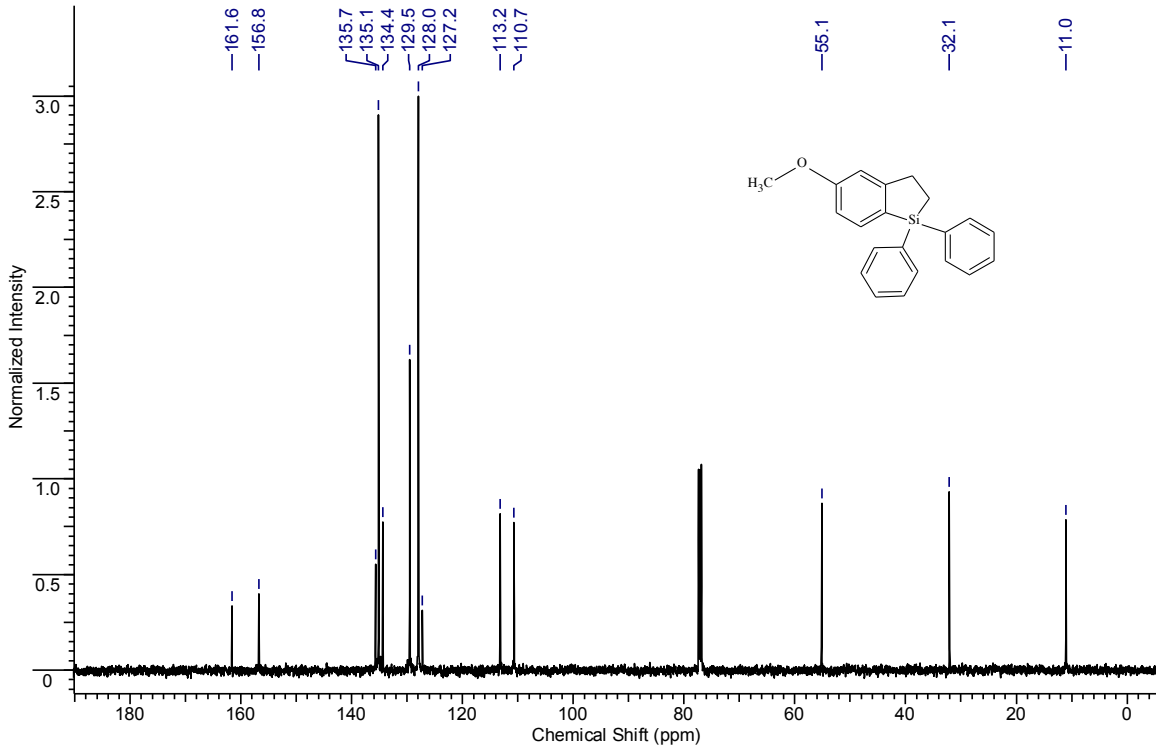

7.62
7.61
7.43
7.41
7.40
7.38
7.37
7.26
7.20
6.97
3.82
3.21
3.19
3.18
1.57
1.57
1.56
1.55
1.54
Normalized Intensity
Chemical Shift (ppm)
4.14
6.69
1.05
1.00
3.27
2.25
2.44

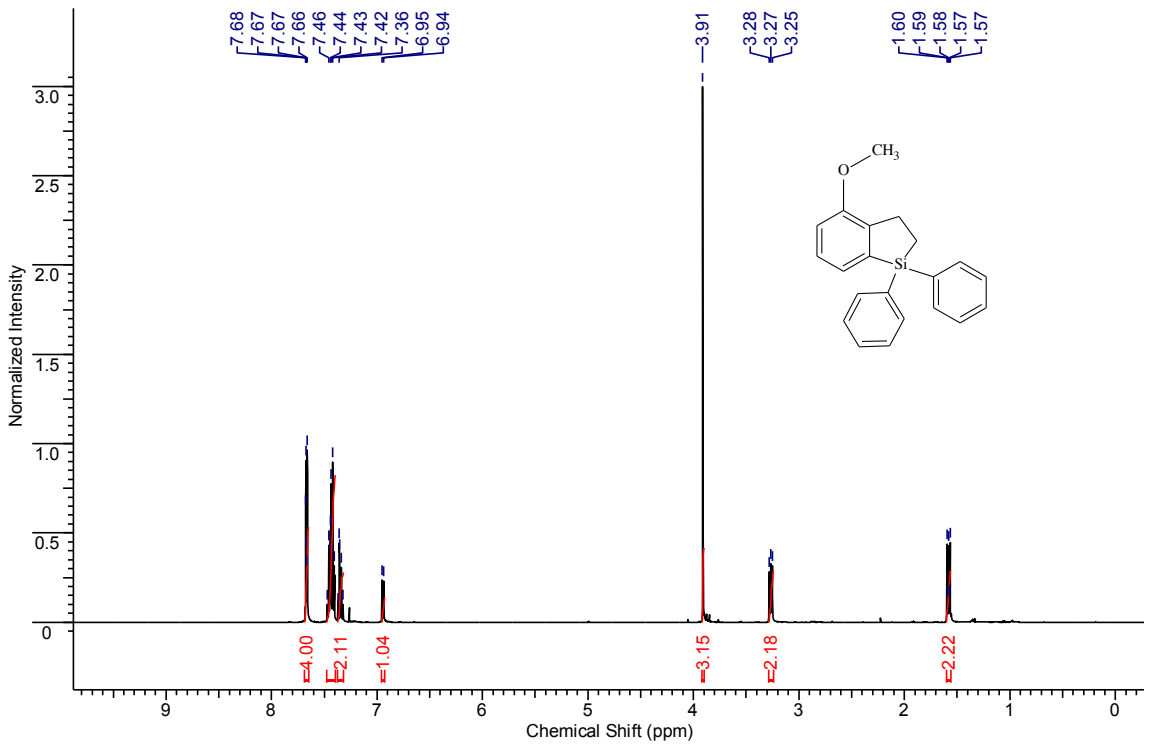

158.1
146.4
137.7
135.2
135.2
129.6
128.0
126.7
117.0
116.7
55.5
30.9
11.2
Normalized Intensity
Chemical Shift (ppm)

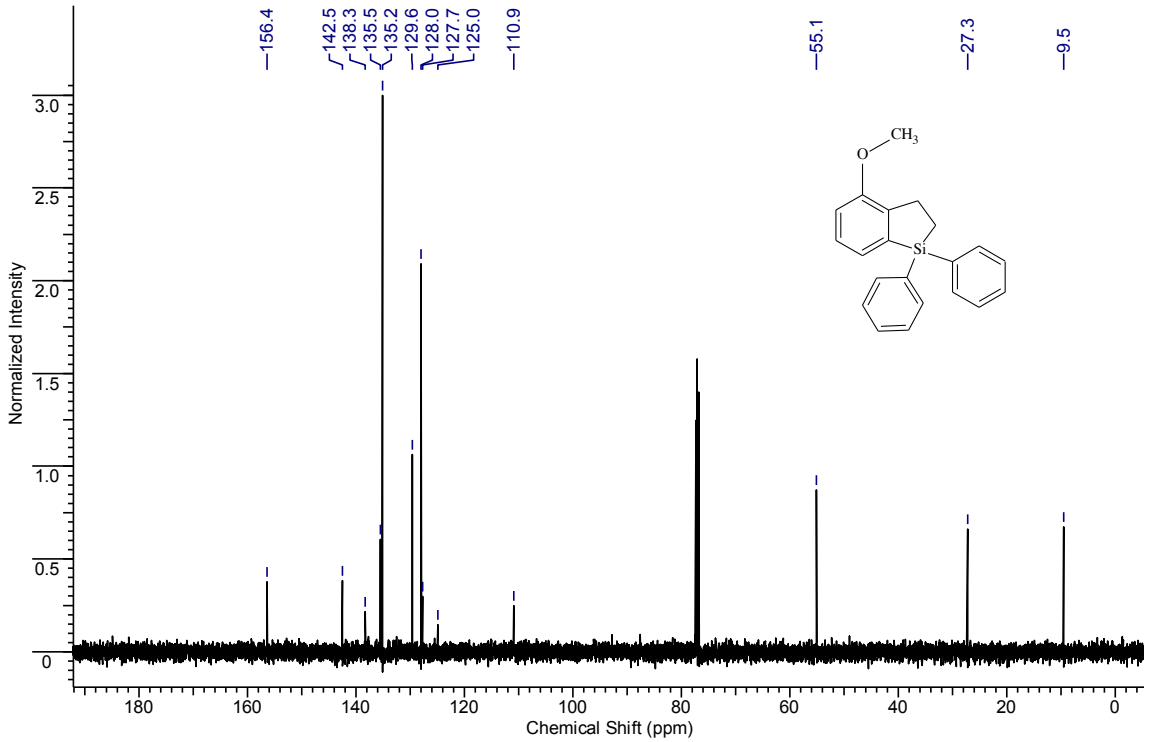
114c:


7.65
7.65
7.64
7.63
7.63
7.44
7.43
7.42
7.40
6.92
6.91
3.87
3.27
3.26
3.24
1.59
1.58
1.56
Normalized Intensity
Chemical Shift (ppm)
5.23
6.75
1.10
3.22
2.32
2.46
H3C
O
Si

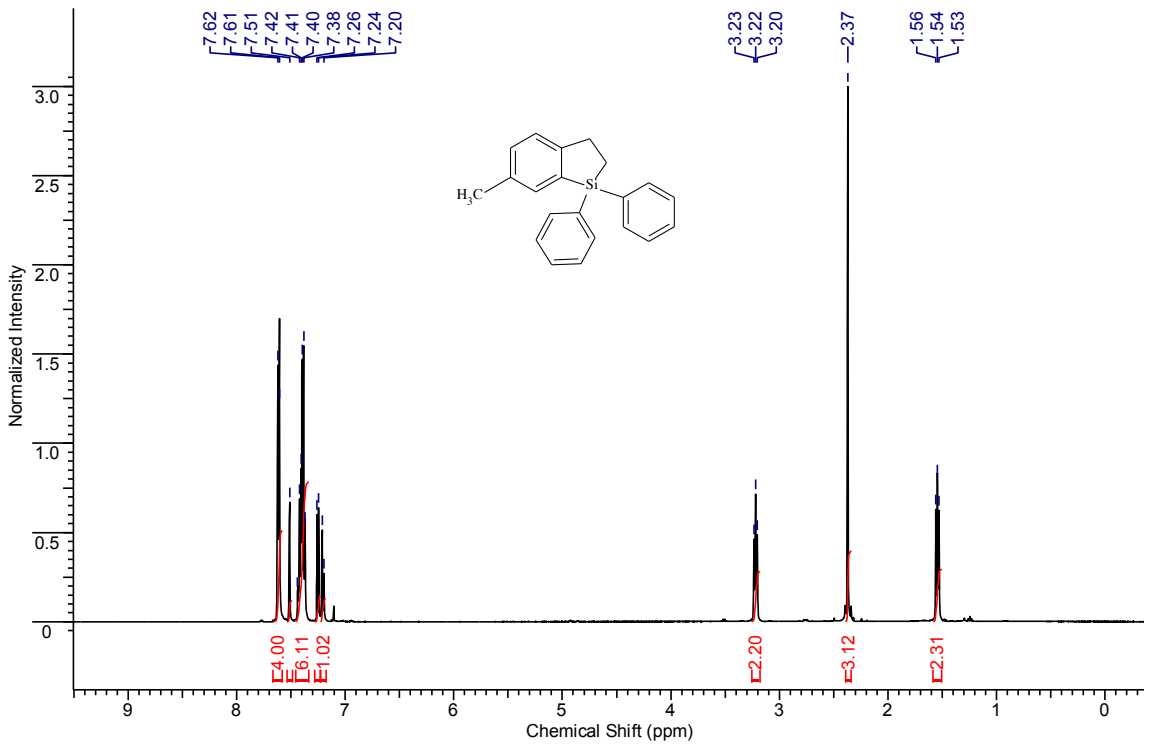

161.6
156.8
135.7
135.1
134.4
129.5
128.0
127.2
113.2
110.7
55.1
32.1
11.0
Normalized Intensity
Chemical Shift (ppm)
H3C
O
Si

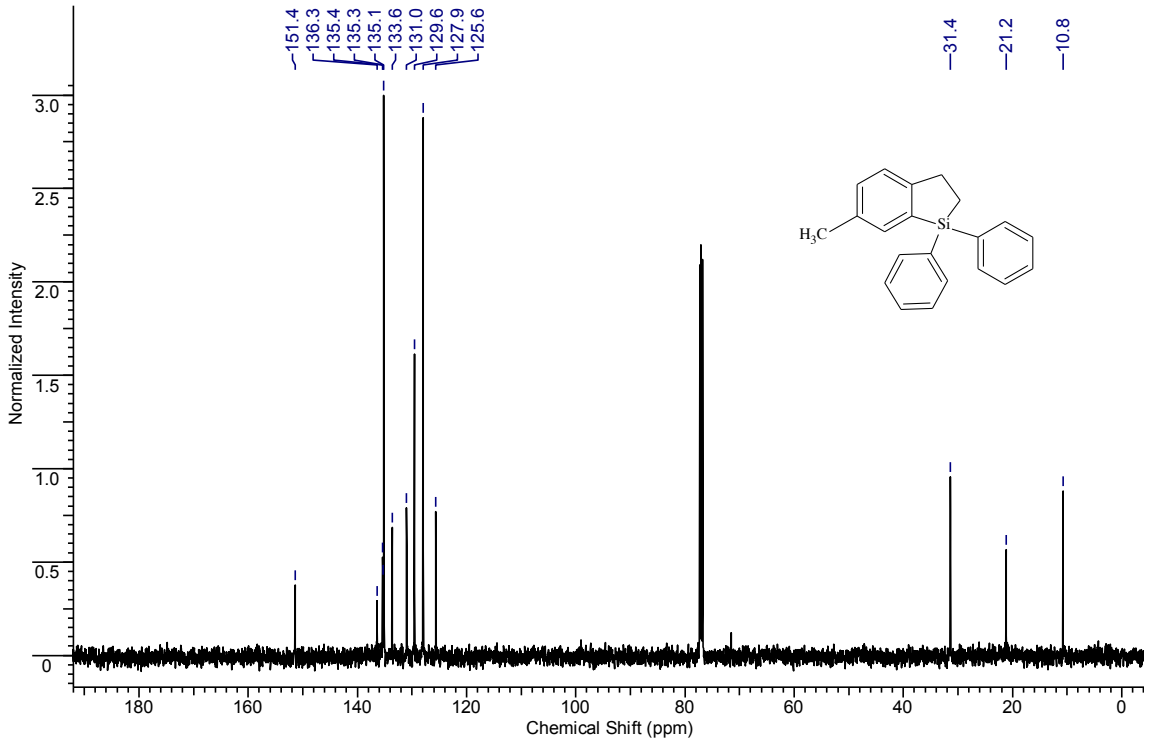
114d:


7.68
7.67
7.67
7.66
7.46
7.44
7.43
7.42
7.36
6.95
6.94
3.91
3.28
3.27
3.25
1.60
1.59
1.58
1.57
1.57
O
CH3
Si
Normalized Intensity
Chemical Shift (ppm)
4.00
2.11
1.04
3.15
2.18
2.22

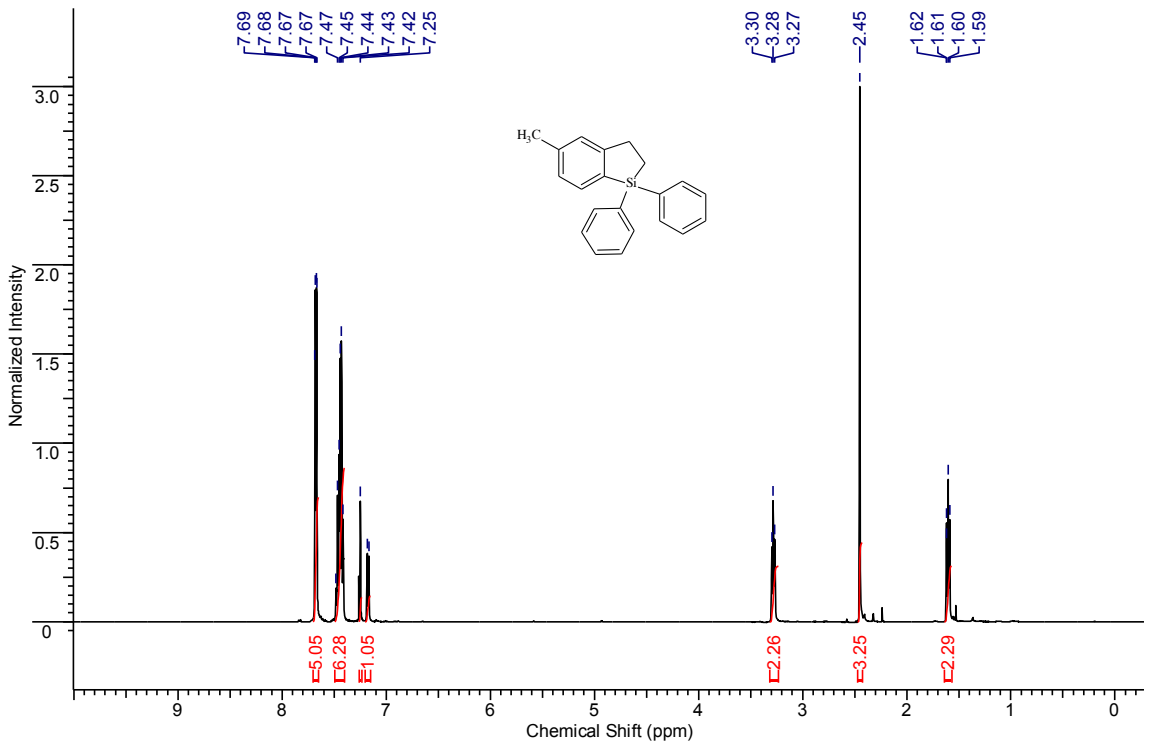

156.4
142.5
138.3
135.5
135.2
129.6
128.0
127.7
125.0
110.9
55.1
27.3
9.5
O
CH3
Si
Normalized Intensity
Chemical Shift (ppm)

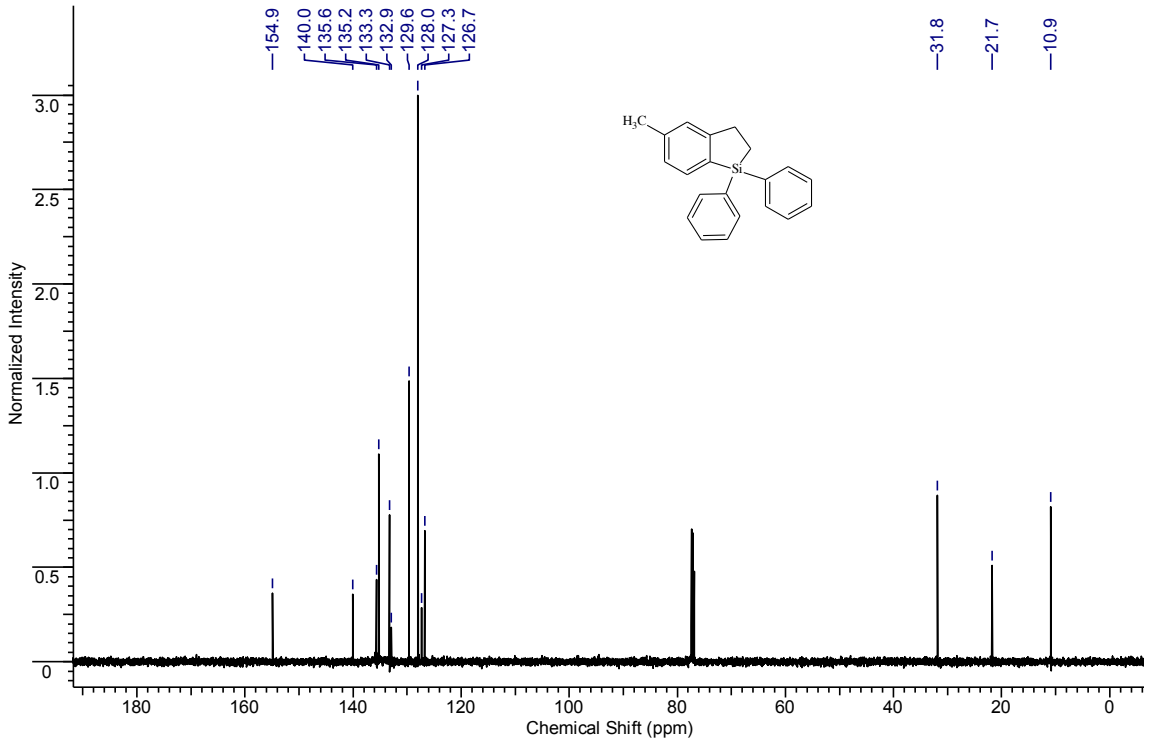
114e:


7.62
7.61
7.51
7.42
7.41
7.40
7.38
7.26
7.24
7.20
3.23
3.22
3.20
2.37
1.56
1.54
1.53
Si
H3C
Normalized Intensity
Chemical Shift (ppm)
4.00
6.11
1.02
2.20
3.12
2.31


151.4
136.3
135.4
135.3
135.1
133.6
131.0
129.6
127.9
125.6
31.4
21.2
10.8
Si
H3C
Normalized Intensity
Chemical Shift (ppm)

114f:


7.69
7.68
7.67
7.67
7.47
7.45
7.44
7.43
7.42
7.25
3.30
3.28
3.27
2.45
1.62
1.61
1.60
1.59
H3C
Si
Normalized Intensity
Chemical Shift (ppm)
5.05
6.28
1.05
2.26
3.25
2.29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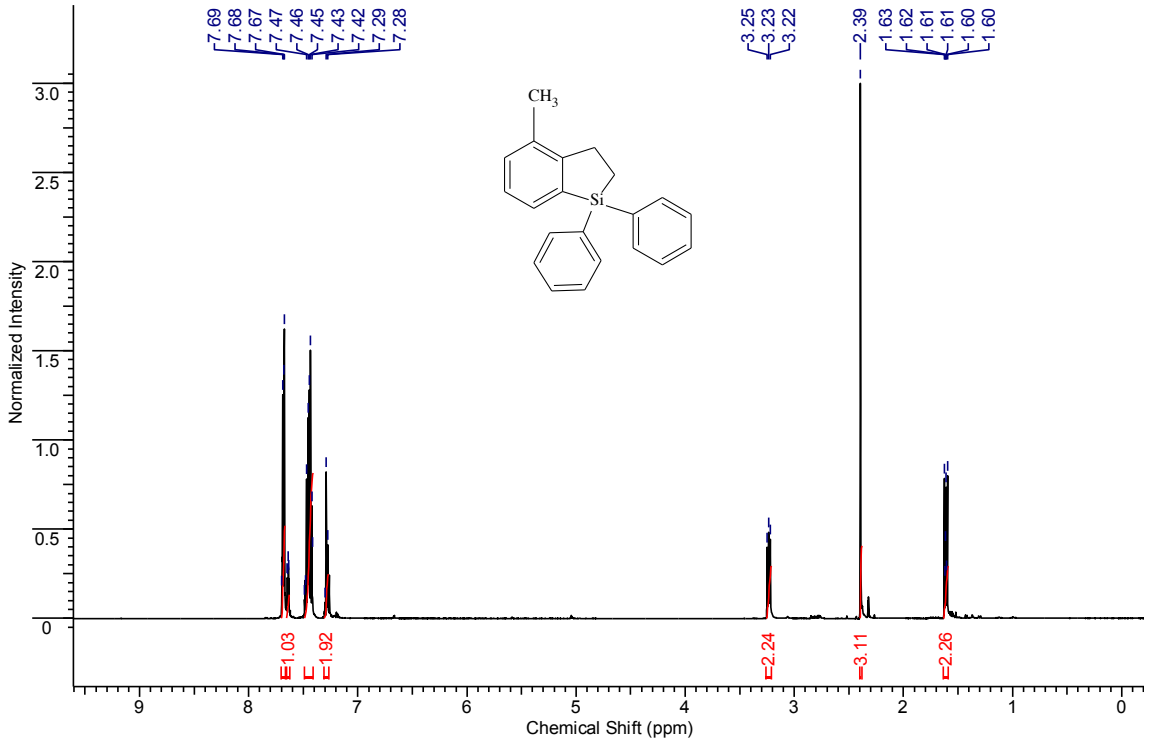
140.0
135.6
135.2
133.3
132.9
129.6
128.0
127.3
126.7
31.8
21.7
10.9
H3C
Si
Normalized Intensity
Chemical Shift (ppm)

114g: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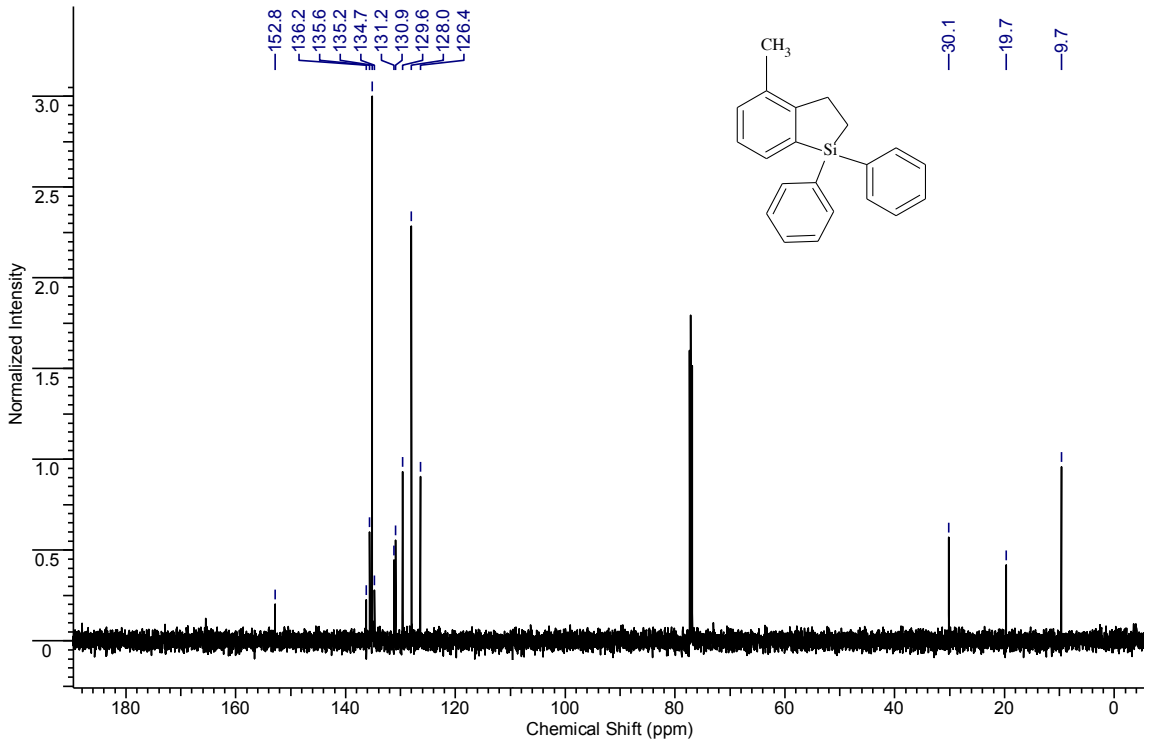
7.68
7.67
7.47
7.46
7.45
7.43
7.42
7.29
7.28
3.25
3.23
3.22
2.39
1.63
1.62
1.61
1.61
1.60
1.60
CH3
Si
Normalized Intensity
Chemical Shift (ppm)
1.03
1.92
2.24
3.11
2.26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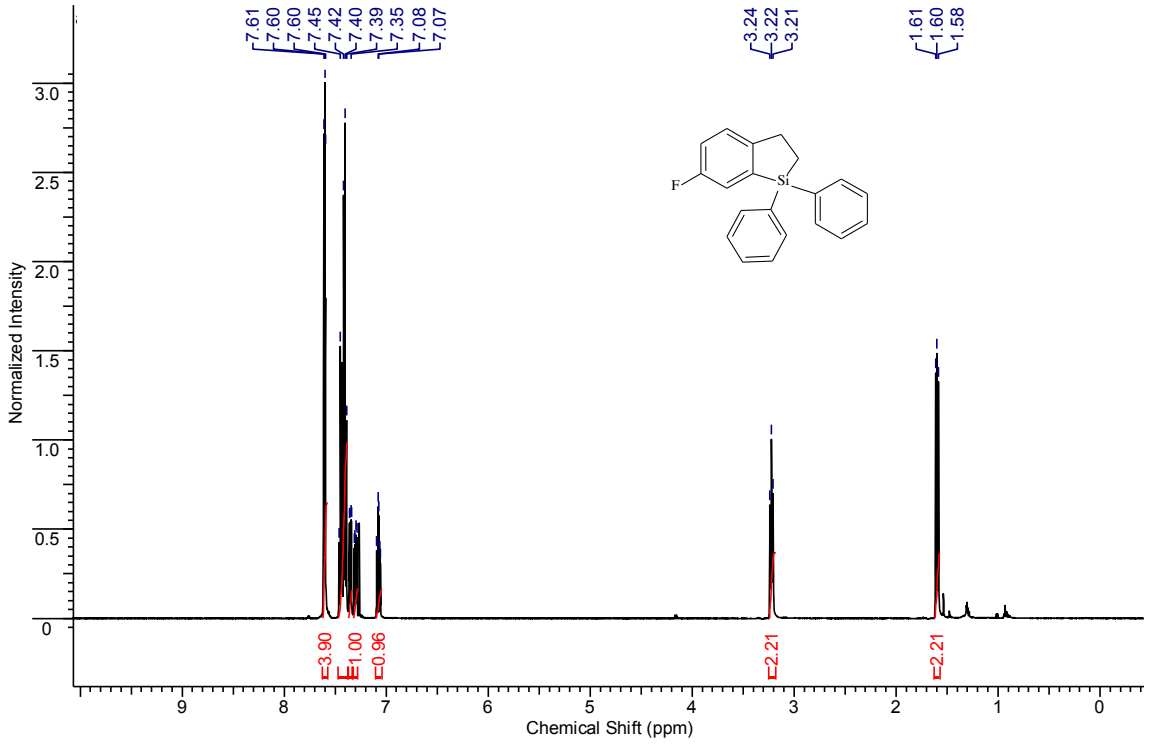
136.2
135.6
135.2
134.7
131.2
130.9
129.6
128.0
126.4
30.1
19.7
9.7
CH3
Si
Normalized Intensity
Chemical Shift (ppm)

114h: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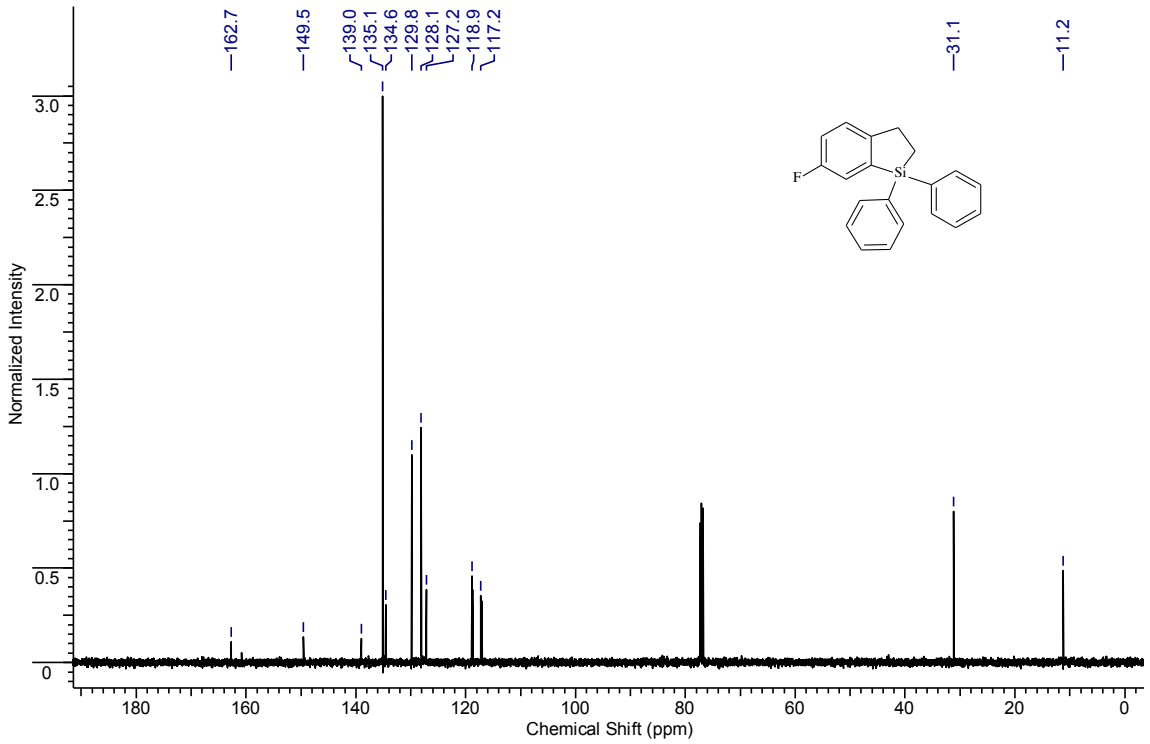
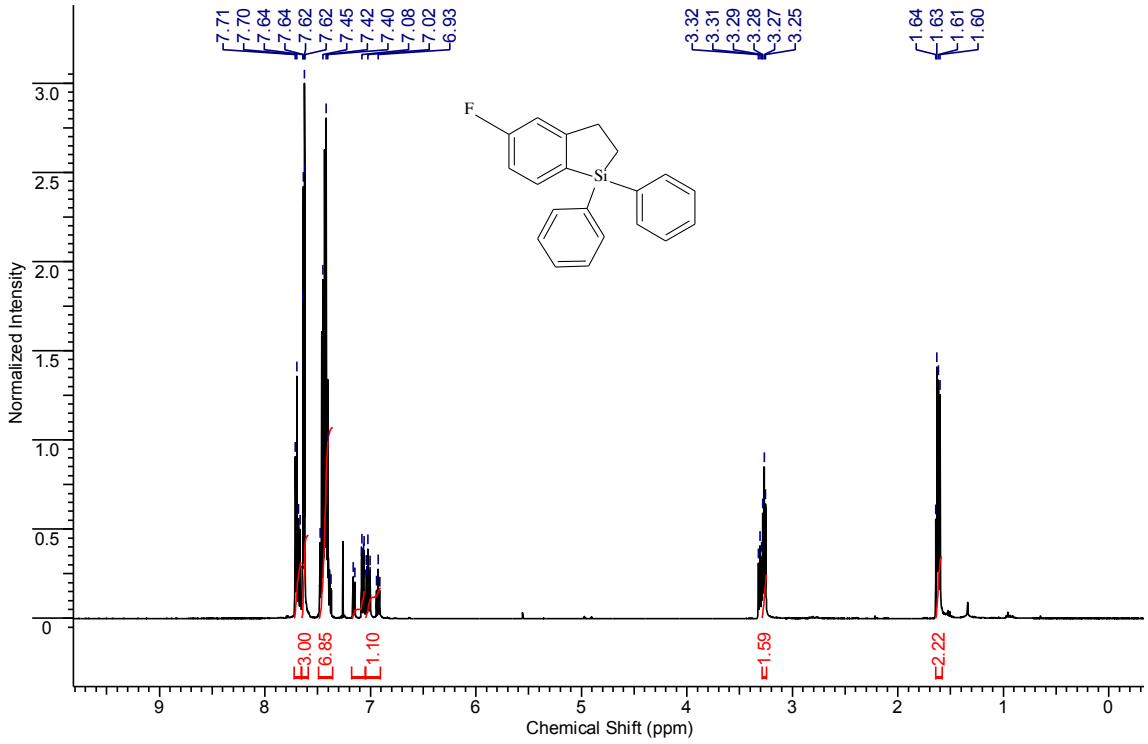
7.60
7.60
7.45
7.42
7.40
7.39
7.35
7.08
7.07
3.24
3.22
3.21
1.61
1.60
1.58
F
Si
Normalized Intensity
3.90
1.00
0.96
2.21
2.21
Chemical Shift (ppm)


162.7
149.5
139.0
135.1
134.6
129.8
128.1
127.2
118.9
117.2
31.1
11.2
F
Si
Normalized Intensity
Chemical Shift (ppm)

114i:


7.71
7.70
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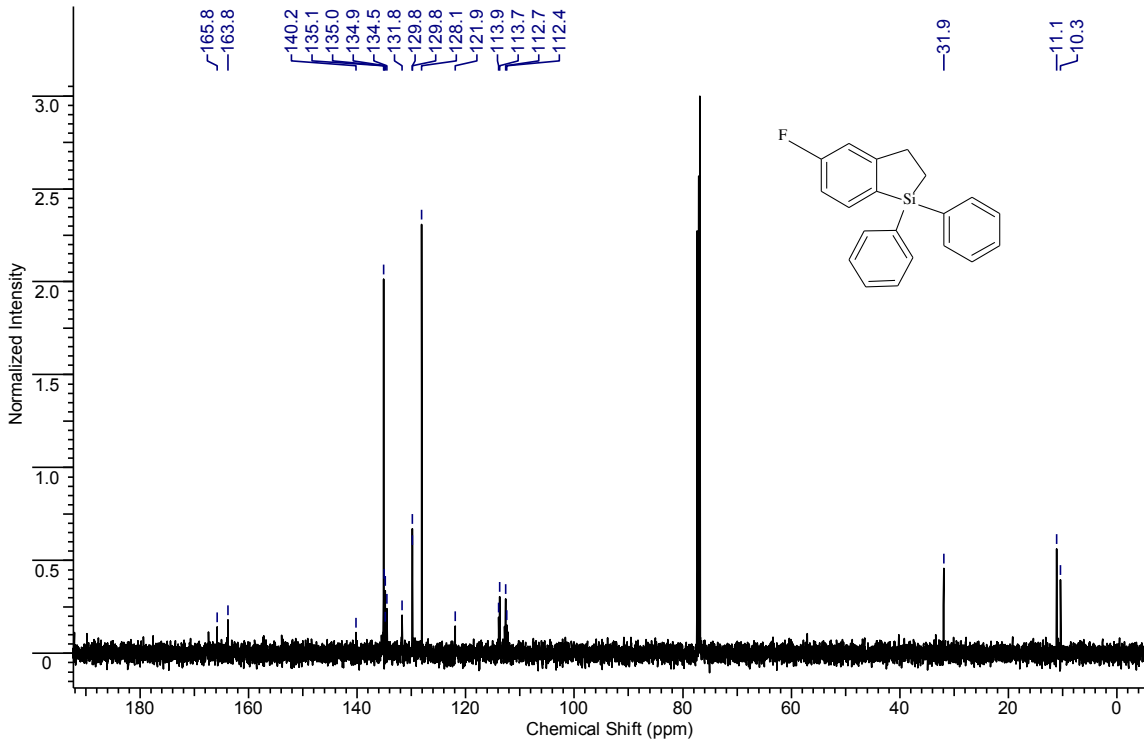
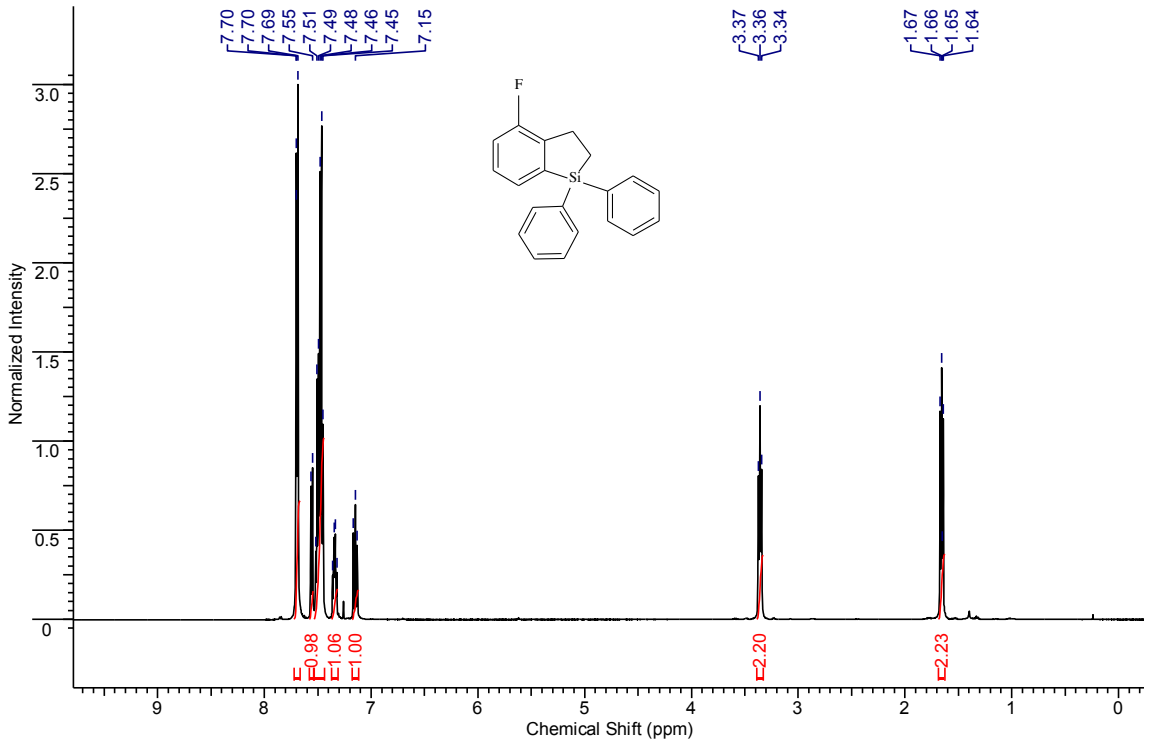
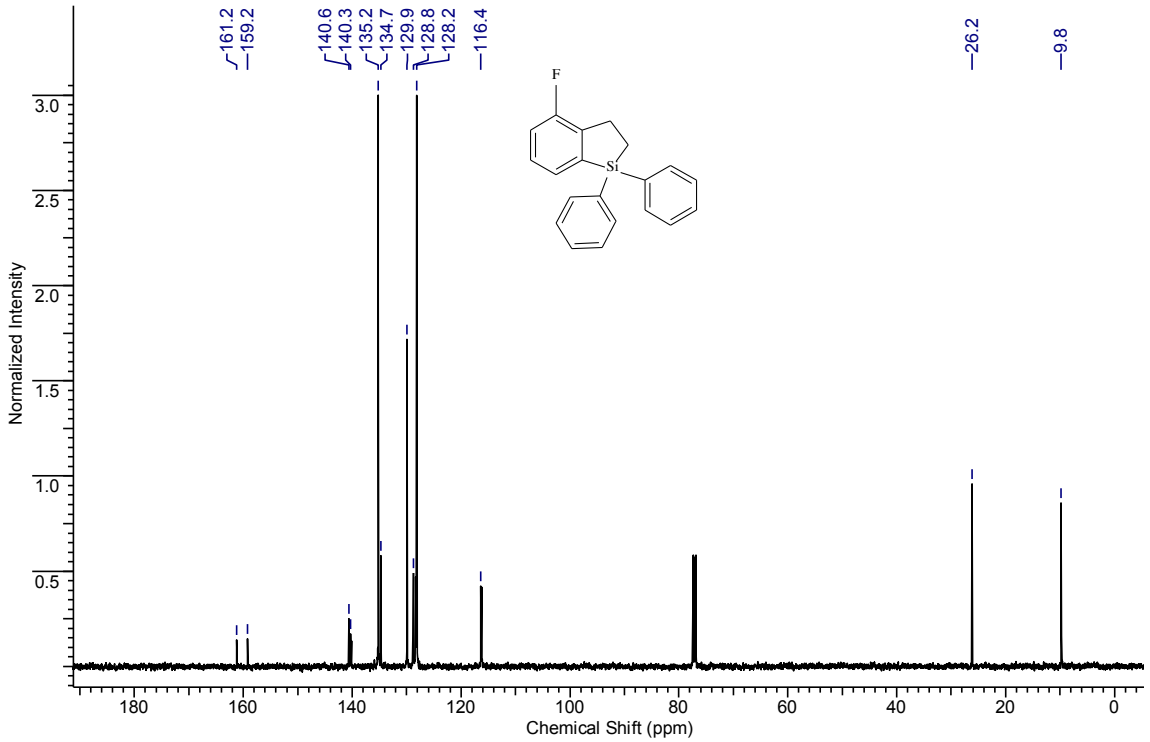
7.64
7.62
7.62
7.45
7.42
7.40
7.08
7.02
6.93
3.32
3.31
3.29
3.28
3.27
3.25
1.64
1.63
1.61
1.60
F
Si
Normalized Intensity
3.0
2.5
2.0
1.5
1.0
0.5
0
3.00
6.85
1.10
1.59
2.22
9
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

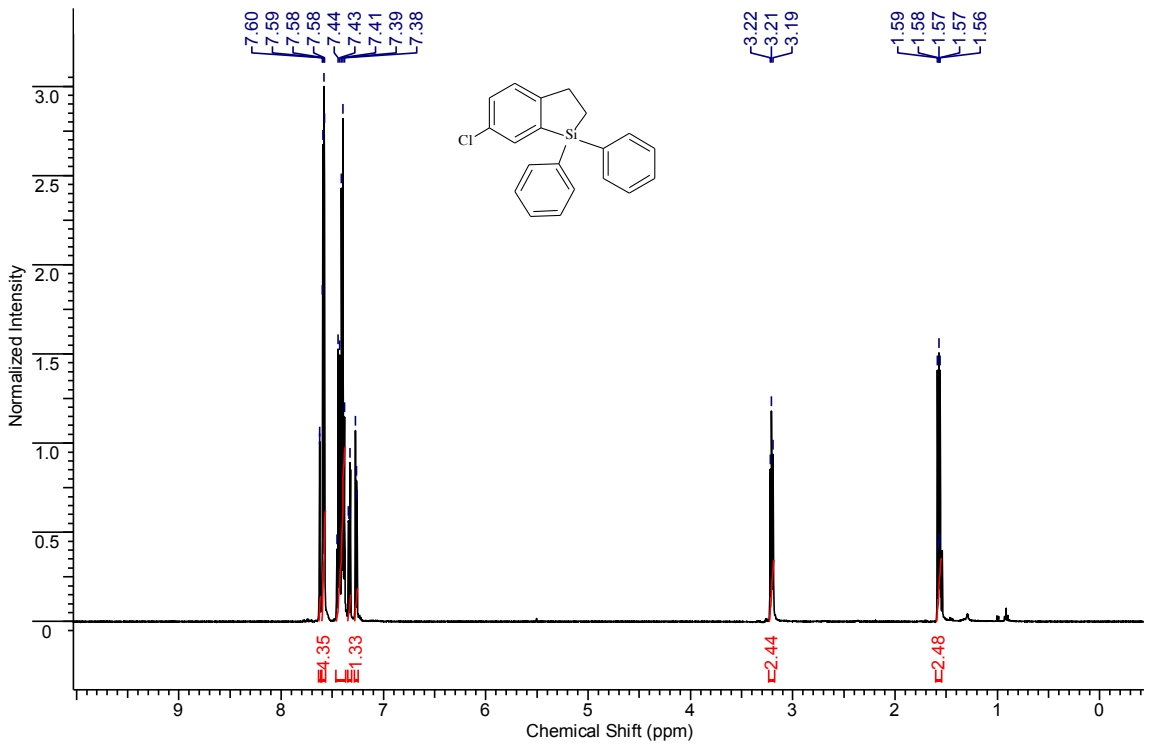

165.8
163.8
140.2
135.1
135.0
134.9
134.5
131.8
129.8
129.8
128.1
121.9
113.9
113.7
112.7
112.4
31.9
11.1
10.3
F
Si
Normalized Intensity
3.0
2.5
2.0
1.5
1.0
0.5
0
180
160
140
120
100
80
60
40
20
0
Chemical Shift (ppm)

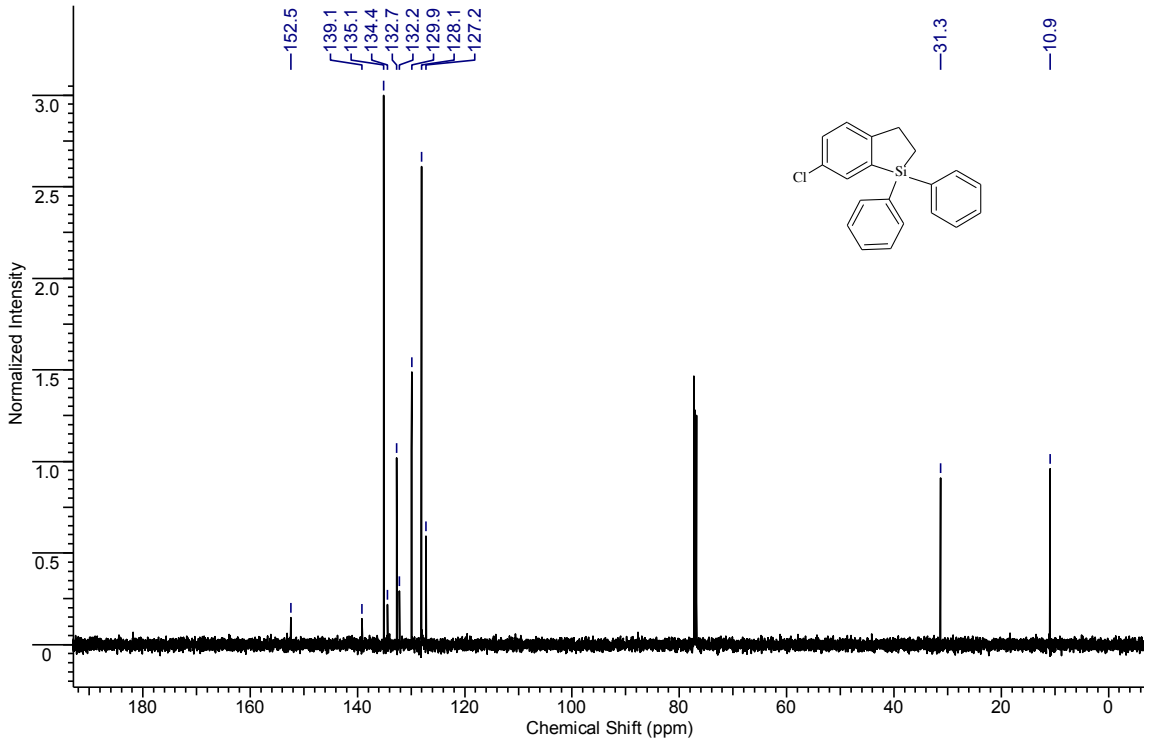
114j:


7.70
7.70
7.69
7.55
7.51
7.49
7.48
7.46
7.45
7.15
3.37
3.36
3.34
1.67
1.66
1.65
1.64
F
Si
Normalized Intensity
Chemical Shift (ppm)
0.98
1.06
1.00
2.20
2.23

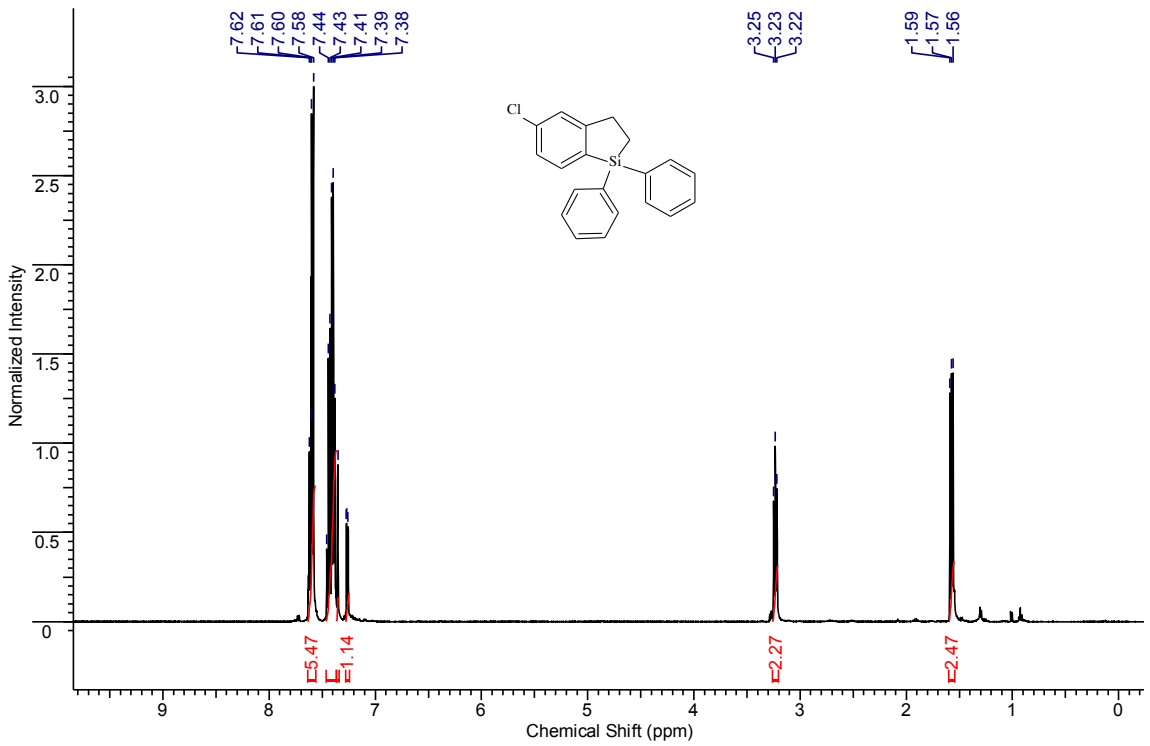

161.2
159.2
140.6
140.3
135.2
134.7
129.9
128.8
128.2
116.4
26.2
9.8
F
Si
Normalized Intensity
Chemical Shift (ppm)

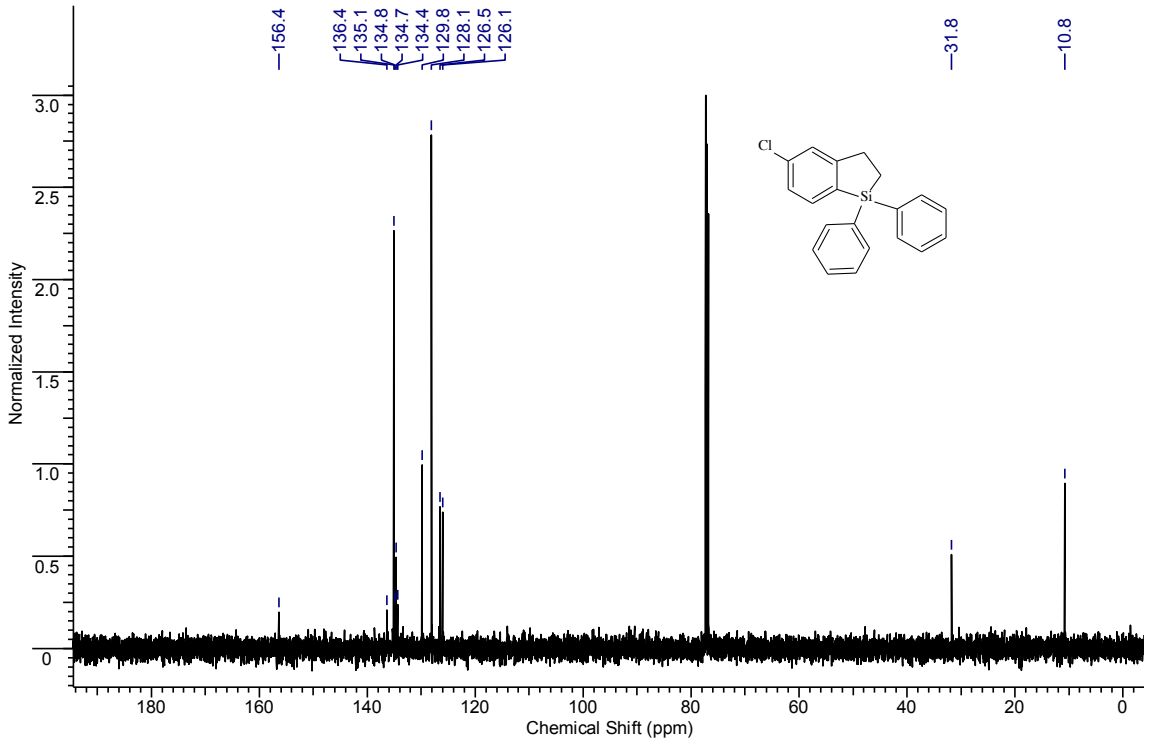
114k:


7.60
7.59
7.58
7.58
7.44
7.43
7.41
7.39
7.38
3.22
3.21
3.19
1.59
1.58
1.57
1.57
1.56
Cl
Si
Normalized Intensity
Chemical Shift (ppm)
4.35
1.33
2.44
2.48

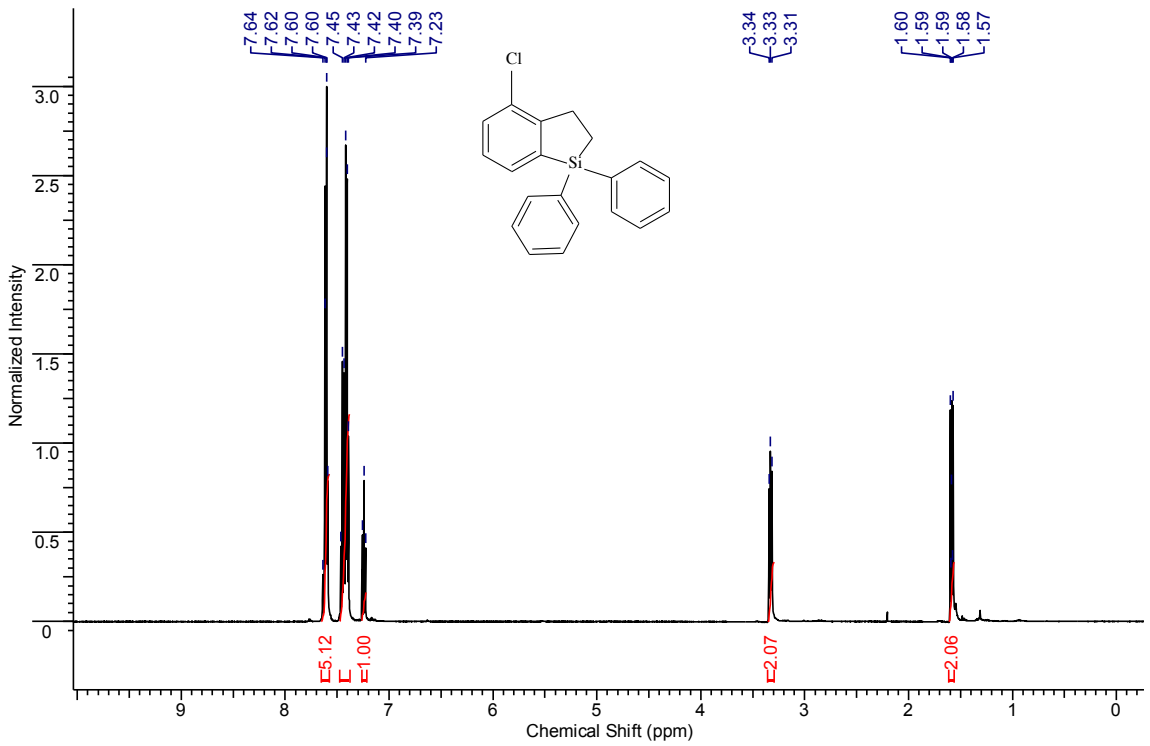

152.5
139.1
135.1
134.4
132.7
132.2
129.9
128.1
127.2
31.3
10.9
Cl
Si
Normalized Intensity
Chemical Shift (ppm)

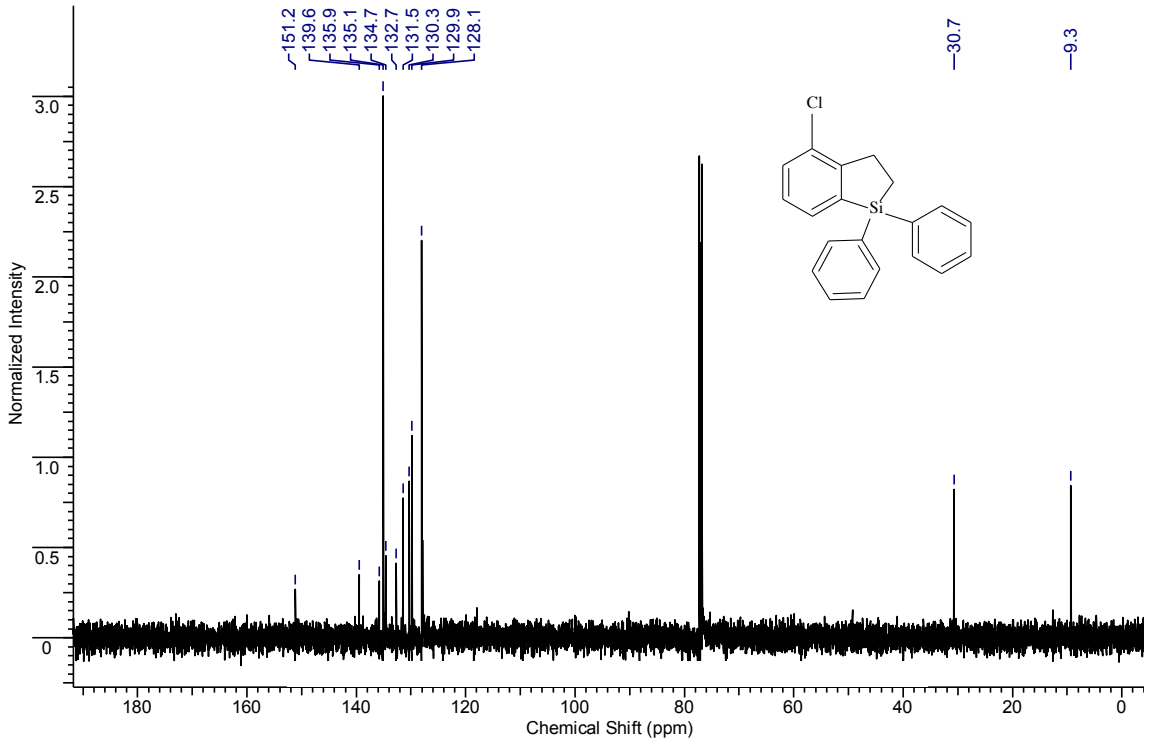
114l:


7.62
7.61
7.60
7.58
7.44
7.43
7.41
7.39
7.38
3.25
3.23
3.22
1.59
1.57
1.56
Cl
Si
Normalized Intensity
Chemical Shift (ppm)
5.47
1.14
2.27
2.47

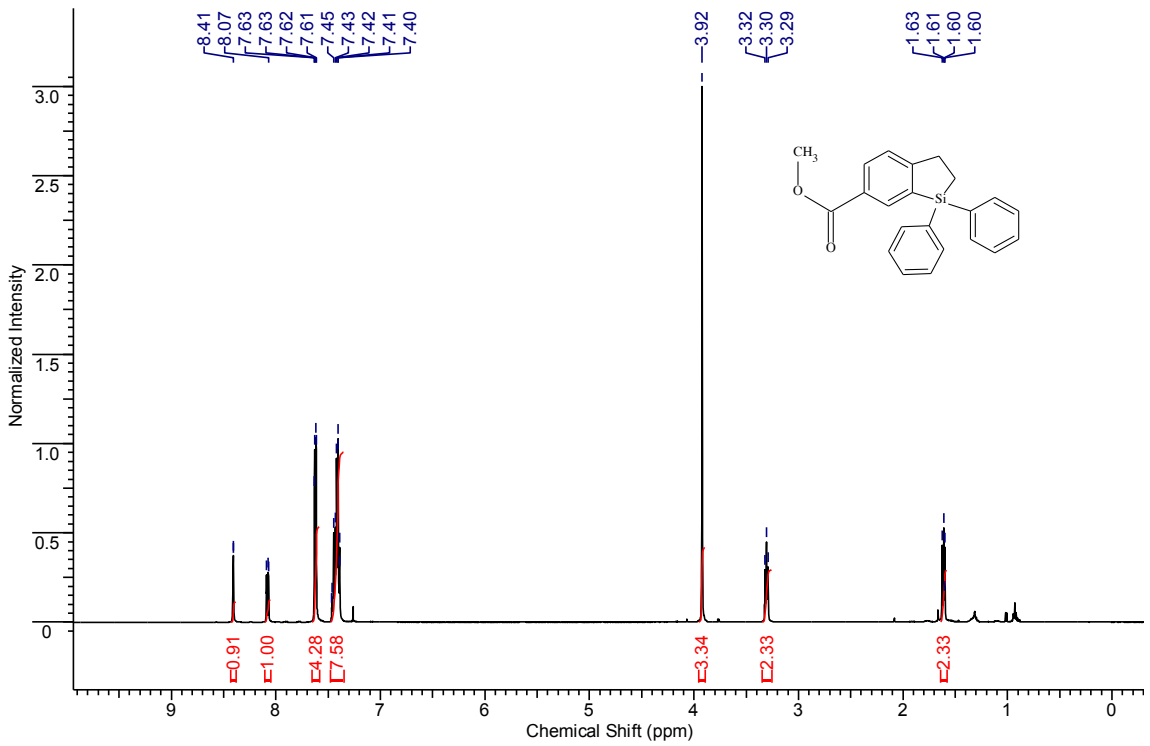

156.4
136.4
135.1
134.8
134.7
134.4
129.8
128.1
126.5
126.1
31.8
10.8
Cl
Si
Normalized Intensity
Chemical Shift (ppm)

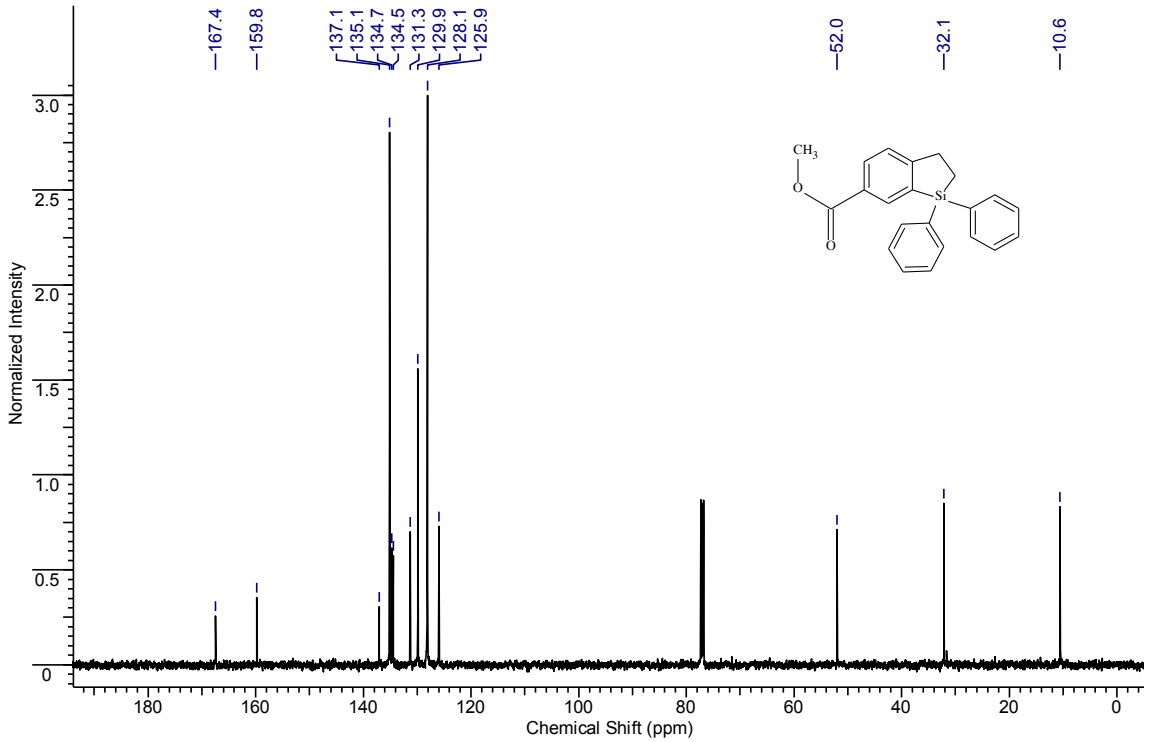
114m:


7.64
7.62
7.60
7.60
7.45
7.43
7.42
7.40
7.39
7.23
3.34
3.33
3.31
1.60
1.59
1.59
1.58
1.57
Cl
Si
Normalized Intensity
Chemical Shift (ppm)
5.12
1.00
2.07
2.06

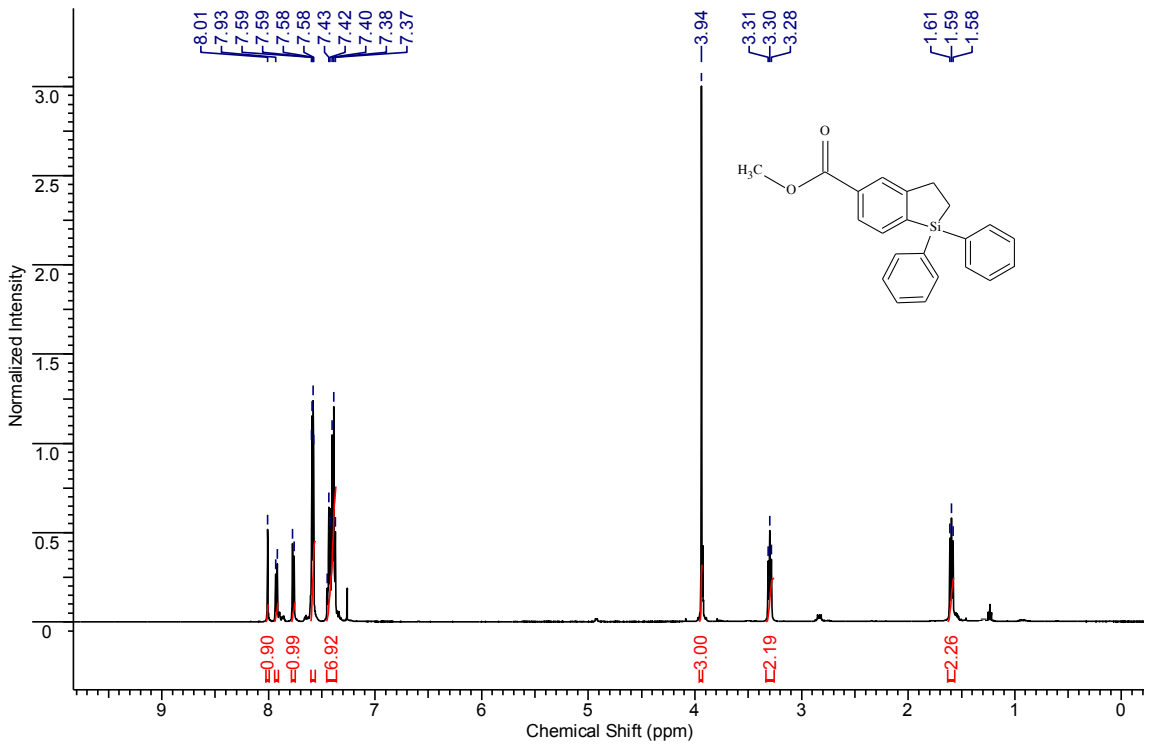

151.2
139.6
135.9
135.1
134.7
132.7
131.5
130.3
129.9
128.1
30.7
9.3
Cl
Si
Normalized Intensity
Chemical Shift (ppm)

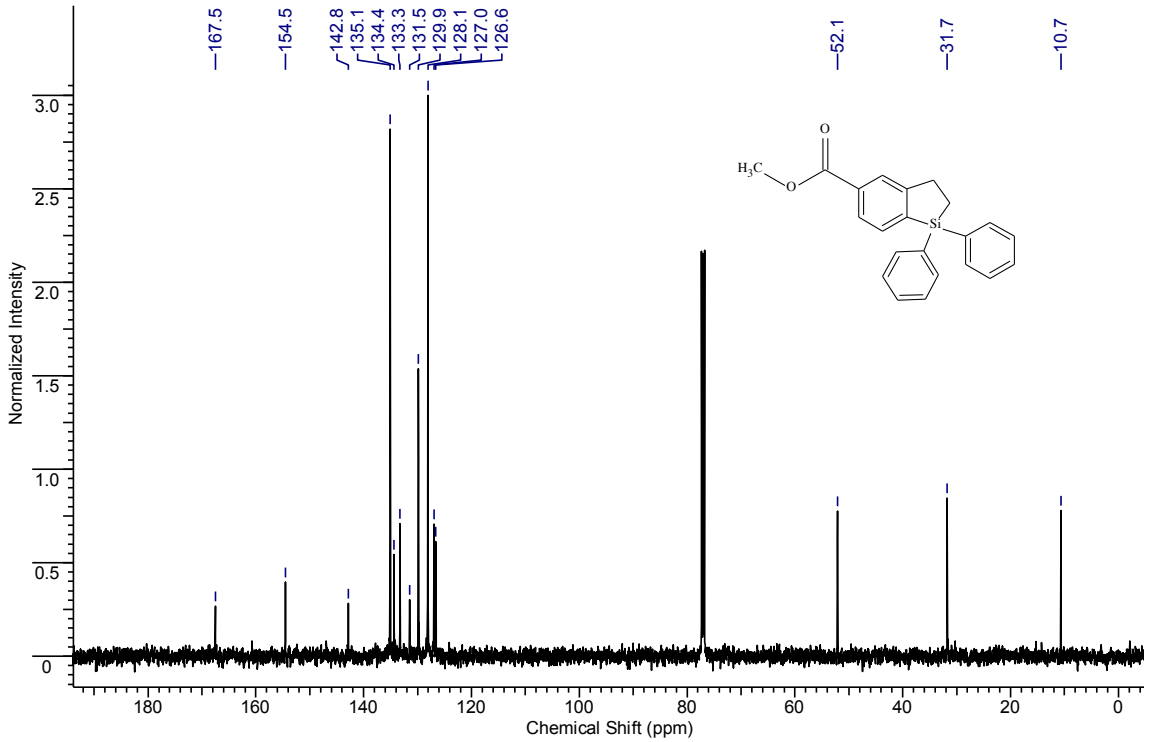
114n:


8.41
8.07
7.63
7.63
7.62
7.61
7.45
7.43
7.42
7.41
7.40
3.92
3.32
3.30
3.29
1.63
1.61
1.60
1.60
Normalized Intensity
Chemical Shift (ppm)
0.91
1.00
4.28
7.58
3.34
2.33
2.33

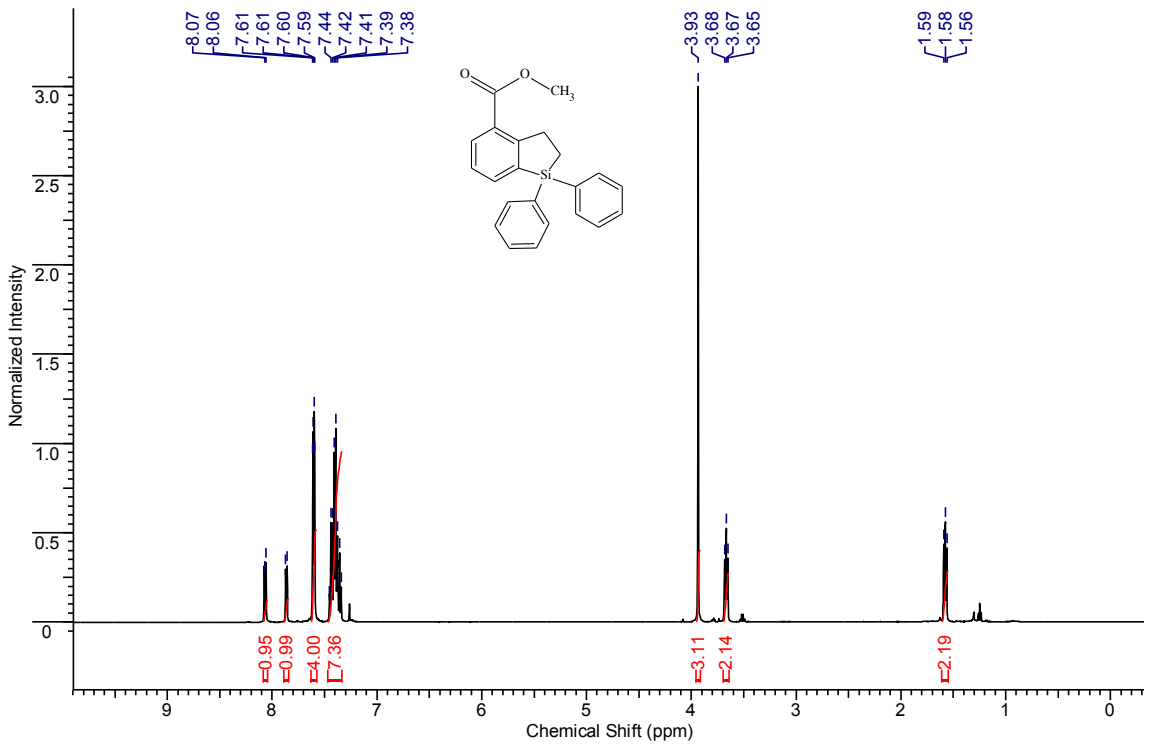

167.4
159.8
137.1
135.1
134.7
134.5
131.3
129.9
128.1
125.9
52.0
32.1
10.6
Normalized Intensity
Chemical Shift (ppm)

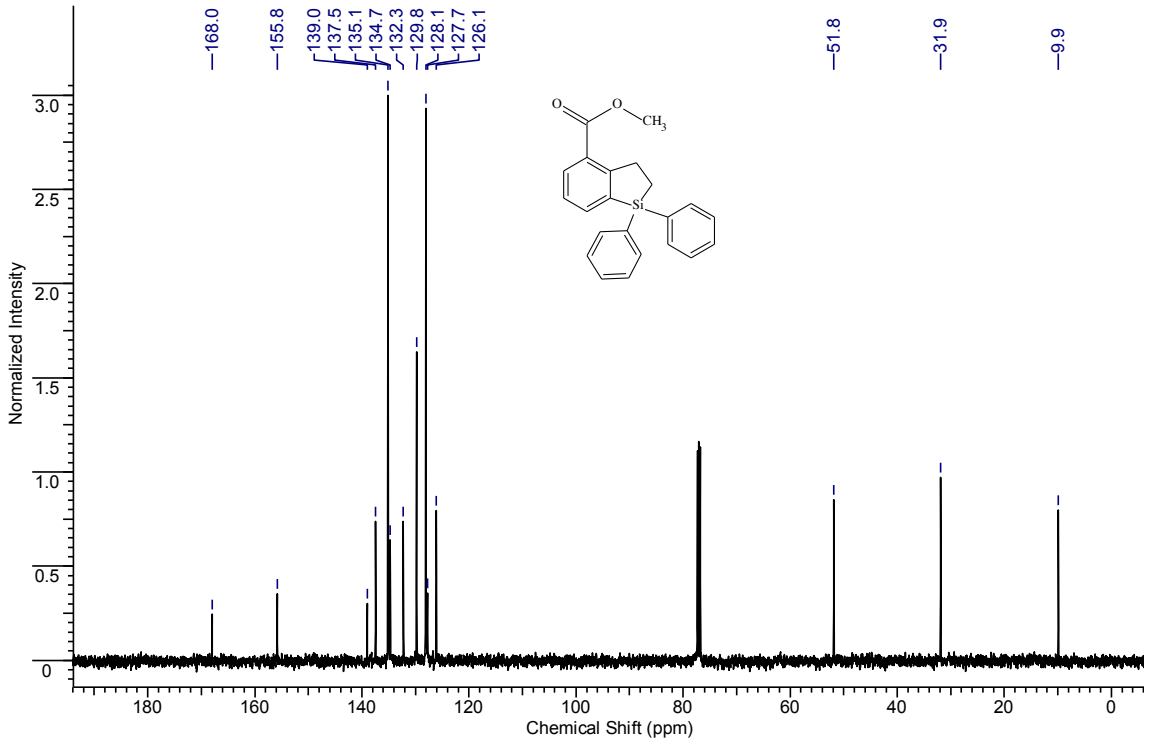
114o:


8.01
7.93
7.59
7.59
7.58
7.58
7.43
7.42
7.40
7.38
7.37
3.94
3.31
3.30
3.28
1.61
1.59
1.58
0.90
0.99
6.92
3.00
2.19
2.26
Normalized Intensity
Chemical Shift (ppm)

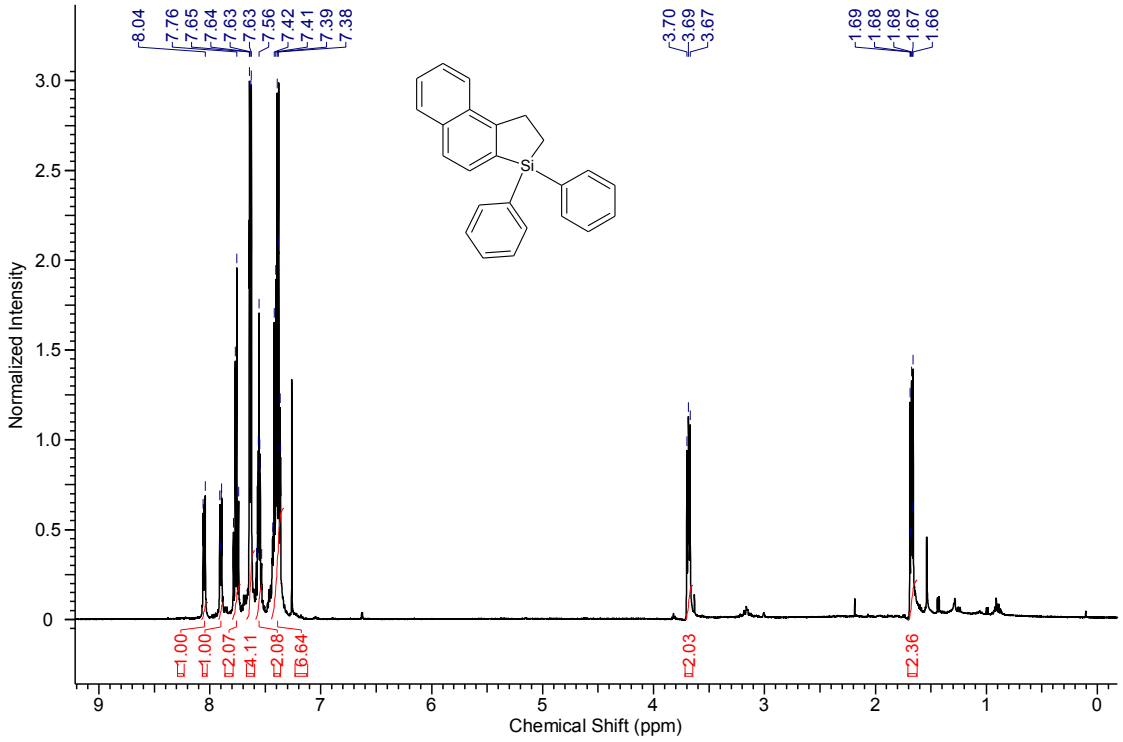

167.5
154.5
142.8
135.1
134.4
133.3
131.5
129.9
128.1
127.0
126.6
52.1
31.7
10.7
Normalized Intensity
Chemical Shift (ppm)

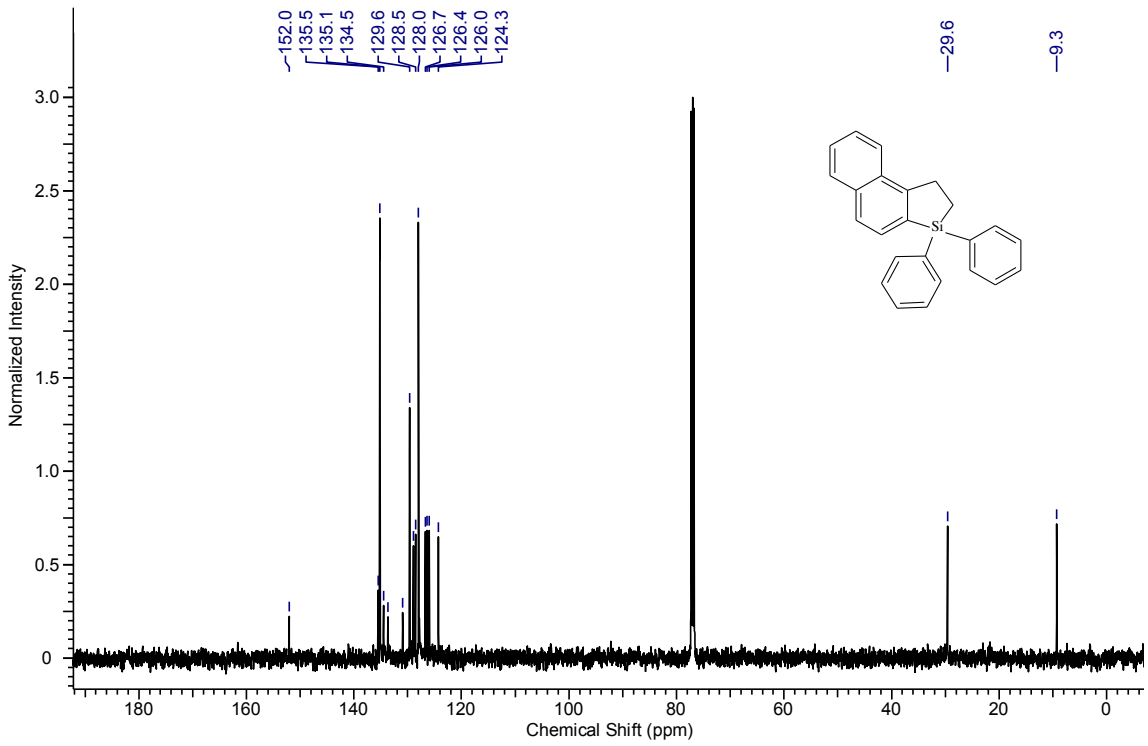
114p:


8.07
8.06
7.61
7.61
7.60
7.59
7.44
7.42
7.41
7.39
7.38
3.93
3.68
3.67
3.65
1.59
1.58
1.56
O
O
CH3
Si
Normalized Intensity
3.0
2.5
2.0
1.5
1.0
0.5
0
0.95
0.99
4.00
7.36
3.11
2.14
2.19
9
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

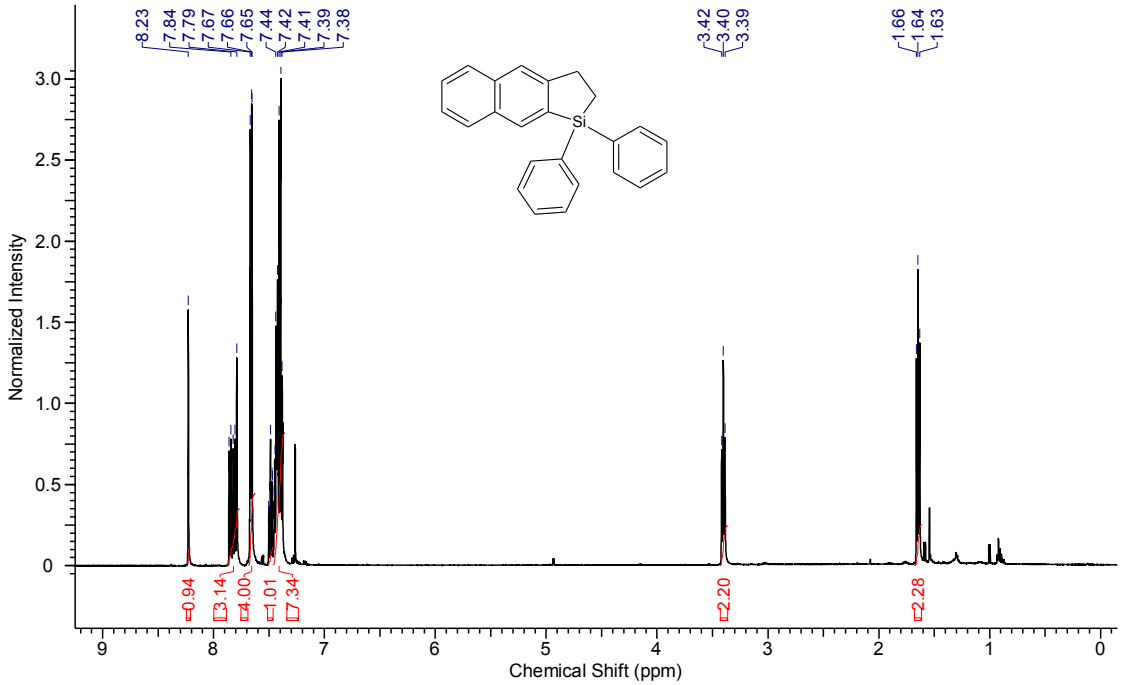

168.0
155.8
139.0
137.5
135.1
134.7
132.3
129.8
128.1
127.7
126.1
51.8
31.9
9.9
O
O
CH3
Si
Normalized Intensity
3.0
2.5
2.0
1.5
1.0
0.5
0
180
160
140
120
100
80
60
40
20
0
Chemical Shift (ppm)

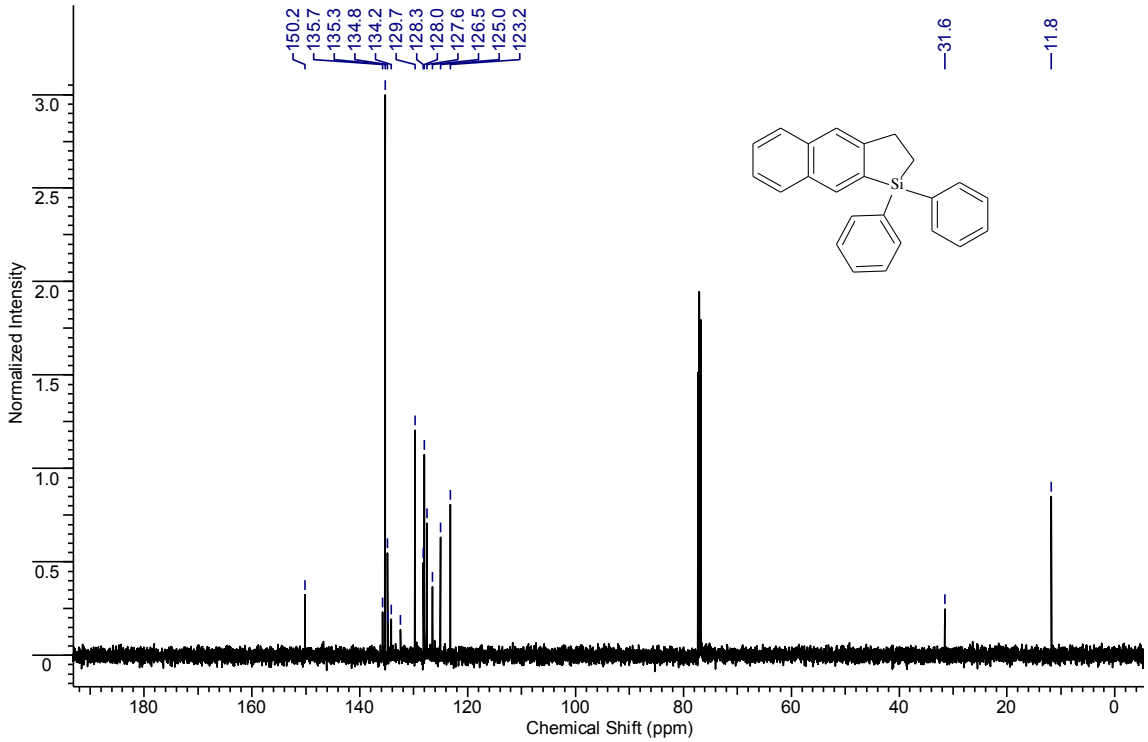
114q:


8.04
7.76
7.65
7.64
7.63
7.63
7.56
7.42
7.41
7.39
7.38
3.70
3.69
3.67
1.69
1.68
1.68
1.67
1.66
Si
Normalized Intensity
Chemical Shift (ppm)
1.00
1.00
2.07
4.11
2.08
6.64
2.03
2.36

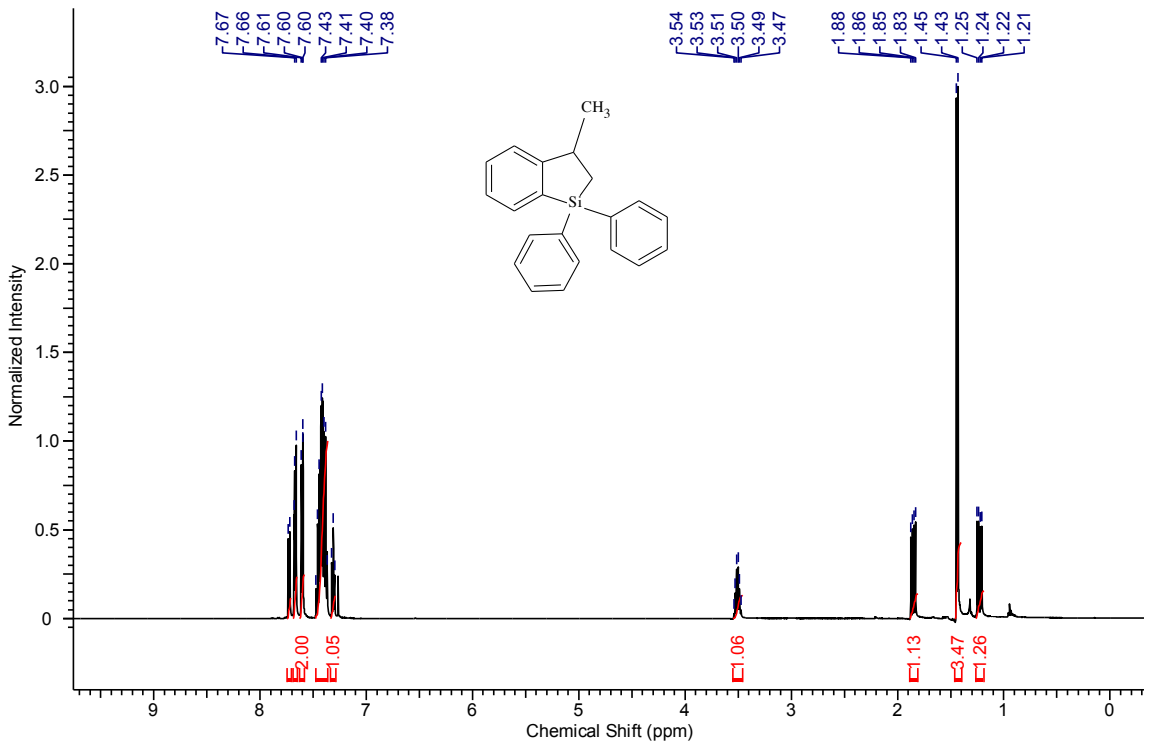

152.0
135.5
135.1
134.5
129.6
128.5
128.0
126.7
126.4
126.0
124.3
29.6
9.3
Si
Normalized Intensity
Chemical Shift (ppm)

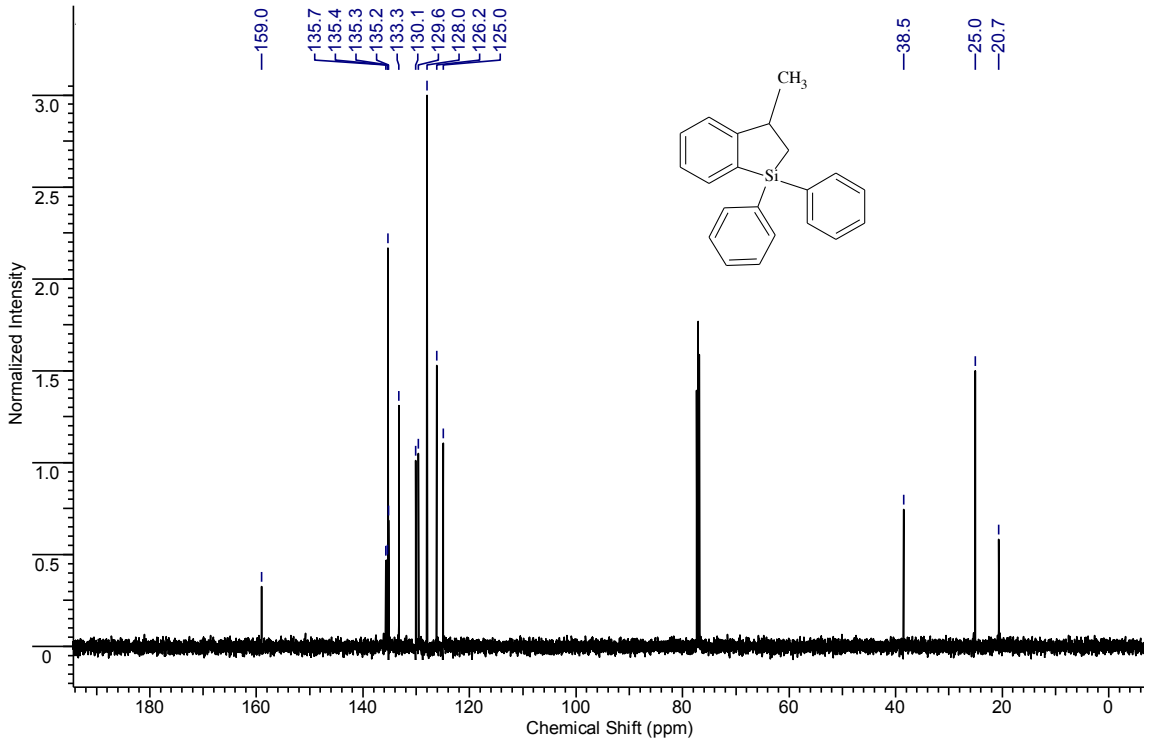
114r:


8.23
7.84
7.79
7.67
7.66
7.65
7.44
7.42
7.41
7.39
7.38
3.42
3.40
3.39
1.66
1.64
1.63
Si
0.94
3.14
4.00
1.01
7.34
2.20
2.28
Normalized Intensity
Chemical Shift (ppm)

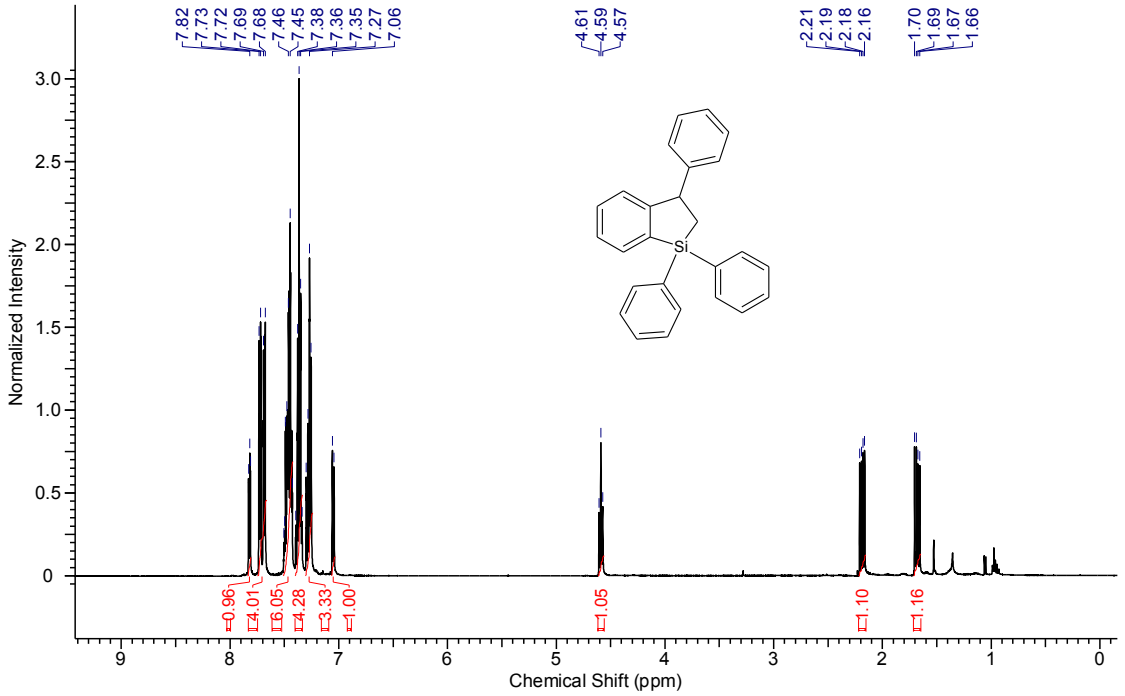

150.2
135.7
135.3
134.8
134.2
129.7
128.3
128.0
127.6
126.5
125.0
123.2
31.6
11.8
Si
Normalized Intensity
Chemical Shift (ppm)

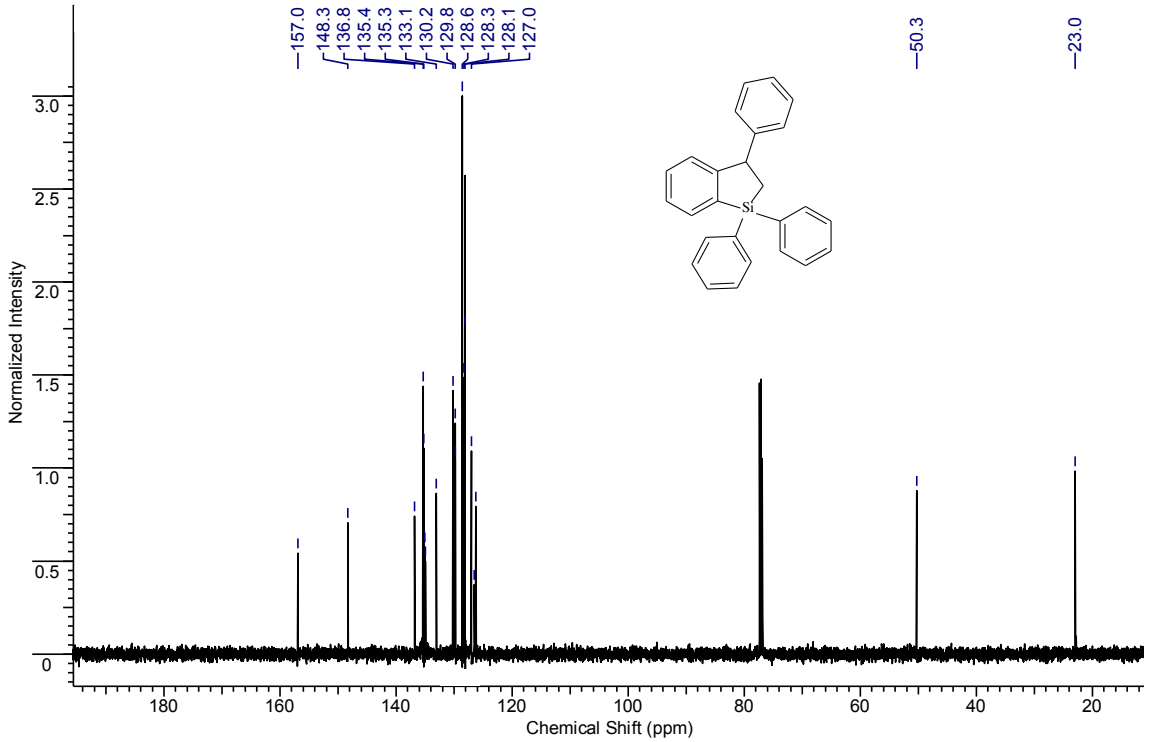
114s:


7.67
7.66
7.61
7.60
7.60
7.43
7.41
7.40
7.38
3.54
3.53
3.51
3.50
3.49
3.47
1.88
1.86
1.85
1.83
1.45
1.43
1.25
1.24
1.22
1.21
CH3
Si
Normalized Intensity
Chemical Shift (ppm)
2.00
1.05
1.06
1.13
3.47
1.26

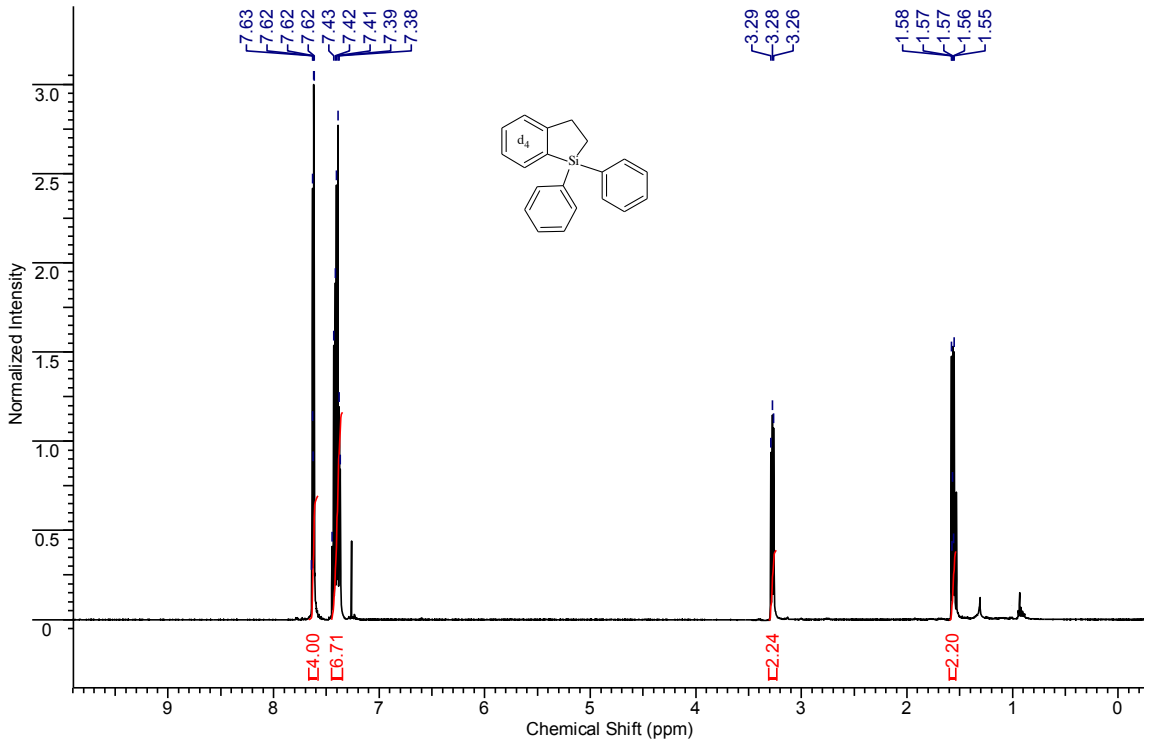

159.0
135.7
135.4
135.3
135.2
133.3
130.1
129.6
128.0
126.2
125.0
38.5
25.0
20.7
CH3
Si
Normalized Intensity
Chemical Shift (ppm)

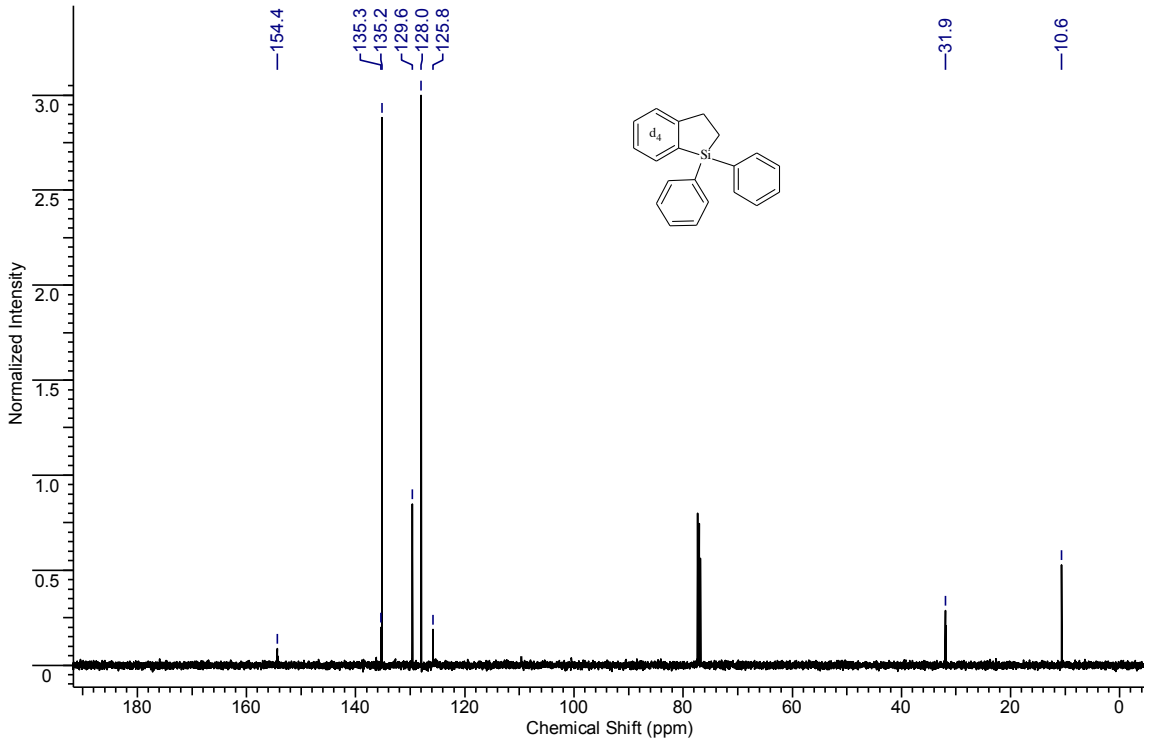
114t:


7.82
7.73
7.72
7.69
7.68
7.46
7.45
7.38
7.36
7.35
7.27
7.06
4.61
4.59
4.57
2.21
2.19
2.18
2.16
1.70
1.69
1.67
1.66
Si
Normalized Intensity
Chemical Shift (ppm)
0.96
4.01
6.05
4.28
3.33
1.00
1.05
1.10
1.16

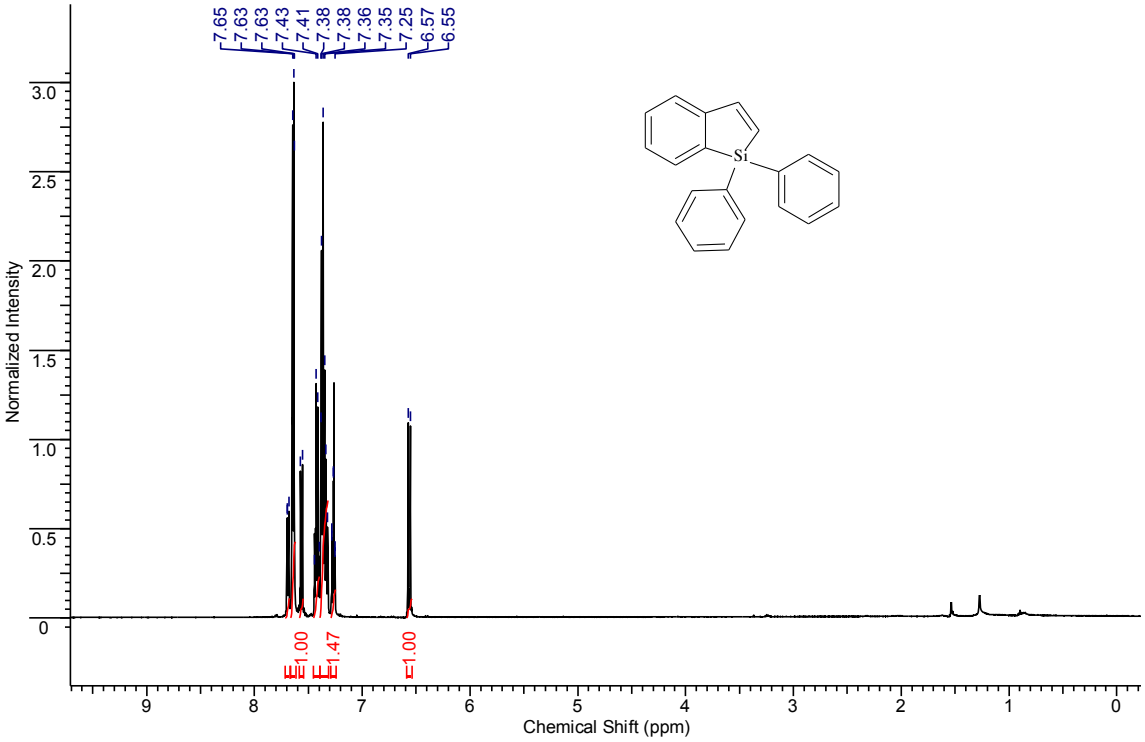

157.0
148.3
136.8
135.4
135.3
133.1
130.2
129.8
128.6
128.3
128.1
127.0
50.3
23.0
Si
Normalized Intensity
Chemical Shift (ppm)

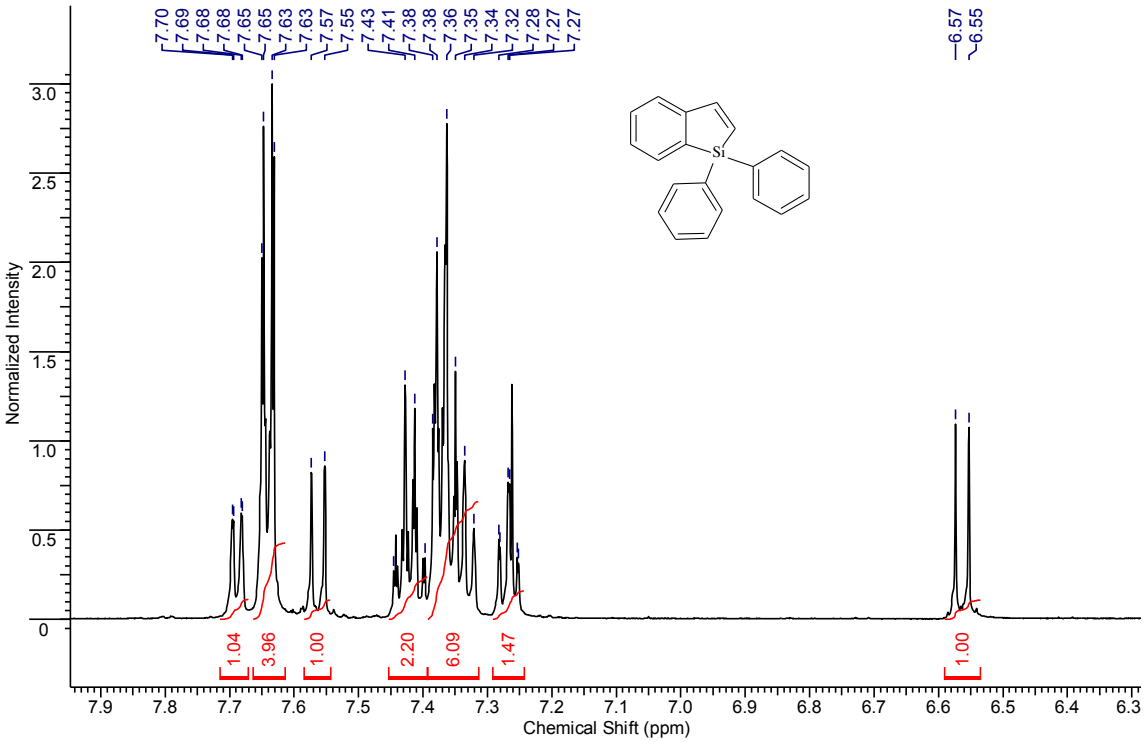
114-d_4:


7.63
7.62
7.62
7.62
7.43
7.42
7.41
7.39
7.38
3.29
3.28
3.26
1.58
1.57
1.57
1.56
1.55
d4
Si
Normalized Intensity
Chemical Shift (ppm)
4.00
6.71
2.24
2.20

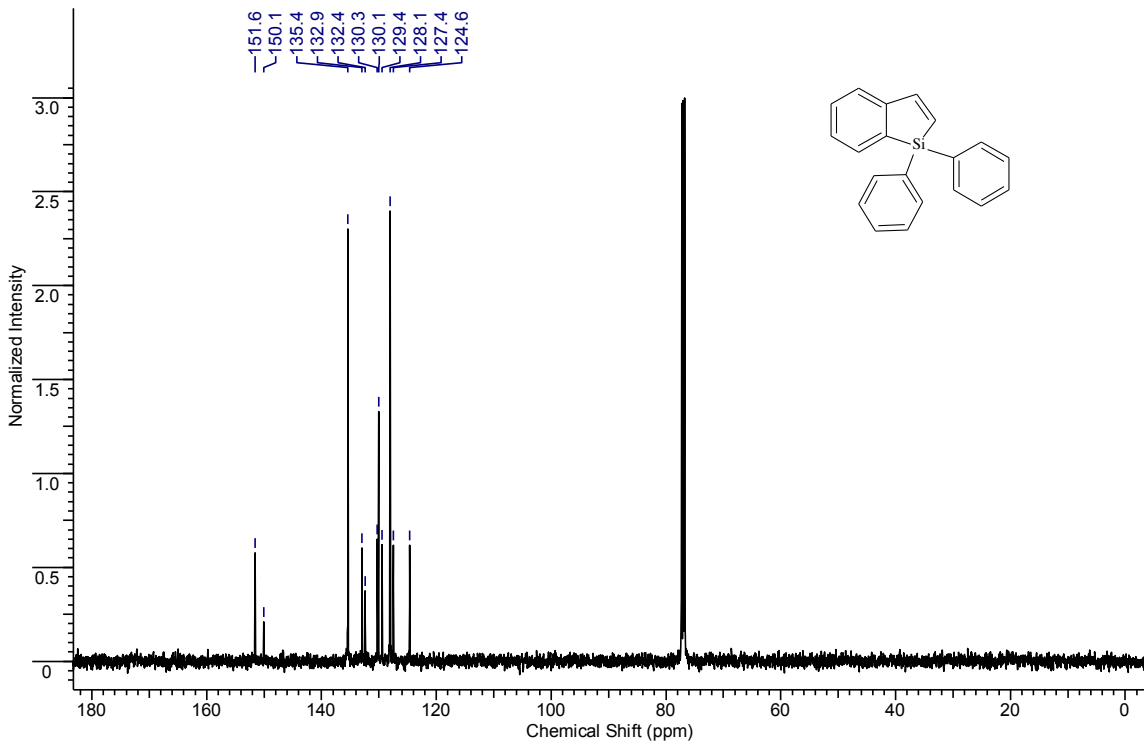

154.4
135.3
135.2
129.6
128.0
125.8
31.9
10.6
d4
Si
Normalized Intensity
Chemical Shift (ppm)

124a:

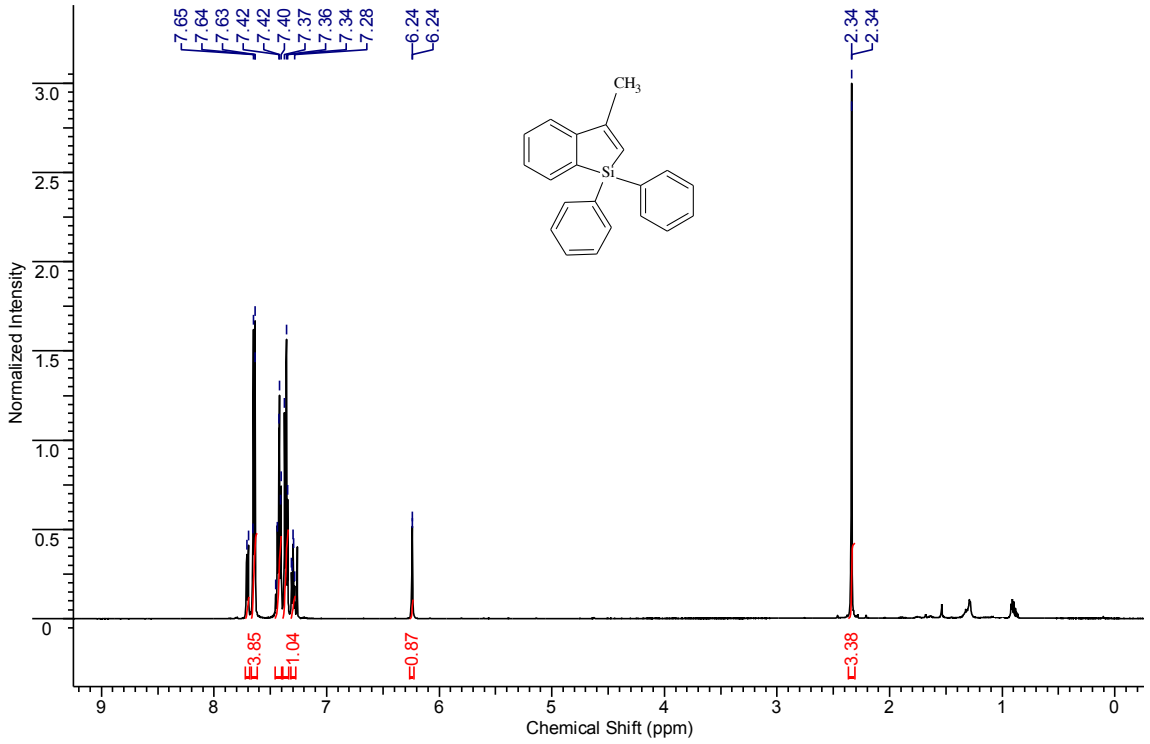

7.65
7.63
7.63
7.43
7.41
7.38
7.38
7.36
7.35
7.25
6.57
6.55
Si
Normalized Intensity
Chemical Shift (ppm)
1.00
1.47
1.00

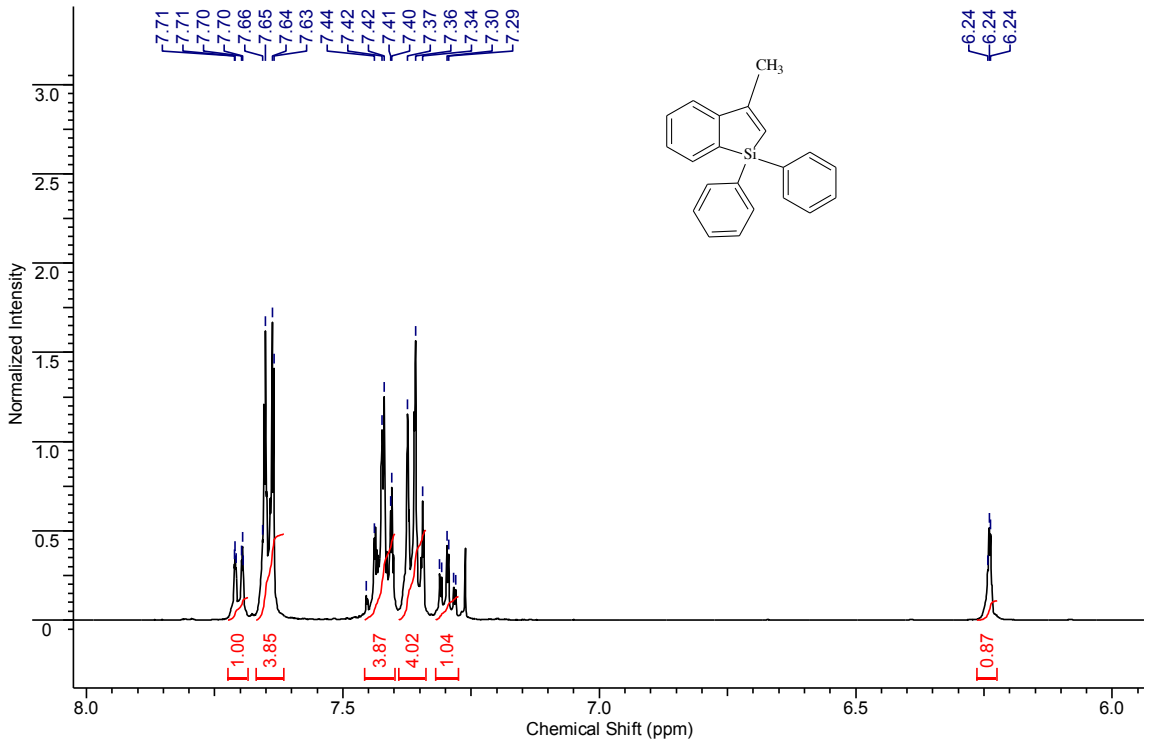

7.70
7.69
7.68
7.68
7.65
7.65
7.63
7.63
7.57
7.55
7.43
7.41
7.38
7.38
7.36
7.35
7.34
7.32
7.28
7.27
7.27
6.57
6.55
Si
Normalized Intensity
Chemical Shift (ppm)
1.04
3.96
1.00
2.20
6.09
1.47
1.00

124a:

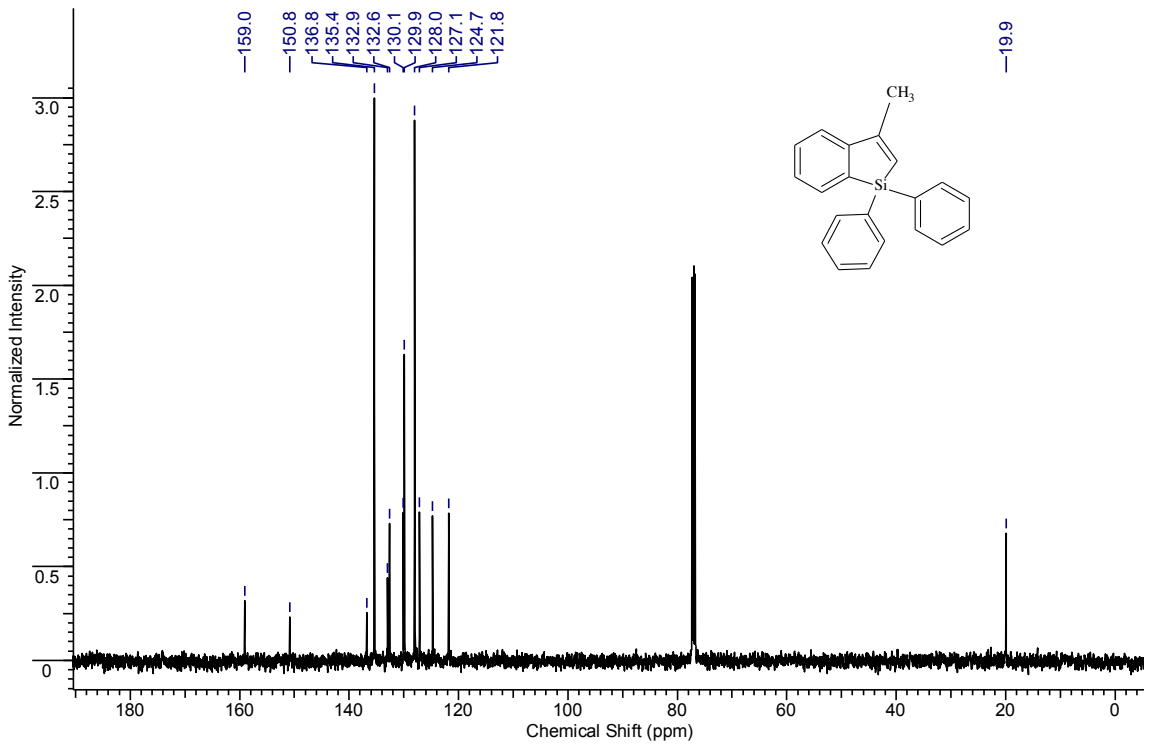

151.6
150.1
135.4
132.9
132.4
130.3
130.1
129.4
128.1
127.4
124.6
Si
Normalized Intensity
3.0
2.5
2.0
1.5
1.0
0.5
0
180
160
140
120
100
80
60
40
20
0
Chemical Shift (ppm)

124s:

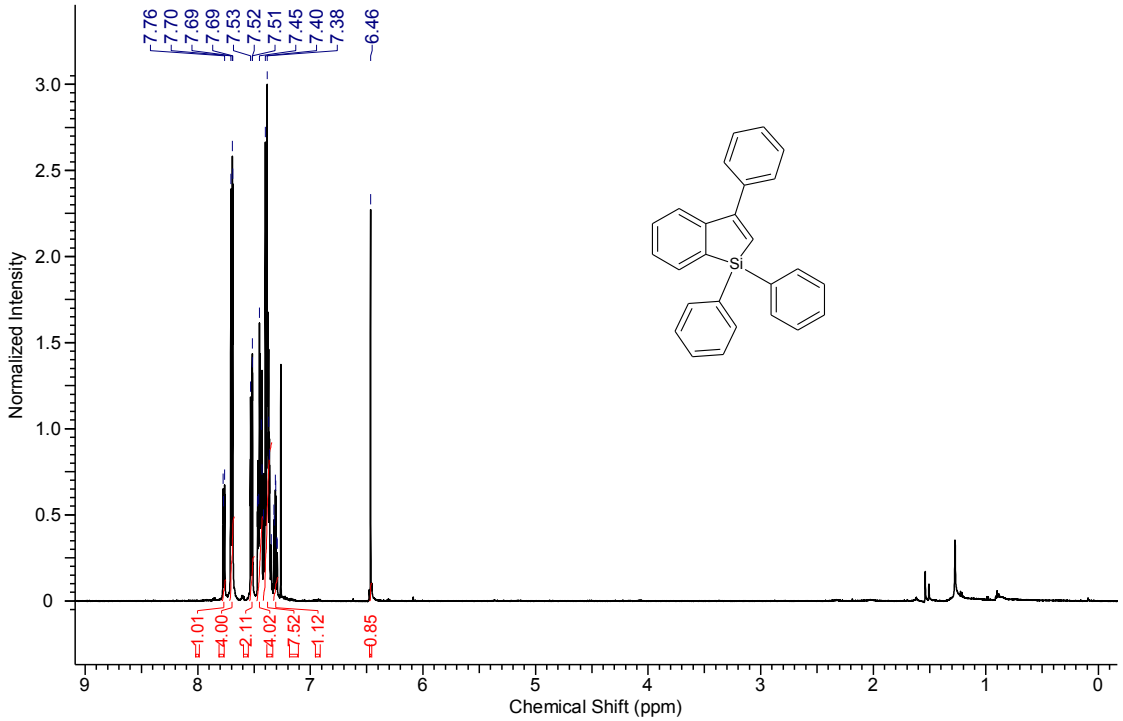

7.65
7.64
7.63
7.42
7.42
7.40
7.37
7.36
7.34
7.28
6.24
6.24
2.34
2.34
CH3
Si
Normalized Intensity
3.85
1.04
0.87
3.38
Chemical Shift (ppm)

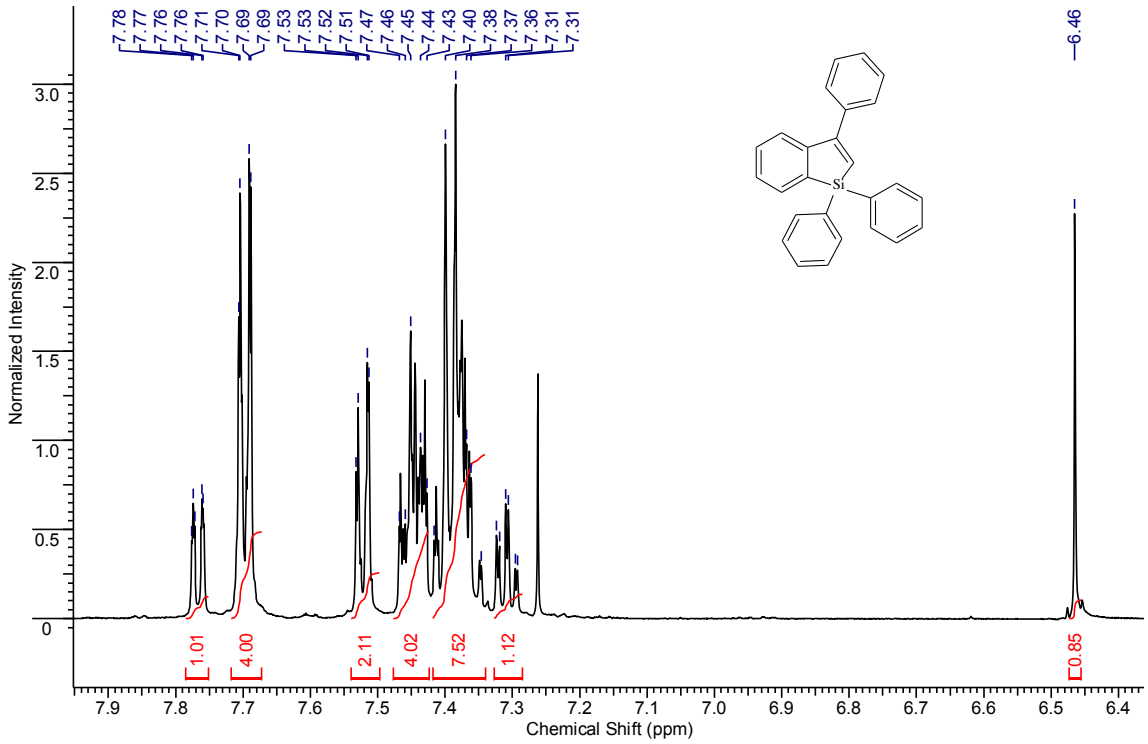

7.71
7.71
7.70
7.70
7.66
7.65
7.64
7.63
7.44
7.42
7.42
7.41
7.40
7.37
7.36
7.34
7.30
7.29
6.24
6.24
6.24
CH3
Si
Normalized Intensity
1.00
3.85
3.87
4.02
1.04
0.87
Chemical Shift (ppm)

124s:

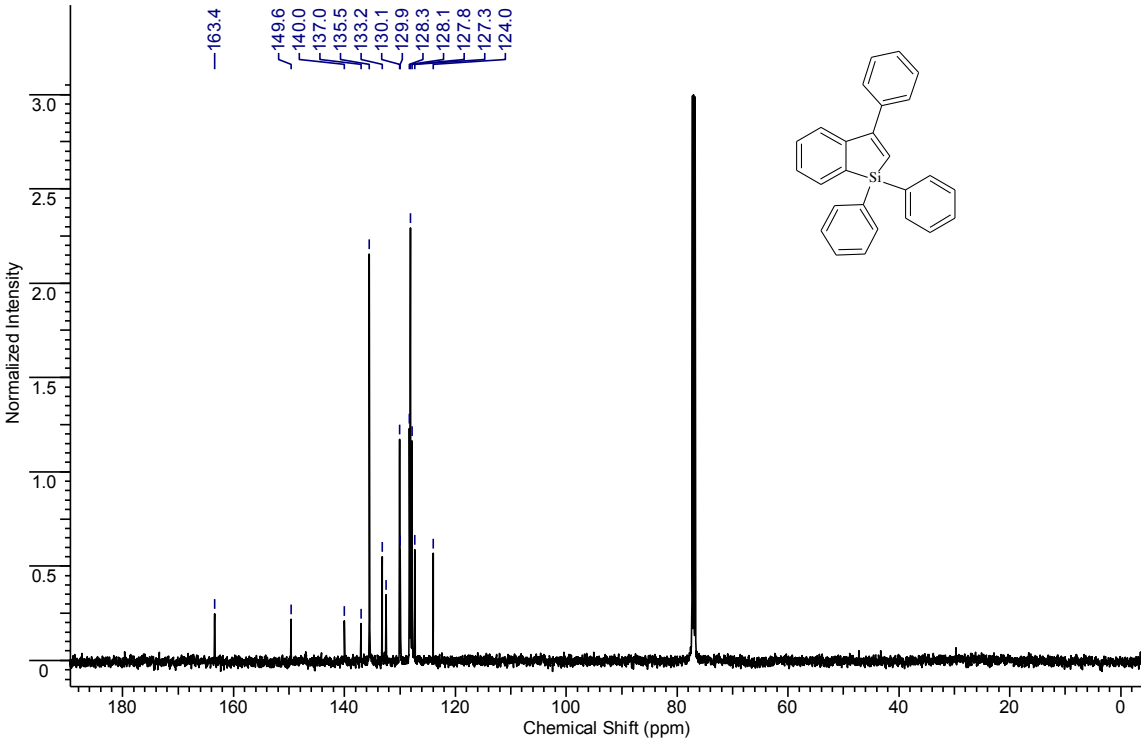

159.0
150.8
136.8
135.4
132.9
132.6
130.1
129.9
128.0
127.1
124.7
121.8
19.9
CH3
Si
Normalized Intensity
3.0
2.5
2.0
1.5
1.0
0.5
0
180
160
140
120
100
80
60
40
20
0
Chemical Shift (ppm)

124t:

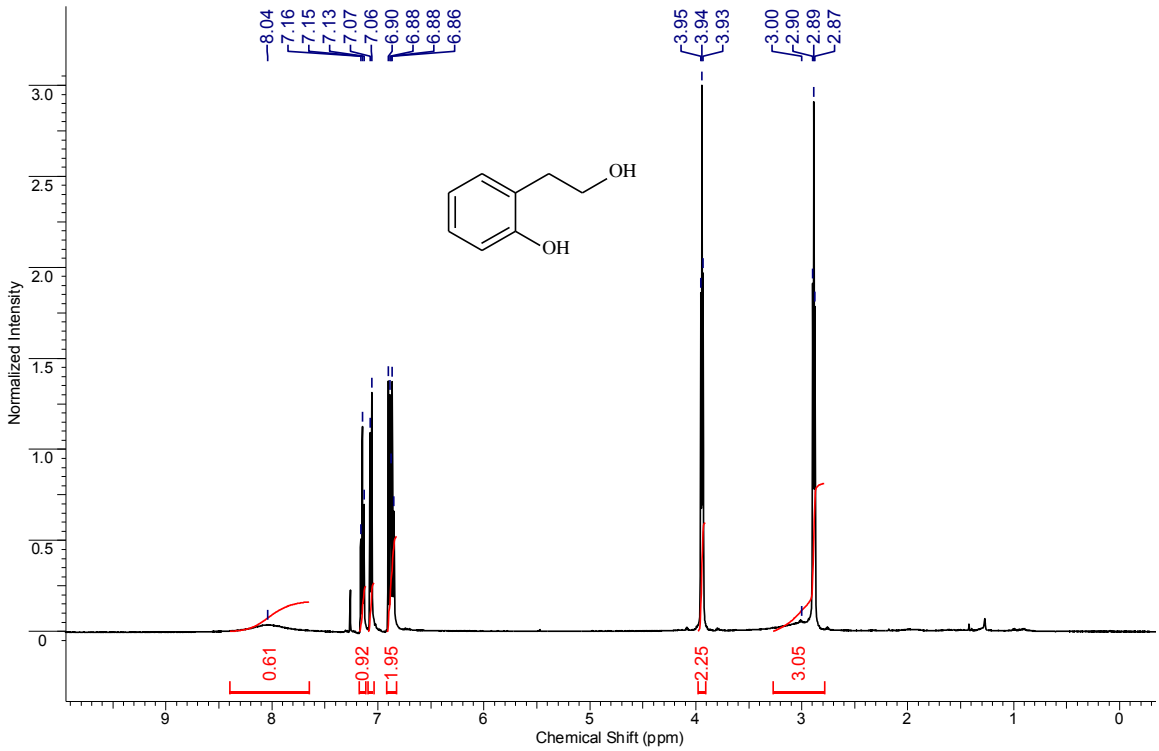

7.76
7.70
7.69
7.69
7.53
7.52
7.51
7.45
7.40
7.38
6.46
Normalized Intensity
Chemical Shift (ppm)
1.01
4.00
2.11
4.02
7.52
1.12
0.85
Si

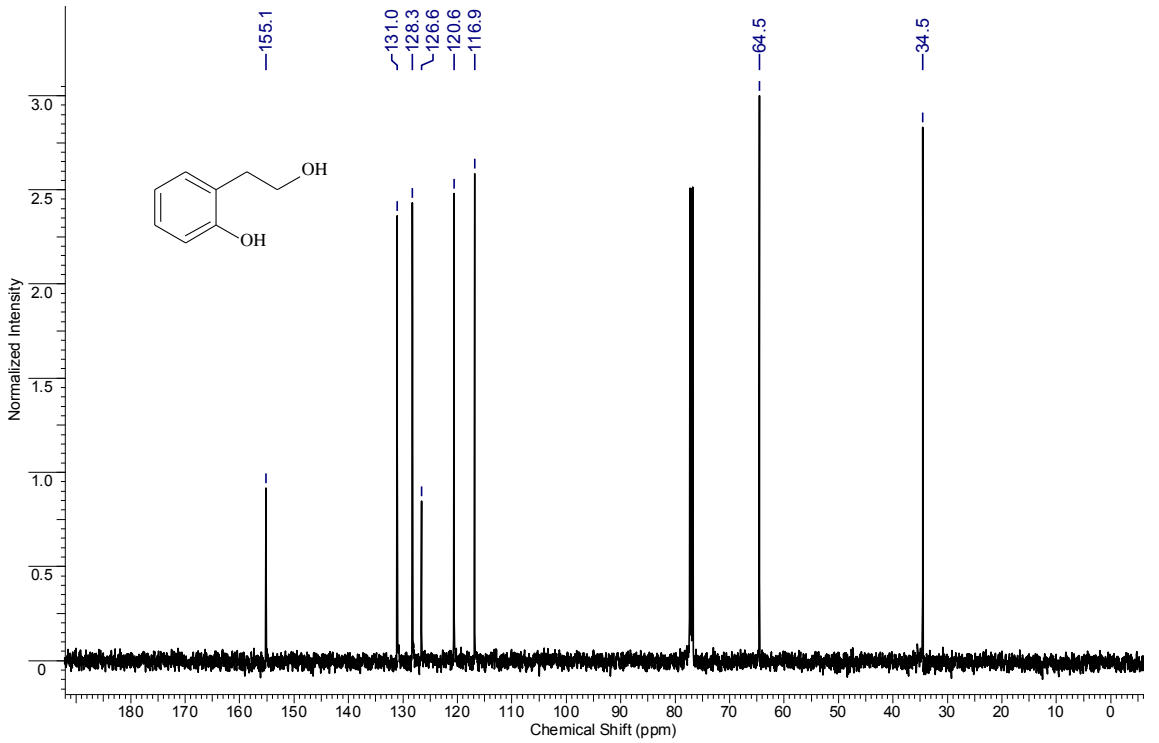

7.78
7.77
7.76
7.76
7.71
7.70
7.69
7.69
7.53
7.52
7.51
7.47
7.46
7.45
7.44
7.43
7.40
7.38
7.37
7.36
7.31
7.31
6.46
Normalized Intensity
Chemical Shift (ppm)
1.01
4.00
2.11
4.02
7.52
1.12
0.85
Si

124t:

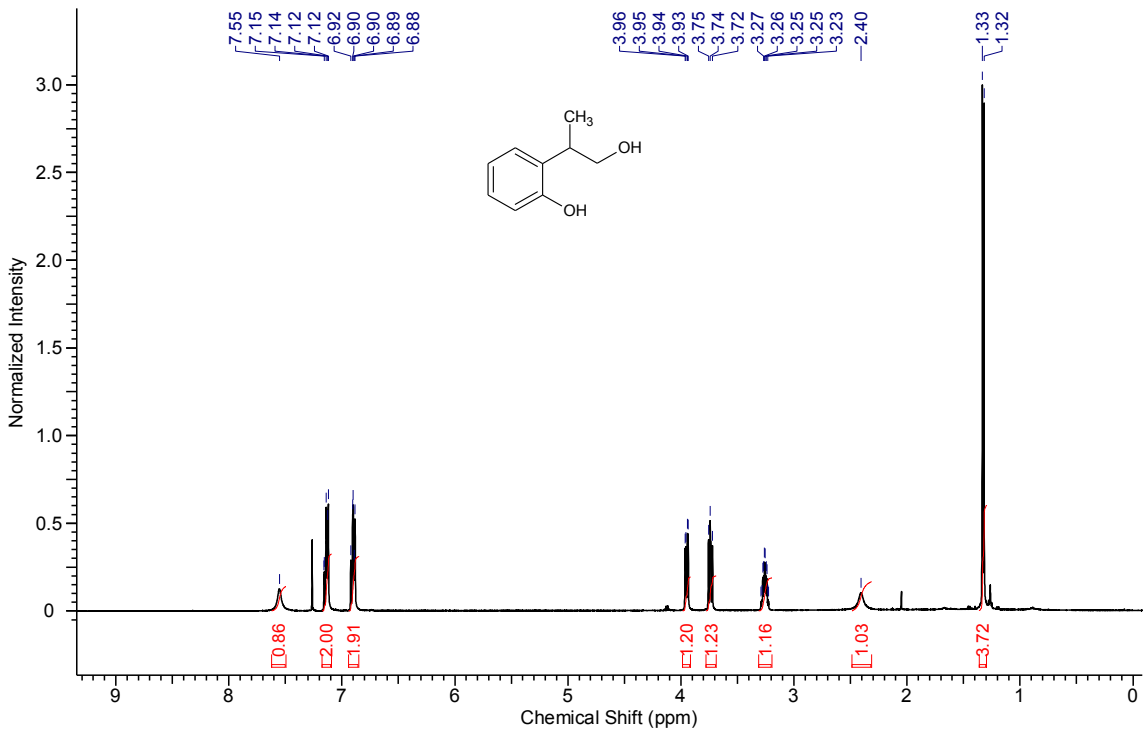

163.4
149.6
140.0
137.0
135.5
133.2
130.1
129.9
128.3
128.1
127.8
127.3
124.0
Si
Normalized Intensity
3.0
2.5
2.0
1.5
1.0
0.5
0
180
160
140
120
100
80
60
40
20
0
Chemical Shift (ppm)

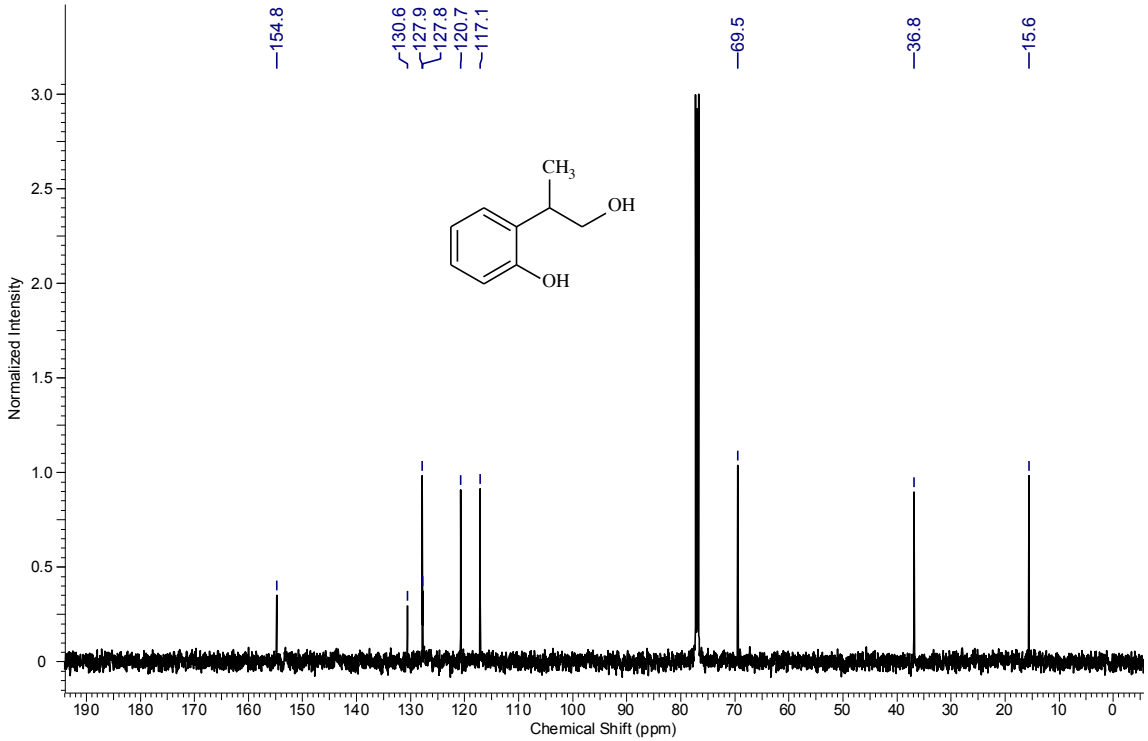
118a:


8.04
7.16
7.15
7.13
7.07
7.06
6.90
6.88
6.88
6.86
3.95
3.94
3.93
3.00
2.90
2.89
2.87
OH
OH
Normalized Intensity
Chemical Shift (ppm)
0.61
0.92
1.95
2.25
3.05

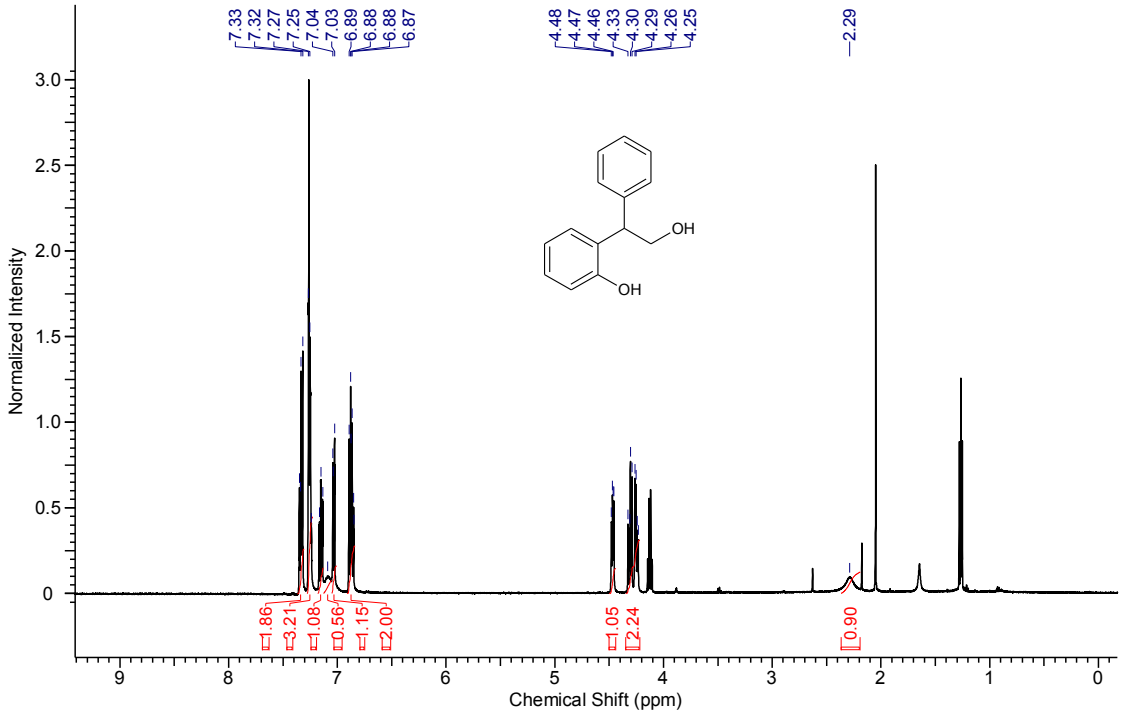

155.1
131.0
128.3
126.6
120.6
116.9
64.5
34.5
OH
OH
Normalized Intensity
Chemical Shift (ppm)

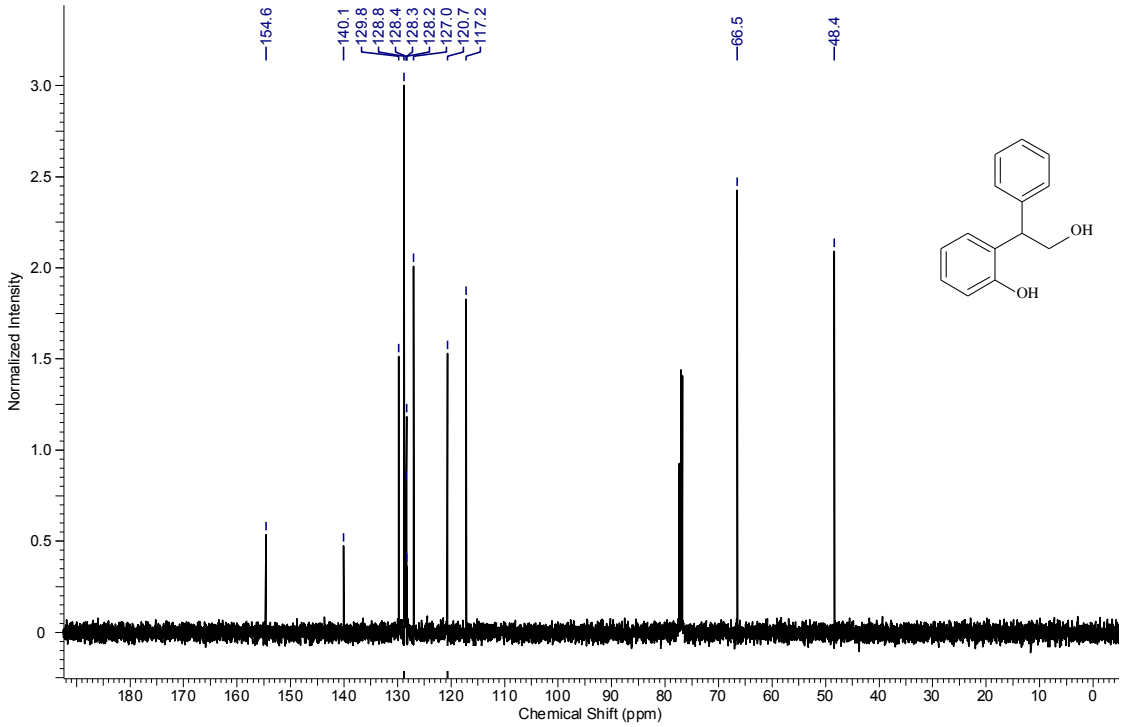
118s:


7.55
7.15
7.14
7.12
7.12
6.92
6.90
6.90
6.89
6.88
3.96
3.95
3.94
3.93
3.75
3.74
3.72
3.27
3.26
3.25
3.25
3.23
2.40
1.33
1.32
CH3
OH
OH
Normalized Intensity
0.86
2.00
1.91
1.20
1.23
1.16
1.03
3.72
Chemical Shift (ppm)

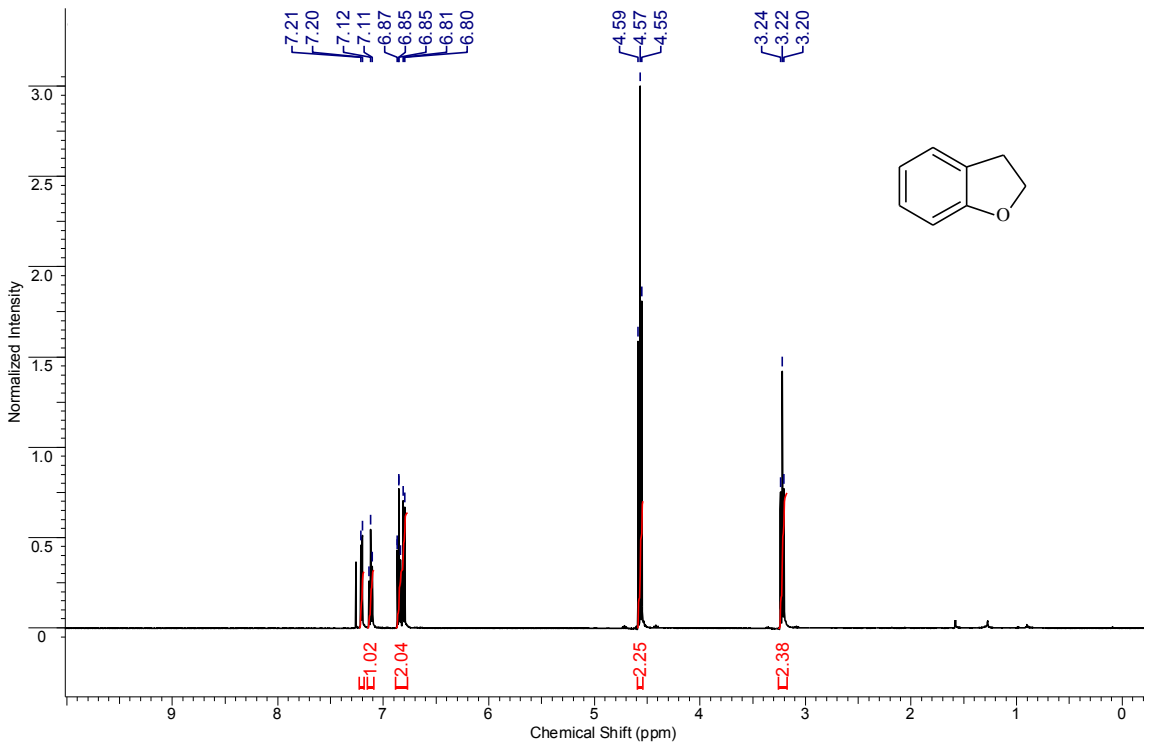

154.8
130.6
127.9
127.8
120.7
117.1
69.5
36.8
15.6
CH3
OH
OH
Normalized Intensity
Chemical Shift (ppm)

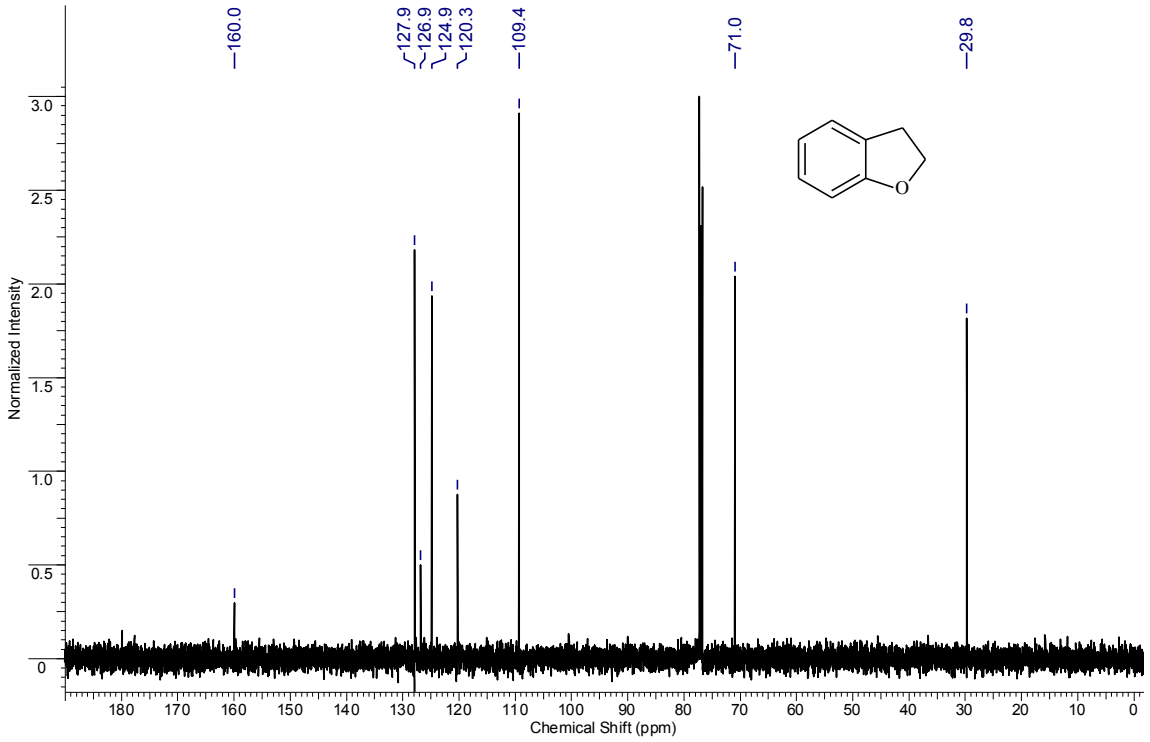
118t:


7.33
7.32
7.27
7.25
7.04
7.03
6.89
6.88
6.88
6.87
4.48
4.47
4.46
4.33
4.30
4.29
4.26
4.25
2.29
OH
OH
1.86
3.21
1.08
0.56
1.15
2.00
1.05
2.24
0.90
Normalized Intensity
Chemical Shift (ppm)


154.6
140.1
129.8
128.8
128.4
128.3
128.2
127.0
120.7
117.2
66.5
48.4
OH
OH
Normalized Intensity
Chemical Shift (ppm)

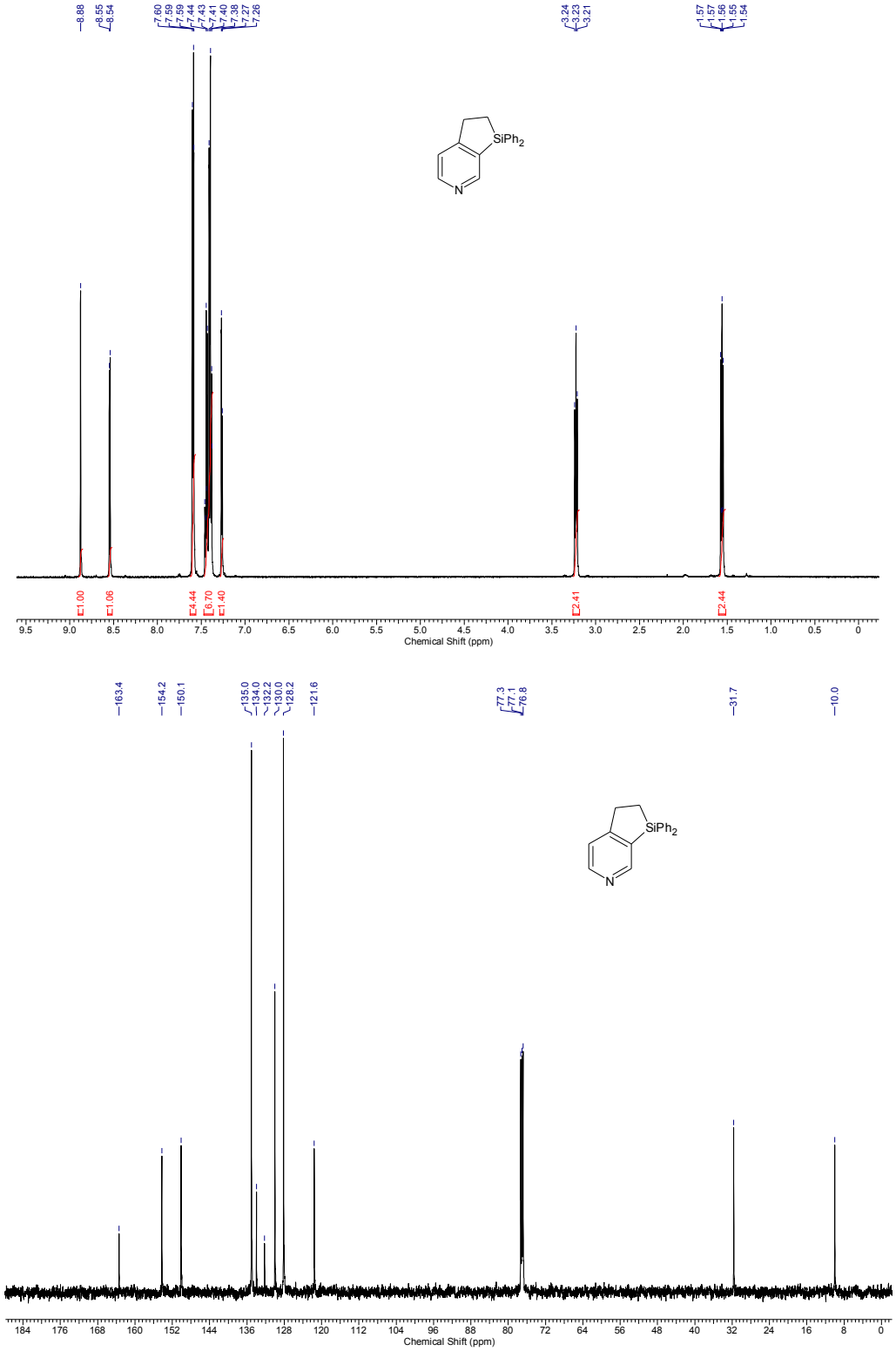
125:


7.21
7.20
7.12
7.11
6.87
6.85
6.85
6.81
6.80
4.59
4.57
4.55
3.24
3.22
3.20
Normalized Intensity
Chemical Shift (ppm)
1.02
2.04
2.25
2.38
O

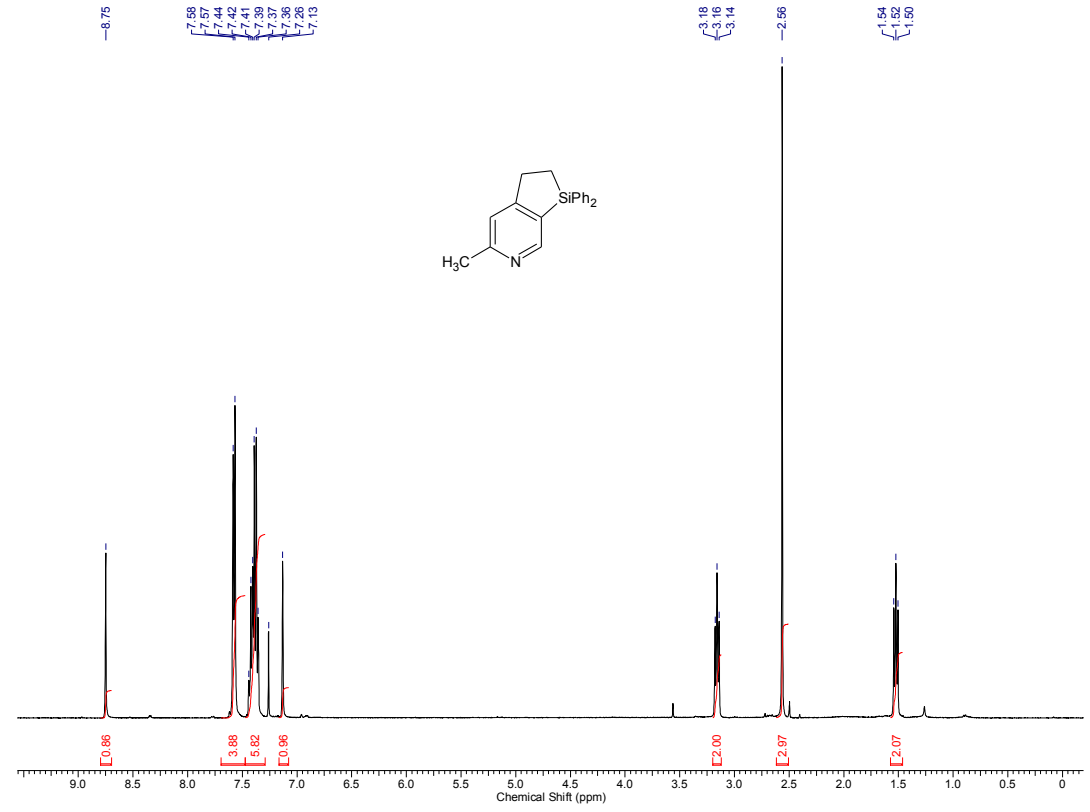

160.0
127.9
126.9
124.9
120.3
109.4
71.0
29.8
Normalized Intensity
Chemical Shift (ppm)
O

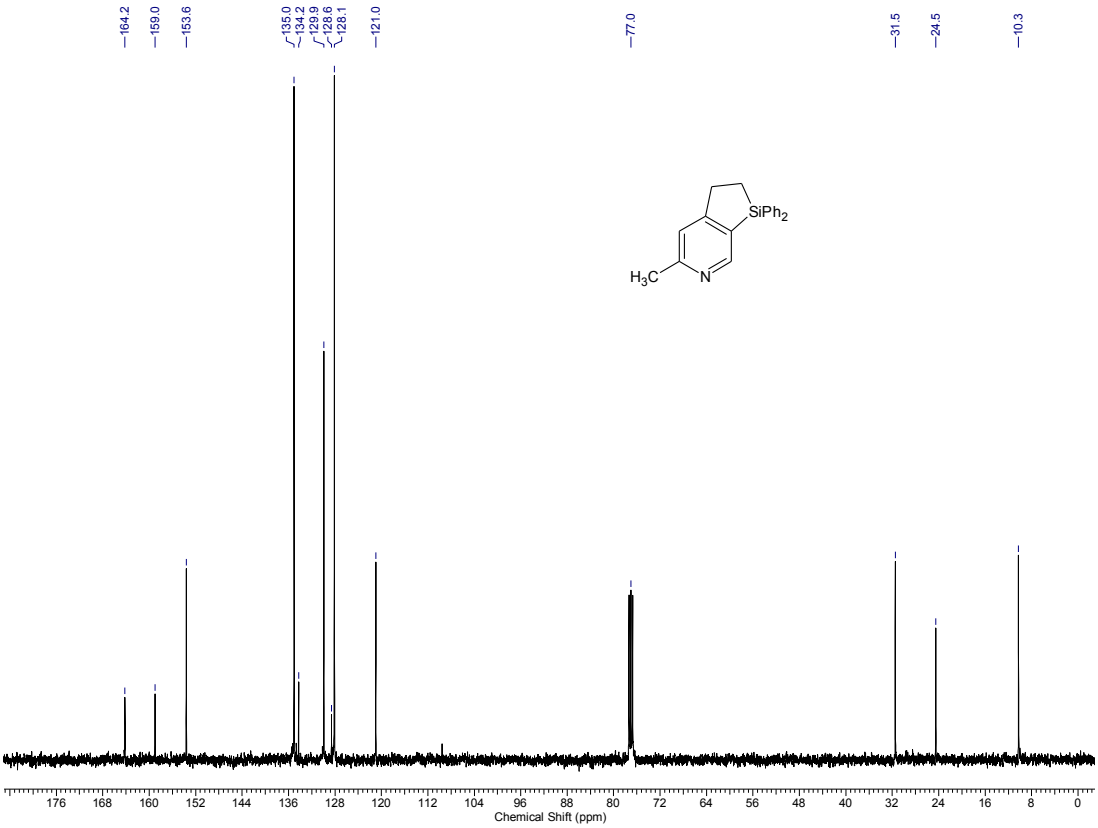
APPENDIX B. ^{1}H and ^{13}C spectra of fused heteroaromatic dihydrosiloles **131** and the products of their further transformations

131a:

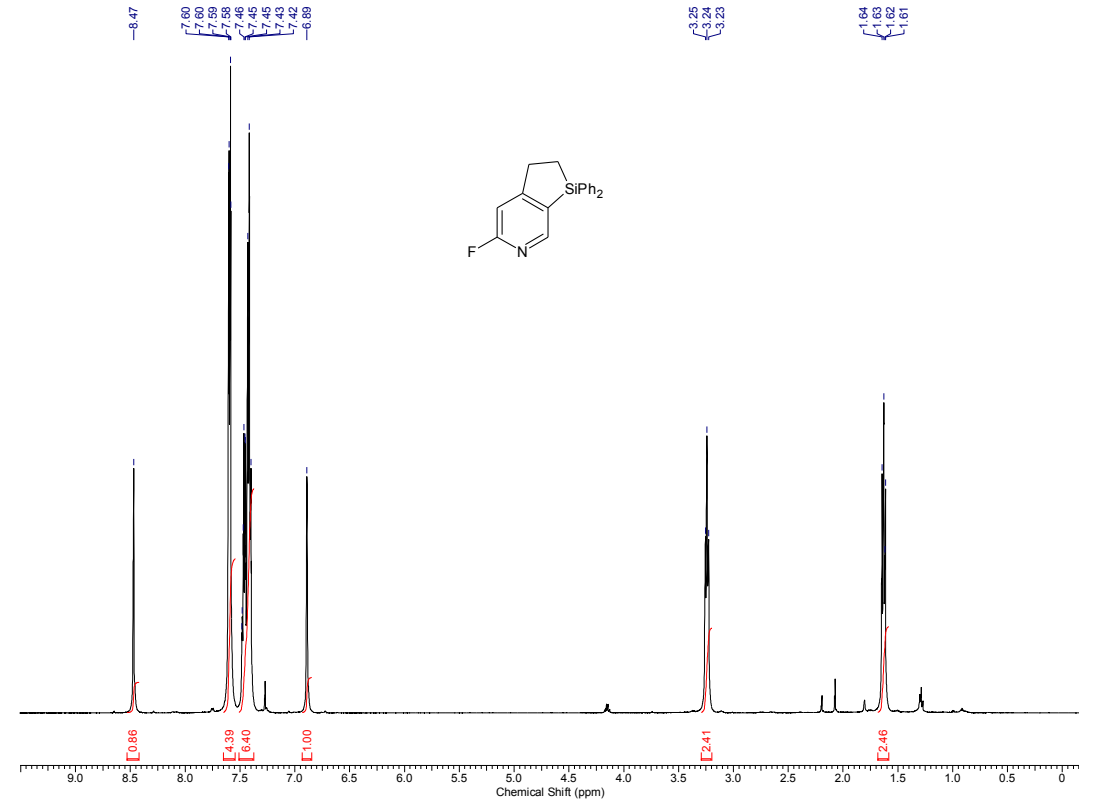


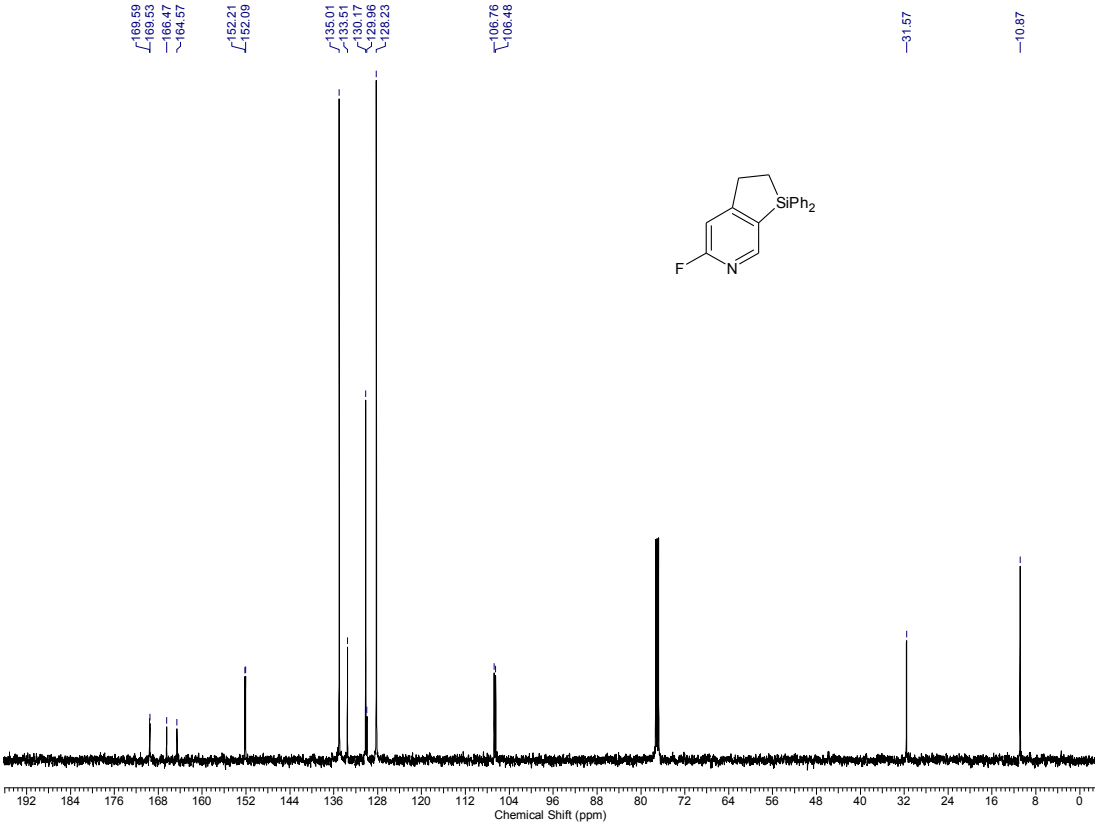
131b:


8.75
7.58
7.57
7.44
7.42
7.41
7.39
7.37
7.36
7.26
7.13
3.18
3.16
3.14
2.56
1.54
1.52
1.50
SiPh2
H3C
N
0.86
3.88
5.82
0.96
2.00
2.97
2.07
Chemical Shift (ppm)

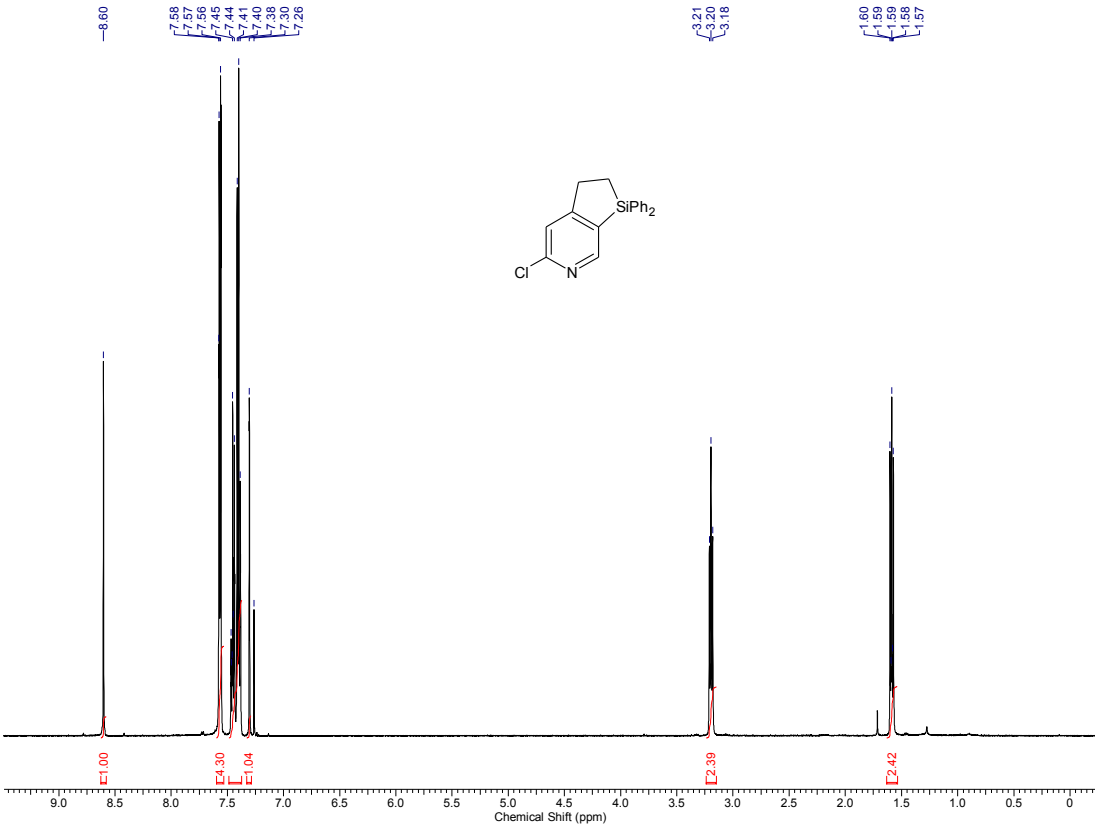

164.2
159.0
153.6
135.0
134.2
129.9
128.6
128.1
121.0
77.0
31.5
24.5
10.3
SiPh2
H3C
N
Chemical Shift (ppm)

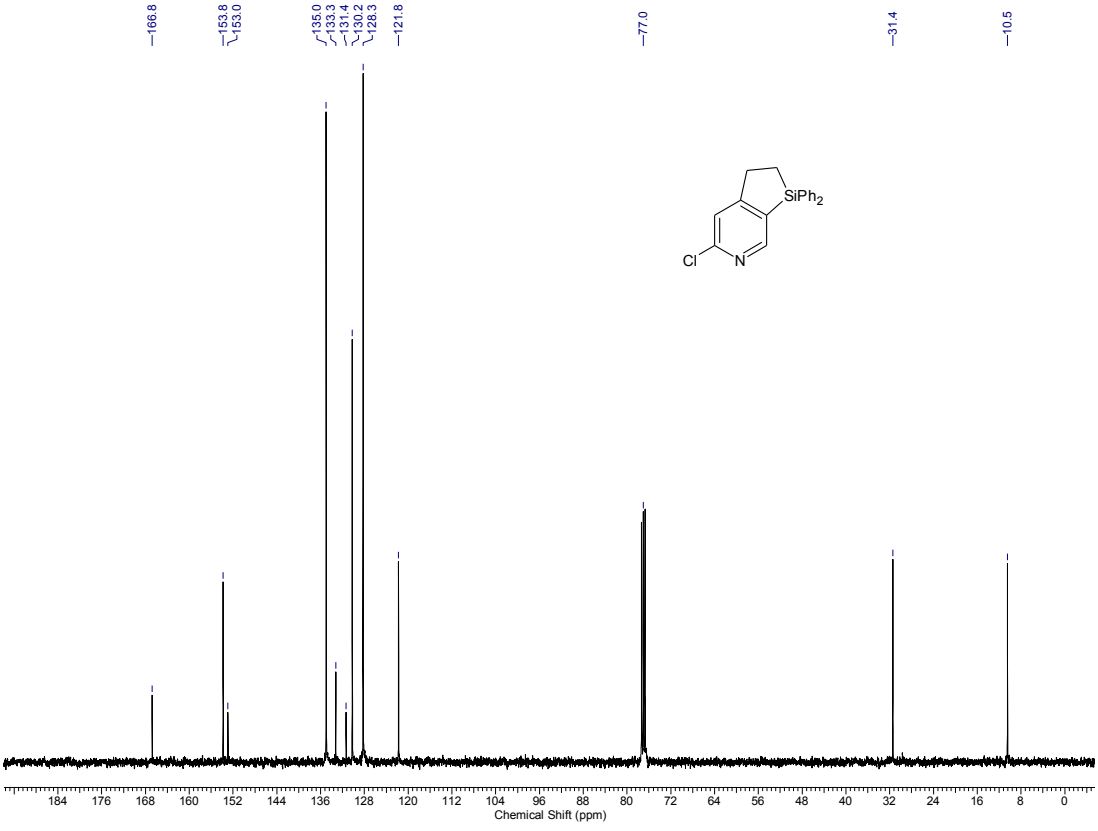
131c:


8.47
7.60
7.60
7.59
7.58
7.46
7.45
7.45
7.43
7.42
6.89
3.25
3.24
3.23
1.64
1.63
1.62
1.61
SiPh2
F
N
0.86
4.39
6.40
1.00
2.41
2.46
Chemical Shift (ppm)

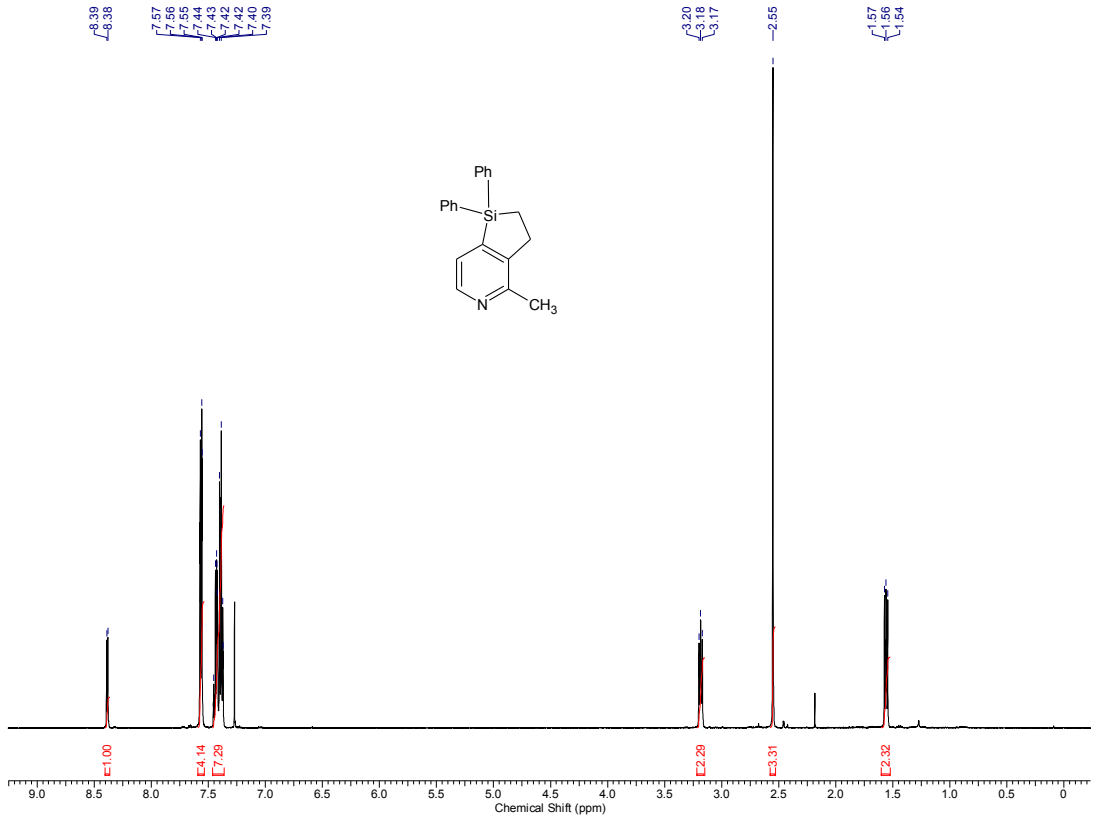

169.59
169.53
166.47
164.57
152.21
152.09
135.01
133.51
130.17
129.96
128.23
106.76
106.48
31.57
10.87
SiPh2
F
N
Chemical Shift (ppm)

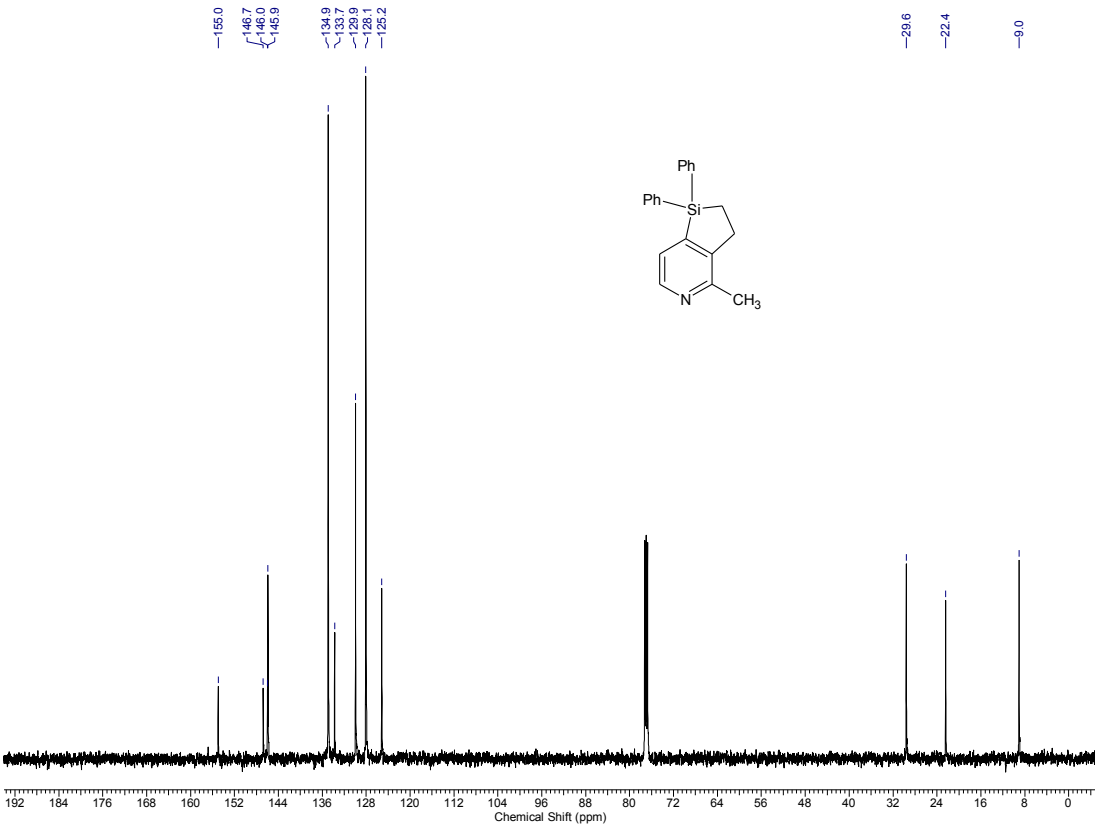
131d:


8.60
7.58
7.57
7.56
7.45
7.44
7.41
7.40
7.38
7.30
7.26
3.21
3.20
3.18
1.60
1.59
1.59
1.58
1.57
SiPh2
Cl
N
1.00
4.30
1.04
2.39
2.42
Chemical Shift (ppm)

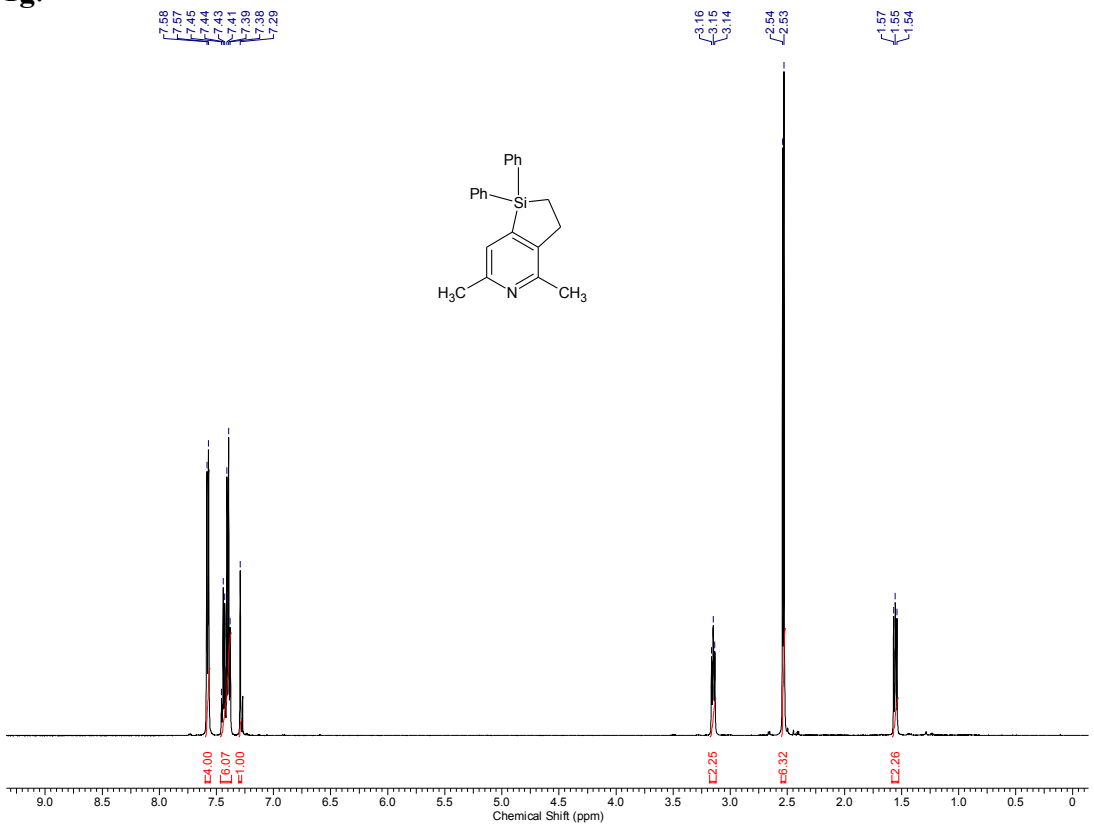

166.8
153.8
153.0
135.0
133.3
131.4
130.2
128.3
121.8
77.0
31.4
10.5
SiPh2
Cl
N
Chemical Shift (ppm)

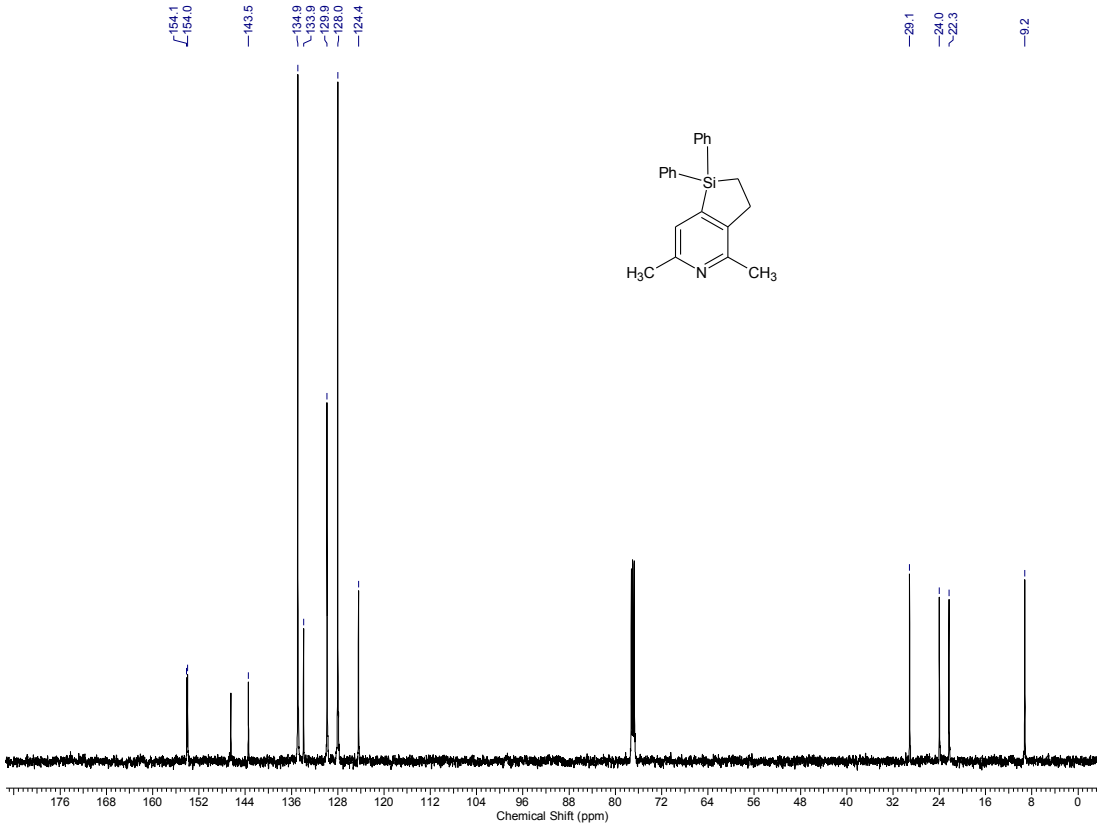
131f:


8.39
8.38
7.57
7.56
7.55
7.44
7.43
7.42
7.42
7.40
7.39
3.20
3.18
3.17
2.55
1.57
1.56
1.54
Ph
Ph
Si
N
CH3
1.00
4.14
7.29
2.29
3.31
2.32
Chemical Shift (ppm)

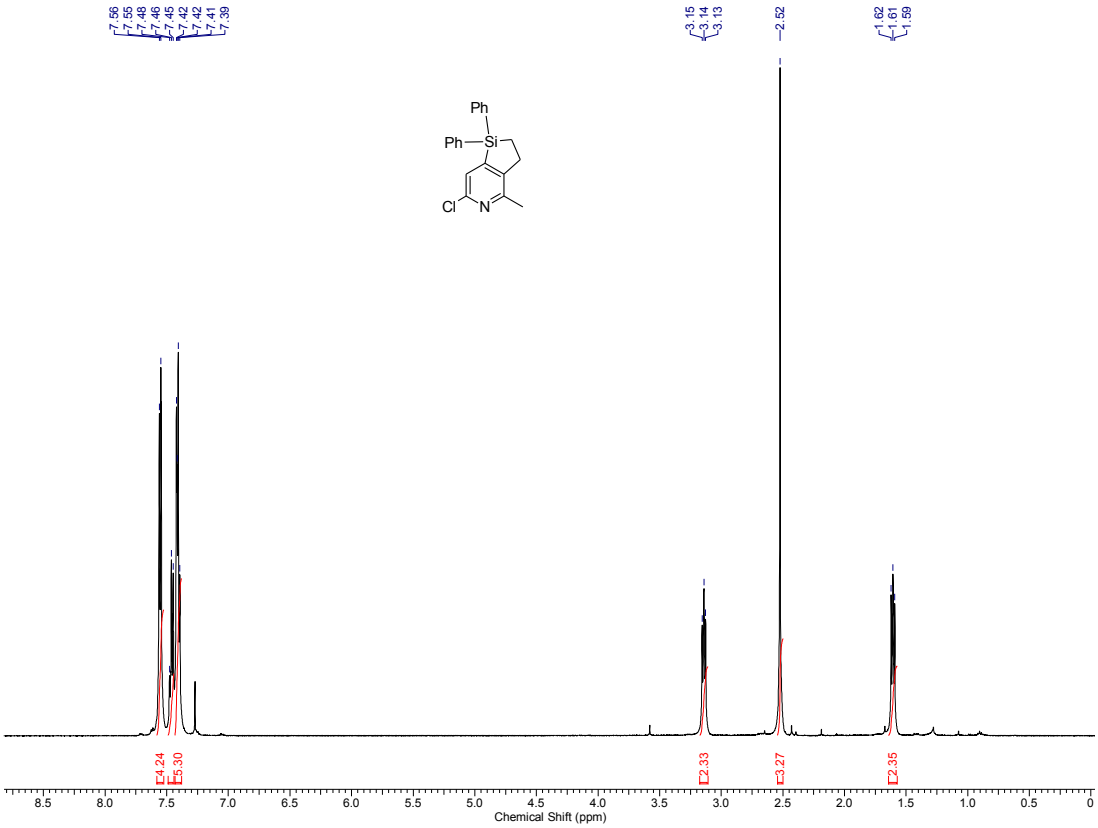

155.0
146.7
146.0
145.9
134.9
133.7
129.9
128.1
125.2
29.6
22.4
9.0
Ph
Ph
Si
N
CH3
Chemical Shift (ppm)

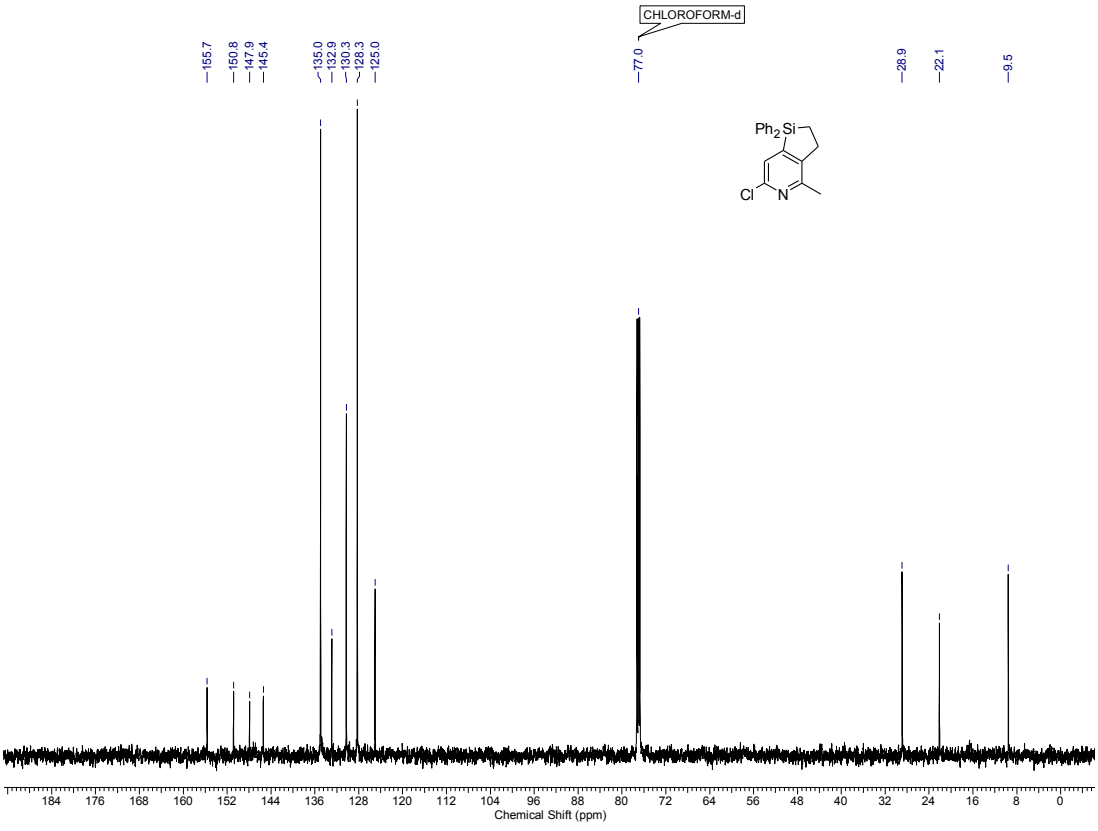
131g:


7.58
7.57
7.45
7.44
7.43
7.41
7.39
7.38
7.29
3.16
3.15
3.14
2.54
2.53
1.57
1.55
1.54
Ph
Ph
Si
H3C
N
CH3
4.00
6.07
1.00
2.25
6.32
2.26
Chemical Shift (ppm)

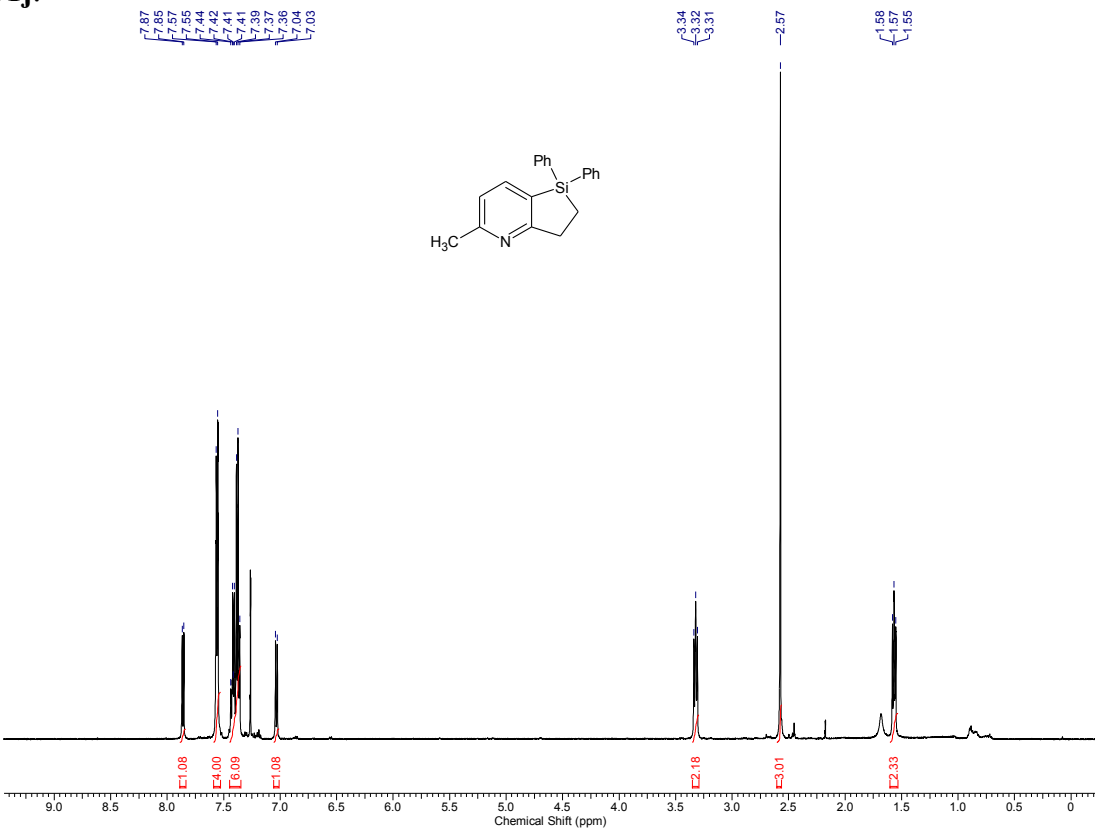

154.1
154.0
143.5
134.9
133.9
129.9
128.0
124.4
29.1
24.0
22.3
9.2
Ph
Ph
Si
H3C
N
CH3
Chemical Shift (ppm)

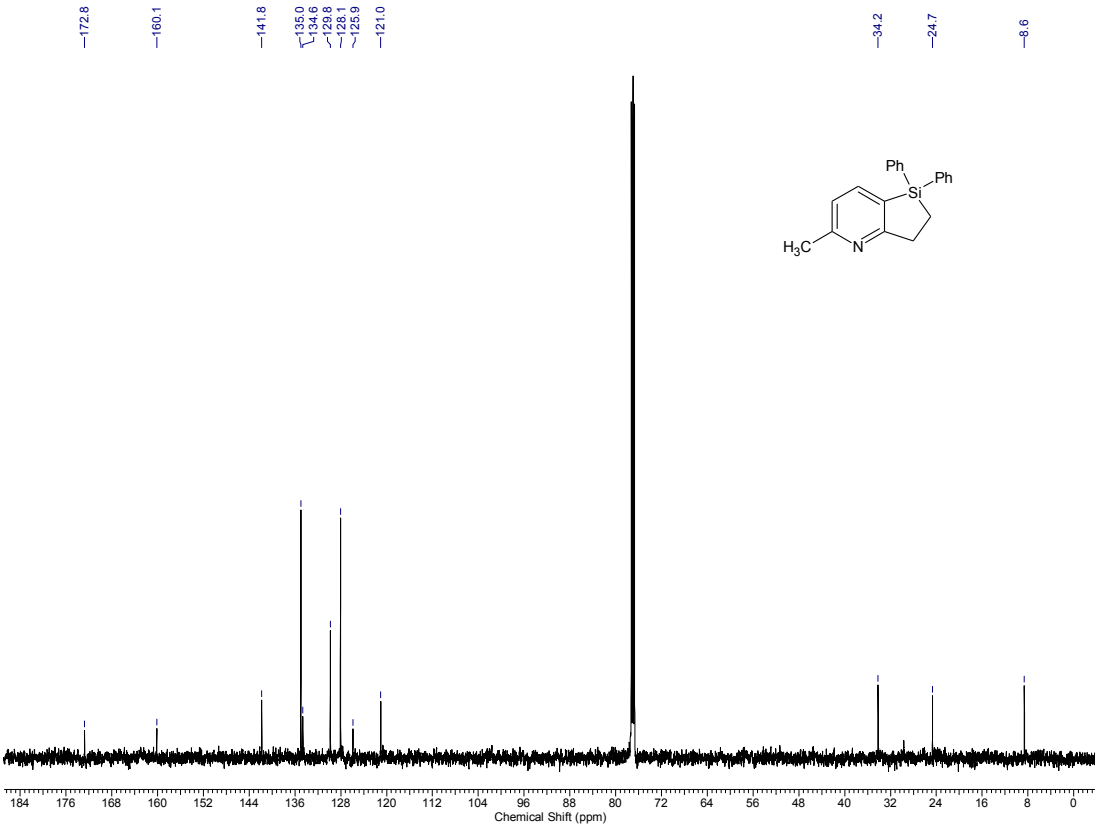
131h:


7.56
7.55
7.48
7.46
7.45
7.42
7.42
7.41
7.39
3.15
3.14
3.13
2.52
1.62
1.61
1.59
Ph
Ph
Si
Cl
N
4.24
5.30
2.33
3.27
2.35
Chemical Shift (ppm)

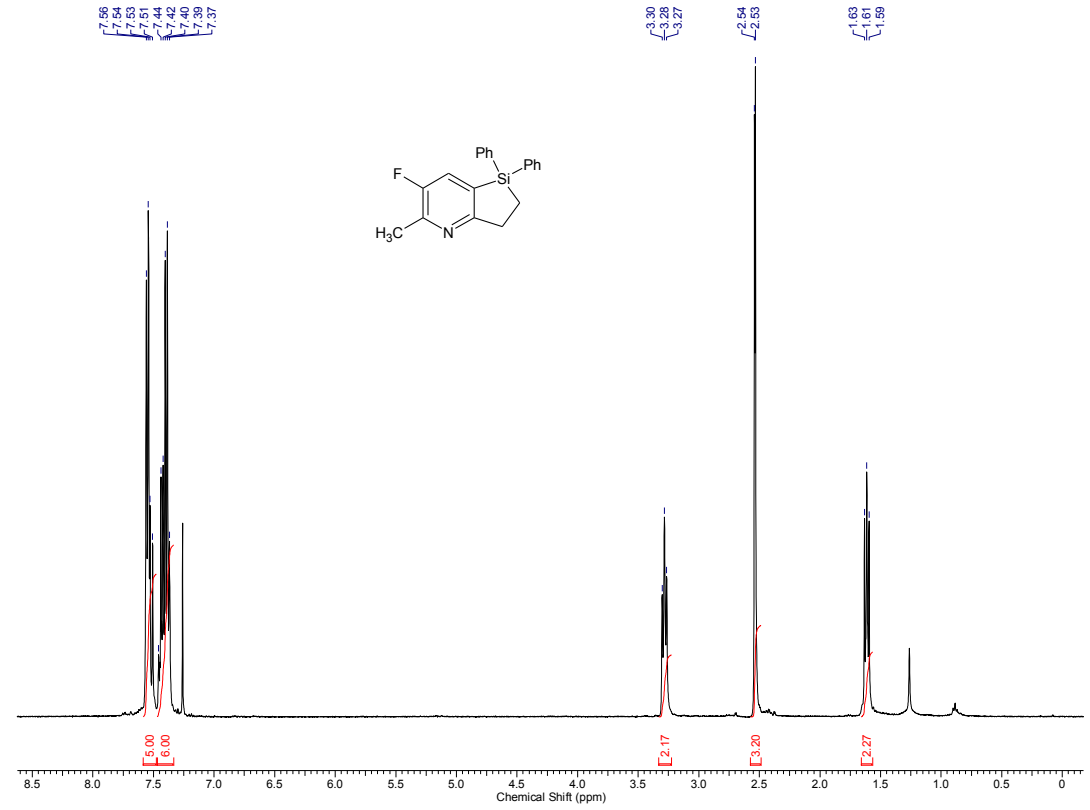

CHLOROFORM-d
155.7
150.8
147.9
145.4
135.0
132.9
130.3
128.3
125.0
77.0
28.9
22.1
9.5
Ph2Si
Cl
N
Chemical Shift (ppm)

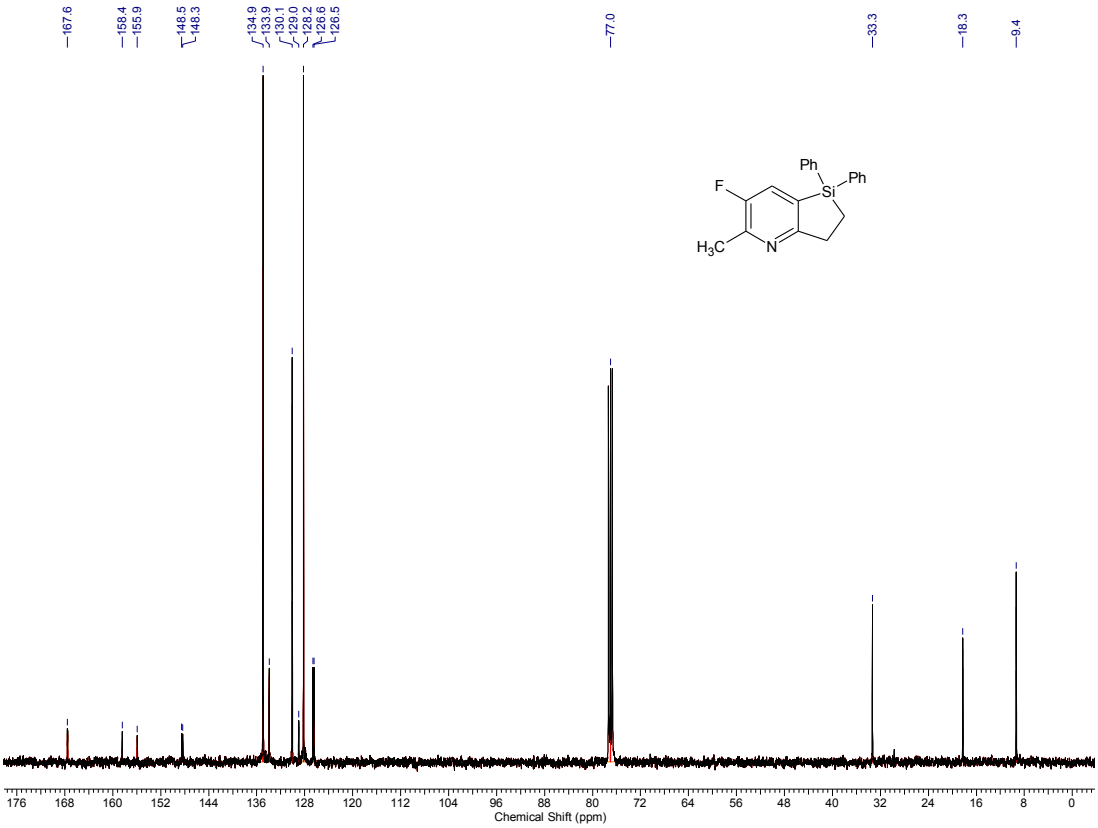
131j:


7.87
7.85
7.57
7.55
7.44
7.42
7.41
7.39
7.37
7.36
7.04
7.03
3.34
3.32
3.31
2.57
1.58
1.57
1.55
Ph
Si
Ph
H3C
N
1.08
4.00
6.09
1.08
2.18
3.01
2.33
Chemical Shift (ppm)

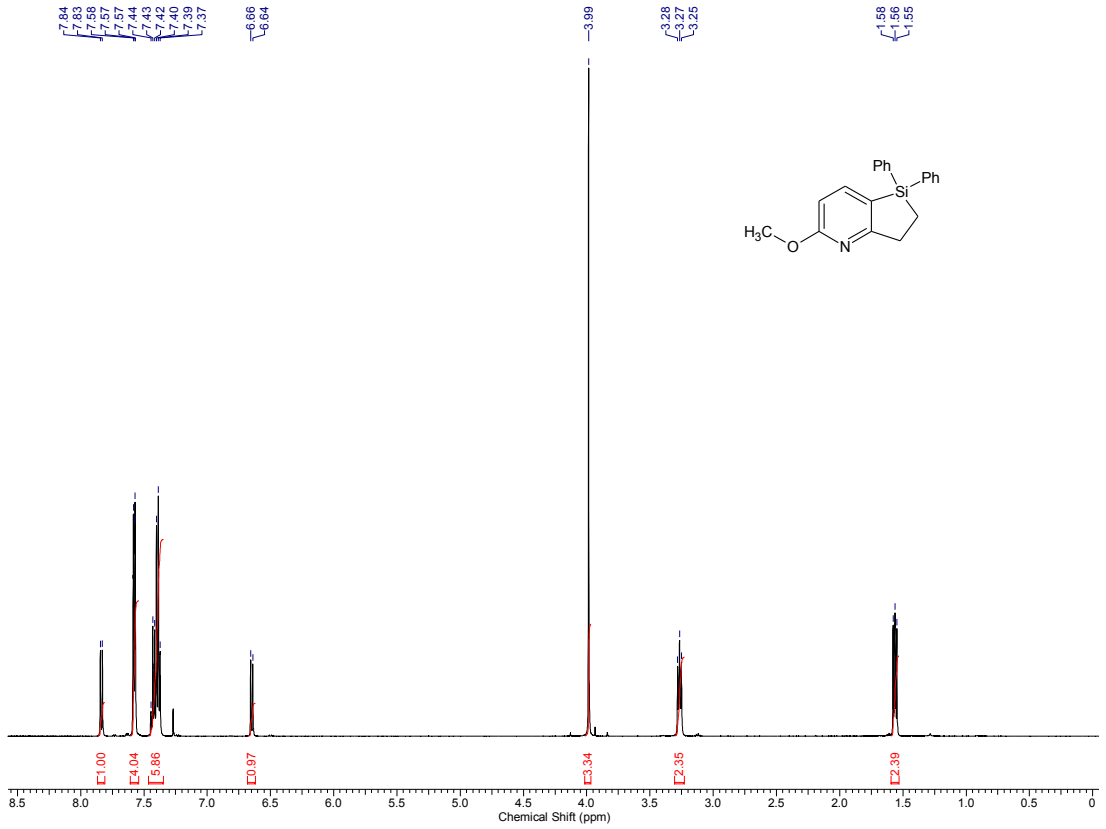

172.8
160.1
141.8
135.0
134.6
129.8
128.1
125.9
121.0
34.2
24.7
8.6
Ph
Si
Ph
H3C
N
Chemical Shift (ppm)

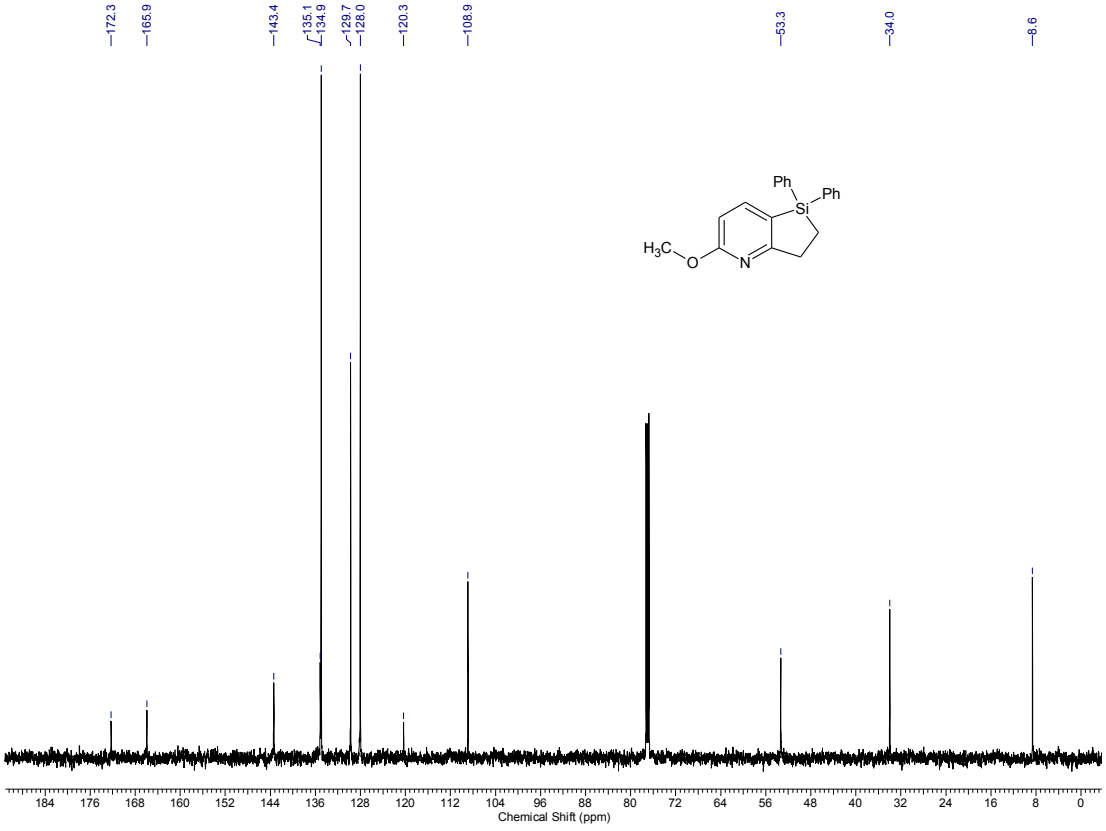
131k:


7.56
7.54
7.53
7.51
7.44
7.42
7.40
7.39
7.37
3.30
3.28
3.27
2.54
2.53
1.63
1.61
1.59
Ph
Ph
Si
F
H3C
N
5.00
6.00
2.17
3.20
2.27
Chemical Shift (ppm)

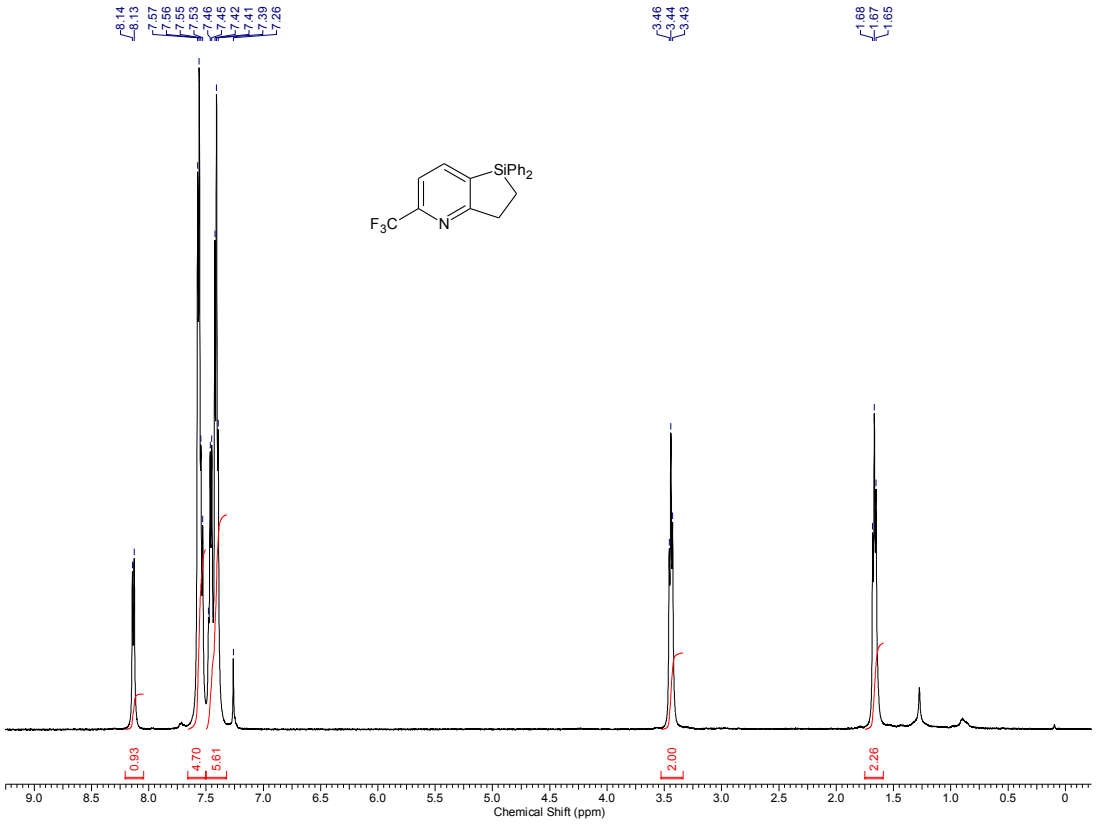

167.6
158.4
155.9
148.5
148.3
134.9
133.9
130.1
129.0
128.2
126.6
126.5
77.0
33.3
18.3
9.4
Ph
Ph
Si
F
H3C
N
Chemical Shift (ppm)

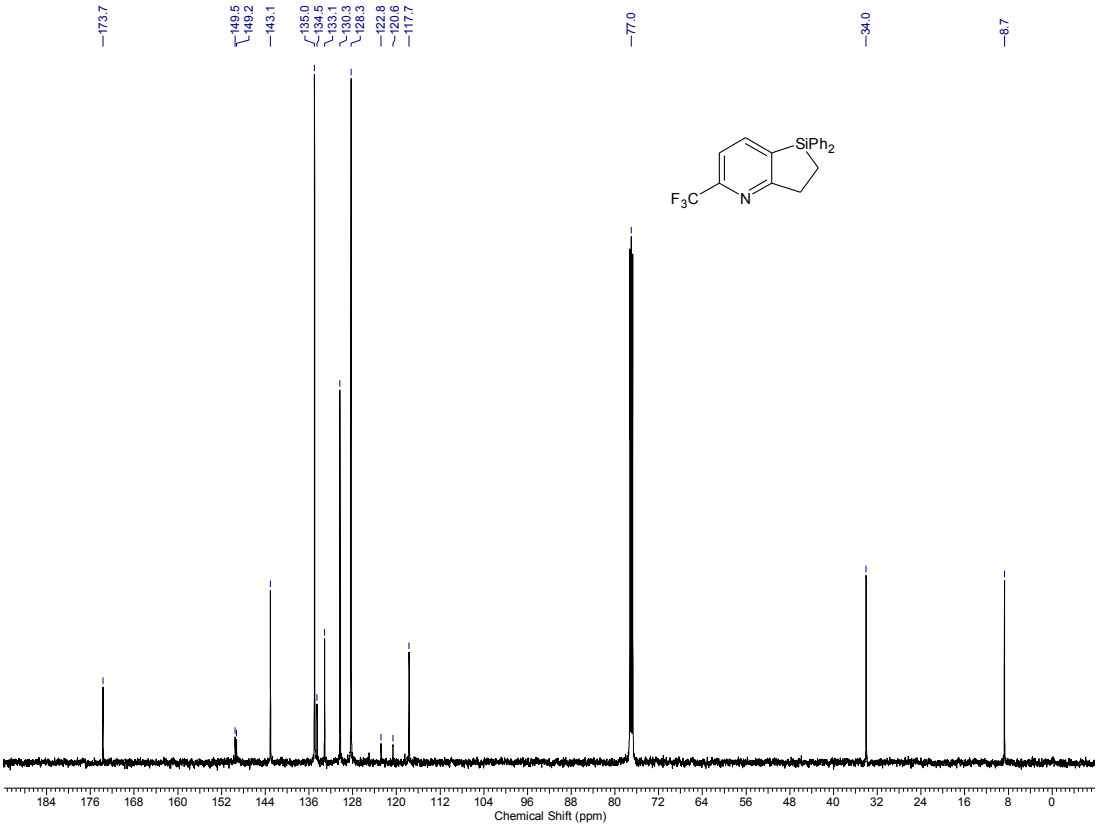
131l:


7.84
7.83
7.58
7.57
7.57
7.44
7.43
7.42
7.40
7.39
7.37
6.66
6.64
3.99
3.28
3.27
3.25
1.58
1.56
1.55
Ph
Ph
Si
H3C
O
N
1.00
4.04
5.86
0.97
3.34
2.35
2.39
Chemical Shift (ppm)

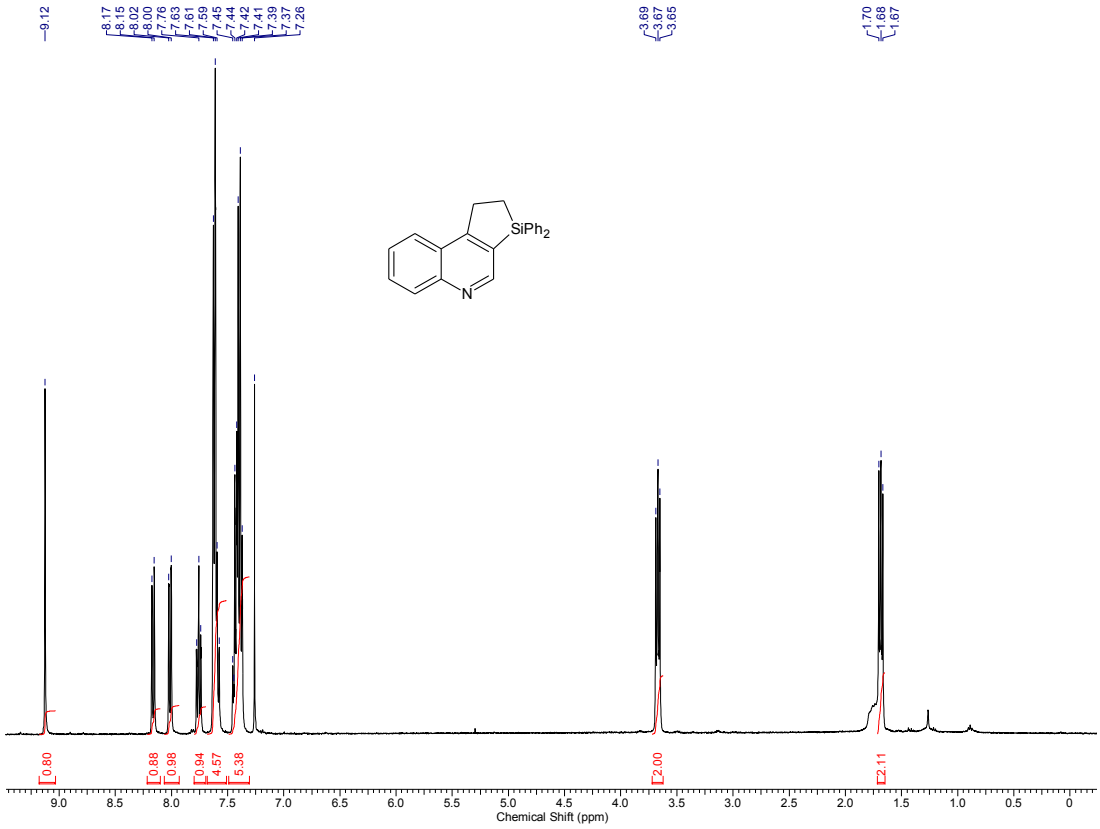

172.3
165.9
143.4
135.1
134.9
129.7
128.0
120.3
108.9
53.3
34.0
8.6
Ph
Ph
Si
H3C
O
N
Chemical Shift (ppm)

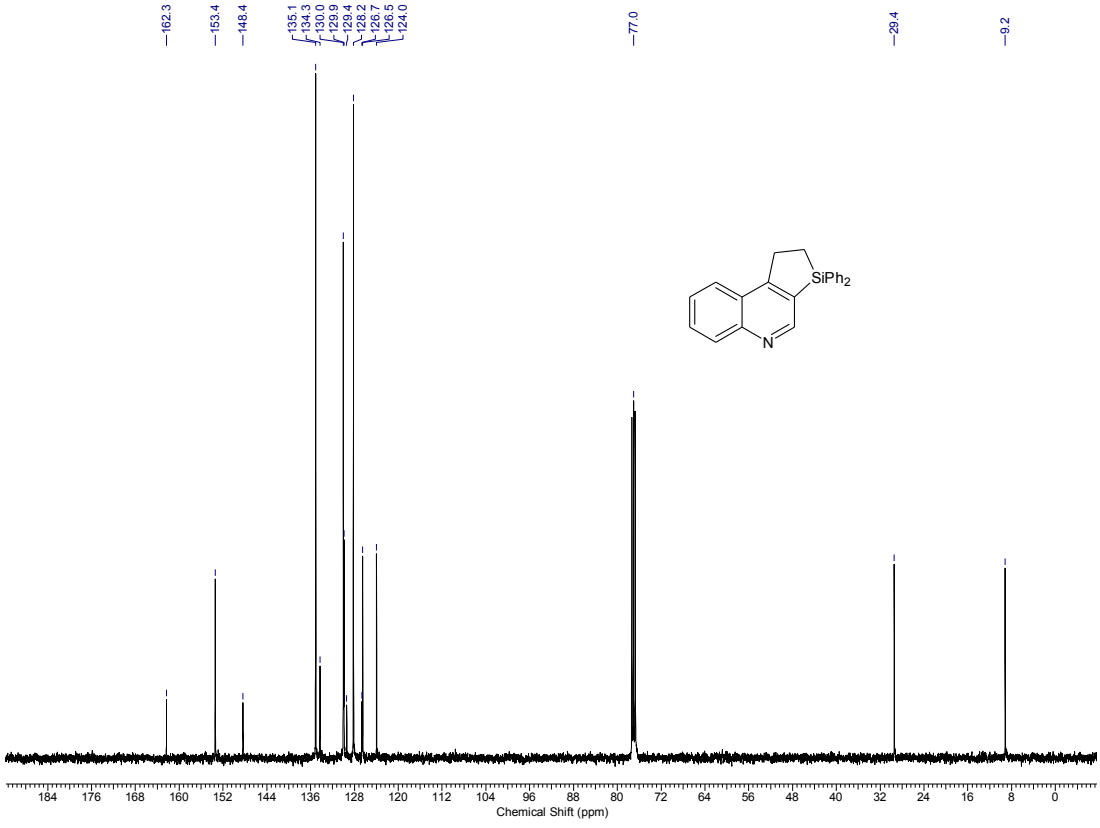
131m:


8.14
8.13
7.57
7.56
7.55
7.53
7.46
7.45
7.42
7.41
7.39
7.26
3.46
3.44
3.43
1.68
1.67
1.65
SiPh2
F3C
N
0.93
4.70
5.61
2.00
2.26
Chemical Shift (ppm)

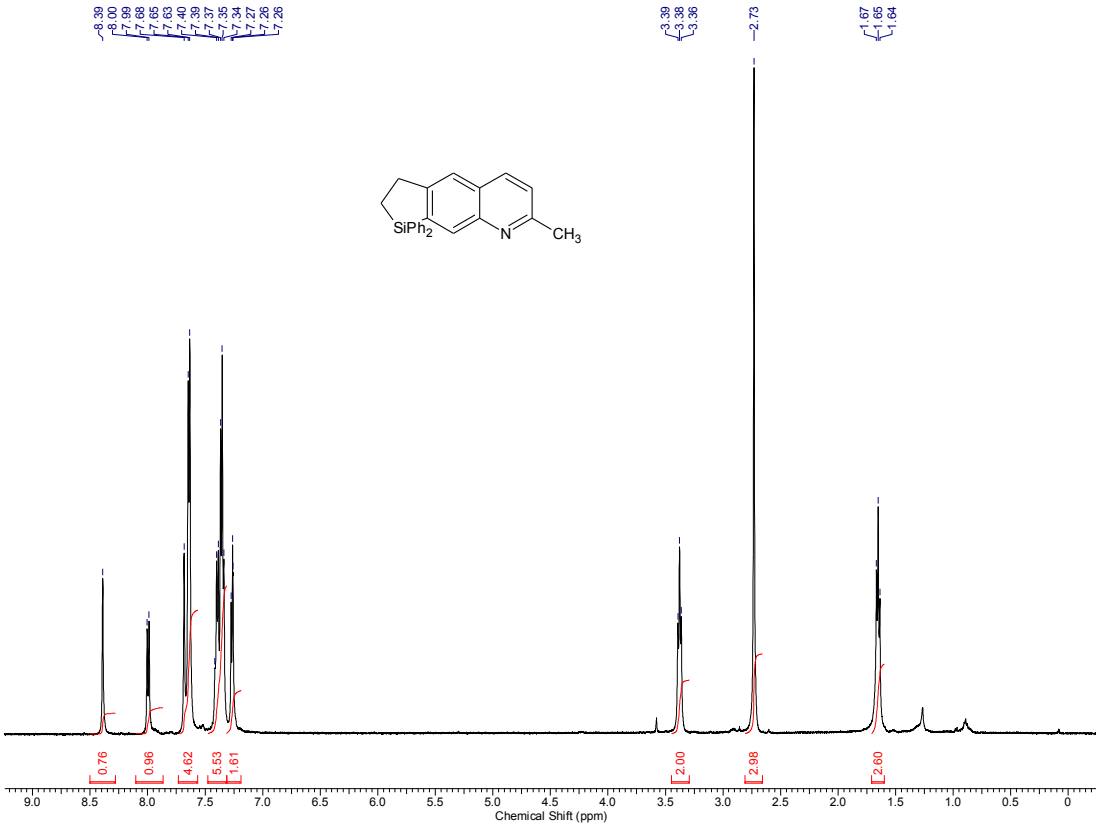

173.7
149.5
149.2
143.1
135.0
134.5
133.1
130.3
128.3
122.8
120.6
117.7
77.0
34.0
8.7
SiPh2
F3C
N
Chemical Shift (ppm)

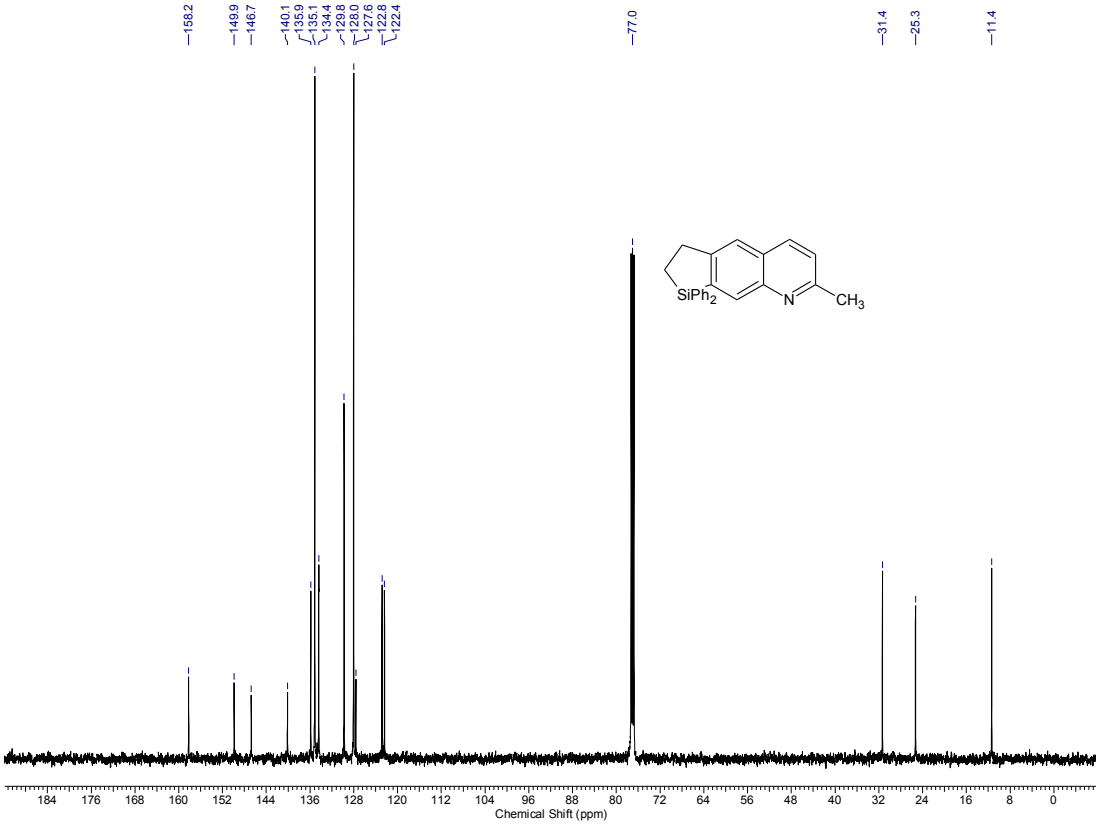
131n:


9.12
8.17
8.15
8.02
8.00
7.76
7.63
7.61
7.59
7.45
7.44
7.42
7.41
7.39
7.37
7.26
3.69
3.67
3.65
1.70
1.68
1.67
SiPh2
N
0.80
0.88
0.98
0.94
4.57
5.38
2.00
2.11
Chemical Shift (ppm)

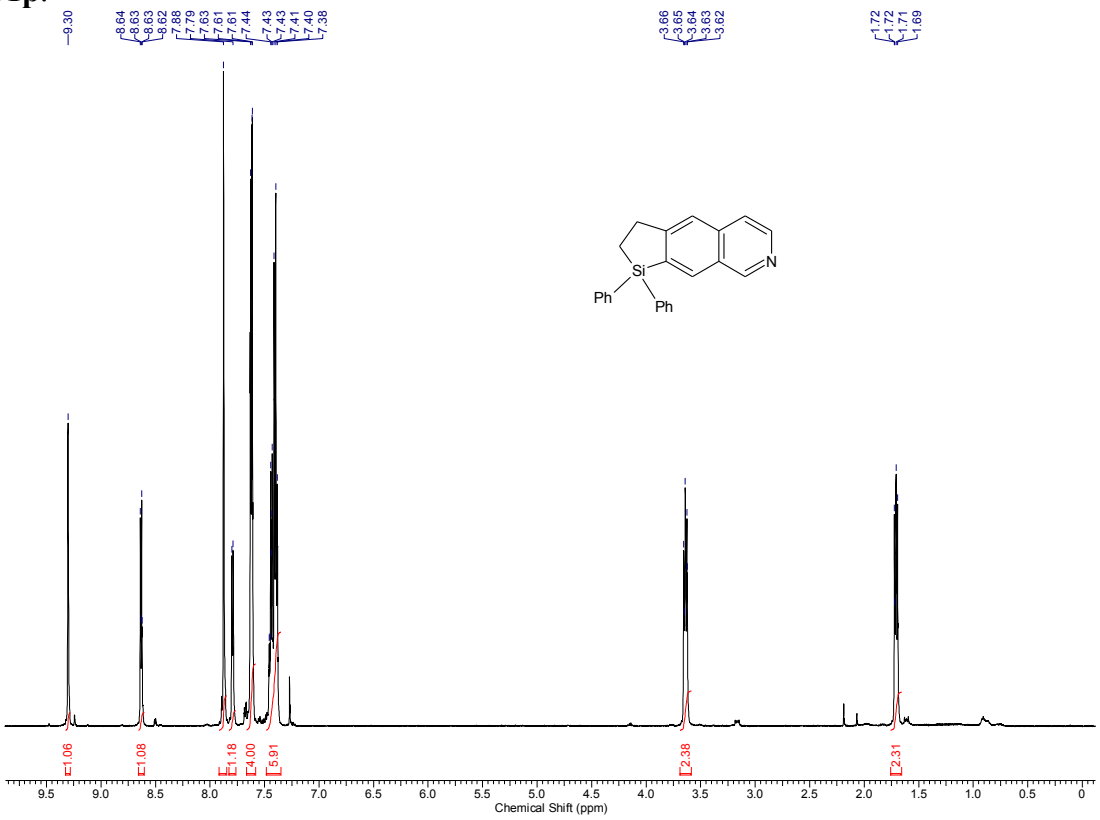

162.3
153.4
148.4
135.1
134.3
130.0
129.9
129.4
128.2
126.7
126.5
124.0
77.0
29.4
9.2
SiPh2
N
Chemical Shift (ppm)

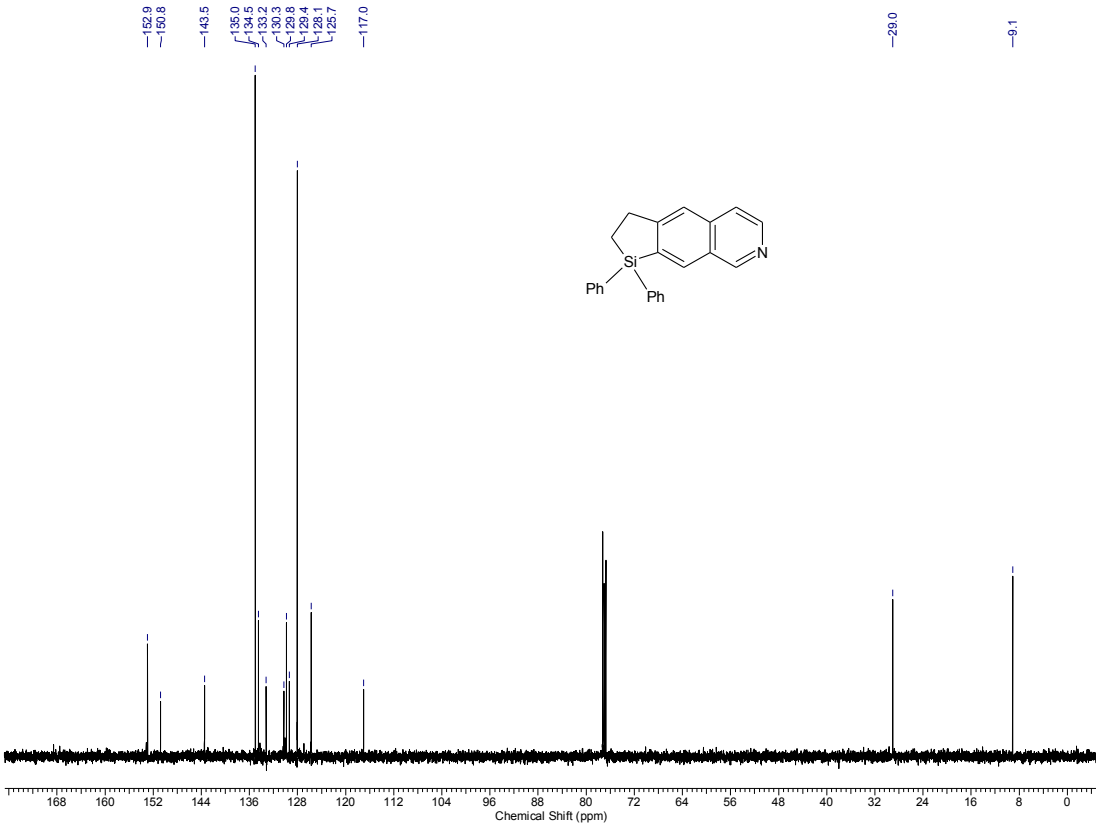
131o:


8.39
8.00
7.89
7.68
7.65
7.63
7.40
7.39
7.37
7.35
7.34
7.27
7.26
7.25
3.39
3.38
3.36
2.73
1.67
1.65
1.64
SiPh2
N
CH3
0.76
0.96
4.62
5.53
1.61
2.00
2.98
2.60
Chemical Shift (ppm)

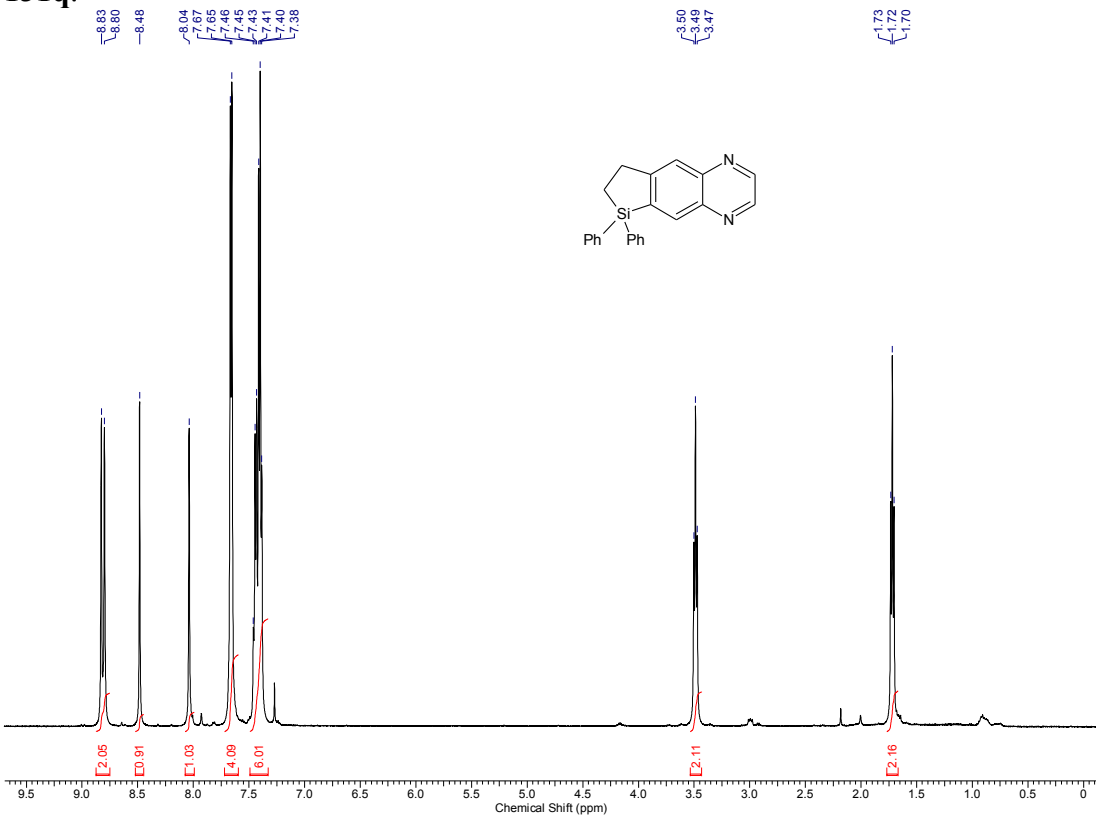

158.2
149.9
146.7
140.1
135.9
135.1
134.4
129.8
128.0
127.6
122.8
122.4
77.0
31.4
25.3
11.4
SiPh2
N
CH3
Chemical Shift (ppm)

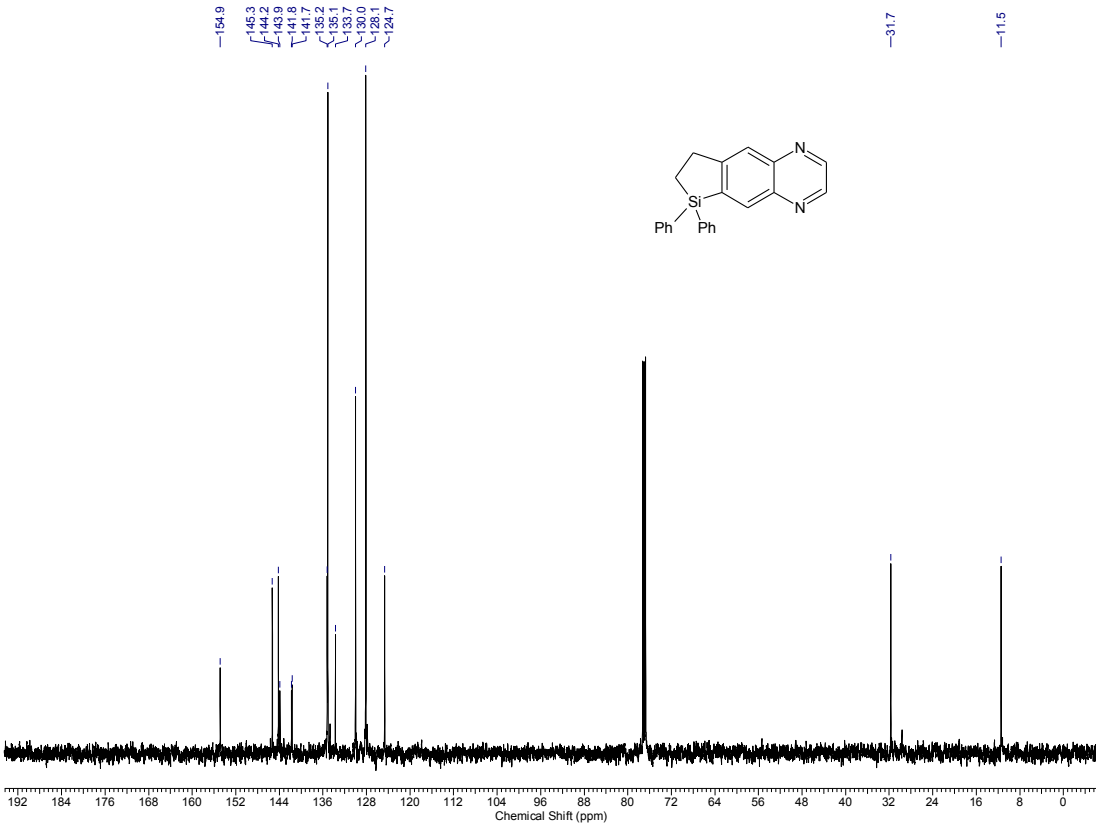
131p:


9.30
8.64
8.63
8.63
8.62
7.88
7.79
7.63
7.61
7.61
7.44
7.43
7.43
7.41
7.40
7.38
3.66
3.65
3.64
3.63
3.62
1.72
1.72
1.71
1.69
Si
N
Ph
Ph
1.06
1.08
1.18
4.00
5.91
2.38
2.31
Chemical Shift (ppm)

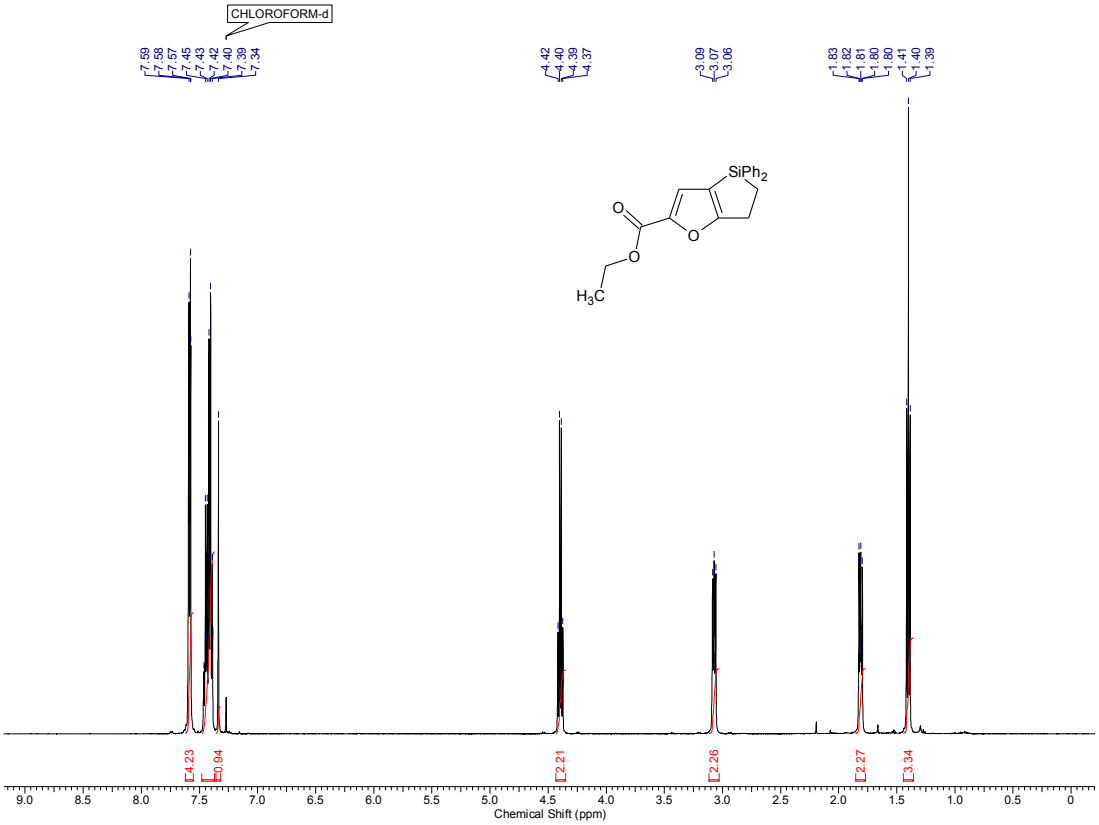

152.9
150.8
143.5
135.0
134.5
133.2
130.3
129.8
129.4
128.1
125.7
117.0
29.0
9.1
Si
N
Ph
Ph
Chemical Shift (ppm)

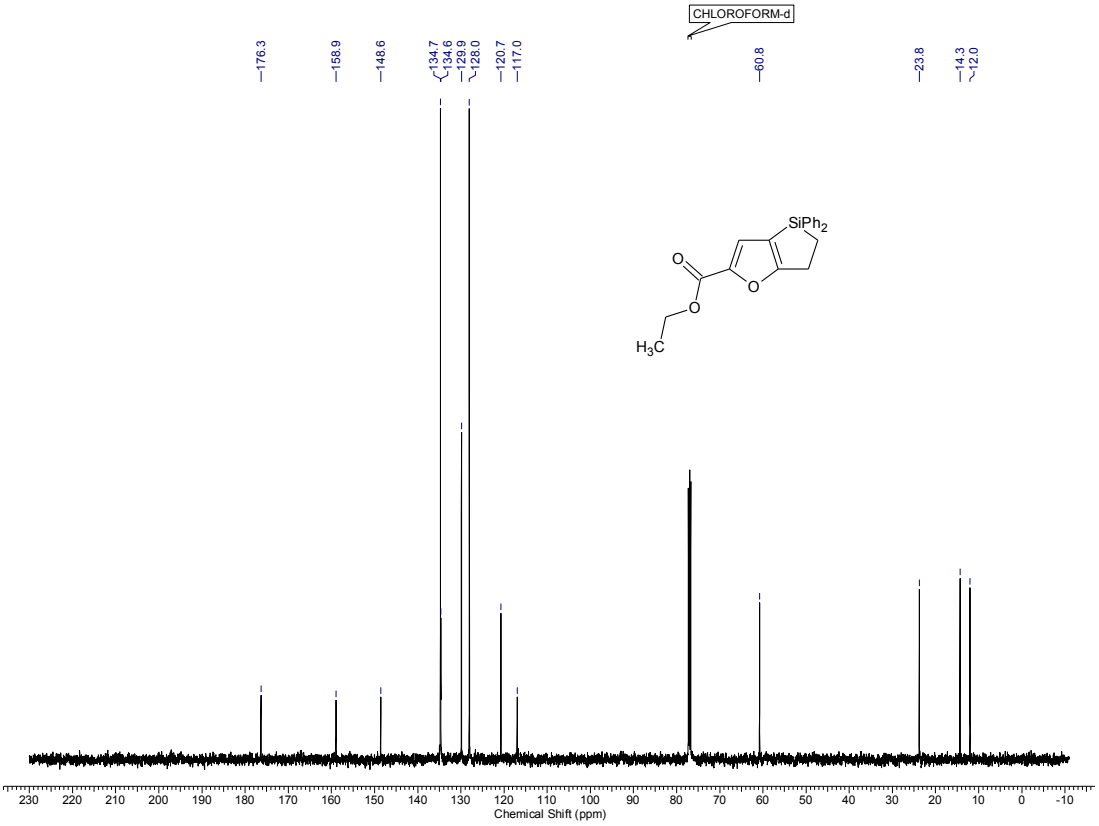
131q:


8.83
8.80
8.48
8.04
7.67
7.65
7.46
7.45
7.43
7.41
7.40
7.38
3.50
3.49
3.47
1.73
1.72
1.70
N
Si
N
Ph
Ph
2.05
0.91
1.03
4.09
6.01
2.11
2.16
Chemical Shift (ppm)

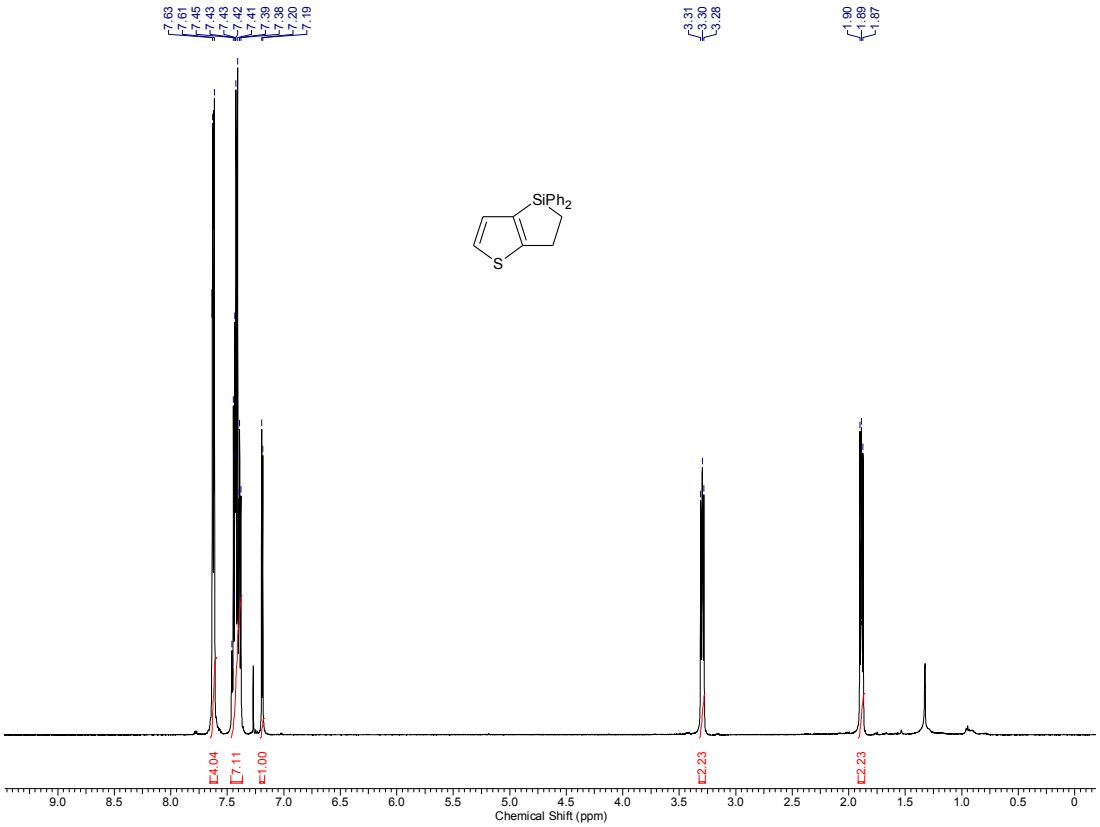

154.9
145.3
144.2
143.9
141.8
141.7
135.2
135.1
133.7
130.0
128.1
124.7
31.7
11.5
N
Si
N
Ph
Ph
Chemical Shift (ppm)

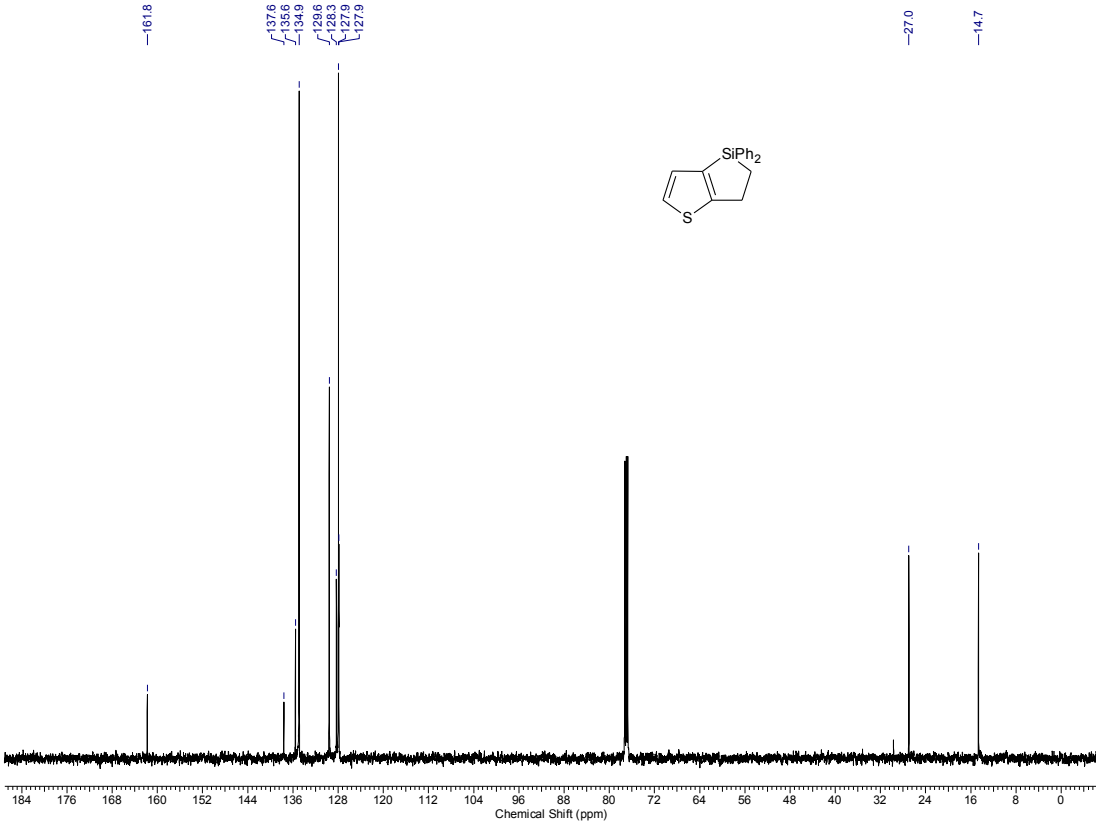
131aa:


CHLOROFORM-d
7.59
7.58
7.57
7.45
7.43
7.42
7.40
7.39
7.34
4.42
4.40
4.39
4.37
3.09
3.07
3.06
1.83
1.82
1.81
1.80
1.80
1.41
1.40
1.39
SiPh2
O
O
O
H3C
4.23
0.94
2.21
2.26
2.27
3.34
Chemical Shift (ppm)

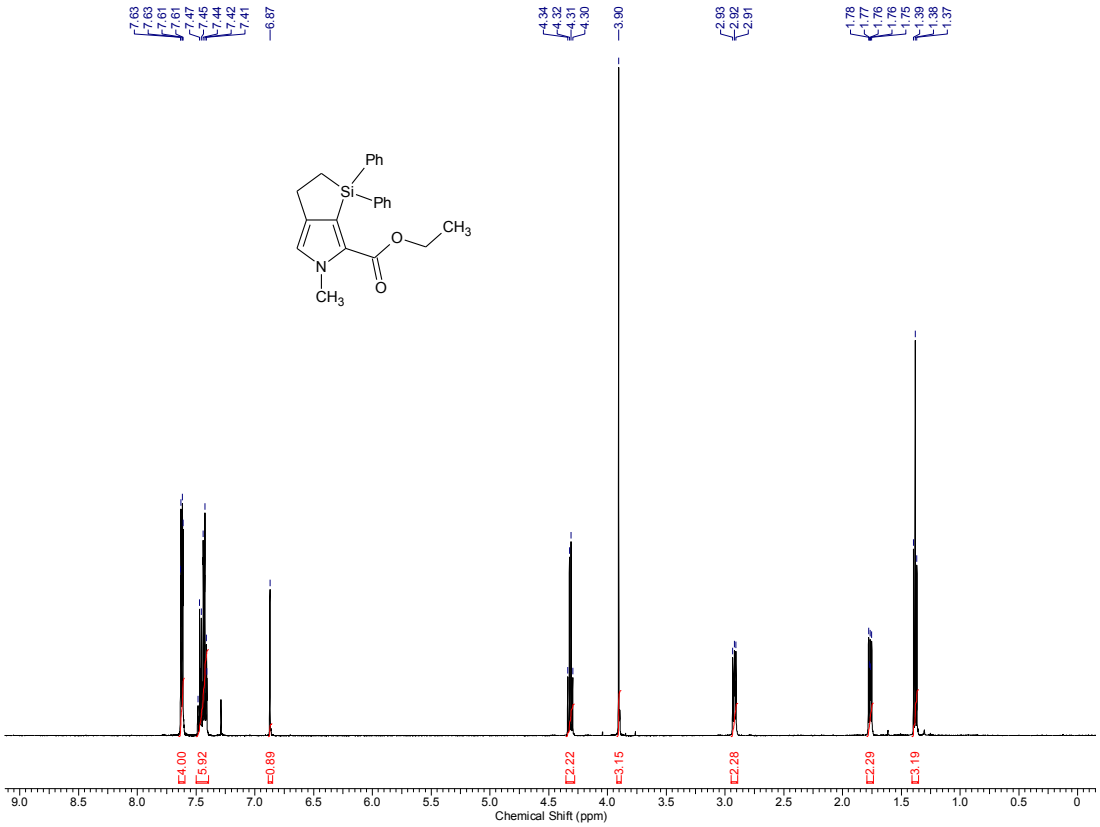

CHLOROFORM-d
176.3
158.9
148.6
134.7
134.6
129.9
128.0
120.7
117.0
60.8
23.8
14.3
12.0
SiPh2
O
O
O
H3C
Chemical Shift (ppm)

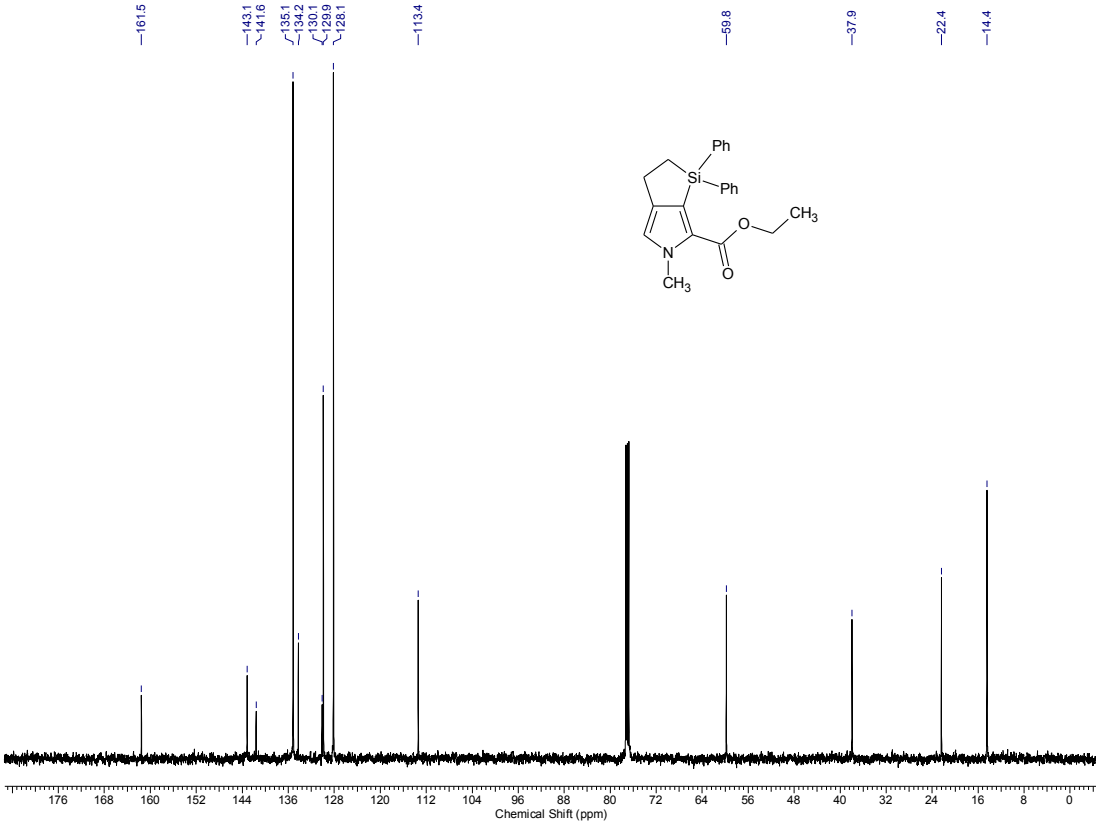
131bb:


7.63
7.61
7.45
7.43
7.43
7.42
7.41
7.38
7.20
7.19
3.31
3.30
3.28
1.90
1.89
1.87
SiPh2
S
4.04
7.11
1.00
2.23
2.23
Chemical Shift (ppm)

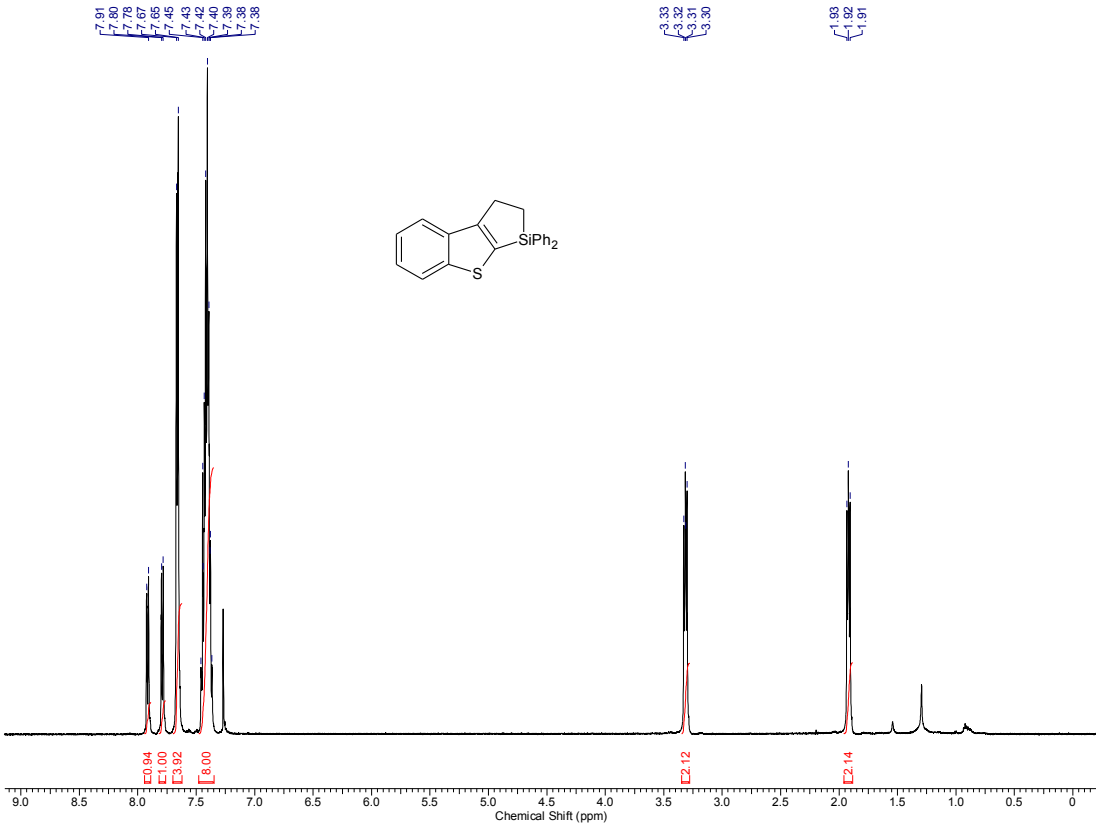

161.8
137.6
135.6
134.9
129.6
128.3
127.9
127.9
27.0
14.7
SiPh2
S
Chemical Shift (ppm)

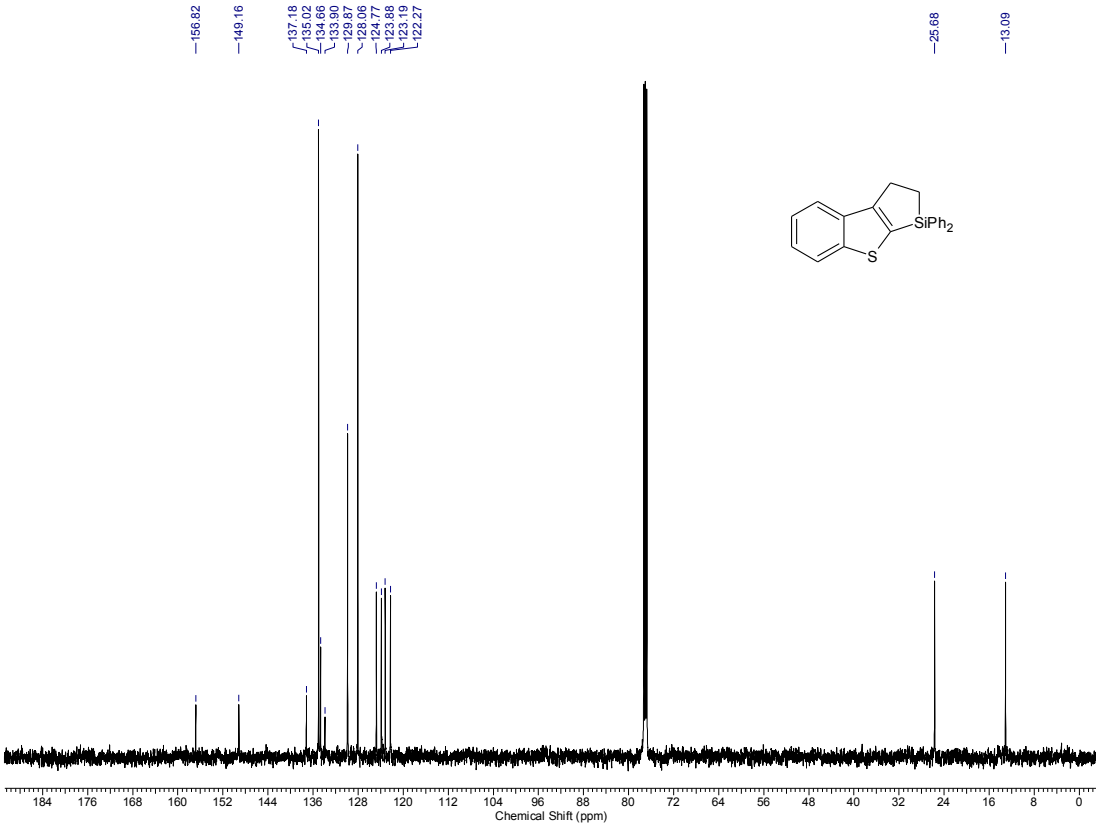
131cc:


7.63
7.63
7.61
7.61
7.47
7.45
7.44
7.42
7.41
6.87
4.34
4.32
4.31
4.30
3.90
2.93
2.92
2.91
1.78
1.77
1.76
1.76
1.75
1.39
1.38
1.37
Ph
Si
Ph
O
CH3
N
CH3
O
E4.00
E5.92
E0.89
E2.22
E3.15
E2.28
E2.29
E3.19
Chemical Shift (ppm)

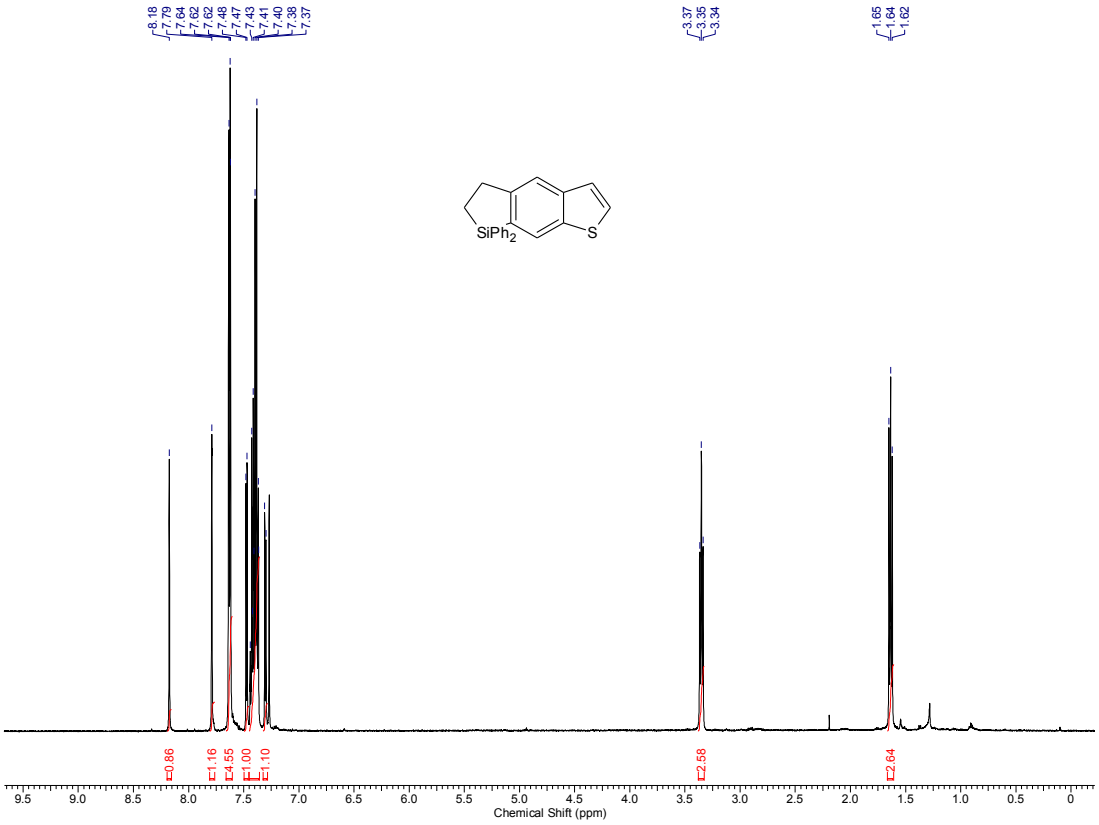

161.5
143.1
141.6
135.1
134.2
130.1
129.9
128.1
113.4
59.8
37.9
22.4
14.4
Ph
Si
Ph
O
CH3
N
CH3
O
Chemical Shift (ppm)

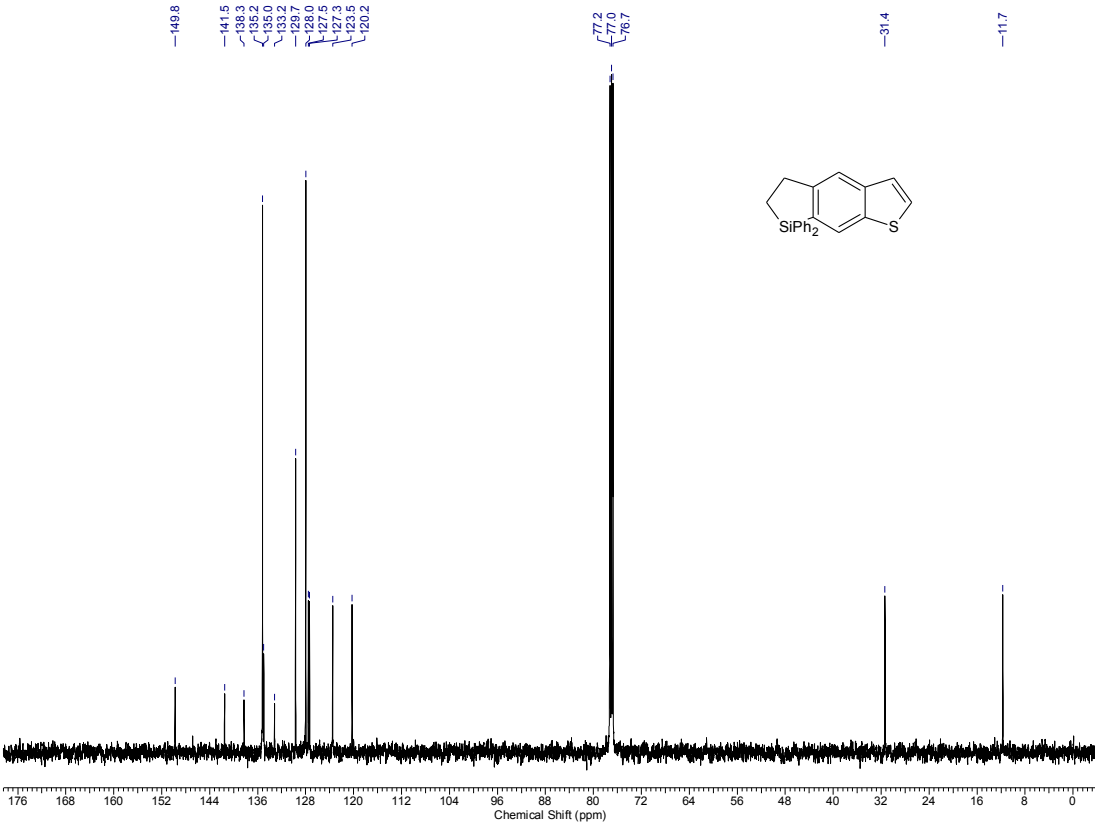
131dd:


7.91
7.80
7.78
7.67
7.65
7.45
7.43
7.42
7.40
7.39
7.38
7.38
3.33
3.32
3.31
3.30
1.93
1.92
1.91
SiPh2
S
0.94
1.00
3.92
8.00
2.12
2.14
Chemical Shift (ppm)

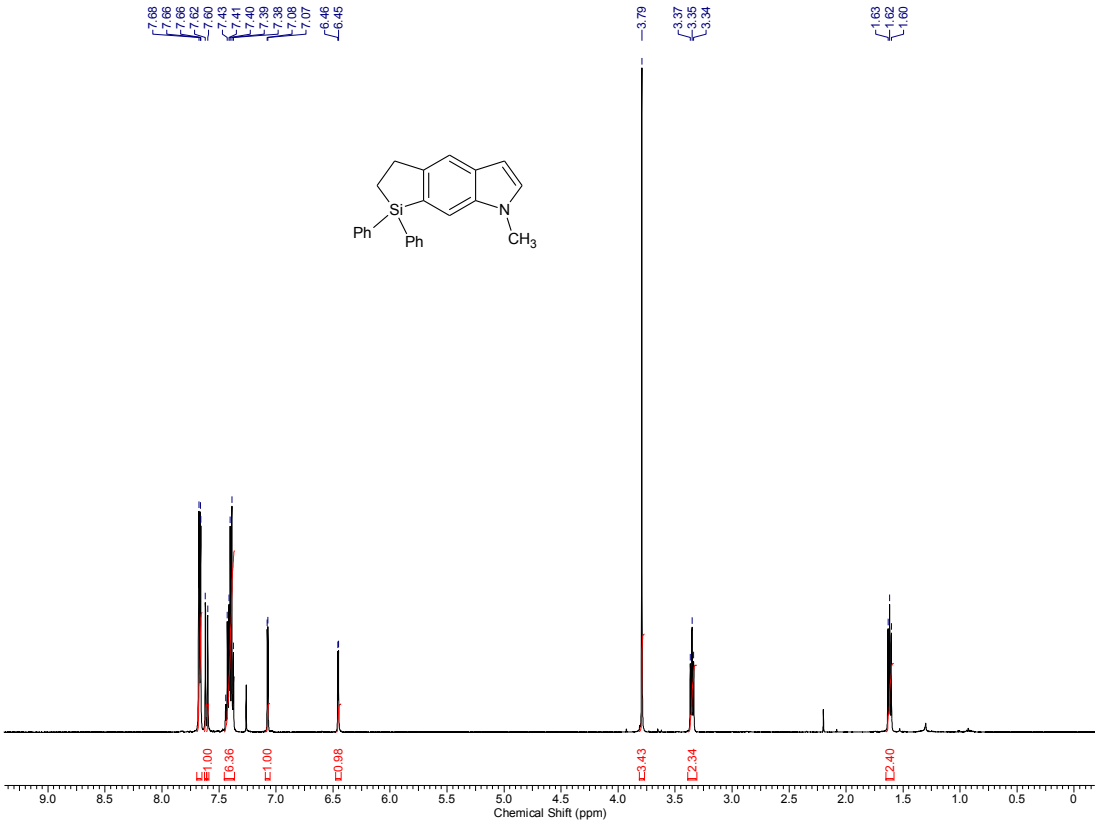

156.82
149.16
137.18
135.02
134.66
133.90
129.87
128.06
124.77
123.88
123.19
122.27
25.68
13.09
SiPh2
S
Chemical Shift (ppm)

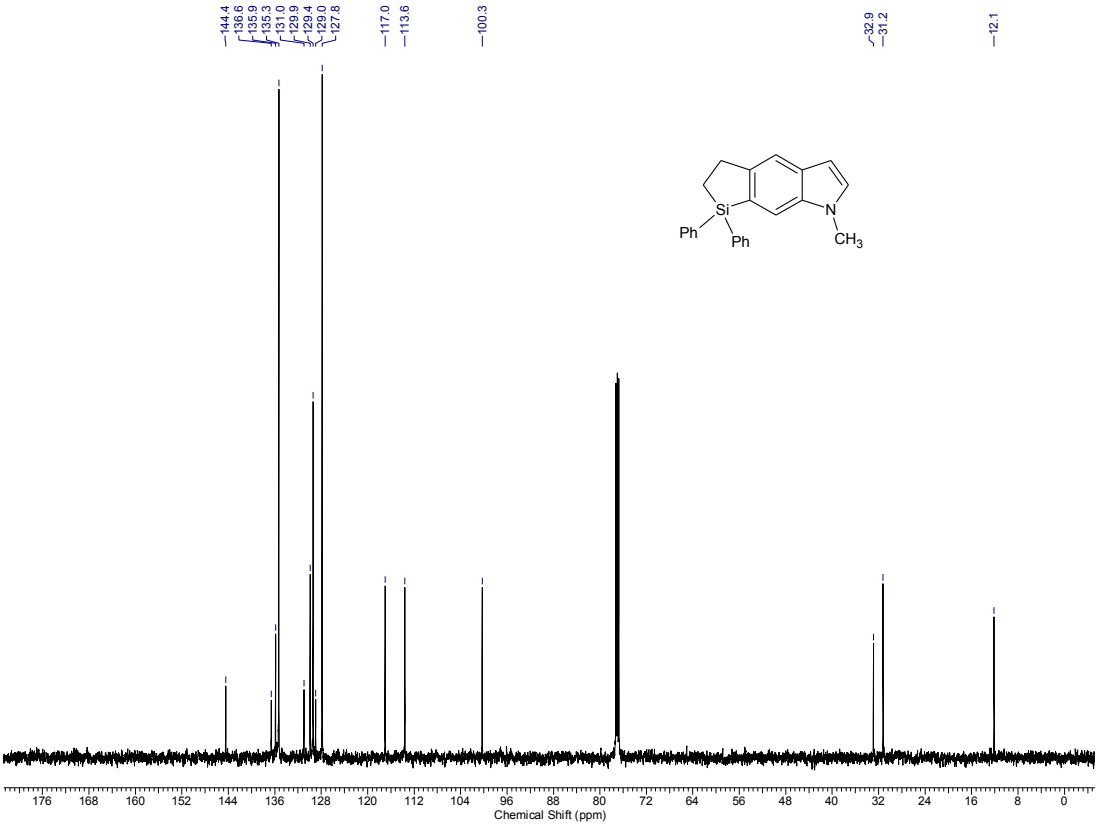
131ee:


8.18
7.79
7.64
7.62
7.62
7.48
7.47
7.43
7.41
7.40
7.39
7.37
3.37
3.35
3.34
1.65
1.64
1.62
SiPh2
S
0.86
1.16
4.55
1.00
1.10
2.58
2.64
Chemical Shift (ppm)

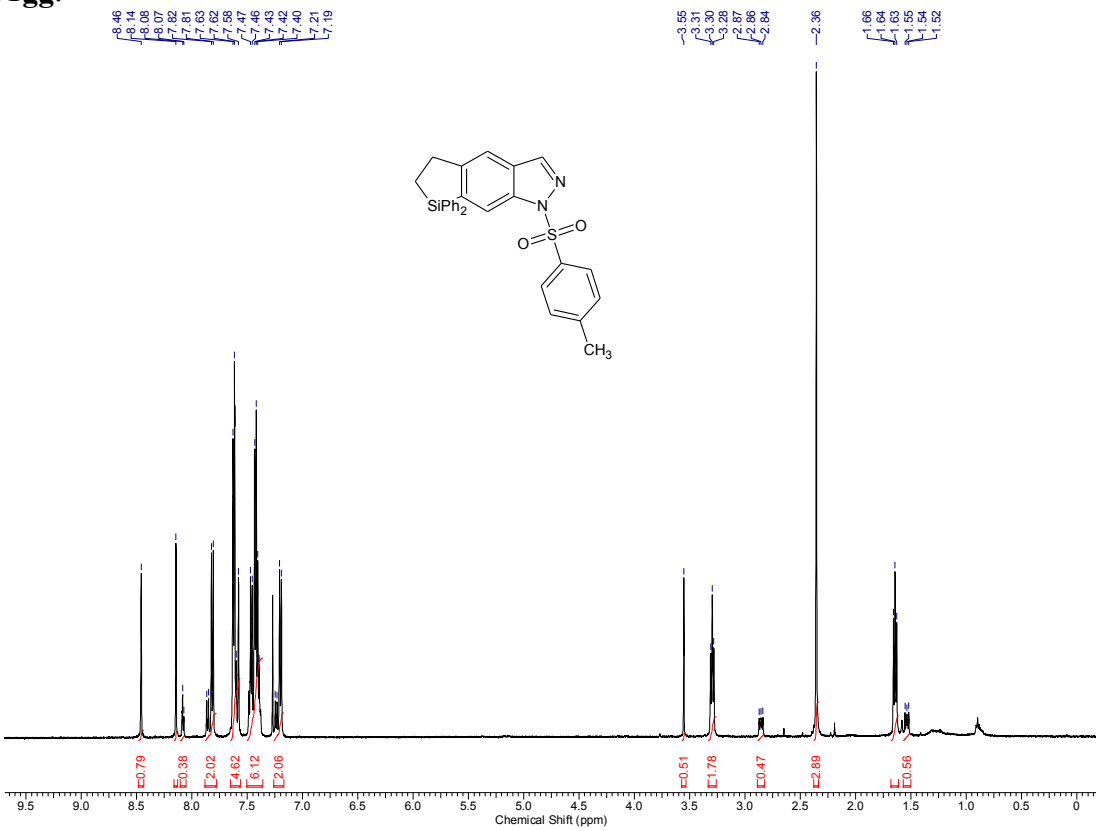

149.8
141.5
138.3
135.2
135.0
133.2
129.7
128.0
127.5
127.3
123.5
120.2
77.2
77.0
76.7
31.4
11.7
SiPh2
S
Chemical Shift (ppm)

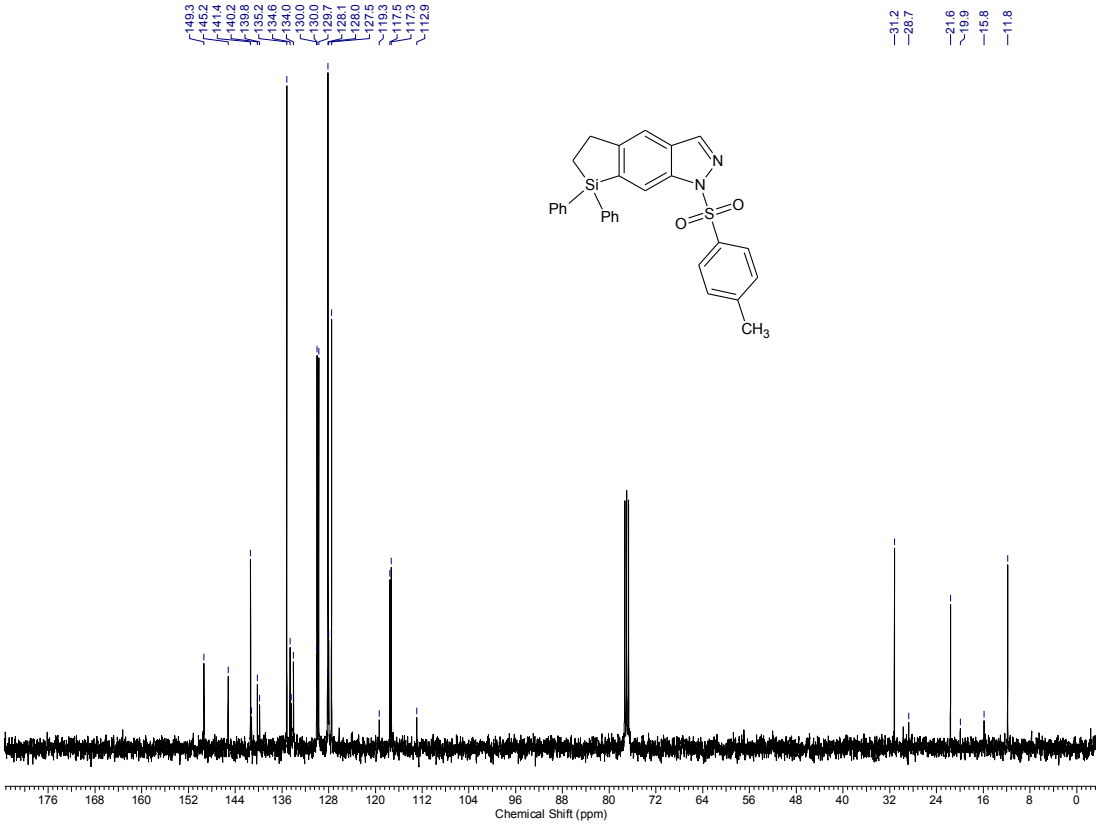
131ff:


7.68
7.66
7.66
7.62
7.60
7.43
7.41
7.40
7.39
7.38
7.08
7.07
6.46
6.45
3.79
3.37
3.35
3.34
1.63
1.62
1.60
Si
Ph
Ph
N
CH3
1.00
6.36
1.00
0.98
3.43
2.34
2.40
Chemical Shift (ppm)

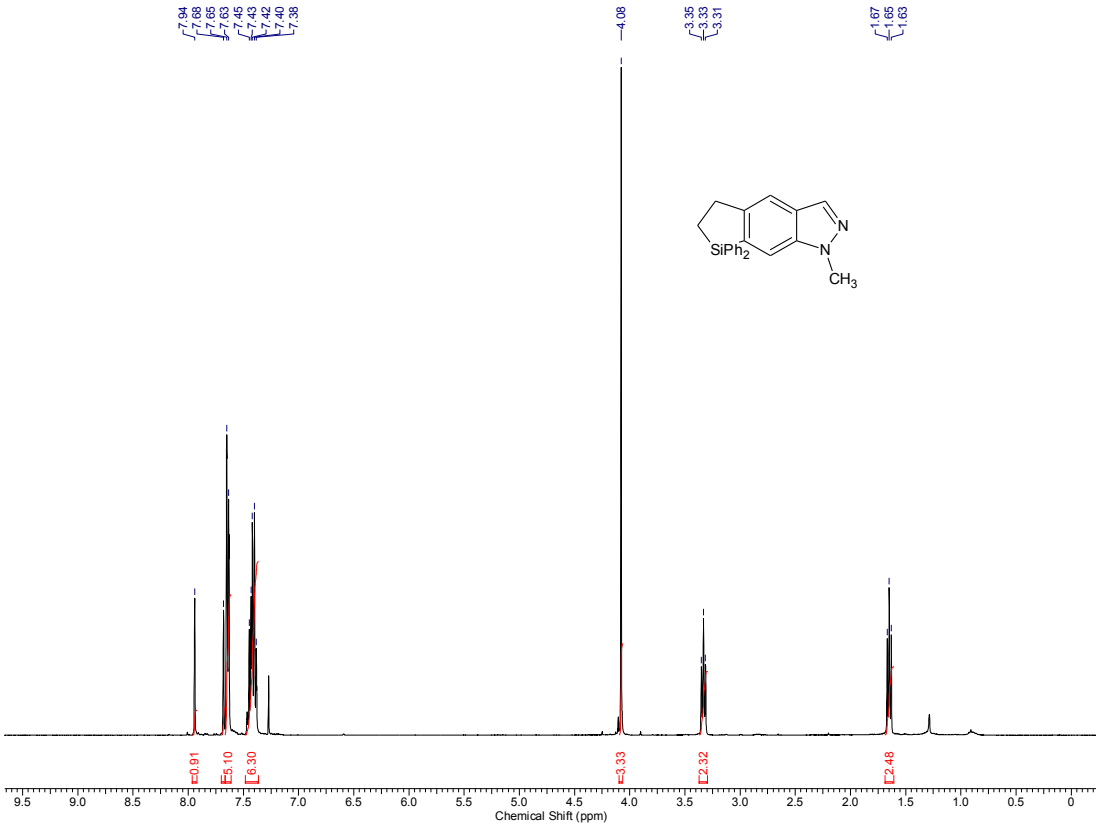

144.4
136.6
135.9
135.3
131.0
129.9
129.4
129.0
127.8
117.0
113.6
100.3
32.9
31.2
12.1
Si
Ph
Ph
N
CH3
Chemical Shift (ppm)

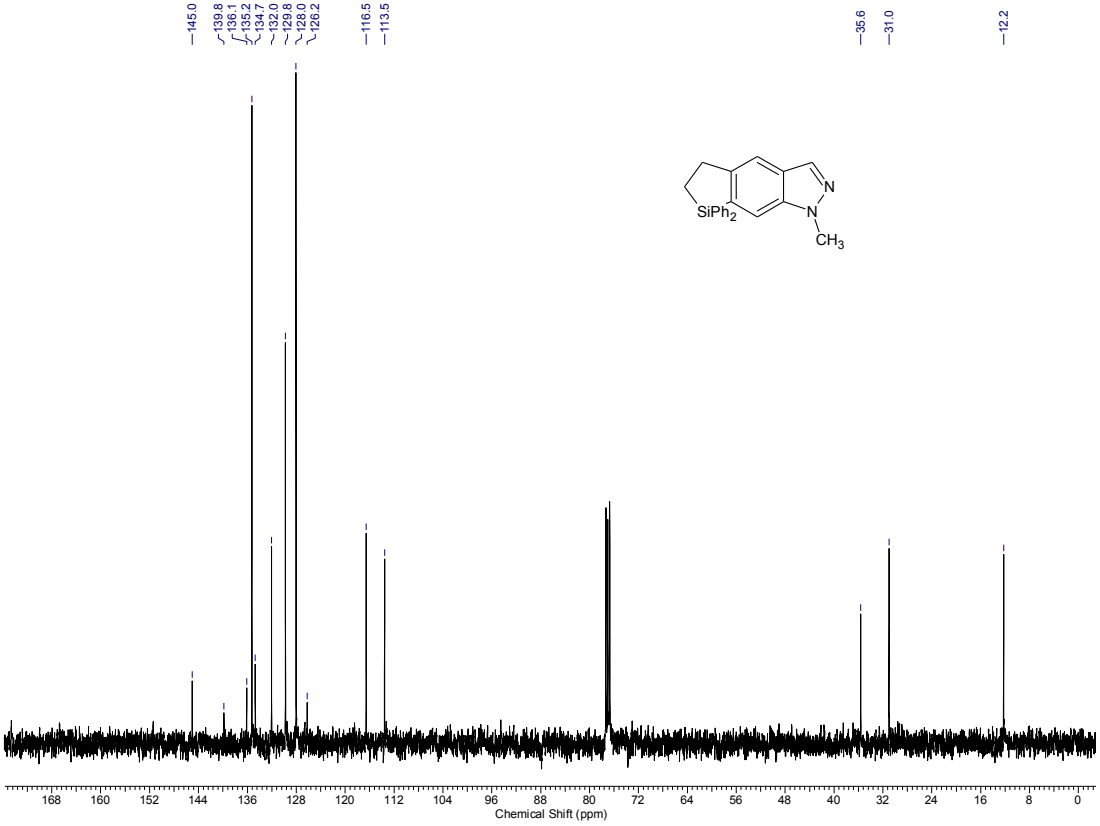
131gg:


8.46
8.14
8.08
8.07
7.82
7.81
7.63
7.62
7.58
7.47
7.46
7.43
7.42
7.40
7.21
7.19
3.55
3.31
3.30
3.28
2.87
2.86
2.84
2.36
1.66
1.64
1.63
1.55
1.54
1.52
SiPh2
N
N
S
O
O
CH3
0.79
0.38
2.02
4.62
6.12
2.06
0.51
1.78
0.47
2.89
0.56
Chemical Shift (ppm)

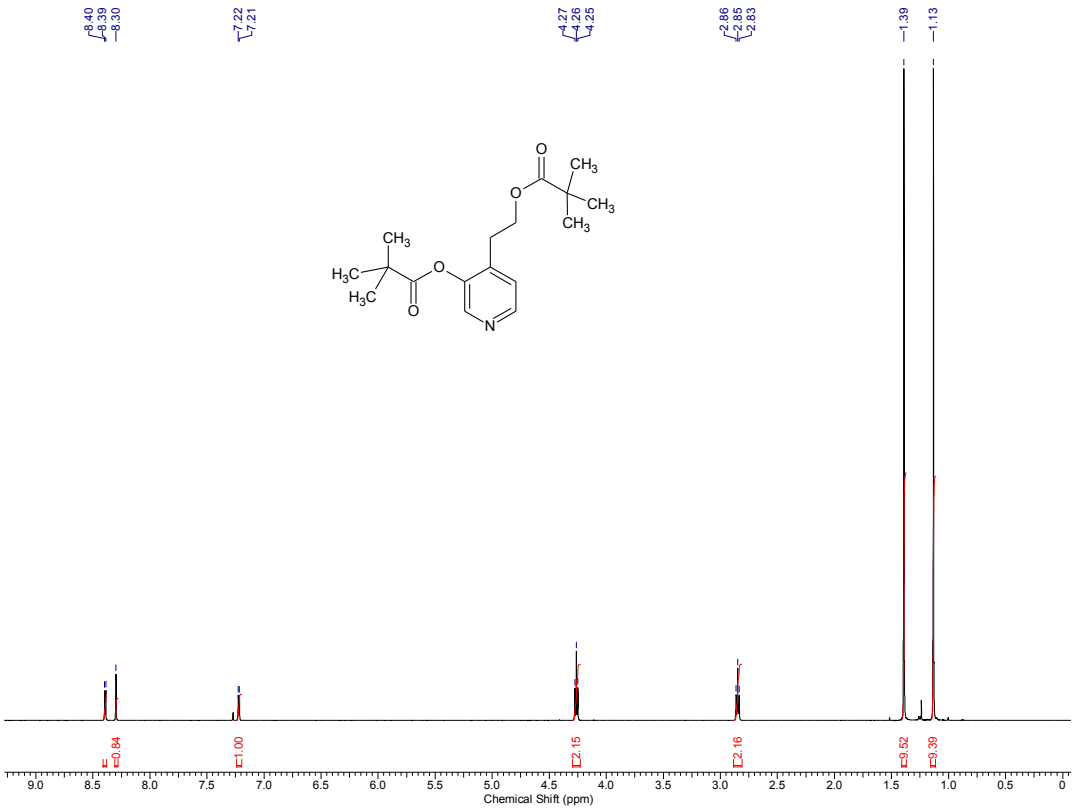

149.3
145.2
141.4
140.2
139.8
135.2
134.6
134.0
130.0
130.0
129.7
128.1
128.0
127.5
119.3
117.5
117.3
112.9
31.2
28.7
21.6
19.9
15.8
11.8
Si
Ph
Ph
N
N
S
O
O
CH3
Chemical Shift (ppm)

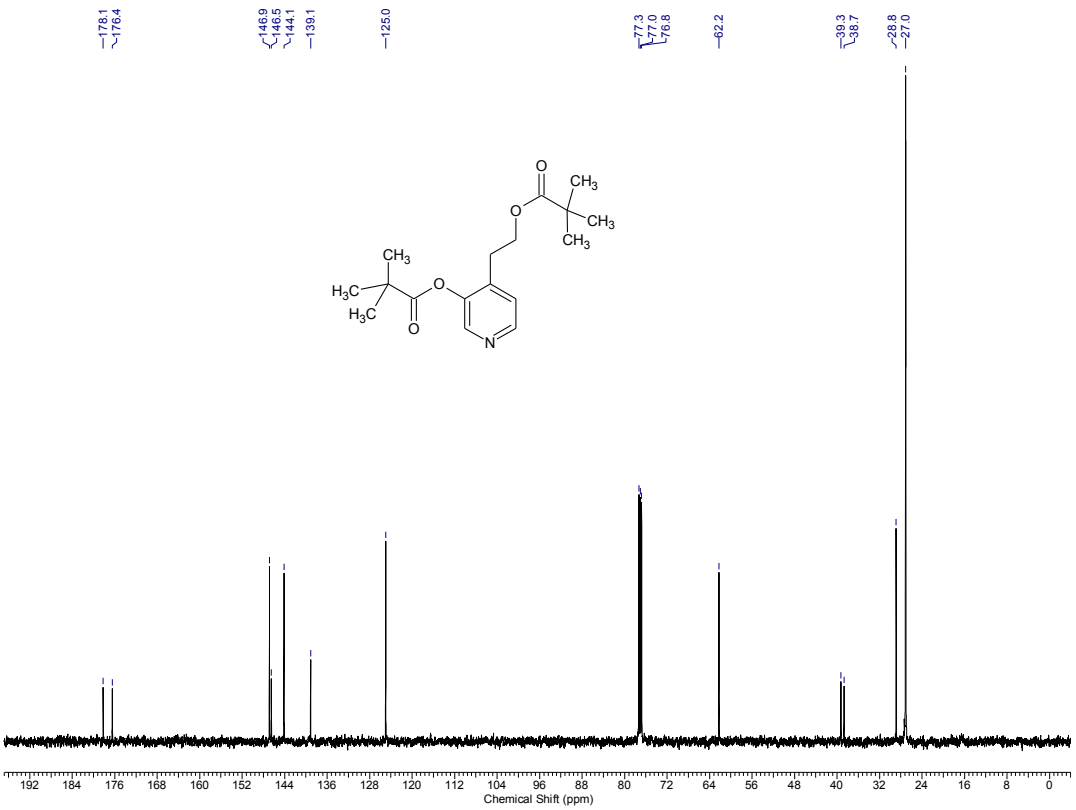
131hh:


7.94
7.68
7.65
7.63
7.45
7.43
7.42
7.40
7.38
4.08
3.35
3.33
3.31
1.67
1.65
1.63
SiPh2
N
N
CH3
I=0.91
I=5.10
I=6.30
I=3.33
I=2.32
I=2.48
Chemical Shift (ppm)

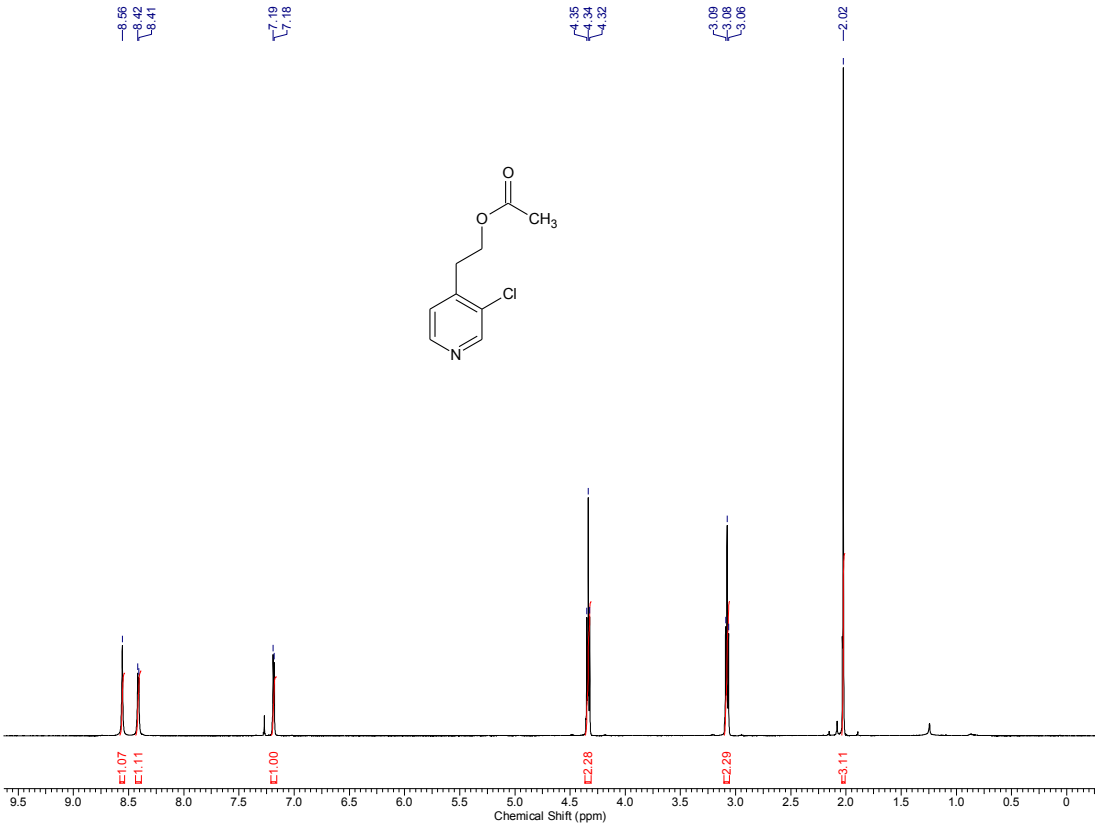

145.0
139.8
136.1
135.2
134.7
132.0
129.8
128.0
126.2
116.5
113.5
35.6
31.0
12.2
SiPh2
N
N
CH3
Chemical Shift (ppm)

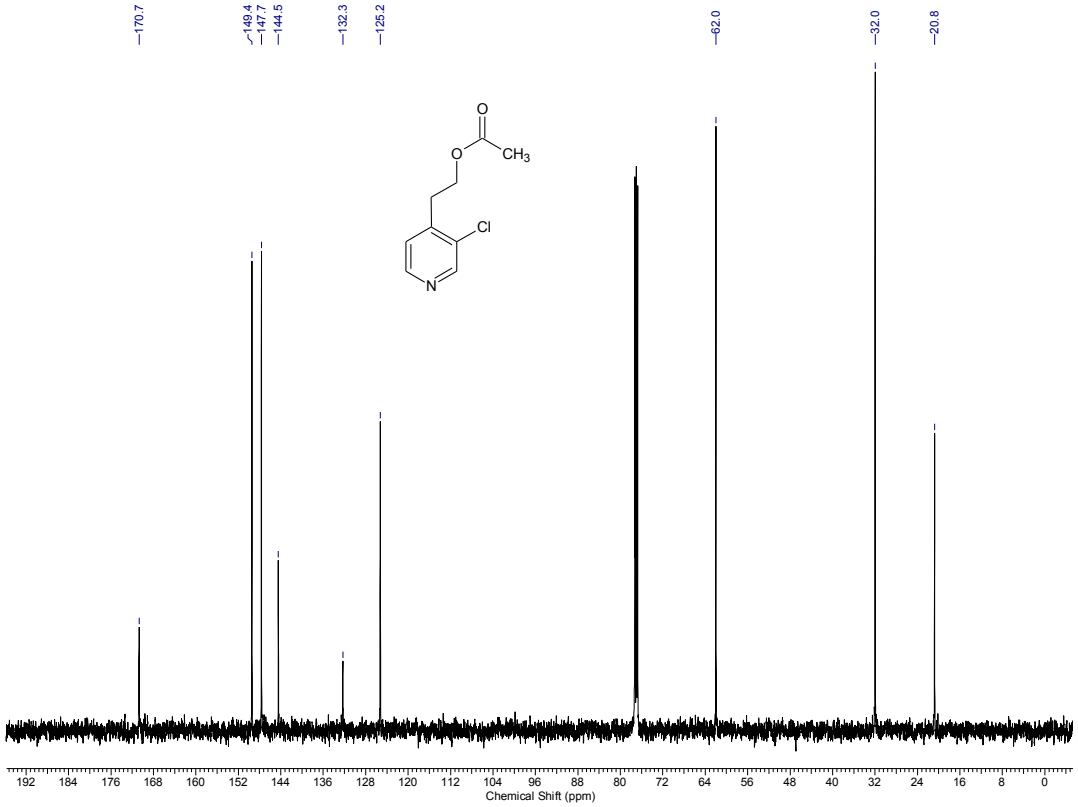
132:


8.40
8.39
8.30
7.22
7.21
4.27
4.26
4.25
2.86
2.85
2.83
1.39
1.13
0.84
1.00
2.15
2.16
9.52
9.39
Chemical Shift (ppm)

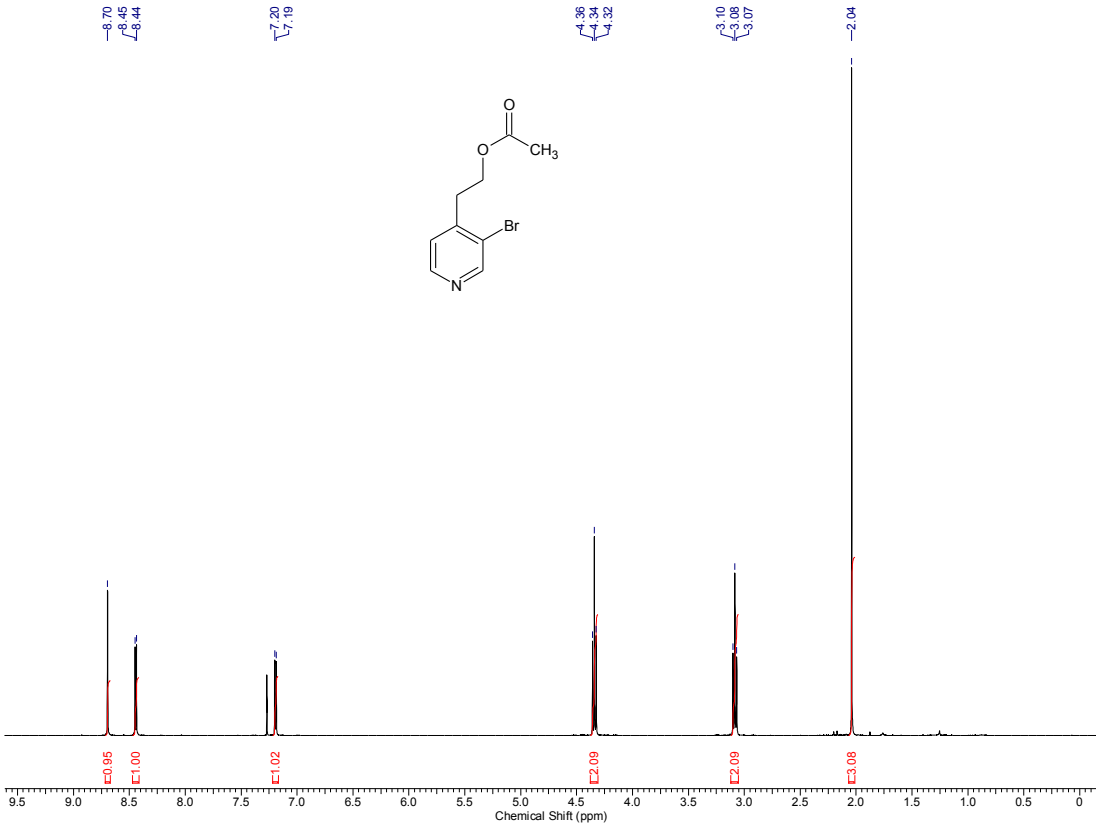

178.1
176.4
146.9
146.5
144.1
139.1
125.0
77.3
77.0
76.8
62.2
39.3
38.7
28.8
27.0
Chemical Shift (ppm)

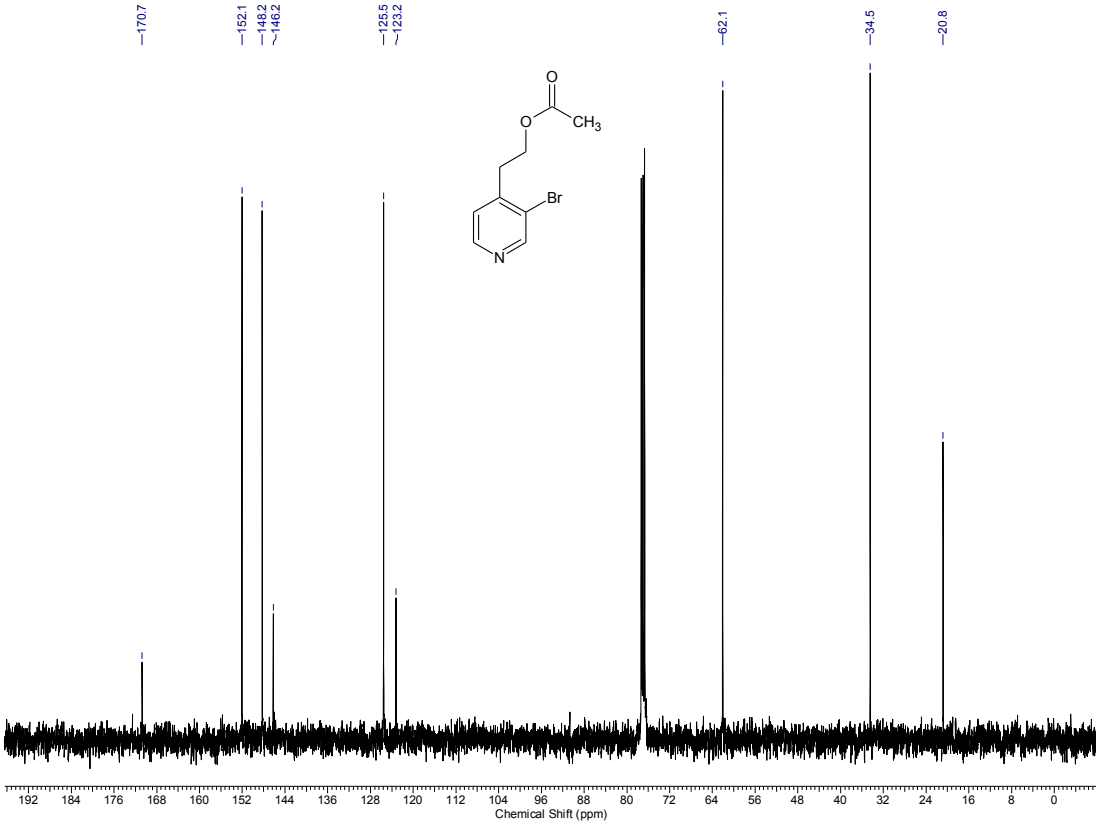
134a:


8.56
8.42
8.41
7.19
7.18
4.35
4.34
4.32
3.09
3.08
3.06
2.02
O
O
CH3
Cl
N
1.07
1.11
1.00
2.28
2.29
3.11
Chemical Shift (ppm)

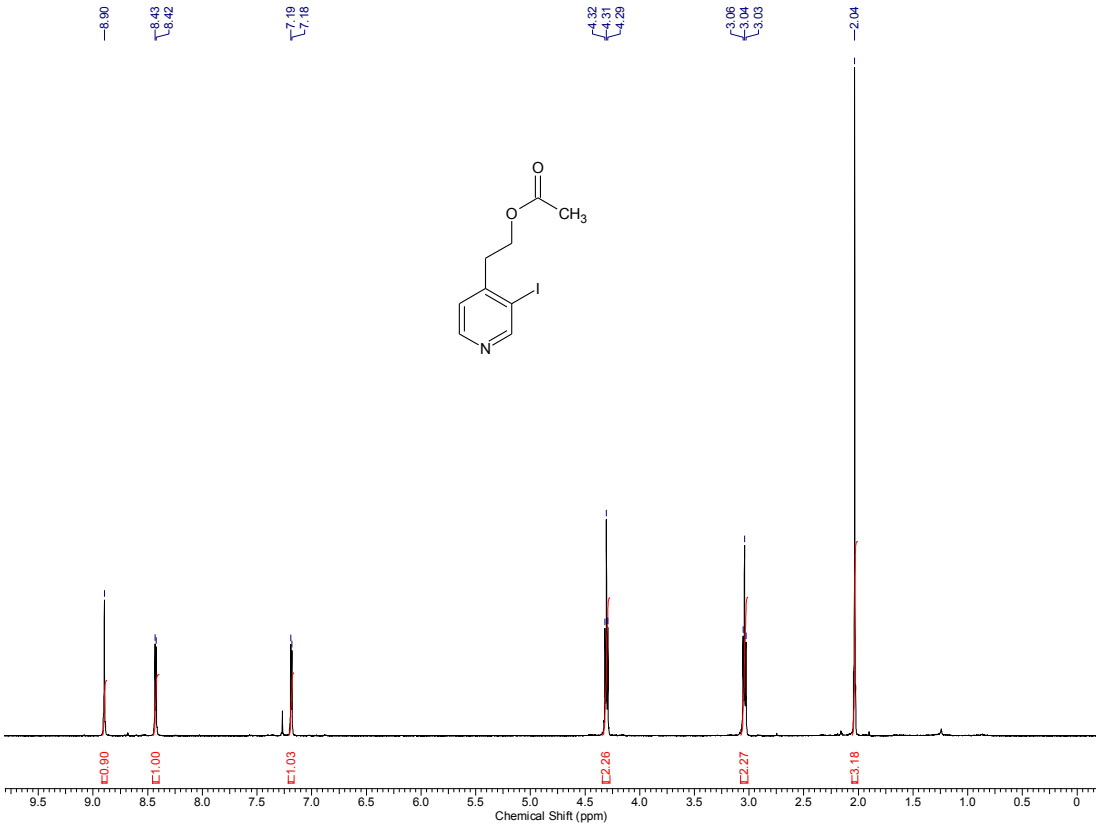

170.7
149.4
147.7
144.5
132.3
125.2
62.0
32.0
20.8
O
O
CH3
Cl
N
Chemical Shift (ppm)

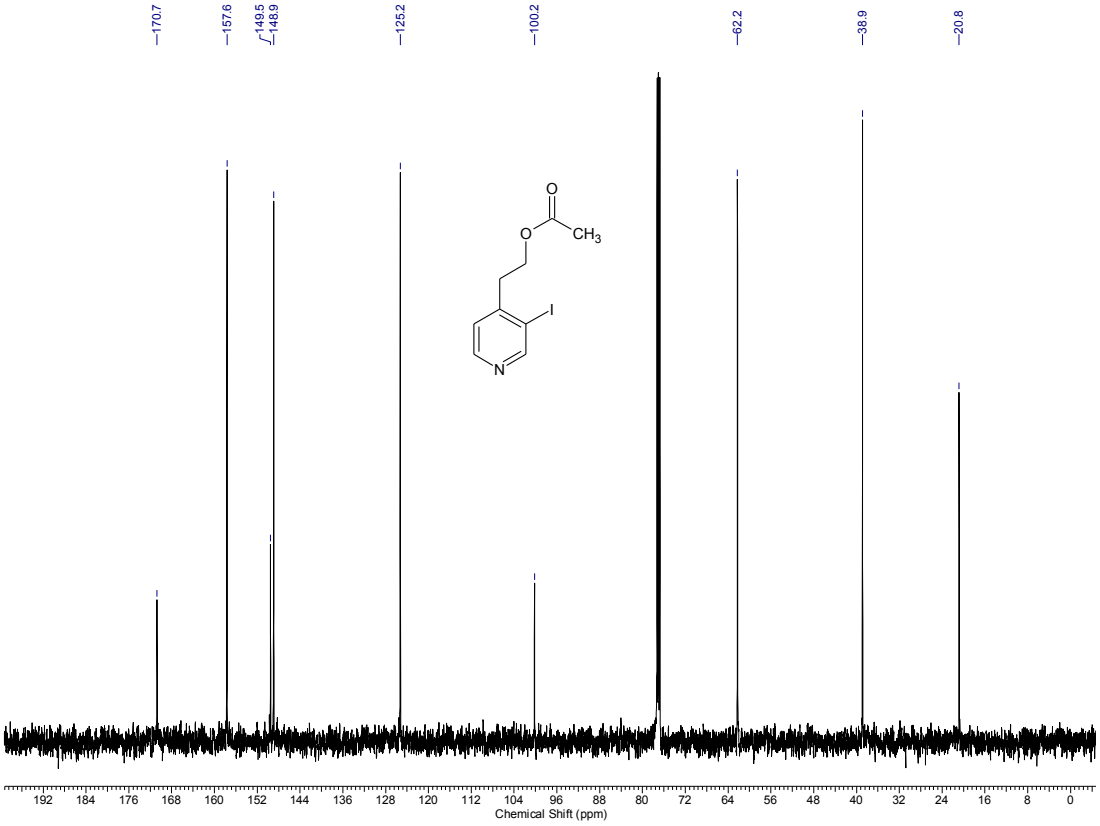
134b:


8.70
8.45
8.44
7.20
7.19
4.36
4.34
4.32
3.10
3.08
3.07
2.04
O
O
CH3
Br
N
0.95
1.00
1.02
2.09
2.09
3.08
Chemical Shift (ppm)

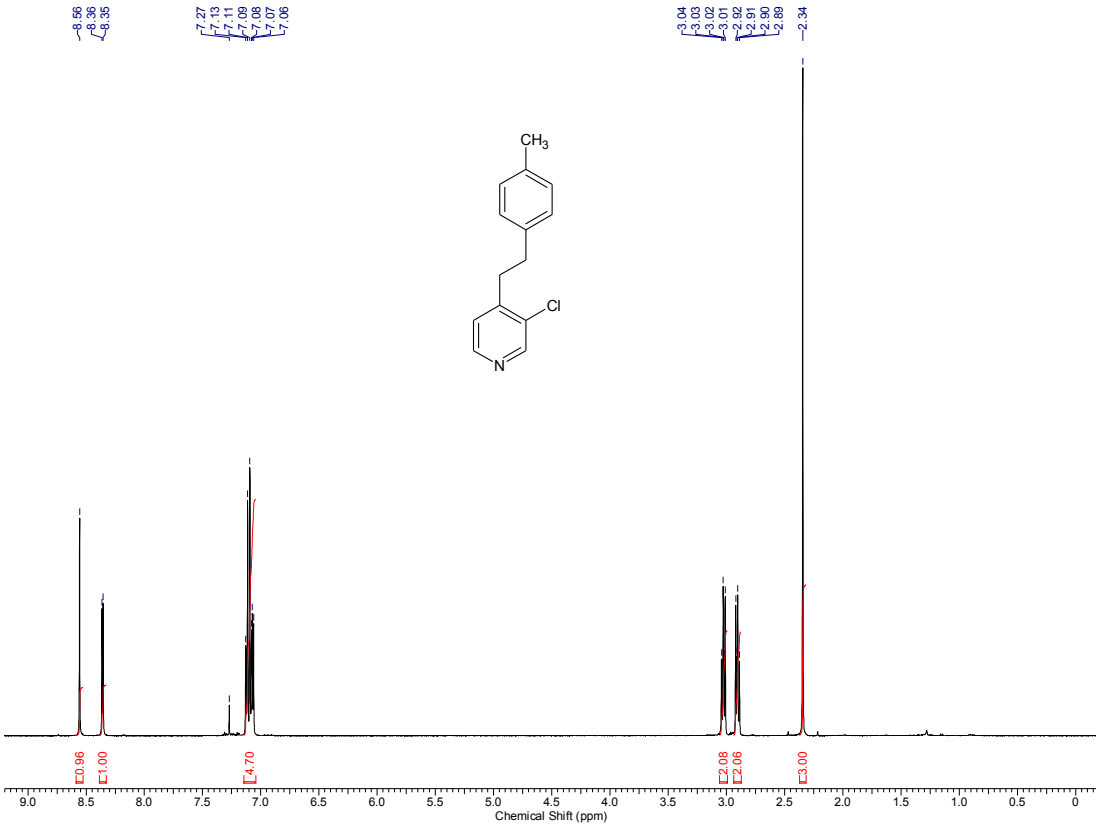

170.7
152.1
148.2
146.2
125.5
123.2
62.1
34.5
20.8
O
O
CH3
Br
N
Chemical Shift (ppm)

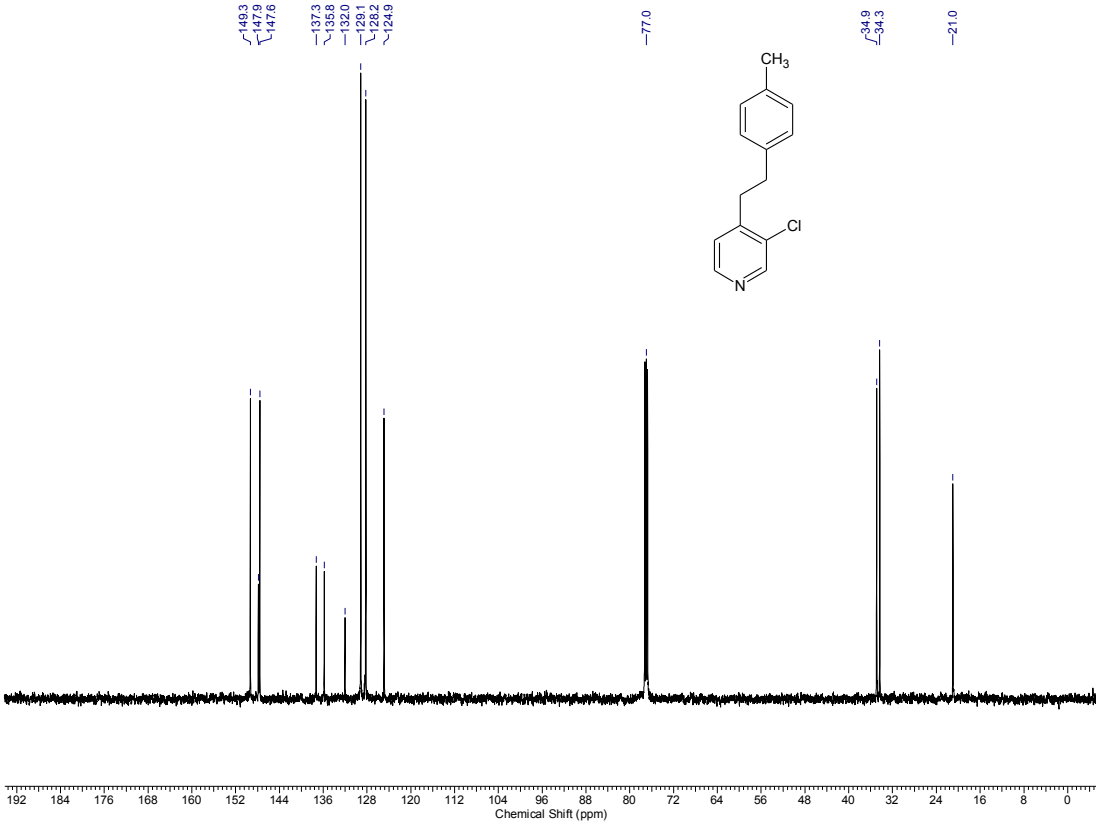
134c:


8.90
8.43
8.42
7.19
7.18
4.32
4.31
4.29
3.06
3.04
3.03
2.04
O
O
CH3
I
N
0.90
1.00
1.03
2.26
2.27
3.18
Chemical Shift (ppm)

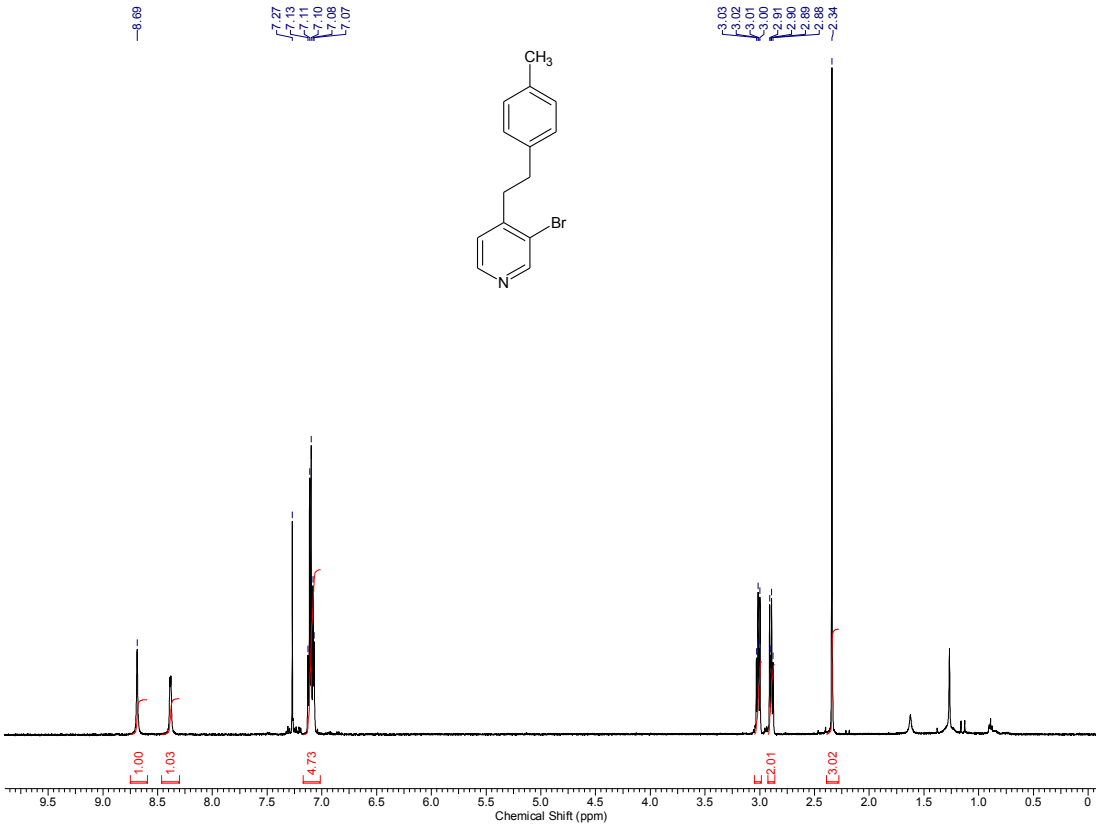

170.7
157.6
149.5
148.9
125.2
100.2
62.2
38.9
20.8
O
O
CH3
I
N
Chemical Shift (ppm)

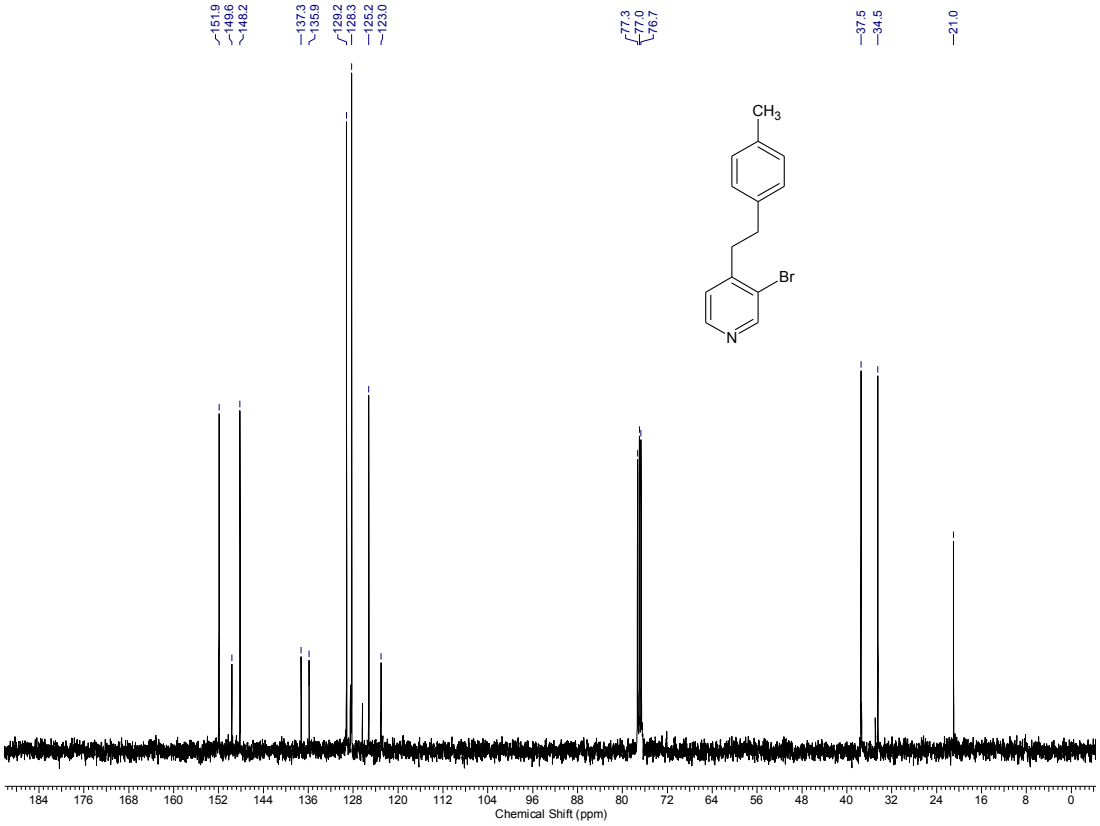
135a:


8.56
8.36
8.35
7.27
7.13
7.11
7.09
7.08
7.07
7.06
3.04
3.03
3.02
3.01
2.92
2.91
2.90
2.89
2.34
CH3
Cl
N
0.96
1.00
4.70
2.08
2.06
3.00
Chemical Shift (ppm)

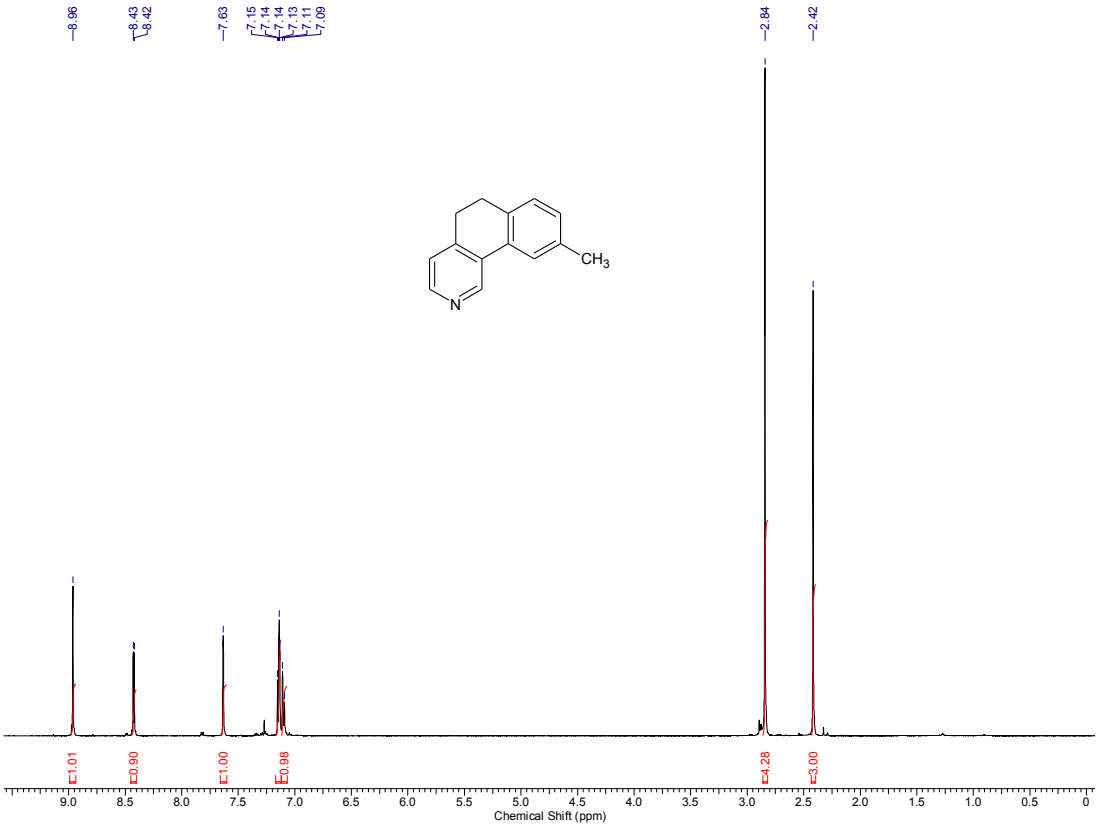

149.3
147.9
147.6
137.3
135.8
132.0
129.1
128.2
124.9
77.0
34.9
34.3
21.0
CH3
Cl
N
Chemical Shift (ppm)

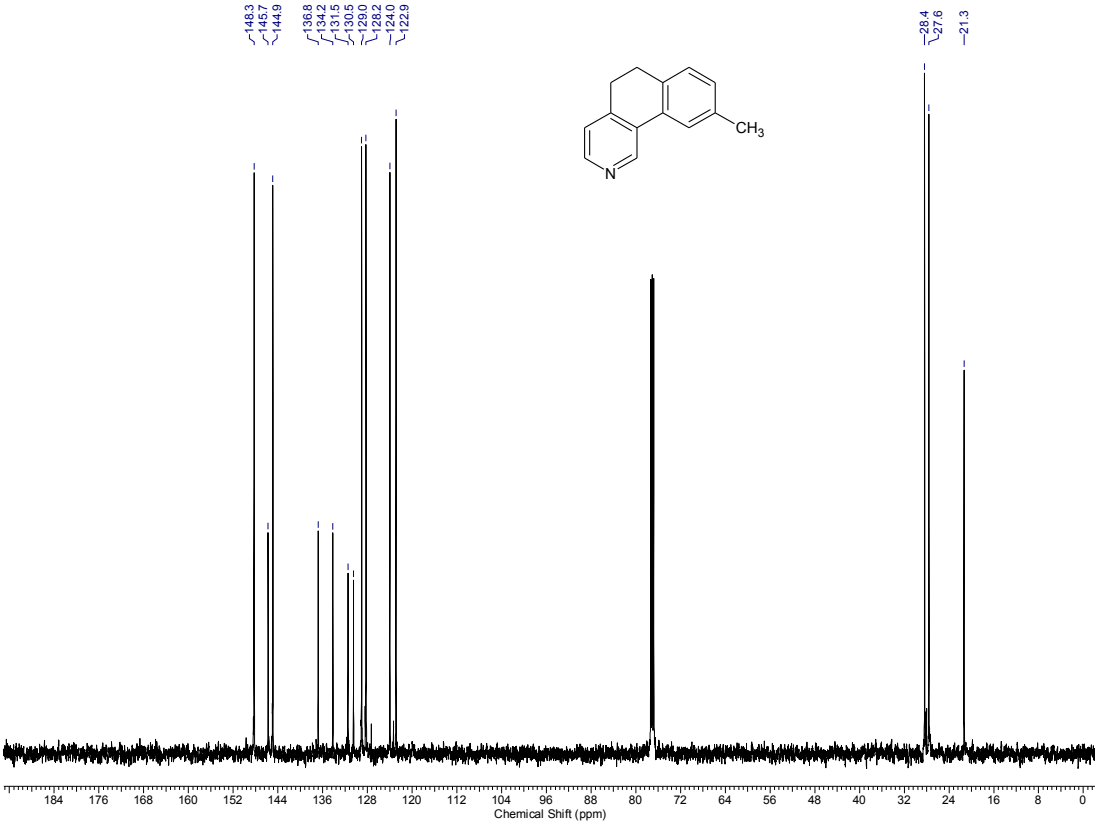
135b:


8.69
7.27
7.13
7.11
7.10
7.08
7.07
3.03
3.02
3.01
3.00
2.91
2.90
2.89
2.88
2.34
CH3
Br
N
1.00
1.03
4.73
2.01
3.02
Chemical Shift (ppm)

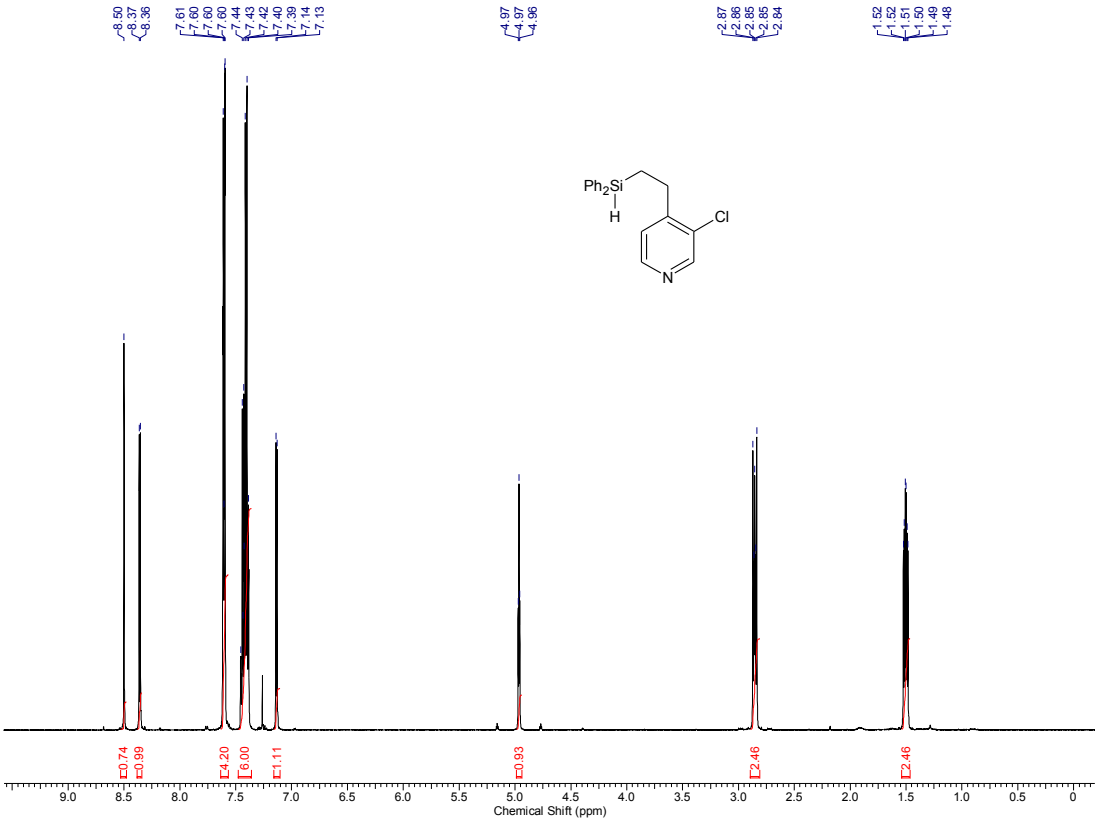

151.9
149.6
148.2
137.3
135.9
129.2
128.3
125.2
123.0
77.3
77.0
76.7
37.5
34.5
21.0
CH3
Br
N
Chemical Shift (ppm)

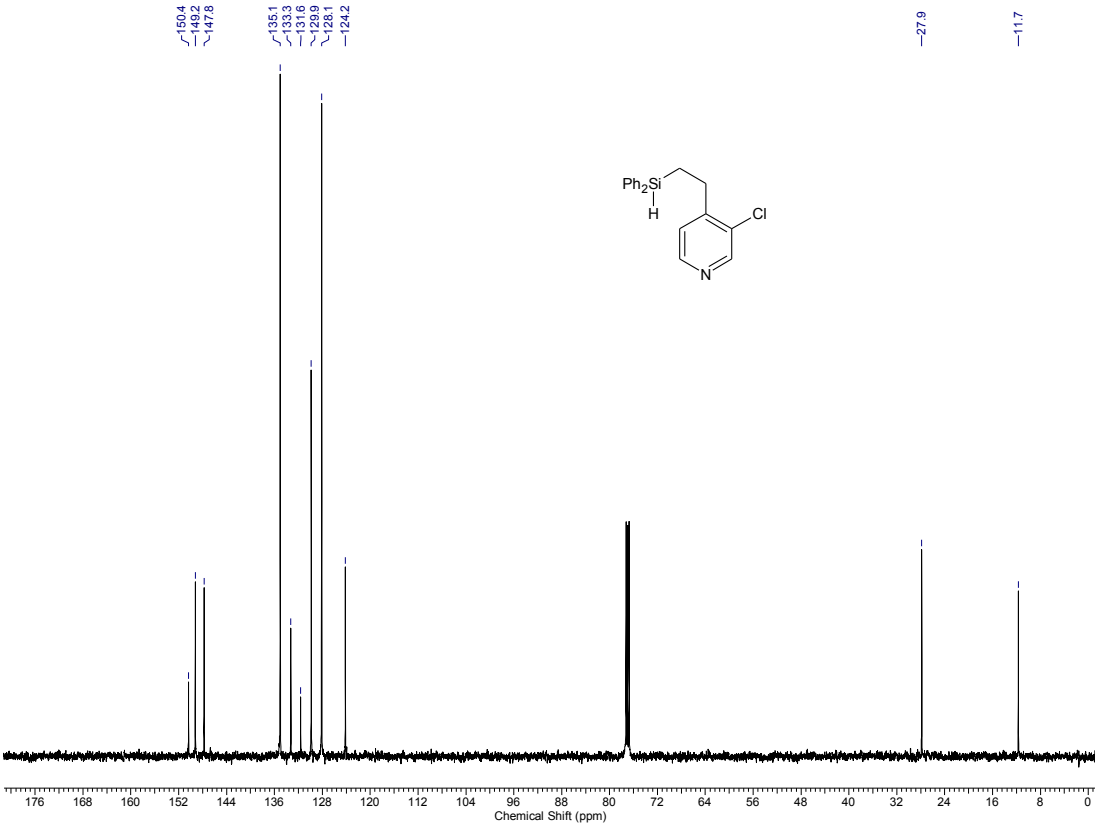
136:


8.96
8.43
8.42
7.63
7.15
7.14
7.14
7.13
7.11
7.09
2.84
2.42
CH3
N
1.01
0.90
1.00
0.98
4.28
3.00
Chemical Shift (ppm)

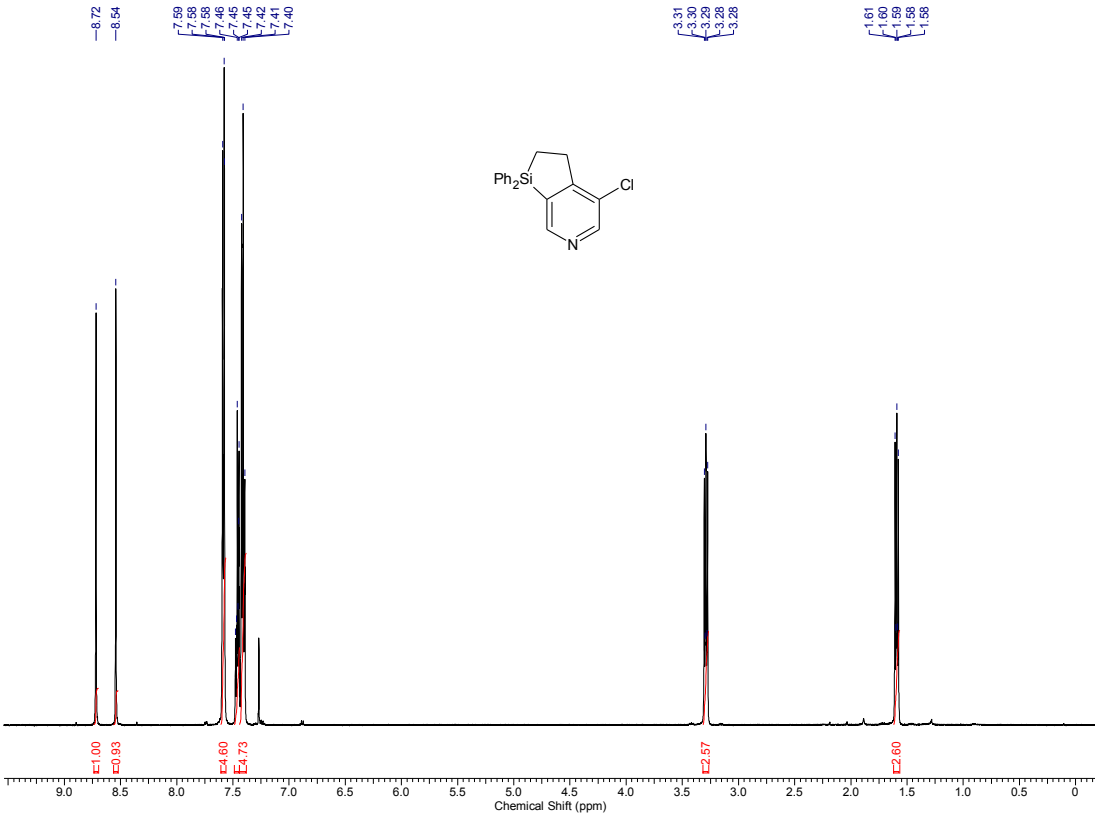

148.3
145.7
144.9
136.8
134.2
131.5
130.5
129.0
128.2
124.0
122.9
28.4
27.6
21.3
CH3
N
Chemical Shift (ppm)

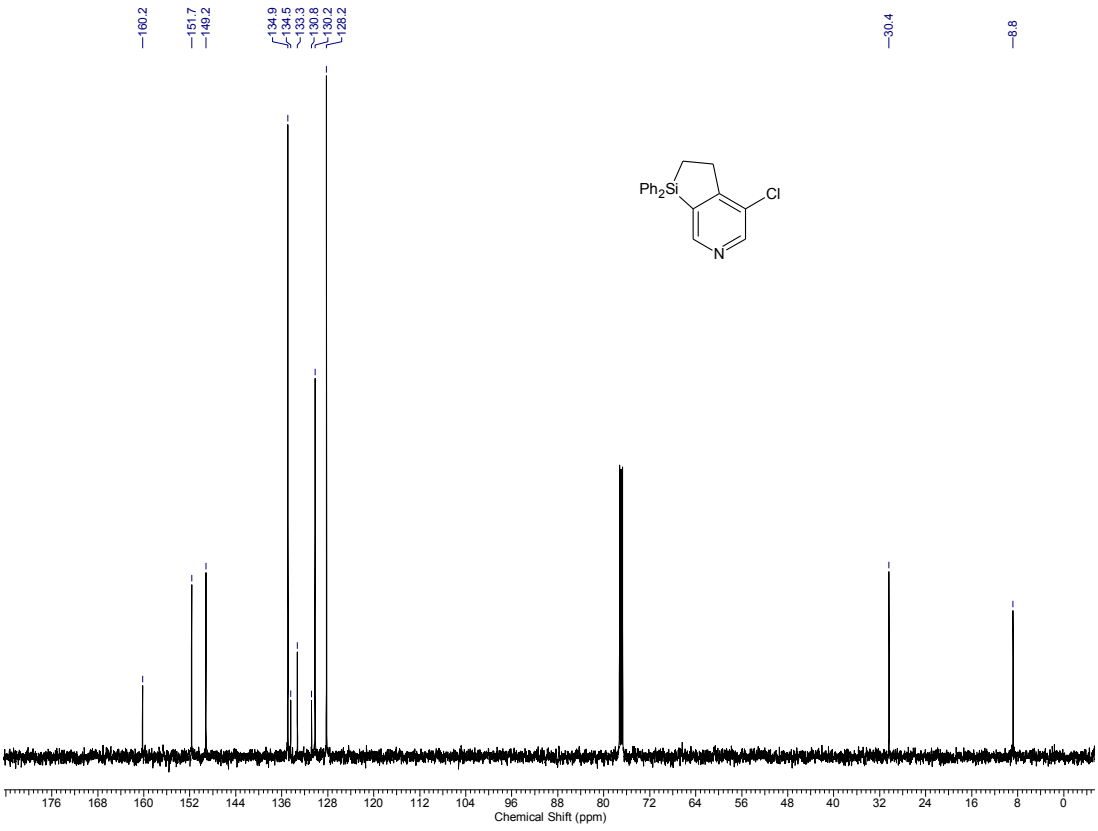
130d':


8.50
8.37
8.36
7.61
7.60
7.60
7.60
7.44
7.43
7.42
7.40
7.39
7.14
7.13
4.97
4.97
4.96
2.87
2.86
2.85
2.85
2.84
1.52
1.52
1.51
1.50
1.49
1.48
Ph2Si
H
Cl
N
0.74
0.99
4.20
6.00
1.11
0.93
2.46
2.46
Chemical Shift (ppm)

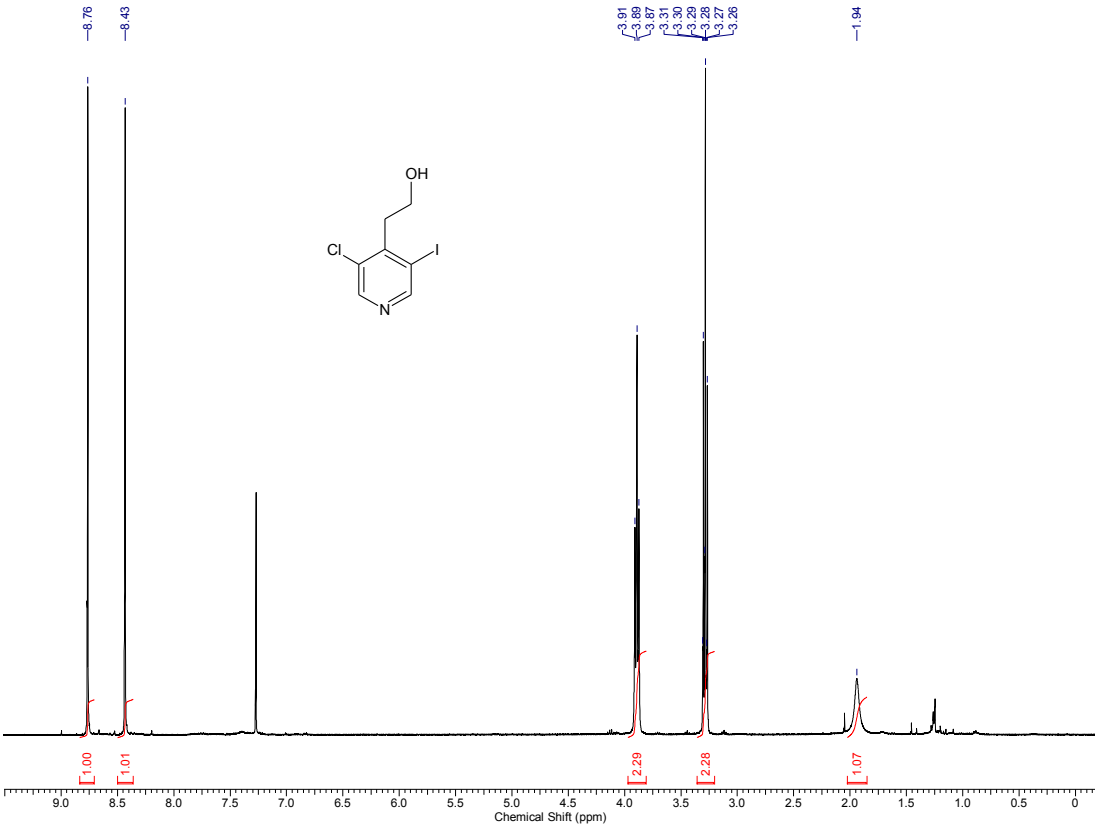

150.4
149.2
147.8
135.1
133.3
131.6
129.9
128.1
124.2
27.9
11.7
Ph2Si
H
Cl
N
Chemical Shift (ppm)

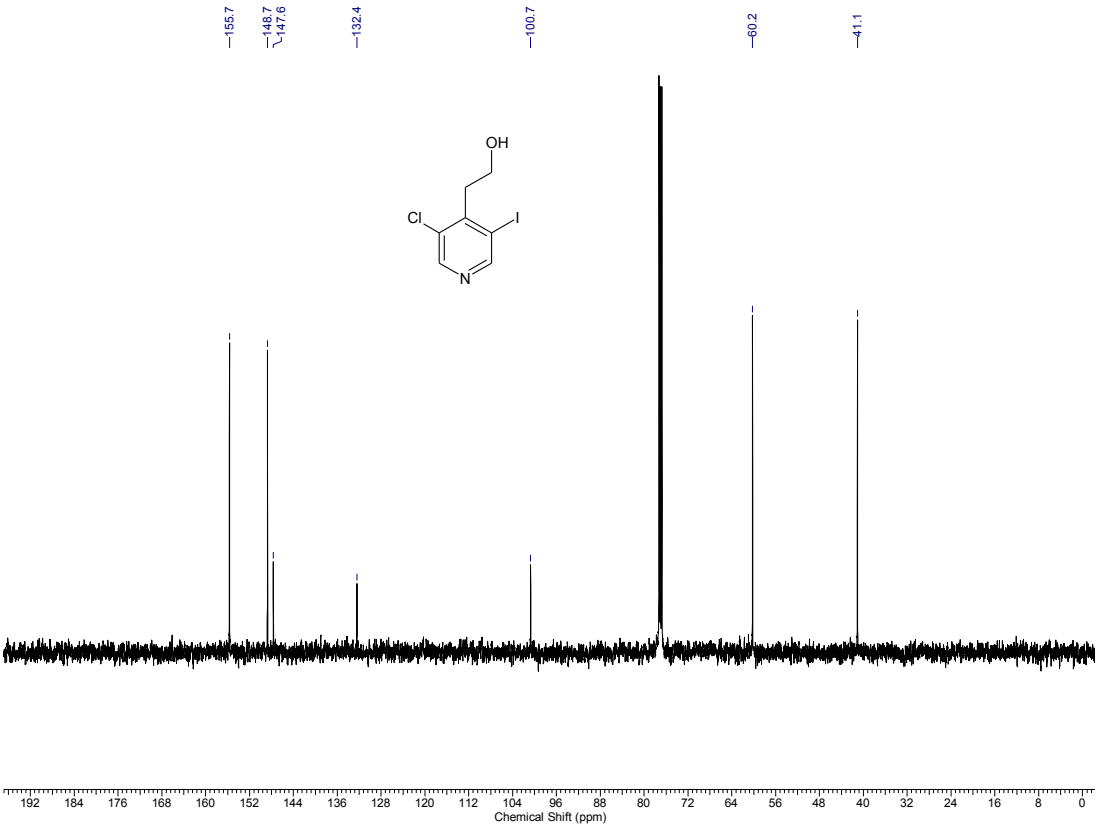
131d':


8.72
8.54
7.59
7.58
7.58
7.58
7.46
7.45
7.45
7.42
7.41
7.40
3.31
3.30
3.29
3.28
3.28
1.61
1.60
1.59
1.58
1.58
Ph2Si
Cl
N
1.00
0.93
4.60
4.73
2.57
2.60
Chemical Shift (ppm)


160.2
151.7
149.2
134.9
134.5
133.3
130.8
130.2
128.2
30.4
8.8
Ph2Si
Cl
N
Chemical Shift (ppm)

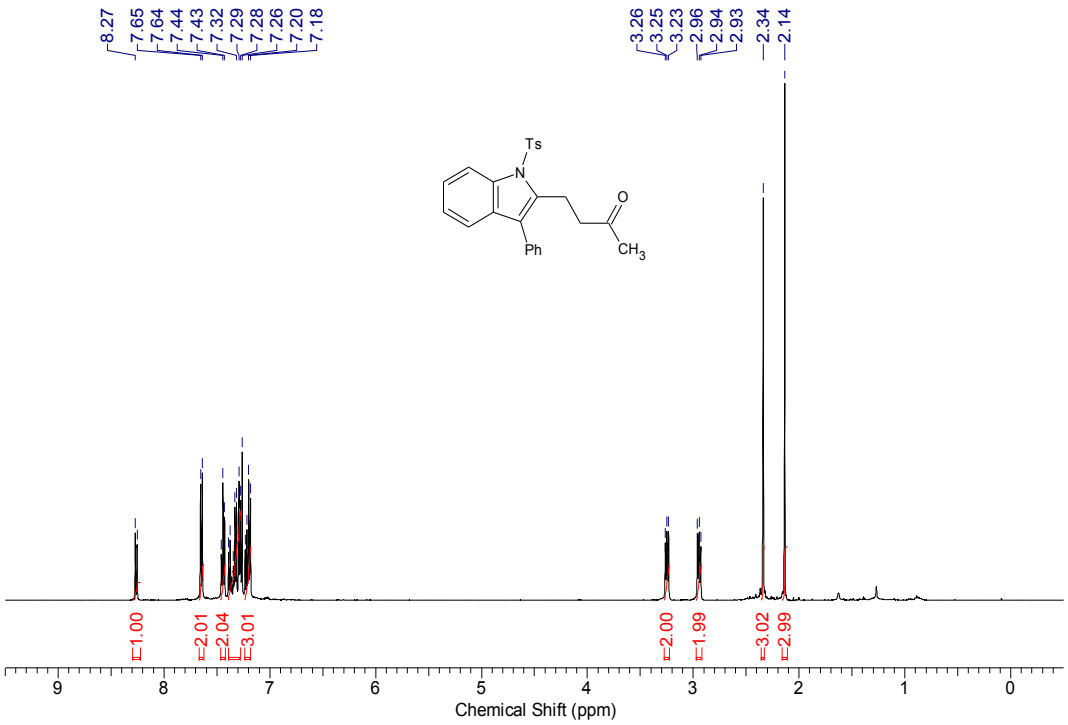
137:

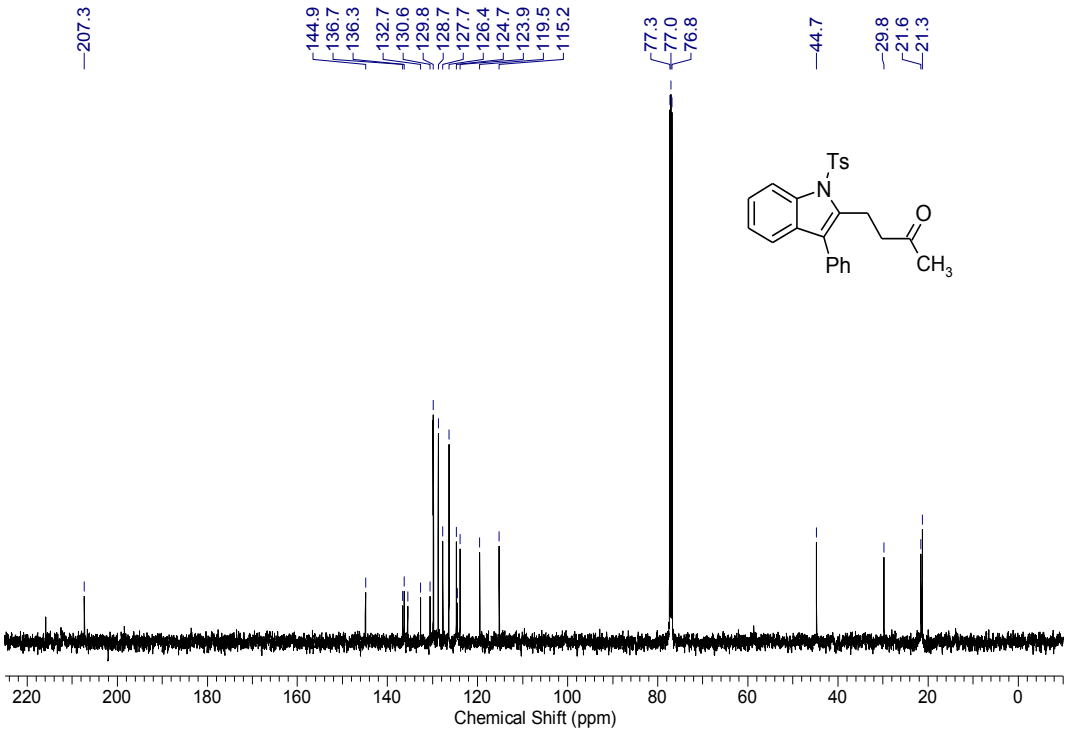

8.76
8.43
3.91
3.89
3.87
3.31
3.30
3.29
3.28
3.27
3.26
1.94
OH
Cl
I
N
1.00
1.01
2.29
2.28
1.07
Chemical Shift (ppm)


155.7
148.7
147.6
132.4
100.7
60.2
41.1
OH
Cl
I
N
Chemical Shift (ppm)

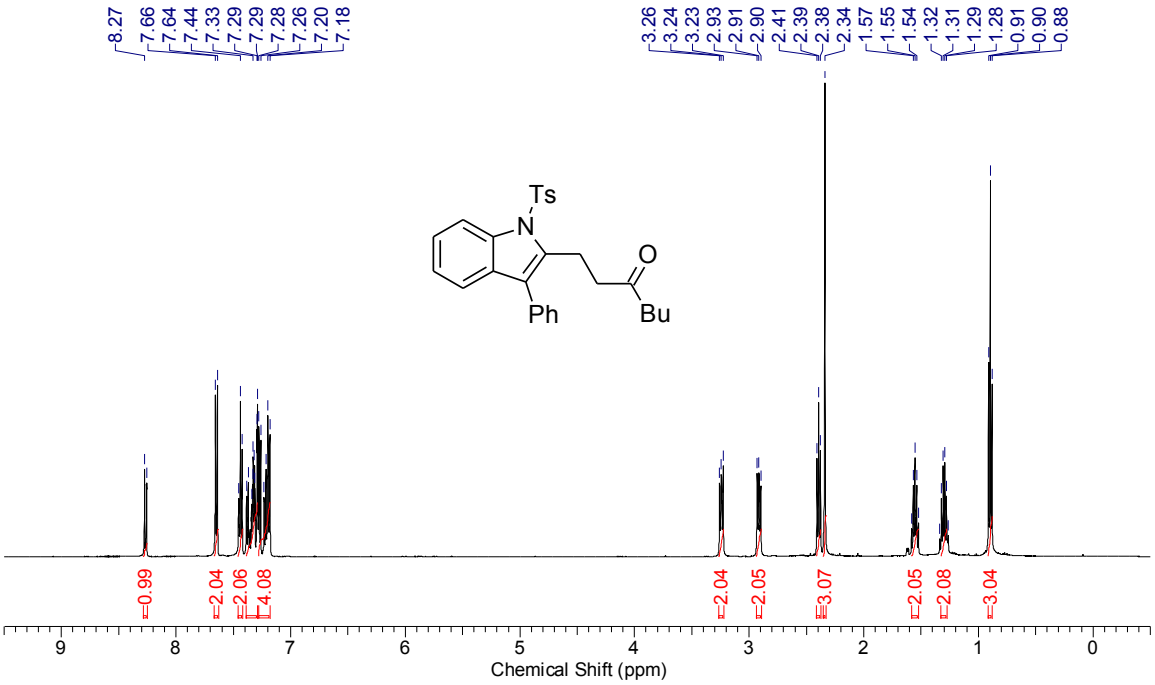
APPENDIX C. ^{1}H and ^{13}C spectra of indoles **199** and the products of their further transformations

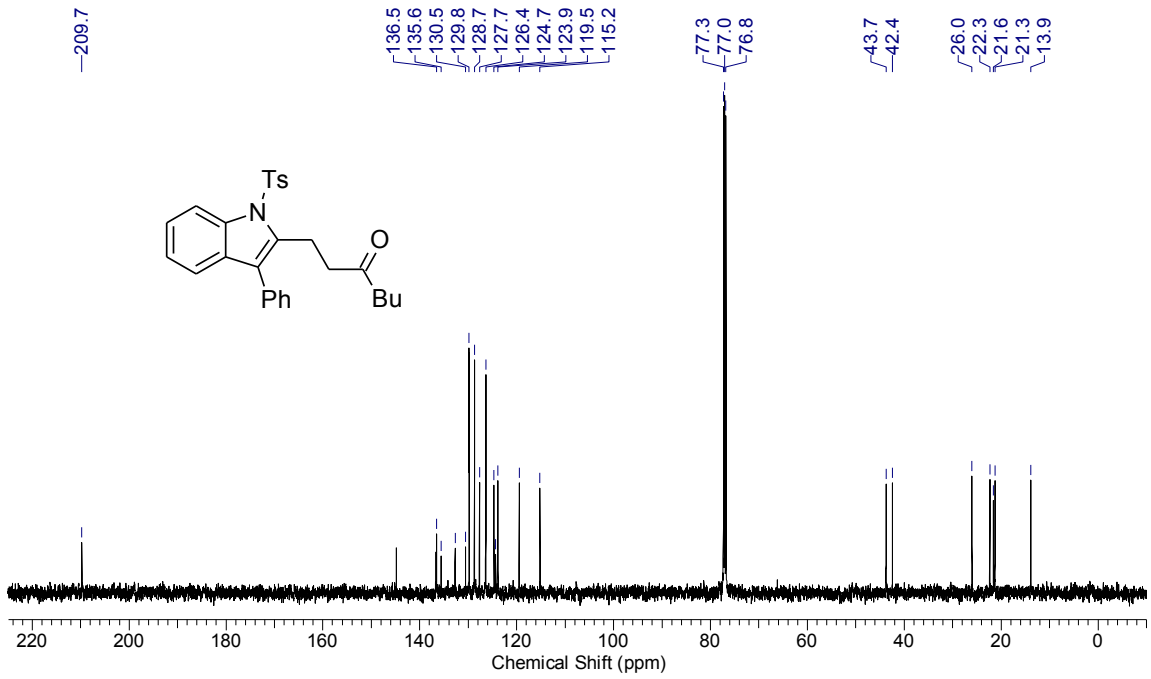
199aa:



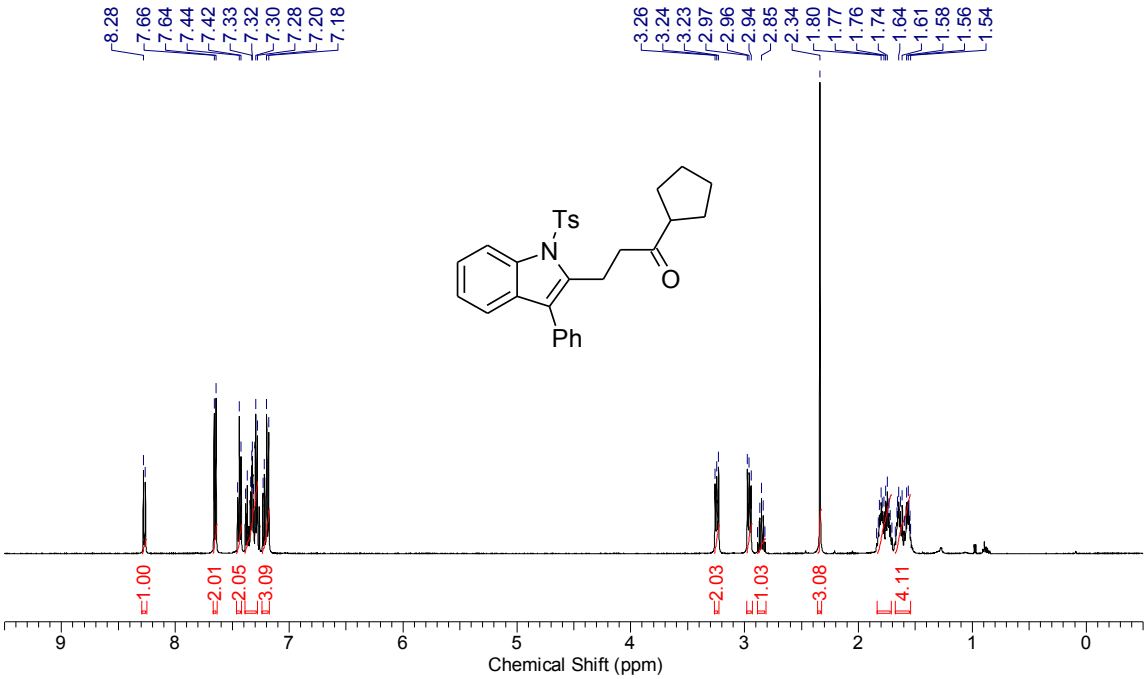


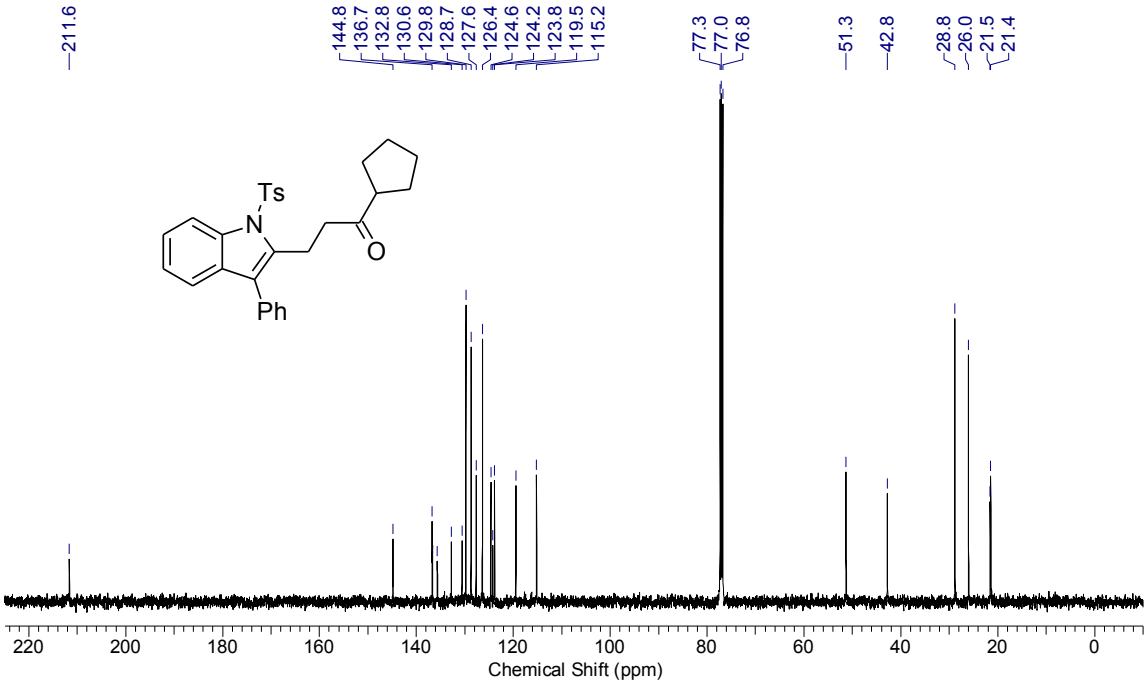
199ab:


8.27
7.66
7.64
7.44
7.33
7.29
7.29
7.28
7.26
7.20
7.18
3.26
3.24
3.23
2.93
2.91
2.90
2.41
2.39
2.38
2.34
1.57
1.55
1.54
1.32
1.31
1.29
1.28
0.91
0.90
0.88
Ts
N
O
Ph
Bu
0.99
2.04
2.06
4.08
2.04
2.05
3.07
2.05
2.08
3.04
Chemical Shift (ppm)

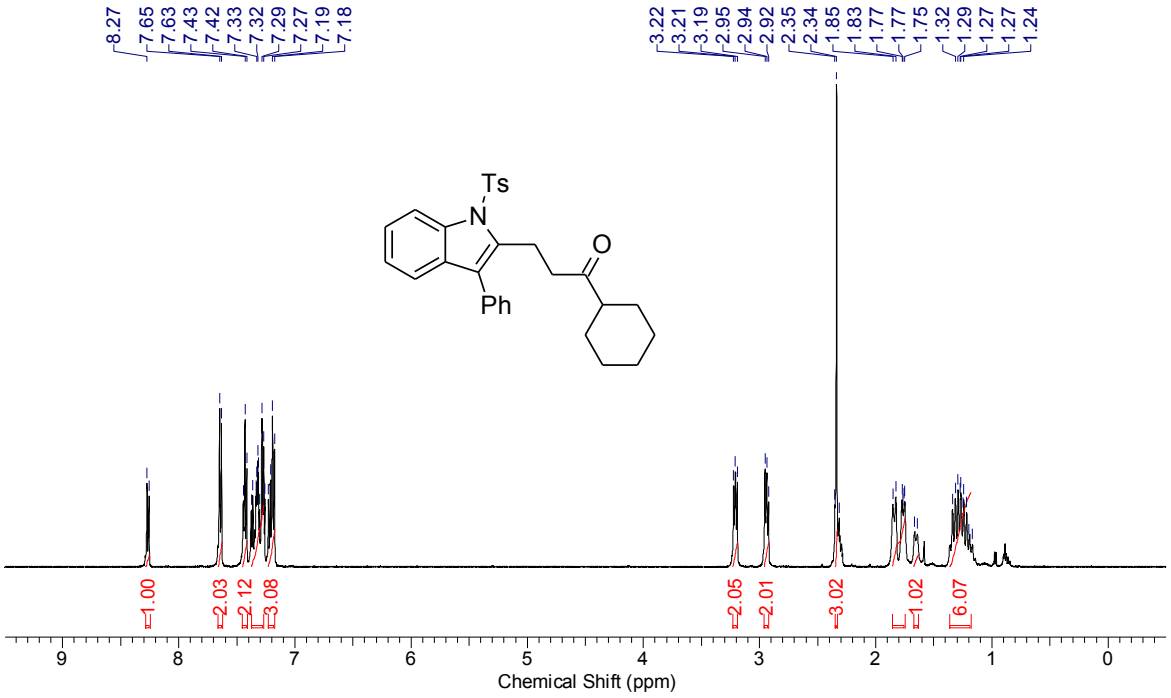

209.7
136.5
135.6
130.5
129.8
128.7
127.7
126.4
124.7
123.9
119.5
115.2
77.3
77.0
76.8
43.7
42.4
26.0
22.3
21.6
21.3
13.9
Ts
N
O
Ph
Bu
Chemical Shift (ppm)

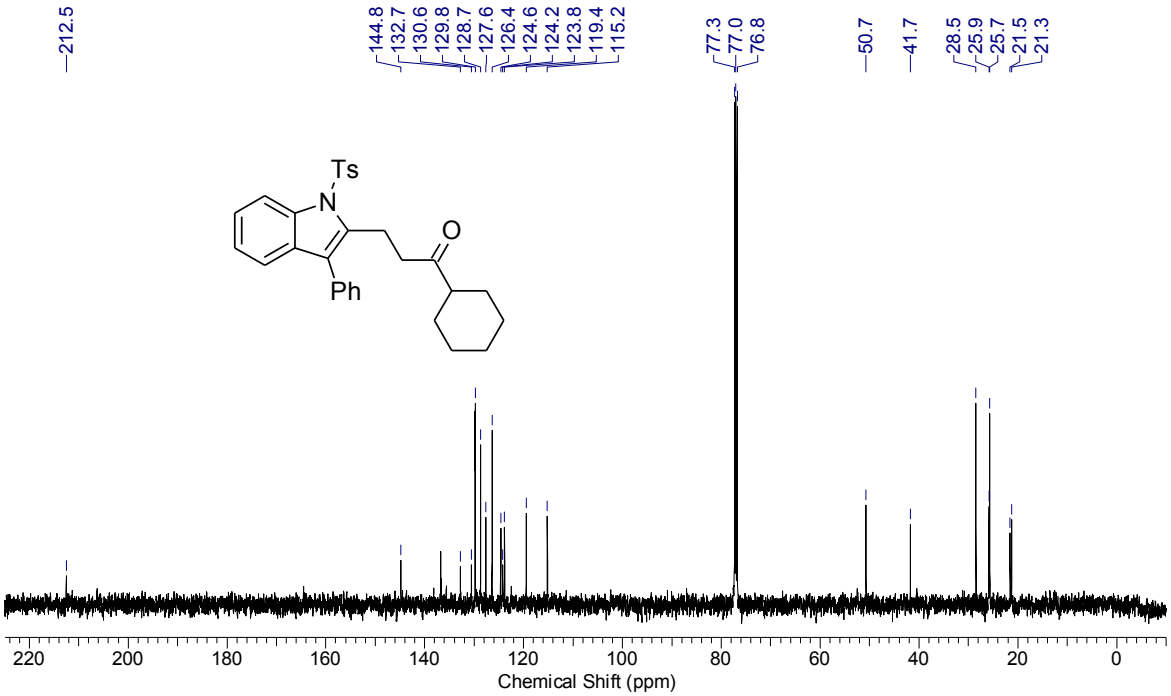
199ac:


8.28
7.66
7.64
7.44
7.42
7.33
7.32
7.30
7.28
7.20
7.18
3.26
3.24
3.23
2.97
2.96
2.94
2.85
2.34
1.80
1.77
1.76
1.74
1.64
1.61
1.58
1.56
1.54
Ts
N
O
Ph
1.00
2.01
2.05
3.09
2.03
1.03
3.08
4.11
Chemical Shift (ppm)

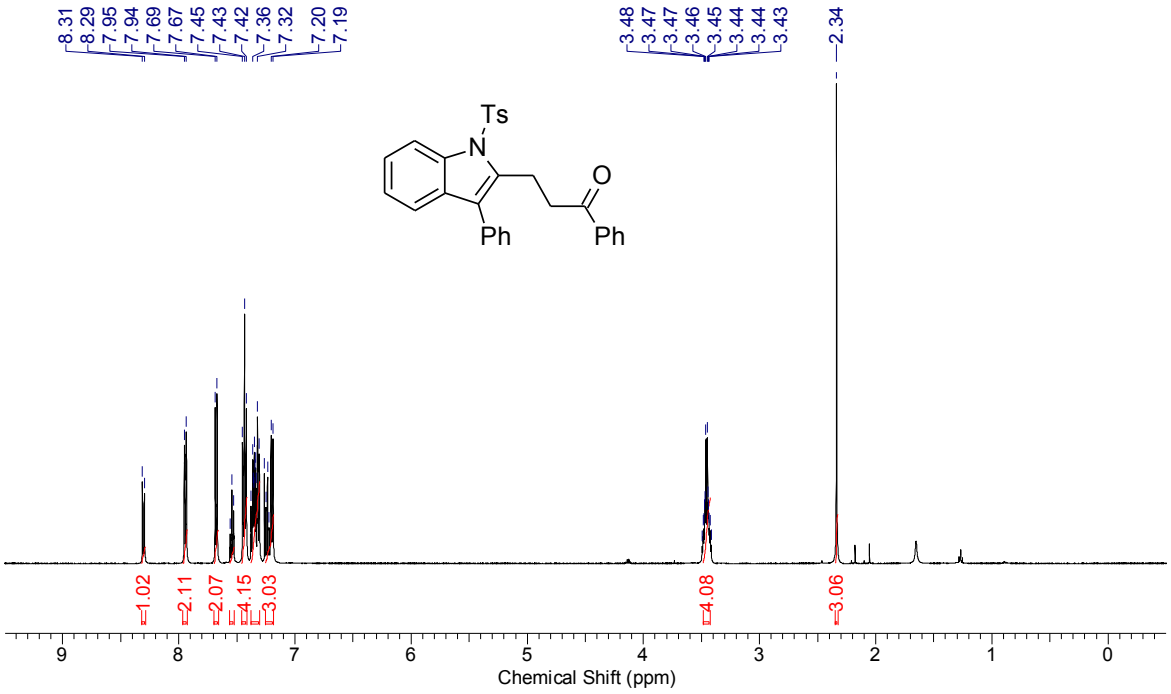

211.6
144.8
136.7
132.8
130.6
129.8
128.7
127.6
126.4
124.6
124.2
123.8
119.5
115.2
77.3
77.0
76.8
51.3
42.8
28.8
26.0
21.5
21.4
Ts
N
O
Ph
Chemical Shift (ppm)

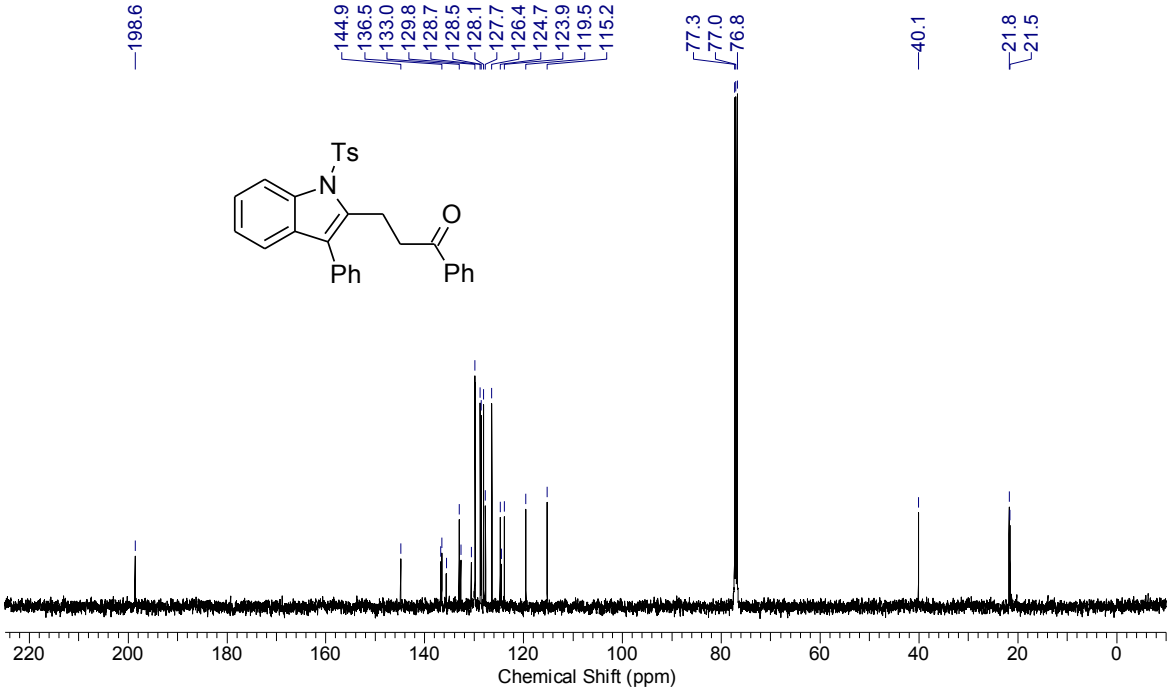
199ad:


8.27
7.65
7.63
7.43
7.42
7.33
7.32
7.29
7.27
7.19
7.18
3.22
3.21
3.19
2.95
2.94
2.92
2.35
2.34
1.85
1.83
1.77
1.77
1.75
1.32
1.29
1.27
1.27
1.24
Ts
N
O
Ph
1.00
2.03
2.12
3.08
2.05
2.01
3.02
1.02
6.07
Chemical Shift (ppm)

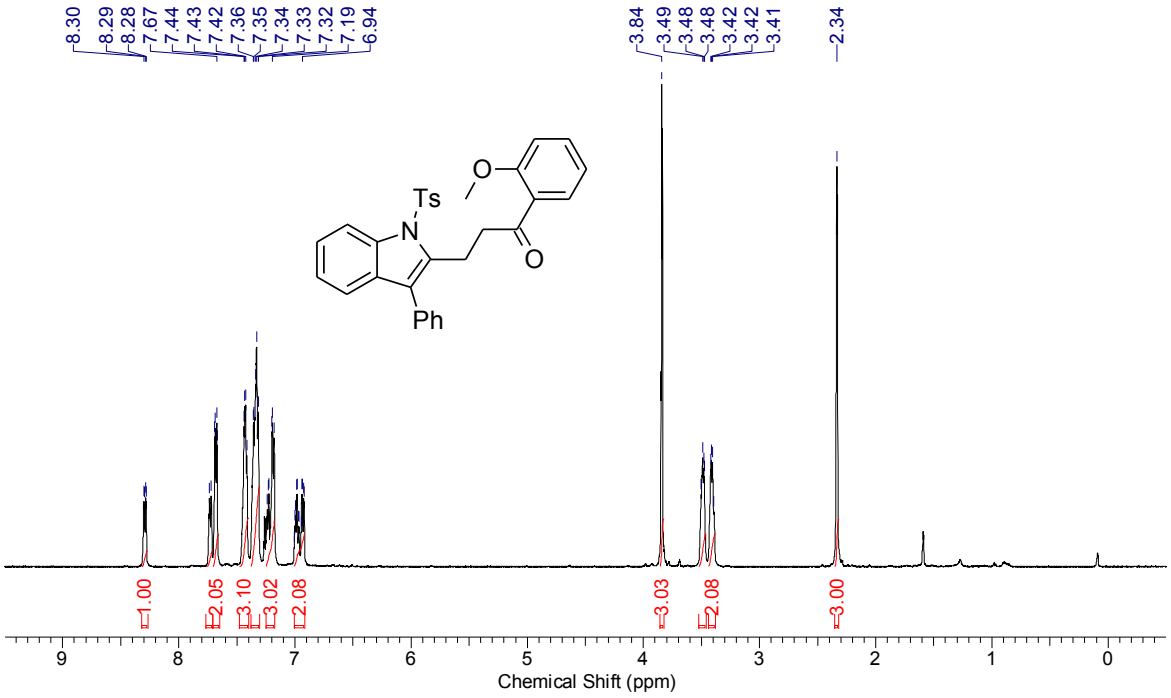

212.5
144.8
132.7
130.6
129.8
128.7
127.6
126.4
124.6
124.2
123.8
119.4
115.2
77.3
77.0
76.8
50.7
41.7
28.5
25.9
25.7
21.5
21.3
Ts
N
O
Ph
Chemical Shift (ppm)

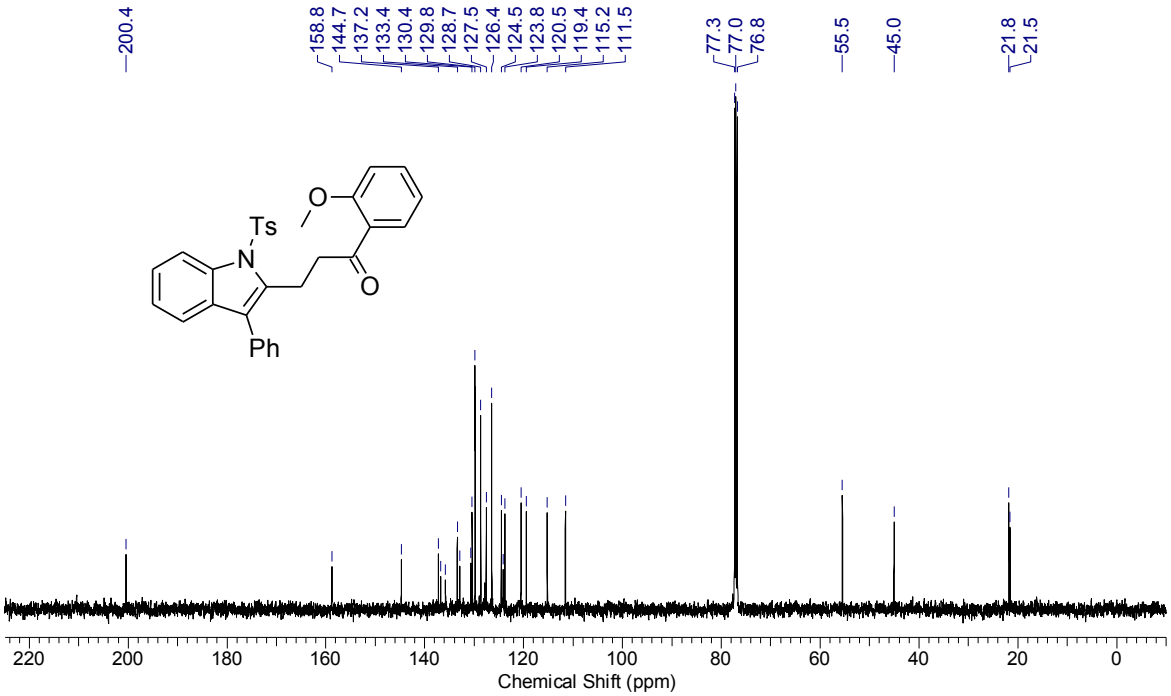
199ae:


8.31
8.29
7.95
7.94
7.69
7.67
7.45
7.43
7.42
7.36
7.32
7.20
7.19
3.48
3.47
3.47
3.46
3.45
3.44
3.44
3.43
2.34
Ts
N
O
Ph
Ph
1.02
2.11
2.07
4.15
3.03
4.08
3.06
Chemical Shift (ppm)

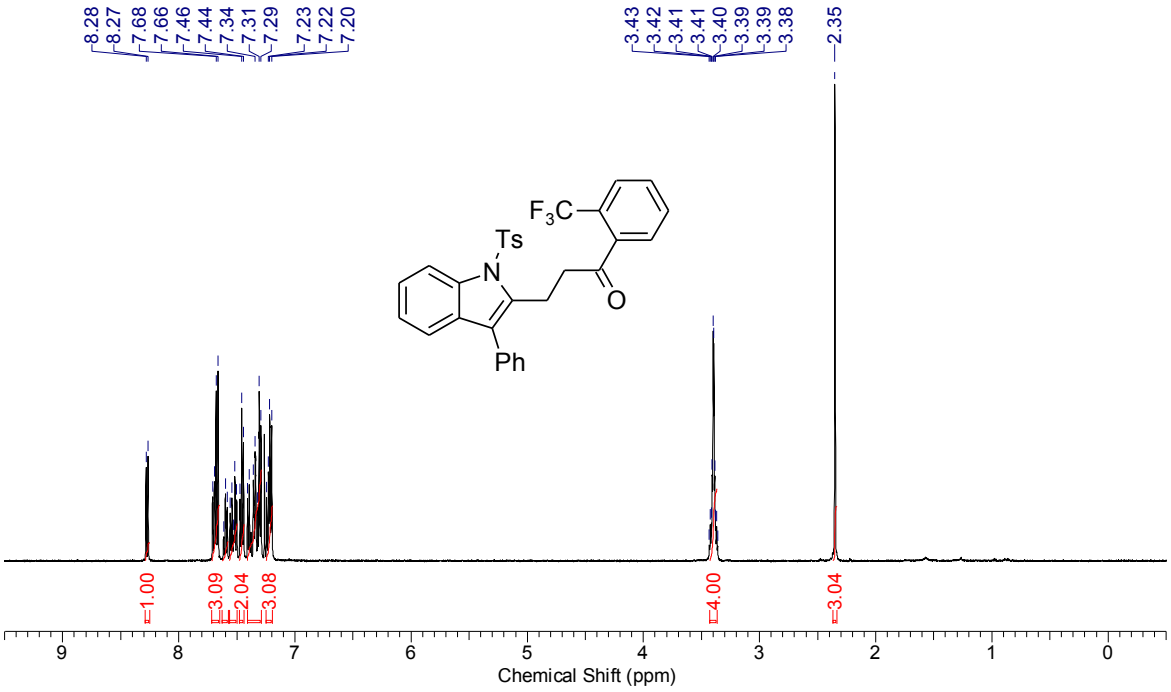

198.6
144.9
136.5
133.0
129.8
128.7
128.5
128.1
127.7
126.4
124.7
123.9
119.5
115.2
77.3
77.0
76.8
40.1
21.8
21.5
Ts
N
O
Ph
Ph
Chemical Shift (ppm)

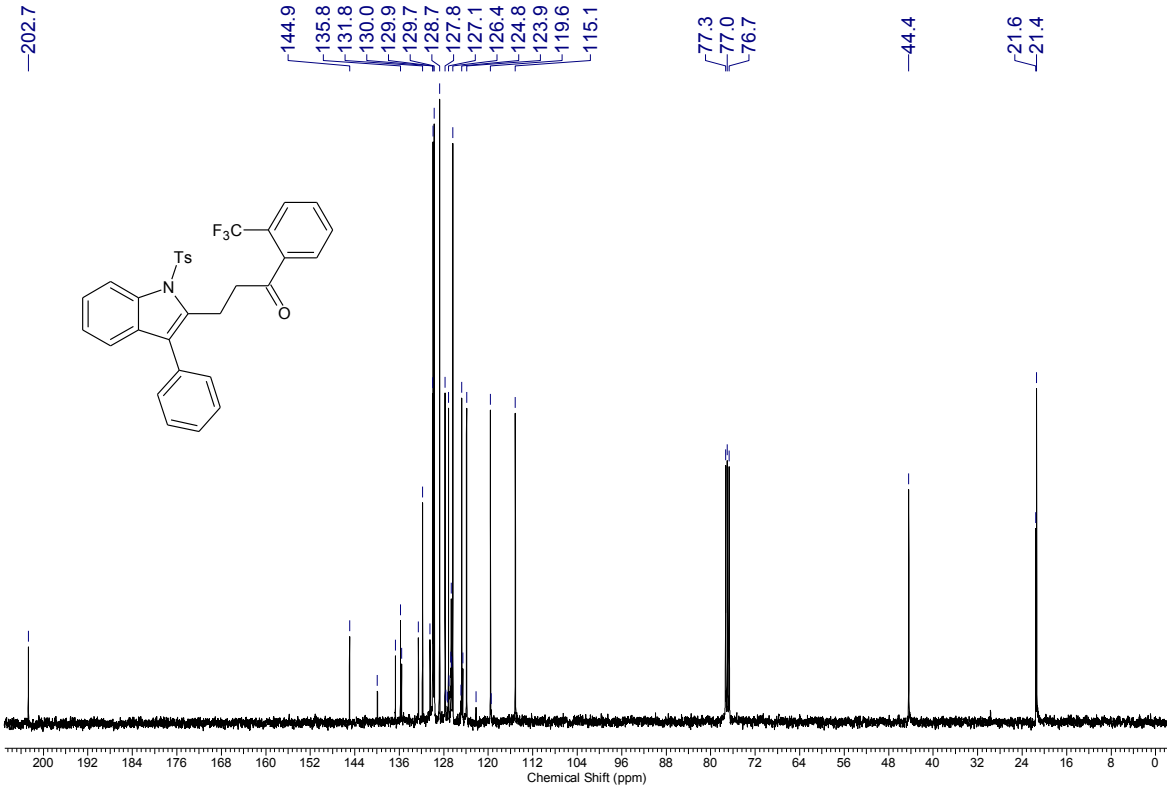
199af:


8.30
8.29
8.28
7.67
7.44
7.43
7.42
7.36
7.35
7.34
7.33
7.32
7.19
6.94
3.84
3.49
3.48
3.48
3.42
3.42
3.41
2.34
Ts
N
O
O
Ph
1.00
2.05
3.10
3.02
2.08
3.03
2.08
3.00
Chemical Shift (ppm)

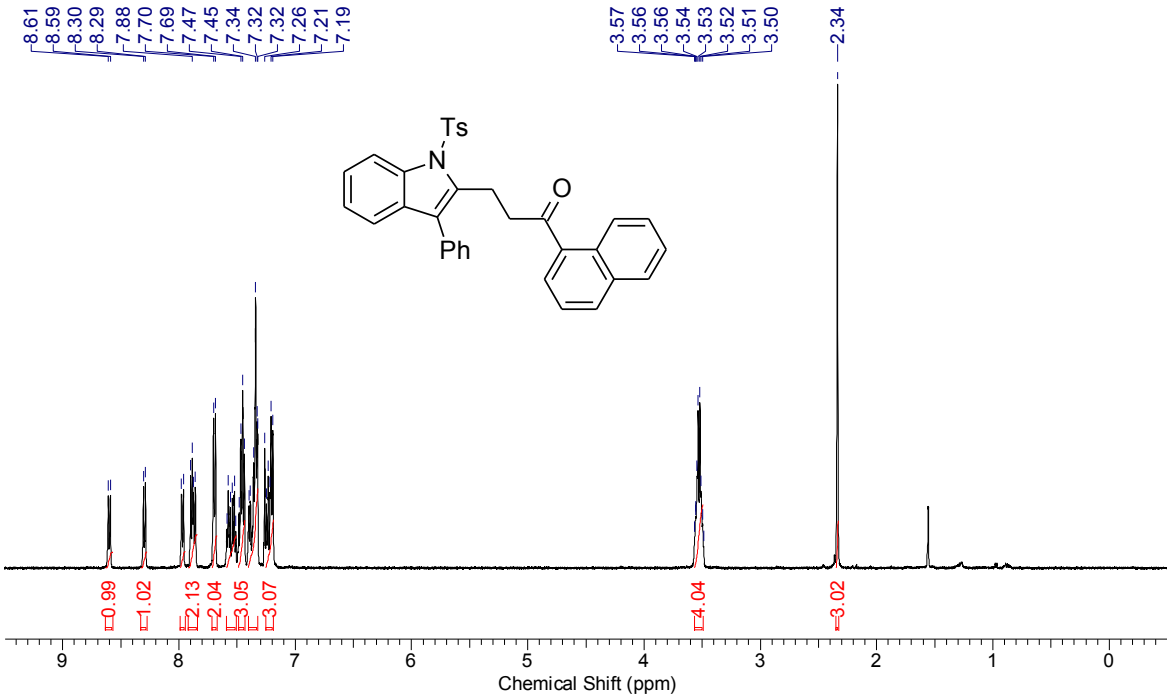

200.4
158.8
144.7
137.2
133.4
130.4
129.8
128.7
127.5
126.4
124.5
123.8
120.5
119.4
115.2
111.5
77.3
77.0
76.8
55.5
45.0
21.8
21.5
Ts
N
O
O
Ph
Chemical Shift (ppm)

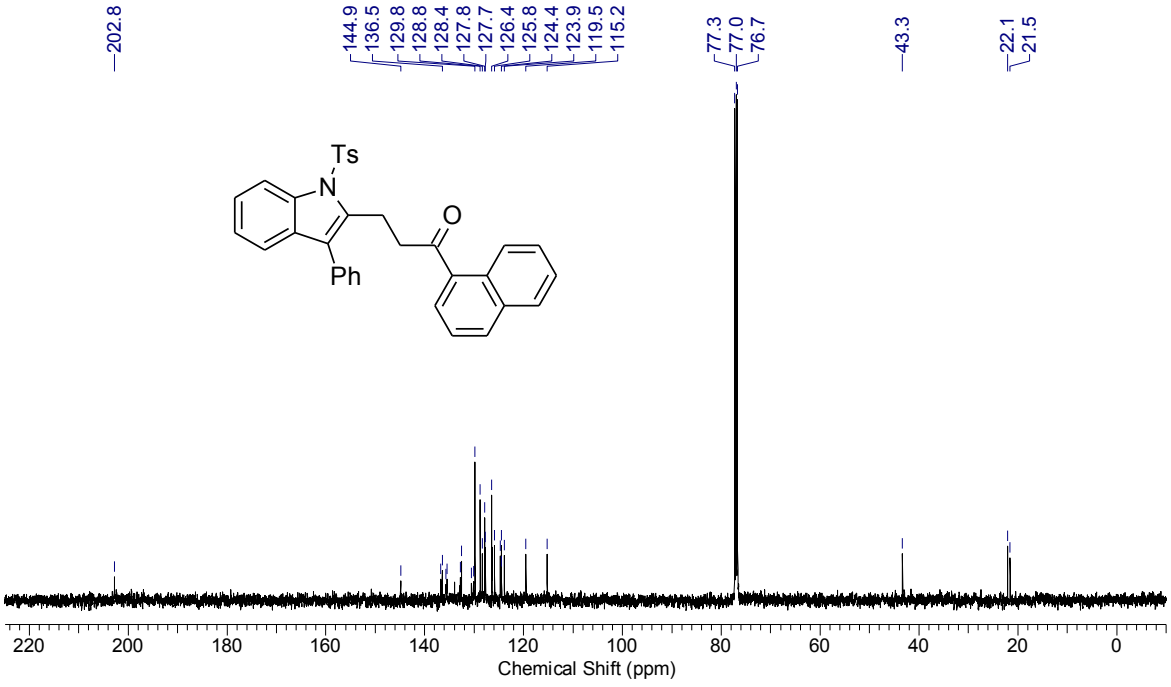
199ag:


8.28
8.27
7.68
7.66
7.46
7.44
7.34
7.31
7.29
7.23
7.22
7.20
3.43
3.42
3.41
3.41
3.40
3.39
3.39
3.38
2.35
F3C
Ts
N
O
Ph
1.00
3.09
2.04
3.08
4.00
3.04
Chemical Shift (ppm)

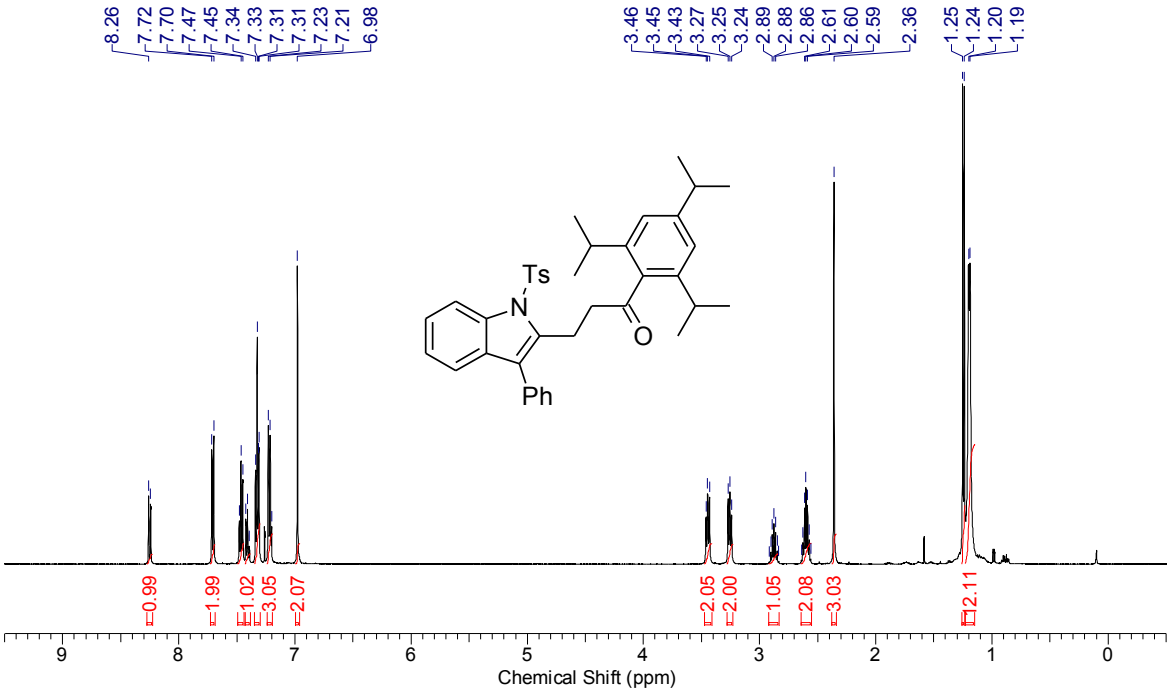

202.7
144.9
135.8
131.8
130.0
129.9
129.7
128.7
127.8
127.1
126.4
124.8
123.9
119.6
115.1
77.3
77.0
76.7
44.4
21.6
21.4
F3C
Ts
N
O
Chemical Shift (ppm)

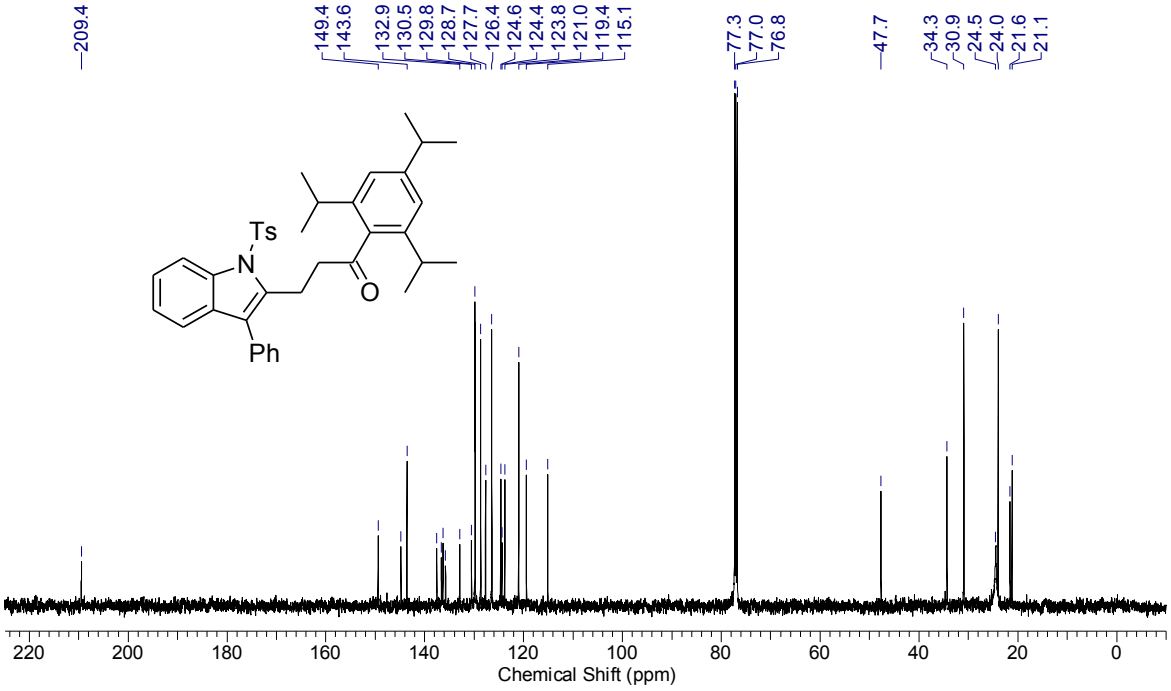
199ah:


8.61
8.59
8.30
8.29
7.88
7.70
7.69
7.47
7.45
7.34
7.32
7.32
7.26
7.21
7.19
3.57
3.56
3.56
3.54
3.53
3.52
3.51
3.50
2.34
Ts
N
O
Ph
0.99
1.02
2.13
2.04
3.05
3.07
4.04
3.02
Chemical Shift (ppm)

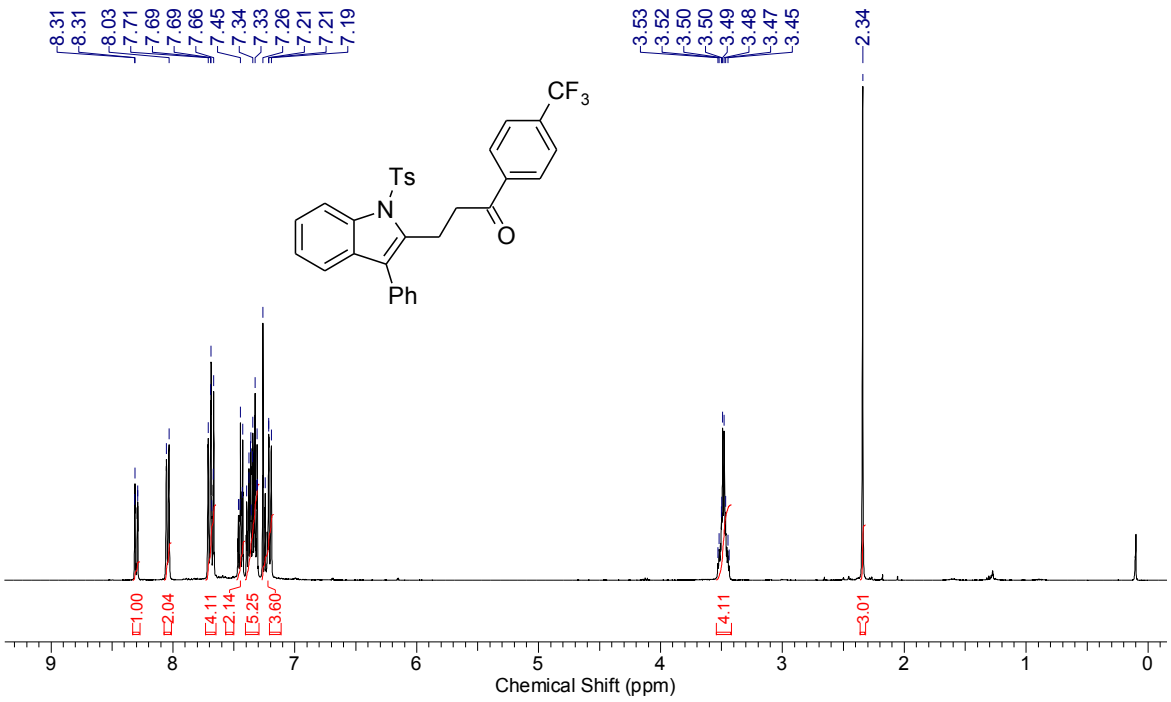

202.8
144.9
136.5
129.8
128.8
128.4
127.8
127.7
126.4
125.8
124.4
123.9
119.5
115.2
77.3
77.0
76.7
43.3
22.1
21.5
Ts
N
O
Ph
Chemical Shift (ppm)

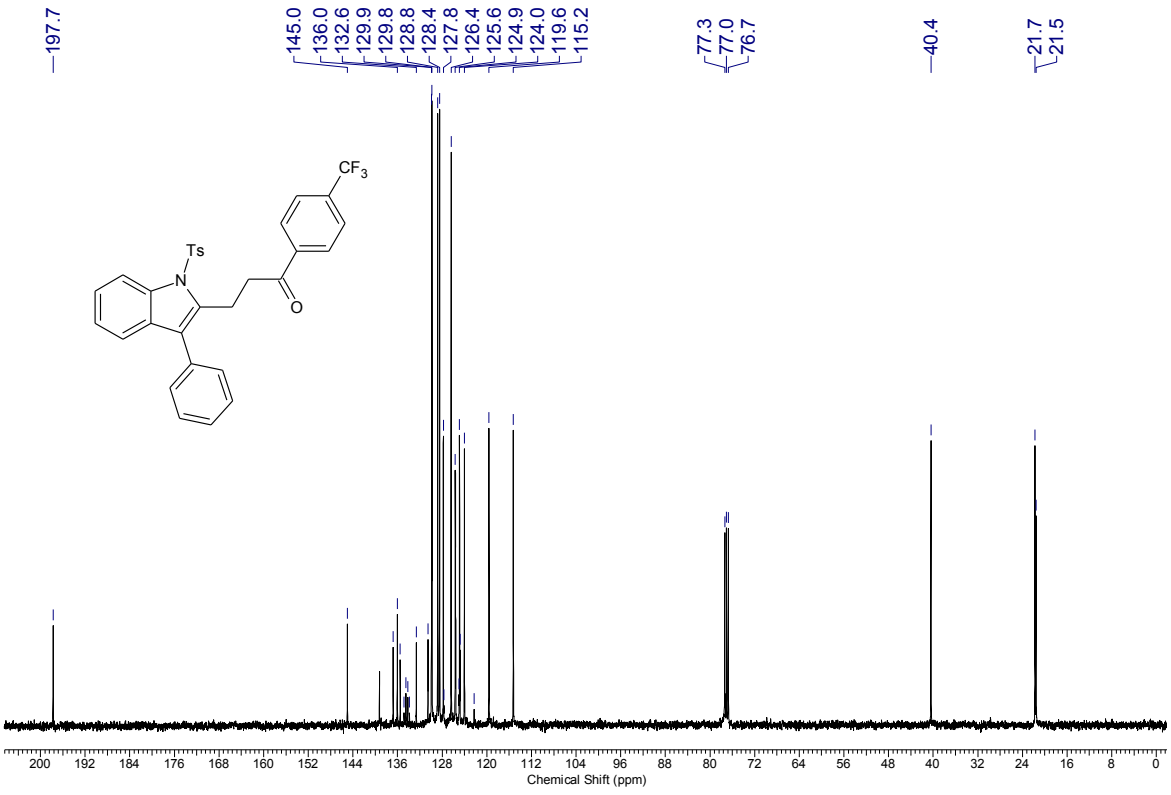
199ai:


8.26
7.72
7.70
7.47
7.45
7.34
7.33
7.31
7.23
7.21
6.98
3.46
3.45
3.43
3.27
3.25
3.24
2.89
2.88
2.86
2.61
2.60
2.59
2.36
1.25
1.24
1.20
1.19
Ts
N
O
Ph
0.99
1.99
1.02
3.05
2.07
2.05
2.00
1.05
2.08
3.03
12.11
Chemical Shift (ppm)

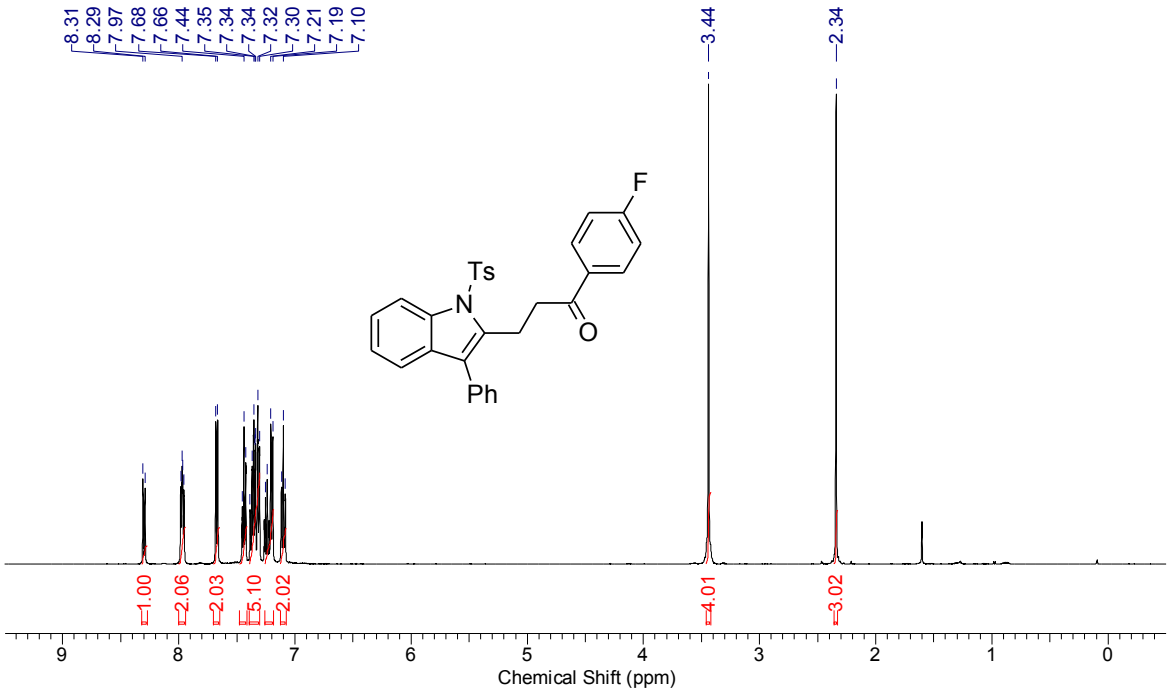

209.4
149.4
143.6
132.9
130.5
129.8
128.7
127.7
126.4
124.6
124.4
123.8
121.0
119.4
115.1
77.3
77.0
76.8
47.7
34.3
30.9
24.5
24.0
21.6
21.1
Ts
N
O
Ph
Chemical Shift (ppm)

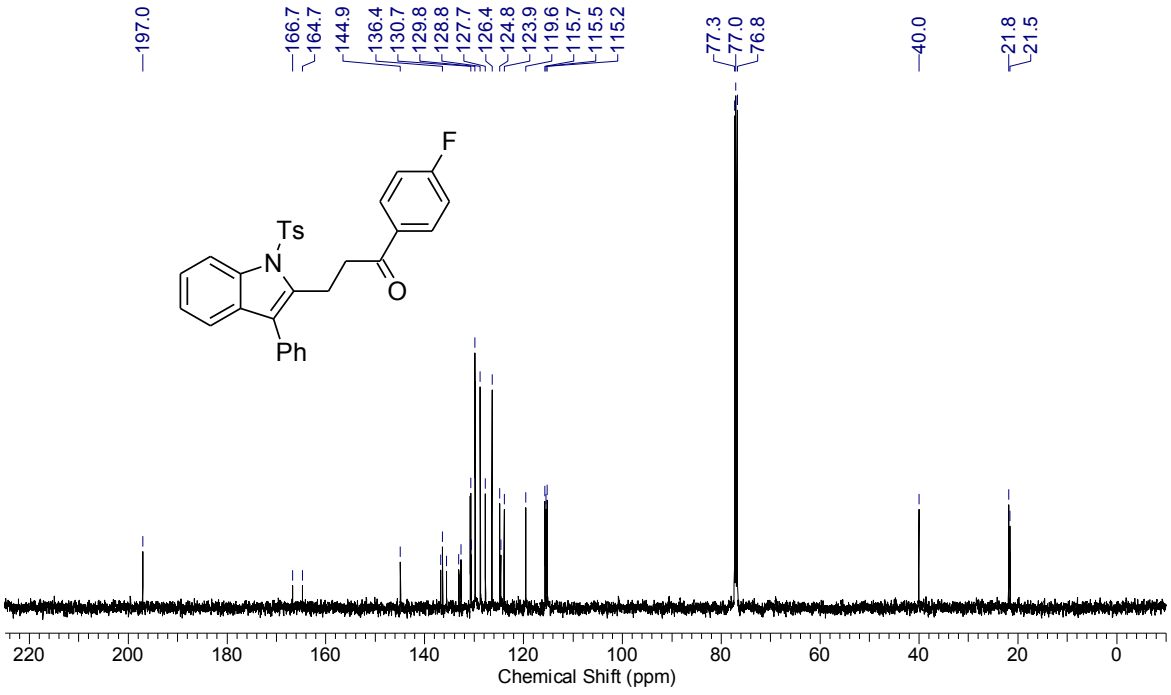
199aj:


8.31
8.31
8.03
7.71
7.69
7.69
7.66
7.45
7.34
7.33
7.26
7.21
7.21
7.19
3.53
3.52
3.50
3.50
3.49
3.48
3.47
3.45
2.34
CF3
Ts
N
O
Ph
1.00
2.04
4.11
2.14
5.25
3.60
4.11
3.01
Chemical Shift (ppm)

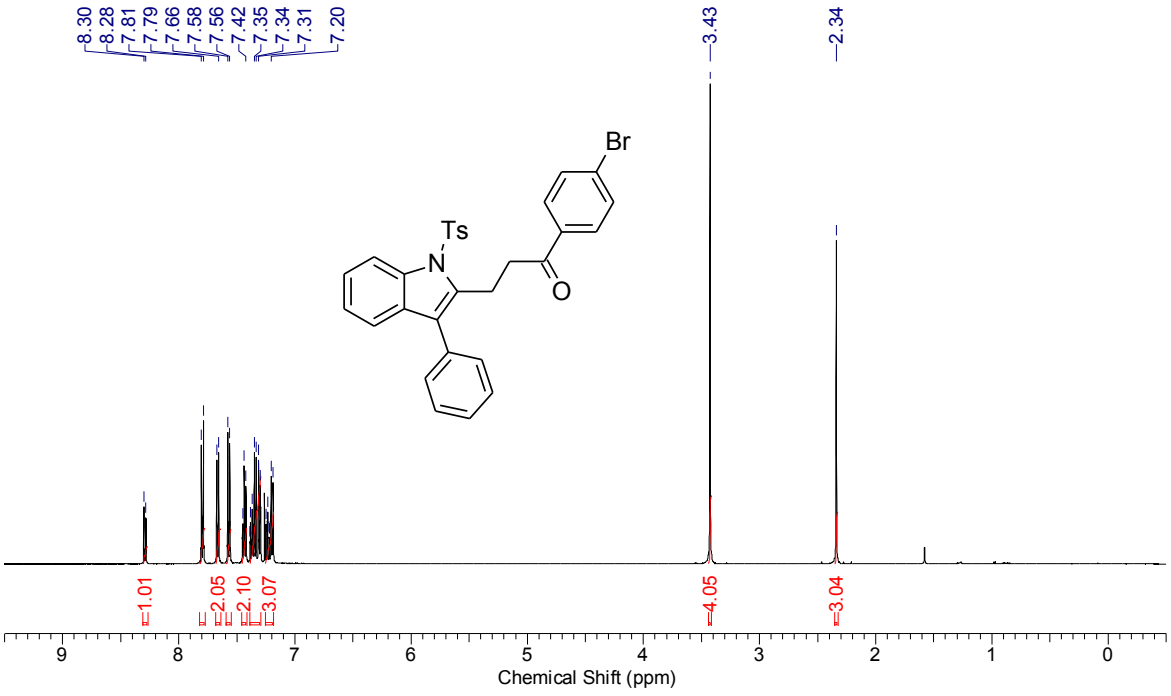

197.7
145.0
136.0
132.6
129.9
129.8
128.8
128.4
127.8
126.4
125.6
124.9
124.0
119.6
115.2
77.3
77.0
76.7
40.4
21.7
21.5
CF3
Ts
N
O
Chemical Shift (ppm)

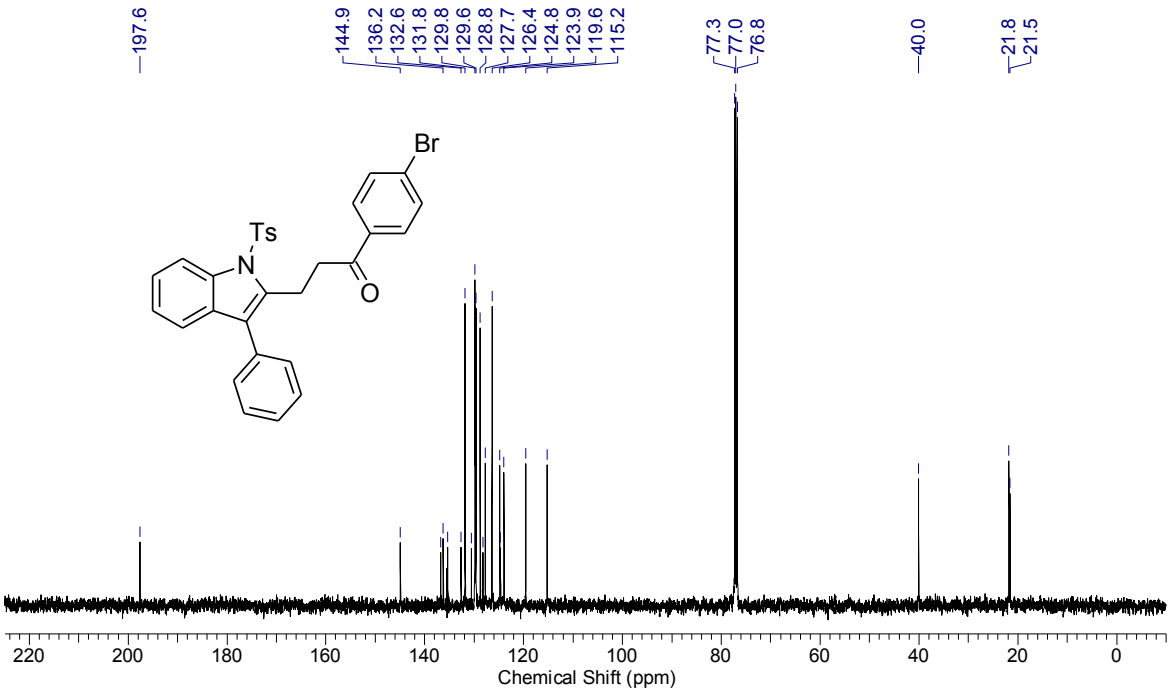
199ak:


8.31
8.29
7.97
7.68
7.66
7.44
7.35
7.34
7.34
7.32
7.30
7.21
7.19
7.10
3.44
2.34
F
Ts
N
O
Ph
1.00
2.06
2.03
5.10
2.02
4.01
3.02
9
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

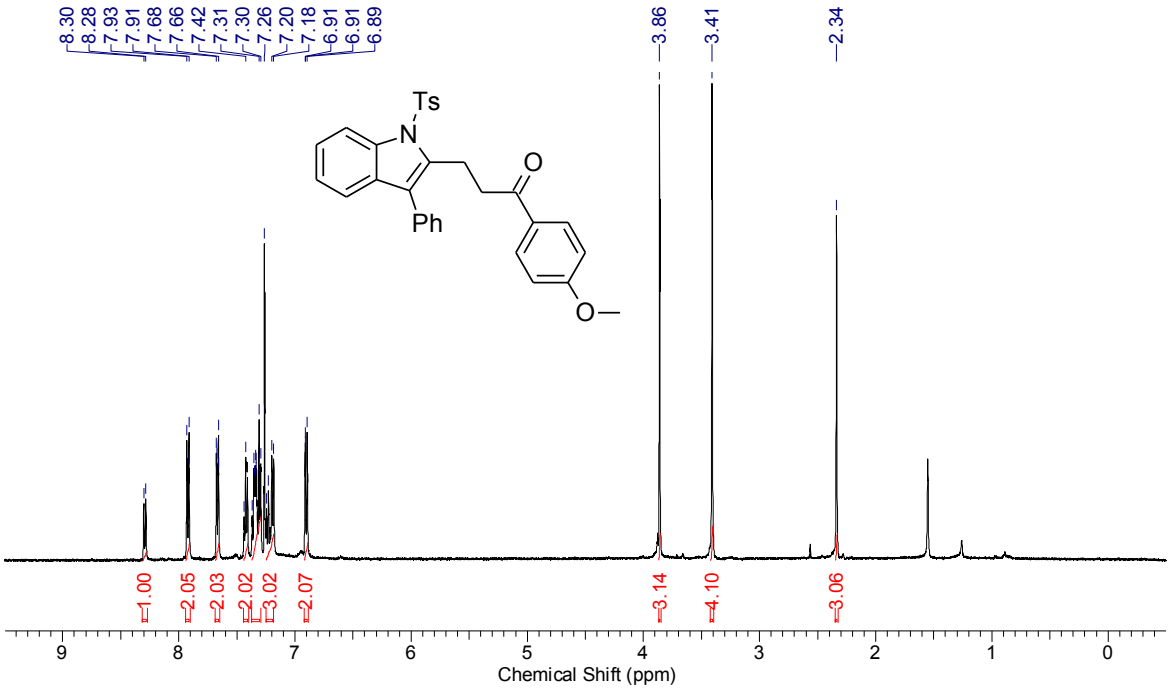

197.0
166.7
164.7
144.9
136.4
130.7
129.8
128.8
127.7
126.4
124.8
123.9
119.6
115.7
115.5
115.2
77.3
77.0
76.8
40.0
21.8
21.5
F
Ts
N
O
Ph
220
200
180
160
140
120
100
80
60
40
20
0
Chemical Shift (ppm)

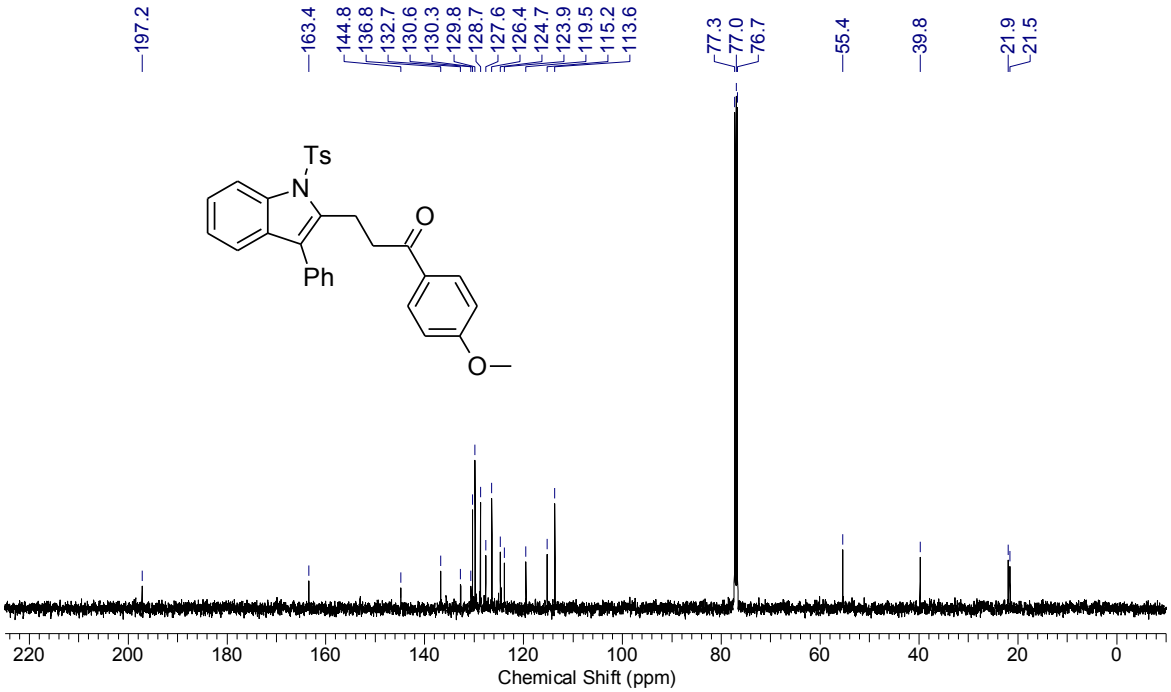
199al:


8.30
8.28
7.81
7.79
7.66
7.58
7.56
7.42
7.35
7.34
7.31
7.20
3.43
2.34
Br
Ts
N
O
1.01
2.05
2.10
3.07
4.05
3.04
Chemical Shift (ppm)

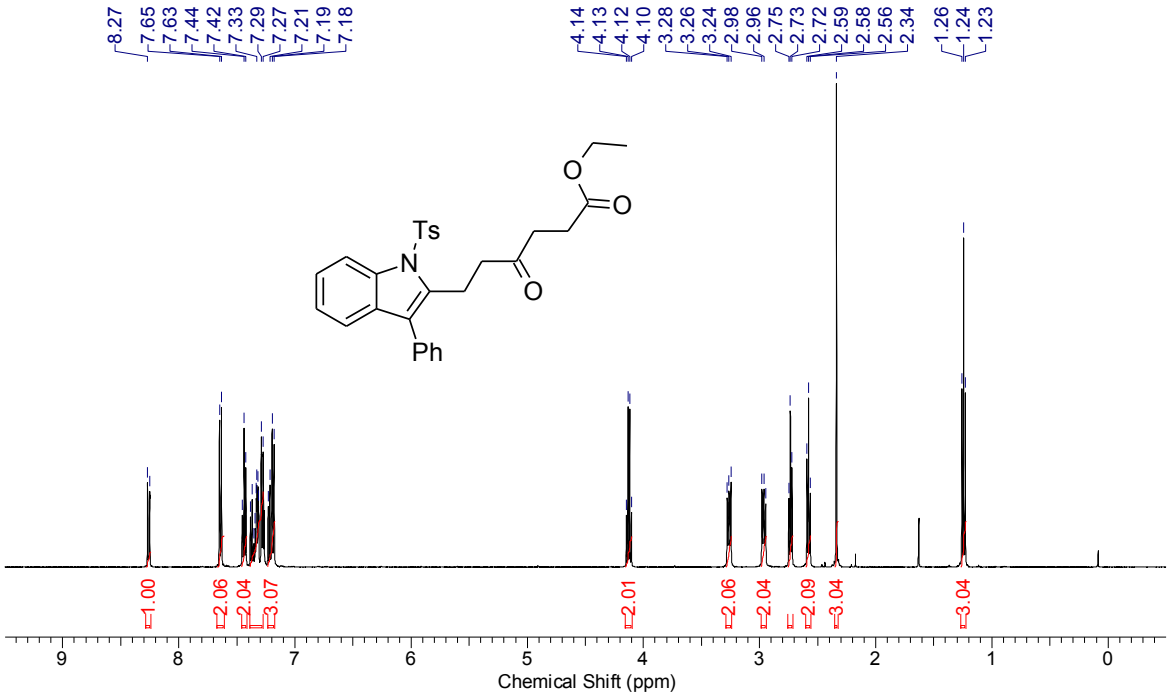

197.6
144.9
136.2
132.6
131.8
129.8
129.6
128.8
127.7
126.4
124.8
123.9
119.6
115.2
77.3
77.0
76.8
40.0
21.8
21.5
Br
Ts
N
O
Chemical Shift (ppm)

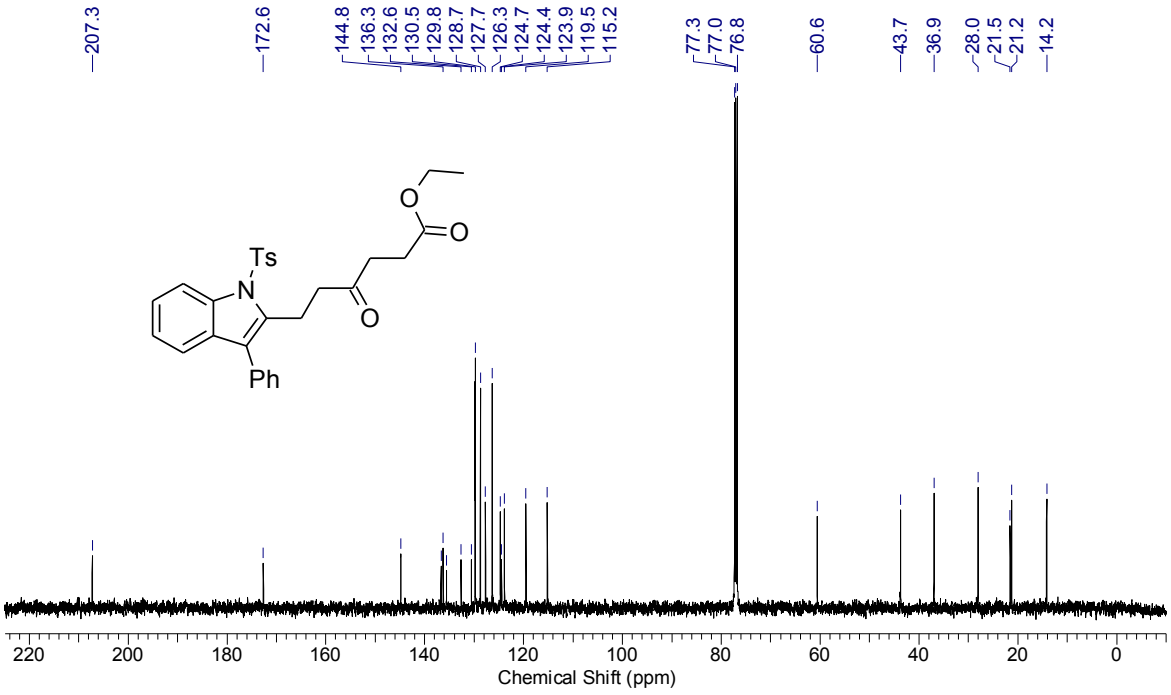
199am:


8.30
8.28
7.93
7.91
7.68
7.66
7.42
7.31
7.30
7.26
7.20
7.18
6.91
6.89
3.86
3.41
2.34
Ts
N
O
Ph
O—
1.00
2.05
2.03
2.02
3.02
2.07
3.14
4.10
3.06
9
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

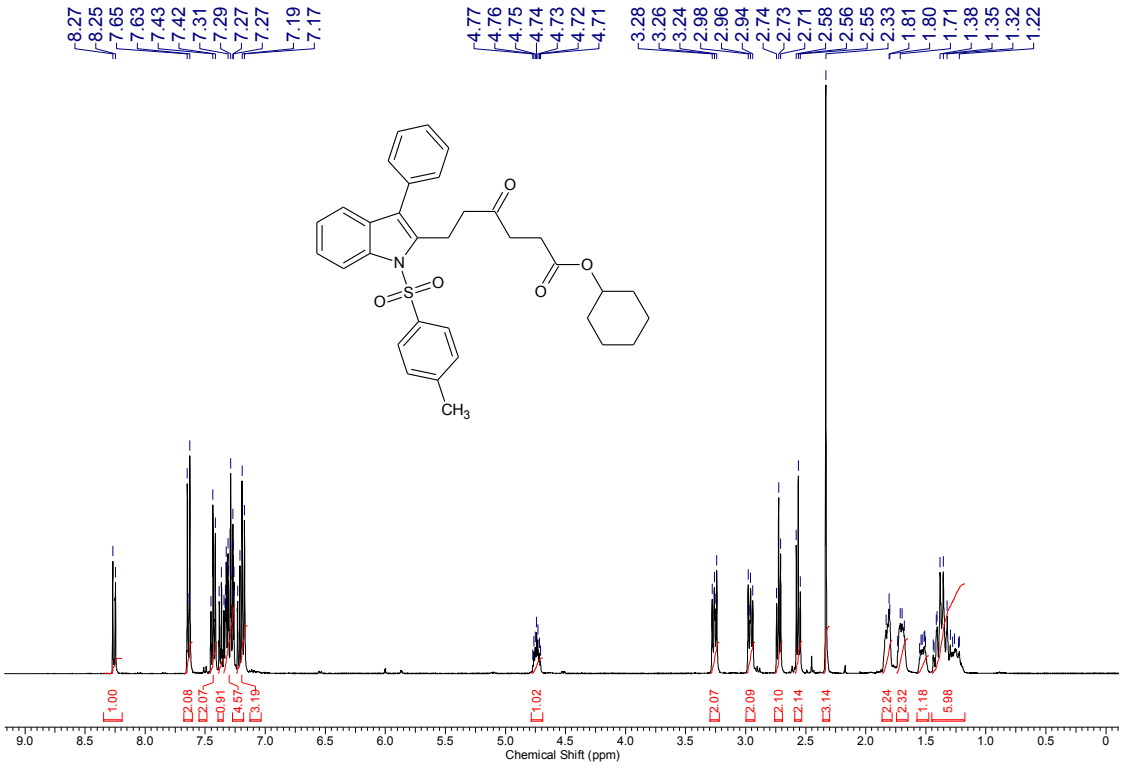

197.2
163.4
144.8
136.8
132.7
130.6
130.3
129.8
128.7
127.6
126.4
124.7
123.9
119.5
115.2
113.6
77.3
77.0
76.7
55.4
39.8
21.9
21.5
Ts
N
O
Ph
O—
220
200
180
160
140
120
100
80
60
40
20
0
Chemical Shift (ppm)

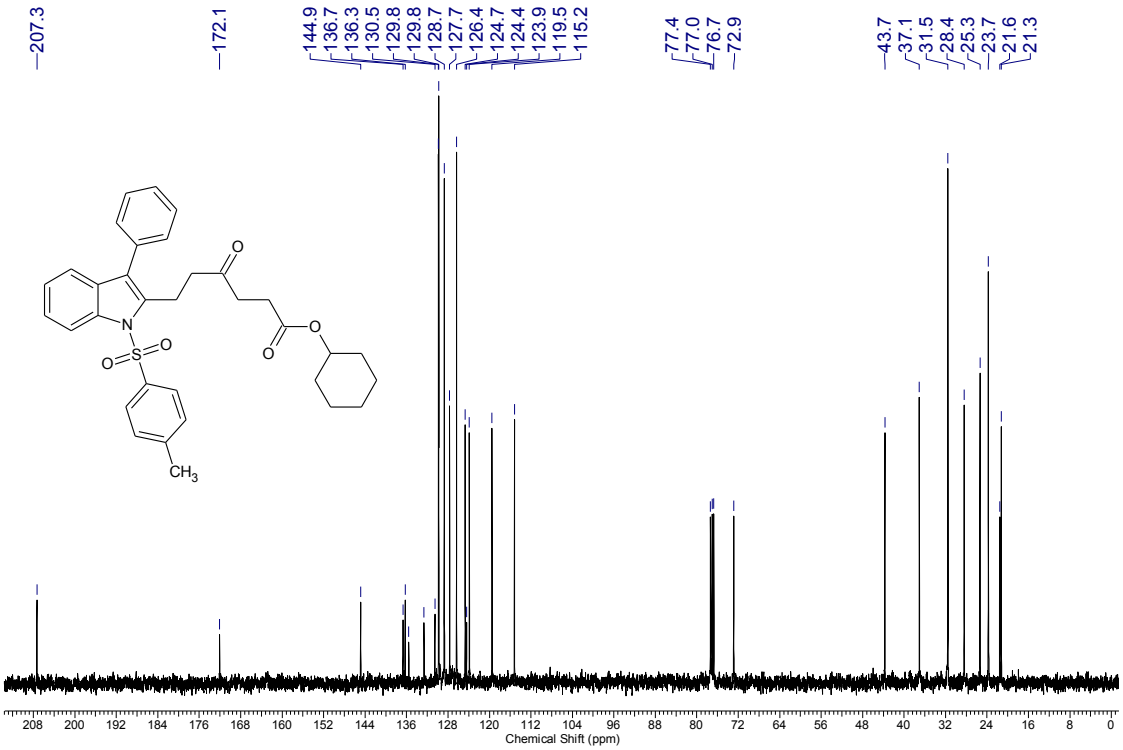
199an:


8.27
7.65
7.63
7.44
7.42
7.33
7.29
7.27
7.21
7.19
7.18
4.14
4.13
4.12
4.10
3.28
3.26
3.24
2.98
2.96
2.75
2.73
2.72
2.59
2.58
2.56
2.34
1.26
1.24
1.23
Ts
N
O
O
O
Ph
1.00
2.06
2.04
3.07
2.01
2.06
2.04
2.09
3.04
3.04
Chemical Shift (ppm)

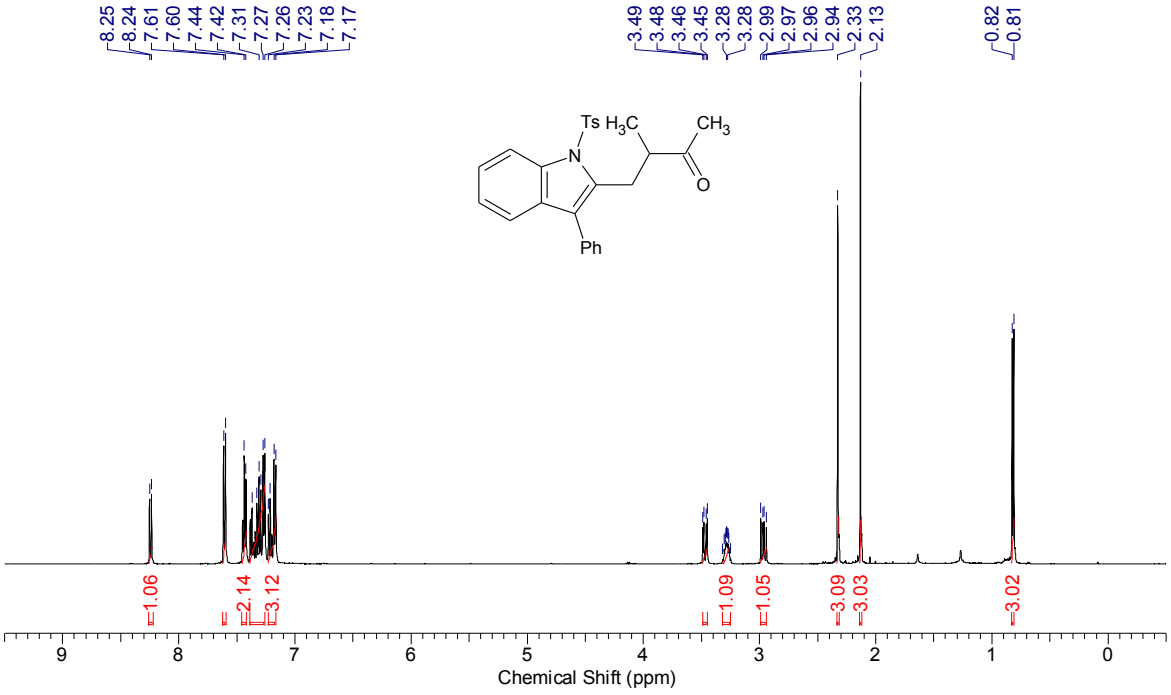

207.3
172.6
144.8
136.3
132.6
130.5
129.8
128.7
127.7
126.3
124.7
124.4
123.9
119.5
115.2
77.3
77.0
76.8
60.6
43.7
36.9
28.0
21.5
21.2
14.2
Ts
N
O
O
O
Ph
Chemical Shift (ppm)

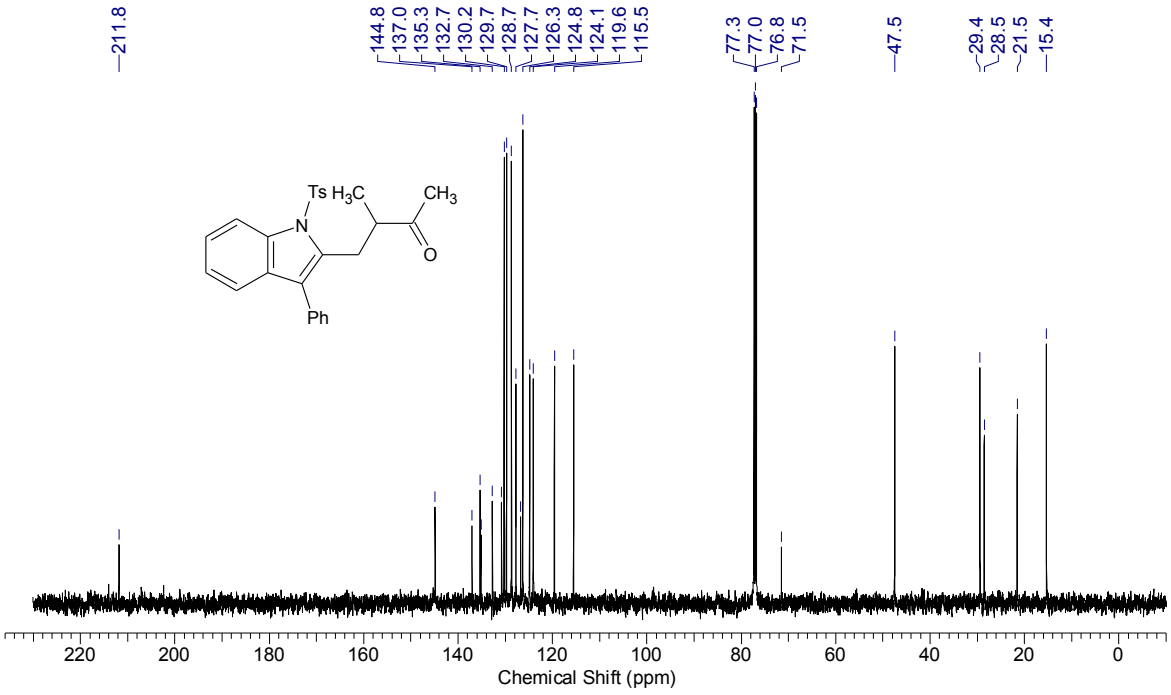
199ao:


8.27
8.25
7.65
7.63
7.43
7.42
7.31
7.29
7.27
7.27
7.19
7.17
4.77
4.76
4.75
4.74
4.73
4.72
4.71
3.28
3.26
3.24
2.98
2.96
2.94
2.74
2.73
2.71
2.58
2.56
2.55
2.33
1.81
1.80
1.71
1.38
1.35
1.32
1.22
O
N
O
S
O
O
O
O
CH3
1.00
2.08
2.07
0.91
4.57
3.19
1.02
2.07
2.09
2.10
2.14
3.14
2.24
2.32
1.18
5.98
Chemical Shift (ppm)

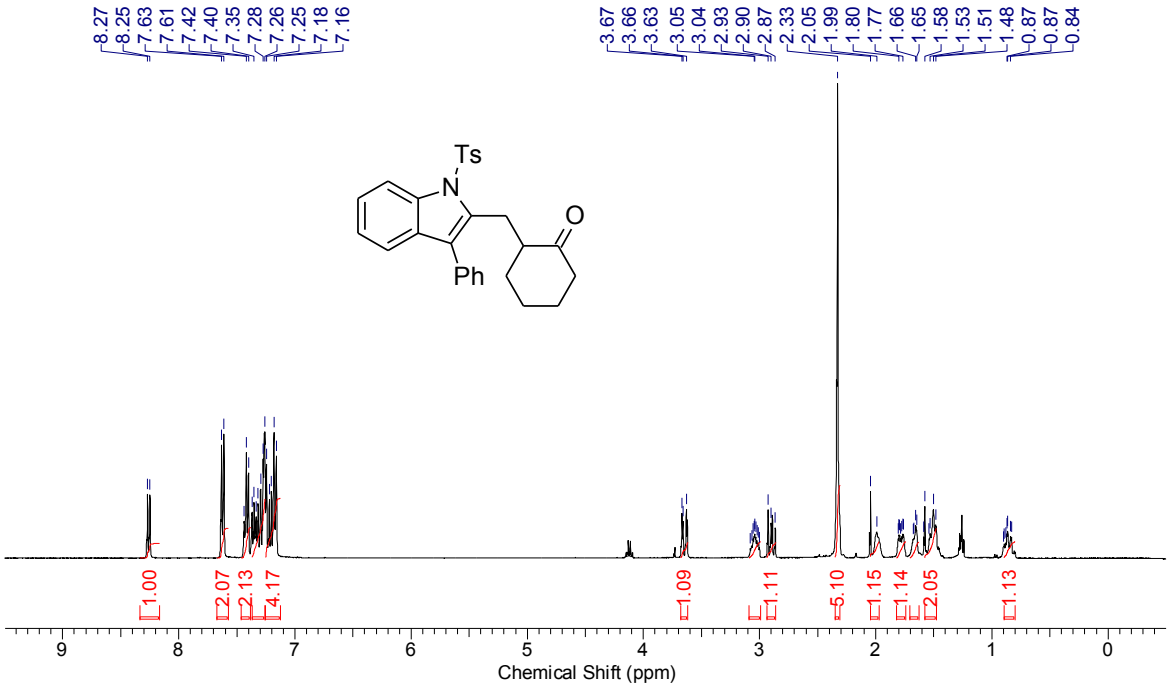

207.3
172.1
144.9
136.7
136.3
130.5
129.8
129.8
128.7
127.7
126.4
124.7
124.4
123.9
119.5
115.2
77.4
77.0
76.7
72.9
43.7
37.1
31.5
28.4
25.3
23.7
21.6
21.3
O
N
O
S
O
O
O
O
CH3
Chemical Shift (ppm)

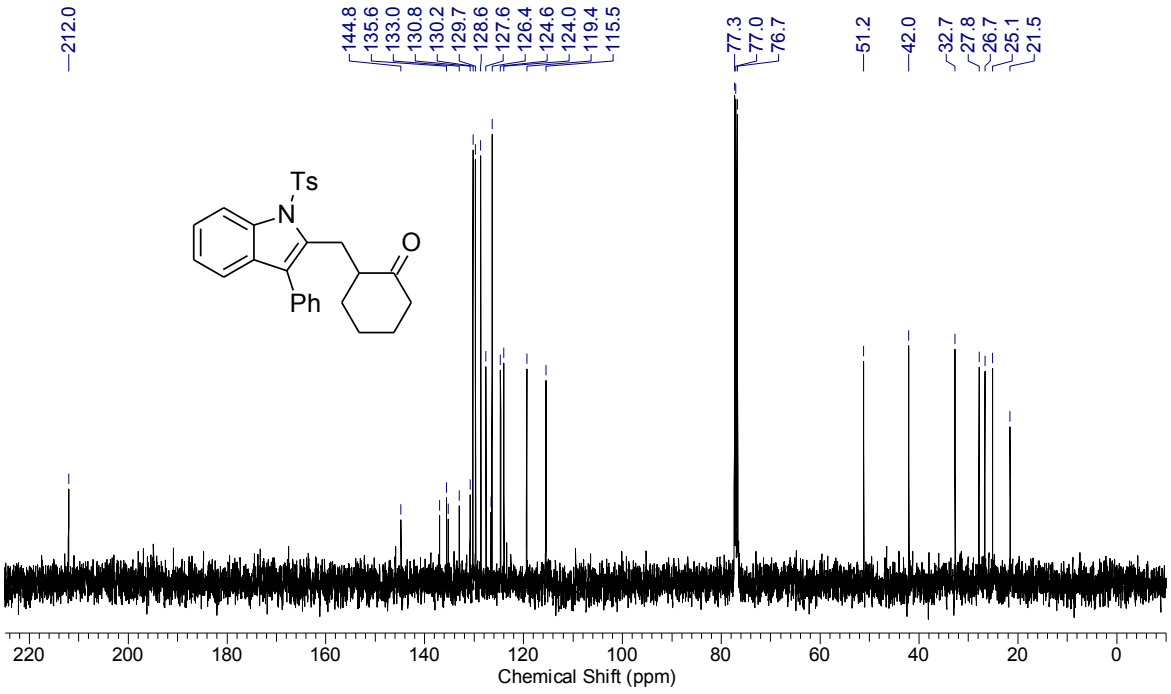
199ap:


8.25
8.24
7.61
7.60
7.44
7.42
7.31
7.27
7.26
7.23
7.18
7.17
3.49
3.48
3.46
3.45
3.28
3.28
2.99
2.97
2.96
2.94
2.33
2.13
0.82
0.81
Ts
H3C
CH3
N
O
Ph
1.06
2.14
3.12
1.09
1.05
3.09
3.03
3.02
Chemical Shift (ppm)

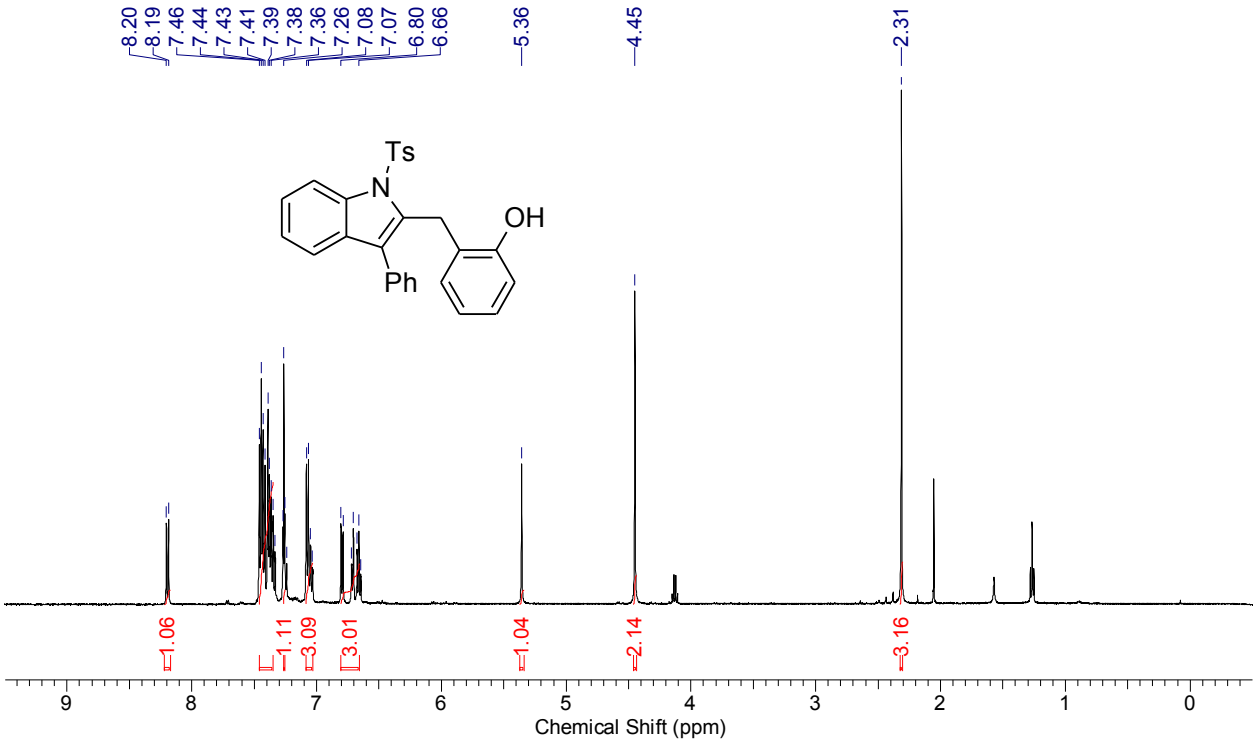

211.8
144.8
137.0
135.3
132.7
130.2
129.7
128.7
127.7
126.3
124.8
124.1
119.6
115.5
77.3
77.0
76.8
71.5
47.5
29.4
28.5
21.5
15.4
Ts
H3C
CH3
N
O
Ph
Chemical Shift (ppm)

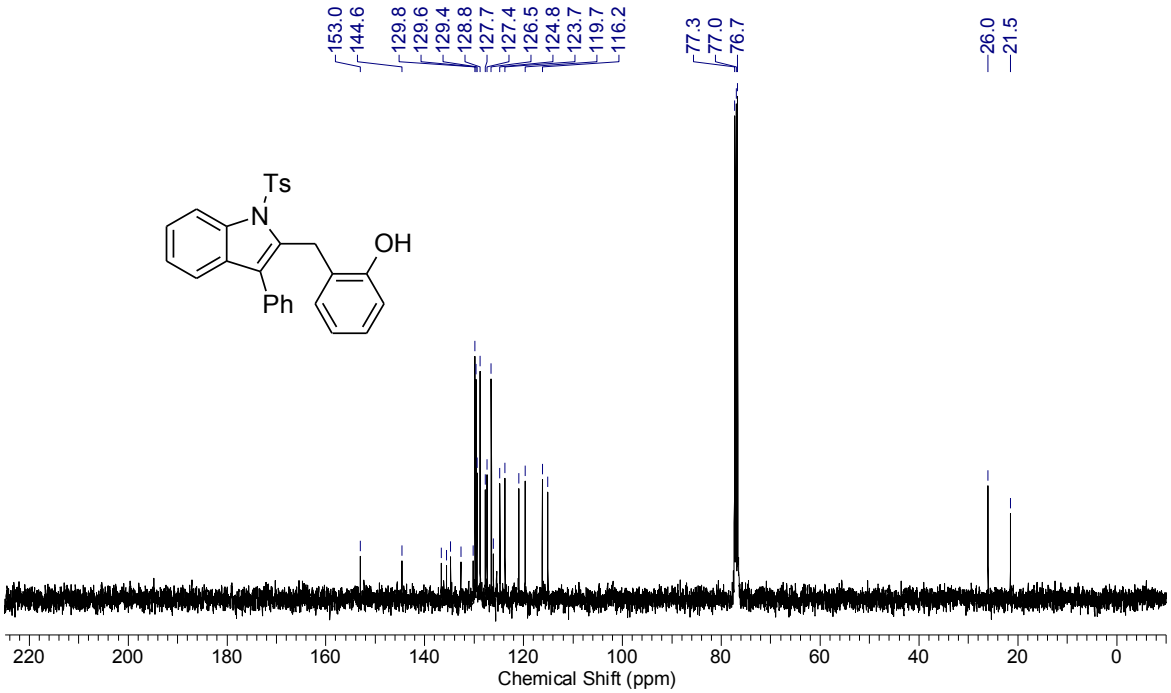
199aq:


8.27
8.25
7.63
7.61
7.42
7.40
7.35
7.28
7.26
7.25
7.18
7.16
3.67
3.66
3.63
3.05
3.04
2.93
2.90
2.87
2.33
2.05
1.99
1.80
1.77
1.66
1.65
1.58
1.53
1.51
1.48
0.87
0.87
0.84
Ts
N
O
Ph
1.00
2.07
2.13
4.17
1.09
1.11
5.10
1.15
1.14
2.05
1.13
Chemical Shift (ppm)

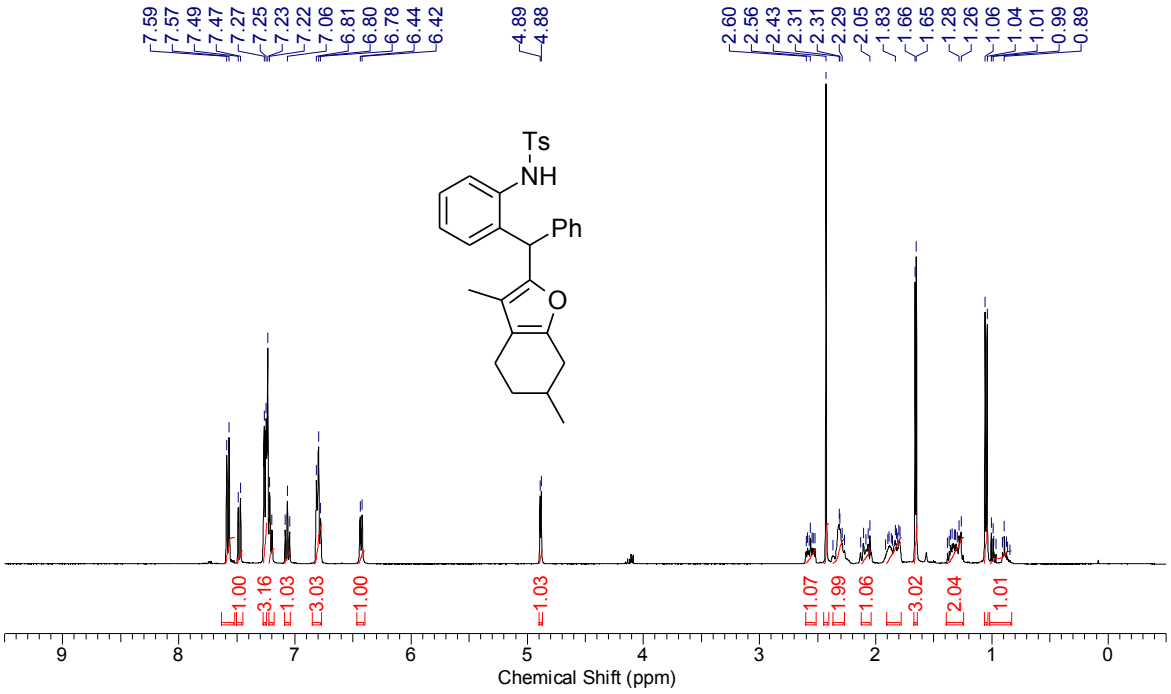

212.0
144.8
135.6
133.0
130.8
130.2
129.7
128.6
127.6
126.4
124.6
124.0
119.4
115.5
77.3
77.0
76.7
51.2
42.0
32.7
27.8
26.7
25.1
21.5
Ts
N
O
Ph
Chemical Shift (ppm)

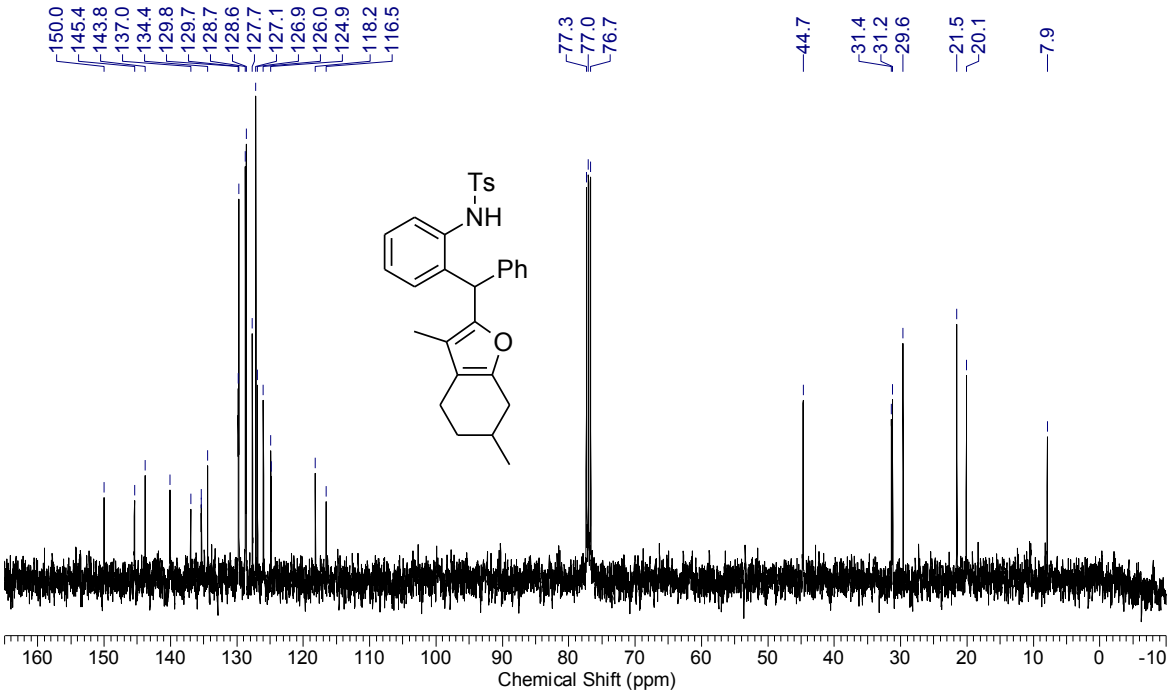
199ar:


8.20
8.19
7.46
7.44
7.43
7.41
7.39
7.38
7.36
7.26
7.08
7.07
6.80
6.66
5.36
4.45
2.31
Ts
N
OH
Ph
1.06
1.11
3.09
3.01
1.04
2.14
3.16
Chemical Shift (ppm)

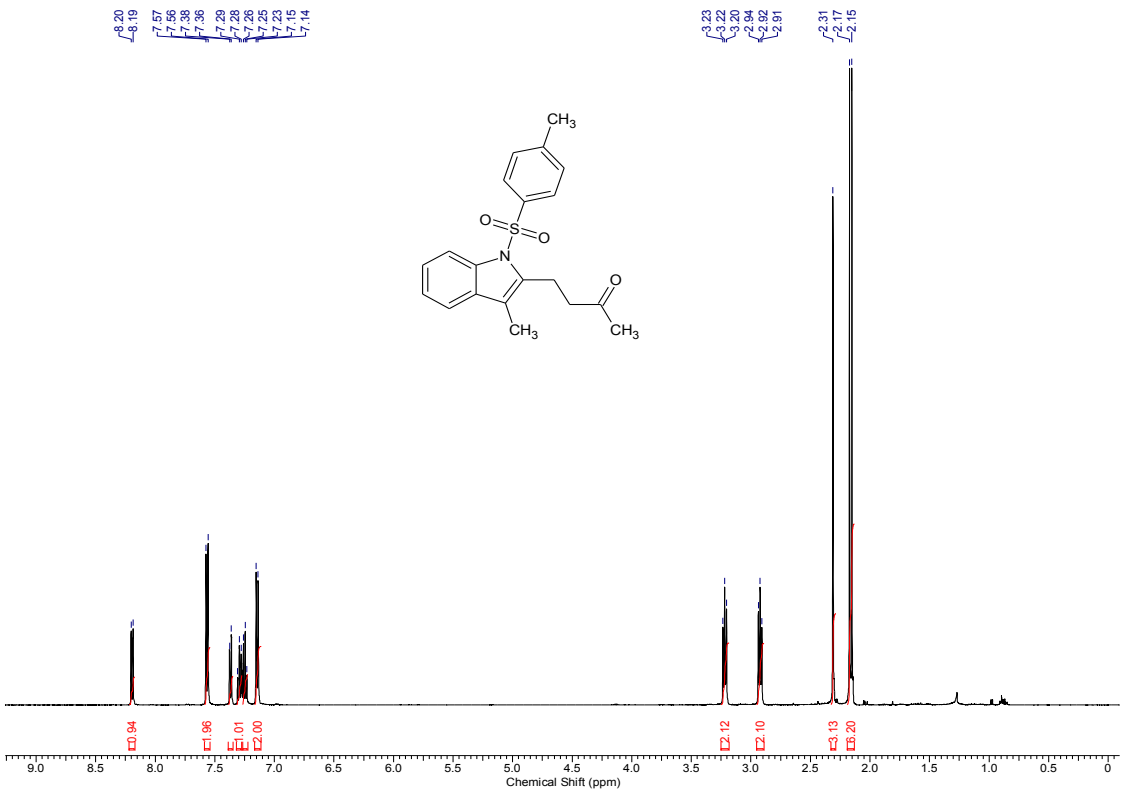

153.0
144.6
129.8
129.6
129.4
128.8
127.7
127.4
126.5
124.8
123.7
119.7
116.2
77.3
77.0
76.7
26.0
21.5
Ts
N
OH
Ph
Chemical Shift (ppm)

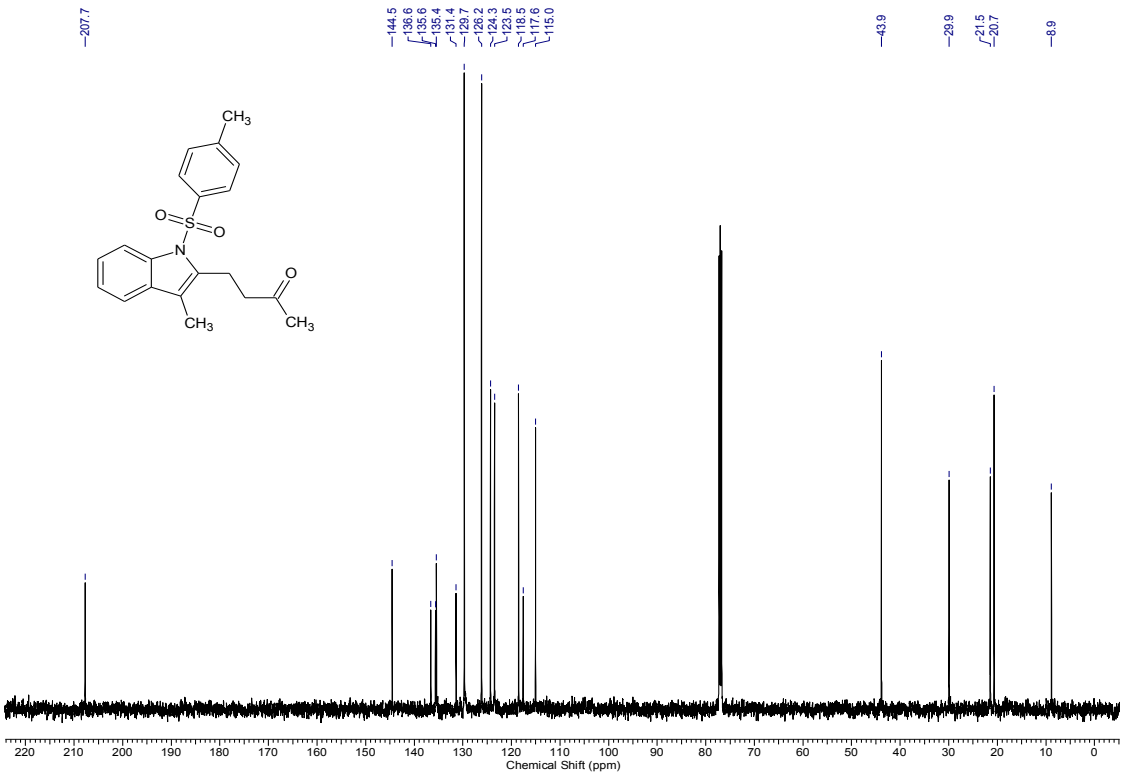
199as:


7.59
7.57
7.49
7.47
7.27
7.25
7.23
7.22
7.06
6.81
6.80
6.78
6.44
6.42
4.89
4.88
2.60
2.56
2.43
2.31
2.31
2.29
2.05
1.83
1.66
1.65
1.28
1.26
1.06
1.04
1.01
0.99
0.89
Ts
NH
Ph
O
1.00
3.16
1.03
3.03
1.00
1.03
1.07
1.99
1.06
3.02
2.04
1.01
Chemical Shift (ppm)

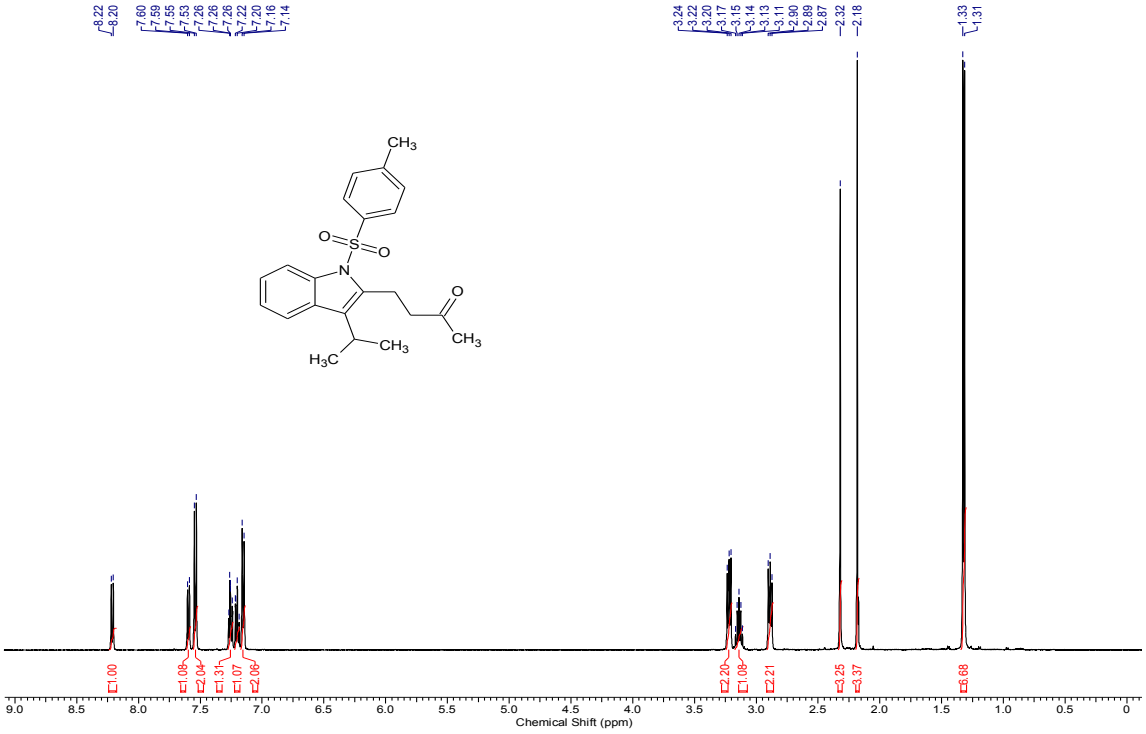

150.0
145.4
143.8
137.0
134.4
129.8
129.7
128.7
128.6
127.7
127.1
126.9
126.0
124.9
118.2
116.5
77.3
77.0
76.7
44.7
31.4
31.2
29.6
21.5
20.1
7.9
Ts
NH
Ph
O
Chemical Shift (ppm)

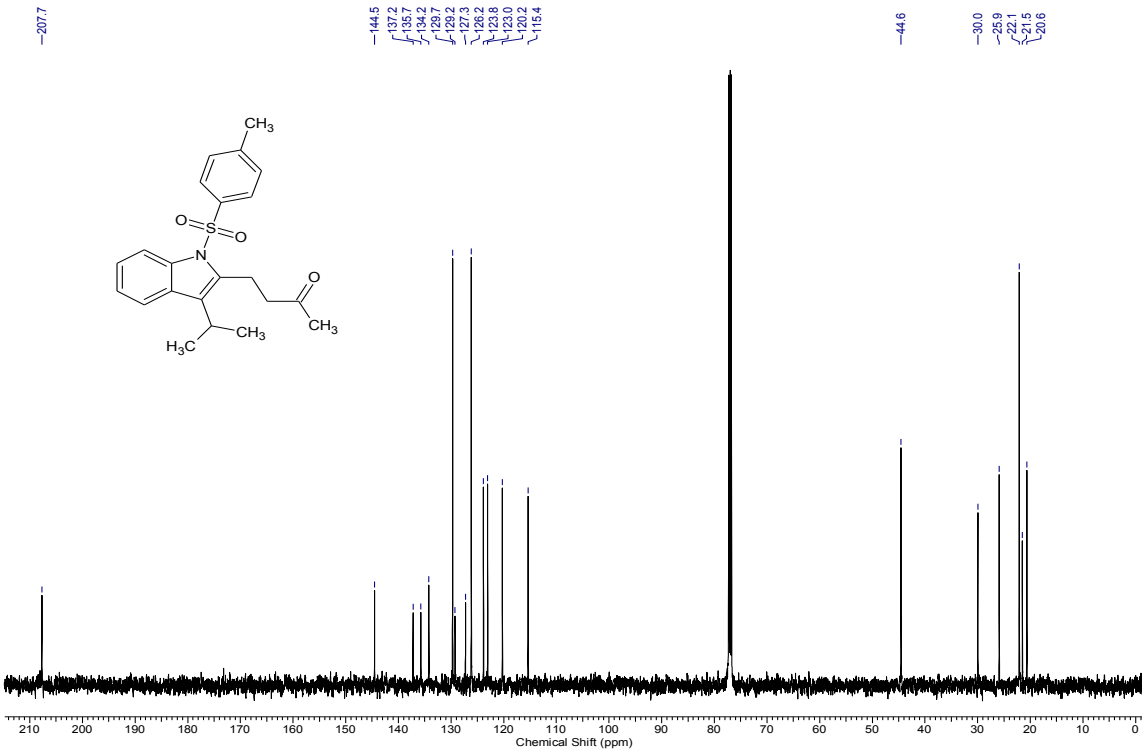
199ba:


8.20
8.19
7.57
7.56
7.38
7.36
7.29
7.28
7.26
7.25
7.23
7.15
7.14
3.23
3.22
3.20
2.94
2.92
2.91
2.31
2.17
2.15
CH3
O
S
O
N
O
CH3
CH3
3.94
1.96
1.01
2.00
2.12
2.10
3.13
5.20
Chemical Shift (ppm)

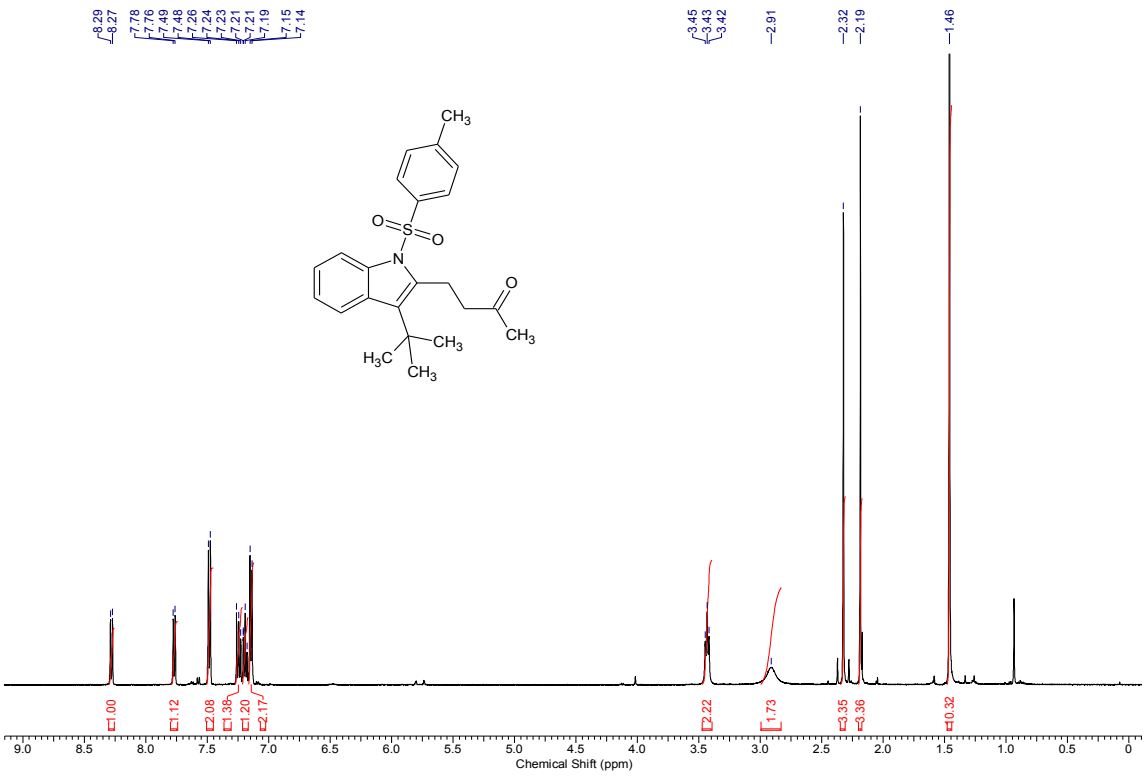

207.7
144.5
136.6
135.6
135.4
131.4
129.7
126.2
124.3
123.5
118.5
117.6
115.0
43.9
29.9
21.5
20.7
8.9
CH3
O
S
O
N
O
CH3
CH3
Chemical Shift (ppm)

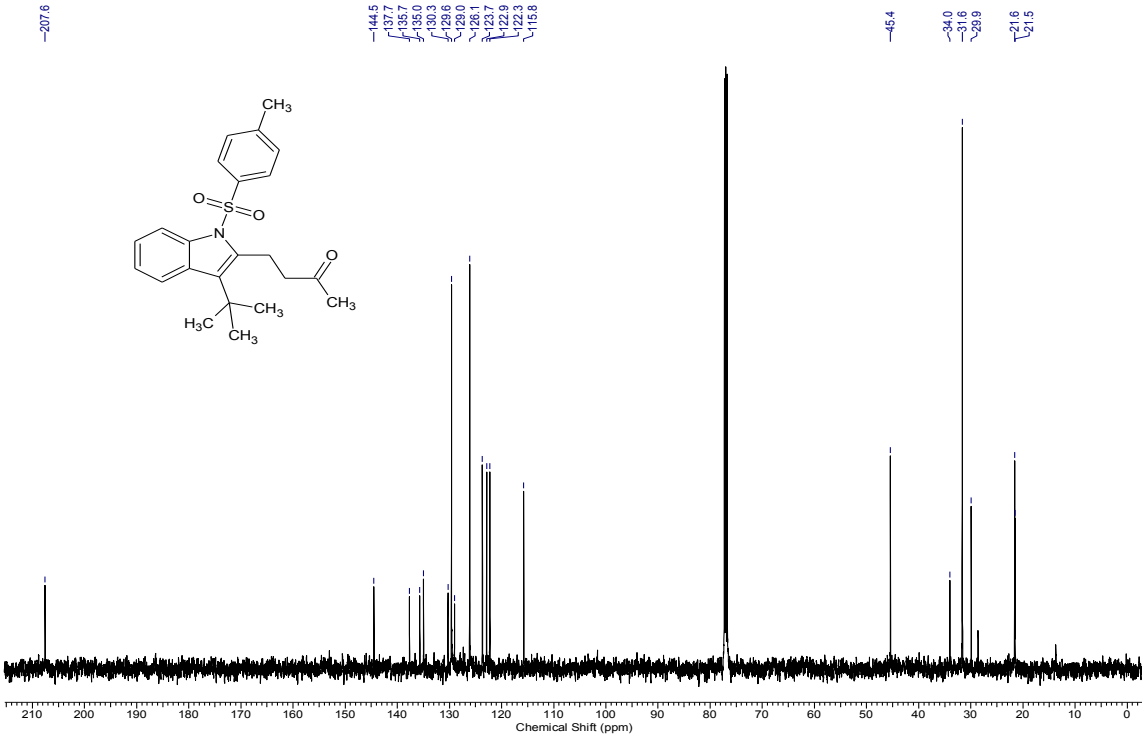
199ca:


8.22
8.20
7.60
7.59
7.55
7.53
7.26
7.26
7.26
7.22
7.20
7.16
7.14
3.24
3.22
3.20
3.17
3.15
3.14
3.13
3.11
2.90
2.89
2.87
2.32
2.18
1.33
1.31
CH3
O
S
O
N
O
CH3
H3C
CH3
1.00
1.08
2.04
1.31
1.07
2.06
2.20
1.08
2.21
3.25
3.37
6.68
Chemical Shift (ppm)

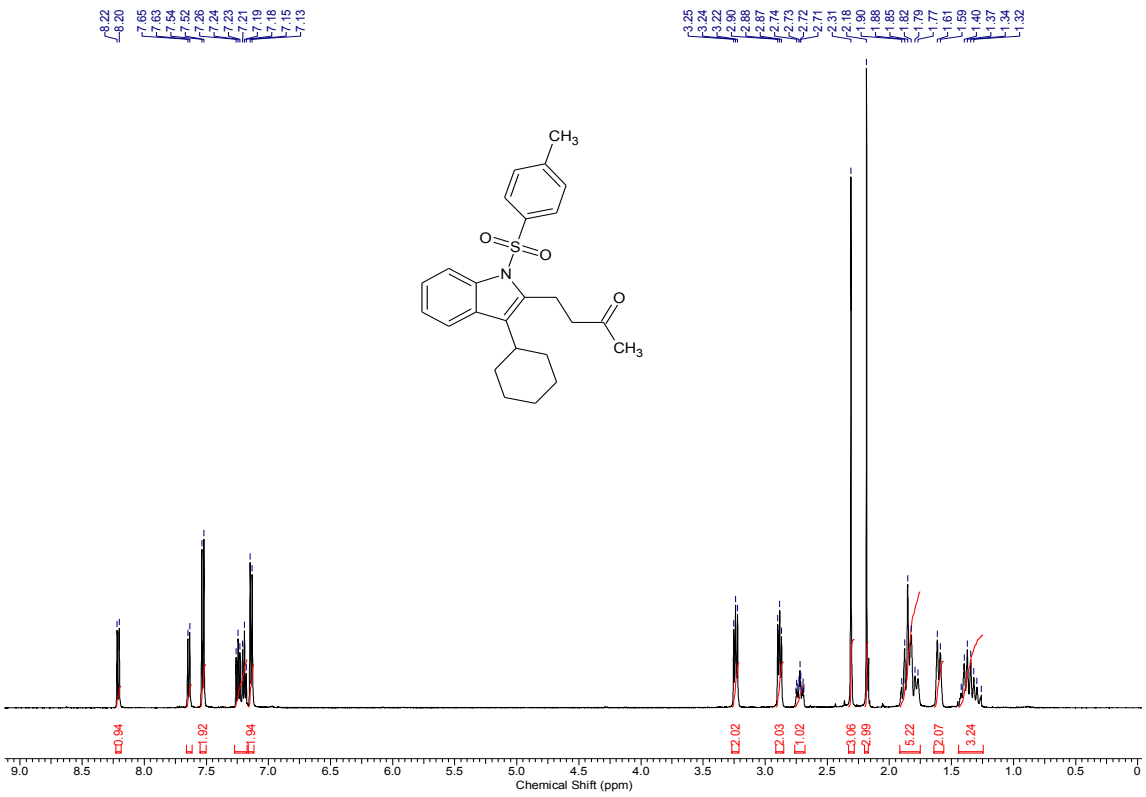

207.7
144.5
137.2
135.7
134.2
129.7
129.2
127.3
126.2
123.8
123.0
120.2
115.4
44.6
30.0
25.9
22.1
21.5
20.6
CH3
O
S
O
N
O
CH3
H3C
CH3
Chemical Shift (ppm)

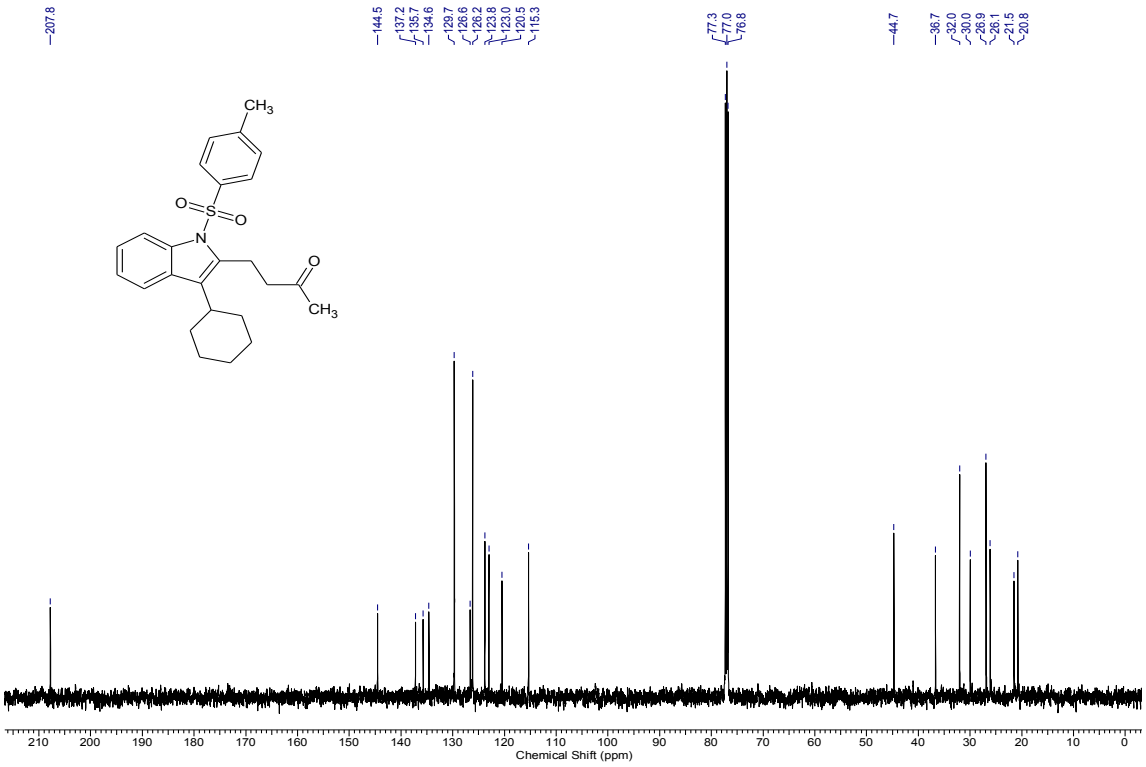
199da:


8.29
8.27
7.78
7.76
7.49
7.48
7.26
7.24
7.23
7.21
7.21
7.19
7.15
7.14
3.45
3.43
3.42
2.91
2.32
2.19
1.46
1.00
1.12
2.08
1.38
1.20
2.17
2.22
1.73
3.35
3.36
10.32
Chemical Shift (ppm)

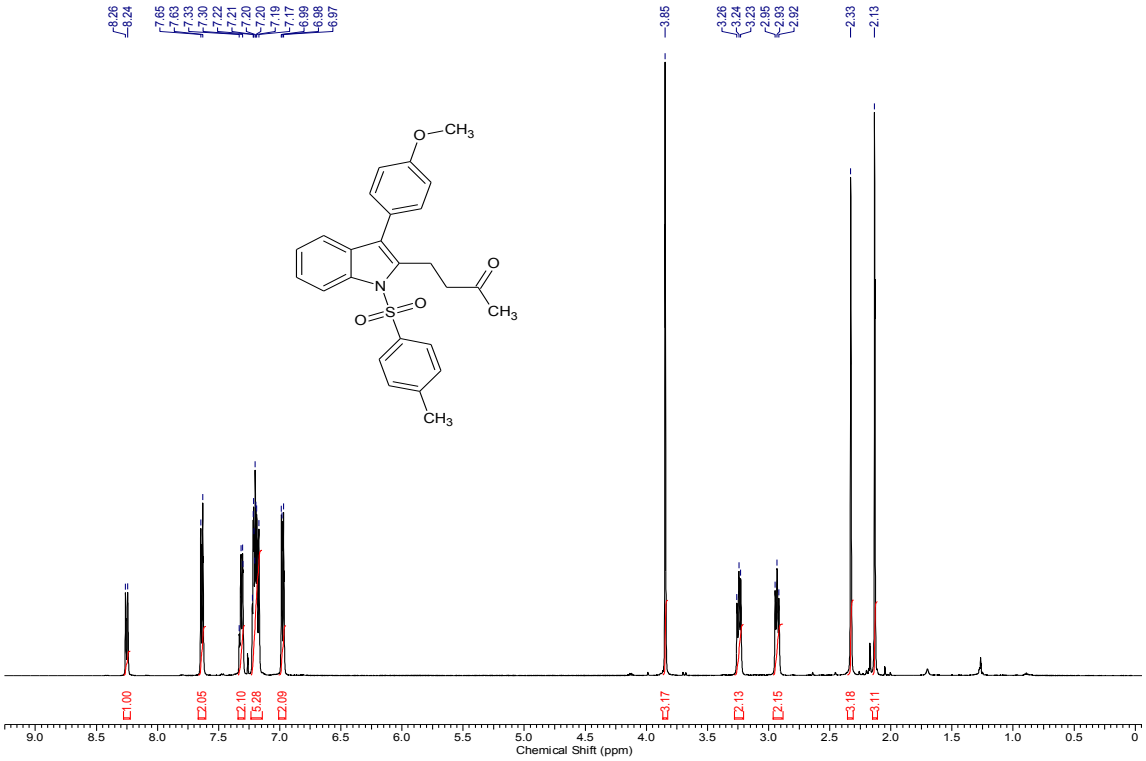

207.6
144.5
137.7
135.7
135.0
130.3
129.6
129.0
126.1
123.7
122.9
122.3
115.8
45.4
34.0
31.6
29.9
21.6
21.5
Chemical Shift (ppm)

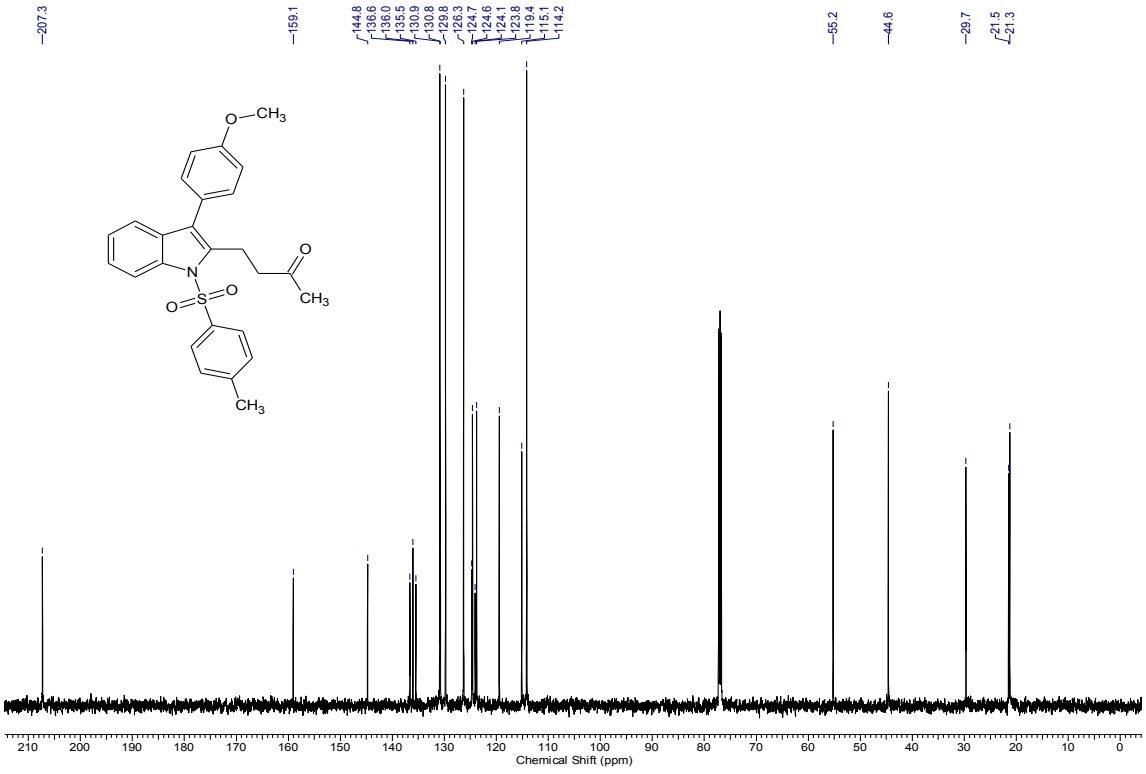
199ea:


8.22
8.20
7.65
7.63
7.54
7.52
7.26
7.24
7.23
7.21
7.19
7.18
7.15
7.13
3.25
3.24
3.22
2.90
2.88
2.87
2.74
2.73
2.72
2.71
2.31
2.18
1.90
1.88
1.85
1.82
1.79
1.77
1.61
1.59
1.40
1.37
1.34
1.32
CH3
O
S
O
N
O
CH3
1.00
1.92
1.94
2.02
2.03
1.02
3.06
2.99
5.22
2.07
3.24
Chemical Shift (ppm)

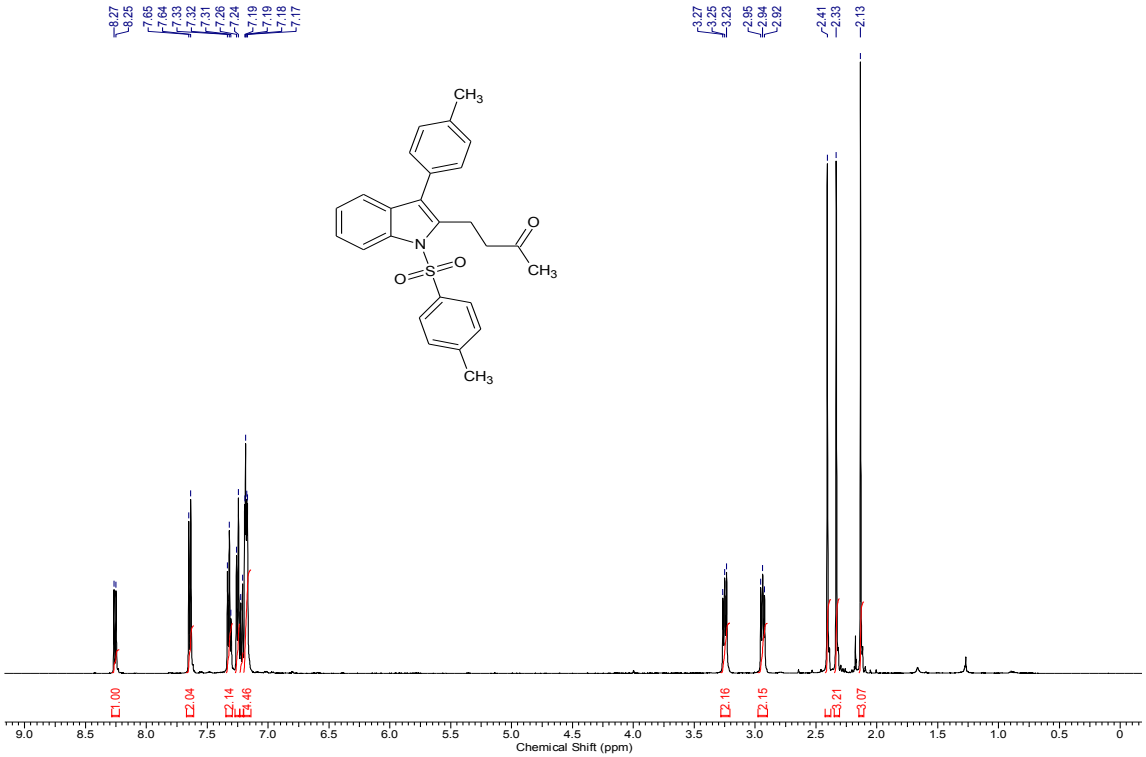

207.8
144.5
137.2
135.7
134.6
129.7
126.6
126.2
123.8
123.0
120.5
115.3
77.3
77.0
76.8
44.7
36.7
32.0
30.0
26.9
26.1
21.5
20.8
CH3
O
S
O
N
O
CH3
Chemical Shift (ppm)

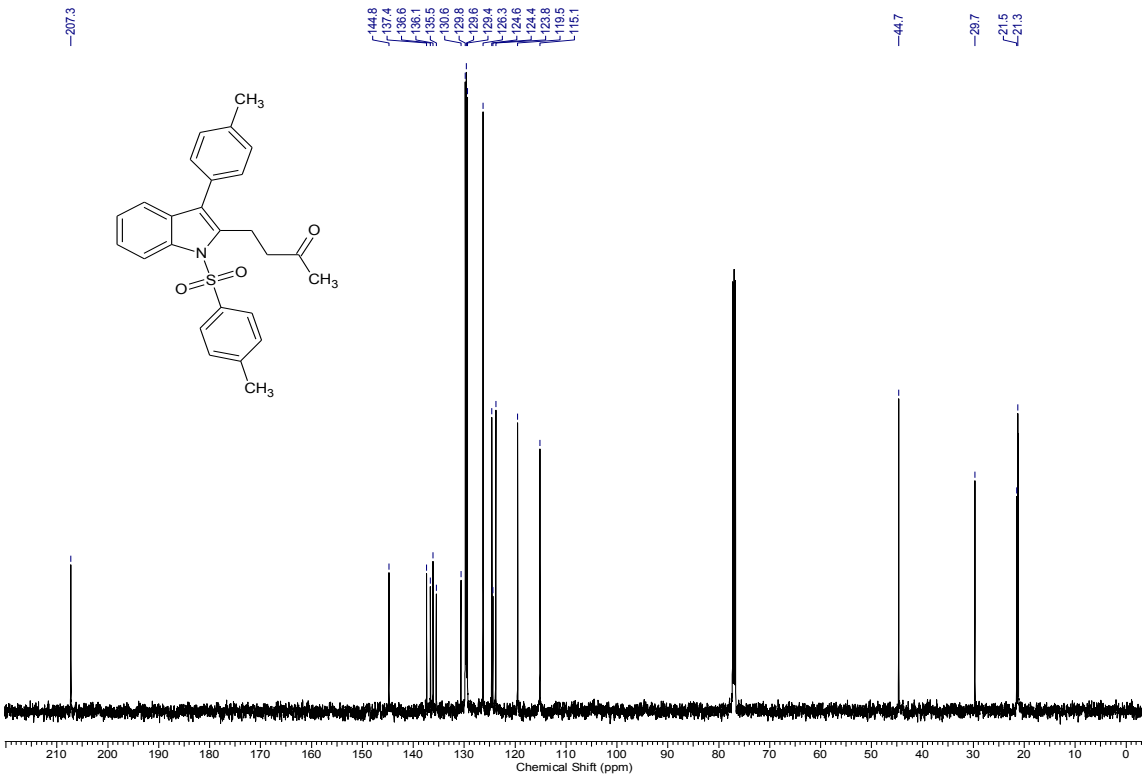
199fa:


8.26
8.24
7.65
7.63
7.33
7.30
7.22
7.21
7.20
7.20
7.19
7.17
6.99
6.98
6.97
3.85
3.26
3.24
3.23
2.95
2.93
2.92
2.33
2.13
1.00
2.05
2.10
5.28
2.09
3.17
2.13
2.15
3.18
3.11
Chemical Shift (ppm)

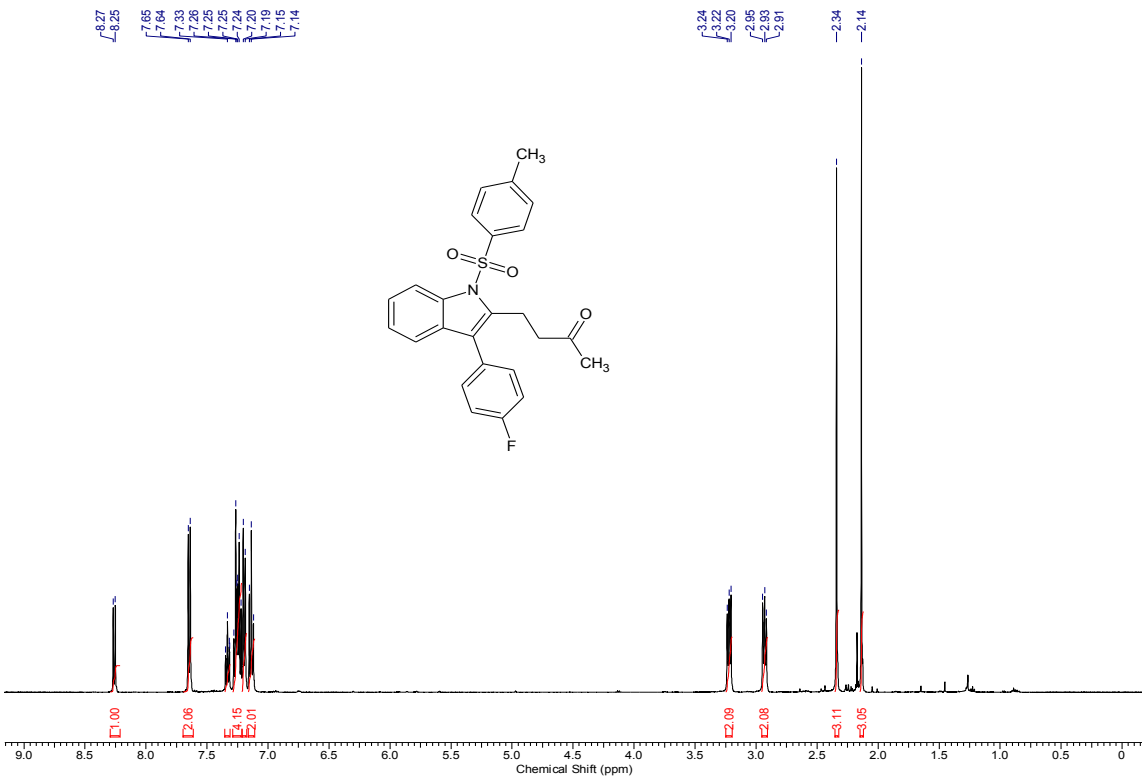

207.3
159.1
144.8
136.6
136.0
135.5
130.9
130.8
129.8
126.3
124.7
124.6
124.1
123.8
119.4
115.1
114.2
55.2
44.6
29.7
21.5
21.3
Chemical Shift (ppm)

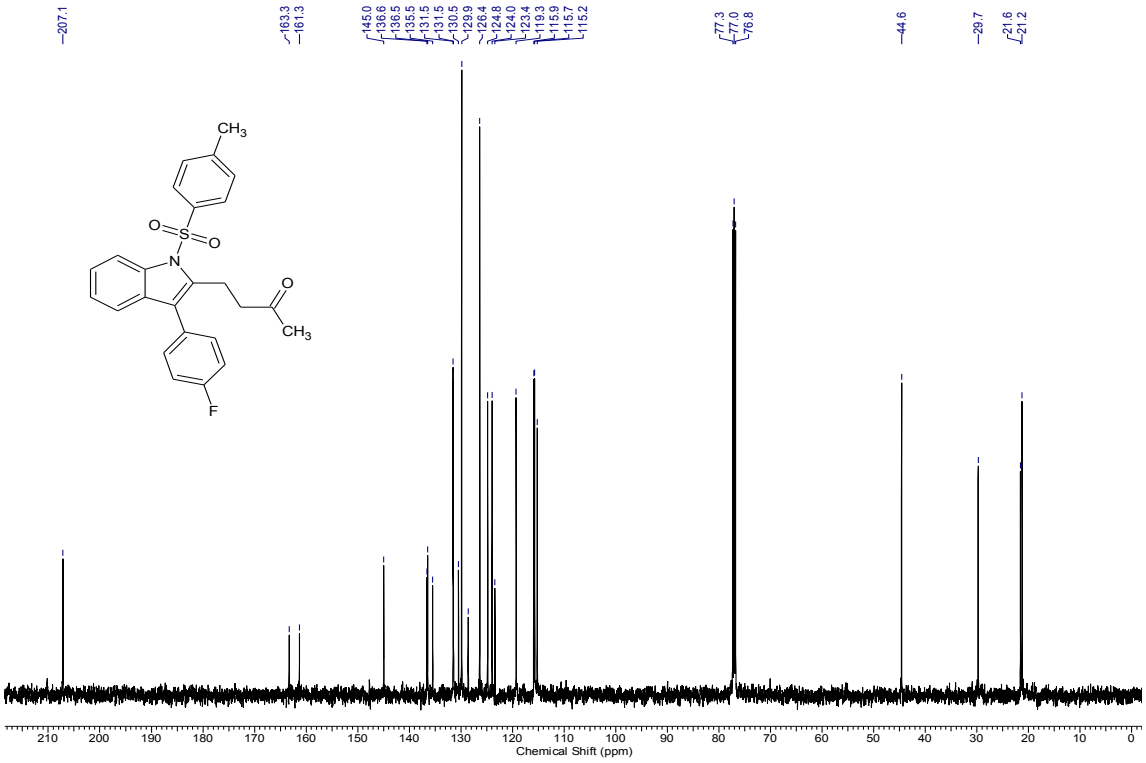
199ga:


8.27
8.25
7.65
7.64
7.33
7.32
7.31
7.26
7.24
7.19
7.19
7.18
7.17
3.27
3.25
3.23
2.95
2.94
2.92
2.41
2.33
2.13
CH3
O
N
O
S
O
CH3
CH3
1.00
2.04
2.14
4.46
2.16
2.15
3.21
3.07
Chemical Shift (ppm)

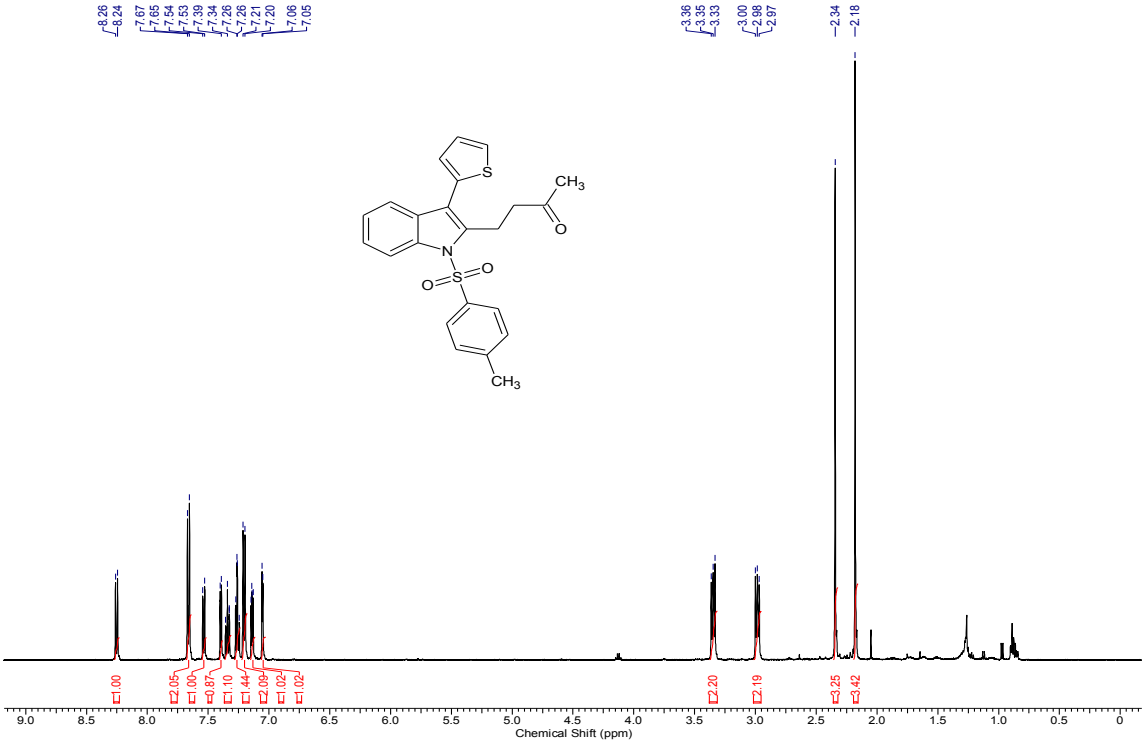

207.3
144.8
137.4
136.6
136.1
135.5
130.6
129.8
129.6
129.4
126.3
124.6
124.4
123.8
119.5
115.1
44.7
29.7
21.5
21.3
CH3
O
N
O
S
O
CH3
CH3
Chemical Shift (ppm)

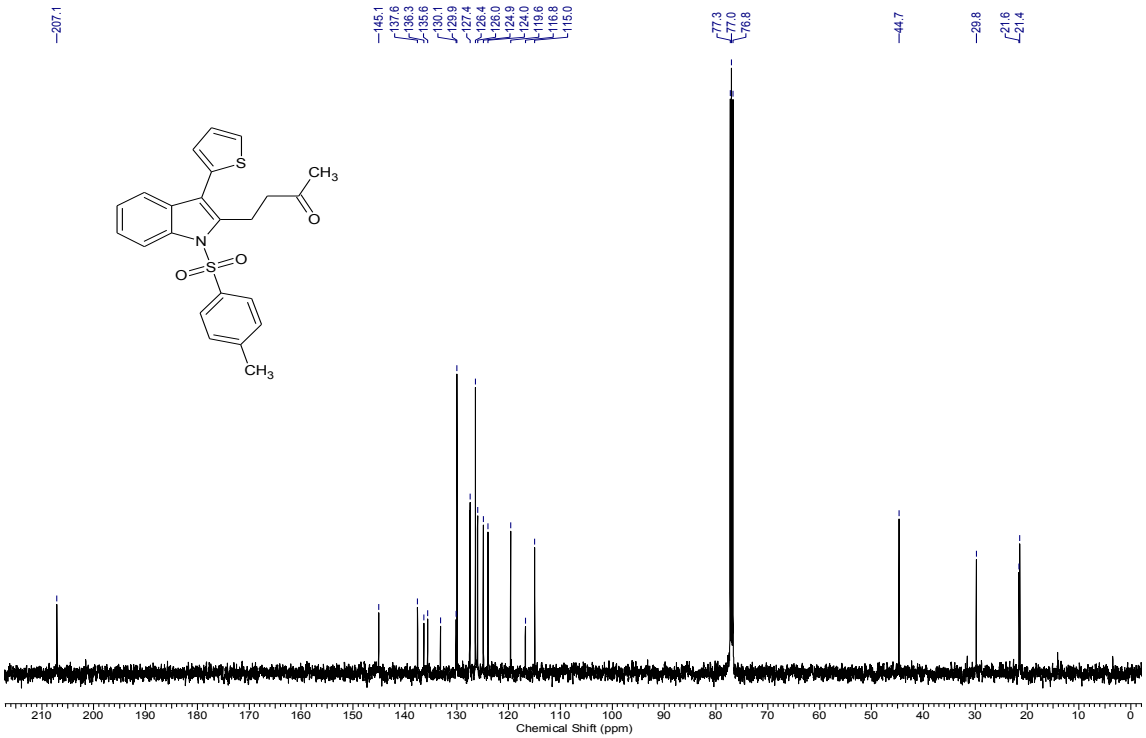
199ha:


8.27
8.25
7.65
7.64
7.33
7.26
7.25
7.25
7.24
7.20
7.19
7.15
7.14
3.24
3.22
3.20
2.95
2.93
2.91
2.34
2.14
CH3
O
S
O
N
O
CH3
F
1.00
2.06
4.15
2.01
2.09
2.08
3.11
3.05
Chemical Shift (ppm)

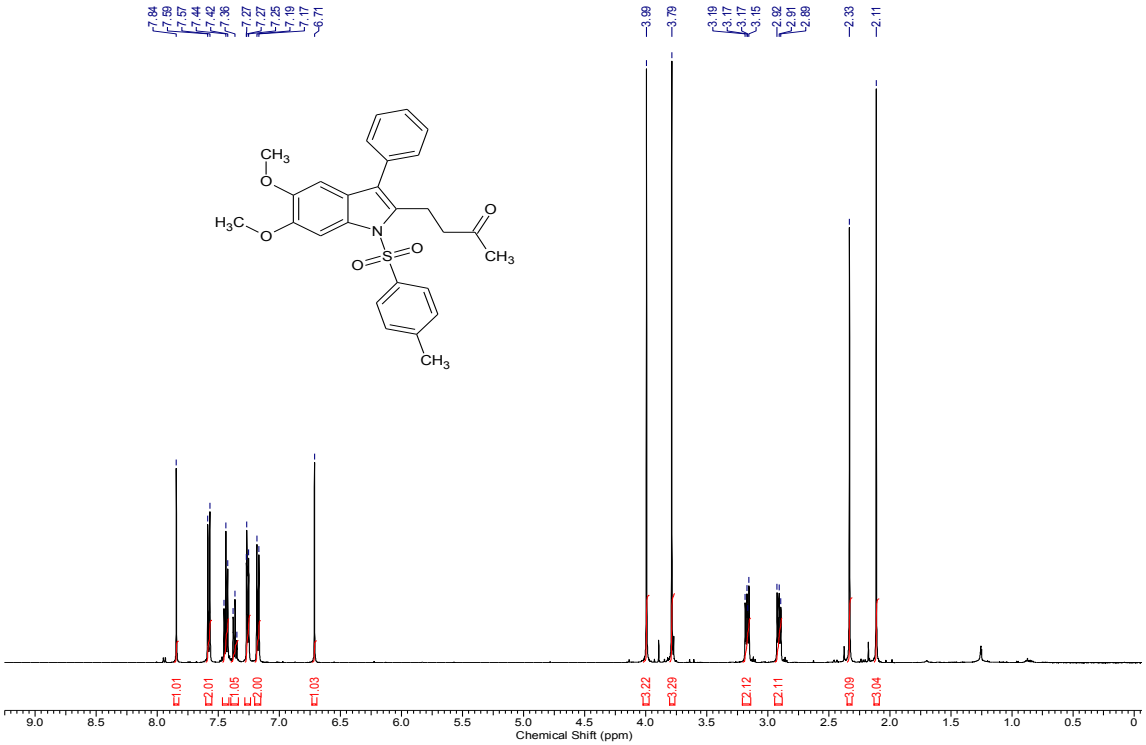

207.1
163.3
161.3
145.0
136.6
136.5
135.5
131.5
131.5
130.5
129.9
126.4
124.8
124.0
123.4
119.3
115.9
115.7
115.2
77.3
77.0
76.8
44.6
29.7
21.6
21.2
CH3
O
S
O
N
O
CH3
F
Chemical Shift (ppm)

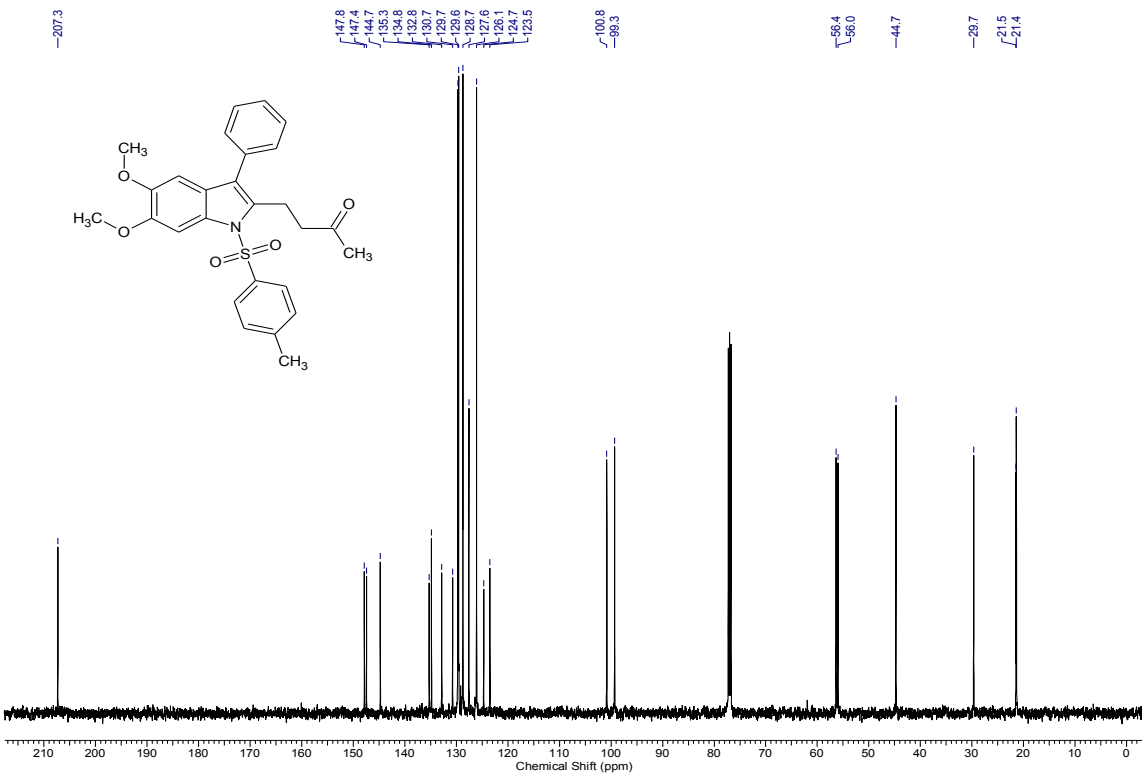
199ia:


8.26
8.24
7.67
7.65
7.54
7.53
7.39
7.34
7.26
7.26
7.21
7.20
7.06
7.05
3.36
3.35
3.33
3.00
2.98
2.97
2.34
2.18
S
CH3
O
N
O
S
O
CH3
1.00
2.05
1.08
0.87
1.10
1.44
2.09
1.02
1.02
2.20
2.19
3.25
3.42
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
Chemical Shift (ppm)

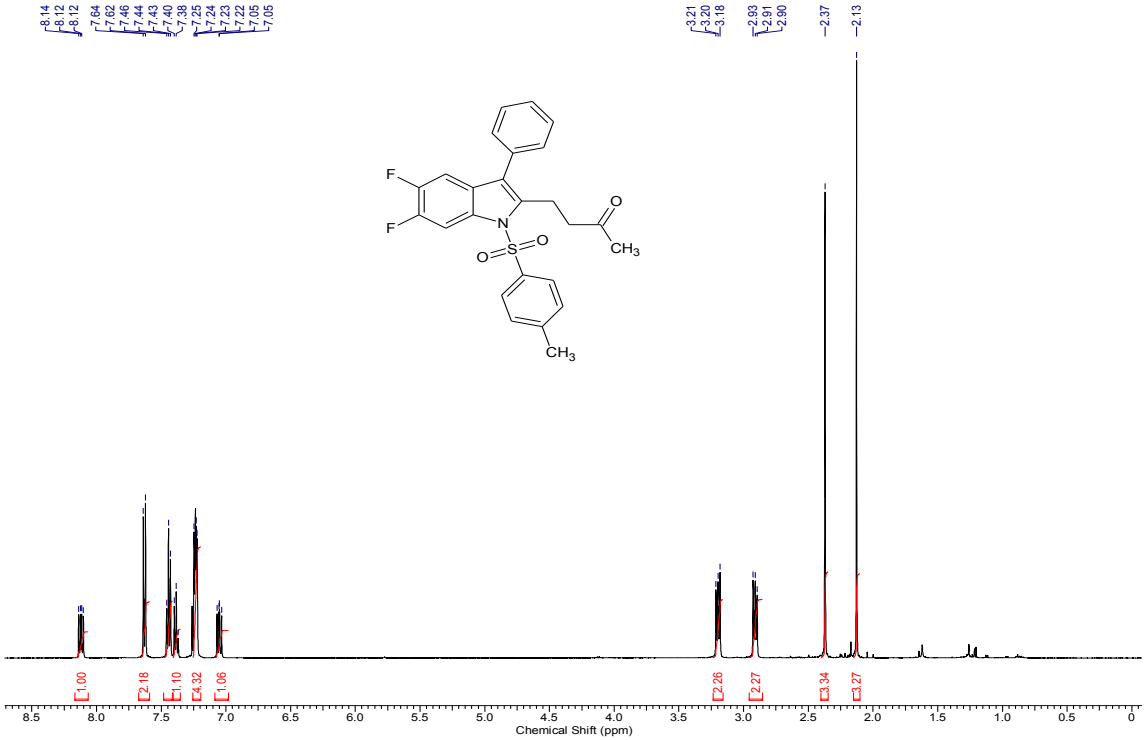

207.1
145.1
137.6
136.3
135.6
130.1
129.9
127.4
126.4
126.0
124.9
124.0
119.6
116.8
115.0
77.3
77.0
76.8
44.7
29.8
21.6
21.4
S
CH3
O
N
O
S
O
CH3
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Chemical Shift (ppm)

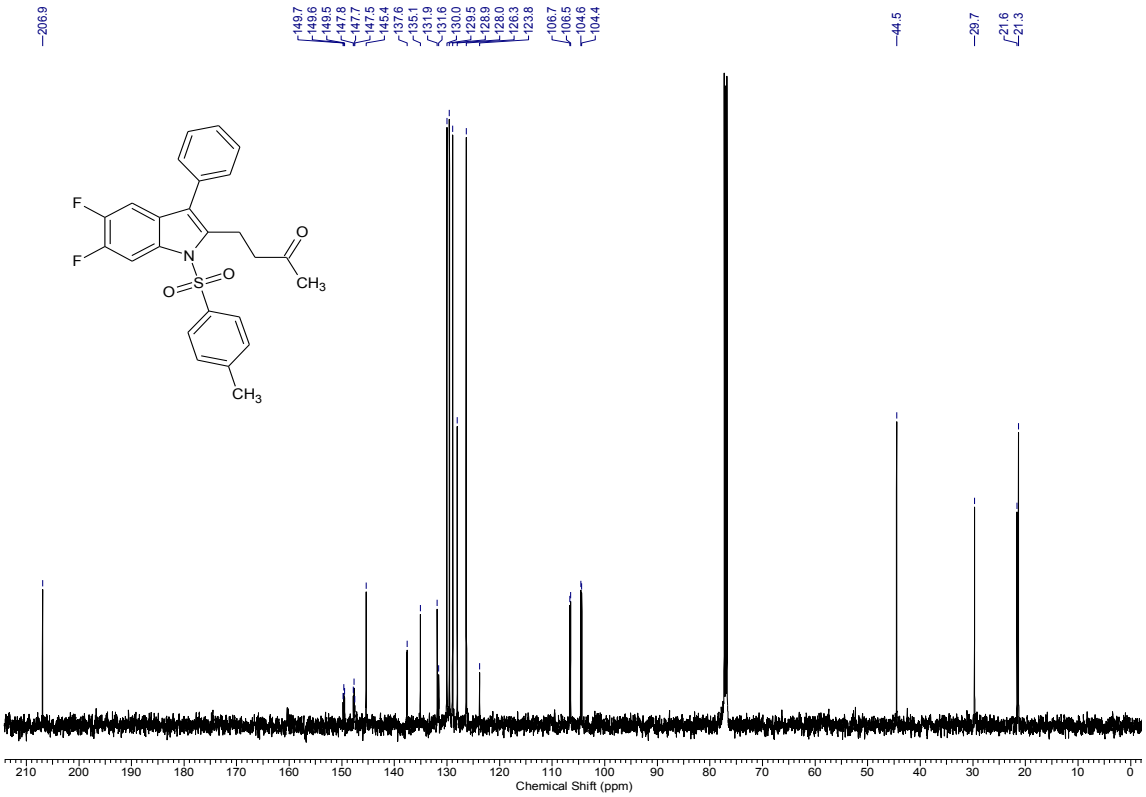
199ja:


7.84
7.59
7.57
7.44
7.42
7.36
7.27
7.27
7.25
7.19
7.17
6.71
3.99
3.79
3.19
3.17
3.17
3.15
2.92
2.91
2.89
2.33
2.11
1.01
2.01
1.05
2.00
1.03
3.22
3.29
2.12
2.11
3.09
3.04
Chemical Shift (ppm)

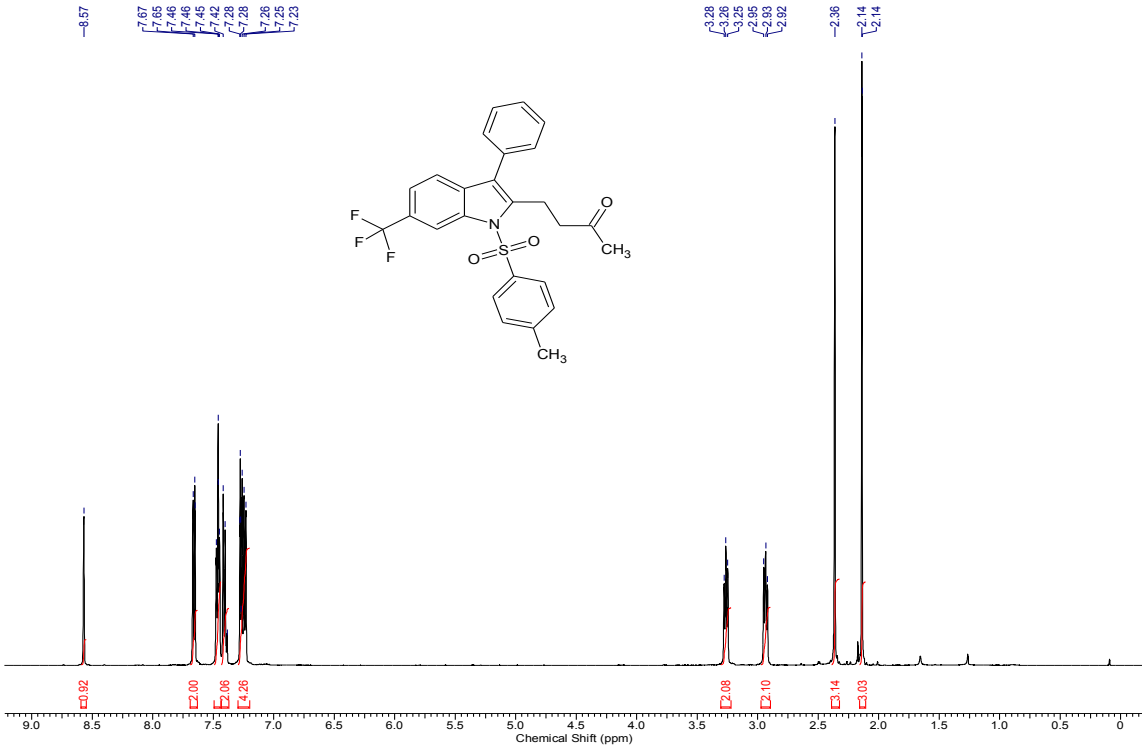

207.3
147.8
147.4
144.7
135.3
134.8
132.8
130.7
129.7
129.6
128.7
127.6
126.1
124.7
123.5
100.8
99.3
56.4
56.0
44.7
29.7
21.5
21.4
Chemical Shift (ppm)

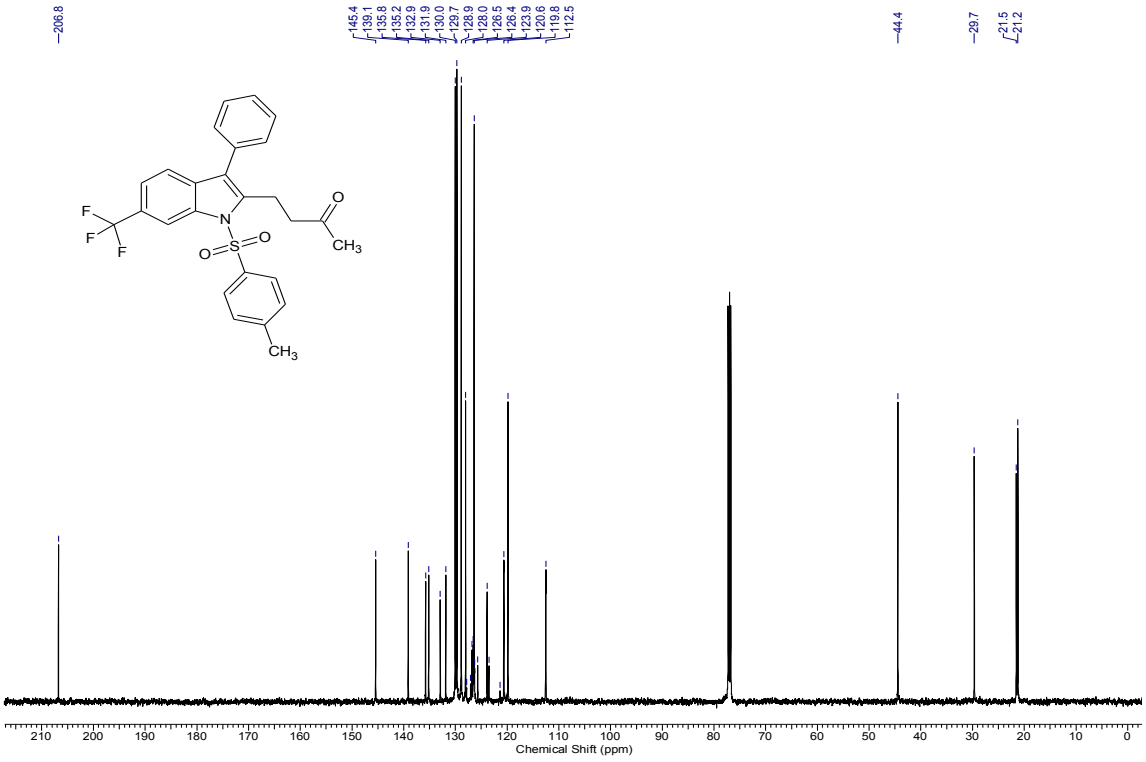
199ka:


8.14
8.12
8.12
7.64
7.62
7.46
7.44
7.43
7.40
7.38
7.25
7.24
7.23
7.22
7.05
7.05
3.21
3.20
3.18
2.93
2.91
2.90
2.37
2.13
F
F
N
S
O
O
O
CH3
CH3
1.00
2.18
1.10
4.32
1.06
2.26
2.27
3.34
3.27
Chemical Shift (ppm)

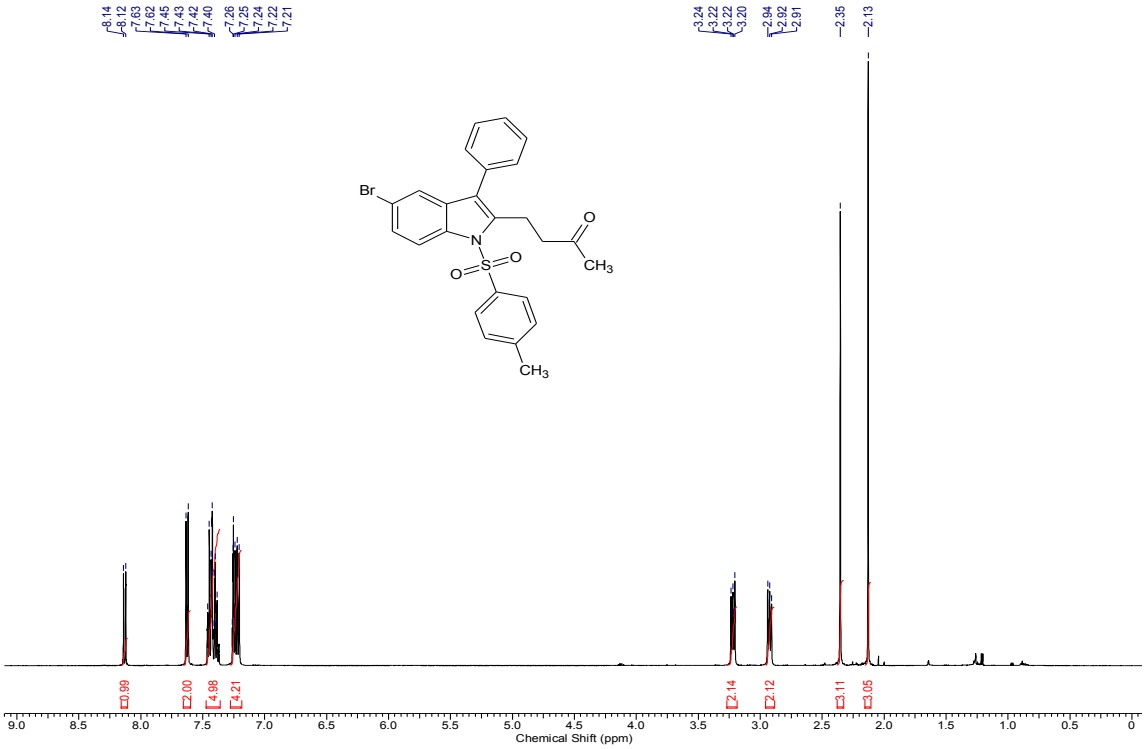

206.9
149.7
149.6
149.5
147.8
147.7
147.5
145.4
137.6
135.1
131.9
131.6
130.0
129.5
128.9
128.0
126.3
123.8
106.7
106.5
104.6
104.4
44.5
29.7
21.6
21.3
F
F
N
S
O
O
O
CH3
CH3
Chemical Shift (ppm)

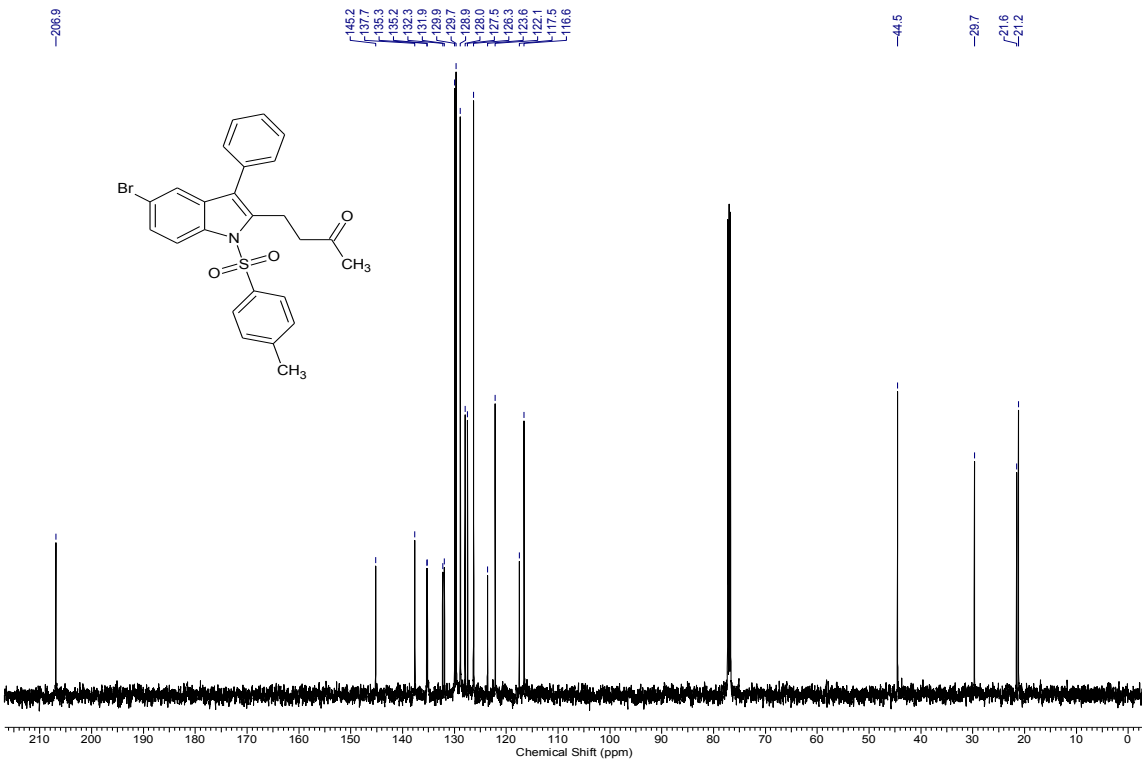
199la:


8.57
7.67
7.65
7.46
7.46
7.45
7.42
7.28
7.28
7.26
7.25
7.23
3.28
3.26
3.25
2.95
2.93
2.92
2.36
2.14
2.14
F
F
F
N
S
O
O
O
CH3
CH3
0.92
2.00
2.06
4.26
2.08
2.10
3.14
3.03
Chemical Shift (ppm)

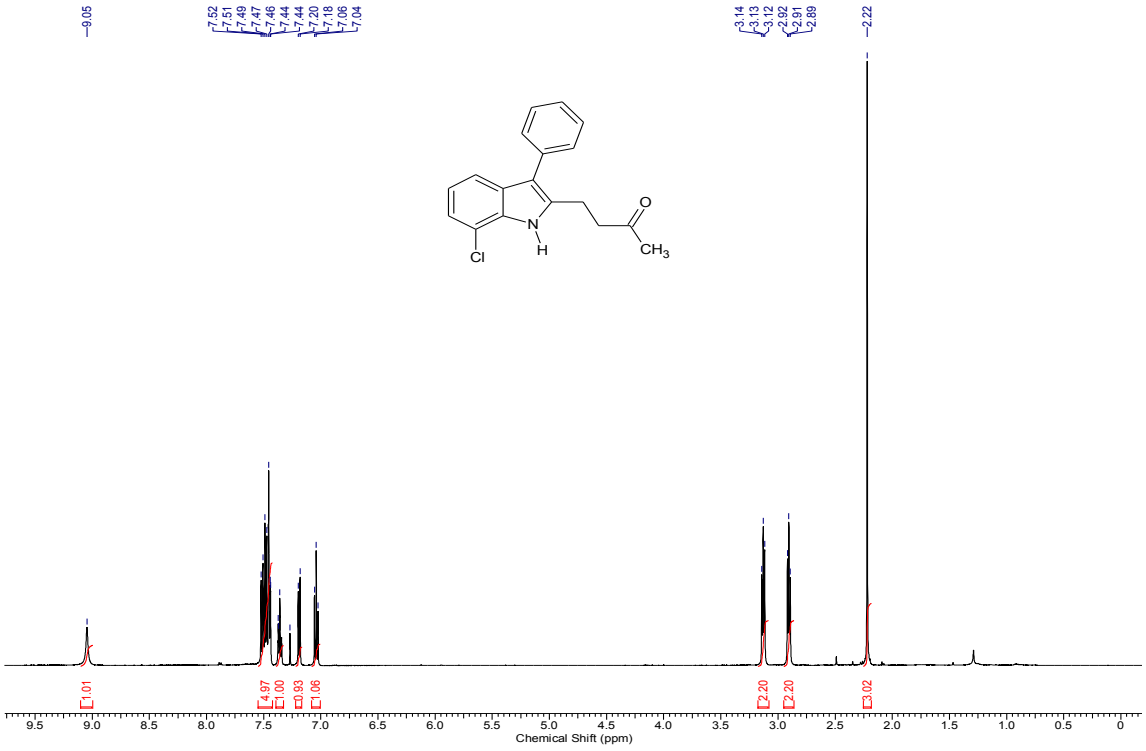

206.8
145.4
139.1
135.8
135.2
132.9
131.9
130.0
129.7
128.9
128.0
126.5
126.4
123.9
120.6
119.8
112.5
44.4
29.7
21.5
21.2
F
F
F
N
S
O
O
O
CH3
CH3
Chemical Shift (ppm)

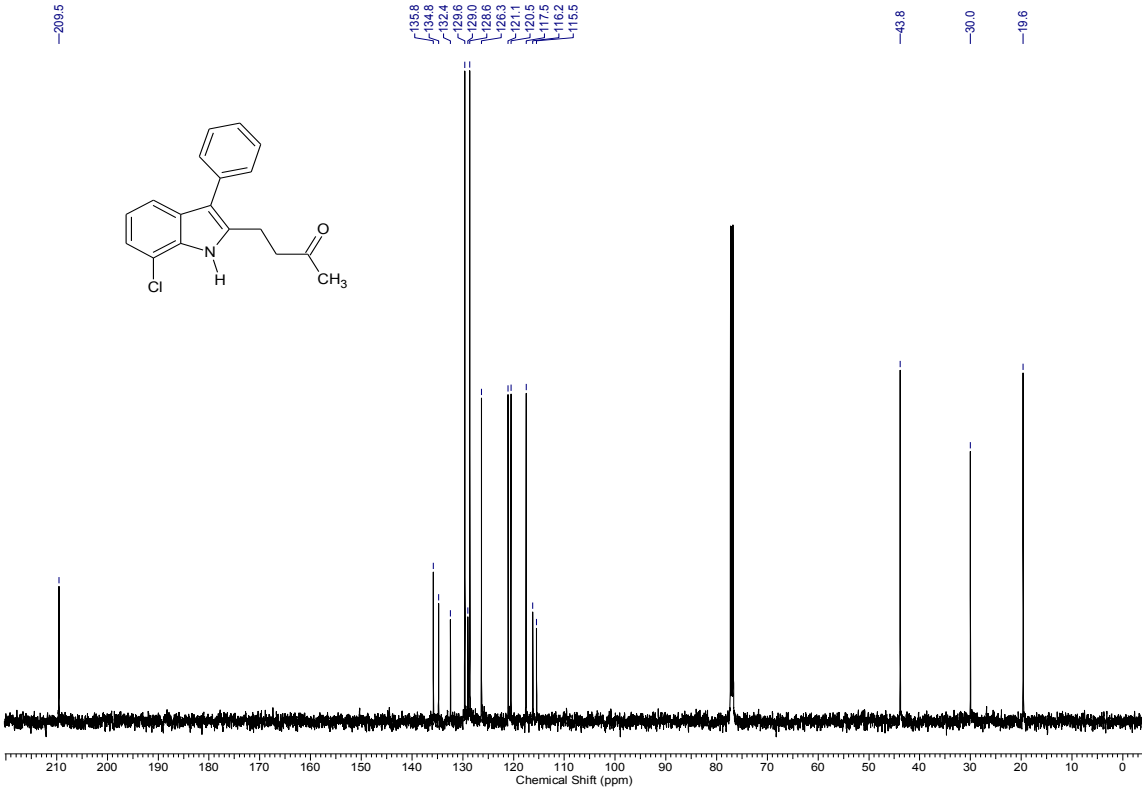
199ma:


8.14
8.12
7.63
7.62
7.45
7.43
7.42
7.40
7.26
7.25
7.24
7.22
7.21
3.24
3.22
3.22
3.20
2.94
2.92
2.91
2.35
2.13
Br
O
N
O
S
O
CH3
CH3
0.99
2.00
4.98
4.21
2.14
2.12
3.11
3.05
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
Chemical Shift (ppm)

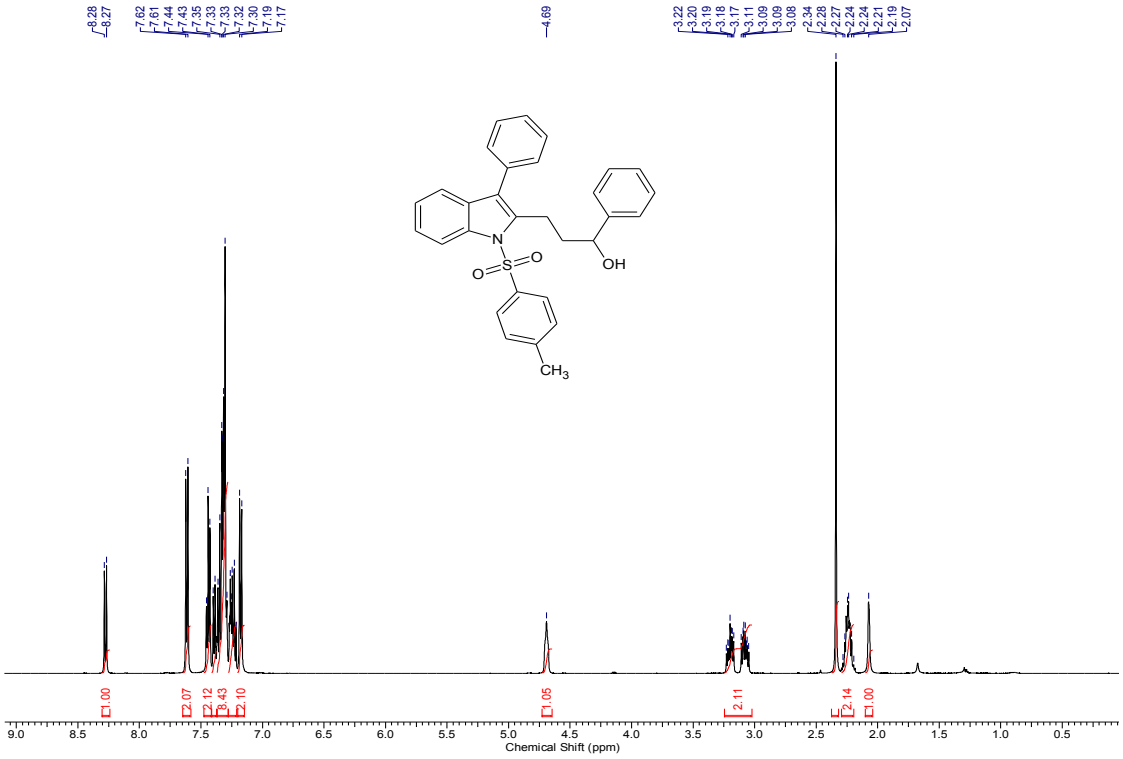

206.9
145.2
137.7
135.3
135.2
132.3
131.9
129.9
129.7
128.9
128.0
127.5
126.3
123.6
122.1
117.5
116.6
44.5
29.7
21.6
21.2
Br
O
N
O
S
O
CH3
CH3
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Chemical Shift (ppm)

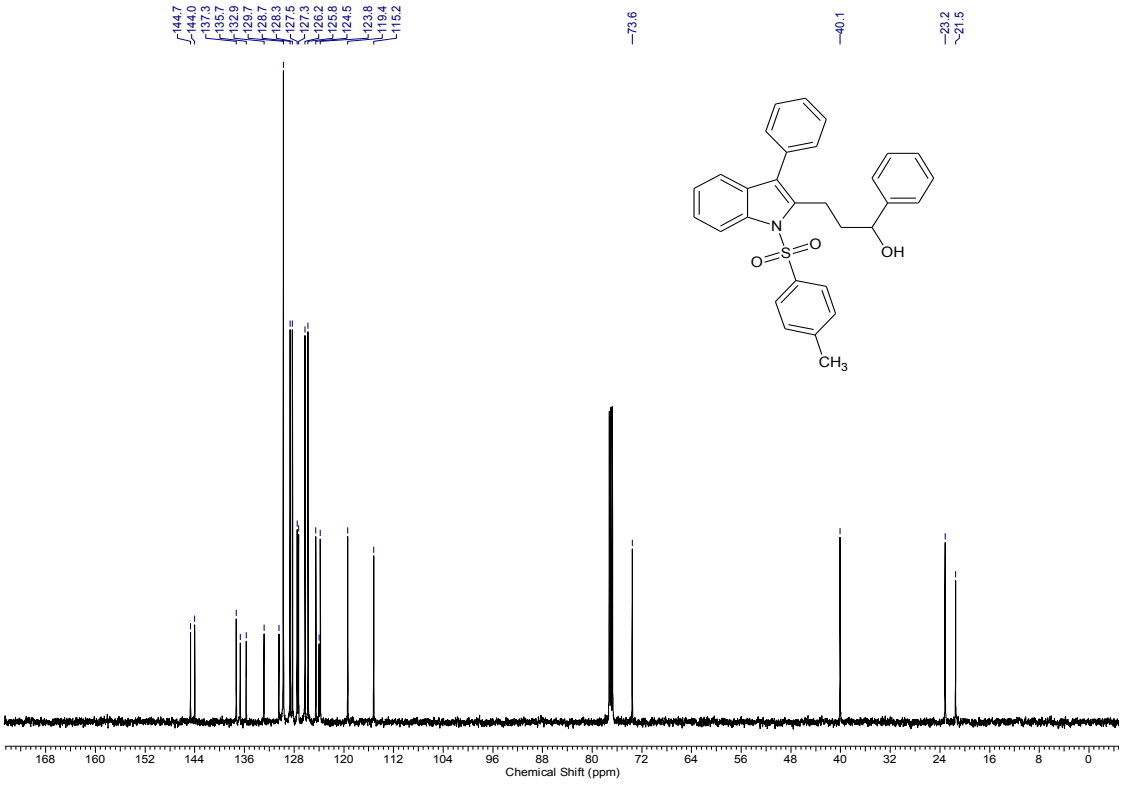
199oa:


9.05
7.52
7.51
7.49
7.47
7.46
7.44
7.44
7.20
7.18
7.06
7.04
3.14
3.13
3.12
2.92
2.91
2.89
2.22
O
N
H
Cl
CH3
1.01
4.97
1.00
0.93
1.06
2.20
2.20
3.02
Chemical Shift (ppm)

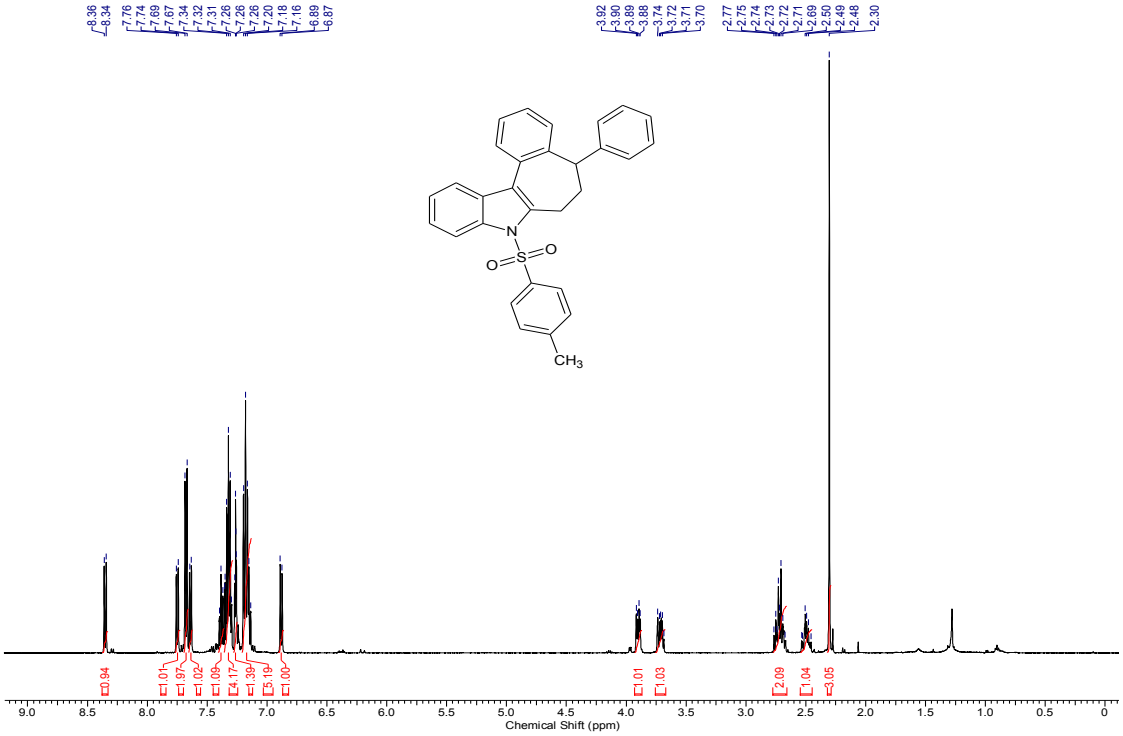

209.5
135.8
134.8
132.4
129.6
129.0
128.6
126.3
121.1
120.5
117.5
116.2
115.5
43.8
30.0
19.6
O
N
H
Cl
CH3
Chemical Shift (ppm)

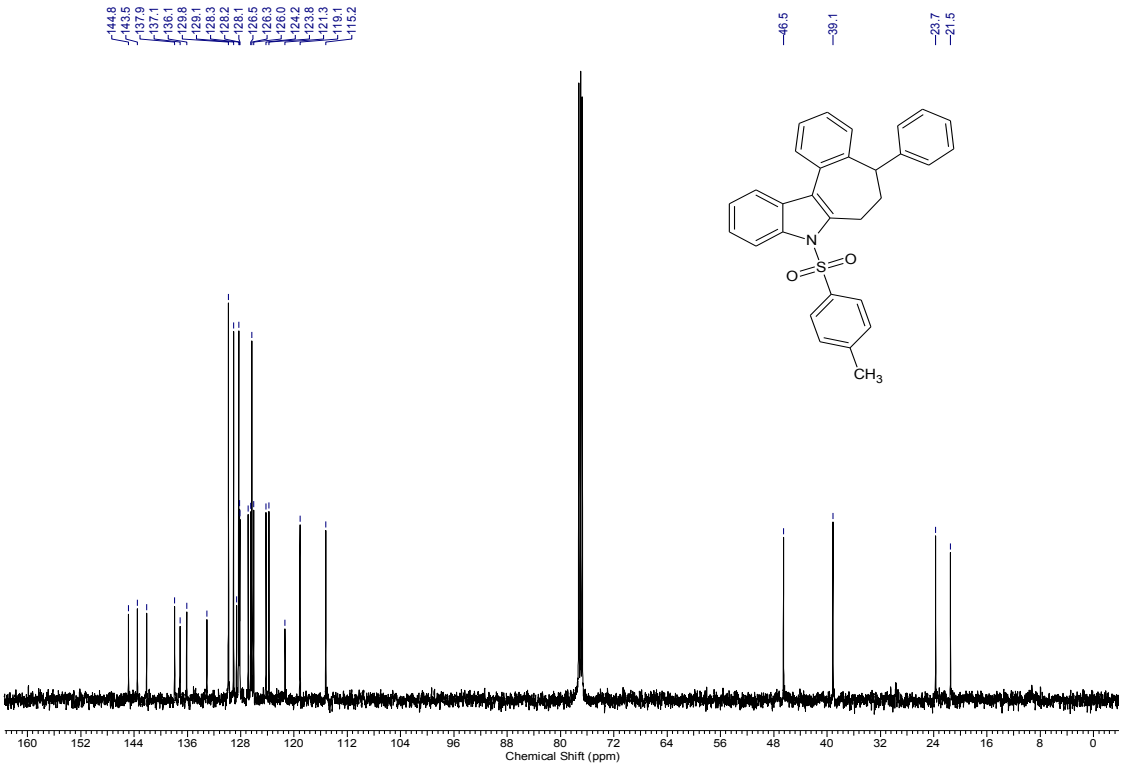
205:


8.28
8.27
7.62
7.61
7.44
7.43
7.35
7.33
7.33
7.32
7.30
7.19
7.17
4.69
3.22
3.20
3.19
3.18
3.17
3.11
3.09
3.09
3.08
2.34
2.28
2.27
2.24
2.24
2.21
2.19
2.07
1.00
2.07
2.12
8.43
2.10
1.05
2.11
2.14
1.00
N
S
O
O
OH
CH3
Chemical Shift (ppm)

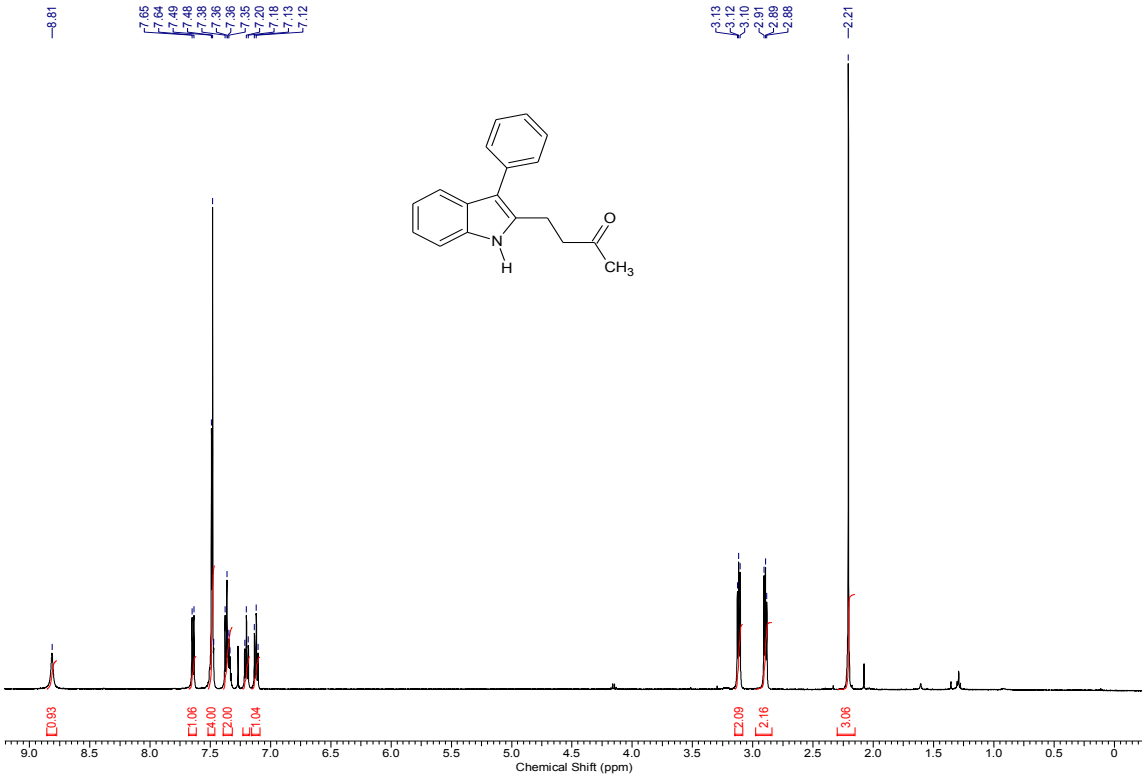

144.7
144.0
137.3
135.7
132.9
129.7
128.7
128.3
127.5
127.3
126.2
125.8
124.5
123.8
119.4
115.2
73.6
40.1
23.2
21.5
N
S
O
O
OH
CH3
Chemical Shift (ppm)

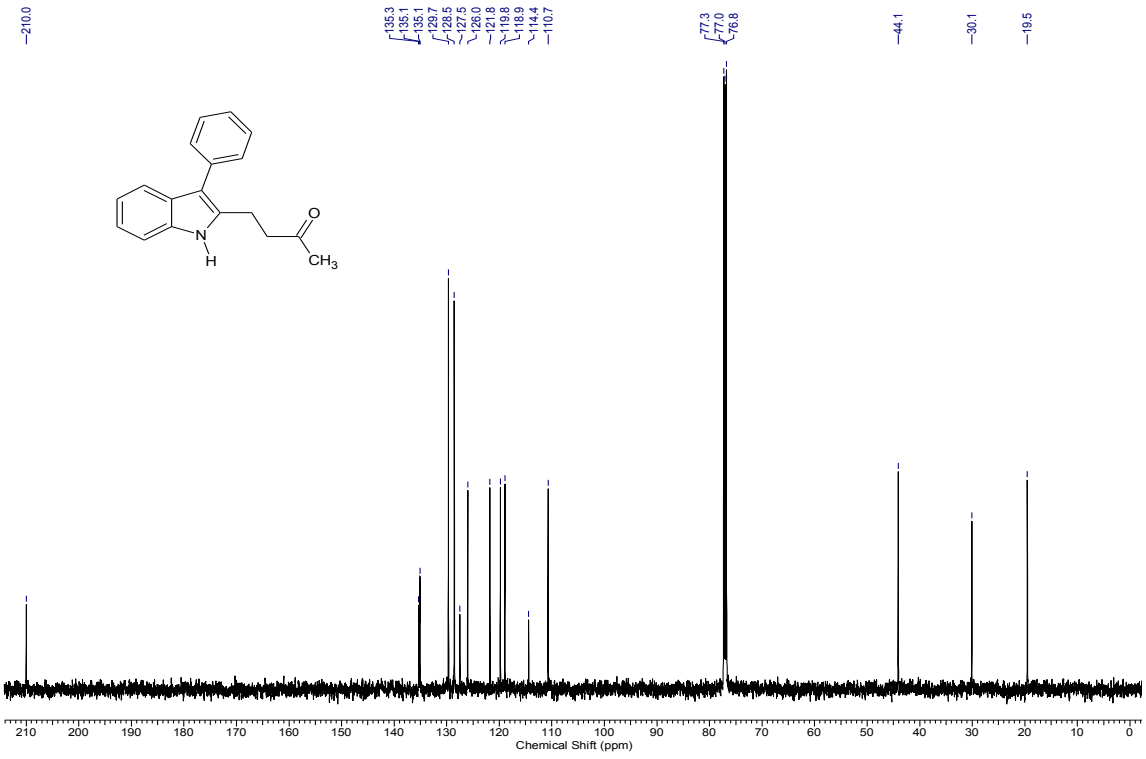
200:


8.36
8.34
7.76
7.74
7.69
7.67
7.34
7.32
7.31
7.26
7.26
7.26
7.20
7.18
7.16
6.89
6.87
3.92
3.90
3.89
3.88
3.74
3.72
3.71
3.70
2.77
2.75
2.74
2.73
2.72
2.71
2.69
2.50
2.49
2.48
2.30
N
S
O
O
CH3
1.00
1.01
0.97
1.02
1.09
4.17
1.39
3.19
1.00
1.01
1.03
2.09
1.04
3.05
Chemical Shift (ppm)

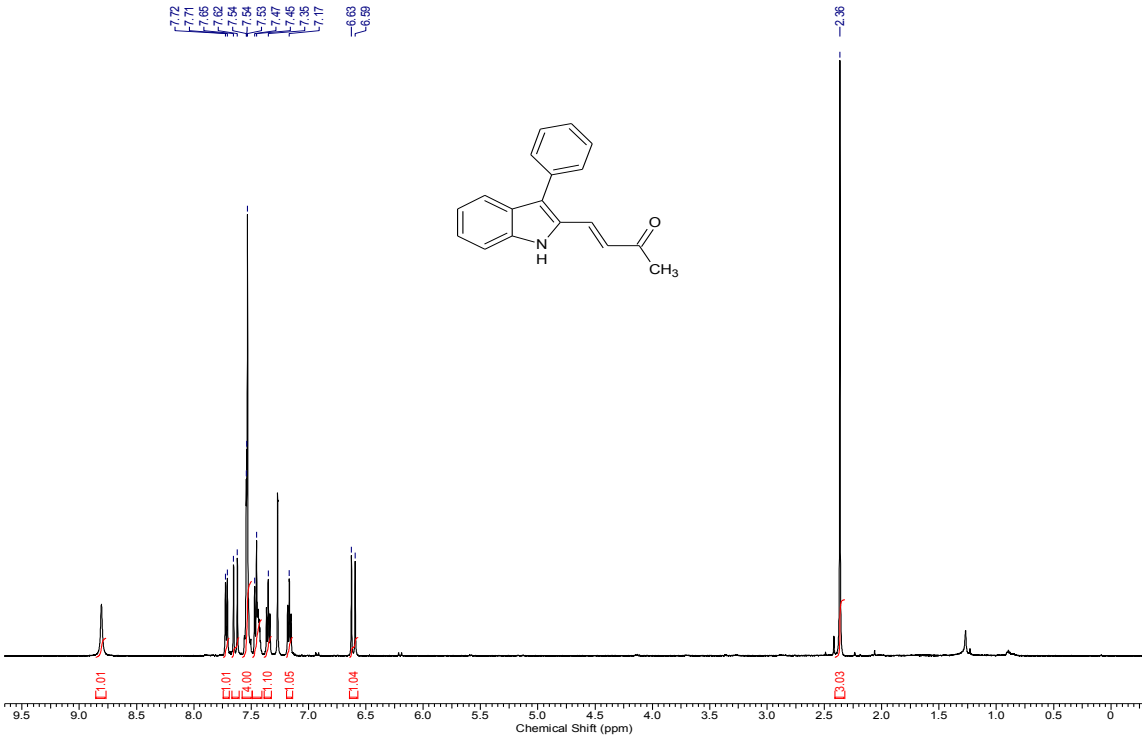

144.8
143.5
137.9
137.1
136.1
129.8
129.1
128.3
128.2
128.1
126.5
126.3
126.0
124.2
123.8
121.3
119.1
115.2
46.5
39.1
23.7
21.5
N
S
O
O
CH3
Chemical Shift (ppm)

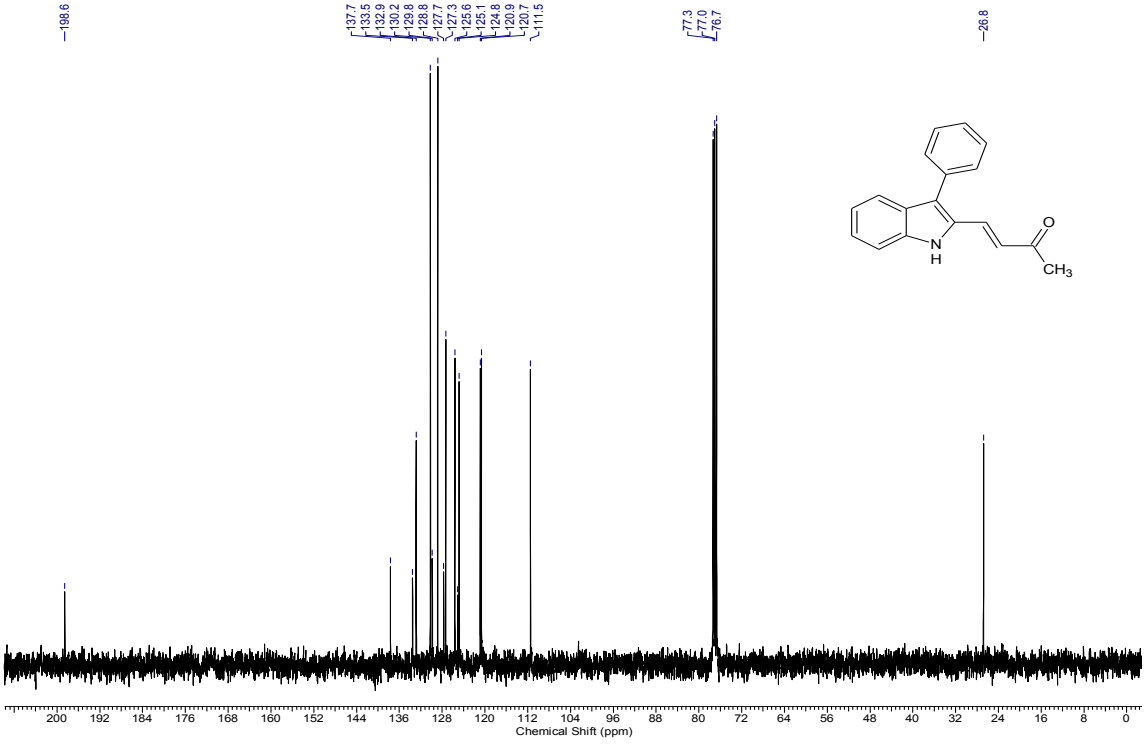
201:


8.81
7.65
7.64
7.49
7.48
7.38
7.36
7.36
7.35
7.20
7.18
7.13
7.12
3.13
3.12
3.10
2.91
2.89
2.88
2.21
O
N
H
CH3
0.93
1.06
4.00
2.00
1.04
2.09
2.16
3.06
Chemical Shift (ppm)

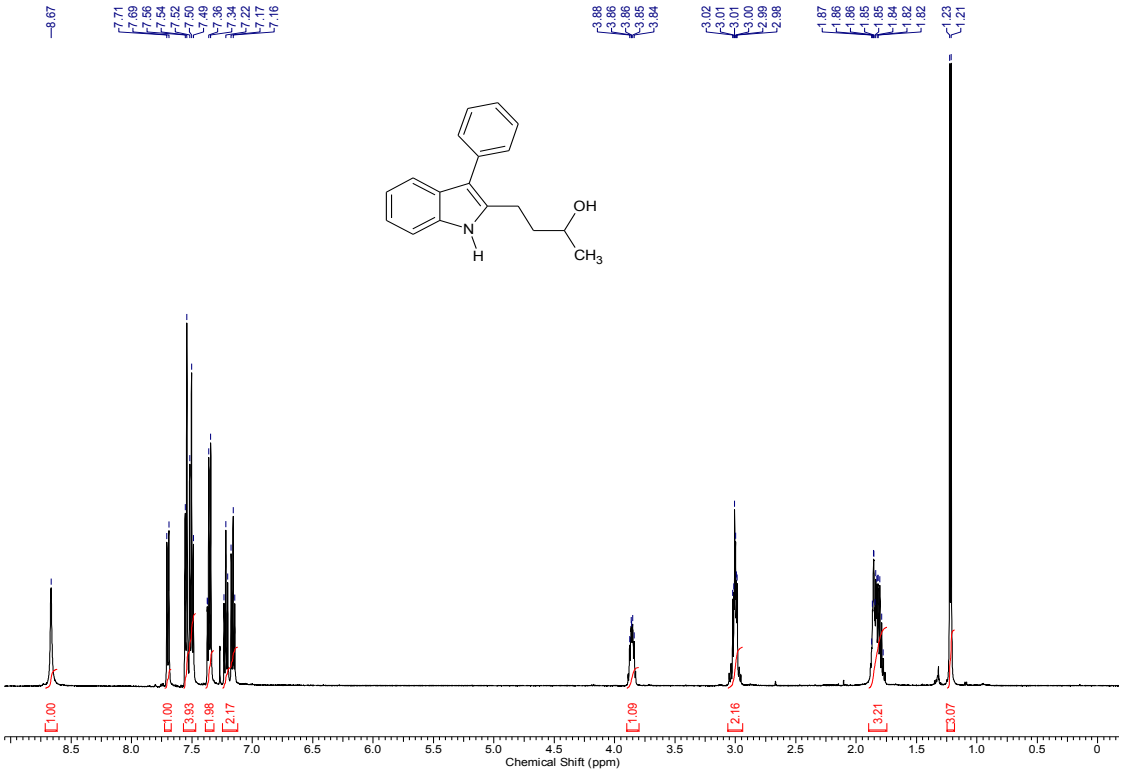

210.0
135.3
135.1
135.1
129.7
128.5
127.5
126.0
121.8
119.8
118.9
114.4
110.7
77.3
77.0
76.8
44.1
30.1
19.5
O
N
H
CH3
Chemical Shift (ppm)

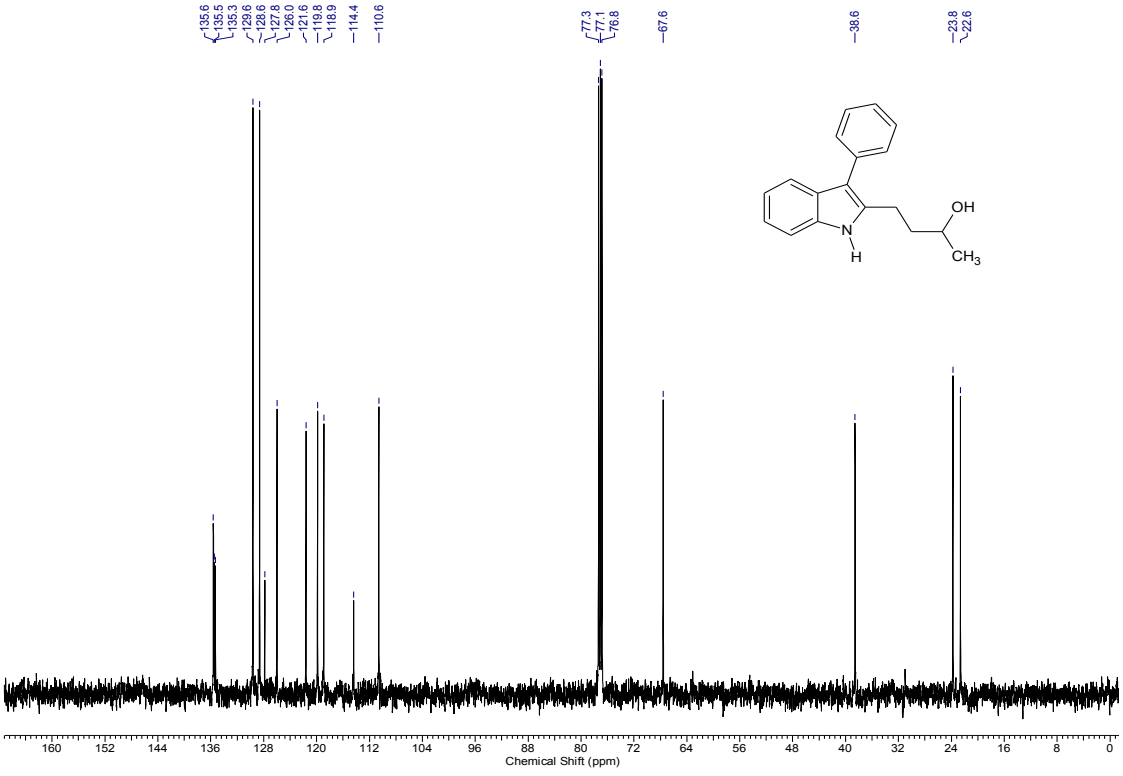
202:


7.72
7.71
7.65
7.62
7.54
7.54
7.53
7.47
7.45
7.35
7.17
6.63
6.59
2.36
1.01
1.01
4.00
1.10
1.05
1.04
3.03
O
N
H
CH3
Chemical Shift (ppm)

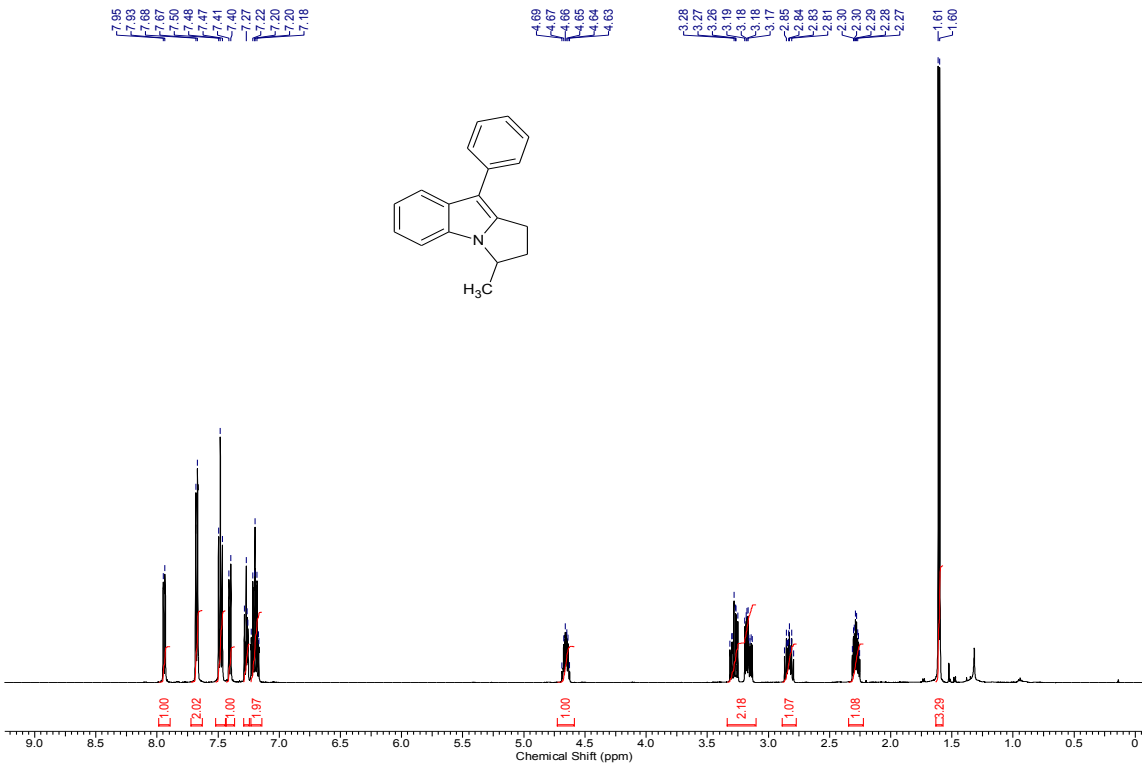

198.6
137.7
133.5
132.9
130.2
129.8
128.8
127.7
127.3
125.6
125.1
124.8
120.9
120.7
111.5
77.3
77.0
76.7
26.8
O
N
H
CH3
Chemical Shift (ppm)

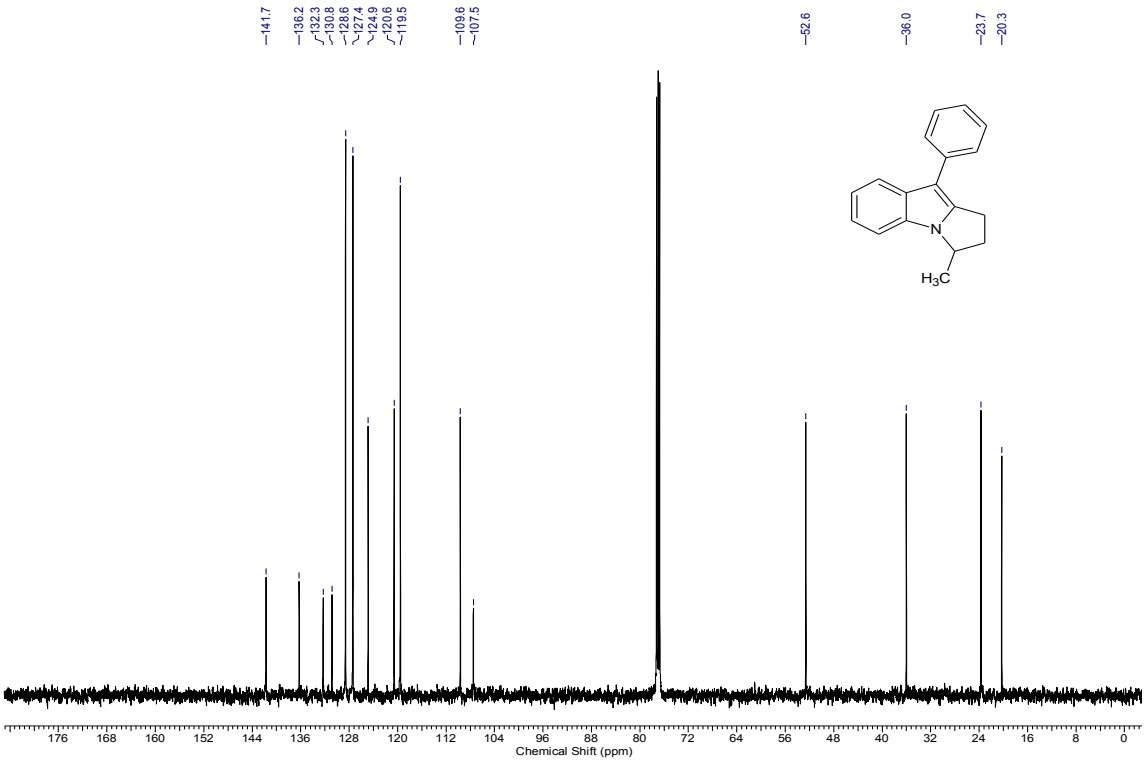
203:


8.67
7.71
7.69
7.56
7.54
7.52
7.50
7.49
7.36
7.34
7.22
7.17
7.16
3.88
3.86
3.86
3.85
3.84
3.02
3.01
3.01
3.00
2.99
2.98
1.87
1.86
1.86
1.85
1.85
1.84
1.82
1.82
1.23
1.21
OH
N
H
CH3
1.00
1.00
3.93
1.98
2.17
1.09
2.16
3.21
3.07
Chemical Shift (ppm)


135.6
135.5
135.3
129.6
128.6
127.8
126.0
121.6
119.8
118.9
114.4
110.6
77.3
77.1
76.8
67.6
38.6
23.8
22.6
OH
N
H
CH3
Chemical Shift (ppm)

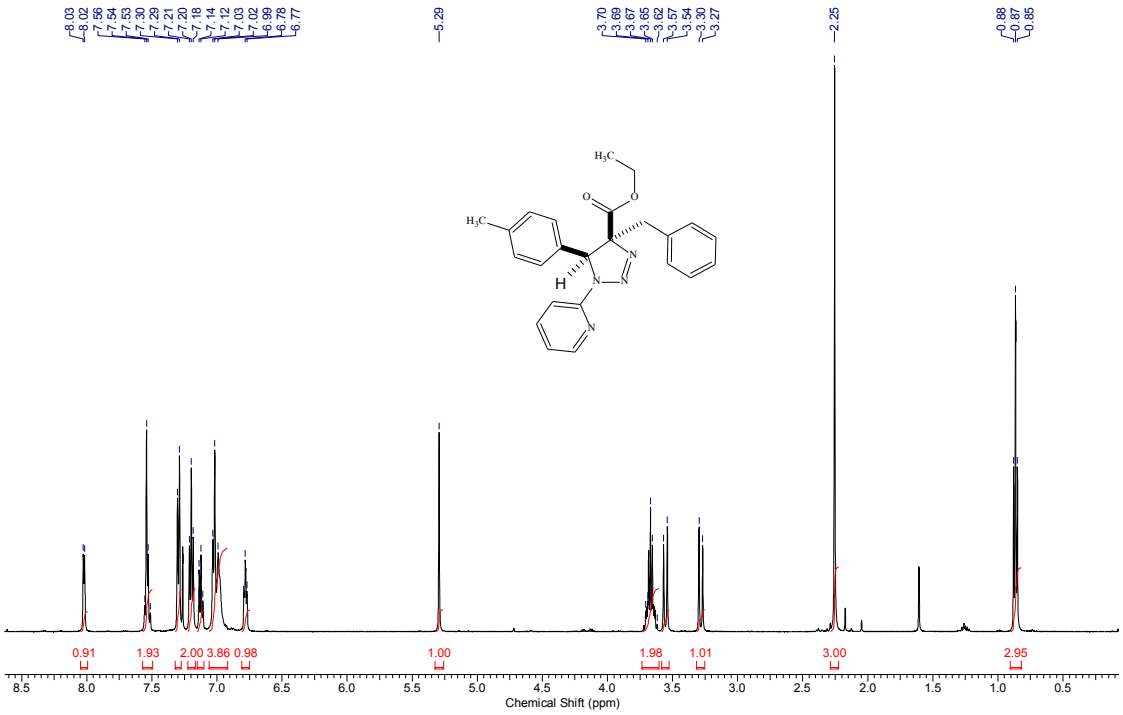
204:

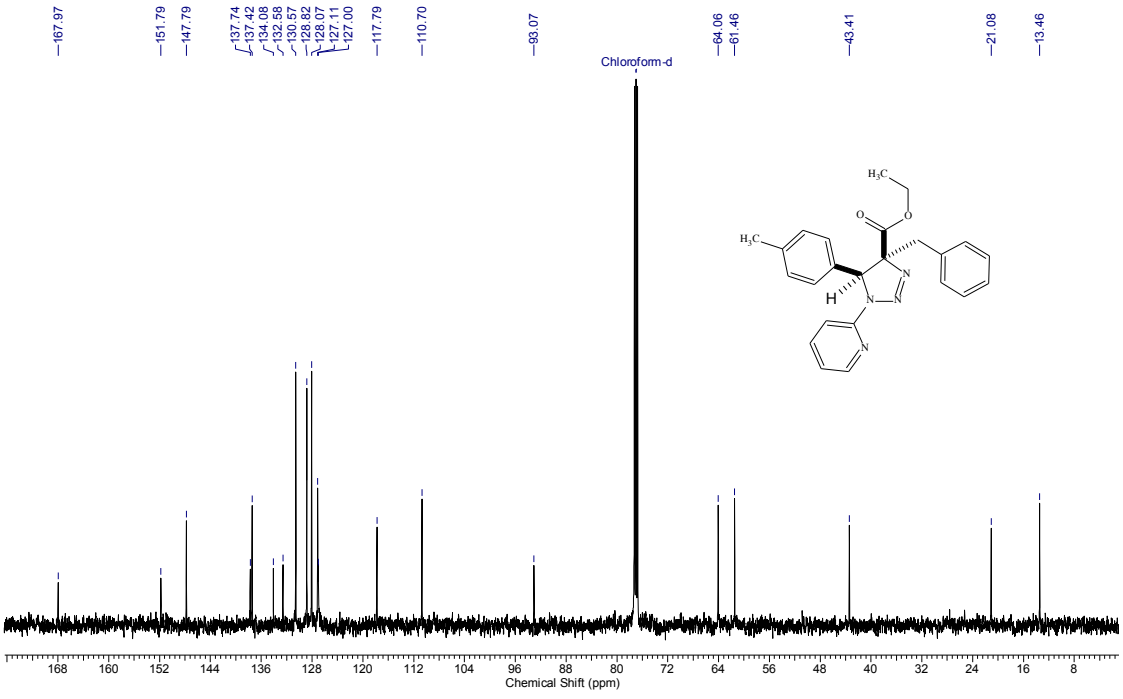

7.95
7.93
7.68
7.67
7.50
7.48
7.47
7.41
7.40
7.27
7.22
7.20
7.20
7.18
4.69
4.67
4.66
4.65
4.64
4.63
3.28
3.27
3.26
3.19
3.18
3.18
3.17
2.85
2.84
2.83
2.81
2.30
2.30
2.29
2.28
2.27
1.61
1.60
1.00
2.02
1.00
1.97
1.00
2.18
1.07
1.08
3.29
N
H3C
Chemical Shift (ppm)


141.7
136.2
132.3
130.8
128.6
127.4
124.9
120.6
119.5
109.6
107.5
52.6
36.0
23.7
20.3
N
H3C
Chemical Shift (ppm)

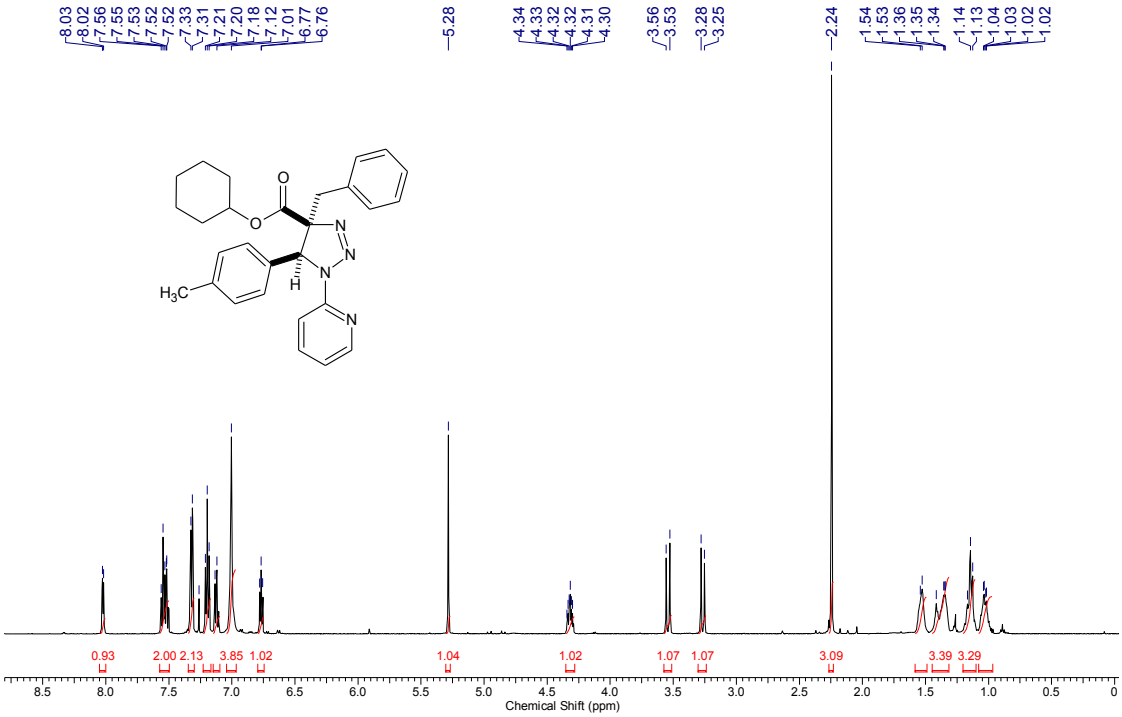
APPENDIX D. ^{1}H and ^{13}C spectra of dihydrobenzosiloles **217** and pyrroles **221**

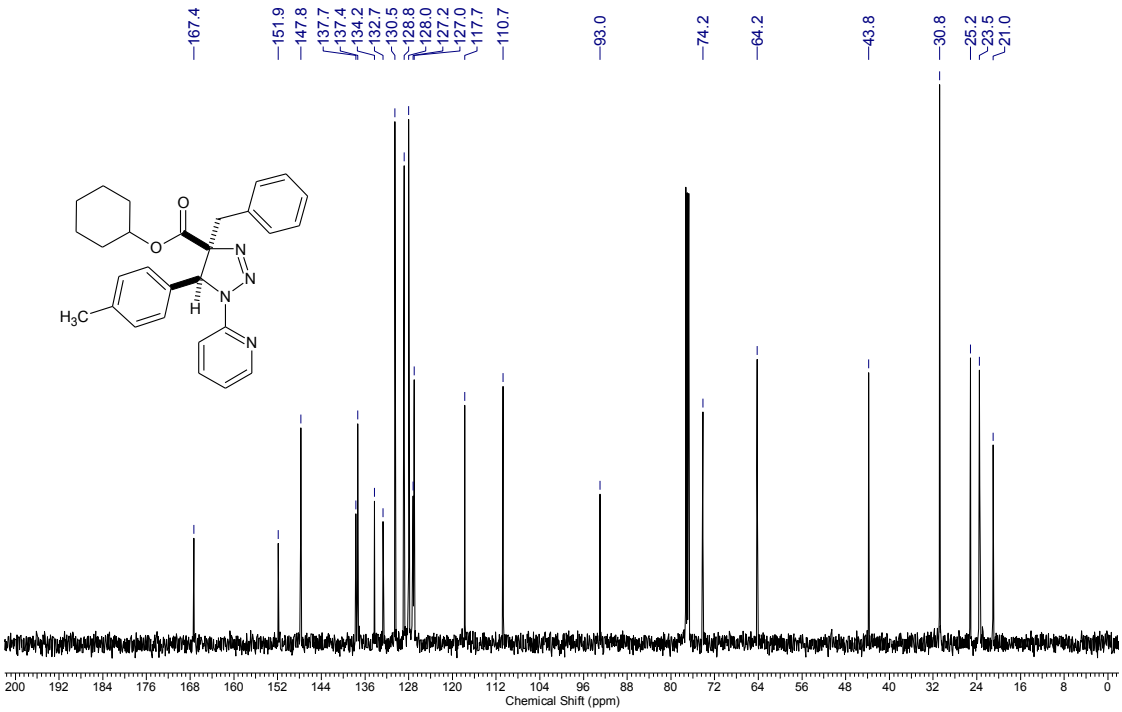
217aa:



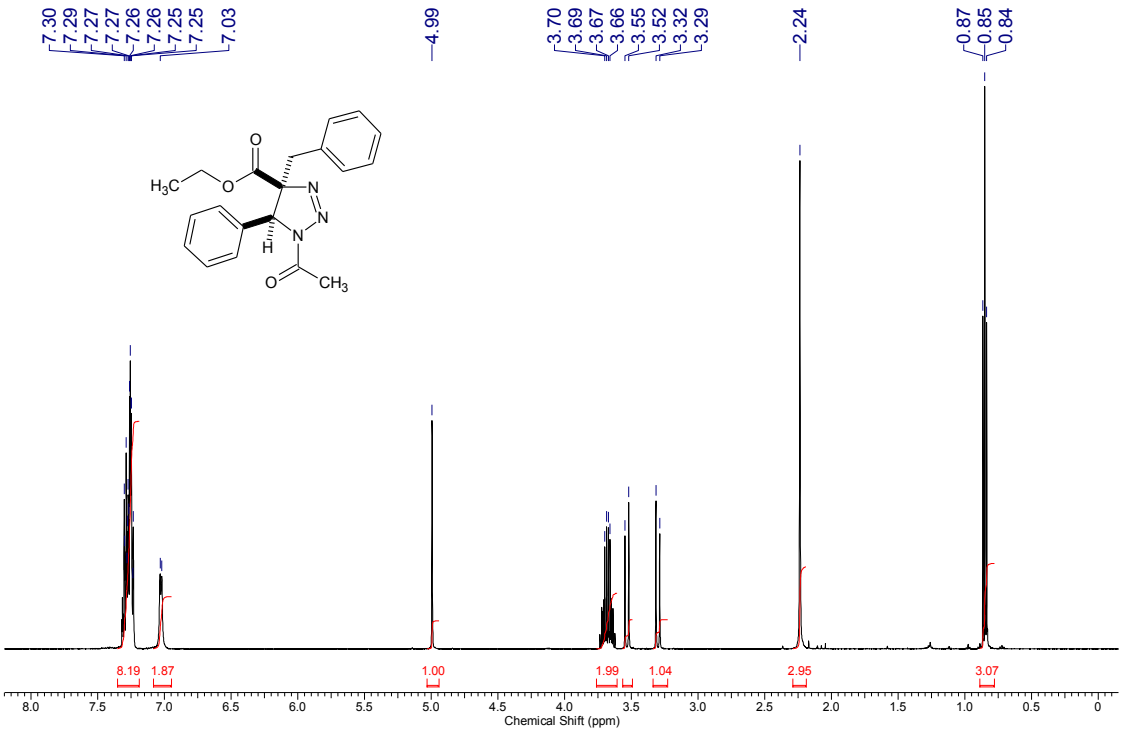


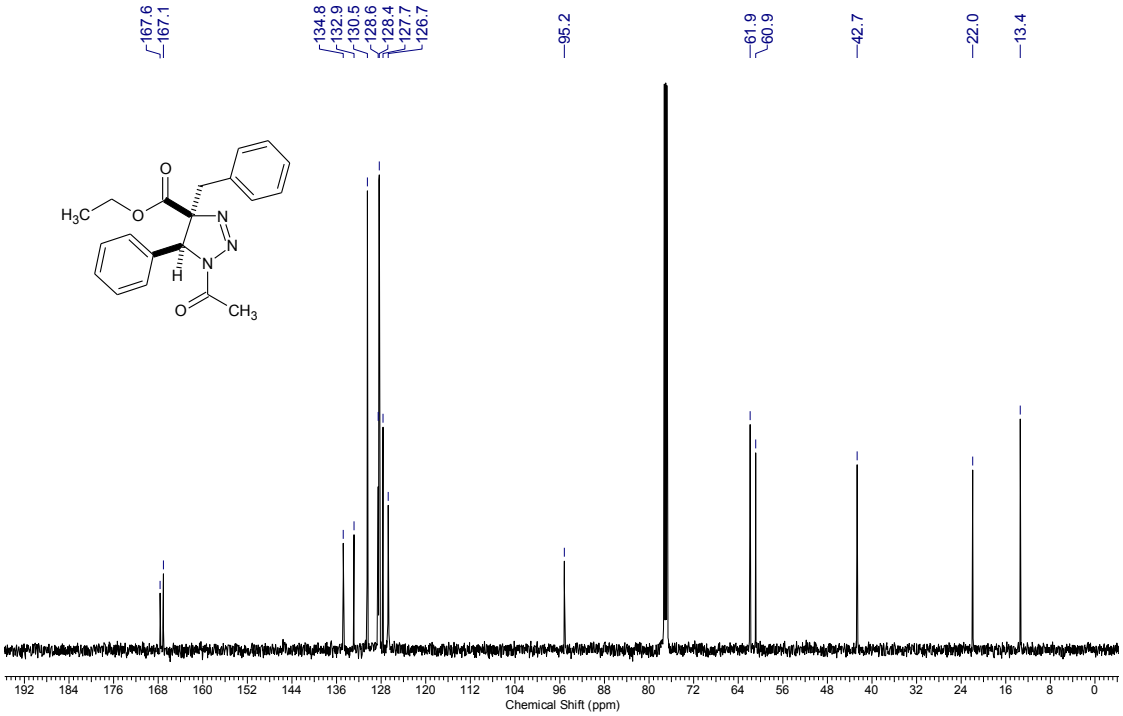
217ab:


8.03
8.02
7.56
7.55
7.53
7.52
7.52
7.33
7.31
7.21
7.20
7.18
7.12
7.01
6.77
6.76
5.28
4.34
4.33
4.32
4.32
4.31
4.30
3.56
3.53
3.28
3.25
2.24
1.54
1.53
1.36
1.35
1.34
1.14
1.13
1.04
1.03
1.02
1.02
O
O
N
N
N
H
H3C
N
0.93
2.00
2.13
3.85
1.02
1.04
1.02
1.07
1.07
3.09
3.39
3.29
Chemical Shift (ppm)

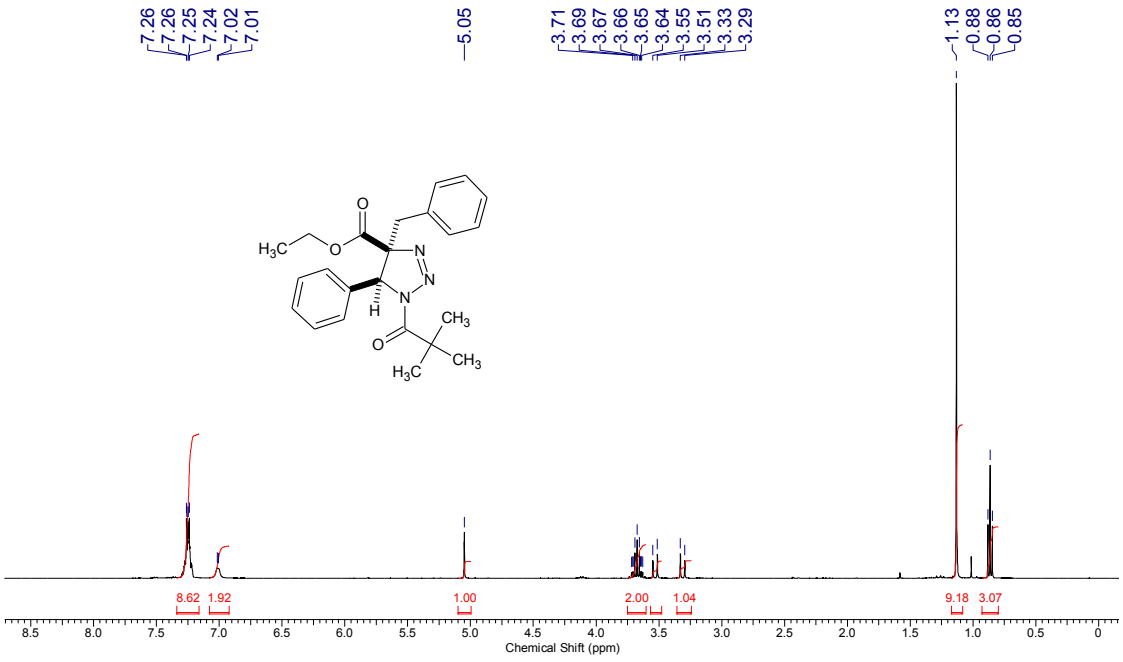

167.4
151.9
147.8
137.7
137.4
134.2
132.7
130.5
128.8
128.0
127.2
127.0
117.7
110.7
93.0
74.2
64.2
43.8
30.8
25.2
23.5
21.0
O
O
N
N
N
H
H3C
N
Chemical Shift (ppm)

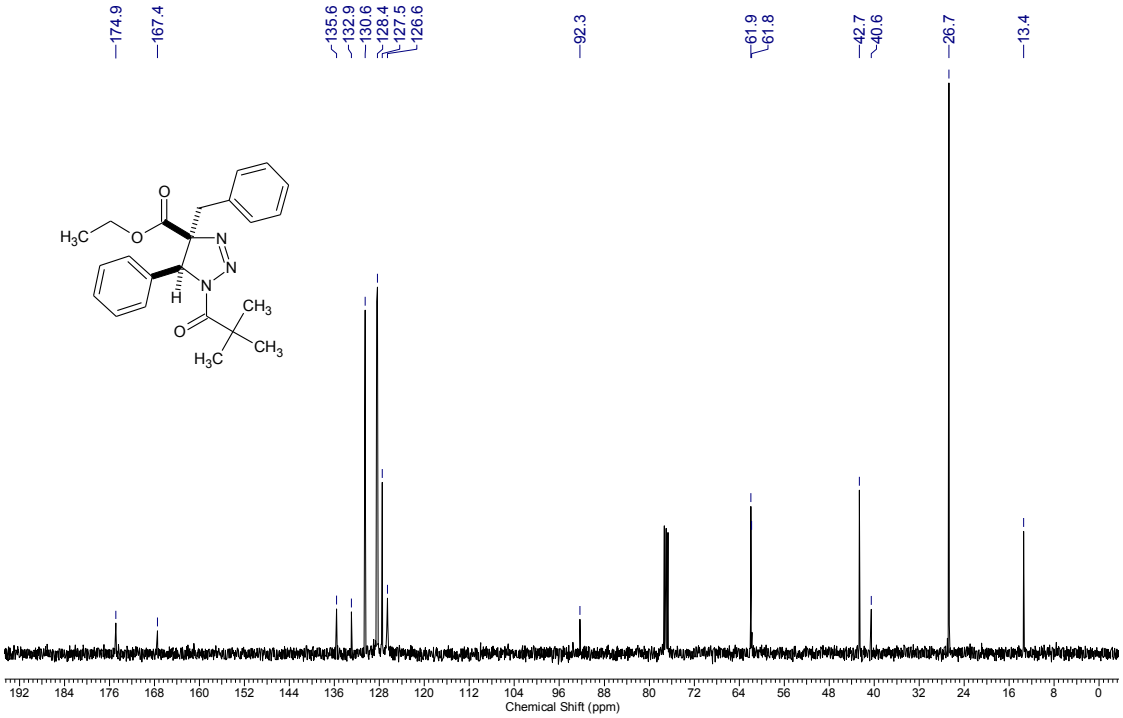
217ac:


7.30
7.29
7.27
7.27
7.26
7.26
7.25
7.25
7.03
4.99
3.70
3.69
3.67
3.66
3.55
3.52
3.32
3.29
2.24
0.87
0.85
0.84
8.19
1.87
1.00
1.99
1.04
2.95
3.07
Chemical Shift (ppm)

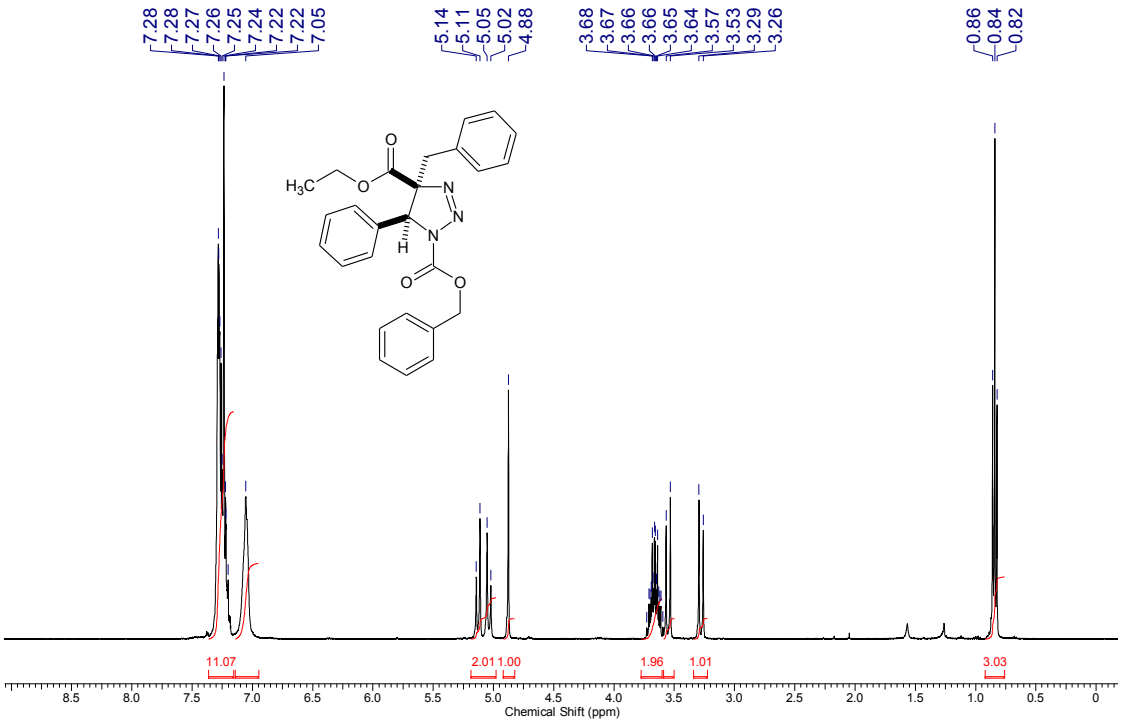

167.6
167.1
134.8
132.9
130.5
128.6
128.4
127.7
126.7
95.2
61.9
60.9
42.7
22.0
13.4
Chemical Shift (ppm)

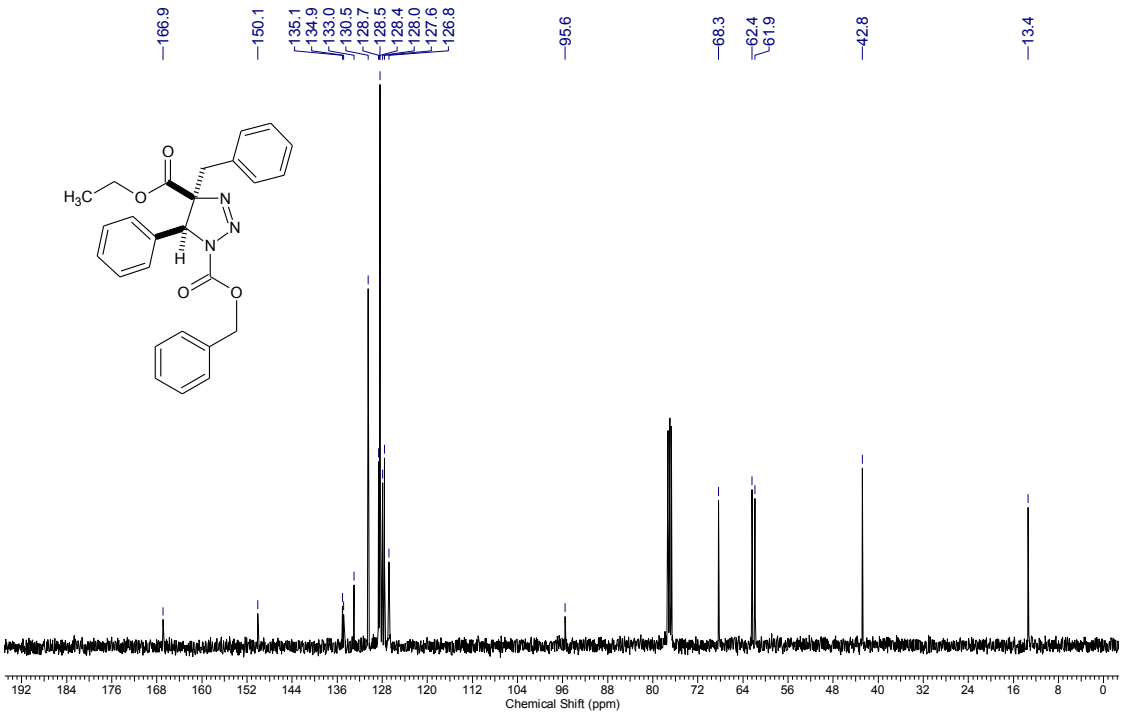
217ad:


7.26
7.26
7.25
7.24
7.02
7.01
5.05
3.71
3.69
3.67
3.66
3.65
3.64
3.55
3.51
3.33
3.29
1.13
0.88
0.86
0.85
8.62
1.92
1.00
2.00
1.04
9.18
3.07
Chemical Shift (ppm)

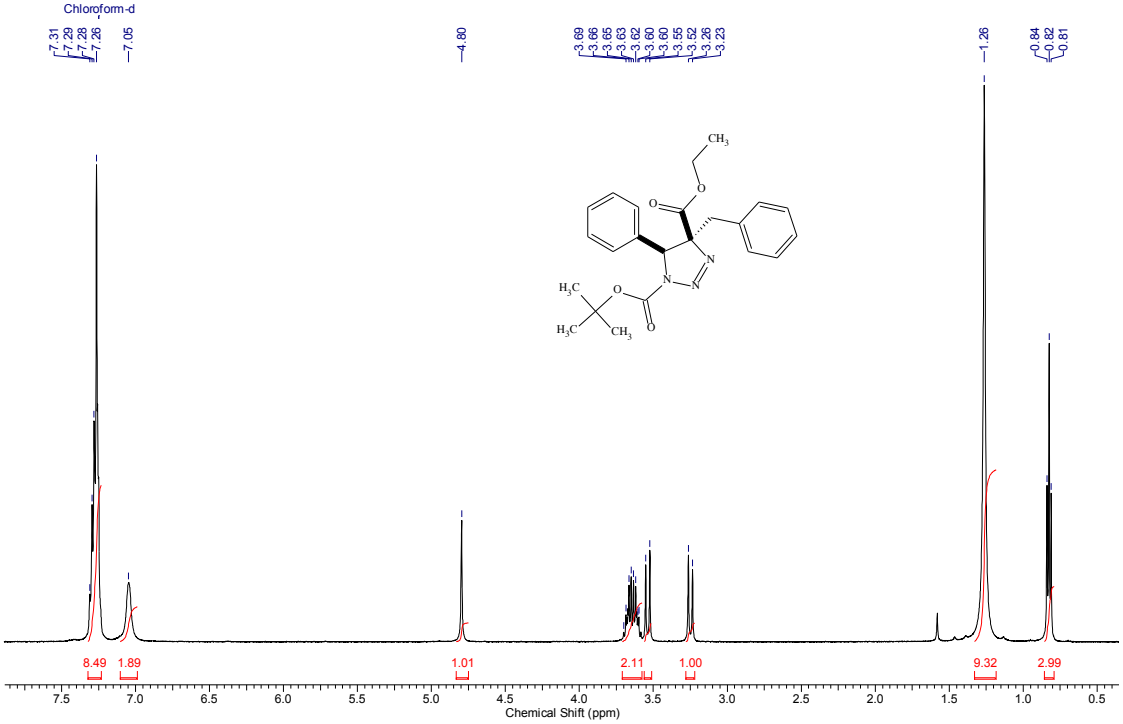

174.9
167.4
135.6
132.9
130.6
128.4
127.5
126.6
92.3
61.9
61.8
42.7
40.6
26.7
13.4
Chemical Shift (ppm)

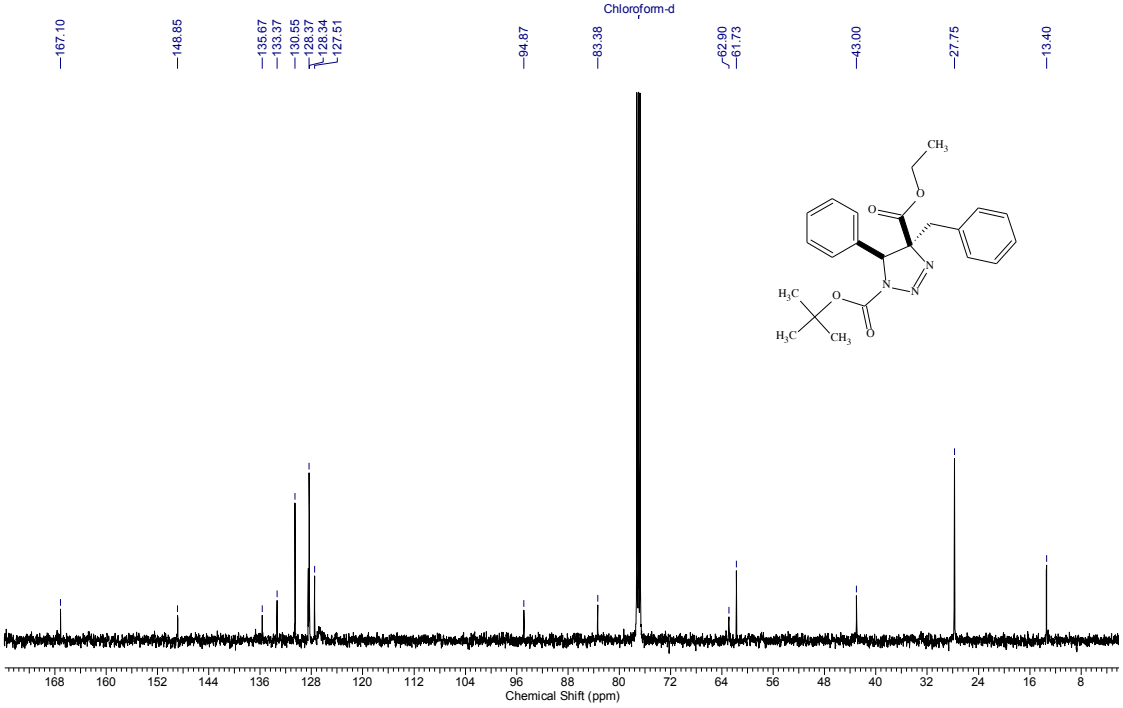
217ae:


7.28
7.28
7.27
7.26
7.25
7.24
7.22
7.22
7.05
5.14
5.11
5.05
5.02
4.88
3.68
3.67
3.66
3.66
3.65
3.64
3.57
3.53
3.29
3.26
0.86
0.84
0.82
11.07
2.01
1.00
1.96
1.01
3.03
Chemical Shift (ppm)

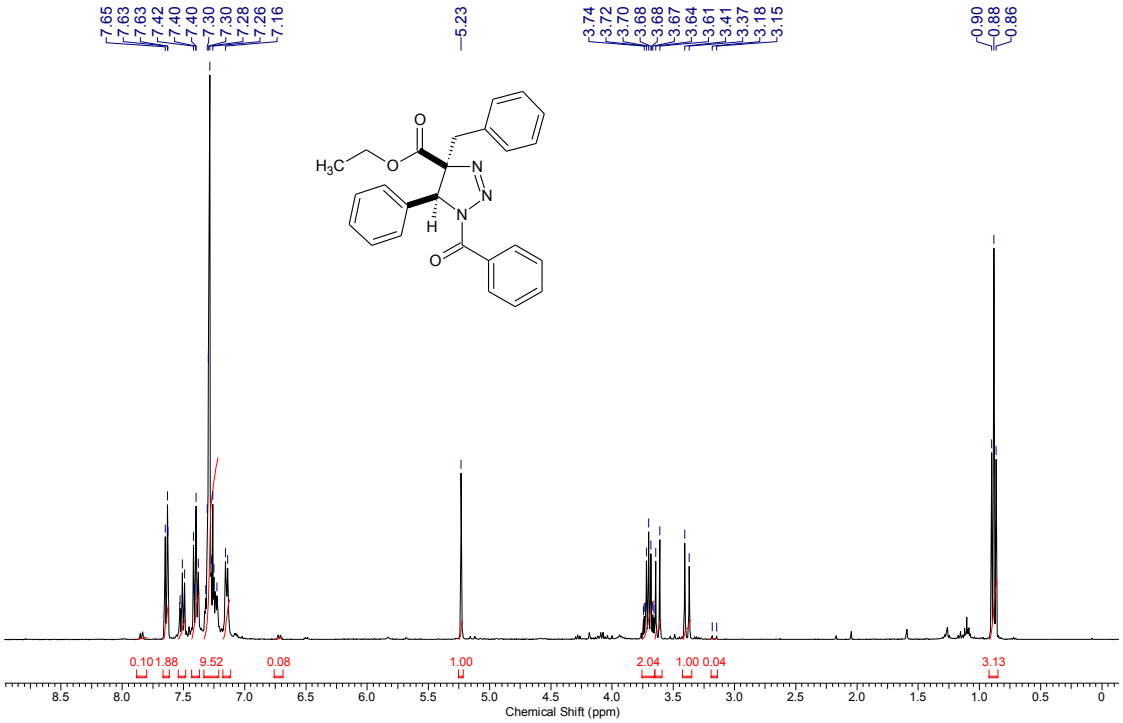

166.9
150.1
135.1
134.9
133.0
130.5
128.7
128.5
128.4
128.0
127.6
126.8
95.6
68.3
62.4
61.9
42.8
13.4
Chemical Shift (ppm)

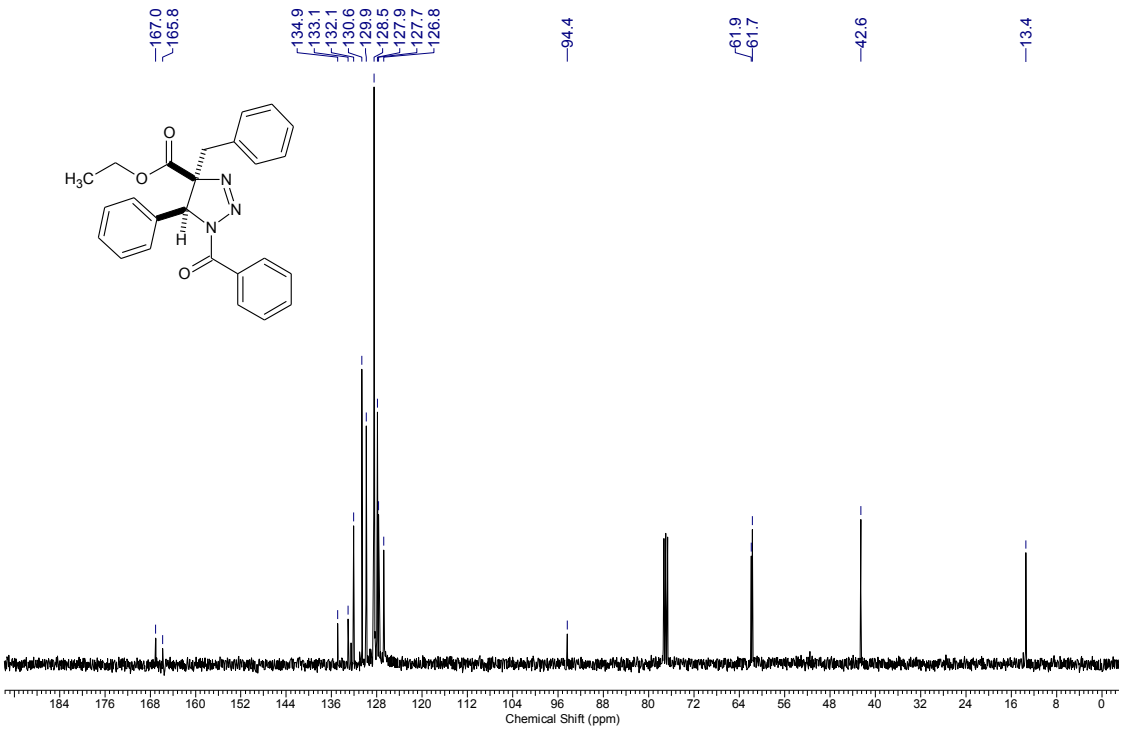
217af:


Chloroform-d
7.31
7.29
7.28
7.26
7.05
4.80
3.69
3.66
3.65
3.63
3.62
3.60
3.60
3.55
3.52
3.26
3.23
1.26
0.84
0.82
0.81
8.49
1.89
1.01
2.11
1.00
9.32
2.99
Chemical Shift (ppm)

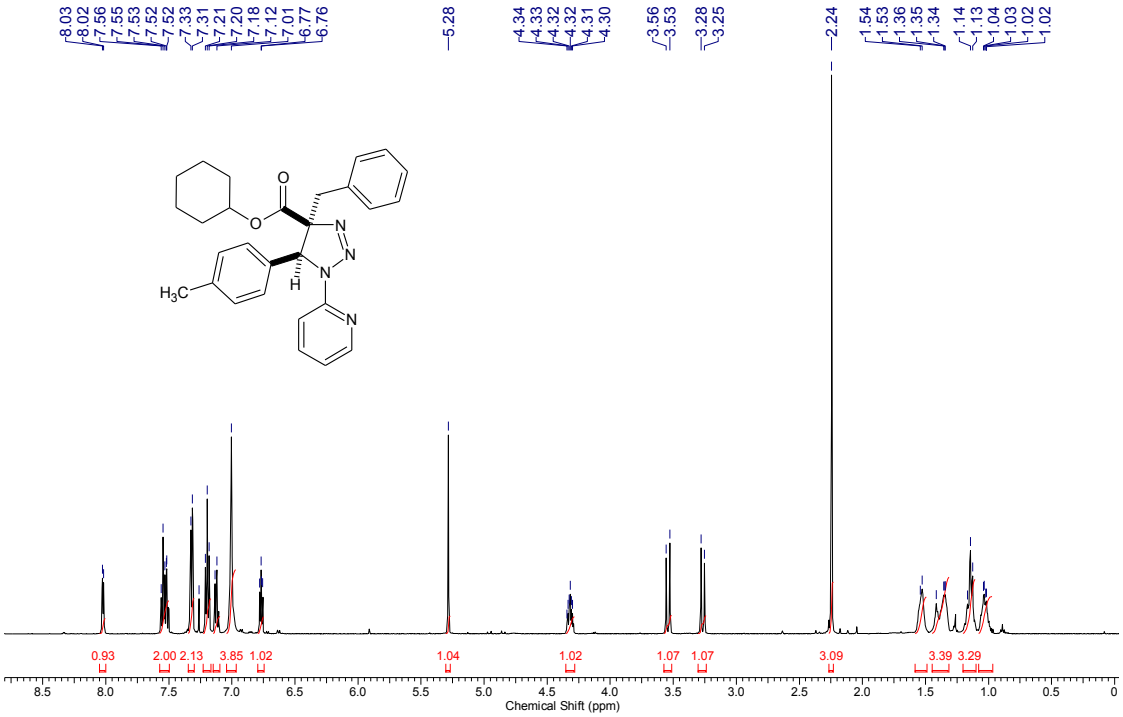

Chloroform-d
167.10
148.85
135.67
133.37
130.55
128.37
128.34
127.51
94.87
83.38
62.90
61.73
43.00
27.75
13.40
Chemical Shift (ppm)

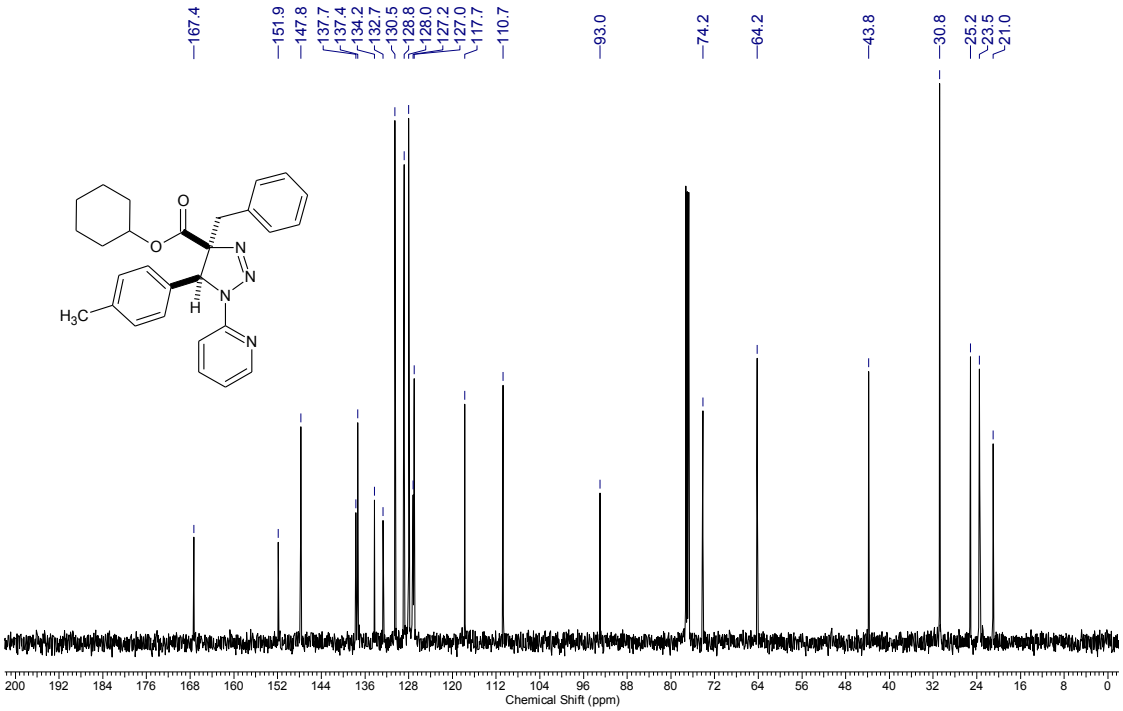
217ag:


7.65
7.63
7.63
7.42
7.40
7.40
7.30
7.30
7.28
7.26
7.16
5.23
3.74
3.72
3.70
3.68
3.68
3.67
3.64
3.61
3.41
3.37
3.18
3.15
0.90
0.88
0.86
0.10 1.88 9.52 0.08 1.00 2.04 1.00 0.04 3.13
Chemical Shift (ppm)

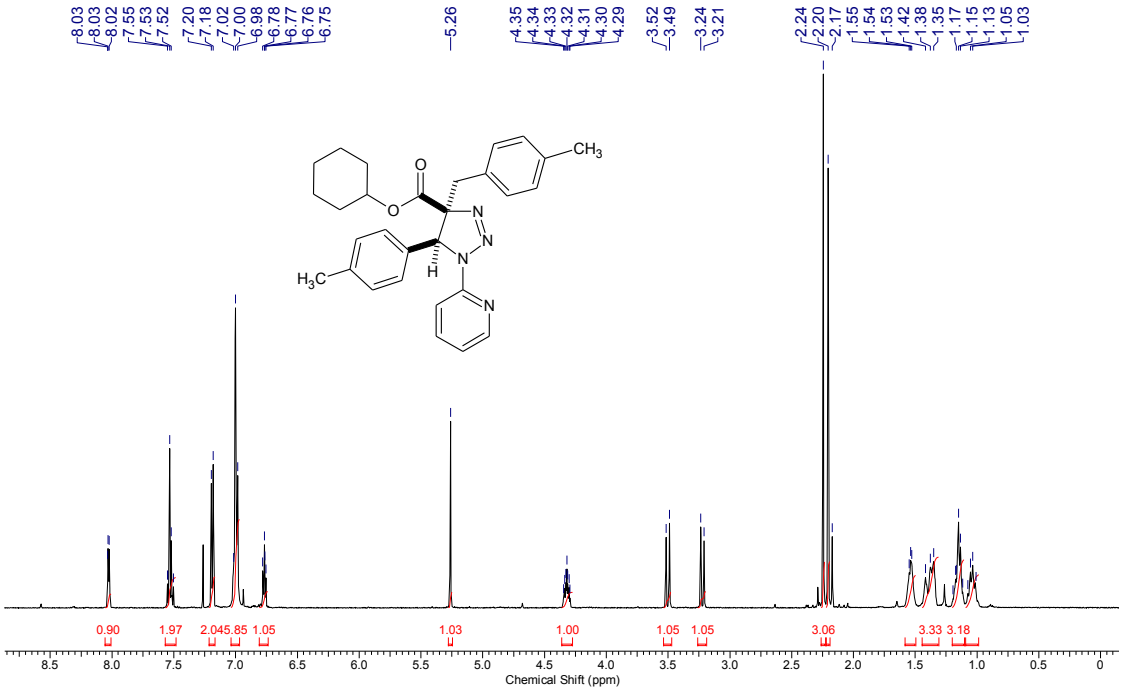

167.0
165.8
134.9
133.1
132.1
130.6
129.9
128.5
127.9
127.7
126.8
94.4
61.9
61.7
42.6
13.4
Chemical Shift (ppm)

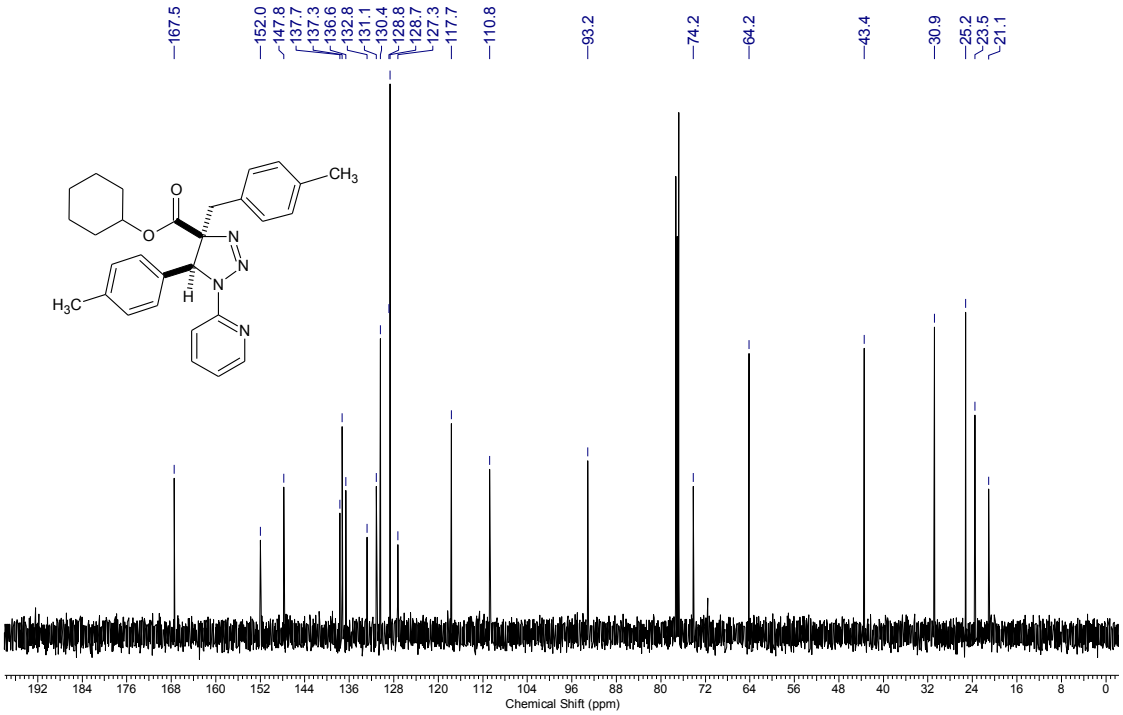
217aj:


8.03
8.02
7.56
7.55
7.53
7.52
7.52
7.33
7.31
7.21
7.20
7.18
7.12
7.01
6.77
6.76
5.28
4.34
4.33
4.32
4.32
4.31
4.30
3.56
3.53
3.28
3.25
2.24
1.54
1.53
1.36
1.35
1.34
1.14
1.13
1.04
1.03
1.02
1.02
O
O
N
N
N
H
H3C
N
0.93
2.00
2.13
3.85
1.02
1.04
1.02
1.07
1.07
3.09
3.39
3.29
Chemical Shift (ppm)

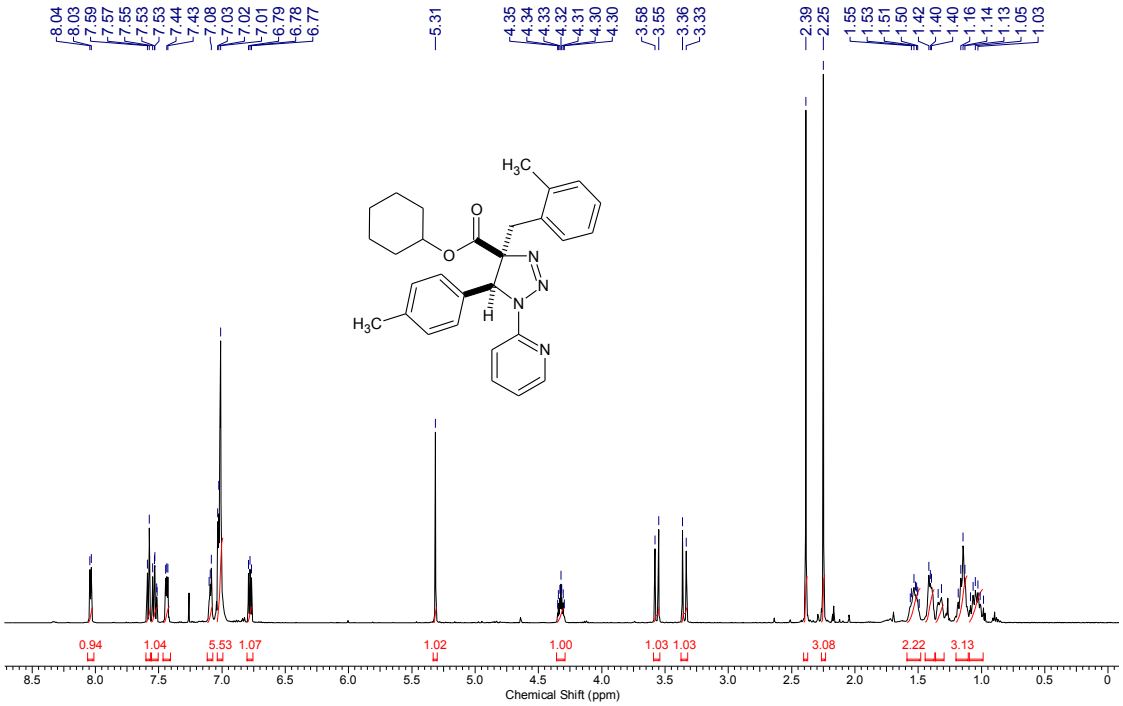

167.4
151.9
147.8
137.7
137.4
134.2
132.7
130.5
128.8
128.0
127.2
127.0
117.7
110.7
93.0
74.2
64.2
43.8
30.8
25.2
23.5
21.0
O
O
N
N
N
H
H3C
N
Chemical Shift (ppm)

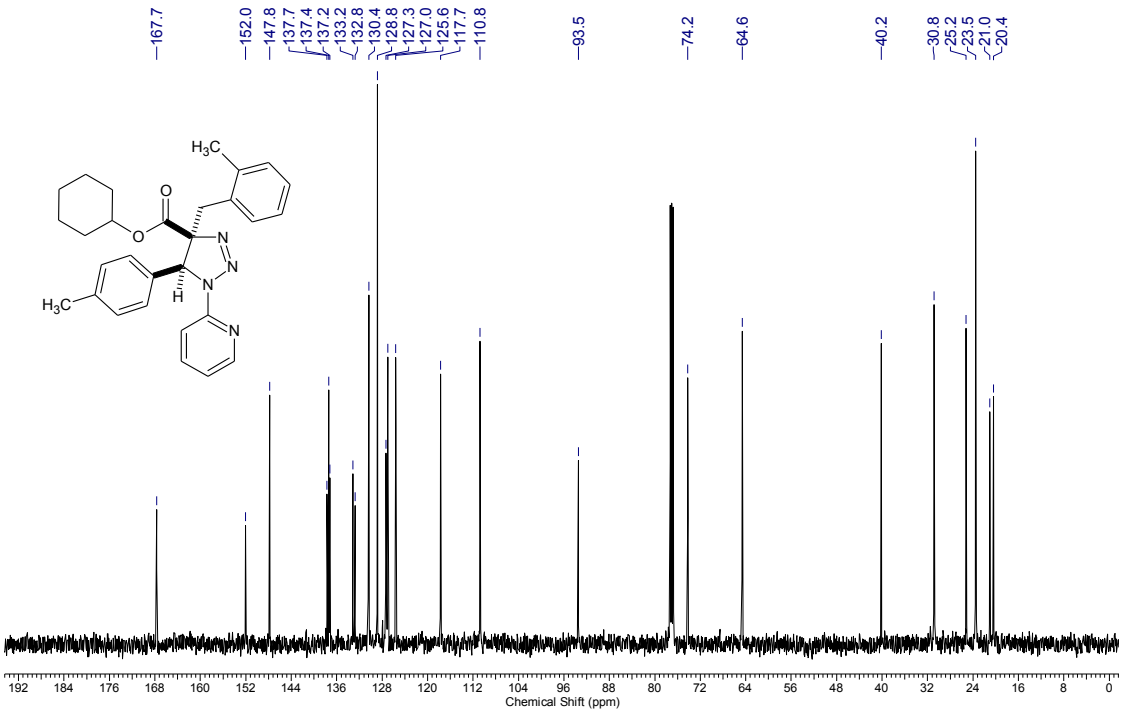
217ak:


8.03
8.03
8.02
7.55
7.53
7.52
7.20
7.18
7.02
7.00
6.98
6.78
6.77
6.76
6.75
5.26
4.35
4.34
4.33
4.32
4.31
4.30
4.29
3.52
3.49
3.24
3.21
2.24
2.20
2.17
1.55
1.54
1.53
1.42
1.38
1.35
1.17
1.15
1.13
1.05
1.03
CH3
O
O
N
N
N
H
H3C
N
0.90
1.97
2.04
5.85
1.05
1.03
1.00
1.05
1.05
3.06
3.33
3.18
Chemical Shift (ppm)

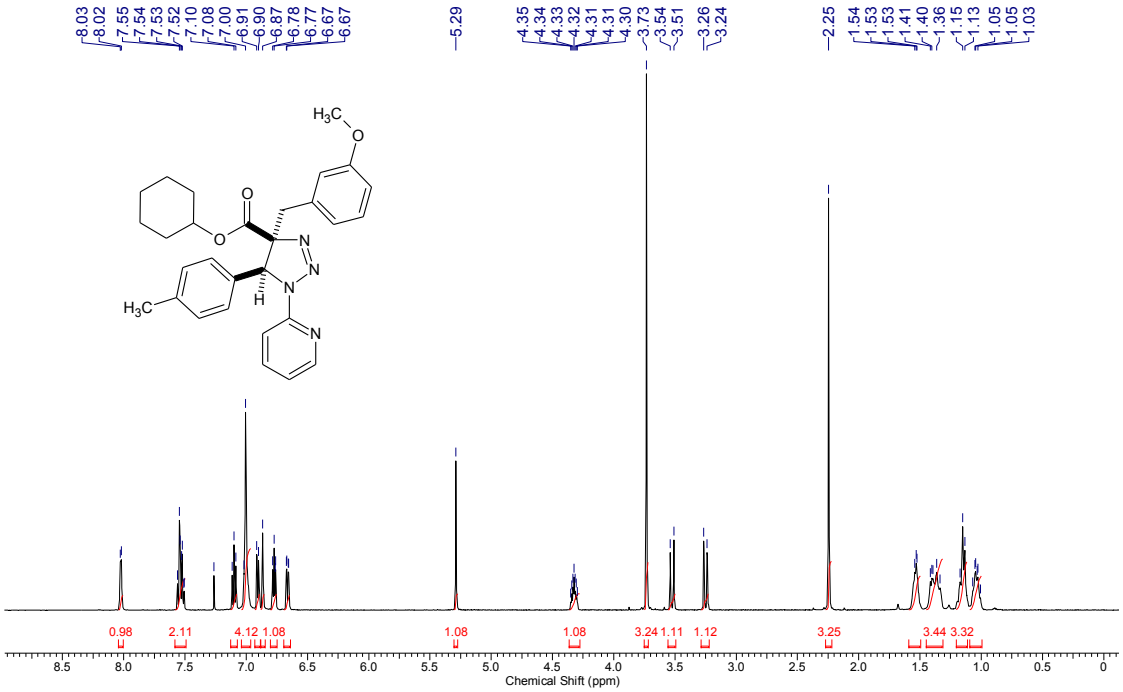

167.5
152.0
147.8
137.7
137.3
136.6
132.8
131.1
130.4
128.8
128.7
127.3
117.7
110.8
93.2
74.2
64.2
43.4
30.9
25.2
23.5
21.1
CH3
O
O
N
N
N
H
H3C
N
Chemical Shift (ppm)

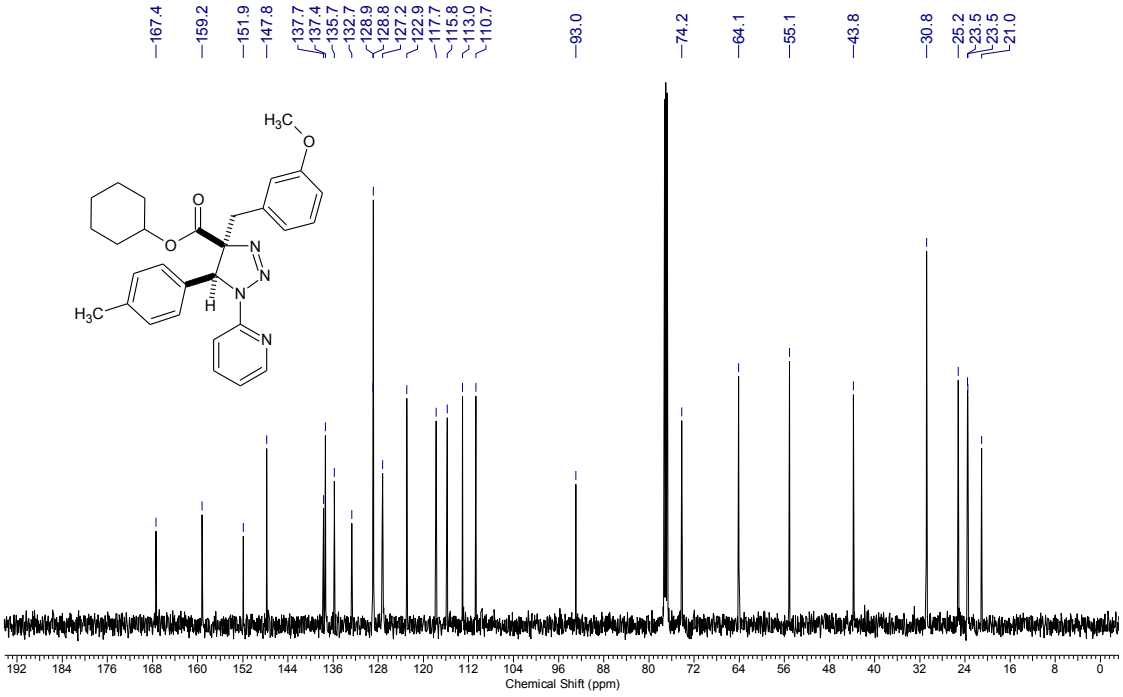
217al:


8.04
8.03
7.59
7.57
7.55
7.53
7.53
7.44
7.43
7.08
7.03
7.02
7.01
6.79
6.78
6.77
5.31
4.35
4.34
4.33
4.32
4.31
4.30
4.30
3.58
3.55
3.36
3.33
2.39
2.25
1.55
1.53
1.51
1.50
1.42
1.40
1.40
1.16
1.14
1.13
1.05
1.03
0.94
1.04
5.53
1.07
1.02
1.00
1.03
1.03
3.08
2.22
3.13
Chemical Shift (ppm)

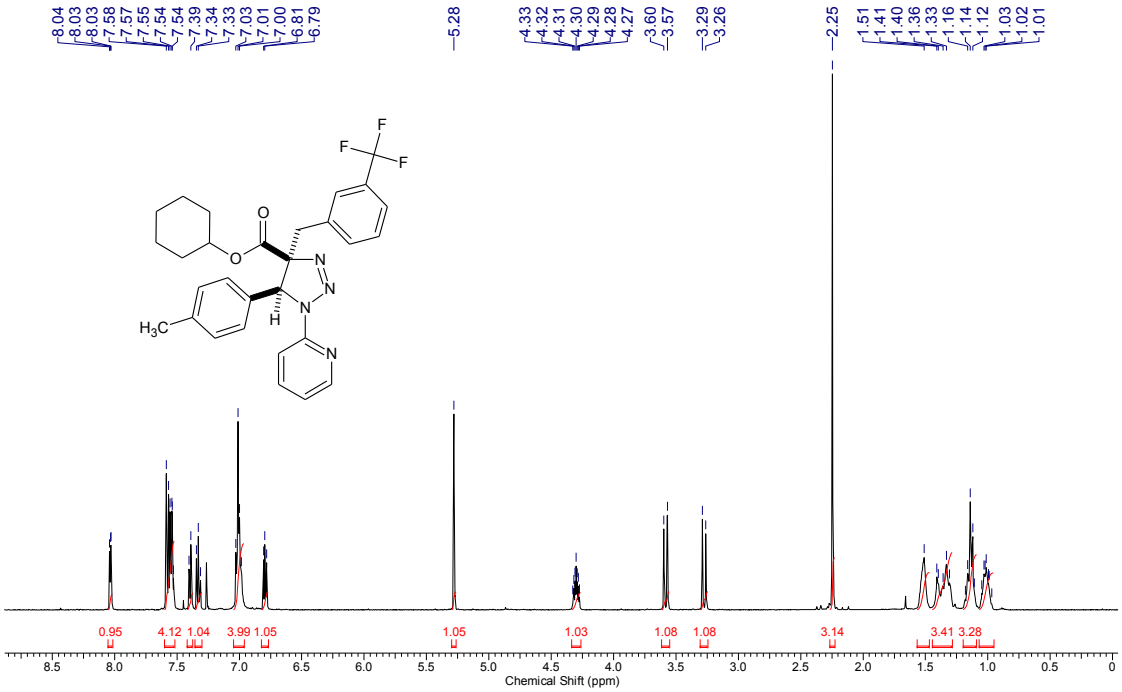

167.7
152.0
147.8
137.7
137.4
137.2
133.2
132.8
130.4
128.8
127.3
127.0
125.6
117.7
110.8
93.5
74.2
64.6
40.2
30.8
25.2
23.5
21.0
20.4
Chemical Shift (ppm)

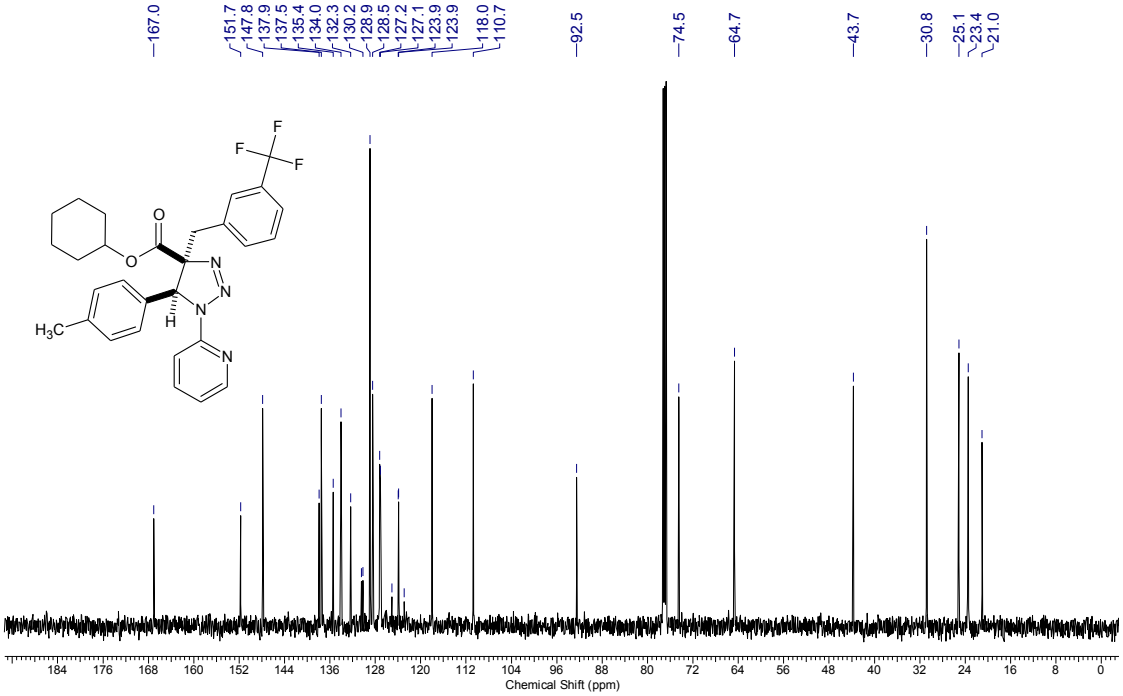
217am:


8.03
8.02
7.55
7.54
7.53
7.52
7.10
7.08
7.00
6.91
6.90
6.87
6.78
6.77
6.67
6.67
5.29
4.35
4.34
4.33
4.32
4.31
4.31
4.30
3.73
3.54
3.51
3.26
3.24
2.25
1.54
1.53
1.53
1.41
1.40
1.36
1.15
1.13
1.05
1.05
1.03
H3C
O
O
O
N
N
N
H
H3C
N
0.98
2.11
4.12
1.08
1.08
1.08
3.24
1.11
1.12
3.25
3.44
3.32
Chemical Shift (ppm)

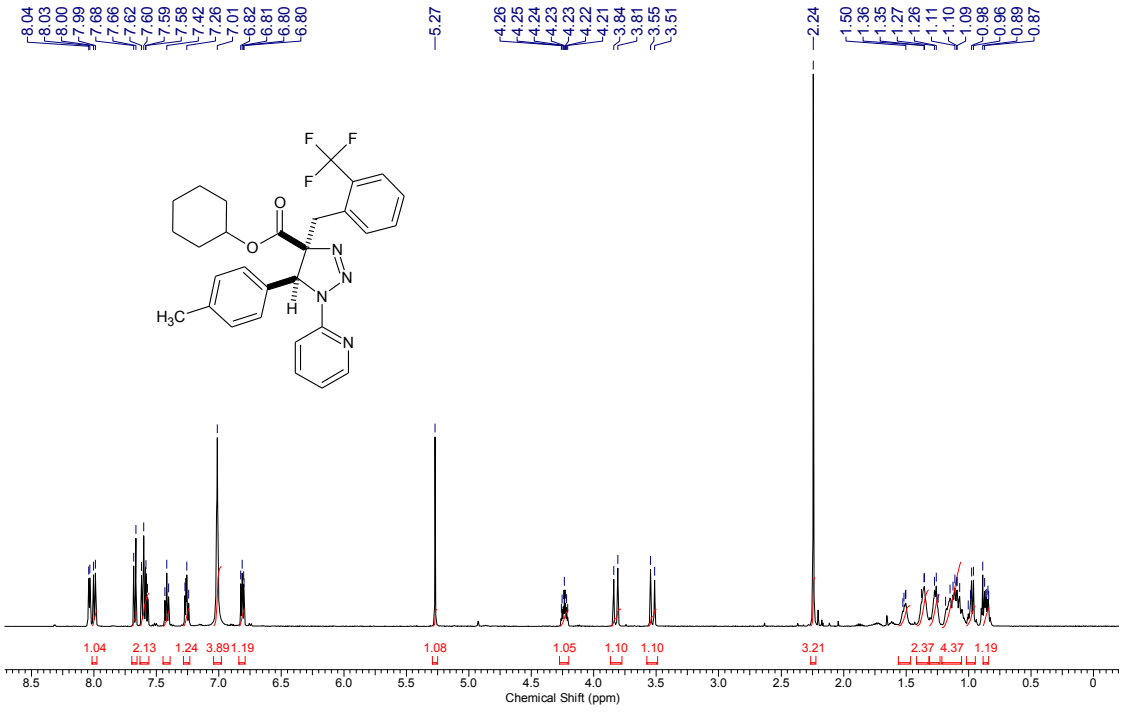

167.4
159.2
151.9
147.8
137.7
137.4
135.7
132.7
128.9
128.8
127.2
122.9
117.7
115.8
113.0
110.7
93.0
74.2
64.1
55.1
43.8
30.8
25.2
23.5
23.5
21.0
H3C
O
O
O
N
N
N
H
H3C
N
Chemical Shift (ppm)

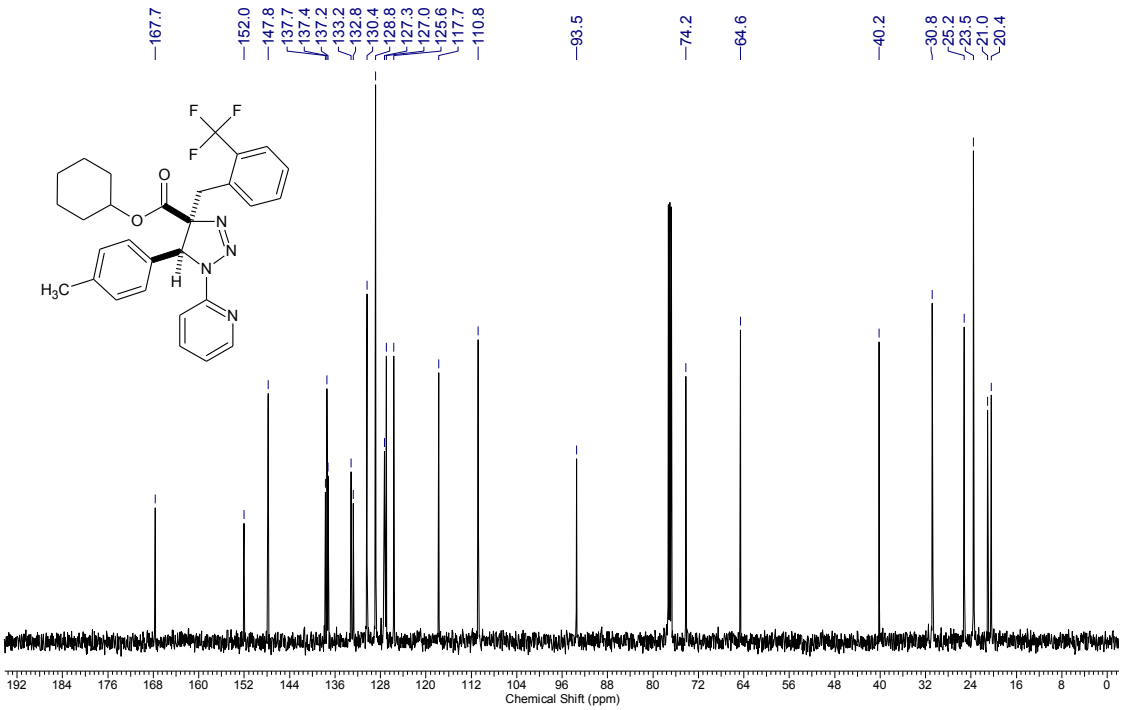
217an:


8.04
8.03
8.03
7.58
7.57
7.55
7.54
7.54
7.39
7.34
7.33
7.03
7.01
7.00
6.81
6.79
5.28
4.33
4.32
4.31
4.30
4.29
4.28
4.27
3.60
3.57
3.29
3.26
2.25
1.51
1.41
1.40
1.36
1.33
1.16
1.14
1.12
1.03
1.02
1.01
F
F
F
O
O
N
N
N
H
H3C
N
0.95
4.12
1.04
3.99
1.05
1.05
1.03
1.08
1.08
3.14
3.41
3.28
Chemical Shift (ppm)

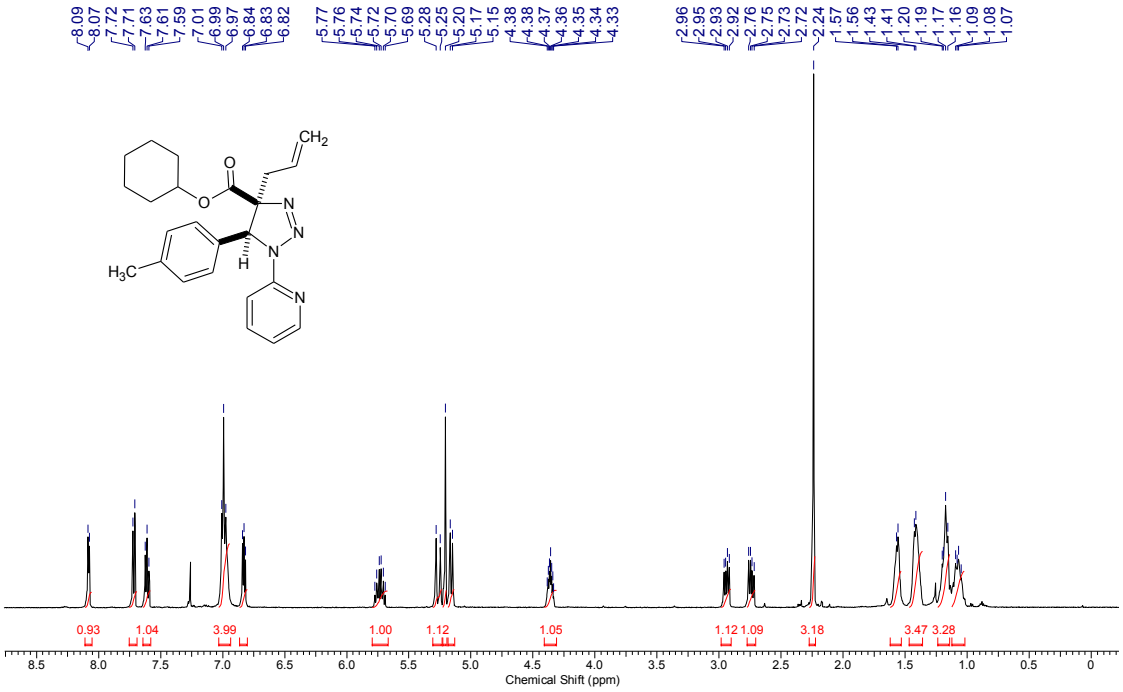

167.0
151.7
147.8
137.9
137.5
135.4
134.0
132.3
130.2
128.9
128.5
127.2
127.1
123.9
123.9
118.0
110.7
92.5
74.5
64.7
43.7
30.8
25.1
23.4
21.0
F
F
F
O
O
N
N
N
H
H3C
N
Chemical Shift (ppm)

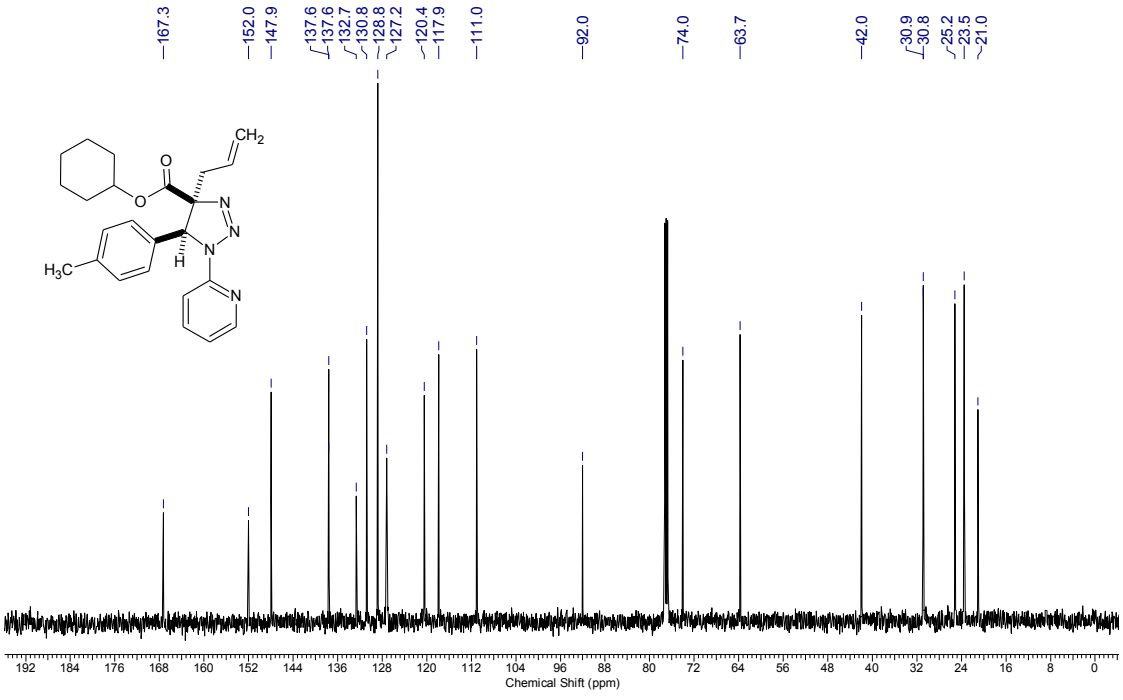
217ao:


8.04
8.03
8.00
7.99
7.68
7.66
7.62
7.60
7.59
7.58
7.42
7.26
7.01
6.82
6.81
6.80
6.80
5.27
4.26
4.25
4.24
4.23
4.23
4.22
4.21
3.84
3.81
3.55
3.51
2.24
1.50
1.36
1.35
1.27
1.26
1.11
1.10
1.09
0.98
0.96
0.89
0.87
F
F
F
O
O
N
N
N
H
H3C
N
1.04
2.13
1.24
3.89
1.19
1.08
1.05
1.10
1.10
3.21
2.37
4.37
1.19
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
Chemical Shift (ppm)

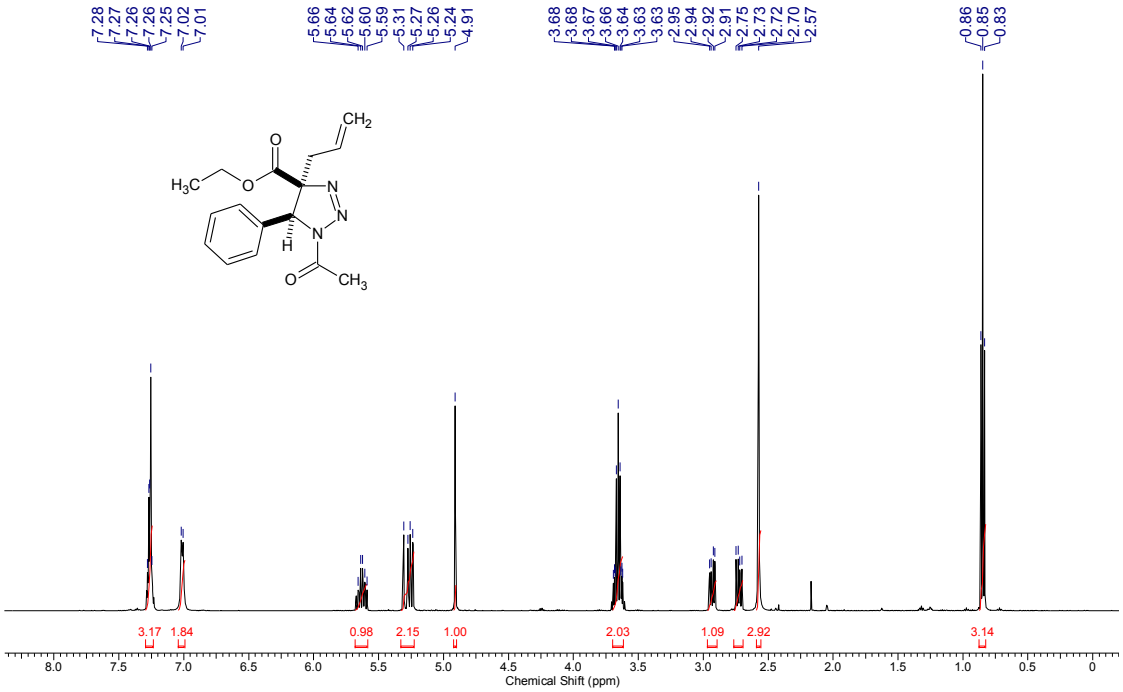

167.7
152.0
147.8
137.7
137.4
137.2
133.2
132.8
130.4
128.8
127.3
127.0
125.6
117.7
110.8
93.5
74.2
64.6
40.2
30.8
25.2
23.5
21.0
20.4
F
F
F
O
O
N
N
N
H
H3C
N
192
184
176
168
160
152
144
136
128
120
112
104
96
88
80
72
64
56
48
40
32
24
16
8
0
Chemical Shift (ppm)

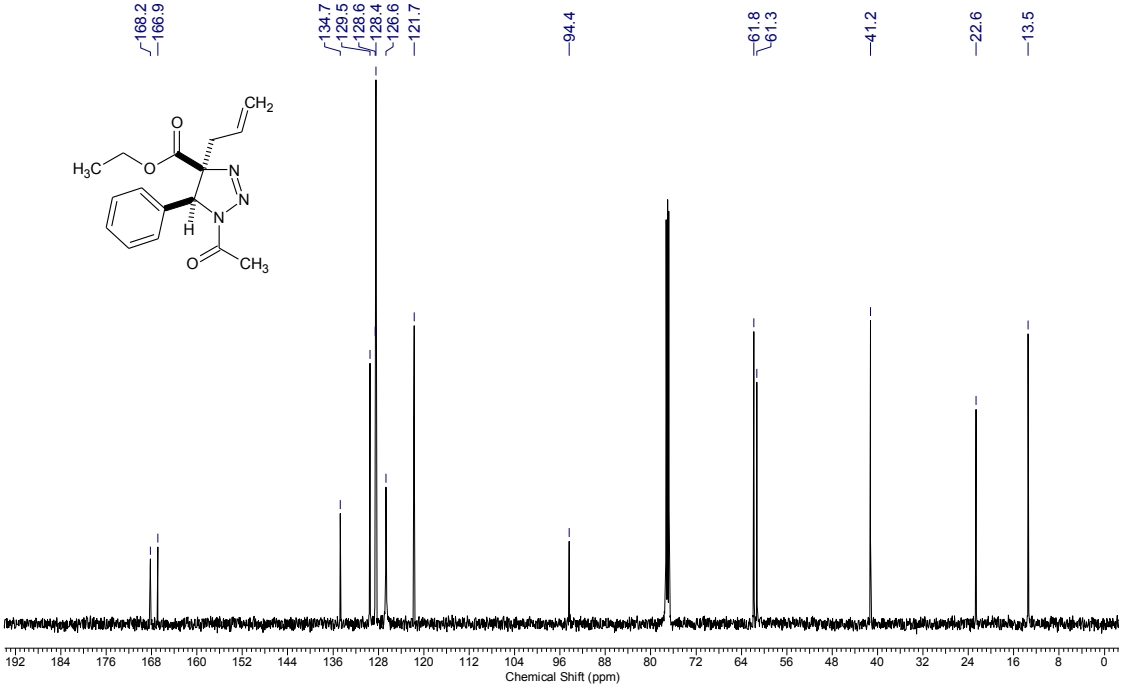
217ap:


8.09
8.07
7.72
7.71
7.63
7.61
7.59
7.01
6.99
6.97
6.84
6.83
6.82
5.77
5.76
5.74
5.72
5.70
5.69
5.28
5.25
5.20
5.17
5.15
4.38
4.38
4.37
4.36
4.35
4.34
4.33
2.96
2.95
2.93
2.92
2.76
2.75
2.73
2.72
2.24
1.57
1.56
1.43
1.41
1.20
1.19
1.17
1.16
1.09
1.08
1.07
CH2
O
O
N
N
N
H
H3C
N
0.93
1.04
3.99
1.00
1.12
1.05
1.12
1.09
3.18
3.47
3.28
Chemical Shift (ppm)

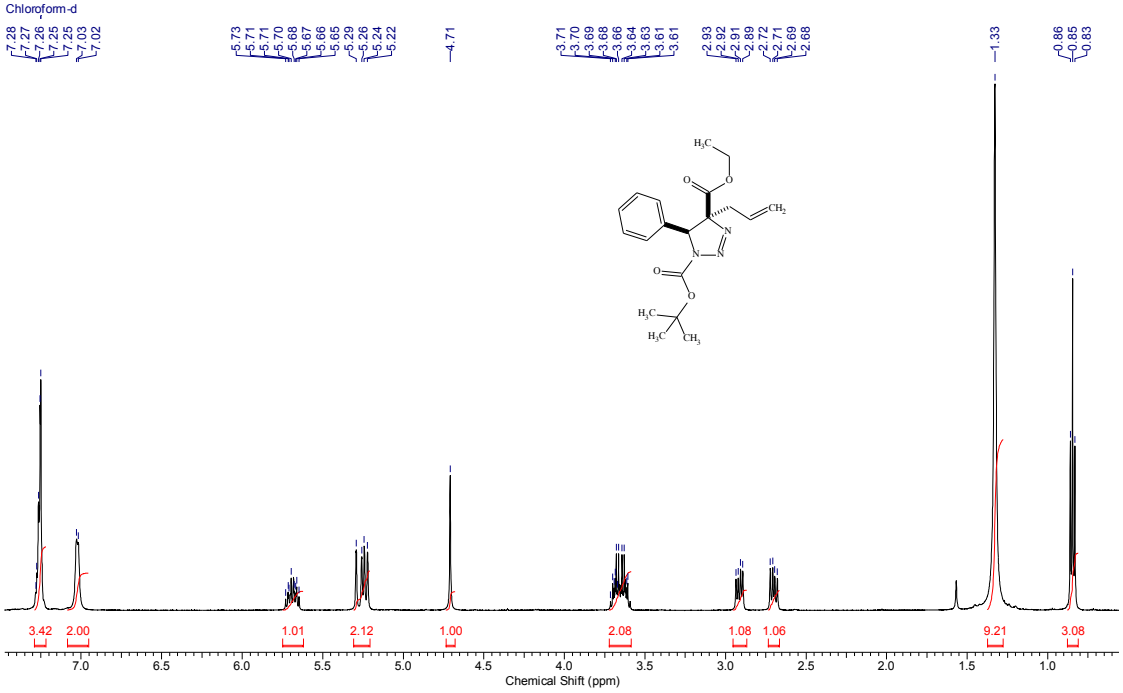

167.3
152.0
147.9
137.6
137.6
132.7
130.8
128.8
127.2
120.4
117.9
111.0
92.0
74.0
63.7
42.0
30.9
30.8
25.2
23.5
21.0
CH2
O
O
N
N
N
H
H3C
N
Chemical Shift (ppm)

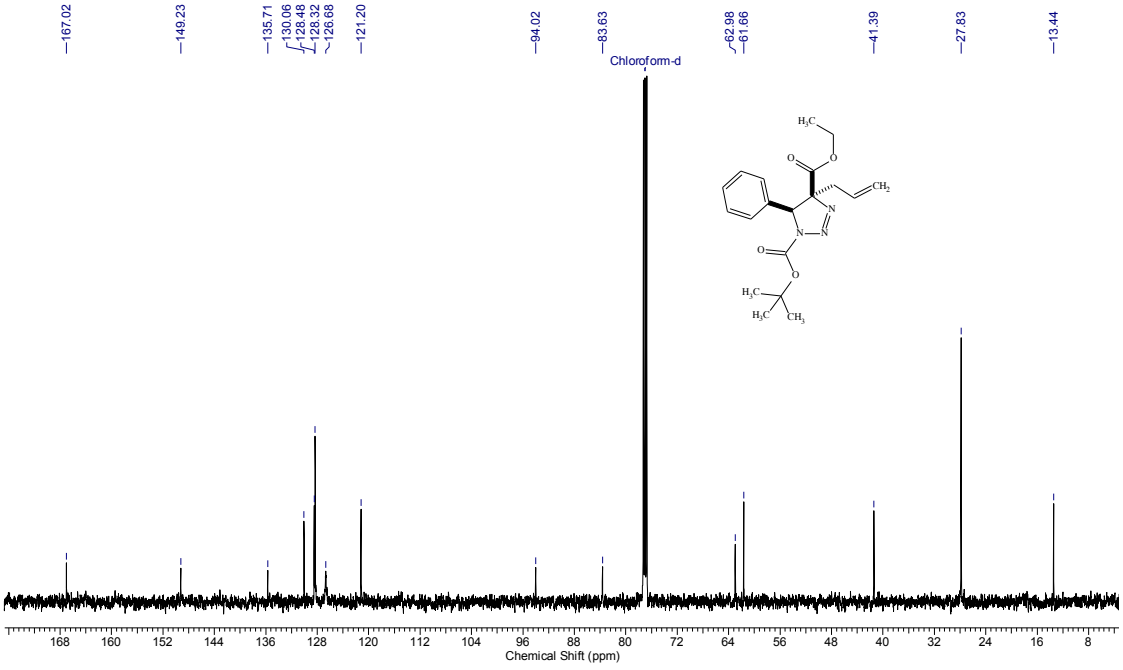
217aq:


7.28
7.27
7.26
7.26
7.25
7.02
7.01
5.66
5.64
5.62
5.60
5.59
5.31
5.27
5.26
5.24
4.91
3.68
3.68
3.67
3.66
3.64
3.63
3.63
2.95
2.94
2.92
2.91
2.75
2.73
2.72
2.70
2.57
0.86
0.85
0.83
CH2
O
H3C
O
N
N
N
H
O
CH3
3.17
1.84
0.98
2.15
1.00
2.03
1.09
2.92
3.14
Chemical Shift (ppm)

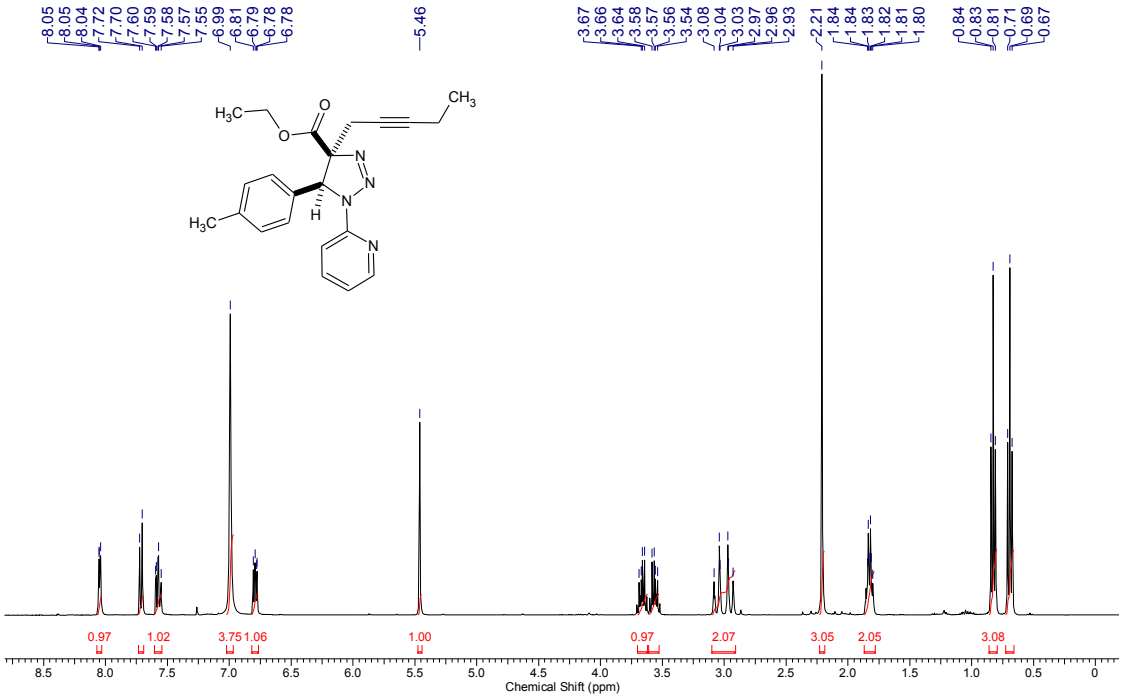

168.2
166.9
134.7
129.5
128.6
128.4
126.6
121.7
94.4
61.8
61.3
41.2
22.6
13.5
CH2
O
H3C
O
N
N
N
H
O
CH3
Chemical Shift (ppm)

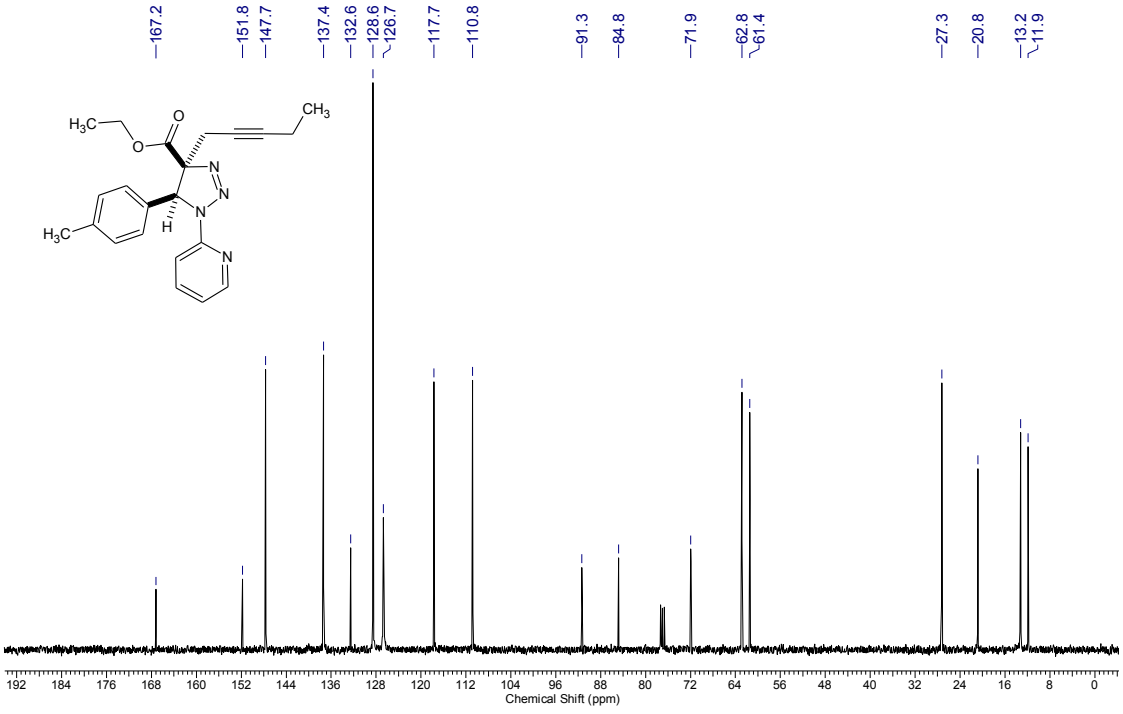
217ar:


Chloroform-d
7.28
7.27
7.26
7.25
7.25
7.03
7.02
5.73
5.71
5.71
5.70
5.68
5.67
5.66
5.65
5.29
5.26
5.24
5.22
4.71
3.71
3.70
3.69
3.68
3.66
3.64
3.63
3.61
3.61
2.93
2.92
2.91
2.89
2.72
2.71
2.69
2.68
1.33
0.86
0.85
0.83
3.42
2.00
1.01
2.12
1.00
2.08
1.08
1.06
9.21
3.08
Chemical Shift (ppm)

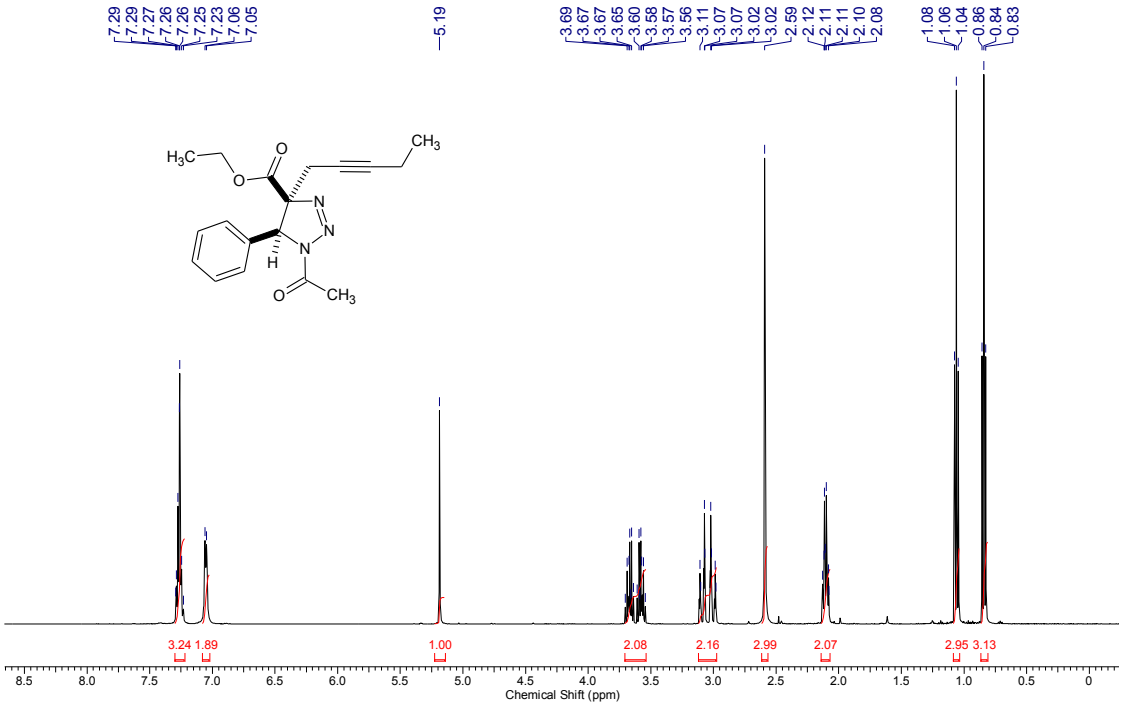

167.02
149.23
135.71
130.06
128.48
128.32
126.68
121.20
94.02
83.63
62.98
61.66
41.39
27.83
13.44
Chloroform-d
Chemical Shift (ppm)

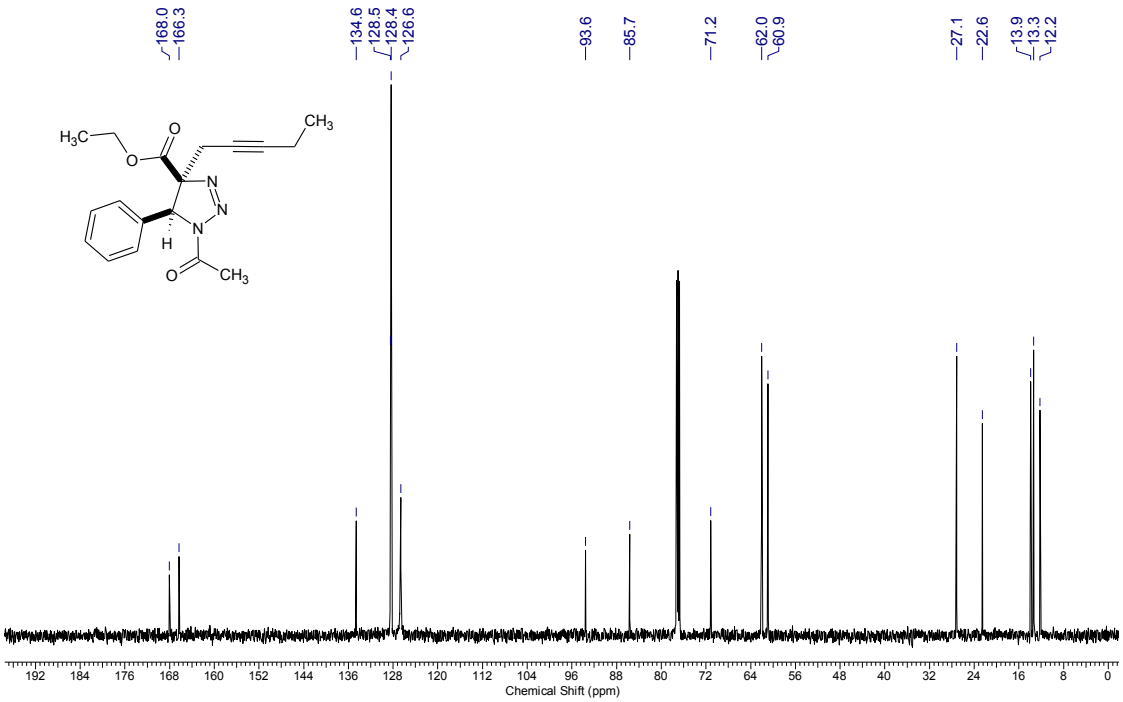
217as:


8.05
8.05
8.04
7.72
7.70
7.60
7.59
7.58
7.57
7.55
6.99
6.81
6.79
6.78
6.78
5.46
3.67
3.66
3.64
3.58
3.57
3.56
3.54
3.08
3.04
3.03
2.97
2.96
2.93
2.21
1.84
1.84
1.83
1.82
1.81
1.80
0.84
0.83
0.81
0.71
0.69
0.67
0.97
1.02
3.75
1.06
1.00
0.97
2.07
3.05
2.05
3.08
Chemical Shift (ppm)

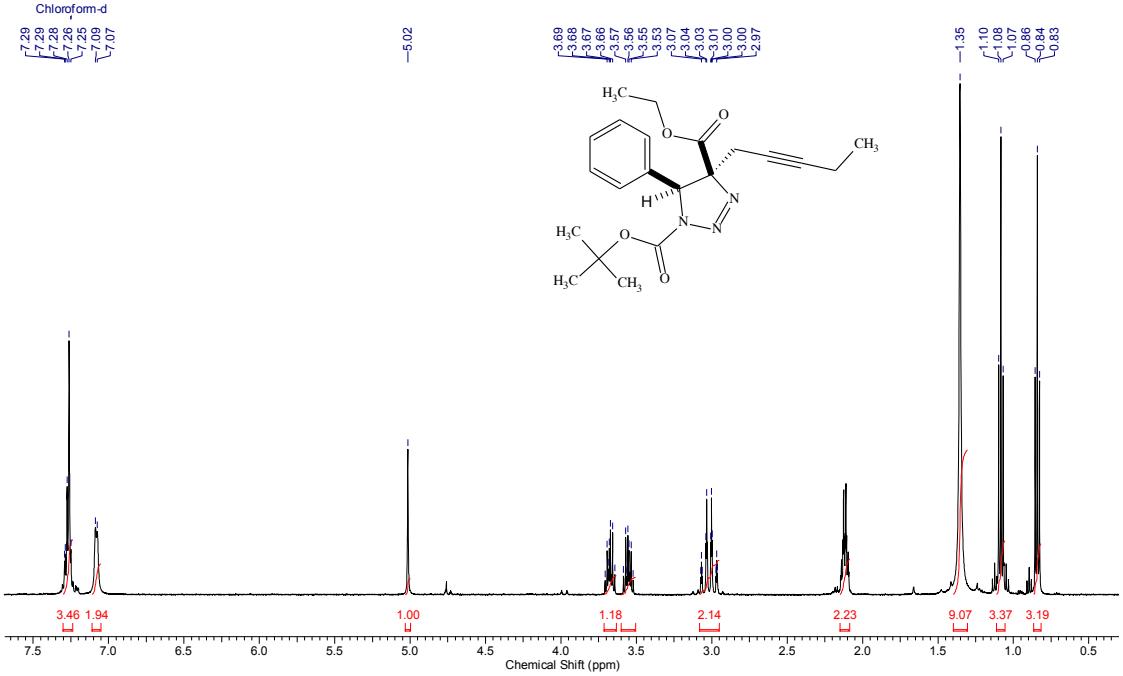

167.2
151.8
147.7
137.4
132.6
128.6
126.7
117.7
110.8
91.3
84.8
71.9
62.8
61.4
27.3
20.8
13.2
11.9
Chemical Shift (ppm)

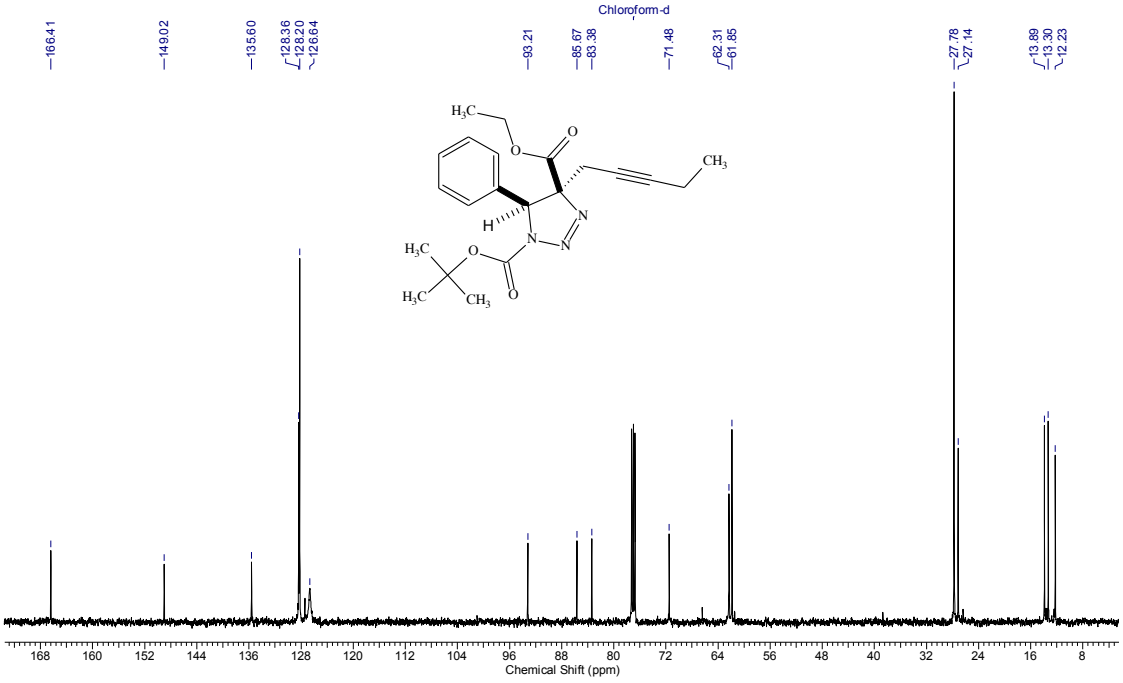
217at:


7.29
7.29
7.27
7.26
7.26
7.25
7.23
7.06
7.05
5.19
3.69
3.67
3.67
3.65
3.60
3.58
3.57
3.56
3.11
3.07
3.07
3.02
3.02
2.59
2.12
2.11
2.11
2.10
2.08
1.08
1.06
1.04
0.86
0.84
0.83
3.24
1.89
1.00
2.08
2.16
2.99
2.07
2.95
3.13
Chemical Shift (ppm)

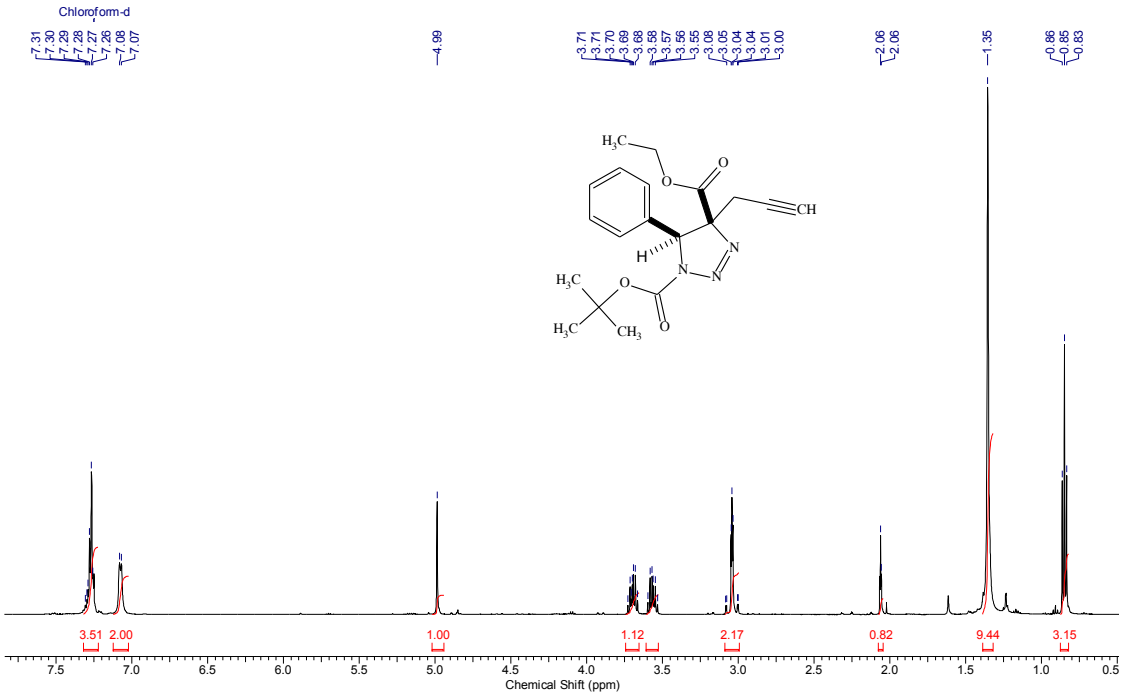

168.0
166.3
134.6
128.5
128.4
126.6
93.6
85.7
71.2
62.0
60.9
27.1
22.6
13.9
13.3
12.2
Chemical Shift (ppm)

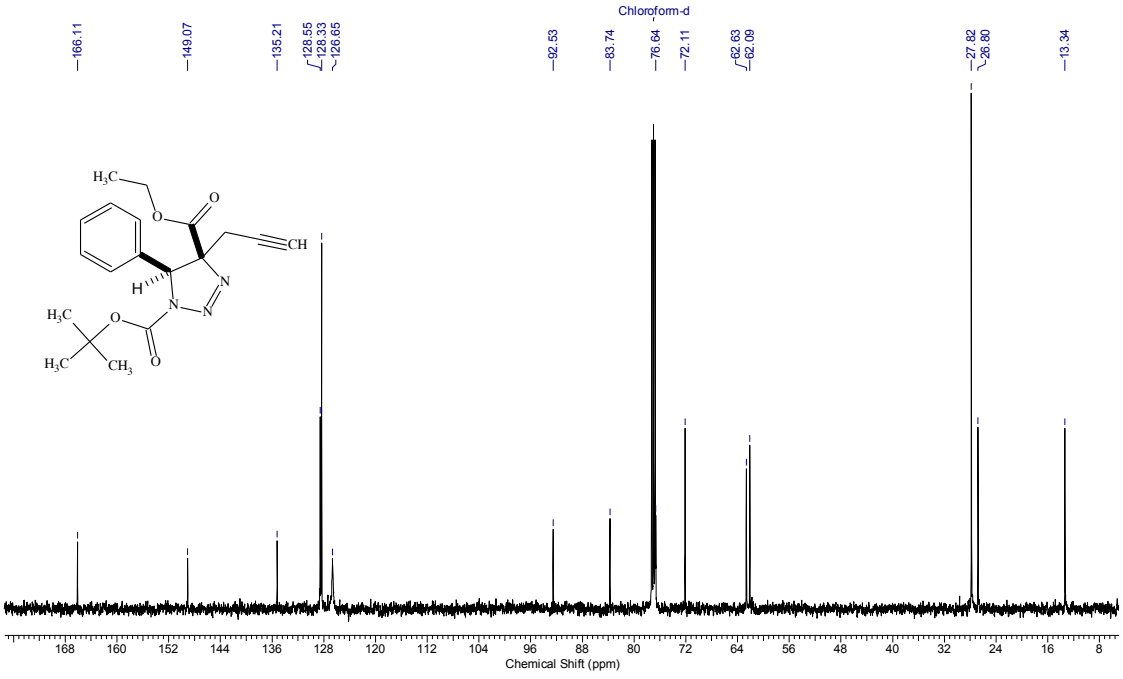
217au:


Chloroform-d
7.29
7.29
7.28
7.26
7.25
7.09
7.07
5.02
3.69
3.68
3.67
3.66
3.57
3.56
3.55
3.53
3.07
3.04
3.03
3.01
3.00
3.00
2.97
1.35
1.10
1.08
1.07
0.86
0.84
0.83
3.46
1.94
1.00
1.18
2.14
2.23
9.07
3.37
3.19
Chemical Shift (ppm)

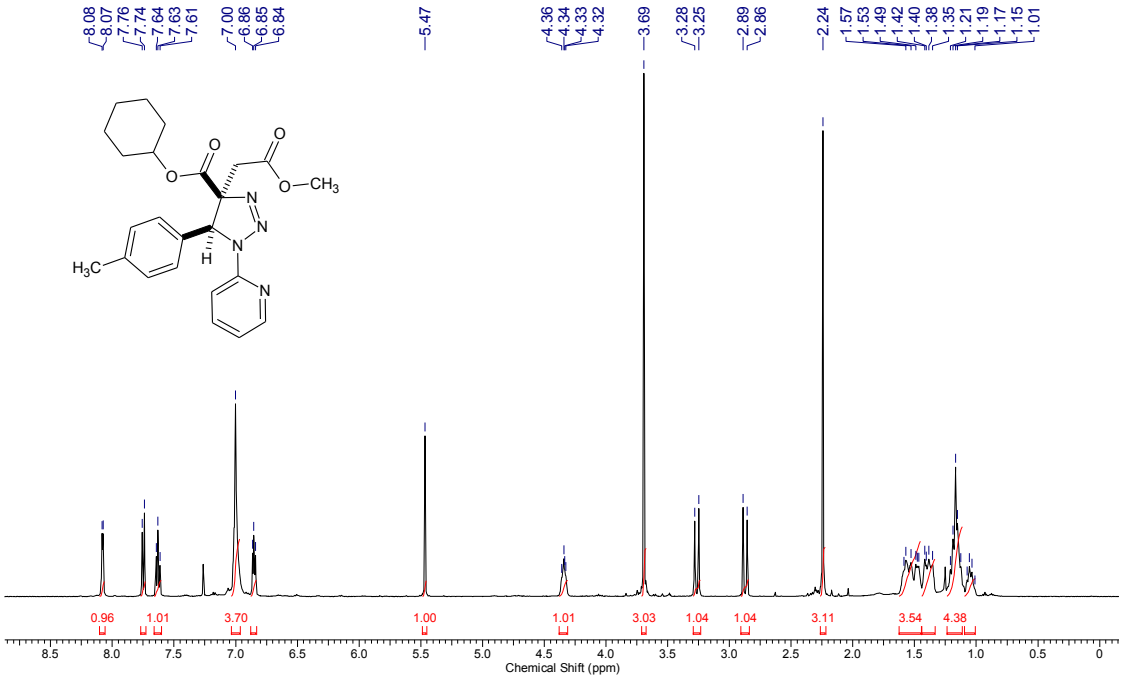

Chloroform-d
166.41
149.02
135.60
128.36
128.20
126.64
93.21
86.67
83.38
71.48
62.31
61.85
27.78
27.14
13.89
13.30
12.23
Chemical Shift (ppm)

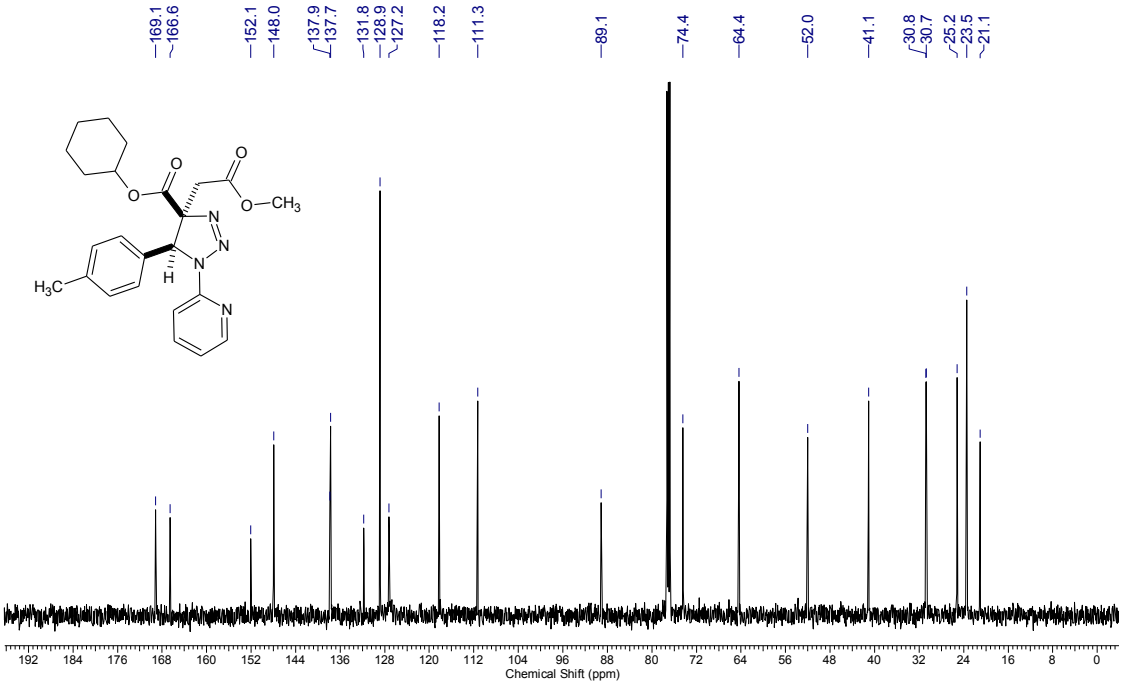
217av:


Chloroform-d
7.31
7.30
7.29
7.28
7.27
7.26
7.08
7.07
4.99
3.71
3.71
3.70
3.69
3.68
3.58
3.57
3.56
3.55
3.08
3.05
3.04
3.04
3.01
3.00
2.06
2.06
1.35
0.86
0.85
0.83
3.51
2.00
1.00
1.12
2.17
0.82
9.44
3.15
Chemical Shift (ppm)

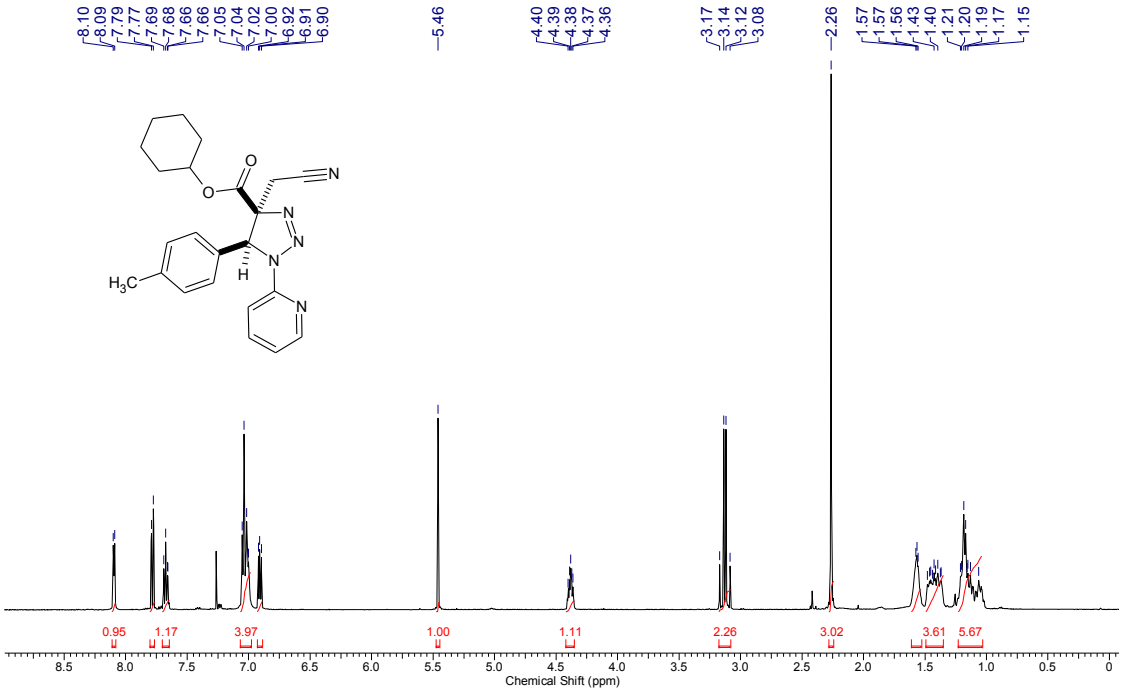

Chloroform-d
166.11
149.07
135.21
128.55
128.33
126.65
92.53
83.74
76.64
72.11
62.63
62.09
27.82
26.80
13.34
Chemical Shift (ppm)

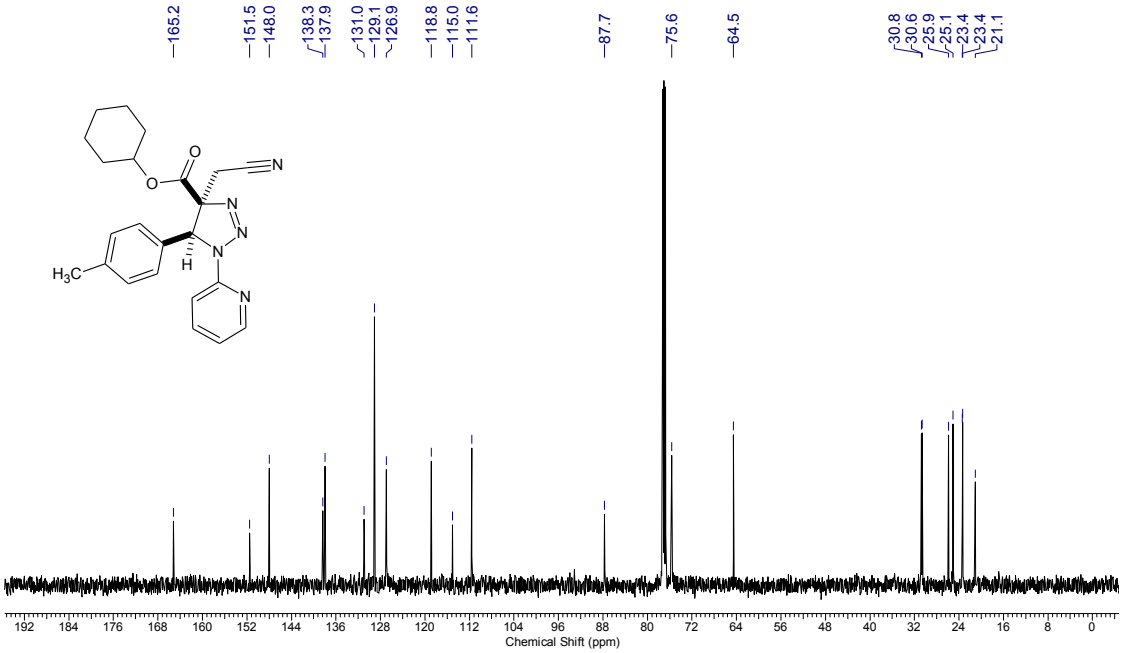
217aw:


8.08
8.07
7.76
7.74
7.64
7.63
7.61
7.00
6.86
6.85
6.84
5.47
4.36
4.34
4.33
4.32
3.69
3.28
3.25
2.89
2.86
2.24
1.57
1.53
1.49
1.42
1.40
1.38
1.35
1.21
1.19
1.17
1.15
1.01
0.96
1.01
3.70
1.00
1.01
3.03
1.04
1.04
3.11
3.54
4.38
Chemical Shift (ppm)

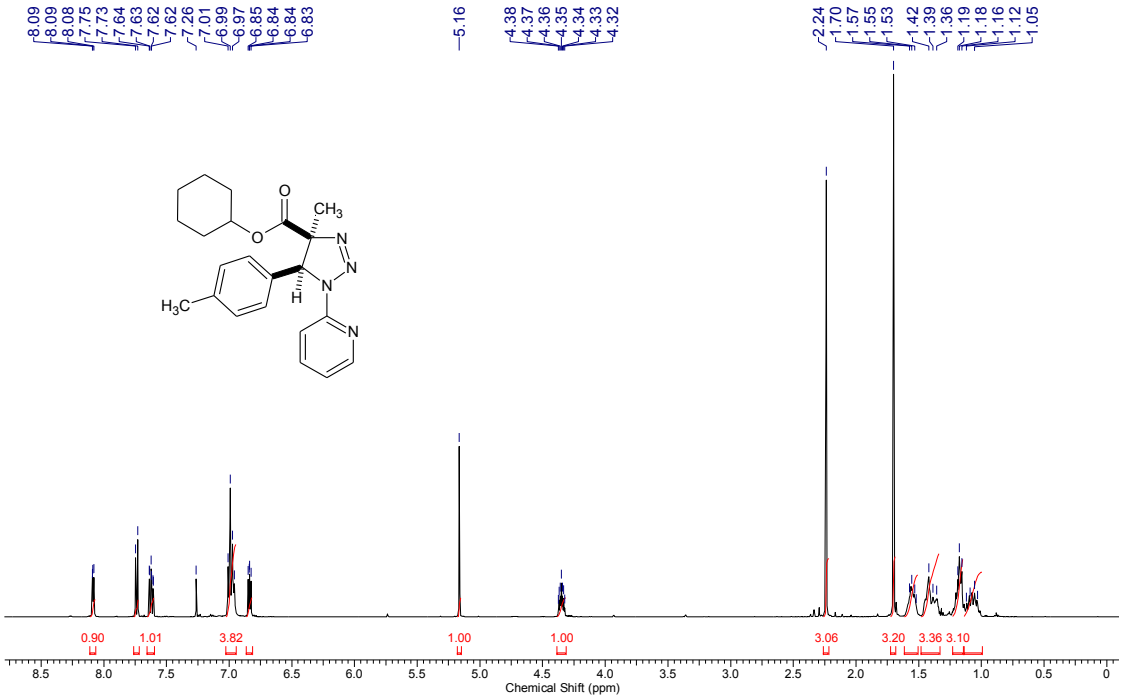

169.1
166.6
152.1
148.0
137.9
137.7
131.8
128.9
127.2
118.2
111.3
89.1
74.4
64.4
52.0
41.1
30.8
30.7
25.2
23.5
21.1
Chemical Shift (ppm)

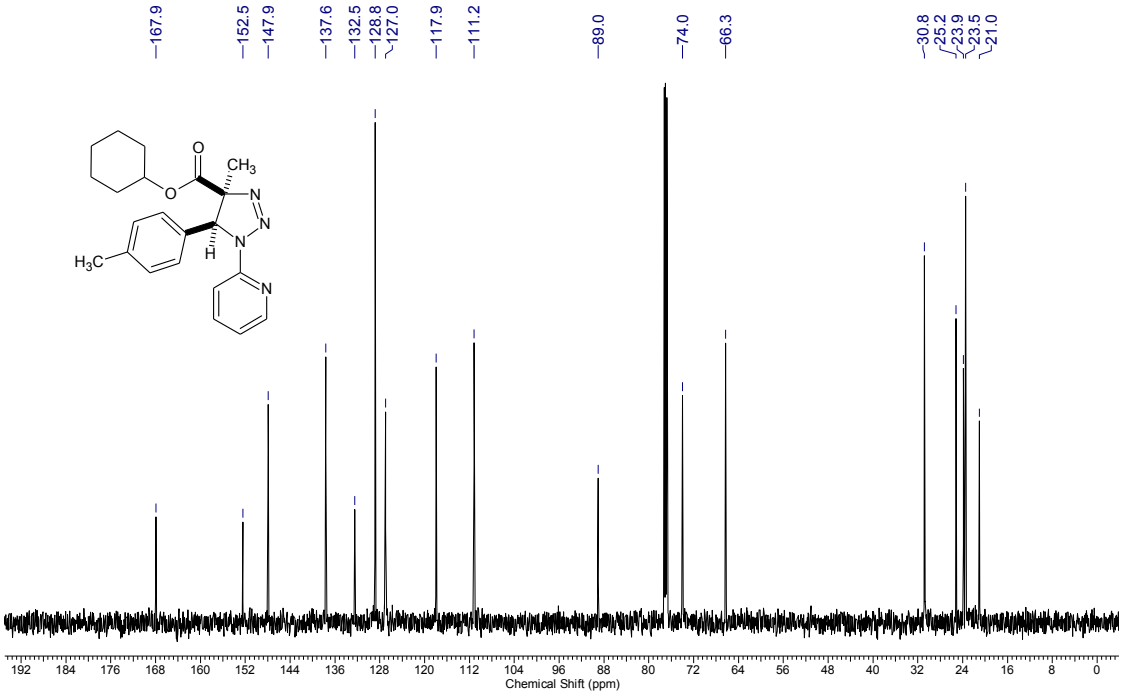
217ax:


8.10
8.09
7.79
7.77
7.69
7.68
7.66
7.66
7.05
7.04
7.02
7.00
6.92
6.91
6.90
5.46
4.40
4.39
4.38
4.37
4.36
3.17
3.14
3.12
3.08
2.26
1.57
1.57
1.56
1.43
1.40
1.21
1.20
1.19
1.17
1.15
O
O
N
N
N
N
H
H3C
N
0.95
1.17
3.97
1.00
1.11
2.26
3.02
3.61
5.67
Chemical Shift (ppm)

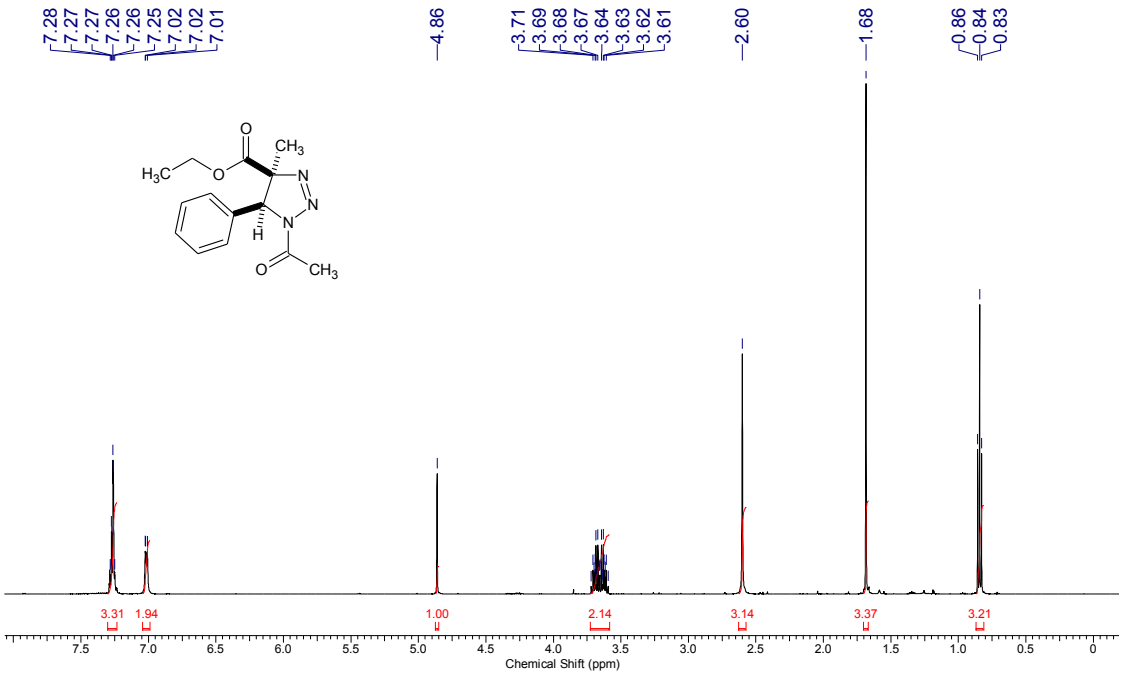

165.2
151.5
148.0
138.3
137.9
131.0
129.1
126.9
118.8
115.0
111.6
87.7
75.6
64.5
30.8
30.6
25.9
25.1
23.4
23.4
21.1
O
O
N
N
N
N
H
H3C
N
Chemical Shift (ppm)

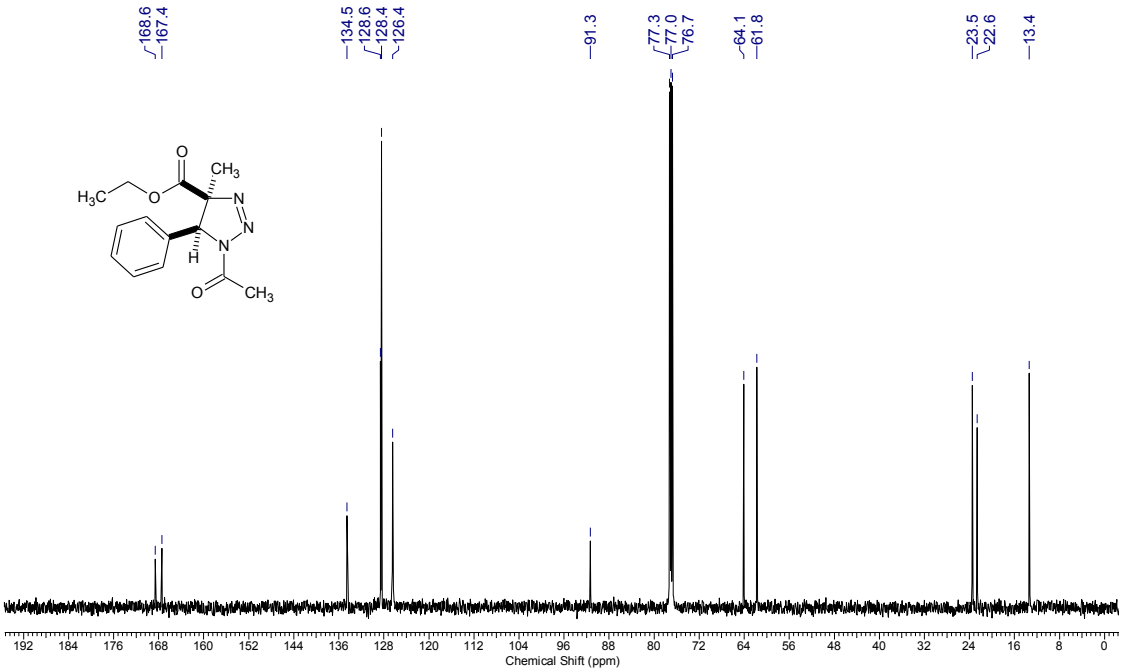
217ay:


8.09
8.09
8.08
8.08
7.75
7.73
7.64
7.63
7.62
7.62
7.26
7.01
6.99
6.97
6.85
6.84
6.84
6.83
5.16
4.38
4.37
4.36
4.35
4.34
4.33
4.32
2.24
1.70
1.57
1.55
1.53
1.42
1.39
1.36
1.19
1.18
1.16
1.12
1.05
O
CH3
O
N
N
N
H
H3C
N
0.90
1.01
3.82
1.00
1.00
3.06
3.20
3.36
3.10
Chemical Shift (ppm)

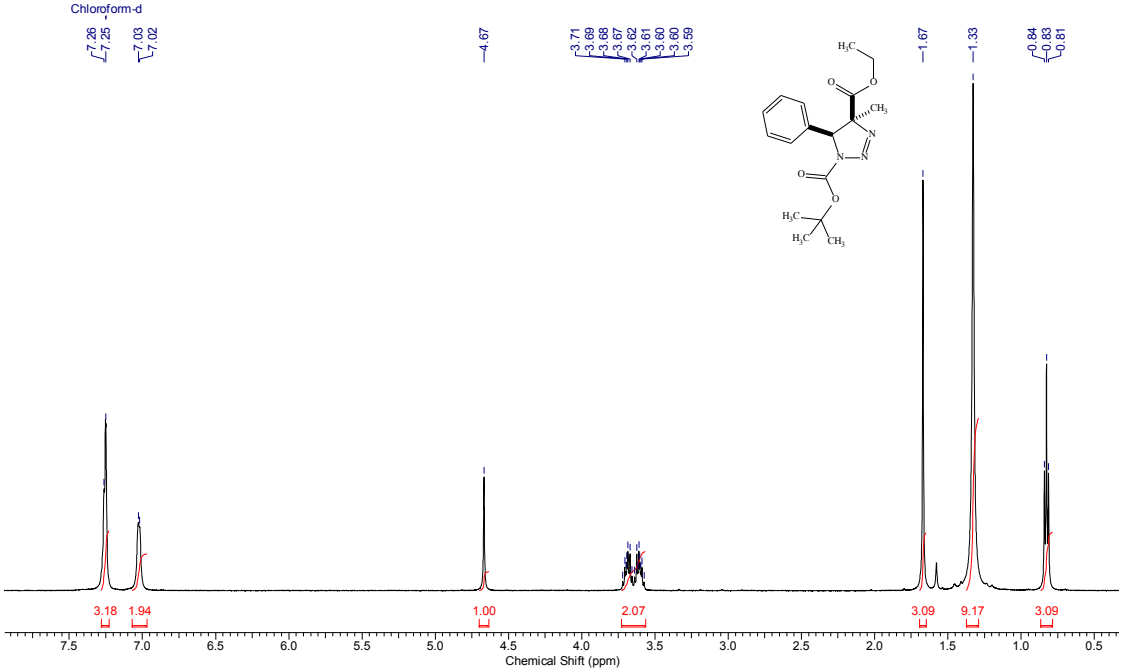

167.9
152.5
147.9
137.6
132.5
128.8
127.0
117.9
111.2
89.0
74.0
66.3
30.8
25.2
23.9
23.5
21.0
O
CH3
O
N
N
N
H
H3C
N
Chemical Shift (ppm)

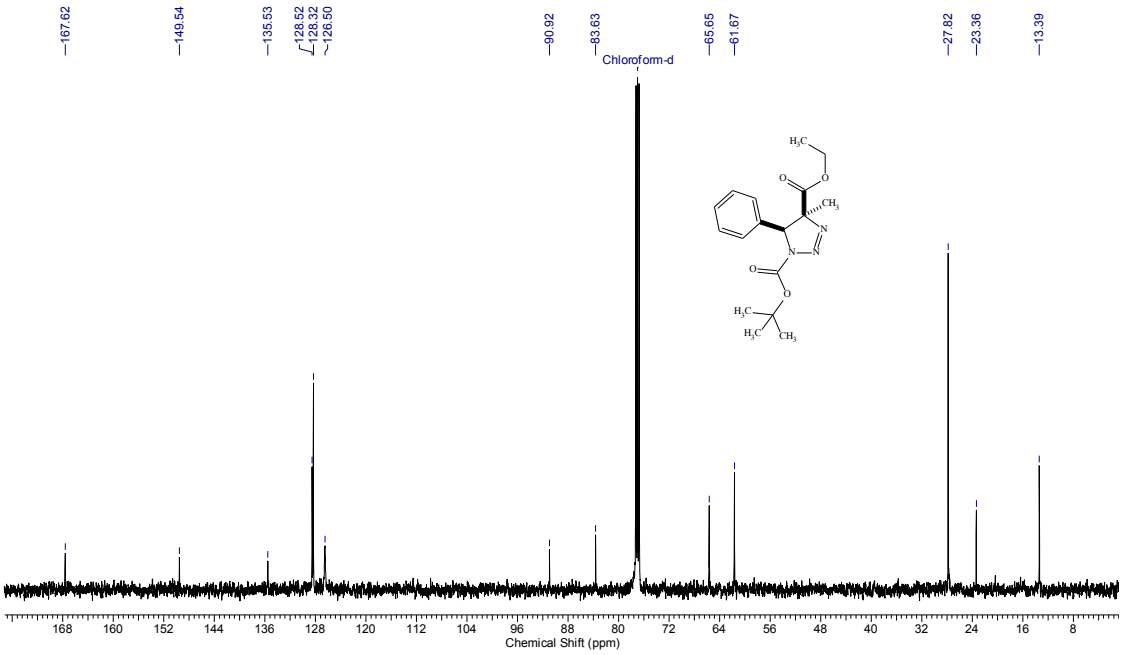
217az:


7.28
7.27
7.27
7.26
7.26
7.25
7.02
7.02
7.01
4.86
3.71
3.69
3.68
3.67
3.64
3.63
3.62
3.61
2.60
1.68
0.86
0.84
0.83
3.31
1.94
1.00
2.14
3.14
3.37
3.21
Chemical Shift (ppm)

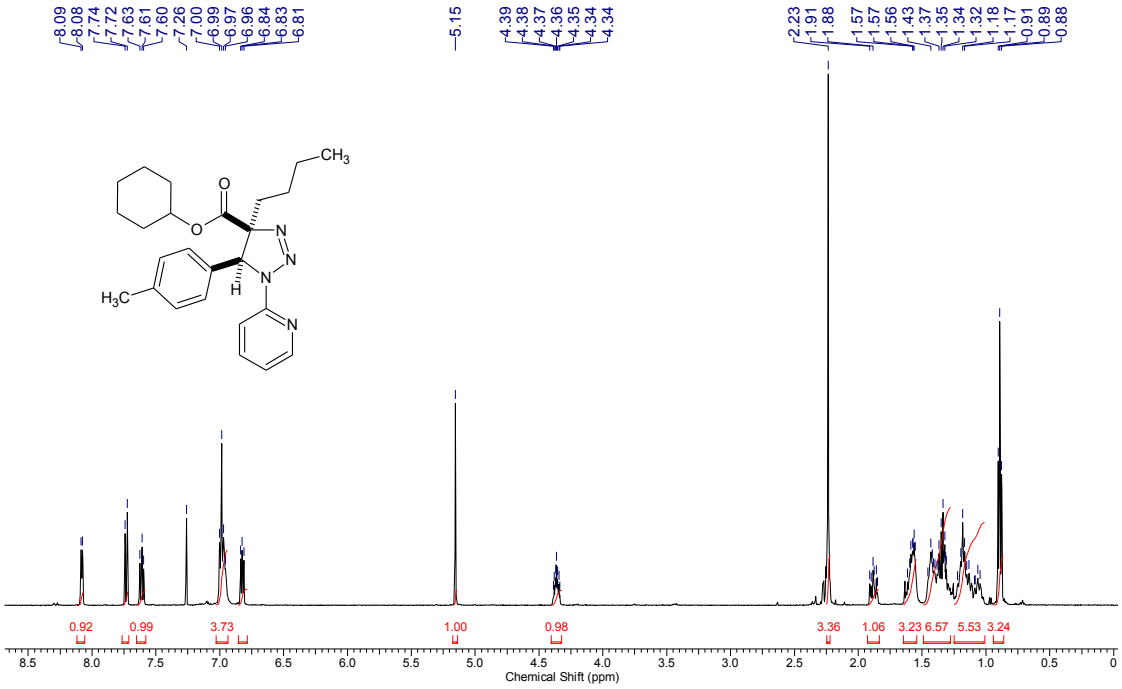

168.6
167.4
134.5
128.6
128.4
126.4
91.3
77.3
77.0
76.7
64.1
61.8
23.5
22.6
13.4
Chemical Shift (ppm)

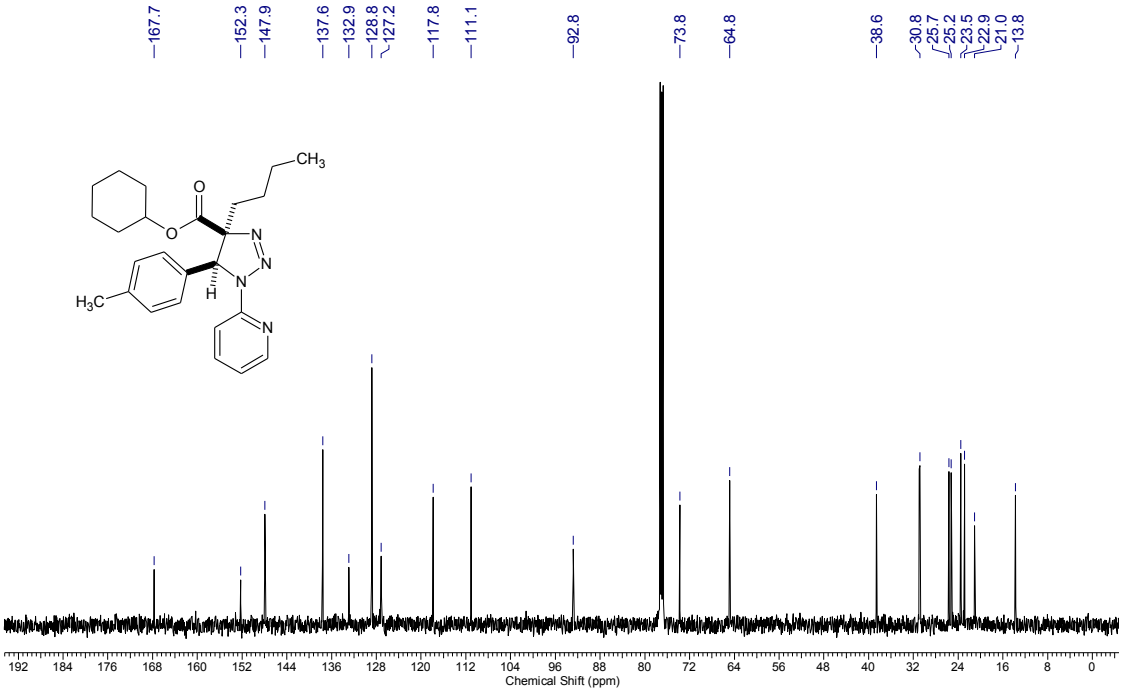
217ba:


Chloroform-d
7.26
7.25
7.03
7.02
4.67
3.71
3.69
3.68
3.67
3.62
3.61
3.60
3.60
3.59
1.67
1.33
0.84
0.83
0.81
3.18
1.94
1.00
2.07
3.09
9.17
3.09
Chemical Shift (ppm)

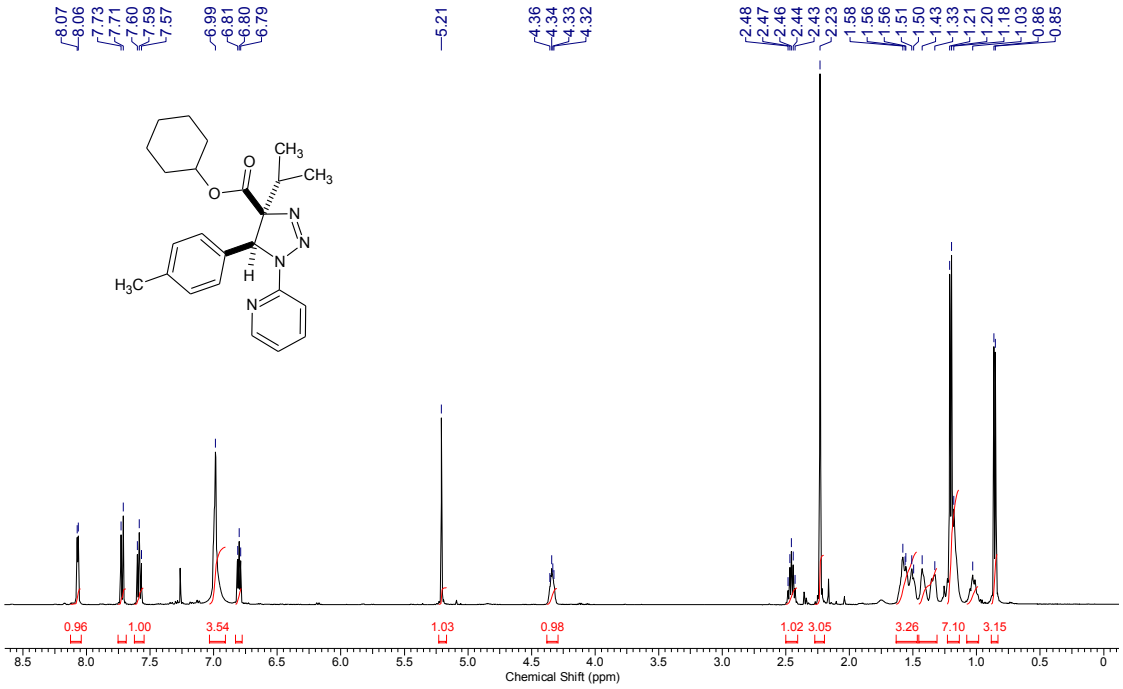

167.62
149.54
135.53
128.52
128.32
126.50
90.92
83.63
Chloroform-d
65.65
61.67
27.82
23.36
13.39
Chemical Shift (ppm)

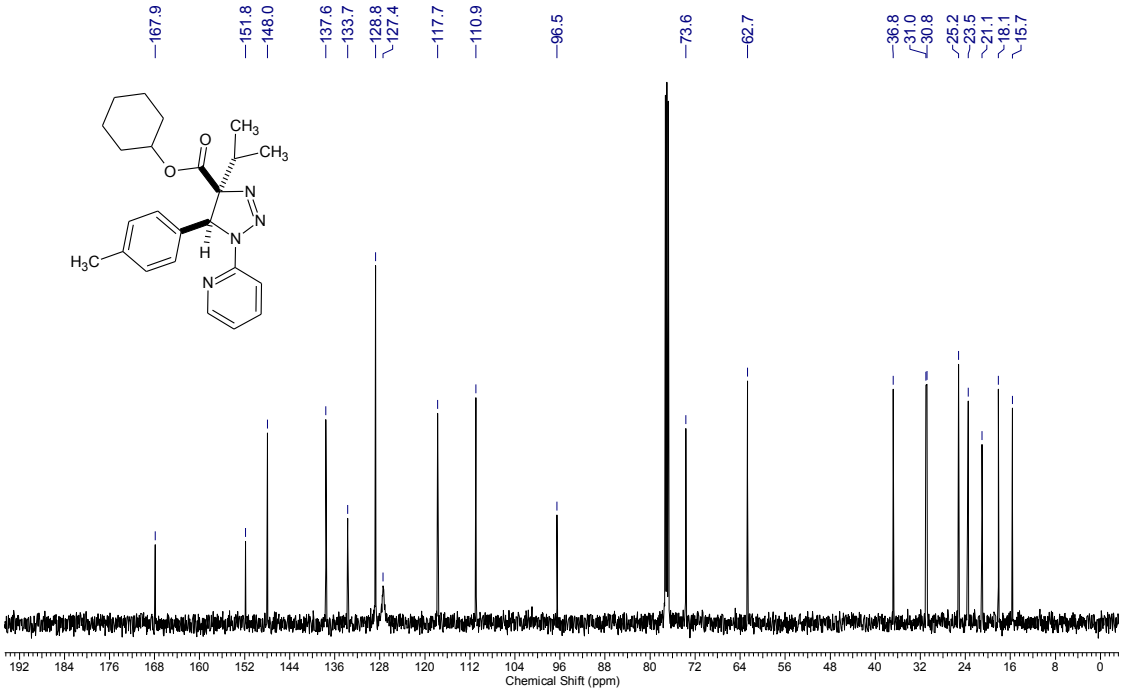
217bb:


8.09
8.08
7.74
7.72
7.63
7.61
7.60
7.26
7.00
6.99
6.97
6.96
6.84
6.83
6.81
5.15
4.39
4.38
4.37
4.36
4.35
4.34
4.34
2.23
1.91
1.88
1.57
1.57
1.56
1.43
1.37
1.35
1.34
1.32
1.18
1.17
0.91
0.89
0.88
CH3
O
O
N
N
N
H
H3C
N
0.92
0.99
3.73
1.00
0.98
3.36
1.06
3.23
6.57
5.53
3.24
Chemical Shift (ppm)

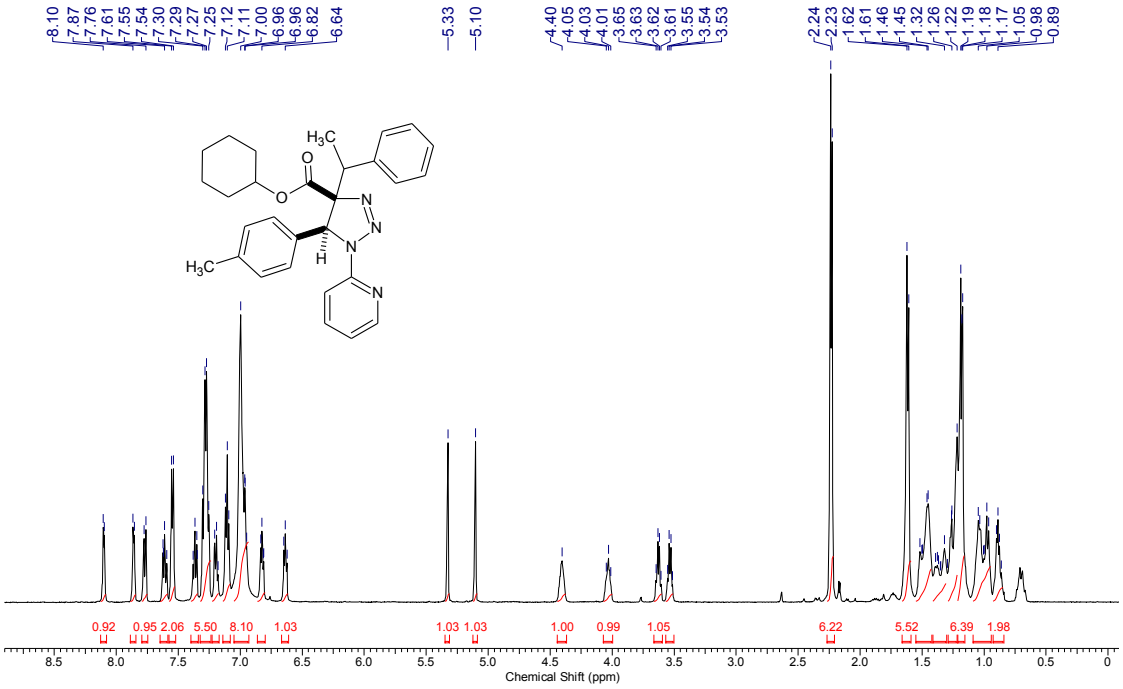

167.7
152.3
147.9
137.6
132.9
128.8
127.2
117.8
111.1
92.8
73.8
64.8
38.6
30.8
25.7
25.2
23.5
22.9
21.0
13.8
CH3
O
O
N
N
N
H
H3C
N
Chemical Shift (ppm)

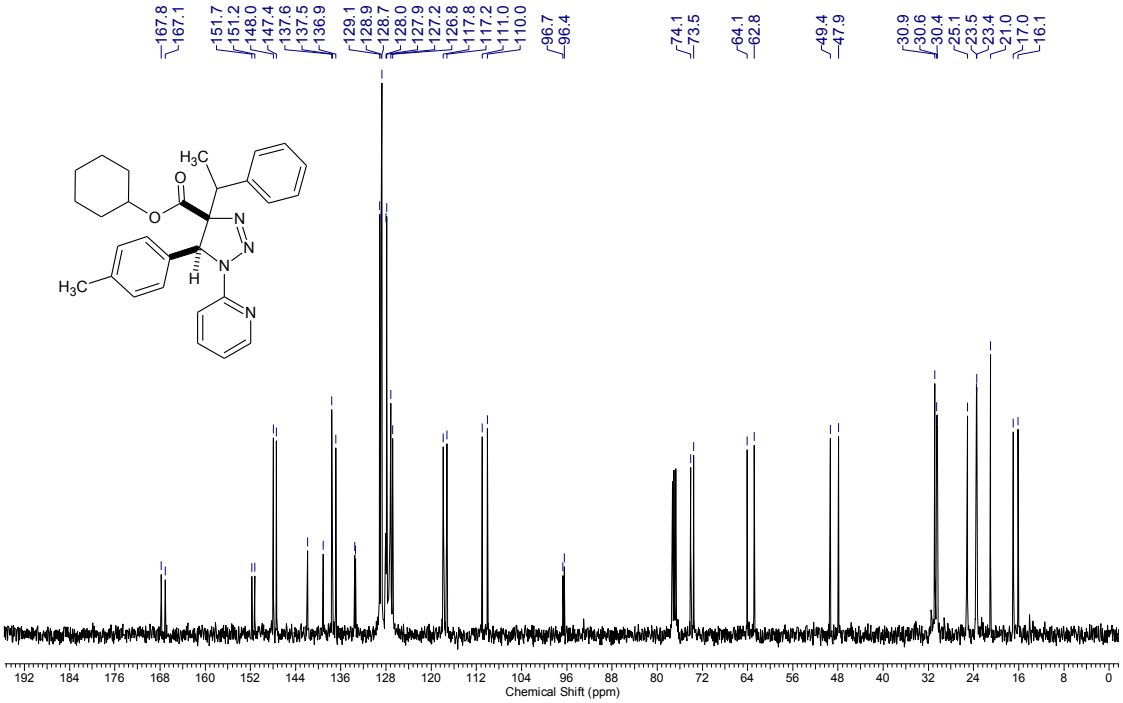
217bc:


8.07
8.06
7.73
7.71
7.60
7.59
7.57
6.99
6.81
6.80
6.79
5.21
4.36
4.34
4.33
4.32
2.48
2.47
2.46
2.44
2.43
2.23
1.58
1.56
1.56
1.51
1.50
1.43
1.33
1.21
1.20
1.18
1.03
0.86
0.85
0.96
1.00
3.54
1.03
0.98
1.02
3.05
3.26
7.10
3.15
Chemical Shift (ppm)

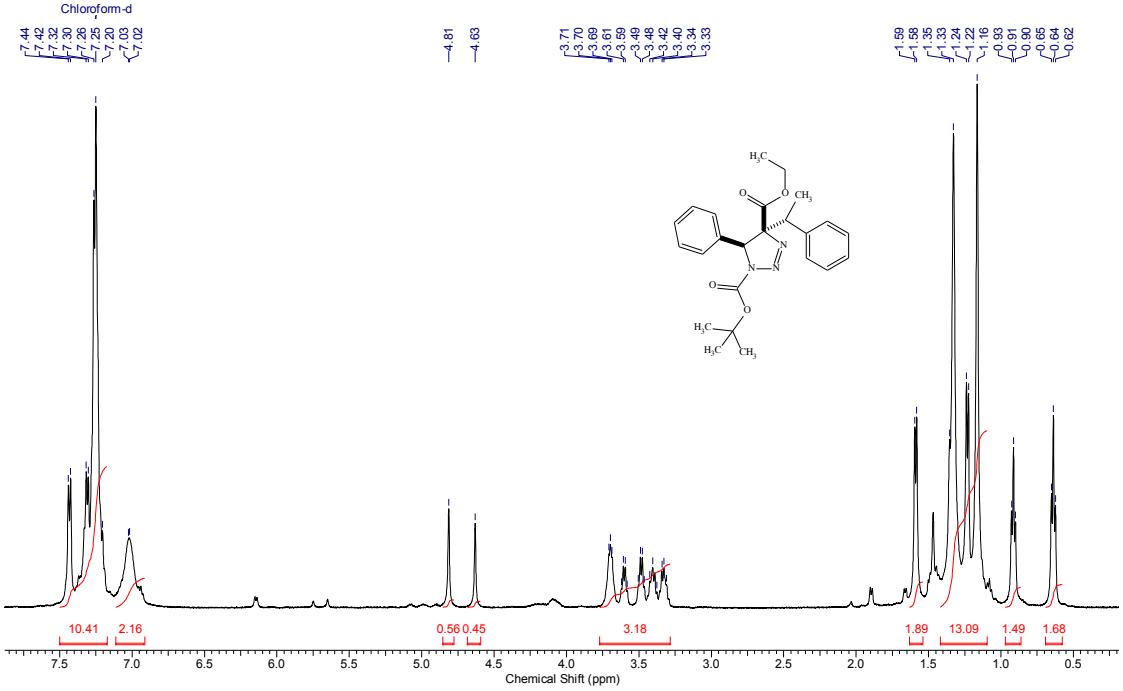

167.9
151.8
148.0
137.6
133.7
128.8
127.4
117.7
110.9
96.5
73.6
62.7
36.8
31.0
30.8
25.2
23.5
21.1
18.1
15.7
Chemical Shift (ppm)

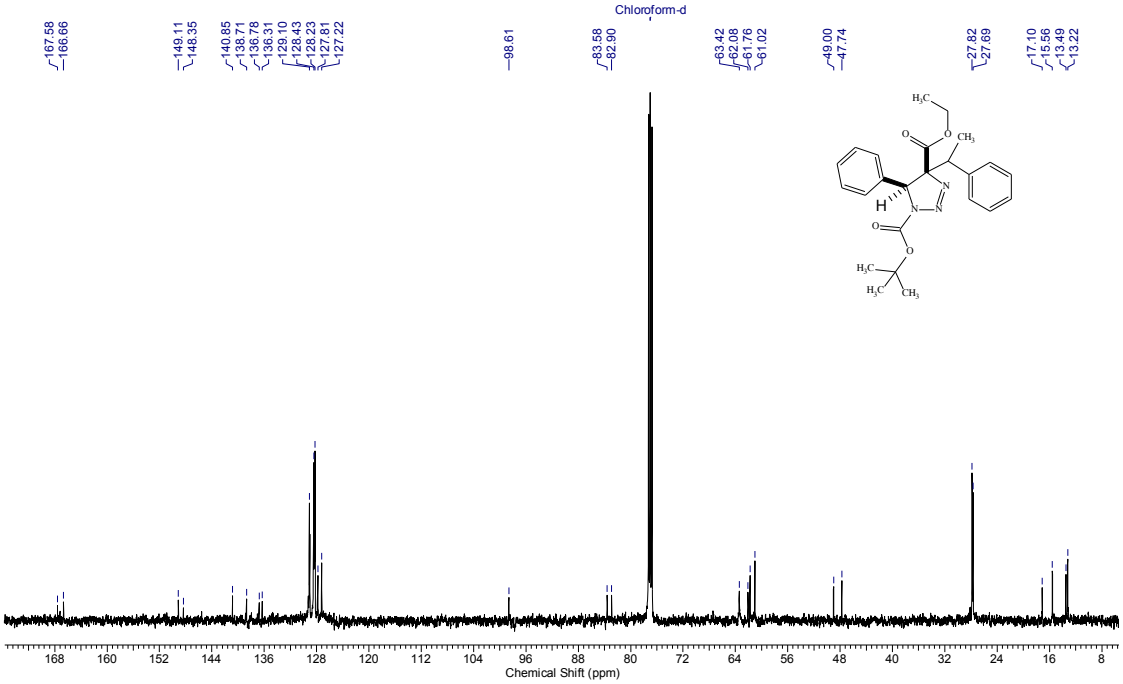
217bd:


8.10
7.87
7.76
7.61
7.55
7.54
7.30
7.29
7.27
7.25
7.12
7.11
7.00
6.96
6.96
6.82
6.64
5.33
5.10
4.40
4.05
4.03
4.01
3.65
3.63
3.62
3.61
3.55
3.54
3.53
2.24
2.23
1.62
1.61
1.46
1.45
1.32
1.26
1.22
1.19
1.18
1.17
1.05
0.98
0.89
0.92
0.95
2.06
5.50
8.10
1.03
1.03
1.03
1.00
0.99
1.05
6.22
5.52
6.39
1.98
Chemical Shift (ppm)

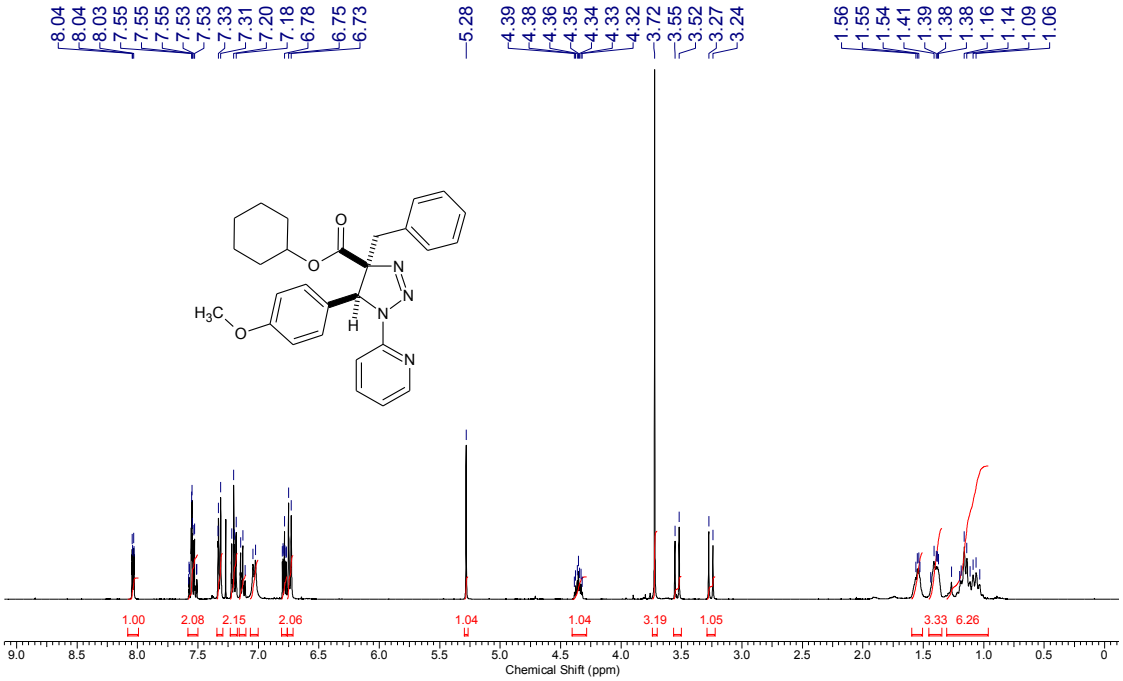

167.8
167.1
151.7
151.2
148.0
147.4
137.6
137.5
136.9
129.1
128.9
128.7
128.0
127.9
127.2
126.8
117.8
117.2
111.0
110.0
96.7
96.4
74.1
73.5
64.1
62.8
49.4
47.9
30.9
30.6
30.4
25.1
23.5
23.4
21.0
17.0
16.1
Chemical Shift (ppm)

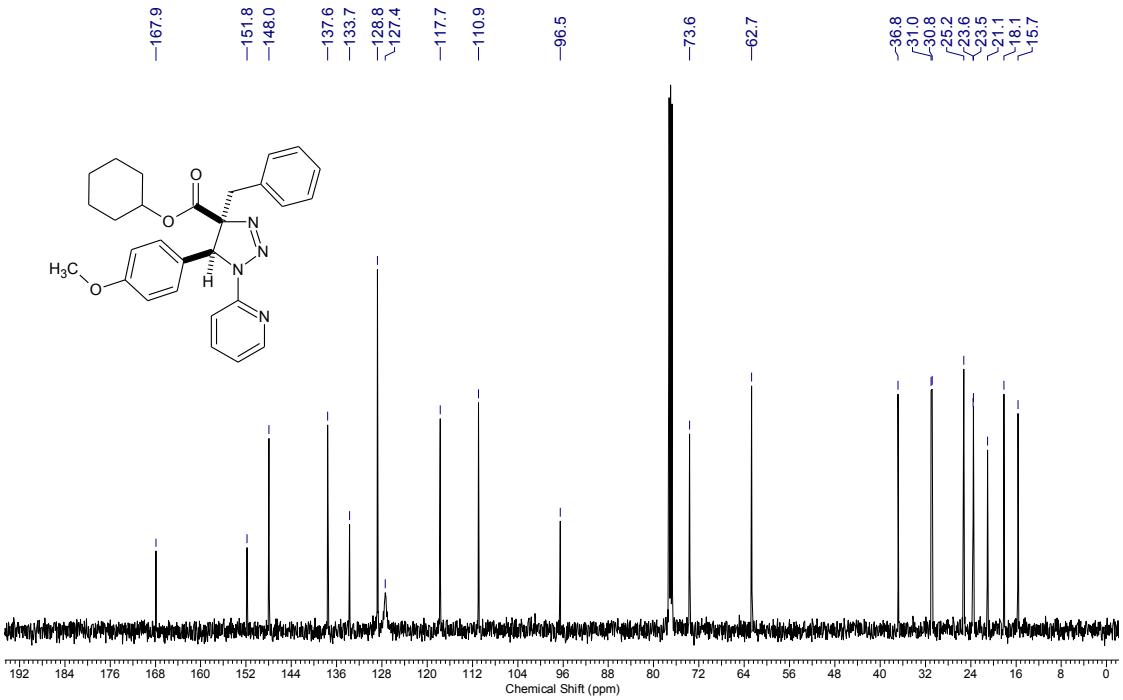
217be:


Chloroform-d
7.44
7.42
7.32
7.30
7.26
7.25
7.20
7.03
7.02
4.81
4.63
3.71
3.70
3.69
3.61
3.59
3.49
3.48
3.42
3.40
3.34
3.33
1.59
1.58
1.35
1.33
1.24
1.22
1.16
0.93
0.91
0.90
0.65
0.64
0.62
10.41
2.16
0.56
0.45
3.18
1.89
13.09
1.49
1.68
Chemical Shift (ppm)

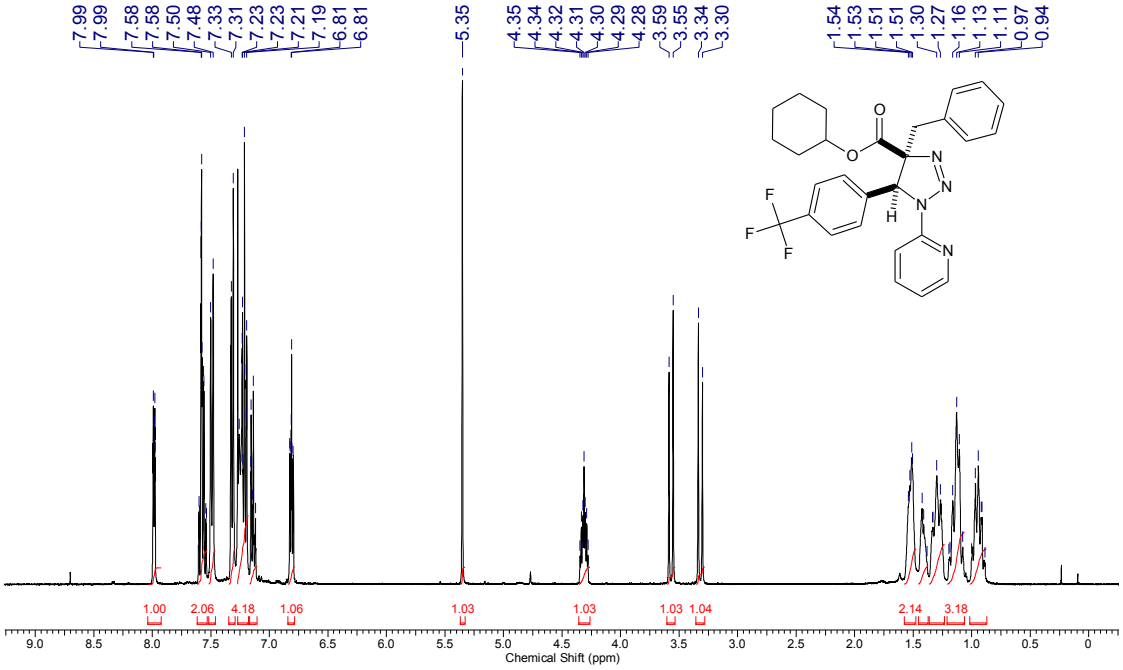

Chloroform-d
167.58
166.66
149.11
148.35
140.85
138.71
138.78
136.31
129.10
128.43
128.23
127.81
127.22
98.61
83.58
82.90
63.42
62.08
61.76
61.02
49.00
47.74
27.82
27.69
17.10
15.56
13.49
13.22
Chemical Shift (ppm)

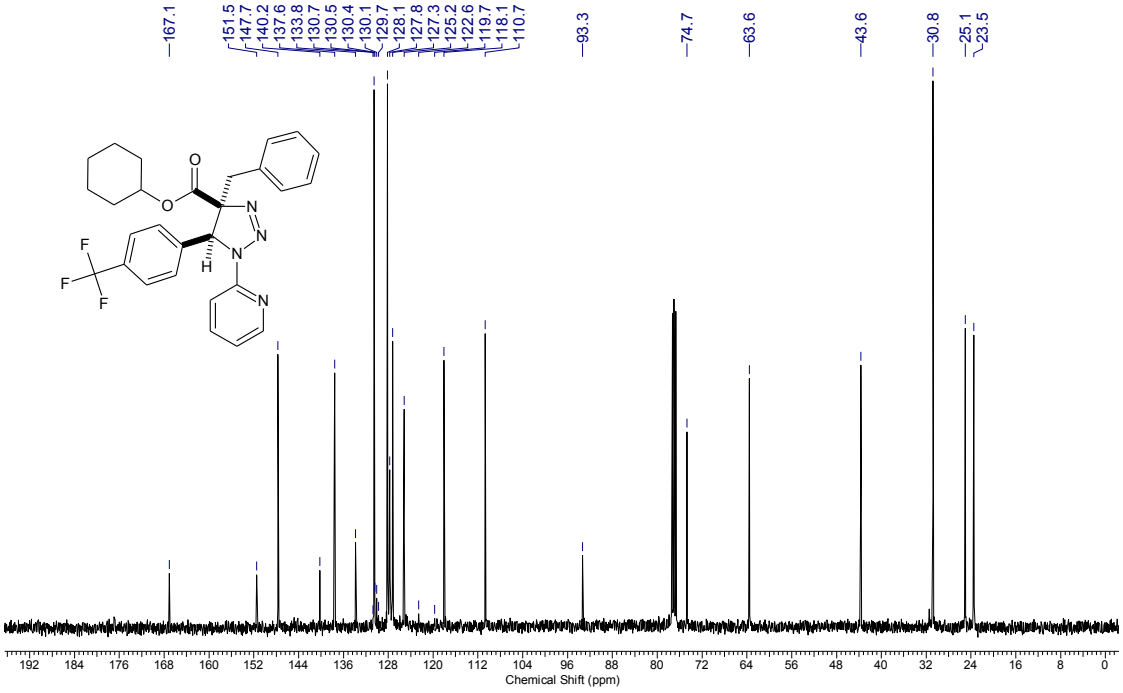
217bf:


8.04
8.04
8.03
7.55
7.55
7.55
7.53
7.53
7.33
7.31
7.20
7.18
6.78
6.75
6.73
5.28
4.39
4.38
4.36
4.35
4.34
4.33
4.32
3.72
3.55
3.52
3.27
3.24
1.56
1.55
1.54
1.41
1.39
1.38
1.38
1.16
1.14
1.09
1.06
1.00
2.08
2.15
2.06
1.04
1.04
3.19
1.05
3.33
6.26
Chemical Shift (ppm)

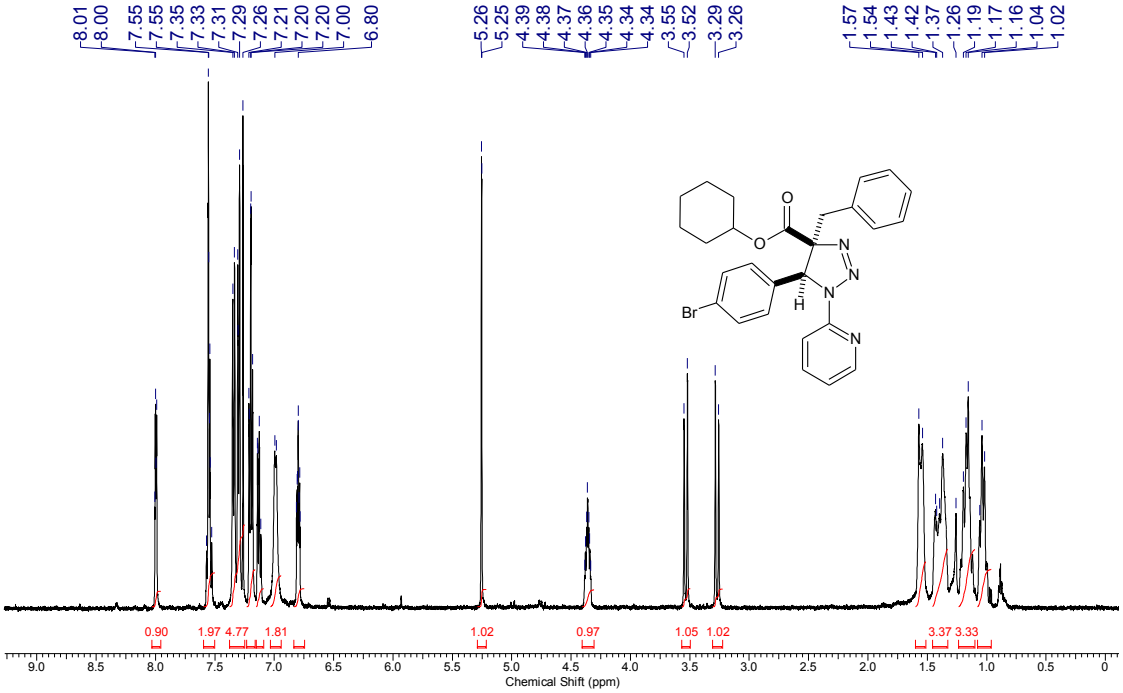

167.9
151.8
148.0
137.6
133.7
128.8
127.4
117.7
110.9
96.5
73.6
62.7
36.8
31.0
30.8
25.2
23.6
23.5
21.1
18.1
15.7
Chemical Shift (ppm)

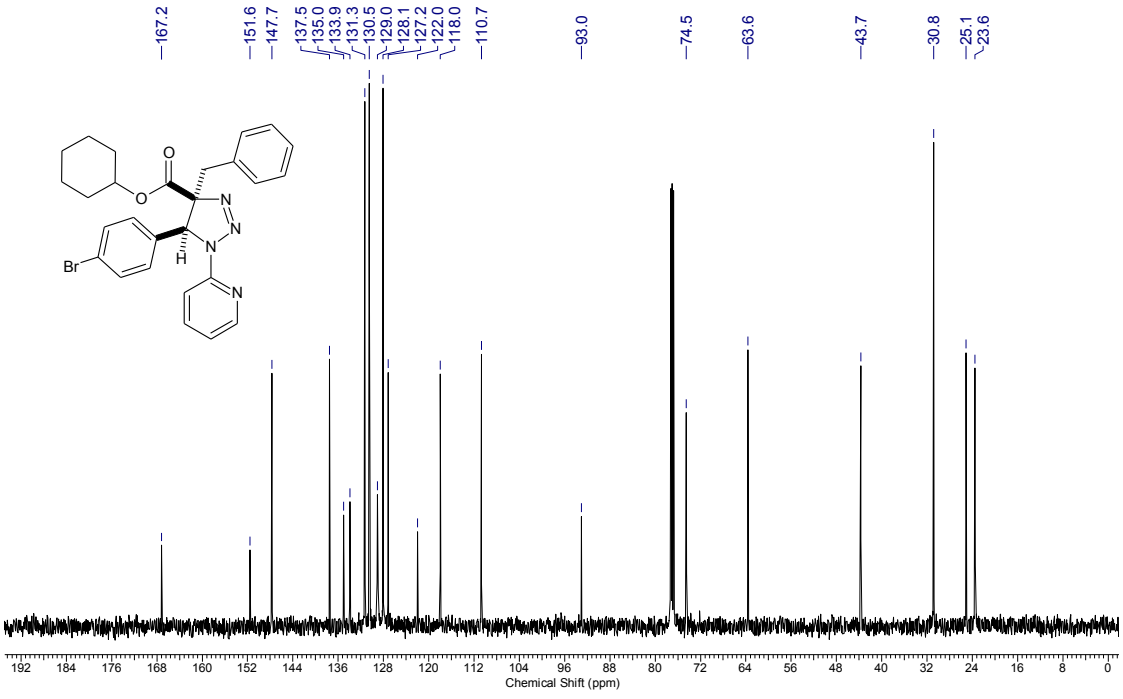
217bg:


7.99
7.99
7.58
7.58
7.50
7.48
7.33
7.31
7.23
7.23
7.21
7.19
6.81
6.81
5.35
4.35
4.34
4.32
4.31
4.30
4.29
4.28
3.59
3.55
3.34
3.30
1.54
1.53
1.51
1.51
1.30
1.27
1.16
1.13
1.11
0.97
0.94
1.00
2.06
4.18
1.06
1.03
1.03
1.03
1.04
2.14
3.18
Chemical Shift (ppm)

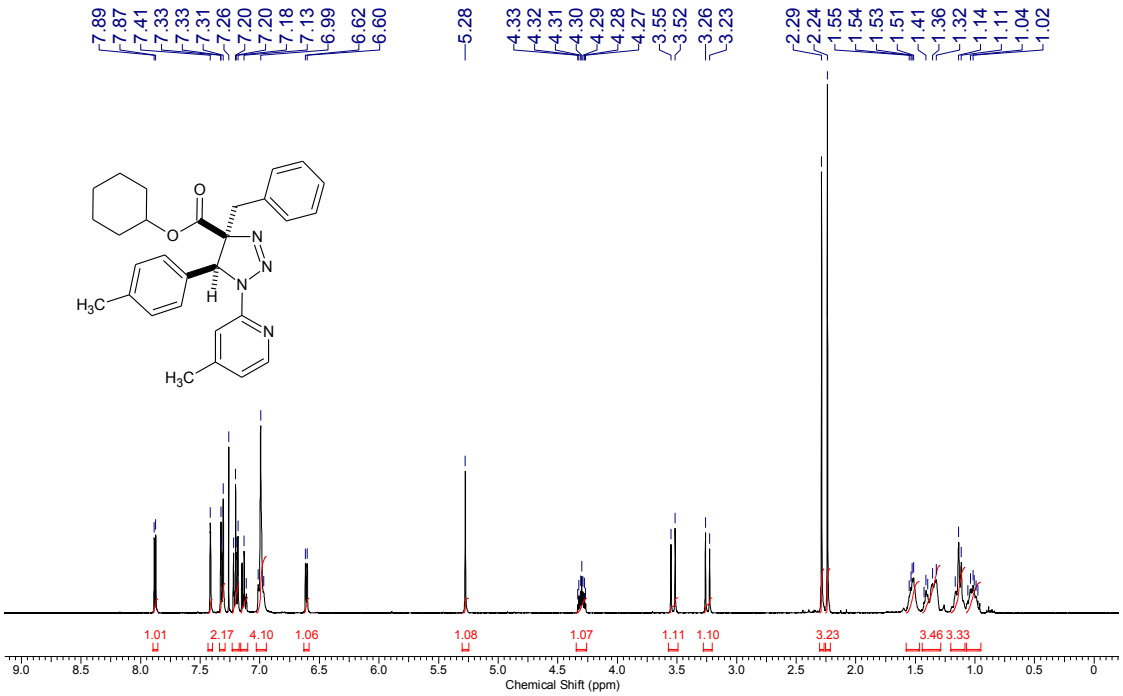

167.1
151.5
147.7
140.2
137.6
133.8
130.7
130.5
130.4
130.1
129.7
128.1
127.8
127.3
125.2
122.6
119.7
118.1
110.7
93.3
74.7
63.6
43.6
30.8
25.1
23.5
Chemical Shift (ppm)

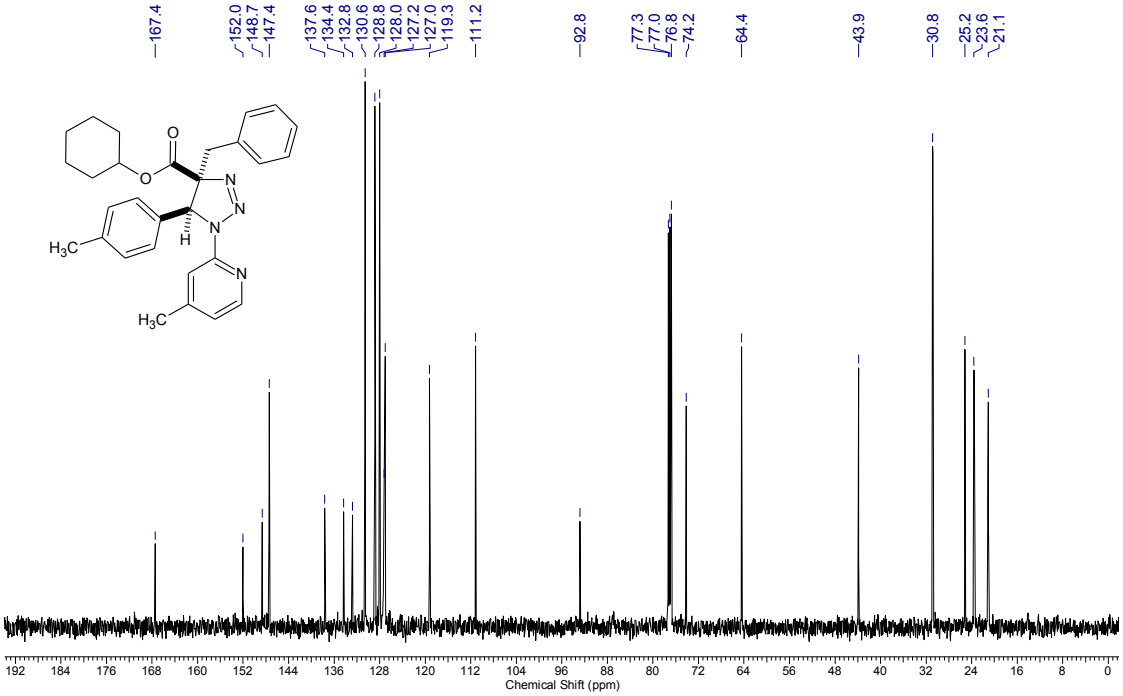
217bh:


8.01
8.00
7.55
7.55
7.35
7.33
7.31
7.29
7.26
7.21
7.20
7.20
7.00
6.80
5.26
5.25
4.39
4.38
4.37
4.36
4.35
4.34
4.34
3.55
3.52
3.29
3.26
1.57
1.54
1.43
1.42
1.37
1.26
1.19
1.17
1.16
1.04
1.02
0.90
1.97
4.77
1.81
1.02
0.97
1.05
1.02
3.37
3.33
Chemical Shift (ppm)

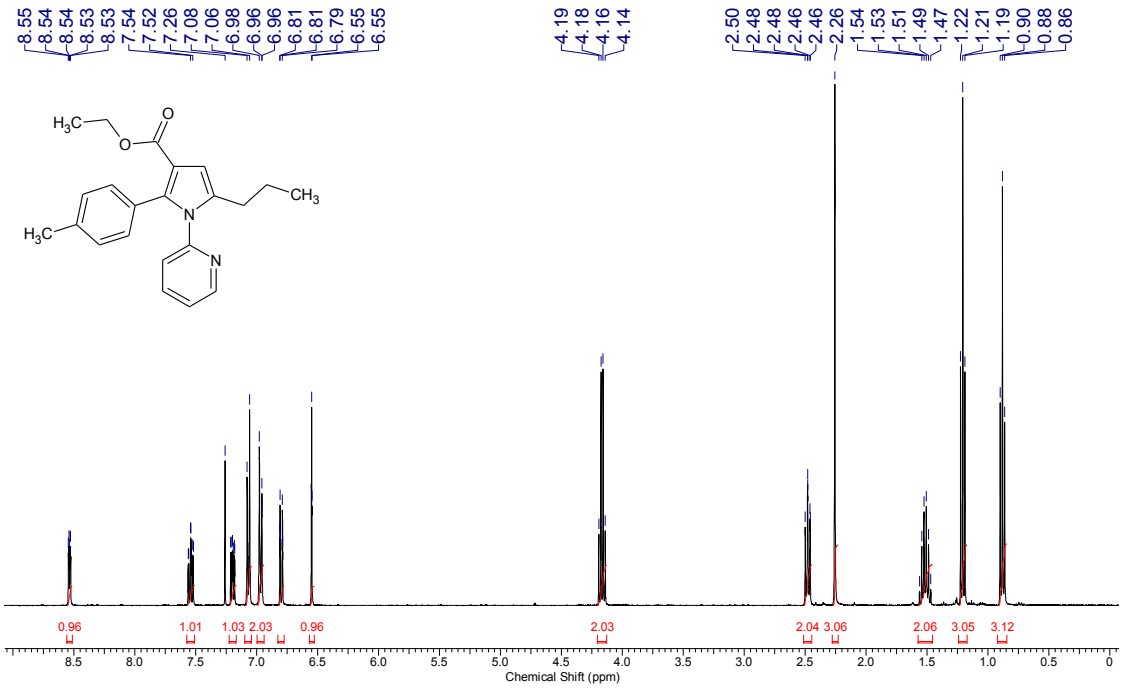

167.2
151.6
147.7
137.5
135.0
133.9
131.3
130.5
129.0
128.1
127.2
122.0
118.0
110.7
93.0
74.5
63.6
43.7
30.8
25.1
23.6
Chemical Shift (ppm)

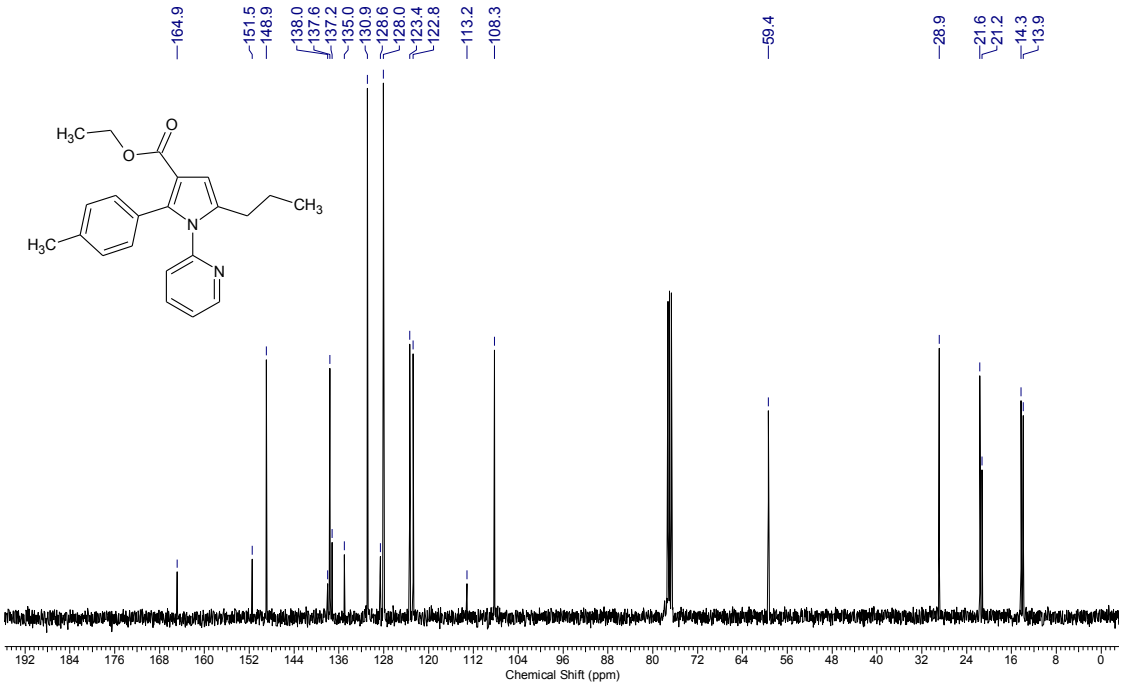
217bi:


7.89
7.87
7.41
7.33
7.33
7.31
7.26
7.20
7.20
7.18
7.13
6.99
6.62
6.60
5.28
4.33
4.32
4.31
4.30
4.29
4.28
4.27
3.55
3.52
3.26
3.23
2.29
2.24
1.55
1.54
1.53
1.51
1.41
1.36
1.32
1.14
1.11
1.04
1.02
1.01
2.17
4.10
1.06
1.08
1.07
1.11
1.10
3.23
3.46
3.33
Chemical Shift (ppm)

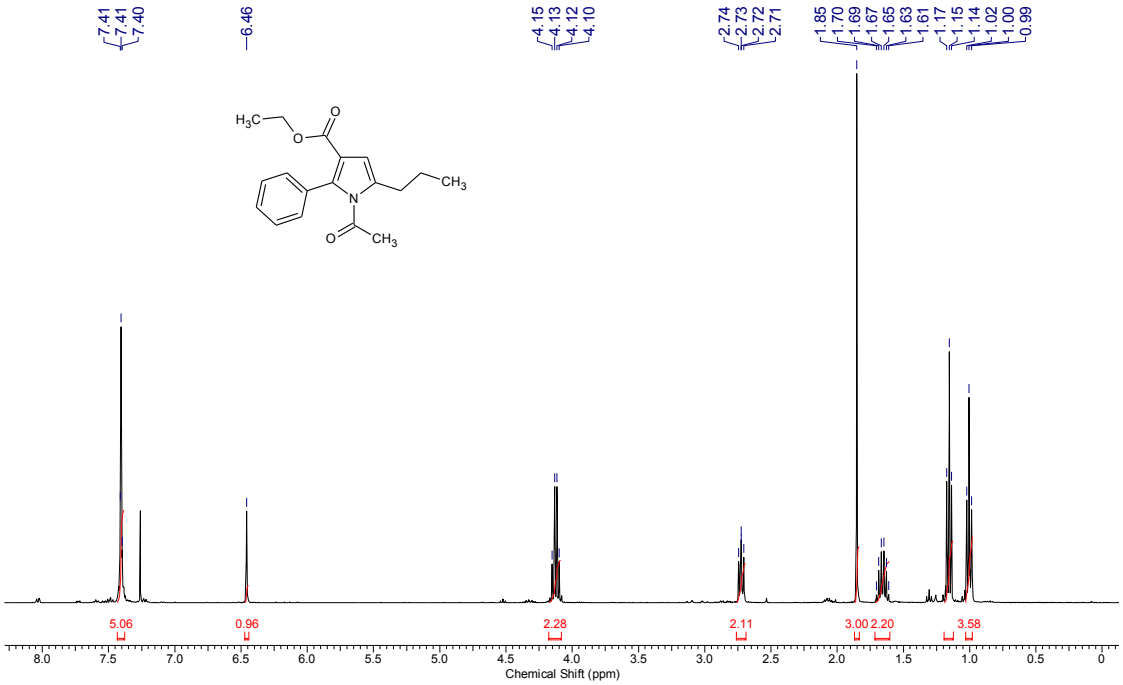

167.4
152.0
148.7
147.4
137.6
134.4
132.8
130.6
128.8
128.0
127.2
127.0
119.3
111.2
92.8
77.3
77.0
76.8
74.2
64.4
43.9
30.8
25.2
23.6
21.1
Chemical Shift (ppm)

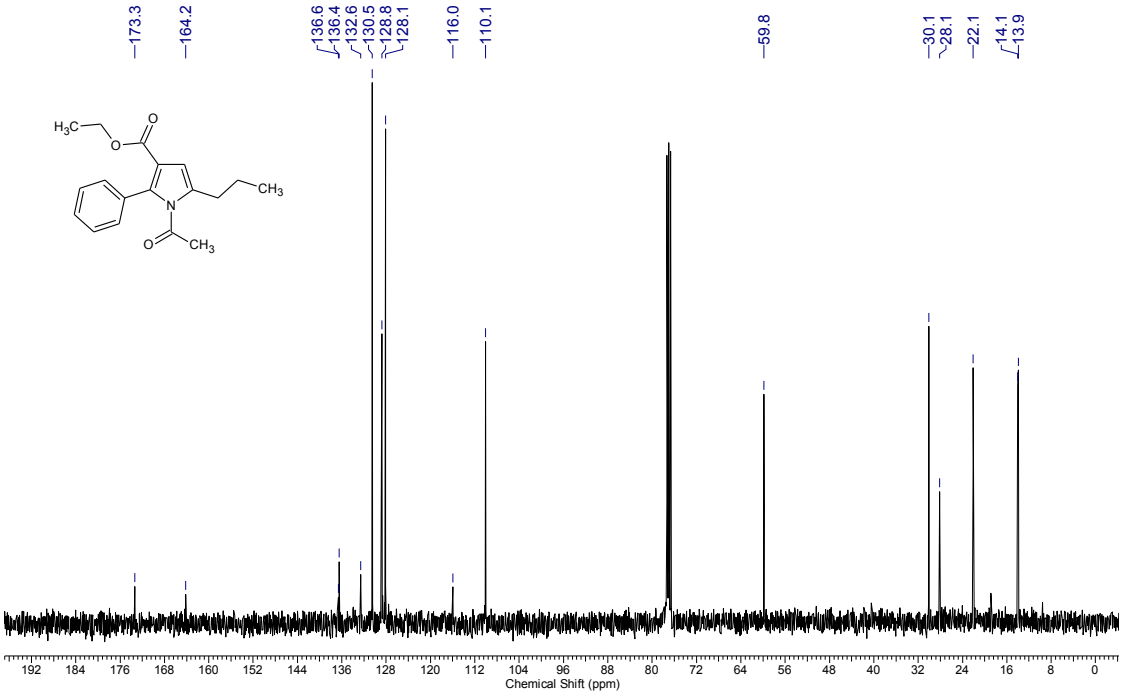
221a:


8.55
8.54
8.54
8.53
8.53
7.54
7.52
7.26
7.08
7.06
6.98
6.96
6.96
6.81
6.81
6.79
6.55
6.55
4.19
4.18
4.16
4.14
2.50
2.48
2.48
2.46
2.46
2.26
1.54
1.53
1.51
1.49
1.47
1.22
1.21
1.19
0.90
0.88
0.86
0.96
1.01
1.03
2.03
0.96
2.03
2.04
3.06
2.06
3.05
3.12
Chemical Shift (ppm)


164.9
151.5
148.9
138.0
137.6
137.2
135.0
130.9
128.6
128.0
123.4
122.8
113.2
108.3
59.4
28.9
21.6
21.2
14.3
13.9
Chemical Shift (ppm)

221b:


7.41
7.41
7.40
6.46
4.15
4.13
4.12
4.10
2.74
2.73
2.72
2.71
1.85
1.70
1.69
1.67
1.65
1.63
1.61
1.17
1.15
1.14
1.02
1.00
0.99
5.06
0.96
2.28
2.11
3.00
2.20
3.58
Chemical Shift (ppm)


173.3
164.2
136.6
136.4
132.6
130.5
128.8
128.1
116.0
110.1
59.8
30.1
28.1
22.1
14.1
13.9
Chemical Shift (ppm)

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PUBLICATIONS: "A New Reactivity Mode of Diazocompounds: Diastereoselective 1,3-Aminoalkylation Reaction of *β*-Amino-*α*-Diazoesters Towards Triazolines" Kuznetsov, A.; Gulevich, A. V.; Wink, D. J. Gevorgyan, V. *submitted*.

"Brönsted Acid-Catalyzed One-Pot Synthesis of Indoles from *o*-Aminobenzylalcohols and Furans" Kuznetsov, A.; Makarov, A.; Butin, A.; Gevorgyan, V. *J. Org. Chem.* **2013**, *78,* 12144-12153.

"Fused Heteroaromatic Dihydrosiloles: Synthesis and Double-Fold Modification" Kuznetsov, A.; Onishi, Y.; Inamoto, Y.; Gevorgyan, V. *Org. Lett.* **2013**, *15*, 2498-2501.

"General and Practical One-Pot Synthesis of Dihydrobenzosiloles from Styrenes" Kuznetsov, A.; Gevorgyan, V. *Org. Lett.* **2012**, *14*, 914-917.

"Synthesis and Reactivity of 5-Br(I)-indolizines and Their Parallel Cross-Coupling Reactions" Kuznetsov, A. G.; Bush, A. A.; Babaev, E. V. *Tetrahedron*, **2008**, *64*, 749-756.

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"Pd Black in Water as an Efficient Catalyst of the Suzuki Reaction" Kuznetsov, A. G.; Korolev, D. N.; Bumagin, N. A. *Rus. Chem. Bull., Int. Ed.* **2003**, *52*, 1882-1883.

PRESENTATIONS: "Fused Heteroaromatic Dihydrosiloles: Synthesis and Double-Fold Modification" 30th H. C. Brown Lectures in Organic Chemistry (April **2013**, Purdue University, West Laffayette, IN). Kuznetsov, A.; Onishi, Y.; Inamoto, Y.; Gevorgyan, V. (poster)

"General and Practical One-Pot Synthesis of Dihydrobenzosiloles from Styrenes" at *4th Chicago Organic Simposium*, (April **2012**, University of Illinois at Chicago, Chicago, IL). Kuznetsov, A.; Gevorgyan, V. (poster)

"Synthesis of Libraries of Imidazo[1,2-a]pyridines Based on a Cu-Catalyzed Tri-Component Coupling Reaction" 3rd National CMLD Meeting (July **2011**, Chicago, IL). Kuznetsov, A.; Chernyak, D.; Gevorgyan, V. (poster, talk)

"Development of the Effective Strategy of Functionalization of Indolizines" International Lomonosov Conference of Students and Postgraduates (April 2007, Moscow, Russian Federation). Kuznetsov, A. G.; Bush, A. A.; Babaev, E. V. (talk)

"Novel Approaches to 5-substituted Indolizines" 3rd EuroAsian Heterocyclic Meeting "Heterocycles in Organic and Combinatorial

Chemistry" (EAMH-2004, Novosibirsk, Russian Federation). Kuznetsov, A. G.; Bush, A. A.; Babaev, E. V. (poster)