Supplementary Information for

Desymmetrization of Difluoromethylene Groups by C–F Bond Activation

Trevor W. Butcher, Jonathan L. Yang, Willi M. Amberg, Nicholas B. Watkins, Natalie D. Wilkinson, and John F. Hartwig*

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GENERAL INFORMATION

All air-sensitive manipulations were conducted under an inert atmosphere in a nitrogen-filled glovebox or by standard Schlenk techniques. Although the cyclometalated iridium-allyl precatalysts are known to be air-stable and iridium-catalyzed allylic substitution reactions are themselves only moderately air-sensitive, all iridium-catalyzed allylic substitution reactions were conducted in a nitrogen-filled glovebox. Unless stated otherwise, reagents and solvents were purchased from commercial suppliers and used without further purification. Tetrahydrofuran was purified by passing it through a solvent column composed of activated A-1 alumina and degassed by the freeze-pump-thaw method.

Nuclear magnetic resonance (NMR) spectra were acquired on commercial instruments (300, 400, 500 and 600 MHz with respect to ^{1}H) at the NMR facility of the University of California, Berkeley. Chemical shifts are reported relative to residual solvent peaks ($CDCl_3$ = 7.26 ppm for ^{1}H NMR spectra and 77.16 ppm for ^{13}C NMR spectra). For ^{19}F NMR spectra, chemical shifts are reported relative to the δ –113.15 resonance of PhF used as an external reference. The following abbreviations are used in reporting NMR data: s, singlet; d, doublet; t, triplet; q, quartet; p, pentet; hept, heptet; AB, AB quartet; m, multiplet.

HPLC analyses were carried out on either an Agilent Infinity II chiral HPLC system or a Shimadzu VP series chiral HPLC with Chiralpak columns. High-resolution mass spectra were recorded on a commercial high-resolution mass spectrometer at the Micro Mass Analytical Facility operated by the College of Chemistry, University of California, Berkeley, or with an Agilent Time of Flight (Q-TOF) mass spectrometer in ESI mode. Optical rotations were measured on a Perkin Elmer 241 Automatic Polarimeter. Given the enantiomeric excess (*ee*) of each sample, values are typically provided for both the measured optical rotation and the corrected optical rotation. Analytical thin layer chromatography (TLC) was performed on Kieselgel 60 F254 glass plates precoated with a 0.25 mm thickness of silica gel. Preparative thin layer chromatography (PTLC) was performed on Analtech glass plates precoated with a 1.00 mm thickness of silica gel The TLC plates were visualized with UV light and by staining with $KMnO_4$. Column chromatography was generally performed on a Teledyne Isco Combiflash® R_f system with Redi*Sep* Gold™ columns. Iridium catalysts were prepared from the corresponding ligands according to literature procedures, precipitated from ether, washed with ether, and used without further purification (further details are provided herein).[1] Nucleophiles **2a**, **2b**, **2d**, **2f**, and **2j** were obtained from commercial sources.

Malonate **2c**[2] and malononitrile **2e**[3] were prepared according to literature procedures. Silyl ketene acetals **2g**, **2h**, and **2i** were prepared according to literature procedures.[4] Allylic electrophiles **1a**, **1c**, **1d**, **1f**, and **1g** are known and were prepared in one step according to a literature procedure.[5] Allylic electrophiles **1b**, **1e**, and **1j** were prepared by an analogous procedure and they are new compounds; the details of their synthesis is discussed herein. Allylic electrophile **1h** was prepared according to a literature procedure.[6] Allylic electrophile **1i** was prepared by a novel route involving radical deoxygenation (discussed herein).

PROPOSED MECHANISM

The following mechanism is proposed for the defluorinative alkylation of 3-substituted 3,3-difluoropropenes (Figure S1). The configurations of the products of defluorinative alkylation are the opposite of those of previous allylic substitution reactions and of allylic fluoroalkylation reactions with the same enantiomer of the catalyst, implying that the reactive π-allyl intermediate formed during defluorinative alkylation is the *exo*-π-allyl, rather than the *endo*-π-allyl intermediates of previous iridium-catalyzed allylic substitution reactions. This mechanism is supported by previous computations, related mechanistic studies of iridium-catalyzed allylic substitution, our assignment of the absolute configuration of the products, and the investigations discussed below.[2,7]

We have directly observed the resting state of the catalyst during the current defluorinative alkylation reactions and assigned the structure as a mixture of diastereomeric Ir(I) olefin complexes. The same resting state is observed for reactions conducted with lithium, sodium, or potassium malonates. The identity of the resting state indicates that C–F bond oxidative addition is turnover-limiting in each of these cases. We have also observed that (1,1-difluoroallyl)benzene reacts with lithium malonate 44 times faster than with sodium malonate and 3300 times faster than with potassium malonate in the presence of our iridium catalyst. Taken together, these data demonstrate that the counterion strongly influences the rate of C–F oxidative addition. The conclusion that oxidative addition is rate limiting also is consistent with the trend in rates of reactions of alkali metal malonates. This trend runs parallel to the relative fluorophilicities of the counterions (Li>Na>K) and opposite the trend of nucleophilicity of the corresponding malonate salts (K>Na>Li).

We have also determined that reactions of malonate anions with 3-fluorocinnamyl trifluoroacetate (which also proceed by nucleophilic attack on a fluorinated π-allyl intermediate) occur rapidly regardless of the counterion for the malonate anion, with a half-life significantly shorter ($t_{1/2}$ < 1 min) than the half-life of reactions of this nucleophile with 3-substituted 3,3-difluoropropenes and lithium ($t_{1/2}$ = 29.3 min), sodium ($t_{1/2}$ = 23.6 h), or potassium malonates ($t_{1/2}$ > 1150 h). This comparison of rates demonstrates that reductive elimination by outer-sphere attack of the nucleophile on the π-allyl intermediate is too fast to be turnover limiting and, therefore, cannot explain the difference in reactivity between the malonate salts in the present reaction. Collectively, these results provide strong evidence for a cation-assisted, turnover-limiting oxidative addition of the C–F bond during the defluorinative alkylation. We have also demonstrated that oxidative addition is irreversible, enantiodetermining, and proceeds from a mixture of rapidly interconverting diastereomeric resting states under Curtin Hammett control. Lastly, we have developed a stereochemical model that explains the opposite configuration of products derived from 3-fluoroallylic electrophiles and 3-substituted 3,3-difluoropropenes (see section "Model for Stereochemical Induction" for more details).

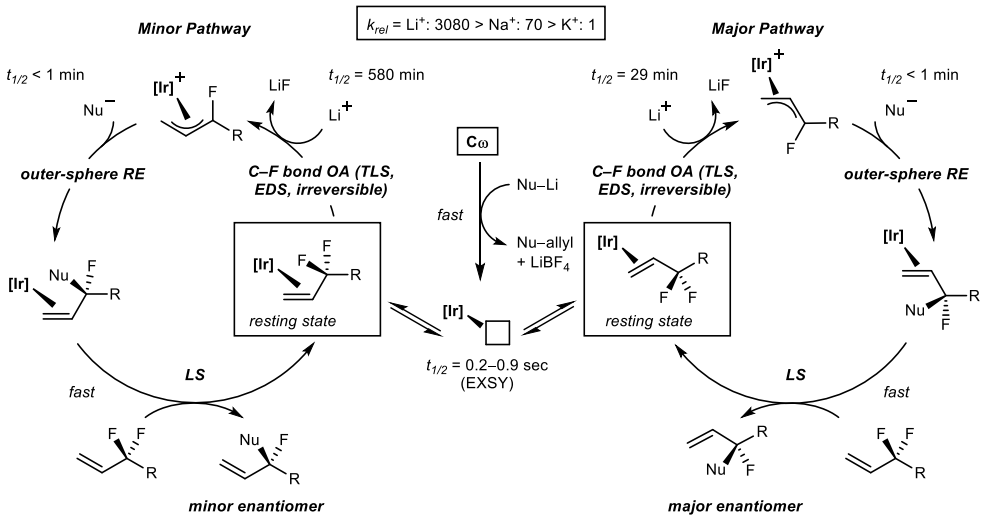
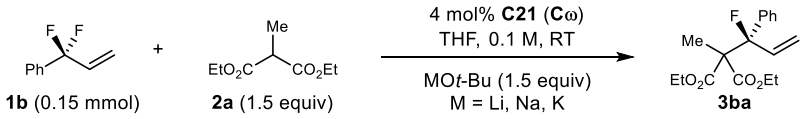


Figure S1. Proposed mechanism of enantioselective defluorinative alkylation. OA = oxidative addition; RE = reductive elimination; TLS = turnover-limiting step; EDS = enantiodetermining step.

RELATIVE RATES OF REACTIONS WITH LITHIUM, SODIUM, AND POTASSIUM MALONATE

Reactions of (1,1-difluoroallyl)benzene (**1b**) with malonates derived from diethyl methyl malonate (**2a**) and an alkali metal *tert*-butoxide (M = Li, Na, or K) were conducted under the reaction conditions illustrated in the scheme below (Figure S2). An internal standard (4,4'-difluoro-1,1'-biphenyl) was added directly to the reaction, and aliquots of the reaction mixture were removed, diluted in $CDCl_3$ at –40 °C, and subsequently analyzed by NMR spectroscopy periodically. The first half-life for reactions with lithium *tert*-butoxide ($t_{1/2}$ = 29.3 min) and sodium *tert*-butoxide ($t_{1/2}$ = 23.6 h) were approximated by linear interpolation from the two time points nearest to 50% yield. Although reactions conducted with potassium *tert*-butoxide did not reach 50% yield in the time studied, a lower bound for this half-life was determined by linear extrapolation to 50% yield using the origin (0%, 0 h) and the latest time point measured (3.5%, 81 h) ($t_{1/2}$ > 1150 h). The initial rates for each reaction were approximated from an early time point for each reaction (40% conv. for Li, 15% conv. for Na, and 3.5% conv. for K). From these data, the relative initial rates are 3080 (Li), 70 (Na), and 1 (K). *Note:* Complete mass balance was observed. Error was estimated to be ± 2% yield for each data point.



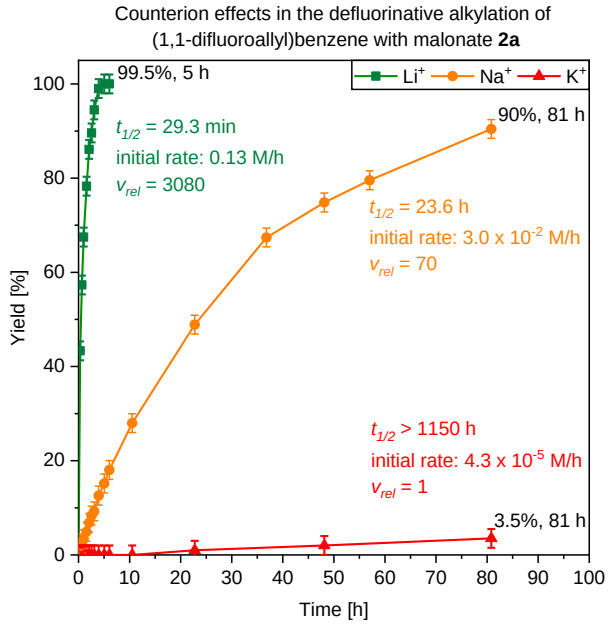
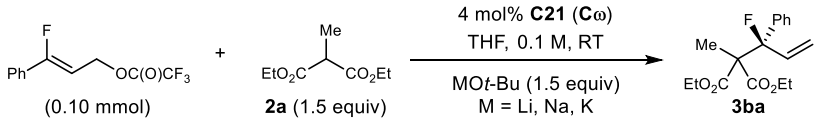


Figure S2. Counterion effects on the defluorinative alkylation reactions. Figure prepared with the Origin 2019 (9.6) software package.

To gain information about the rate of nucleophilic attack on π-allyl intermediates, we studied the rates of reactions of 3-fluorocinnamyl trifluoroacetate with lithium, sodium, and potassium malonate under conditions that are identical to those used to study the reactions of (1,1-difluoroallyl)benzene (**1b**) described above. The rates of these reactions provide information on the mechanism of the reaction of the 1,1-difluoroallyl electrophiles because reactions of 3-fluoroallylic trifluoroacetates proceed through fluorine-containing π-allyl intermediates that have the same connectivity of the intermediates from reaction of the 1,1-difluoroallyl electrophiles. We have demonstrated that the allylic substitution of 3-fluorocinnamyl trifluoroacetate proceeds with half-lives significantly shorter than 1 minute with malonate anion as the nucleophile bearing any of the alkali metal cations. Because this rate is much faster than the overall rate of the catalytic cycle (and oxidative addition is irreversible), reductive elimination by an outer-sphere nucleophilic attack cannot be turnover limiting in the reactions of 3-substituted 3,3-difluoropropenes with malonates (figure S3).



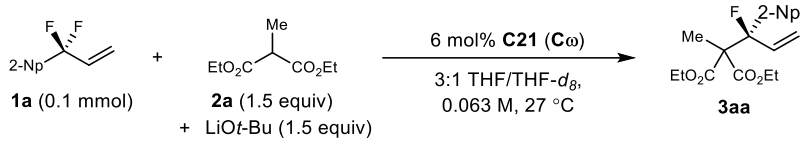
Yield of **3ba** over time for the reaction of Li, Na, and K malonates with 3-fluorocinnamyl trilfuoroacetate

	Li^+	Na^+	K^+
2 min	>98%	96%	96%
10 min	>98%	>98%	>98%

Figure S3. Rates of reactions of 3-fluorocinnamyl trifluoroacetate with Li, Na, and K malonates.

OBSERVATION OF THE CATALYST RESTING STATE: IR(I) OLEFIN COMPLEXES

The allylic fluoroalkylation of 2-(1,1-difluoroallyl)naphthalene (**1a**) with a mixture of diethyl methyl malonate (**2a**), lithium *tert*-butoxide, and catalyst **C21** (**Cω**) was conducted in a 3:1 mixture of THF and THF-d_8 in an NMR sample tube. The reaction was monitored by ^{1}H, ^{19}F, and ^{31}P NMR spectroscopy at 27 °C. Reaction conditions are outlined in the following scheme. The reaction was monitored for 3 hours (up to ~90% conversion), during which time no change in the identity of the resting state was observed. The following data demonstrate that the resting state is a mixture of diasteromeric Ir(I) olefin complexes. The resting state of the analogous reactions conducted with sodium *tert*-butoxide and potassium *tert*-butoxide were the same as that with lithium *tert*-butoxide.



The following NMR data indicate that the resting state of the catalyst is a ~4:1 mixture of diastereomeric Ir(I) olefin complexes. The ^{19}F NMR spectrum contains two pairs of doublets, each pair with a coupling constant that is diagnostic of geminal F–F coupling within a desymmetrized CF_2 group.

^{19}F NMR (565 MHz, 3:1 THF/THF-d_8) δ -74.70 (d, $^2J_{FF}$ = 230.2 Hz, minor dia., 1F); -74.99 (d, $^2J_{FF}$ = 232.4 Hz, major dia., 1F); -94.61 (dd, $^2J_{FF}$ = 232.4, $^3J_{HF}$ = 33.9 Hz, major dia., 1F); -97.08 (dd, $^2J_{FF}$ = 230.2, $^3J_{HF}$ = 34.9 Hz, minor dia., 1F).

^{31}P NMR (243 MHz, 3:1 THF/THF-d_8) δ 133.3 (s, major dia.), 133.0 (s, minor dia.).

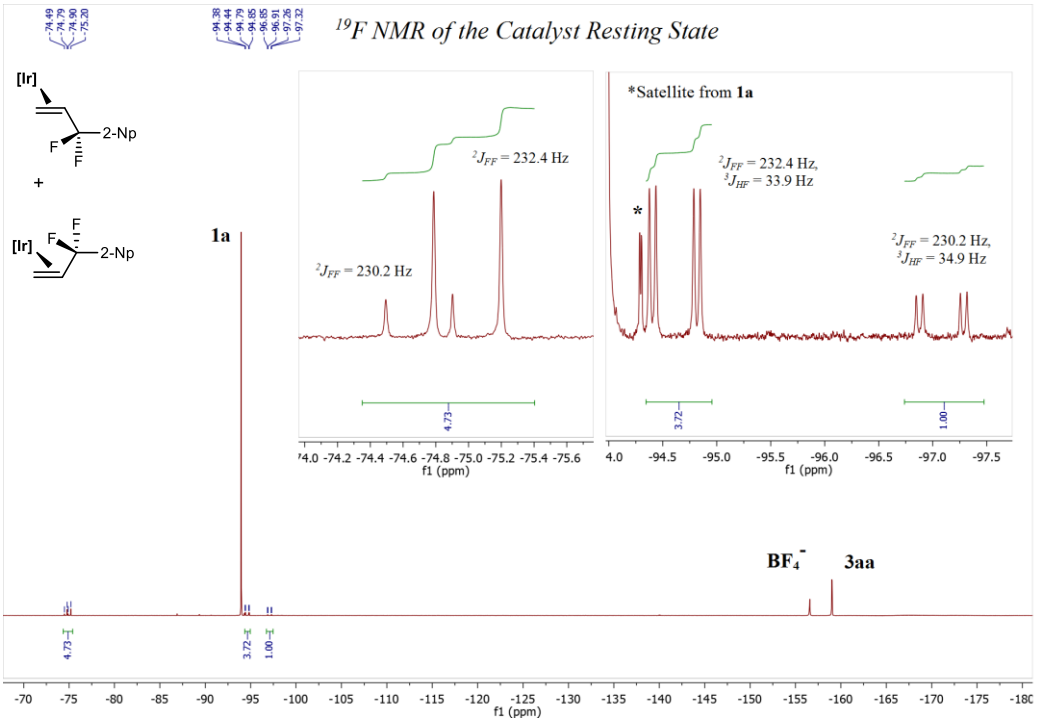


Figure S4. ^{19}F NMR spectrum of the reaction of 2-(1,1-difluoroallyl)naphthalene (**1a**) with malonate **2a** in the presence of catalyst **Cω** (**C21**). The resonances in the insets are those of the catalyst resting state.

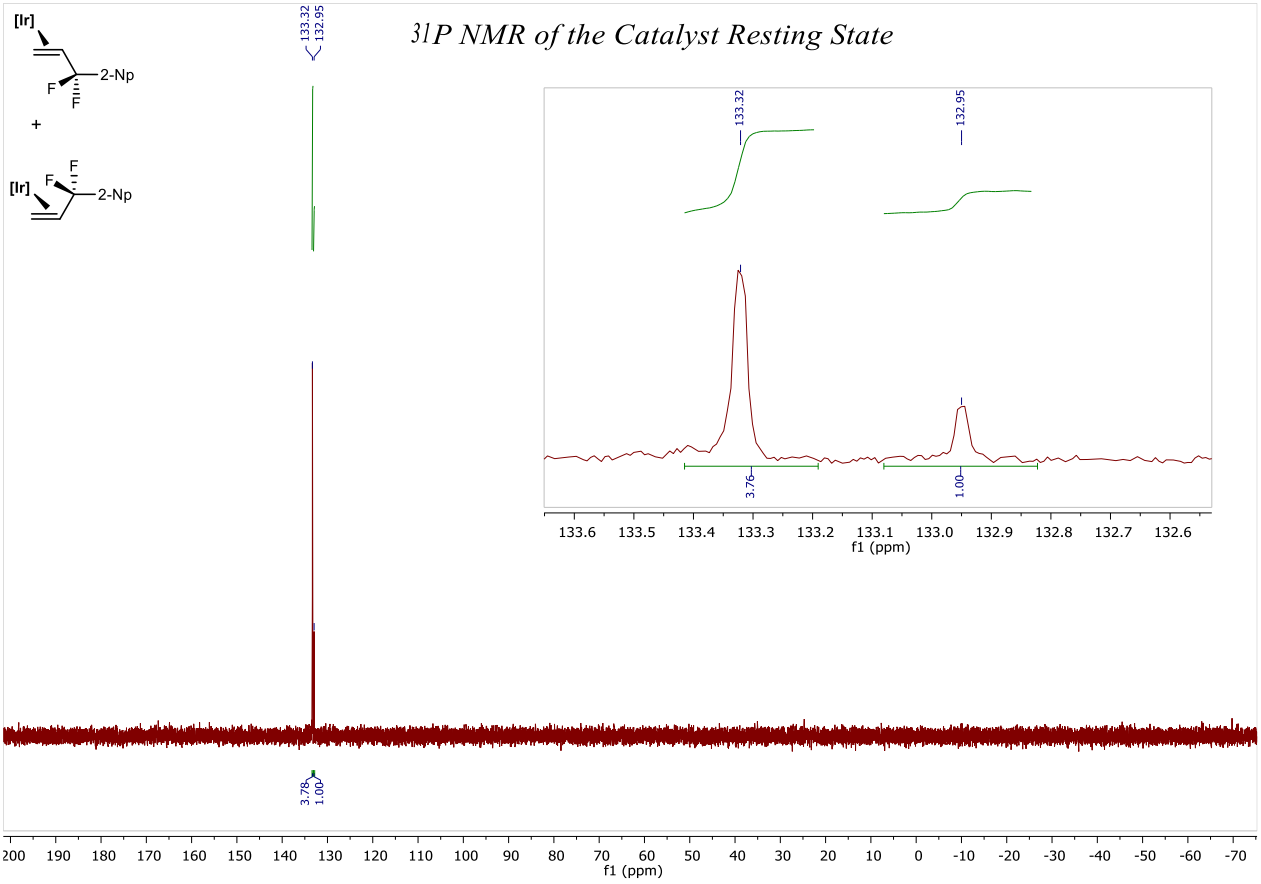


Figure S5. ^{31}P NMR spectrum of the reaction of 2-(1,1-difluoroallyl)naphthalene (**1a**) with malonate **2a** in the presence of catalyst **Cω** (**C21**). The two resonances expanded in the inset correspond to the two diastereomers of the resting state of the catalyst.

EXSY NMR Studies of Ir(I) Olefin Complexes

The catalyst resting state was generated *in situ* by conducting the allylic fluoroalkylation of 2-(1,1-difluoroallyl)naphthalene (**1a**) with a mixture of diethyl methyl malonate (**2a**), potassium *tert*-butoxide, and catalyst **C21** (**Cω**) in THF-d_8 in an NMR sample tube. The catalyst loading was 20 mol%, and the reaction concentration was 0.15 M to facilitate characterization. At this concentration, the resonances in the ^{19}F and ^{31}P NMR spectrum were the same as those in figure S4 & S5, but the ^{31}P NMR signals were slightly shifted and were better resolved. A ^{31}P-^{31}P EXSY experiment was conducted with two mixing times: 0 ms and 400 ms. The presence of well-defined off-diagonal peaks demonstrates that the diastereomeric iridium olefin complexes undergo rapid exchange. The rate constants for exchange were calculated to be $k_{1(\text{forward})} = 0.79\ s^{-1}$ and $k_{-1(\text{backwards})}$

= 3.08 s^{-1} using the EXSYCALC software in Mestrenova. These rate constants are consistent with the 4:1 diastereomeric ratio observed. The corresponding first-order half-lives for exchange are: $t_{1/2(forward)}$ = 0.88 s and $t_{1/2(backwards)}$ = 0.23 s. These data demonstrate that exchange of the olefin complexes occurs more rapidly than subsequent oxidative addition, demonstrating Curtin-Hammett kinetics. Therefore, the relative energies of the transition states for oxidative addition control the enantioselectivity of the reaction, not the relative concentrations of the olefin complexes preceding the enantiodetermining oxidative addition.

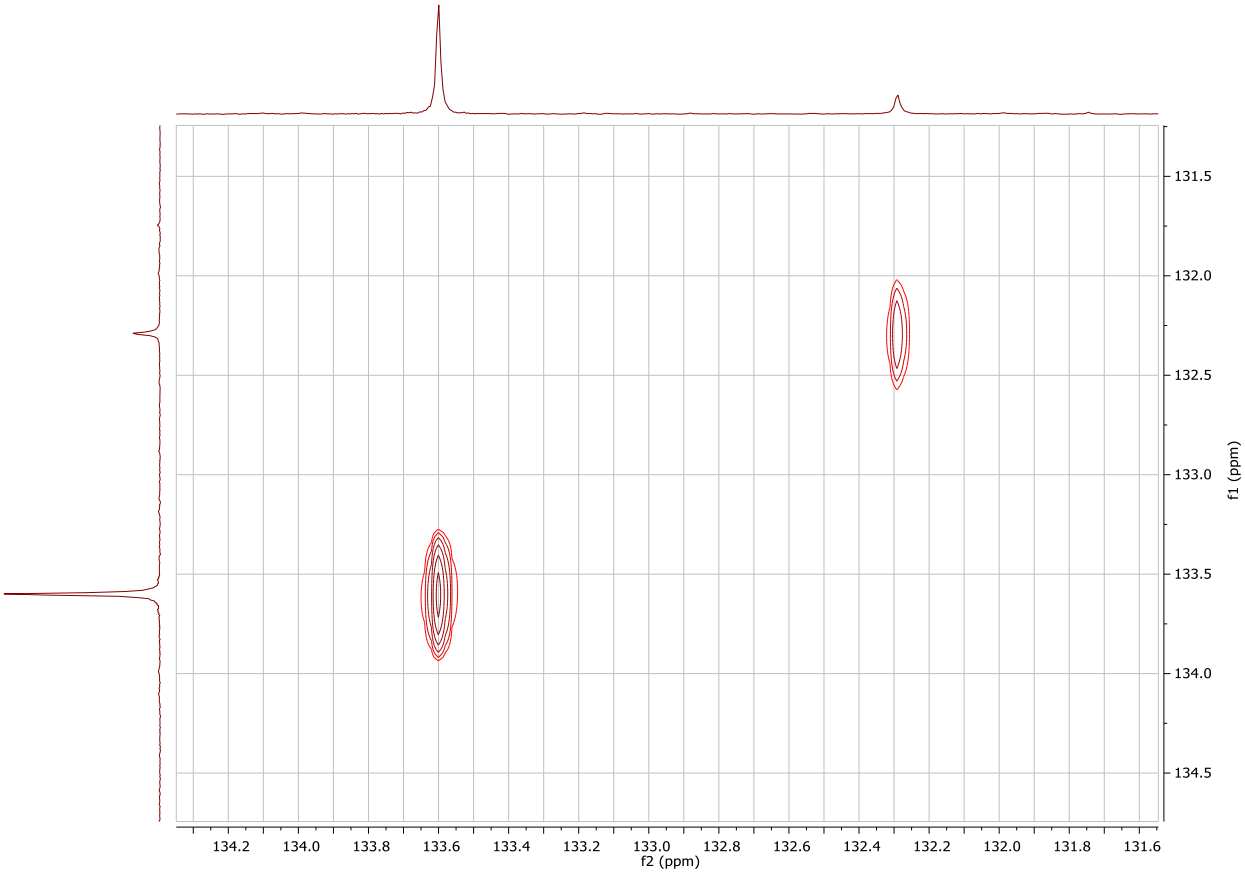


Figure S6. ^{31}P-^{31}P EXSY NMR spectrum of the catalyst resting state (mixing time = 0 ms).

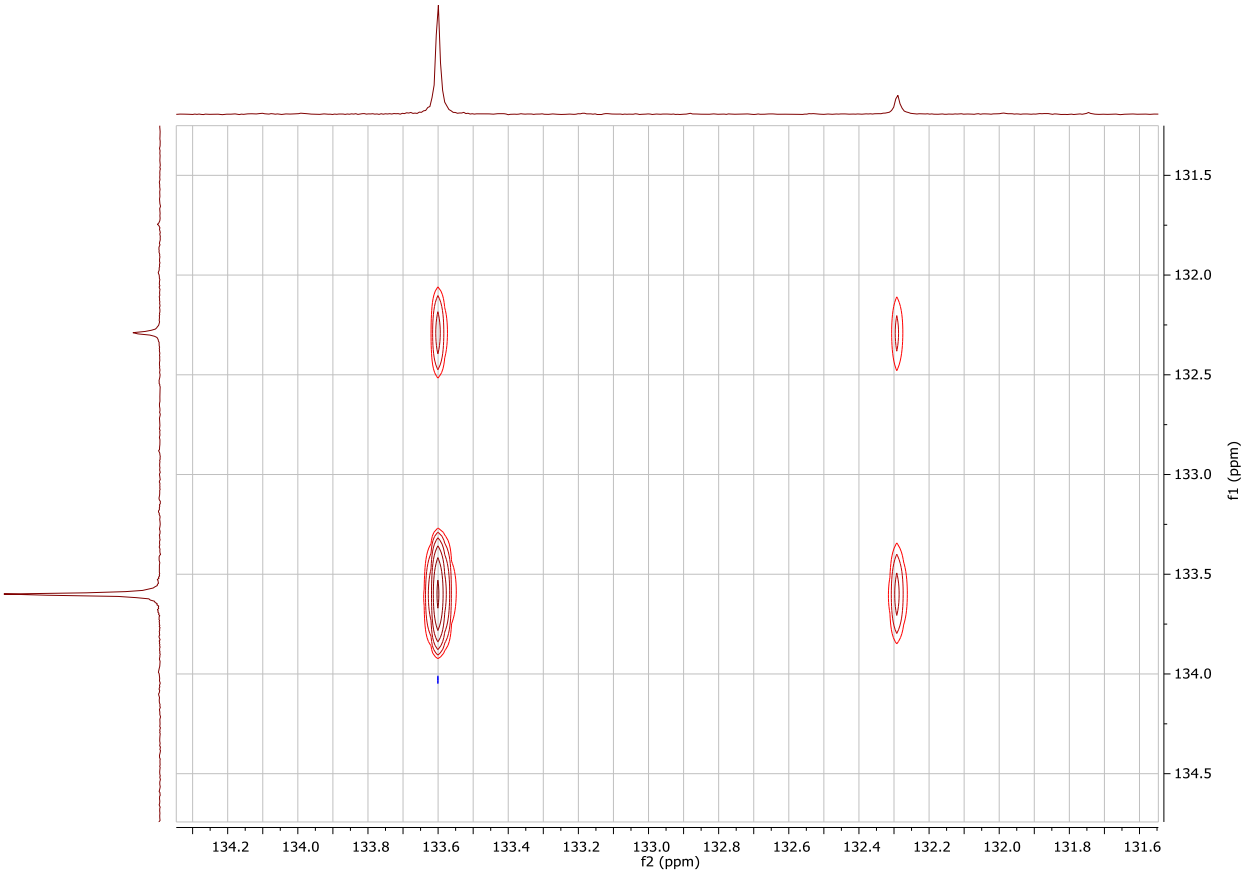


Figure S7. ^{31}P-^{31}P EXSY NMR spectrum of the catalyst resting state (mixing time = 400 ms).

DETERMINATION OF THE ABSOLUTE CONFIGURATION OF THE PRODUCTS

Product **3ba** and **3be** were each prepared by iridium-catalyzed allylic substitution of 3-fluoro allylic esters, as we previously reported.[2] In the previous publication, **3ba** and **3be** were prepared from an iridium catalyst derived from (*R*,*R*,*R*)-**L2**. The absolute configurations of the products **3ba** and **3be** derived from 3-fluoro allylic esters and a catalyst derived from (*R*,*R*,*R*)-**L2** were established to be (*S*) in this previous publication by analogy to the configuration of a product in the series that was characterized by single-crystal X-ray diffraction. Because the signs of the optical rotations of the products prepared from 3-substituted 3,3-difluoropropenes are the opposite of the products in our previous publication, the absolute configuration of **3ba** and **3be** were assigned as (*R*). Although compound **3bd** has been previously prepared,[2] its absolute configuration was not assigned because it formed in low enantioselectivity and its absolute configuration depended on the counterion of the nucleophile. Its absolute configuration can now be assigned by

analogy to the other products formed in the current work because it forms in high er when prepared from 3-substituted 3,3-difluoropropenes.

These data are summarized below:

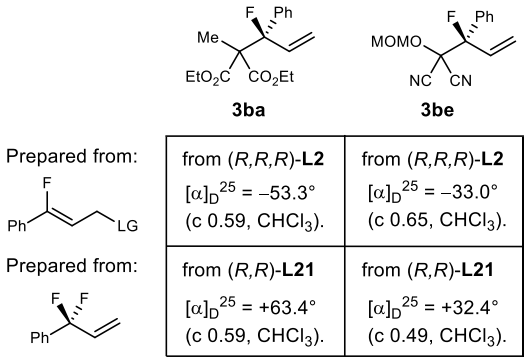
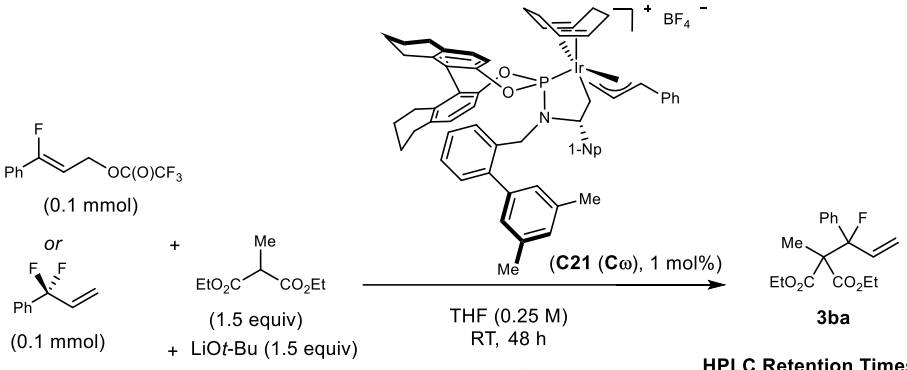


Figure S8. Optical rotation data for the assignment of absolute configurations. LG = leaving group (e.g. $OC(O)CF_3$, $OP(O)(OEt)_2$).

To assess further whether the configuration of product **3** formed from 3-fluoroallylic esters is the opposite of that formed from 3-substituted 3,3-difluoropropenes under otherwise identical reaction conditions, we conducted the following experiment outlined in Figure S9. Each of these electrophiles was treated with aliquots of the same solution of **C21** (**Cω**) and aliquots of the same solution of lithium *tert*-butoxide and malonate **2a**. The resulting reaction mixtures were stirred at room temperature for 48 hours, then concentrated *in vacuo*. The product was purified by preparative TLC. Optical rotations and HPLC data indicate that the absolute configurations of the products are the opposite of each other.



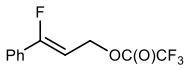
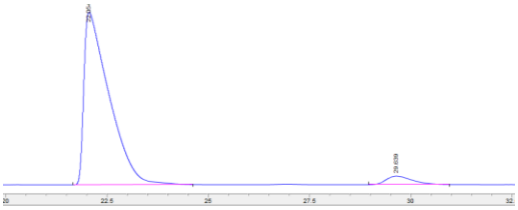
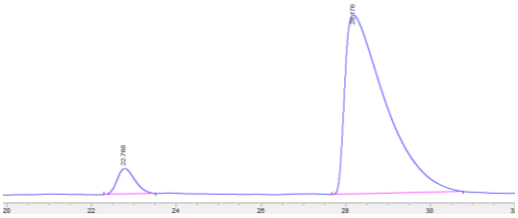
Compound	Isolated Yield	er	Optical Rotation (corrected for er)	HPLC Retention Times (OD-H, 0.1% IPA/hex, 0.7 mL/min)
Product **3ba** derived from: 	85% (26.3 mg)	5:95	$[\alpha]_D^{25}$ = –63.9° (c 0.59, $CHCl_3$).	t_R (major): 23 min t_R (minor): 28 min
Product **3ba** derived from: 	86% (26.5 mg)	94:6	$[\alpha]_D^{25}$ = +66.3° (c 0.53, $CHCl_3$).	t_R (major): 29 min t_R (minor): 22 min

Figure S9. Formation of products with the opposite absolute configuration from 3-substituted 3,3-difluoropropenes and 3-fluoroallylic esters under identical reaction conditions. Relevant HPLC data are provided below:



HPLC Trace for the product derived from 3-fluorocinnamyl trifluoroacetate.



HPLC trace for the product derived from (1,1-difluoroallyl)benzene.

HPLC data for the racemate are given with product characterization data for product **3ba**.

MODEL FOR STEREOCHEMICAL INDUCTION

Our experimental data lead to a model that explains the opposite configuration of products derived from 3-fluorocinnamyl electrophiles and 3-substituted 3,3-difluoropropenes. In short, we provide evidence that oxidative addition of the C–F bond is irreversible and that the π-allyl intermediates do not interconvert: these two results demonstrate that oxidative addition of the C–F bond is enantiodetermining. Therefore, the relative energies of the transition states for oxidative addition determine the enantioselectivity of the reaction, and these transition states come from ionization of the Ir-olefin complexes, which are the resting states of the catalyst. The diastereomeric olefin complexes rapidly interconvert before the formation of the π-allyl intermediate via oxidative addition (as determined by EXSY experiments), indicating the enantioselectivity is determined by the difference in transition state energies for oxidative addition ($\Delta\Delta G^{\ddagger}$), not the ratio of olefin complexes, in accordance with the Curtin-Hammett principle. We expect that the relative degree of steric hindrance in two transition states for oxidative addition will be similar to those in the olefin complexes that precede them. We propose a stereochemical model and quadrant diagram, supported by computational studies, that rationalize the opposite configurations of the products derived from 3-fluorocinnamyl esters and 3-substituted 3,3-difluoropropenes.

These proposals are supported by the following mechanistic conclusions:

1. We deduce that π-allyl intermediates do not equilibrate:

(a) We deduce that the π-allyl intermediates equilibrate much more slowly than the nucleophile adds to them. If they equilibrated more rapidly, then both 3-fluorocinnamyl electrophiles and 3-substituted 3,3-difluoropropenes would provide products with the same configuration and enantioselectivity (common intermediate).

(b) The π-allyl intermediates do not equilibrate by π-σ-π interconversion. Closely-related cyclometalated π-allyl iridium intermediates are experimentally known not to undergo π-σ-π interconversion,[7] and DFT calculations provide strong evidence that the η^1 allyl intermediate

required for interconversion by a π-σ-π pathway is too high in energy (22 kcal/mol above the η^3 form) to be a relevant intermediate especially when considering that such a rearrangement must be faster than nucleophilic attack, which is rapid ($t_{1/2}$ < 1 min). This lack of interconversion by this pathway originates from the fact that iridium(III) prefers to maintains an inert, d^6, octahedral geometry.

2. We deduce that oxidative addition of the C–F bond is irreversible:

(a) Oxidative addition is irreversible. Reversible oxidative addition is unreasonable because it would require the attack of lithium fluoride (a non-nucleophilic, insoluble salt with a high lattice energy) on the π-allyl intermediate to be competitive with the attack of lithium malonate (a strong, soluble nucleophile) on the π-allyl intermediate (which is rapid, $t_{1/2}$ < 1 min, see discussion in the main text).

(b) To provide experimental evidence for this assertion, we treated our pre-catalyst **Cω** with lithium malonate in the presence of a 2-(1,1-difluoroallyl)naphthalene (**1a**). This mixture rapidly generates the resting state of the catalytic reaction. On the other hand, treating our pre-catalyst with lithium fluoride in the presence of a 2-(1,1-difluoroallyl)naphthalene (**1a**) does not generate the resting state of the catalytic reaction, even after prolonged reaction times. This result demonstrates that lithium malonate rapidly attacks π-allyl iridium species, but lithium fluoride does not.

3. We deduce that the diastereomeric olefin complexes (diastereomeric resting states) preceding oxidative addition interconvert rapidly.

A ^{31}P-^{31}P EXSY NMR experiment was conducted on the diastereomeric olefin complexes (resting state). The presence of a cross peak indicates that these diastereomers interconvert on the timescale of the experiment (400 ms mixing time) at room temperature. Thus, ligand exchange on the trigonal bipyramidal Ir(I) intermediate is much faster than turnover-limiting oxidative addition. The half-life for exchange between these two diastereomeric olefin complexes was calculated from the EXSY NMR data to be $t_{1/2(forward)}$ = 0.88 s and $t_{1/2(backwards)}$ = 0.23 s.

This result explains how an 80:20 ratio of diastereomeric olefin complexes leads to >95:5 er: The olefin complexes interconvert 2000 times faster than they undergo turnover-limiting oxidative addition of the C–F bond. Ultimately, the relative energies of the two transition states for oxidative addition ($\Delta\Delta G^{\ddagger}$) determines the enantioselectivity, not the equilibrium ratio of olefin complexes (Curtin-Hammett kinetics).

4. We advance a stereochemical model (quadrant diagram) that rationalizes the opposite absolute configuration of products derived from 3-fluorocinnamyl electrophiles and 3-substituted 3,3-difluoropropenes:

DFT studies demonstrate that a vertex of the COD ligand and an associated hydrogen atom (illustrated in Fig. S10 below) protrudes into the binding space of the alkene on the allylic electrophile, blocking the northeast quadrant of this binding site. The northwest and southwest quadrants are blocked by the BINOLate group of the phosphoramidite ligand and the *N*-benzyl group of the phosphoramidite ligand, respectively. *Note:* This quadrant diagram has been proposed in the literature.[8] In the analysis below, we do not consider olefin complexes that place the aryl group in the NW or SW quadrant because previous mechanistic studies demonstrate that iridium catalyzed allylic substitutions only proceed through π-allyl complexes bearing substituents in the SE or NE quadrants.

From this model, it becomes clear that binding and subsequent ionization from the *endo* complex of 3-fluorocinnamyl chloride, in which the chloride acts as the leaving group from the terminal position to mimic the types of substrates studied previously, should occur without significant hindrance. In the *endo* complex, the largest substituent (Ph) is placed in the open, southeast quadrant. In contrast, the binding of the *exo* isomer should occur with severe clashes between the Ph group of the alkene and the COD ligand on iridium. These steric interactions are expected to be present in both the ground state alkene complex and the transition state for ionization. This stereochemical model explains the formation of the (*S*) enantiomer of product as the major enantiomer, and this enantiomer is the major enantiomer observed experimentally.

Binding of the olefin and subsequent ionization from the *exo* complex of a 3-substituted 3,3-difluoropropene that is the subject of the current paper should occur without significant

hindrance. In the *exo* complex, the largest substituent (CF_2Ph) is placed in the open, southeast quadrant. In contrast, the binding of the *endo* isomer should occur with severe clashes between the CF_2 group of the alkene and the COD ligand. These steric interactions are expected to be present in both the ground state alkene complex and the transition state for ionization. These phenomena would lead to the formation of the (*R*) enantiomer of the product as the major enantiomer, and this enantiomer is the major enantiomer observed experimentally. Thus, this analysis accurately predicts that the opposite enantiomer should be formed from the two types of electrophiles.

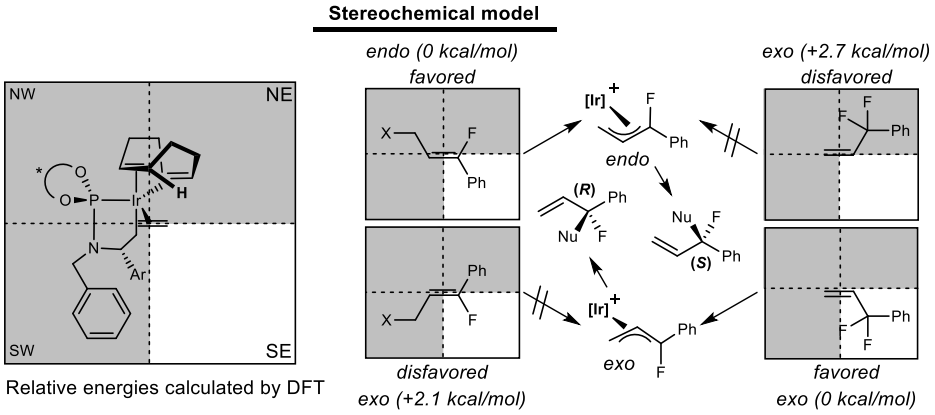


Figure S10. Stereochemical model explaining the opposite absolute configuration of products derived form 3-fluorocinnamyl electrophiles and 3-substituted 3,3-difluoropropenes.

DFT calculations of the corresponding olefin complexes confirm these expected relative energies for the ground state complexes. Furthermore, these specific steric interactions are confirmed by close contacts observed in relevant DFT structures (see the following section).

Previous mechanistic studies on iridium-catalyzed allylic substitution with nonfluorinated substrates have been conducted on systems in which the nucleophile (amine) is less nucleophilic than the leaving group (methyl carbonate anion).[7] Consequently, oxidative addition was reversible and the factors controlling the enantioselectivity in that system ($\Delta\Delta G^{\ddagger}$ for nucleophilic attack, influenced by π-allyl stability) was different from the factors controlling enantioselectivity in this system ($\Delta\Delta G^{\ddagger}$ for oxidative addition, influenced by olefin complex stability).

COMPUTATIONAL STUDIES OF IRIDIUM OLEFIN AND ALLYL COMPLEXES

To further assess the stereochemical model we propose, we have conducted DFT computational studies of the iridium olefin complexes and the corresponding iridium π-allyl intermediates. These studies corroborate our conclusion that the relative energies of *endo* and *exo* olefin complexes for 3-fluorocinnamyl electrophiles are the opposite of those for 3-substituted 3,3-difluoropropenes, that the specific steric interactions suggested by the quadrant model are present, and that η^1-allyl intermediates are energetically inaccessible. These structures and their relative energies are summarized in figure S11 below and shown in detail on the following pages.

Experimental Notes: All DFT calculations were performed with the Gaussian 09 software package.[9] Optimizations of the geometries of all the species at room temperature were conducted at the b3lyp-D3 level of theory.[10,11] The LANL2DZ basis set and pseudo potential[12] were used for the iridium atoms, and the 6-31G(d,p) basis set[13] was used for other atoms. All calculations used pure (spherical-harmonic type) d and f orbitals. Vibrational frequencies were computed at the same level for each structure to determine if the structure is an energy minimum or a transition state and to evaluate its zero-point vibrational energy (ZPVE). Solvent effects were computed based on the gas-phase optimized structures with the same basis sets. Solvation energies in tetrahydrofuran were evaluated by a self-consistent reaction field (SCRF) with the smd model. In this paper, all energies discussed are Gibbs free energies at room temperature in tetrahydrofuran ($\Delta G_{THF\ 298\ K}$). All reported energies are ΔG values with the solvent correction applied. Structural images were generated from CYLView.[14] The computational parameters reported herein are the same as those previously used by our group to examine the origin or regioselectivity in iridium-catalyzed allylic alkylation.[15] Computations were conducted on a truncated version of catalyst **C10** (see figure S11).

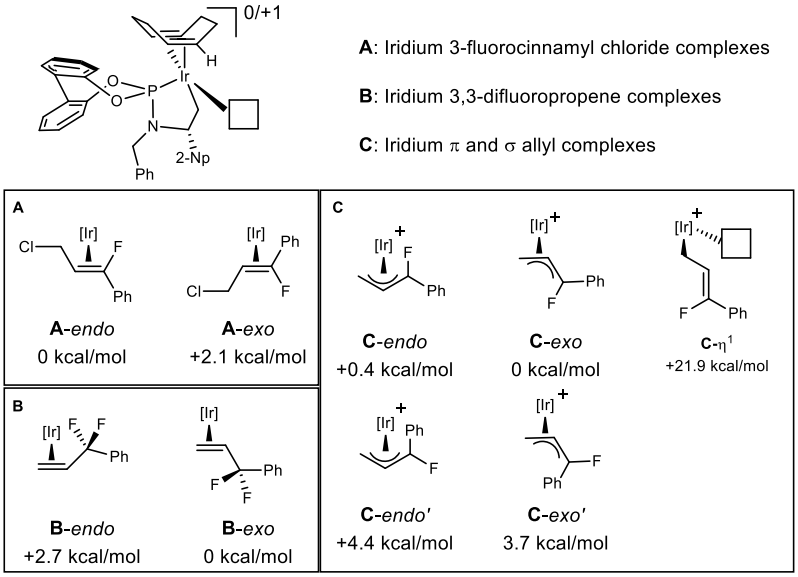
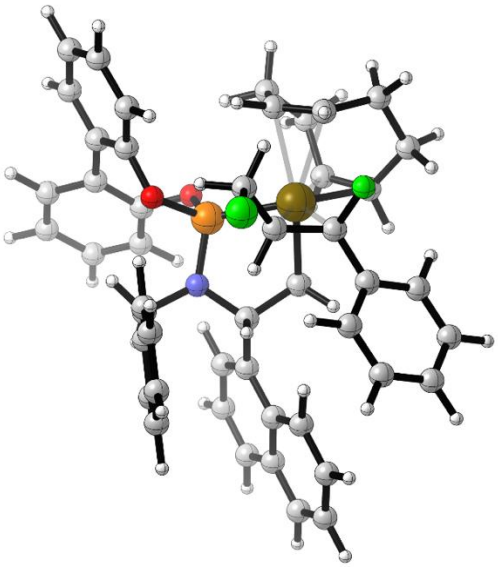
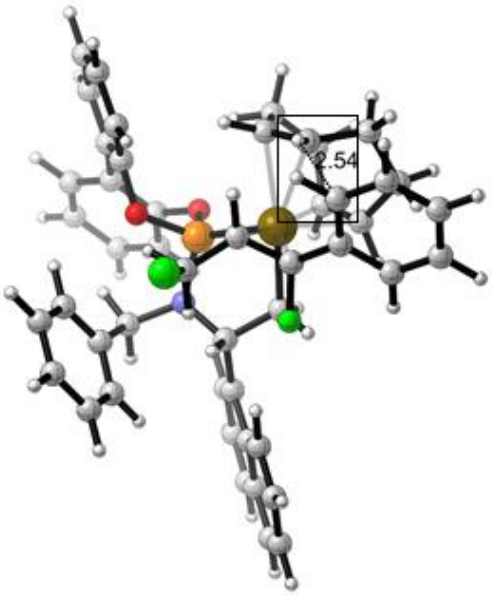


Figure S11. Summary of computed structures and their relative energies

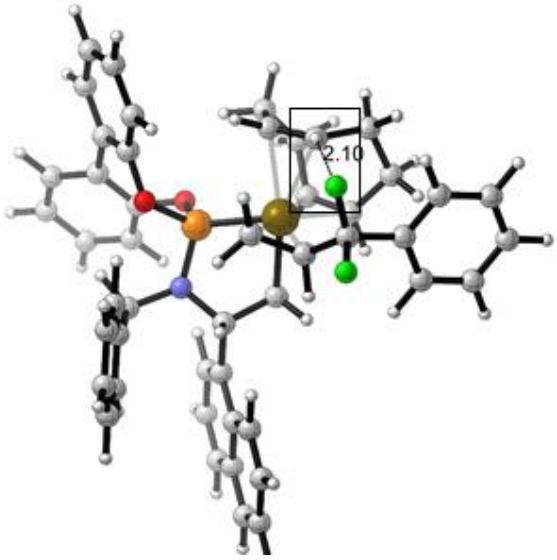


A-*endo* (0 kcal/mol)

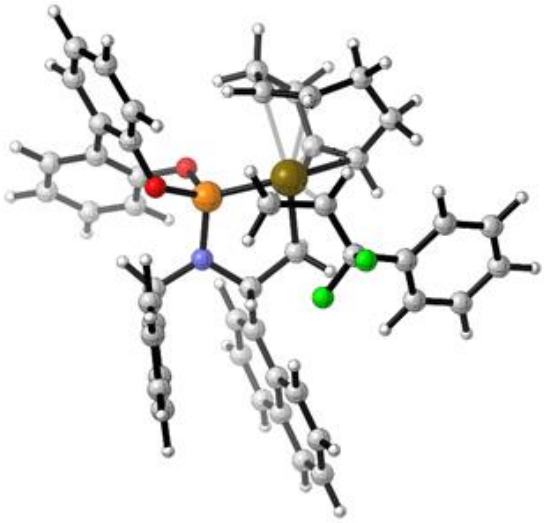


A-*exo* (+2.1 kcal/mol)

A-*exo* is less stable than **A**-*endo* by 2.1 kcal/mol. Note a steric clash of the phenyl ring and a hydrogen atom present on the COD ligand (illustrated in the boxed area) and an accompanying rotation of the olefin about the olefin-Ir bond axis, out of the trigonal plane of the pseudo-trigonal bipyramidal iridium complex **A**-*exo*. The C-H nonbonded distance (2.54 Å) is shorter than the sum of van der Waals radii (2.80 Å).

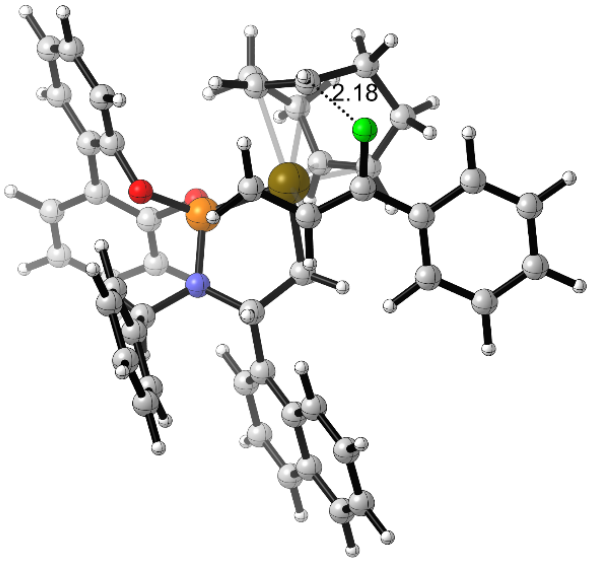


B-*endo* (+2.7 kcal/mol)

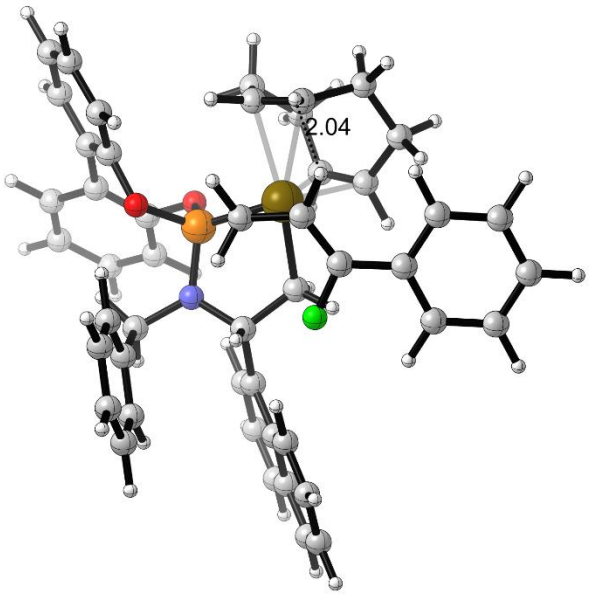


B-*exo* (0 kcal/mol)

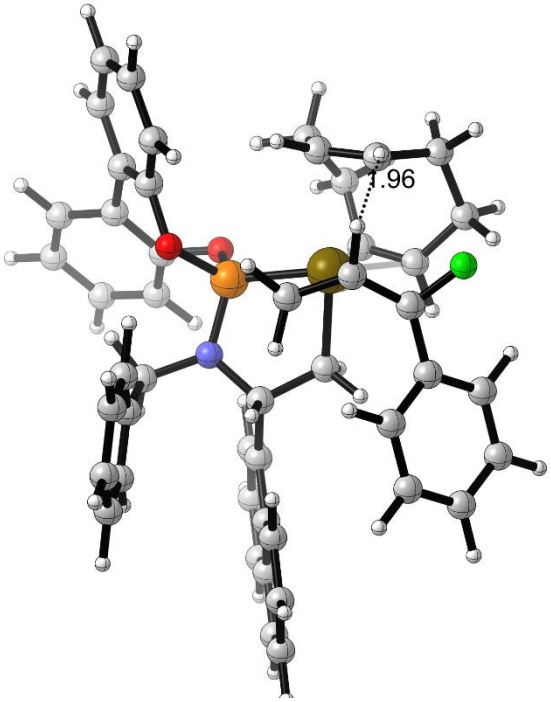
B-*endo* is less stable than **B**-*exo* by 2.7 kcal/mol. Note the steric clash between the CF_2 group and a hydrogen atom present on the COD ligand (illustrated in the boxed area) and an accompanying rotation of olefin about the olefin-Ir bond axis, out of the trigonal plane of the pseudo-trigonal bipyramidal iridium complex **B**-*endo*. The F-H nonbonded distance (2.10 Å) is shorter than the sum of van der Waals radii (2.60 Å).



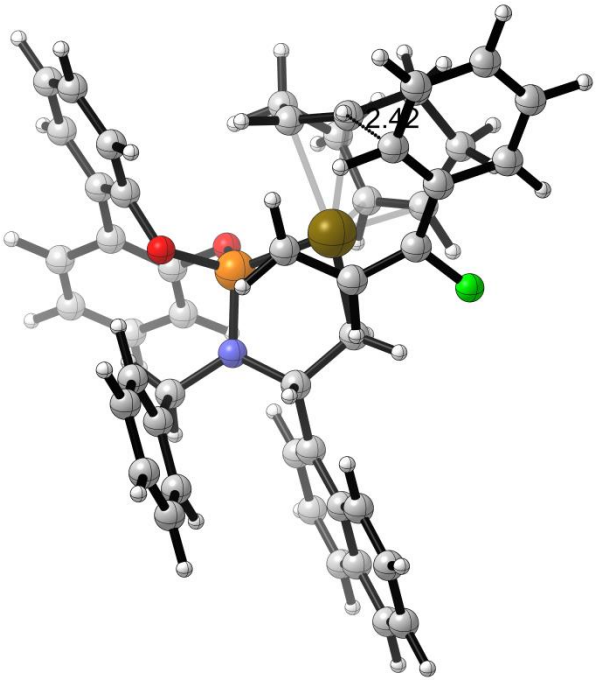
C-*endo* (+0.4 kcal/mol)



C-*exo* (0 kcal/mol)

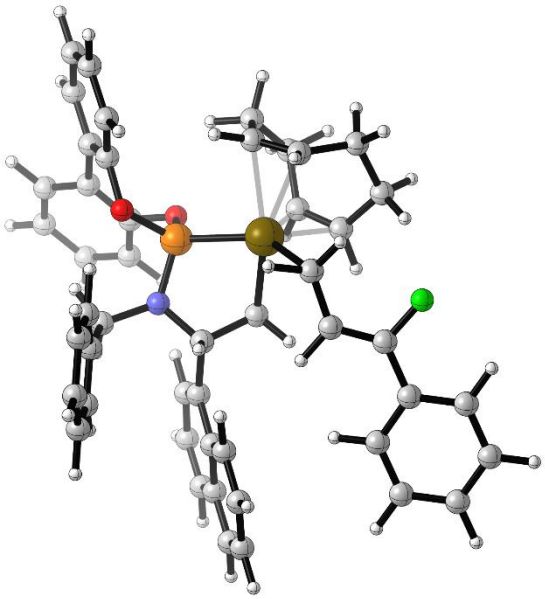


C-*endo'* (+4.4 kcal/mol)



C-*exo'* (+3.7 kcal/mol)

Consistent with previous studies of iridium-catalyzed allylic substitution, π-allyl complexes bearing an *anti* phenyl ring (**C**-*endo*' and **C**-*exo*') are less stable than those bearing a *syn* phenyl ring (**C**-*endo* and **C**-*exo*). Furthermore, these *anti*-substituted π-allyl complexes are unlikely intermediates because they do not arise from ionization of the fluorine atom antiperiplanar to iridium in the ground-state olefin complexes.



C-η^1 (+21.9 kcal/mol)

The energy of the η^1-allyl iridium complex **C**-η^1, which is the intermediate required for π-σ-π interconversion to occur, is 21.9 kcal/mol higher than that of the isomeric η^3-allyl iridium intermediate **C**-*exo*. Because the allyl intermediate is rapidly captured under the reaction conditions, this result implies that the *endo* and *exo* π-allyl intermediates do not interconvert under the reaction conditions. Indeed, previous experimental studies of allylic substitution with cyclometalated phosphoramidite ligands have demonstrated that such interconversions do not occur. This high energy of the η^1 structure relative to the η^3 form may be due to the d^6, octahedral configuration about iridium in the η^3 form.

A-*endo*:

G (EE+Thermal Free Energy Correction) = -3067.027015

Gcorr (Thermal Correction to Free Energy) = 0.734423

EE(RB3LYP, solvent corrected) = -3067.803095

A-*exo*:

G (EE+Thermal Free Energy Correction) = -3067.023385

Gcorr (Thermal Correction to Free Energy) = 0.734889

EE(RB3LYP, solvent corrected) = -3067.800185

B-*endo*:

G (EE+Thermal Free Energy Correction) = -2706.662567

Gcorr (Thermal Correction to Free Energy) = 0.735881

EE(RB3LYP, solvent corrected) = -2707.437767

B-*exo*:

G (EE+Thermal Free Energy Correction) = -2706.667239

Gcorr (Thermal Correction to Free Energy) = 0.736741

EE(RB3LYP, solvent corrected) = -2707.442929

C-*endo*:

G (EE+Thermal Free Energy Correction) = -2606.62744

Gcorr (Thermal Correction to Free Energy) = 0.735815

EE(RB3LYP, solvent corrected) = -2607.446511

C-*exo*:

G (EE+Thermal Free Energy Correction) = -2606.625771

Gcorr (Thermal Correction to Free Energy) = 0.734175

EE(RB3LYP, solvent corrected) = -2607.445524

C-*endo'*:

G (EE+Thermal Free Energy Correction) =

Gcorr (Thermal Correction to Free Energy) =

EE(RB3LYP, solvent corrected) =

C-*exo'*:

G (EE+Thermal Free Energy Correction) = -2606.621981

Gcorr (Thermal Correction to Free Energy) = 0.735451

EE(RB3LYP, solvent corrected) = -2607.439854

C-η^1:

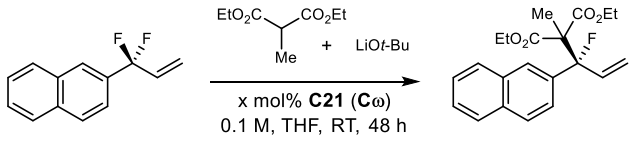
G (EE+Thermal Free Energy Correction) = -2606.583539

Gcorr (Thermal Correction to Free Energy) = 0.730392

EE(RB3LYP, solvent corrected) = -2607.406814

EFFECT OF CATALYST LOADING ON ENANTIOSELECTIVITY

The enantioselectivity of defluorinative alkylation is slightly lower for reactions conducted with higher catalyst loadings than for those conducted with lower catalyst loadings. When the cationic precatalyst **Cω** is attacked by lithium malonate to enter the catalytic cycle, an equivalent of lithium tetrafluoroborate is liberated. We hypothesized that the substitution of fluoride by iridium with the participation of lithium tetrafluoroborate occurs with lower enantioselectivity than that with the participation of lithium malonate. In this case, reactions with higher loadings of the catalyst will generate more $LiBF_4$ and form the product with lower enantioselectivity. Indeed, as shown in Figure S12 (shown below), the enantioselectivity of the reactions with exogenous lithium tetrafluoroborate are lower by an amount comparable to that of the reactions with higher catalyst loading.



	Conv.	er
1 mol% [Ir]	>98%	94.0:6.0
2 mol% [Ir]	>98%	94.0:6.0
5 mol% [Ir]	>98%	93.5:6.5
10 mol% [Ir]	>98%	92.5:7.5

Higher catalyst loadings: Lower enantioselectivity

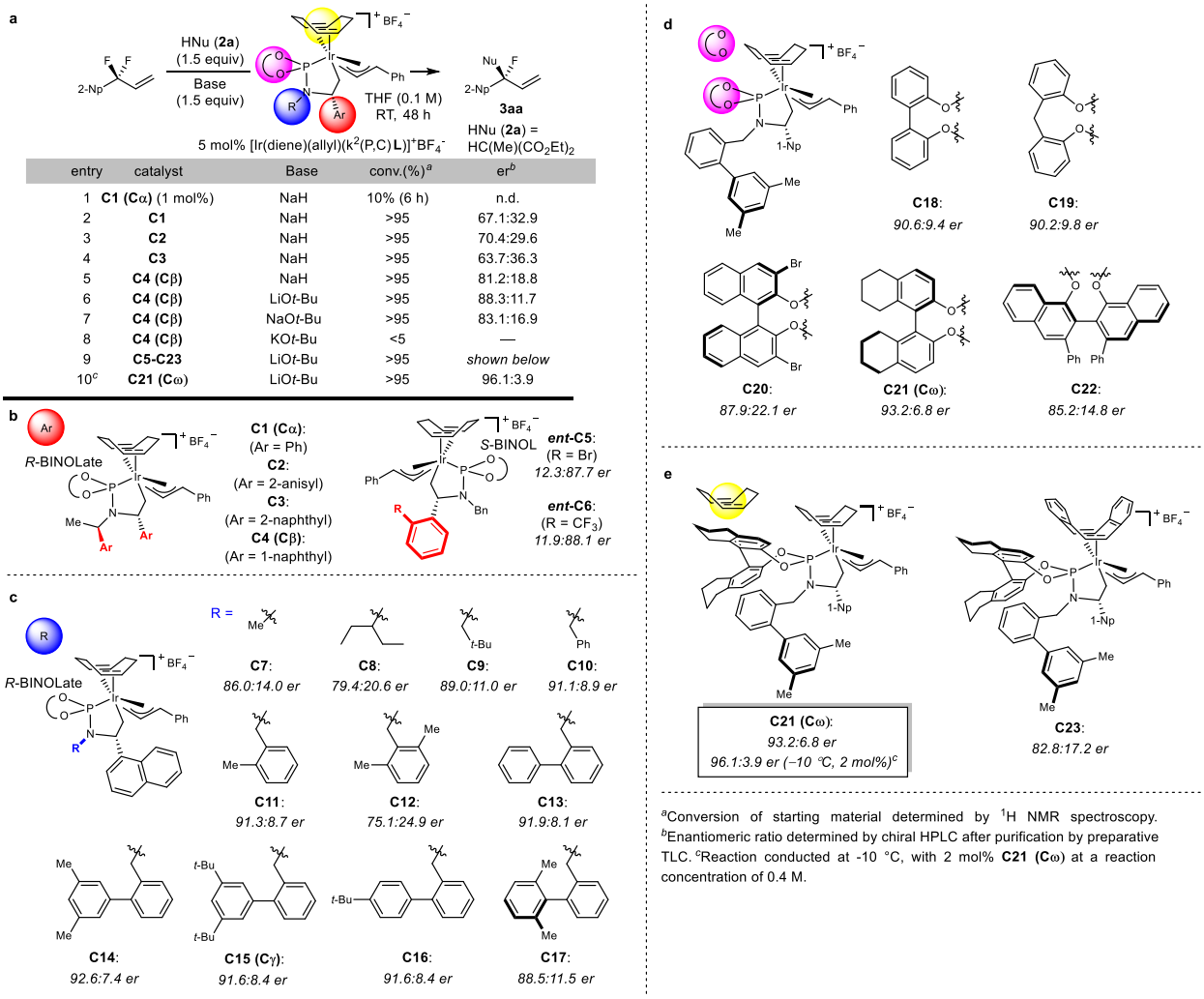
	Conv.	er
2 mol% [Ir] + 0 mol% $LiBF_4$	>98%	94.0:6.0
2 mol% [Ir] + 3 mol% $LiBF_4$	>98%	92.5:7.5
2 mol% [Ir] + 8 mol% $LiBF_4$	>98%	91.5:8.5

Exogenous $LiBF_4$: Lower enantioselectivity

Figure S12. Effect of catalyst loading and exogenous $LiBF_4$ on enantioselectivity.

DEVELOPMENT OF CATALYST Cω

The catalyst structure was modified in an iterative set of experiments outlined in figure S13. The trends of enantioselectivities are nearly the same for reactions conducted with malonates, malononitriles, and silyl ketene acetals. However, the enantioselectivity of products formed from reactions of silyl ketene acetals conducted with catalyst **Cγ** are slightly higher than those of reactions conducted with catalyst **Cω**.



[a]Conversion of starting material determined by ^{1}H NMR spectroscopy. [b]Enantiomeric ratio determined by chiral HPLC after purification by preparative TLC. [c]Reaction conducted at -10 °C, with 2 mol% **C21 (Cω)** at a reaction concentration of 0.4 M.

Figure S13. Development of catalysts for the enantioselective desymmetrization of 3-substituted 3,3-difluoropropenes. **a.** Initial reaction development **b.** Investigation of aryl groups at the site of cyclometallation **c.** Investigation of substituents at the non-cyclometallated site of the catalyst. **d.** Investigation of various diol backbones **e.** Investigation of the structure of the diene.

UNSTABILIZED KETONE ENOLATES IN DEFLUORINATIVE ALKYLATION REACTIONS

Defluorinative alkylation reactions with ketones proceed in good yield; however, these reactions proceed in low enantioselectivity when conducted with the catalysts we developed for reactions of malonates and silyl ketene (Figure S14).

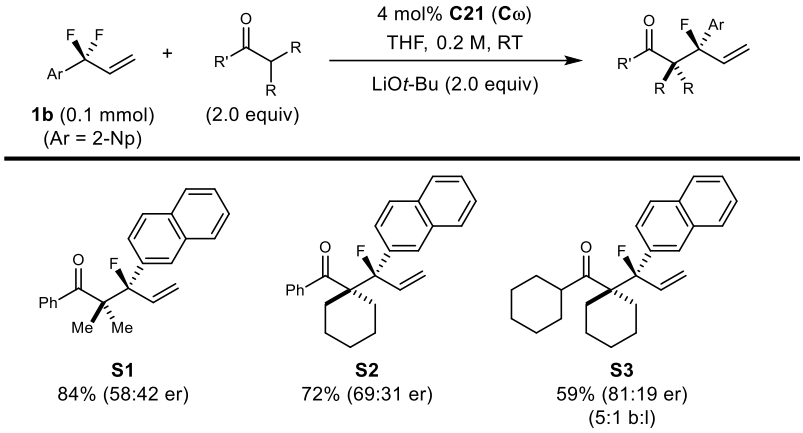
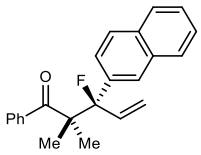


Figure S14. Defluorinative alkylation reactions with ketone nucleophiles.

Note: Defluorinative alkylation reactions with ketones were conducted in an analogous fashion to defluorinative alkylation reactions with malonates under the conditions outlined in Figure S14.

(*R*)-3-fluoro-2,2-dimethyl-3-(naphthalen-2-yl)-1-phenylpent-4-en-1-one (S1)



The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.100 mmol scale. Reaction time: 36 h. Reaction temperature: RT. Catalyst loading: 4 mol%. The product was purified by preparative TLC (5/95 of acetone/hexanes) to provide allylic fluoride **S1** as a clear oil (27.9 mg, 0.0839 mmol, 84%).

The **enantiomeric ratio** was determined to be 58:42 by HPLC analysis with t_R = 8.1 min (minor) and t_R = 9.3 min (major) [AD-H, 1.0% *i*PrOH in hexanes, 0.7 mL/min, 230 nm, 25 °C].

$[\alpha]_D^{25}$ = +1.9° (c 0.49, $CHCl_3$). *Corrected for enantiopurity:* **$[\alpha]_D^{25}$** = +11.9° (c 0.49, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.89 (d, *J* = 1.8 Hz, 1H), 7.87 – 7.80 (m, 3H), 7.52 – 7.48 (m, 3H), 7.45 – 7.42 (m, 2H), 7.40 (t, *J* = 7.4 Hz, 1H), 7.30 (t, *J* = 7.7 Hz, 2H), 6.89 (ddd, *J* = 23.0, 17.0,

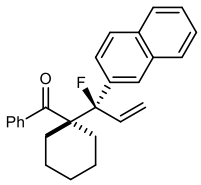
11.1 Hz, 1H), 5.46 (dd, *J* = 17.0, 1.3 Hz, 1H), 5.35 (ddd, *J* = 11.2, 2.8, 1.3 Hz, 1H), 1.39 (s, 3H), 1.38 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 208.2 (d, *J* = 2.4 Hz), 140.7, 137.8 (d, *J* = 23.4 Hz), 136.6 (d, *J* = 18.4 Hz), 132.8, 130.6, 128.6, 127.9, 127.8 (d, *J* = 4.2 Hz), 127.6, 127.5 (d, *J* = 1.9 Hz), 126.5, 126.4, 125.8 (d, *J* = 11.4 Hz), 124.5 (d, *J* = 9.5 Hz), 115.6 (d, *J* = 14.8 Hz), 99.9 (d, *J* = 187.6 Hz), 56.0 (d, *J* = 24.4 Hz), 23.7 (d, *J* = 4.4 Hz), 23.5 (d, *J* = 6.1 Hz).

^{19}F NMR (565 MHz, $CDCl_3$) δ -157.2 (d, *J* = 22.8 Hz).

HRMS (ESI): *m/z* for $C_{23}H_{21}FNaO^+$ $[M+Na]^+$ calcd.: 355.1469, found: 355.1466.

(*R*)-(1-(1-fluoro-1-(naphthalen-2-yl)allyl)cyclohexyl)(phenyl)methanone (S2)



The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.100 mmol scale. Reaction time: 36 h. Reaction temperature: RT. Catalyst loading: 4 mol%. The product was purified by preparative TLC (5/95 of acetone/hexanes) to provide allylic fluoride **S2** as a clear oil (26.9 mg, 0.0722 mmol, 72%).

The **enantiomeric ratio** was determined to be 69:31 by HPLC analysis with t_R = 6.6 min (major) and t_R = 8.8 min (minor) [OD-H, 1.0% *i*PrOH in hexanes, 0.7 mL/min, 230 nm, 25 °C].

$[\alpha]_D^{25}$ = +13.2° (c 0.38, $CHCl_3$). *Corrected for enantiopurity:* **$[\alpha]_D^{25}$** = +34.7° (c 0.38, $CHCl_3$).

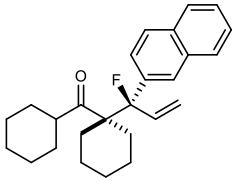
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.88 – 7.80 (m, 4H), 7.59 – 7.56 (m, 2H), 7.52 – 7.48 (m, 3H), 7.42 (t, *J* = 7.4 Hz, 1H), 7.32 (t, *J* = 7.7 Hz, 2H), 6.82 (ddd, *J* = 23.7, 17.0, 11.2 Hz, 1H), 5.44 (dd, *J* = 17.0, 1.3 Hz, 1H), 5.32 (ddd, *J* = 11.2, 3.2, 1.3 Hz, 1H), 2.68 – 2.57 (m, 2H), 1.57 – 1.36 (m, 5H), 1.05 – 0.87 (m, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 207.1, 141.6, 137.9 (d, *J* = 23.8 Hz), 136.5 (d, *J* = 18.7 Hz), 132.8, 132.7, 130.9, 128.6, 128.1 (d, *J* = 6.6 Hz), 128.0, 127.6, 127.4 (d, *J* = 1.9 Hz), 126.5, 126.4, 125.9 (d, *J* = 11.5 Hz), 124.7 (d, *J* = 9.8 Hz), 115.2 (d, *J* = 15.1 Hz), 100.5 (d, *J* = 187.8 Hz), 61.0 (d, *J* = 23.7 Hz), 31.2 (d, *J* = 3.8 Hz), 31.1 (d, *J* = 5.6 Hz), 25.4, 23.0, 23.0.

^{19}F NMR (565 MHz, $CDCl_3$) δ -156.3 – -156.9 (broadened d, *J* = 24.4 Hz)

HRMS (ESI): *m/z* for $C_{26}H_{25}FNaO^+$ $[M+Na]^+$ calcd.: 395.1782, found: 395.1777.

(*R*)-cyclohexyl(1-(1-fluoro-1-(naphthalen-2-yl)allyl)cyclohexyl)methanone (S3)



The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.100 mmol scale. Reaction time: 36 h. Reaction temperature: RT. Catalyst loading: 4 mol%. The product was purified by preparative TLC (5/95 of acetone/hexanes) to provide allylic fluoride **S3** as a clear oil (22.4 mg, 0.0592 mmol, 59%). For this nucleophile, the linear constitutional isomer of the product was observed (5:1 b:l ratio), which may form via an uncatalyzed background reaction. An additional purification by preparative TLC (benzene) provided product **S3** in high purity.

The **enantiomeric ratio** was determined to be 81:19 by HPLC analysis with t_R = 5.0 min (major) and t_R = 5.3 min (minor) [OD-H, 0.3% *i*PrOH in hexanes, 0.8 mL/min, 270 nm, 25 °C].

[α]$_D^{25}$ = +8.0° (c 0.43, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +12.9° (c 0.43, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.88 – 7.81 (m, 2H), 7.82 – 7.77 (m, 2H), 7.53 – 7.46 (m, 2H), 7.43 (dd, *J* = 8.6, 1.9 Hz, 1H), 6.58 (ddd, *J* = 22.2, 17.1, 11.2 Hz, 1H), 5.31 (dd, *J* = 17.1, 1.2 Hz, 1H), 5.26 (ddd, *J* = 11.2, 2.2, 1.2 Hz, 1H), 3.00 (tt, *J* = 11.2, 3.2 Hz, 1H), 2.60 – 2.52 (m, 1H), 2.44 – 2.36 (m, 1H), 1.93 (d, *J* = 11.3 Hz, 1H), 1.82 – 1.10 (m, 15H), 0.84 (qt, *J* = 12.8, 3.8 Hz, 1H).

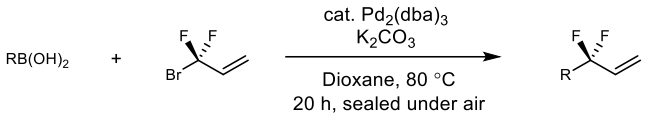
^{13}C NMR (151 MHz, $CDCl_3$) δ 217.0, 138.3 (d, *J* = 23.8 Hz), 137.0 (d, *J* = 18.2 Hz), 132.7, 132.6, 128.6, 127.6, 127.0 (d, *J* = 1.9 Hz), 126.5, 126.4, 126.2 (d, *J* = 11.6 Hz), 125.1 (d, *J* = 9.6 Hz), 115.9 (d, *J* = 13.3 Hz), 100.9 (d, *J* = 186.2 Hz), 61.0 (d, *J* = 22.2 Hz), 47.2 (d, *J* = 3.2 Hz), 30.7, 29.9 (d, *J* = 3.4 Hz), 29.7 (d, *J* = 5.9 Hz), 29.0 (d, *J* = 4.8 Hz), 26.1, 26.1, 26.1, 25.6, 23.7, 23.1.

^{19}F NMR (565 MHz, $CDCl_3$) δ -158.2 (d, *J* = 22.4 Hz).

HRMS (ESI): *m/z* for $C_{26}H_{31}FNaO^+$ $[M+Na]^+$ calcd.: 401.2251, found: 401.2251.

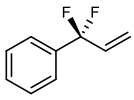
SYNTHESIS OF SUBSTRATES

Fluorinated allylic electrophiles **1a**–**1g**, and **1j** were prepared in one step from commercially-available arylboronic acids according to the following protocol reported by Zhang and coworkers:[5] Fluorinated allylic electrophile **1i** was prepared by a sequence involving radical deoxygenation that is discussed herein. Allylic electrophile **1h** was prepared according to a literature procedure.[6]



Allylic electrophiles **1a**, **1c**, **1d**, **1f**, and **1g** are known compounds. Allylic electrophiles **1b**, **1e**, and **1j** are new compounds; precise details of their synthesis are given below.

(1,1-difluoroallyl)benzene (1b)



The title compound was prepared according to the following procedure. The reaction was conducted under air. Phenylboronic acid (365.8 mg, 3.000 mmol, 1 equiv) and K_2CO_3 (1.244 g, 9.000 mmol, 3 equiv) were weighed directly into a 50 mL Schlenk flask with a single opening sealed with a Teflon plug and containing a magnetic stir bar. $Pd_2(dba)_3$ (11.0 mg, 12.0 µmol, 0.40 mol%) was added, followed by dry dioxane (15.0 mL) and distilled water (27.0 µL, 1.50 mmol, 0.50 equiv). Lastly, 3-bromo-3,3-difluoropropene (495 µL, 4.50 mmol, 1.50 equiv) was added. The Schlenk flask was sealed, and the reaction mixture was stirred vigorously and heated at 80 °C in an oil bath for 20 h. After this time, the reaction mixture was cooled to ambient temperature, diluted with THF, and filtered through a pad of magnesium sulfate. Due to the volatility of the product, the crude reaction mixture was carefully concentrated *in vacuo* at 0 °C. The product was then purified by silica gel column chromatography (0/100 to 10/90 of diethyl ether/pentane) to provide (1,1-difluoroallyl)benzene (**1b**) as a clear, colorless liquid (188.5 mg, 1.223 mmol, 41%). *Note:* It is important that the reaction vessel has little headspace and that the entire vessel is submerged in the heating bath.

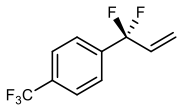
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.52 (ddt, *J* = 5.3, 3.1, 1.6 Hz, 2H), 7.44 (dd, *J* = 5.2, 2.0 Hz, 3H), 6.17 (ddt, *J* = 17.3, 11.0, 9.7 Hz, 1H), 5.58 (dt, *J* = 17.2, 2.8 Hz, 1H), 5.49 (d, *J* = 10.9 Hz, 1H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 136.4 (t, *J* = 27.4 Hz), 134.0 (t, *J* = 30.2 Hz), 130.1 (t, *J* = 1.8 Hz), 128.6, 125.6 (t, *J* = 5.7 Hz), 119.9 (t, *J* = 9.3 Hz), 119.5 (t, *J* = 238.3 Hz).

^{19}F NMR (565 MHz, $CDCl_3$) δ -94.6 (dd, *J* = 9.7, 2.8 Hz).

HRMS (EI): *m/z* for $C_9H_8F_2$ $[M]^+$ calcd.: 154.0594, found: 154.0593

1-(1,1-difluoroallyl)-4-(trifluoromethyl)benzene (1e)



The title compound was prepared according to the following procedure. The reaction was conducted under air. 4-(trifluoromethyl)phenylboronic acid (569.8 mg, 3.000 mmol, 1 equiv) and K_2CO_3 (1.244 g, 9.000 mmol, 3 equiv) were weighed directly into a 50 mL Schlenk flask with a single opening sealed with a Teflon plug and containing a magnetic stir bar. $Pd_2(dba)_3$ (11.0 mg, 12.0 µmol, 0.40 mol%) was added, followed by dry dioxane (15.0 mL) and distilled water (27.0 µL, 1.50 mmol, 0.50 equiv). Lastly, 3-bromo-3,3-difluoropropene (495 µL, 4.50 mmol, 1.50 equiv) was added. The Schlenk flask was sealed and the reaction mixture was stirred vigorously and heated at 80 °C in an oil bath for 20 h. After this time, the reaction mixture was cooled to ambient temperature, diluted with THF, and filtered through a pad of magnesium sulfate. Due to the volatility of the product, the crude reaction mixture was carefully concentrated *in vacuo* at 0 °C. The product was then purified by silica gel column chromatography (0/100 to 10/90 of diethyl ether/pentane) to provide difluoroallylarene **1e** as a clear, colorless liquid (261.5 mg, 1.177 mmol, 39%). *Note:* It is important that the reaction vessel has little headspace and that the entire vessel is submerged in the heating bath.

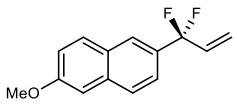
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.70 (d, *J* = 8.2 Hz, 2H), 7.64 (d, *J* = 8.1 Hz, 2H), 6.15 (ddt, *J* = 17.3, 10.9, 9.8 Hz, 1H), 5.59 (dt, *J* = 17.3, 2.8 Hz, 1H), 5.53 (d, *J* = 10.9 Hz, 1H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 140.1 (t, *J* = 27.8 Hz), 133.3 (t, *J* = 29.7 Hz), 132.3 (q, *J* = 32.7 Hz), 126.3 (t, *J* = 5.6 Hz), 125.7 (q, *J* = 3.8 Hz), 123.9 (q, *J* = 272.4 Hz), 120.7 (t, *J* = 9.3 Hz), 118.8 (t, *J* = 239.2 Hz).

^{19}F NMR (565 MHz, $CDCl_3$) δ -63.9, -95.4 (dd, *J* = 9.7, 2.5 Hz).

HRMS (EI): *m/z* for $C_{10}H_7F_5$ $[M]^+$ calcd.: 222.0468, found: 222.0464.

2-(1,1-difluoroallyl)-6-methoxynaphthalene (1j)



The title compound was prepared according to the following procedure. The reaction was conducted under air. (6-methoxynaphthalen-2-yl)boronic acid (2.020 g, 10.00 mmol, 1 equiv) and K_2CO_3 (4.150 g, 30.03 mmol, 3 equiv) were weighed directly into a 50 mL pressure tube

containing a large magnetic stir bar. $Pd_2(dba)_3$ (120.0 mg, 0.2087 mmol, 2.087 mol%) was added, followed by dry dioxane (45 mL) and distilled water (90.0 µL, 5.00 mmol, 0.50 equiv). Lastly, 3-bromo-3,3-difluoropropene (2.50 mL, 3.85 g, 24.1 mmol, 2.41 equiv) was added. The pressure tube was sealed, and the reaction mixture was stirred vigorously and heated at 80 °C in an oil bath for 25 h. After this time, the reaction mixture was cooled to ambient temperature, diluted with THF, and filtered through a pad of magnesium sulfate. The crude reaction mixture was concentrated *in vacuo* and purified by silica gel column chromatography (0/100 to 5/95 of ethyl acetate/hexanes) to provide difluoroallylarene **1j** as a white powder (716.5 mg, 3.059 mmol, 31%). *Note:* It is important that the reaction vessel has little headspace and that the entire vessel is submerged in the heating bath.

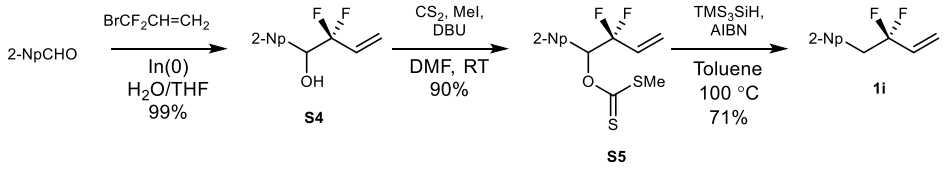
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.94 (s, 1H), 7.80 – 7.77 (m, 2H), 7.53 (dd, *J* = 8.6, 1.8 Hz, 1H), 7.20 (dd, *J* = 8.9, 2.5 Hz, 1H), 7.16 (d, *J* = 2.5 Hz, 1H), 6.24 (ddt, *J* = 17.3, 10.9, 9.7 Hz, 1H), 5.62 (dt, *J* = 17.3, 2.7 Hz, 1H), 5.52 (d, *J* = 10.9 Hz, 1H), 3.94 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 158.8, 135.3, 134.1 (t, *J* = 30.3 Hz), 131.4 (t, *J* = 27.6 Hz), 130.2, 128.1, 127.3, 125.2 (t, *J* = 6.4 Hz), 123.4 (t, *J* = 4.9 Hz), 120.0 (t, *J* = 9.1 Hz), 119.8 (t, *J* = 238.1 Hz), 119.7, 105.8, 55.5.

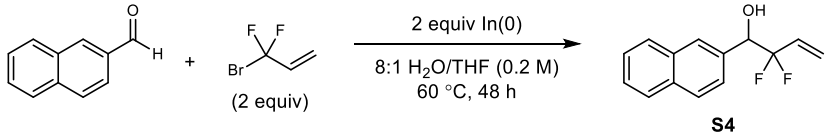
^{19}F NMR (565 MHz, $CDCl_3$) δ -92.6 (d, *J* = 9.8 Hz).

HRMS (EI): *m/z* for $C_{14}H_{12}F_2O$ $[M]^+$ calcd.: 234.0856, found: 234.0857.

Allylic electrophile **1i** was prepared according to the following sequence:



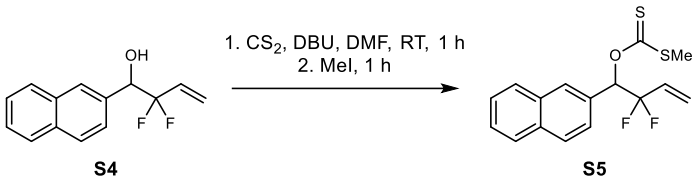
2,2-difluoro-1-(naphthalen-2-yl)but-3-en-1-ol (S4)



The following procedure was adapted from the literature.[16] A 100 mL Schlenk flask with a single opening sealed with a Teflon plug was charged with indium(0) powder (1.837 g, 16.00 mmol) and a magnetic stir bar. The flask was evacuated and refilled with nitrogen three times, and degassed water (40 mL) was added. 3-Bromo-3,3-difluoropropene (2.51 g, 1.63 mL, 16.0 mmol) was added, followed immediately by a solution of 2-naphthaldehyde (1.249 g, 8.000 mmol) in dry, degassed

tetrahydrofuran (4.8 mL). The Teflon plug was sealed, and the flask was heated at 60 °C for 48 h with vigorous stirring. After this time, the reaction mixture was diluted with 1 M HCl (40 mL) and extracted with diethyl ether (3 x 50 mL). The combined organic layers were washed with brine (1 x 20 mL), dried over sodium sulfate, and concentrated *in vacuo*. The resulting residue was purified by column chromatography (0/100 to 30/70 ethyl acetate/hexanes) to provide homoallylic alcohol **S4** as a clear liquid (1.850 g, 7.899 mmol, 99%). All NMR data matched with the literature.[17]

***O*-(2,2-difluoro-1-(naphthalen-2-yl)but-3-en-1-yl) *S*-methyl carbonodithioate (S5)**



S4 **S5**

2,2-difluoro-1-(naphthalen-2-yl)but-3-en-1-ol (**S4**) (1.172 g, 5.003 mmol, 1 equiv) was weighed directly into a dry 100 mL round-bottomed flask. The flask was sealed with a septum and the headspace was replaced with nitrogen. Then, dry DMF (15 mL) was added, followed by DBU (3.00 mL, 20.1 mmol, 4 equiv) and carbon disulfide (3.01 mL, 50.0 mmol, 10 equiv). The resulting solution was stirred at room temperature for one hour. Then, methyl iodide (3.11 mL, 50.0 mmol, 10 equiv) was added, and the resulting solution was stirred at room temperature for one hour. After this time, the reaction was concentrated *in vacuo*, diluted with water (100 mL), and extracted with hexanes (4 x 50 mL). The combined organic layers were washed with water (4 x 50 mL) and brine (30 mL). The organic layer was dried over sodium sulfate and concentrated *in vacuo*. The product was purified by silica gel column chromatography (0/100 to 5/95 of ethyl acetate/hexanes) to provide xanthate **S5** as a white solid (1.4681 g, 4.526 mmol, 90%).

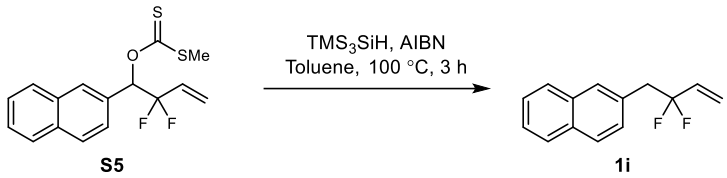
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.90 – 7.82 (m, 4H), 7.54 – 7.49 (m, 3H), 6.89 (dd, J = 11.2, 9.7 Hz, 1H), 5.95 (ddt, J = 17.3, 12.3, 10.9 Hz, 1H), 5.71 (dt, J = 17.4, 2.4 Hz, 1H), 5.54 (d, J = 11.0 Hz, 1H), 2.60 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 214.4, 133.7, 132.9, 129.9, 129.7 (t, *J* = 25.7 Hz), 128.7, 128.4, 128.3, 127.9, 126.9, 126.6, 125.6, 122.4 (t, *J* = 9.2 Hz), 118.2 (dd, *J* = 246.5, 245.1 Hz), 83.0 (t, *J* = 31.5 Hz), 19.5.

^{19}F NMR (565 MHz, $CDCl_3$) δ -104.9 (dt, *J* = 251.2, 10.3 Hz), -108.2 (dt, *J* = 251.3, 12.0 Hz).

HRMS (EI): *m/z* for $C_{16}H_{14}F_2OS_2$ $[M]^+$ calcd.: 324.0454, found: 324.0451.

2-(2,2-difluorobut-3-en-1-yl)naphthalene (1i)



In a nitrogen-filled glove box, a 20 mL vial was charged with xanthate **S5** (600.0 mg, 1.850 mmol, 1 equiv) and AIBN (60.7 mg, 0.370 mmol, 0.200 equiv). Then, dry, degassed toluene (9.25 mL) was added, followed by tris(trimethylsilyl)silane (852 µL, 2.76 mmol, 1.50 equiv). The vial was equipped with a magnetic stir bar, sealed, and the reaction mixture was stirred and heated at 100 °C for 3 hours (*Note:* longer reaction times result in lower isolated yields). After this time, the reaction was cooled to room temperature, diluted with water, and extracted with diethyl ether. The combined organic layers were dried over sodium sulfate and concentrated *in vacuo*. The product was purified by silica gel column chromatography (isocratic, hexanes) to provide *gem*-difluoroalkyl alkene **1i** as a white solid (288.4 mg, 1.321 mmol, 71%).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.87 – 7.80 (m, 3H), 7.74 (d, *J* = 1.7 Hz, 1H), 7.53 – 7.47 (m, 2H), 7.41 (dd, *J* = 8.3, 1.6 Hz, 1H), 5.91 (dq, *J* = 17.4, 11.2 Hz, 1H), 5.60 (dtd, *J* = 17.4, 2.5, 0.8 Hz, 1H), 5.39 (dd, *J* = 11.0, 0.8 Hz, 1H), 3.40 (t, *J* = 15.6 Hz, 2H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 133.4, 132.7, 132.6 (t, *J* = 26.9 Hz), 130.4 (t, *J* = 4.4 Hz), 129.6, 128.6, 128.0, 127.9, 127.8, 126.3, 126.1, 120.4 (t, *J* = 240.6 Hz), 119.7 (t, *J* = 9.2 Hz), 44.3 (t, *J* = 27.5 Hz).

^{19}F NMR (565 MHz, $CDCl_3$) δ -96.3 (q, *J* = 14.7 Hz).

HRMS (EI): *m/z* for $C_{14}H_{12}F_2$ $[M]^+$ calcd.: 218.0907, found: 218.0906.

SYNTHESIS OF NEW LIGANDS AND CATALYSTS

1.) Ligands

Ligands **L1**–**L4**[4] **and L10**[18] and their corresponding amine precursors (**Amine 1-4** and **Amine 10**) were prepared according to the literature. The synthesis and characterization of new ligands **L5–L9** and **L11–L22** are discussed below. A general scheme for their synthesis is provided below (figure S15). The required chiral amines, ketones, and benzylic bromides were obtained from commercial sources. The required aldehydes were obtained from commercial sources or prepared according to literature procedures cited herein.

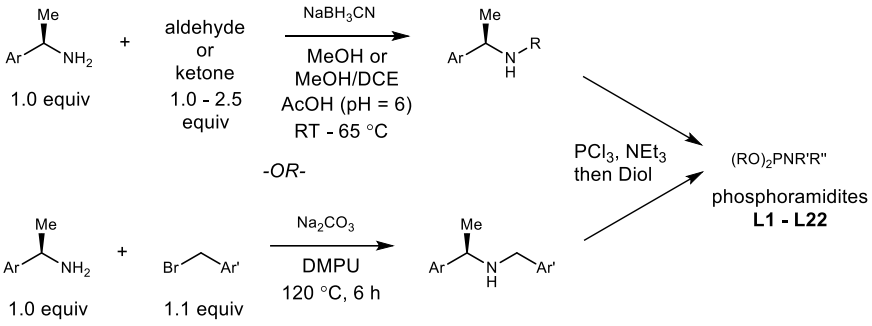


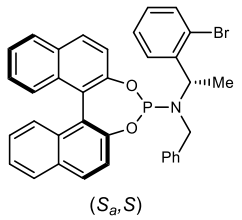
Figure S15. Synthesis of phosphoramidite ligands.

Synthesis of **L5–L9** and **L11–L22**:

Ligands **L5–L9** and **L11–L22** were prepared according to the following general procedure.

In a nitrogen-filled dry box, a 4 mL or 20 mL vial was charged with chiral amine (**Amine)** (1.0 equiv), triethylamine (5.0 equiv), and dichloromethane (0.5 M in chiral amine). The resulting solution was cooled to –40 °C. Then, phosphorus trichloride (1.0 equiv) was added dropwise with stirring at –40 °C, and the resulting suspension was allowed to warm to room temperature and stir for 6 hours. After this time, the reaction mixture was again cooled to –40 °C, and the corresponding diol was added as a solid in one portion. The resulting suspension was stirred at room temperature for 16 h. After this time, the reaction was removed from the glovebox, transferred to a separatory funnel with dichloromethane (20 mL) and quenched with water (20 mL). The product was extracted with dichloromethane (3 x 20 mL), and the combined organic layers were dried over sodium sulfate. Column chromatography on silica afforded the pure ligands.

***ent*-L5**



(S_a,*S*)

***ent*-L5** was prepared from 0.316 mmol of ***ent*-amine 5** according to the general procedure. The product was then purified by silica gel column chromatography (0/100 to 15/85 of ethyl acetate/hexanes) to provide ligand ***ent*-L5** as a white powder (167.4 mg, 0.2769 mmol, 88%).

[α]D25 = +281° (c 0.30, $CHCl_3$).

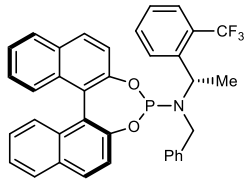
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.11 (d, *J* = 7.3 Hz, 1H), 8.04 (d, *J* = 8.8 Hz, 1H), 7.95 (d, *J* = 8.1 Hz, 1H), 7.85 – 7.82 (m, 2H), 7.69 (d, *J* = 8.7 Hz, 1H), 7.60 – 7.56 (m, 2H), 7.44 (ddd, *J* = 8.0, 6.7, 1.2 Hz, 1H), 7.38 – 7.34 (m, 3H), 7.31 – 7.13 (m, 9H), 4.64 (dq, *J* = 14.1, 7.2 Hz, 1H), 4.07 (d, *J* = 14.9 Hz, 1H), 3.02 (d, *J* = 14.9 Hz, 1H), 1.66 (dd, *J* = 7.2, 4.3 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 150.3 (d, *J* = 5.0 Hz), 149.7, 143.1, 138.2, 133.2, 133.0, 132.7, 131.6, 130.7, 130.5, 130.4, 129.0, 128.9, 128.6 (d, *J* = 3.1 Hz), 128.5, 128.3, 128.2, 128.1, 127.2, 127.1, 127.1, 126.2, 126.2, 125.0, 124.7, 124.3 (d, *J* = 5.4 Hz), 124.0, 122.6, 122.5, 121.7, 56.9 (d, *J* = 25.4 Hz), 49.0 (d, *J* = 4.5 Hz), 22.8 (d, *J* = 32.7 Hz).

^{31}P NMR (243 MHz, $CDCl_3$) δ 141.8.

HRMS (ESI): *m/z* for $C_{35}H_{28}{}^{81}BrNO_2P^+$ $[M+H]^+$ calcd.: 606.1015, found: 606.1013.

***ent*-L6**



(S_a,*S*)

***ent*-L6** was prepared from 0.179 mmol of ***ent*-amine 6** according to the general procedure. The product was then purified by silica gel column chromatography (0/100 to 15/85 of ethyl acetate/hexanes) to provide ligand ***ent*-L6** as a white powder (100.0 mg, 0.1685 mmol, 94%).

[α]D25 = +223° (c 0.64, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.45 (d, *J* = 7.9 Hz, 1H), 8.04 (d, *J* = 8.7 Hz, 1H), 7.96 (d, *J* = 8.2 Hz, 1H), 7.88 (t, *J* = 7.6 Hz, 1H), 7.84 (d, *J* = 8.2 Hz, 1H), 7.81 (d, *J* = 8.9 Hz, 1H), 7.69 (d, *J* = 8.4 Hz, 2H), 7.51 (t, *J* = 7.6 Hz, 1H), 7.45 (ddd, *J* = 8.2, 6.6, 1.3 Hz, 1H), 7.39 – 7.33 (m, 3H), 7.27 (ddd, *J* = 8.5, 6.7, 1.4 Hz, 1H), 7.25 – 7.20 (m, 4H), 7.19 – 7.13 (m, 3H), 4.64 (dq, *J* = 14.1, 7.2 Hz, 1H), 4.07 (d, *J* = 15.7 Hz, 1H), 3.00 (d, *J* = 15.7 Hz, 1H), 1.75 (dd, *J* = 7.1, 4.6 Hz, 3H).

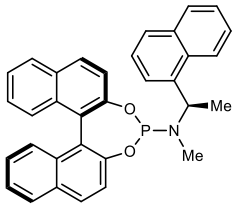
^{13}C NMR (151 MHz, $CDCl_3$) δ 150.1 (d, *J* = 4.8 Hz), 149.6 144.0, 138.1, 133.0, 132.7, 132.6, 131.6, 130.7, 130.5, 130.4, 129.0 (d, *J* = 4.4 Hz), 128.5, 128.3, 128.2, 127.9, 127.5, 127.2, 127.2, 127.0, 126.3, 126.2, 125.9 (q, *J* = 5.7 Hz), 125.0, 124.8, 124.2 (d, *J* = 5.3 Hz), 124.2 (q, *J* = 274.5 Hz), 122.6, 122.5, 121.5, 54.4 (d, *J* = 24.5 Hz), 49.3 (d, *J* = 4.5 Hz), 24.9 (d, *J* = 35.2 Hz).

^{19}F NMR (565 MHz, $CDCl_3$) δ -59.2.

^{31}P NMR (243 MHz, $CDCl_3$) δ 142.0.

HRMS (ESI): *m/z* for $C_{36}H_{27}F_3KNO_2P$+ $[M+K]^+$ calcd.: 632.1363, found: 632.1357.

L7



(R_a,*R*)

L7 was prepared from 0.810 mmol of **amine 7** according to the general procedure. The product was then purified by silica gel column chromatography (1/99 to 10/90 of ethyl acetate/hexanes) to provide ligand **L7** as a white powder (74.6 mg, 0.149 mmol, 18%).

[α]$_D^{25}$ = –437° (c 0.12, $CHCl_3$).

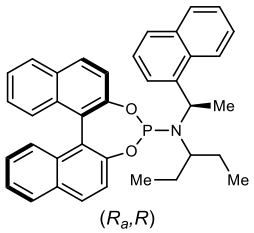
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.32 (dd, *J* = 8.7, 2.7 Hz, 1H), 7.98 (d, *J* = 8.7 Hz, 1H), 7.93 (d, *J* = 8.2 Hz, 1H), 7.91 – 7.86 (m, 3H), 7.81 (d, *J* = 8.1 Hz, 1H), 7.68 – 7.63 (m, 1H), 7.62 (d, *J* = 7.2 Hz, 1H), 7.54 (dd, *J* = 12.6, 8.1 Hz, 2H), 7.51 – 7.32 (m, 6H), 7.28 – 7.21 (m, 2H), 5.62 (dq, *J* = 13.7, 6.8 Hz, 1H), 1.95 – 1.91 (m, 6H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 150.2 (d, *J* = 5.1 Hz), 149.4, 136.5 (d, *J* = 10.8 Hz), 134.1, 132.8, 132.6, 131.6, 131.3, 130.6, 130.2, 130.0, 128.9, 128.3, 128.1, 127.0, 126.9, 126.2, 126.0, 126.0, 125.6, 124.7, 124.7, 124.5, 124.5, 124.5, 123.9 (d, *J* = 5.0 Hz), 123.6 (d, *J* = 9.9 Hz), 122.6 (d, *J* = 2.0 Hz), 122.0, 121.8, 52.7 (d, *J* = 45.0 Hz), 27.3 (d, *J* = 5.8 Hz), 19.8 (d, *J* = 8.0 Hz).

^{31}P NMR (243 MHz, $CDCl_3$) δ 149.5.

HRMS (ESI): *m/z* for $C_{33}H_{27}NO_2P^+$ $[M+H]^+$ calcd.: 500.1774, found: 500.1752.

L8



(R_a,*R*)

L8 was prepared from 1.315 mmol of **amine 8** according to the general procedure. The product was then purified by silica gel column chromatography (1/99 to 15/85 of ethyl acetate/hexanes) to provide ligand **L8** as a white powder (565.4 mg, 1.018 mmol, 77%).

[α]D^{25} = –166° (c 0.43, $CHCl_3$).

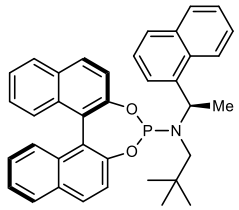
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.39 (d, *J* = 7.2 Hz, 1H), 8.11 (d, *J* = 8.4 Hz, 1H), 8.02 (d, *J* = 8.7 Hz, 1H), 7.97 – 7.93 (m, 2H), 7.86 (d, *J* = 8.2 Hz, 1H), 7.84 (d, *J* = 8.2 Hz, 1H), 7.78 (d, *J* = 8.8 Hz, 1H), 7.69 (t, *J* = 7.7 Hz, 1H), 7.60 (d, *J* = 8.7 Hz, 1H), 7.57 (ddd, *J* = 8.4, 6.7, 1.5 Hz, 1H), 7.53 (ddd, *J* = 7.9, 6.8, 1.1 Hz, 1H), 7.46 – 7.35 (m, 5H), 7.29 – 7.25 (m, 2H), 5.34 (dq, *J* = 14.9, 7.3 Hz, 1H), 3.05 – 2.98 (m, 1H), 1.90 (dd, *J* = 7.4, 3.0 Hz, 3H), 1.55 – 1.37 (m, 2H), 1.18 (dddd, *J* = 15.4, 10.7, 7.6, 2.9 Hz, 1H), 0.96 (t, *J* = 7.4 Hz, 3H), 0.78 (ddt, *J* = 17.9, 14.0, 7.2 Hz, 1H), 0.15 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 150.4 (d, *J* = 7.4 Hz), 149.9, 143.4, 134.1, 133.0, 132.8, 131.5, 130.5, 130.4, 130.1, 129.6, 129.3, 128.4, 128.3, 127.3, 127.3, 127.2, 126.3, 126.1, 126.0, 125.8, 125.5, 124.8, 124.4, 124.2, 124.2 (d, *J* = 7.0 Hz), 122.6 (d, *J* = 1.6 Hz), 122.3, 122.1, 122.0 (d, *J* = 2.4 Hz), 58.4 (d, *J* = 3.6 Hz), 49.8 (d, *J* = 23.9 Hz), 29.1, 25.8 (d, *J* = 31.8 Hz), 24.0, 11.6, 11.5.

^{31}P NMR (243 MHz, $CDCl_3$) δ 147.0.

HRMS (ESI): *m/z* for $C_{37}H_{35}NO_2P^+$ $[M+H]^+$ calcd.: 556.2400, found: 556.2383.

L9



(R_a,*R*)

L9 was prepared from 1.363 mmol of **amine 9** according to the general procedure. The product was then purified by silica gel column chromatography (1/99 to 10/90 of ethyl acetate/hexanes) to provide ligand **L9** as a white powder (619.2 mg, 1.114 mmol, 82%).

[α]D^{25} = –181° (c 0.29, $CHCl_3$).

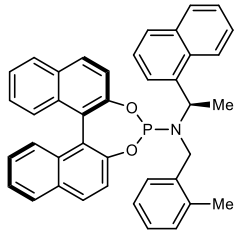
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.28 (dd, *J* = 7.2, 1.2 Hz, 1H), 8.13 – 8.06 (m, 1H), 8.01 (d, *J* = 8.8 Hz, 1H), 7.97 (dd, *J* = 7.5, 1.9 Hz, 1H), 7.93 (d, *J* = 8.1 Hz, 1H), 7.89 (d, *J* = 8.1 Hz, 1H), 7.81 (d, *J* = 8.0 Hz, 1H), 7.72 (t, *J* = 7.7 Hz, 1H), 7.69 (d, *J* = 8.8 Hz, 1H), 7.61 (d, *J* = 8.7 Hz, 1H), 7.59 – 7.52 (m, 2H), 7.42 (ddd, *J* = 8.0, 6.6, 1.2 Hz, 1H), 7.39 – 7.31 (m, 3H), 7.26 – 7.21 (m, 2H), 7.02 (d, *J* = 8.8 Hz, 1H), 5.54 (dq, *J* = 14.6, 7.2 Hz, 1H), 2.60 (dd, *J* = 14.8, 5.1 Hz, 1H), 2.24 (dd, *J* = 14.8, 4.4 Hz, 1H), 1.90 (dd, *J* = 7.3, 3.0 Hz, 3H), 0.70 (s, 9H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 151.0 (d, *J* = 5.9 Hz), 149.5, 140.3 (d, *J* = 1.5 Hz), 133.9, 132.8, 132.6, 131.5, 131.3, 130.3, 130.2, 129.7, 129.1, 128.2, 128.0, 127.8, 127.1, 126.7, 126.1, 126.0, 125.8, 125.6, 125.4, 124.7, 124.3 (d, *J* = 4.2 Hz), 124.3, 124.2 (d, *J* = 5.4 Hz), 122.6, 122.2 (d, *J* = 1.9 Hz), 121.9 (2C), 56.8, 55.0 (d, *J* = 21.6 Hz), 32.1, 29.3, 23.5 (d, *J* = 29.0 Hz).

^{31}P NMR (243 MHz, $CDCl_3$) δ 149.2.

HRMS (ESI): *m/z* for $C_{37}H_{35}NO_2P^+$ $[M+H]^+$ calcd.: 556.2400, found: 556.2422.

L11



(R_a,*R*)

L11 was prepared from 0.472 mmol of **amine 11** according to the general procedure. The product was then purified by silica gel column chromatography (0/99 to 8/92 of ethyl acetate/hexanes) to provide ligand **L11** as a white powder (206.5 mg, 0.3502 mmol, 74%).

[α]$_D^{25}$ = –236° (c 0.27, $CHCl_3$).

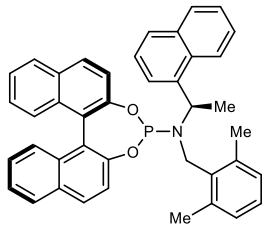
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.22 (d, *J* = 7.2 Hz, 1H), 8.02 (d, *J* = 8.8 Hz, 1H), 7.94 (d, *J* = 8.2 Hz, 1H), 7.92 (d, *J* = 8.3, 1.3 Hz, 1H), 7.87 (d, *J* = 8.1 Hz, 1H), 7.80 (d, *J* = 8.1 Hz, 1H), 7.75 (d, *J* = 8.9 Hz, 1H), 7.71 (t, *J* = 7.6 Hz, 1H), 7.68 (d, *J* = 8.7 Hz, 1H), 7.66 (d, *J* = 8.7 Hz, 1H), 7.49 (ddd, *J* = 8.0, 6.7, 1.0 Hz, 1H), 7.43 (ddd, *J* = 8.0, 6.6, 1.1 Hz, 1H), 7.41 – 7.32 (m, 5H), 7.28 – 7.25 (m, 1H), 7.23 (d, *J* = 8.9 Hz, 1H), 7.21 (ddd, *J* = 8.2, 6.7, 1.3 Hz, 1H), 7.08 (t, *J* = 7.4 Hz, 1H), 7.02 (t, *J* = 7.2 Hz, 1H), 6.85 (d, *J* = 7.4 Hz, 1H), 5.18 (dq, *J* = 14.2, 7.2 Hz, 1H), 3.87 (d, *J* = 16.0 Hz, 1H), 3.30 (dd, *J* = 16.0, 1.6 Hz, 1H), 1.93 (dd, *J* = 7.2, 3.7 Hz, 3H), 1.44 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 150.3 (d, *J* = 5.0 Hz), 149.5, 139.8 (d, *J* = 1.7 Hz), 136.1, 135.8, 133.8, 132.8 (d, *J* = 1.4 Hz), 132.5, 131.5, 131.4, 130.5, 130.2, 129.9, 129.7, 128.9, 128.3, 128.0, 127.9, 127.2, 127.0, 127.0, 126.3, 126.0 (3C), 125.7, 125.6, 125.5, 124.7, 124.5, 124.1 (d, *J* = 2.3 Hz), 124.1 (d, *J* = 5.1 Hz), 122.5 (d, *J* = 2.1 Hz), 122.3 (2C) 121.6, 52.6 (d, *J* = 26.0 Hz), 45.4 (d, *J* = 4.1 Hz), 23.2 (d, *J* = 30.3 Hz), 18.5.

^{31}P NMR (243 MHz, $CDCl_3$) δ 145.2.

HRMS (ESI): *m/z* for $C_{40}H_{33}NO_2P^+$ $[M+H]^+$ calcd.: 590.2243, found: 590.2244.

L12



(R_a,*R*)

L12 was prepared from 0.3455 mmol of **amine 12** according to the general procedure. The product was then purified by silica gel column chromatography (0/99 to 8/92 of ethyl acetate/hexanes) to provide ligand **L12** as a white powder (195.4 mg, 0.3237 mmol, 94%).

[α]$_D^{25}$ = –112° (c 0.38, $CHCl_3$).

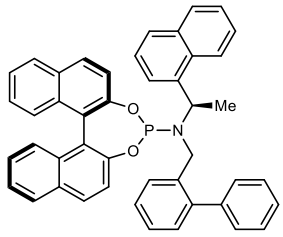
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.36 (d, *J* = 7.0 Hz, 1H), 8.04 (d, *J* = 8.7 Hz, 1H), 7.96 (d, *J* = 8.1 Hz, 1H), 7.87 (d, *J* = 8.1 Hz, 2H), 7.84 (d, *J* = 8.8 Hz, 1H), 7.83 (d, *J* = 8.0 Hz, 1H), 7.79 (dd, *J* = 8.1, 7.1 Hz, 1H), 7.65 (d, *J* = 8.7 Hz, 1H), 7.62 (d, *J* = 8.9 Hz, 1H), 7.48 – 7.33 (m, 5H), 7.31 – 7.22 (m, 2H), 7.20 (ddd, *J* = 8.1, 6.6, 1.3 Hz, 1H), 7.15 (d, *J* = 8.6 Hz, 1H), 6.90 (t, *J* = 7.4 Hz, 1H), 6.67 (d, *J* = 7.5 Hz, 2H), 4.91 (dq, *J* = 14.4, 7.3 Hz, 1H), 4.30 (d, *J* = 14.1 Hz, 1H), 3.59 (dd, *J* = 14.1, 1.7 Hz, 1H), 1.79 (dd, *J* = 7.3, 5.0 Hz, 3H), 1.67 (s, 6H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 151.4 (d, *J* = 6.1 Hz), 149.8, 140.8, 138.6, 134.0, 133.0, 132.7, 132.2, 131.6, 131.0, 130.7, 130.5, 130.0, 128.7, 128.5, 128.5, 128.3, 127.8, 127.2, 127.2, 126.3, 126.2, 125.9, 125.7, 125.6, 124.9, 124.7, 124.3 (d, *J* = 5.3 Hz), 124.0 (d, *J* = 2.5 Hz), 122.6 (d, *J* = 1.7 Hz), 122.4, 122.4, 122.2, 121.9, 52.0 (d, *J* = 22.7 Hz), 43.2 (d, *J* = 2.9 Hz), 24.6 (d, *J* = 36.9 Hz), 19.6.

^{31}P NMR (243 MHz, $CDCl_3$) δ 147.7.

HRMS (ESI): *m/z* for $C_{41}H_{34}KNO_2P^+$ $[M+K]^+$ calcd.: 642.1959, found: 642.1989.

L13



(R_a,R)

L13 was prepared from 0.2208 mmol of **amine 13** according to the general procedure. The product was then purified by silica gel column chromatography (0/99 to 10/90 of ethyl acetate/hexanes) to provide ligand **L13** as a white powder (99.7 mg, 0.1530 mmol, 69%).

[α]$_D^{25}$ = –173° (c 0.12, $CHCl_3$).

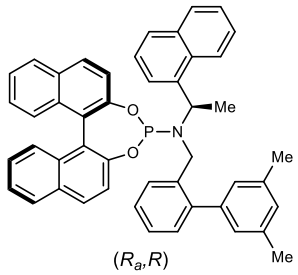
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.01 (d, *J* = 8.7 Hz, 1H), 7.94 (d, *J* = 8.2 Hz, 1H), 7.91 (d, *J* = 8.3 Hz, 1H), 7.81 (d, *J* = 8.0 Hz, 1H), 7.74 (d, *J* = 7.1 Hz, 1H), 7.70 – 7.63 (m, 4H), 7.47 (ddd, *J* = 8.0, 6.7, 1.0 Hz, 1H), 7.45 – 7.33 (m, 7H), 7.29 – 7.20 (m, 2H), 7.17 – 7.11 (m, 1H), 7.07 (td, *J* = 7.5, 1.7 Hz, 1H), 7.04 (td, *J* = 7.3, 1.6 Hz, 1H), 7.02 – 6.95 (m, 3H), 6.85 (dd, *J* = 7.3, 1.6 Hz, 1H), 6.22 (d, *J* = 7.4 Hz, 2H), 5.20 (dq, *J* = 14.0, 7.1 Hz, 1H), 3.88 (d, *J* = 16.4 Hz, 1H), 3.21 (dd, *J* = 16.5, 1.4 Hz, 1H), 1.83 (dd, *J* = 7.1, 2.7 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 150.4 (d, *J* = 4.6 Hz), 149.8, 141.1, 140.1, 138.9 (d, *J* = 4.8 Hz), 135.4, 133.9, 133.0, 132.6, 131.6, 131.6, 130.7, 130.4, 130.2, 129.3, 128.9, 128.9, 128.5, 128.2, 127.9, 127.5, 127.2, 127.2, 127.1, 127.0, 126.5, 126.2, 126.2, 126.1, 126.1, 125.4, 125.3, 124.9, 124.8, 124.2, 124.2, 122.7, 122.7 (d, *J* = 4.3 Hz), 122.5, 121.8, 52.0 (d, *J* = 30.0 Hz), 45.5 (d, *J* = 4.5 Hz), 22.6 (d, *J* = 24.2 Hz).

^{31}P NMR (243 MHz, $CDCl_3$) δ 146.7.

HRMS (ESI): *m/z* for $C_{45}H_{35}NO_2P^+$ $[M+H]^+$ calcd.: 652.2400, found: 652.2406.

L14



(R_a,R)

L14 was prepared from 0.2052 mmol of **amine 14** according to the general procedure. The product was then purified by silica gel column chromatography (0/99 to 10/90 of ethyl acetate/hexanes) to provide ligand **L14** as a white powder (118.6 mg, 0.1744 mmol, 85%).

[α]$_D^{25}$ = –139° (c 0.20, $CHCl_3$).

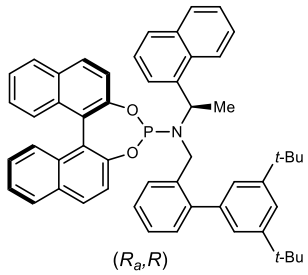
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.03 (d, *J* = 8.7 Hz, 1H), 7.94 (d, *J* = 8.2 Hz, 1H), 7.85 – 7.80 (m, 2H), 7.79 (d, *J* = 7.2 Hz, 1H), 7.71 – 7.66 (m, 3H), 7.64 (d, *J* = 8.6 Hz, 1H), 7.53 (d, *J* = 7.8 Hz, 1H), 7.50 – 7.32 (m, 7H), 7.28 – 7.19 (m, 2H), 7.12 (td, *J* = 7.6, 1.4 Hz, 1H), 7.09 – 7.02 (m, 2H), 6.84 (dd, *J* = 7.5, 1.4 Hz, 1H), 6.77 (s, 1H), 5.94 (s, 2H), 5.15 (dq, *J* = 14.0, 7.1 Hz, 1H), 3.89 (d, *J* = 16.1 Hz, 1H), 3.37 (d, *J* = 16.1 Hz, 1H), 2.08 (s, 6H), 1.78 (dd, *J* = 7.2, 3.0 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 150.3 (d, *J* = 5.0 Hz), 149.7, 141.9, 140.2, 139.2 (d, *J* = 4.3 Hz), 136.8, 135.4, 133.9, 133.0, 132.6, 131.6, 131.5, 130.5, 130.4, 129.9, 129.4, 129.0, 128.5, 128.3, 128.1, 127.8, 127.7, 127.2, 127.2, 127.0, 126.8, 126.2, 126.1, 126.1, 126.0, 125.4, 125.4, 124.9, 124.6, 124.3 (d, *J* = 5.4 Hz), 124.1 (d, *J* = 3.0 Hz), 122.8, 122.6 (d, *J* = 1.7 Hz), 122.5, 121.9, 52.2 (d, *J* = 29.6 Hz), 45.3 (d, *J* = 4.5 Hz), 22.9 (d, *J* = 26.2 Hz), 21.3.

^{31}P NMR (243 MHz, $CDCl_3$) δ 145.0.

HRMS (ESI): *m/z* for $C_{47}H_{38}KNO_2P^+$ $[M+K]^+$ calcd.: 718.2272, found: 718.2254.

L15 (Lγ)



L15 (Lγ) was prepared from 0.2704 mmol of **amine 15** according to the general procedure. The product was then purified by silica gel column chromatography (0/99 to 5/95 of ethyl acetate/hexanes) to provide ligand **L15 (Lγ)** as a white powder (149.4 mg, 0.1956 mmol, 72%).

[α]D^{25} = –126° (c 0.22, $CHCl_3$).

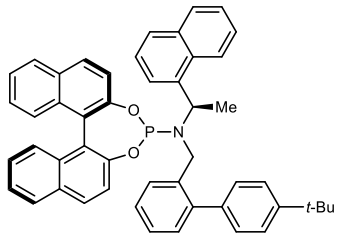
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.01 (d, *J* = 8.7 Hz, 1H), 7.93 (d, *J* = 8.1 Hz, 1H), 7.80 (d, *J* = 8.0 Hz, 1H), 7.77 (d, *J* = 8.2 Hz, 1H), 7.74 – 7.61 (m, 5H), 7.58 (dd, *J* = 5.6, 3.7 Hz, 1H), 7.46 (t, *J* = 7.4 Hz, 1H), 7.43 – 7.27 (m, 7H), 7.25 – 7.19 (m, 2H), 7.09 – 7.06 (m, 2H), 7.01 – 6.95 (m, 1H), 6.87 (d, *J* = 8.8 Hz, 1H), 6.63 (s, 2H), 5.15 (dq, *J* = 13.9, 7.0 Hz, 1H), 4.03 (dd, *J* = 16.2, 2.4 Hz, 1H), 3.74 (d, *J* = 15.9 Hz, 1H), 1.69 (d, *J* = 6.8 Hz, 3H), 1.17 (s, 18H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 150.2, 150.0 (d, *J* = 5.6 Hz), 149.7, 142.6, 140.0, 139.0 (d, *J* = 7.0 Hz), 135.9, 134.1, 133.0, 132.6, 131.6, 131.6, 130.5, 130.3, 130.2, 129.7, 129.1, 128.6, 128.4, 128.4, 128.0, 127.3, 127.2, 126.9, 126.2, 126.2, 126.1, 126.1, 125.5, 125.2, 124.9, 124.5, 124.4 (d, *J* = 5.4 Hz), 124.1 (d, *J* = 4.2 Hz), 123.6, 123.2 (d, *J* = 4.1 Hz), 122.5, 122.4 (d, *J* = 1.8 Hz), 121.6, 120.7, 52.6 (d, *J* = 32.4 Hz), 45.1 (d, *J* = 4.8 Hz), 34.8, 31.6, 22.3 (d, *J* = 17.5 Hz).

^{31}P NMR (243 MHz, $CDCl_3$) δ 145.3.

HRMS (ESI): *m/z* for $C_{53}H_{51}NO_2P^+$ $[M+H]^+$ calcd.: 764.3652, found: 764.3625.

L16



(R_a,R)

L16 was prepared from 0.4365 mmol of **amine 16** according to the general procedure. The product was then purified by silica gel column chromatography (0/100 to 5/95 of ethyl acetate/hexanes) to provide ligand **L16** as a white powder (280.5 mg, 0.3963 mmol, 91%).

[α]$_D^{25}$ = –68.0° (c 0.39, $CHCl_3$).

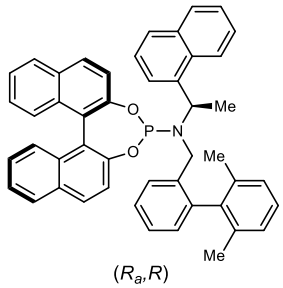
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.02 (d, *J* = 8.7 Hz, 1H), 7.94 (d, *J* = 8.0 Hz, 1H), 7.93 (d, *J* = 8.0 Hz, 1H), 7.83 (d, *J* = 8.1 Hz, 1H), 7.80 (d, *J* = 7.1 Hz, 1H), 7.70 – 7.60 (m, 4H), 7.52 – 7.40 (m, 5H), 7.40 – 7.31 (m, 3H), 7.29 – 7.22 (m, 2H), 7.13 (td, *J* = 7.6, 1.4 Hz, 1H), 7.08 (t, *J* = 7.0 Hz, 1H), 6.96 (d, *J* = 8.4 Hz, 2H), 6.94 (d, *J* = 8.9 Hz, 1H), 6.90 (dd, *J* = 7.5, 1.4 Hz, 1H), 6.14 (d, *J* = 8.2 Hz, 2H), 5.12 (dq, *J* = 14.0, 7.1 Hz, 1H), 3.92 (d, *J* = 16.3 Hz, 1H), 3.21 (d, *J* = 16.3 Hz, 1H), 1.84 (dd, *J* = 7.1, 2.8 Hz, 3H), 1.38 (s, 9H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 150.4 (d, *J* = 4.5 Hz), 149.8, 149.1, 141.3, 139.2 (d, *J* = 4.1 Hz), 137.0, 135.6, 133.9, 133.0, 132.7, 131.6, 131.6, 130.7, 130.4, 130.0, 129.3, 128.9, 128.6, 128.5, 128.1, 127.8, 127.3, 127.2, 127.1, 126.9, 126.2, 126.2, 126.2, 125.4, 125.2, 124.9, 124.8, 124.3, 124.2 (d, *J* = 5.0 Hz), 124.1 (d, *J* = 2.8 Hz), 122.8 (d, *J* = 1.7 Hz), 122.7 (d, *J* = 2.1 Hz), 122.5, 122.5, 121.9, 52.1 (d, *J* = 28.6 Hz), 45.7 (d, *J* = 4.4 Hz), 34.5, 31.6, 22.7 (d, *J* = 25.3 Hz).

^{31}P NMR (243 MHz, $CDCl_3$) δ 146.9.

HRMS (ESI): *m/z* for $C_{49}H_{43}NO_2P^+$ $[M+H]^+$ calcd.: 708.3026, found: 708.3015.

L17



(R_a,R)

L17 was prepared from 0.1231 mmol of **amine 17** according to the general procedure. The product was then purified by silica gel column chromatography (0/99 to 10/90 of ethyl acetate/hexanes) to provide ligand **L17** as a white powder (99.7 mg, 0.1056 mmol, 86%).

[α]D^{25} = –395° (c 0.055, $CHCl_3$).

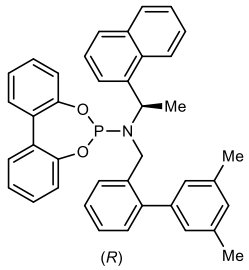
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.09 (d, *J* = 7.2 Hz, 1H), 7.99 (d, *J* = 8.8 Hz, 1H), 7.93 (d, *J* = 8.5 Hz, 1H), 7.92 – 7.89 (m, 2H), 7.86 (d, *J* = 8.5 Hz, 1H), 7.81 (d, *J* = 8.1 Hz, 1H), 7.61 (d, *J* = 8.8 Hz, 1H), 7.57 (t, *J* = 7.7 Hz, 1H), 7.53 – 7.39 (m, 6H), 7.35 (d, *J* = 8.6 Hz, 1H), 7.31 (d, *J* = 8.6 Hz, 1H), 7.25 (ddt, *J* = 10.6, 5.9, 1.7 Hz, 3H), 7.14 (t, *J* = 7.4 Hz, 1H), 7.02 (d, *J* = 8.8 Hz, 1H), 6.96 (t, *J* = 7.5 Hz, 1H), 6.70 (app t, *J* = 7.6 Hz, 2H), 6.47 (d, *J* = 7.5 Hz, 1H), 5.35 (dq, *J* = 14.1, 7.2 Hz, 1H), 3.60 (d, *J* = 17.4 Hz, 1H), 2.91 (d, *J* = 17.6 Hz, 1H), 1.96 (dd, *J* = 7.2, 3.2 Hz, 3H), 1.25 (s, 3H), 0.53 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 150.3 (d, *J* = 5.0 Hz), 149.7, 139.8 (d, *J* = 3.0 Hz), 139.4, 139.0, 136.1, 135.6, 134.5, 134.0, 132.9, 132.7, 131.5, 130.8, 130.4, 130.2, 129.1, 128.7, 128.7, 128.4, 128.0, 127.2, 127.1, 127.0, 126.9, 126.8, 126.6, 126.5, 126.3, 126.1 (3C), 125.6 (2C), 124.9, 124.5, 124.2 (d, *J* = 5.1 Hz), 123.8, 122.6, 122.5, 122.1, 122.1, 121.5, 53.7 (d, *J* = 27.0 Hz), 46.7 (d, *J* = 4.5 Hz), 23.4 (d, *J* = 27.4 Hz), 19.6, 18.7.

^{31}P NMR (243 MHz, $CDCl_3$) δ 146.7.

HRMS (ESI): *m/z* for $C_{47}H_{38}KNO_2P^+$ $[M+K]^+$ calcd.: 718.2272, found: 718.2264.

L18



L18 was prepared from 0.5000 mmol of **amine 14** and 2,2'-biphenol according to the general procedure. The product was then purified by silica gel column chromatography (2/98 to 8/92 of ethyl acetate/hexanes) to provide ligand **L18** as a white powder (258.7 mg, 0.4463 mmol, 89%).

$[\alpha]_D^{25}$ = –74.1° (c 0.38, $CHCl_3$).

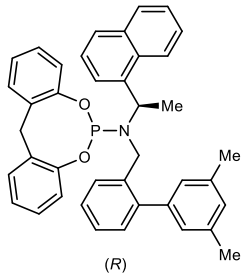
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.83 (d, *J* = 8.1 Hz, 1H), 7.73 – 7.66 (m, 3H), 7.65 (d, *J* = 7.8 Hz, 1H), 7.49 – 7.41 (m, 3H), 7.43 – 7.37 (m, 2H), 7.30 (tt, *J* = 7.8, 1.7 Hz, 1H), 7.27 – 7.17 (m, 4H), 7.16 (t, *J* = 7.4 Hz, 1H), 7.09 (d, *J* = 8.0 Hz, 1H), 7.01 (d, *J* = 7.8 Hz, 1H), 6.98 (d, *J* = 7.5 Hz, 1H), 6.77 (s, 1H), 6.17 (s, 2H), 5.21 (dq, *J* = 13.3, 7.0 Hz, 1H), 4.14 (d, *J* = 16.4 Hz, 1H), 3.57 (d, *J* = 16.3 Hz, 1H), 2.11 (s, 6H), 1.74 (dt, *J* = 7.2, 2.3 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 152.0 (d, *J* = 5.5 Hz), 151.5 (d, *J* = 4.1 Hz), 142.0, 140.4, 138.8 (d, *J* = 4.1 Hz), 137.0, 135.8, 133.9, 131.5, 131.3 (d, *J* = 3.3 Hz), 131.0 (d, *J* = 2.7 Hz), 129.8, 129.8, 129.5, 129.3, 129.2, 128.9, 128.3, 128.0, 127.8, 127.1, 126.8, 126.2, 126.0, 125.4, 125.3, 124.7, 124.3, 124.2 (d, *J* = 3.0 Hz), 123.0 (d, *J* = 2.6 Hz), 122.3, 122.0, 52.3 (d, *J* = 29.5 Hz), 45.1 (d, *J* = 3.6 Hz), 22.5 (d, *J* = 23.8 Hz), 21.3.

^{31}P NMR (243 MHz, $CDCl_3$) δ 146.2.

HRMS (ESI): *m/z* for $C_{39}H_{35}NO_2P^+$ $[M+H]^+$ calcd.: 580.2400, found: 580.2416.

L19



L19 was prepared from 0.5000 mmol of **amine 14** and 2,2'-methylenebisphenol according to the general procedure. The product was then purified by silica gel column chromatography (2/98 to 8/92 of ethyl acetate/hexanes) to provide ligand **L19** as a white powder (239.5 mg, 0.4034 mmol, 81%).

$[\alpha]_D^{25}$ = –119° (c 0.37, $CHCl_3$).

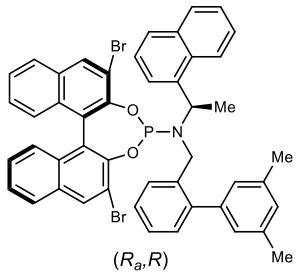
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.97 (d, *J* = 7.8 Hz, 1H), 7.89 – 7.84 (m, 2H), 7.77 (d, *J* = 7.2 Hz, 1H), 7.72 (d, *J* = 8.1 Hz, 1H), 7.49 (t, *J* = 7.4 Hz, 1H), 7.47 – 7.40 (m, 2H), 7.38 (td, *J* = 7.6, 1.5 Hz, 1H), 7.36 – 7.32 (m, 2H), 7.27 (t, *J* = 7.6 Hz, 1H), 7.19 (t, *J* = 7.6 Hz, 1H), 7.15 (t, *J* = 7.6 Hz, 1H), 7.11 (d, *J* = 7.5 Hz, 1H), 7.08 – 7.01 (m, 3H), 6.89 (d, *J* = 7.9 Hz, 1H), 6.81 (s, 1H), 6.51 (s, 2H), 5.29 (dq, *J* = 13.7, 7.1 Hz, 1H), 4.76 (dd, *J* = 16.2, 3.8 Hz, 1H), 4.40 (dd, *J* = 13.0, 2.8 Hz, 1H), 4.21 (dd, *J* = 16.2, 4.1 Hz, 1H), 3.60 (d, *J* = 13.0 Hz, 1H), 2.11 (s, 6H), 1.76 (dd, *J* = 7.1, 2.0 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 151.7 (d, *J* = 5.7 Hz), 151.7 (d, *J* = 6.3 Hz), 142.8, 140.9, 139.1 (d, *J* = 3.9 Hz), 137.4, 136.4, 135.4 (d, *J* = 2.3 Hz), 135.2 (d, *J* = 2.1 Hz), 134.1, 131.5, 130.0, 130.0, 129.7, 129.0, 129.0, 128.4, 128.1 (2C), 127.9, 127.3, 127.0 (2C), 126.4, 126.0, 125.5, 125.5, 124.6, 124.2 (d, *J* = 2.8 Hz), 123.3, 123.1 (d, *J* = 2.9 Hz), 122.8 (d, *J* = 3.0 Hz), 52.7 (d, *J* = 25.9 Hz), 44.6, 34.3, 22.2 (d, *J* = 21.4 Hz), 21.2.

^{31}P NMR (243 MHz, $CDCl_3$) δ 139.1.

HRMS (ESI): *m/z* $C_{40}H_{37}NO_2P^+$ $[M+H]^+$ calcd.: 594.2556, found: 594.2544.

L20



(R_a,*R*)

L20 was prepared from 0.5000 mmol of **amine 14** and (*R*)-3,3'-dibromo-BINOL according to the general procedure. The product was then purified by silica gel column chromatography (2/98 to 8/92 of ethyl acetate/hexanes) to provide ligand **L20** as a white powder (327.8 mg, 0.3914 mmol, 78%).

[α]D^{25} = –246° (c 0.47, $CHCl_3$).

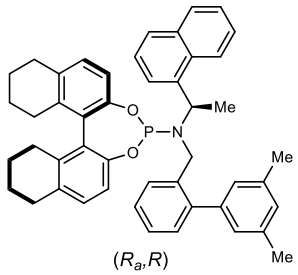
^{1}H NMR (600 MHz, $CDCl_3$) δ ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.36 (s, 1H), 8.17 (s, 1H), 7.88 (d, *J* = 8.3 Hz, 1H), 7.82 (d, *J* = 8.5 Hz, 1H), 7.77 (d, *J* = 7.7 Hz, 1H), 7.77 (d, *J* = 8.3 Hz, 1H), 7.65 (d, *J* = 7.1 Hz, 1H), 7.60 (d, *J* = 7.7 Hz, 1H), 7.58 (d, *J* = 8.1 Hz, 1H), 7.49 – 7.43 (m, 2H), 7.41 (ddd, *J* = 7.2, 6.2, 1.6 Hz, 1H), 7.39 – 7.37 (m, 1H), 7.31 – 7.19 (m, 5H), 6.99 (td, *J* = 7.4, 1.5 Hz, 1H), 6.94 (td, *J* = 7.6, 1.6 Hz, 1H), 6.89 – 6.86 (m, 2H), 6.18 (s, 2H), 5.34 (dq, *J* = 11.7, 7.1 Hz, 1H), 3.99 (d, *J* = 16.2 Hz, 1H), 3.92 (dd, *J* = 16.1, 2.0 Hz, 1H), 2.25 (s, 6H), 1.85 (dd, *J* = 7.1, 2.2 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 147.6 (d, *J* = 8.2 Hz), 146.1, 141.3, 140.2, 137.6 (d, *J* = 6.1 Hz), 137.0, 134.9, 133.8, 133.1, 132.8, 132.0, 132.0, 132.0, 131.8, 131.7, 130.8, 129.1, 128.8, 128.3, 128.0, 127.9, 127.6, 127.4, 127.2, 127.2, 127.0, 126.8, 126.7, 126.6, 126.1, 126.1, 126.1, 125.9 (d, *J* = 6.2 Hz), 125.7, 125.3, 124.8 (d, *J* = 3.9 Hz), 123.0, 123.0, 117.2 (d, *J* = 2.6 Hz), 116.9, 52.4 (d, *J* = 35.0 Hz), 44.5 (d, *J* = 4.6 Hz), 22.7 (d, *J* = 22.2 Hz), 21.4.

^{31}P NMR (243 MHz, $CDCl_3$) δ 144.3.

HRMS (ESI): *m/z* for $C_{47}H_{36}{}^{79}Br^{81}BrNNaO_2P^+$ $[M+Na]^+$ calcd.: 860.0722, found: 860.0698.

L21 (Lω)



L21 (Lω) was prepared from 0.5000 mmol of **amine 14** and (*R*)-H_8-BINOL according to the general procedure. The product was then purified by silica gel column chromatography (2/98 to 8/92 of ethyl acetate/hexanes) to provide ligand **L21** as a white powder (261.7 mg, 0.3805 mmol, 76%).

$[\alpha]_D^{25}$ = –40.0° (c 0.55, $CHCl_3$).

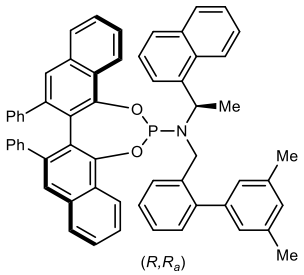
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.80 (d, *J* = 8.2 Hz, 1H), 7.73 (d, *J* = 7.1 Hz, 1H), 7.66 – 7.62 (m, 2H), 7.53 (d, *J* = 7.7 Hz, 1H), 7.45 (ddd, *J* = 8.0, 6.7, 1.0 Hz, 1H), 7.41 (dd, *J* = 8.1, 7.2 Hz, 1H), 7.37 (ddd, *J* = 8.3, 6.7, 1.4 Hz, 1H), 7.18 (dd, *J* = 8.2, 1.1 Hz, 1H), 7.14 – 7.10 (m, 2H), 7.08 (td, *J* = 7.4, 1.5 Hz, 1H), 6.91 (dd, *J* = 7.4, 1.5 Hz, 1H), 6.82 – 6.77 (m, 2H), 6.56 (d, *J* = 8.2 Hz, 1H), 6.13 (s, 2H), 5.10 (dq, *J* = 14.0, 7.1 Hz, 1H), 3.78 (d, *J* = 16.1 Hz, 1H), 3.39 (d, *J* = 16.1 Hz, 1H), 2.91 – 2.73 (m, 3H), 2.72 – 2.59 (m, 3H), 2.27 (dt, *J* = 17.0, 5.8 Hz, 2H), 2.13 (s, 6H), 1.83 – 1.73 (m, 5H), 1.72 (dd, *J* = 7.1, 2.9 Hz, 3H), 1.61 – 1.47 (m, 2H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 149.1, 148.9 (d, *J* = 4.0 Hz), 141.8, 140.4, 139.4 (d, *J* = 4.8 Hz), 138.1 (d, *J* = 1.6 Hz), 137.5, 136.8, 136.1, 134.2 (d, *J* = 1.4 Hz), 133.9, 132.9, 131.5, 129.5, 129.4, 129.4, 129.1, 128.9, 128.2 (d, *J* = 1.4 Hz), 128.2, 128.0, 127.6, 127.0, 126.9, 126.0, 125.9, 125.3, 125.3, 124.2 (d, *J* = 3.0 Hz), 122.9 (d, *J* = 2.8 Hz), 119.2 (d, *J* = 2.7 Hz), 118.5, 52.0 (d, *J* = 30.3 Hz), 45.1 (d, *J* = 4.7 Hz), 29.3, 29.3, 27.9, 27.8, 22.9, 22.9, 22.9, 22.8, 22.7, 22.7.

^{31}P NMR (162 MHz, $CDCl_3$) δ 138.8.

HRMS (ESI): *m/z* for $C_{47}H_{47}NO_2P^+$ $[M+H]^+$ calcd.: 688.3339, found: 688.3327.

L22



L22 was prepared from 0.2282 mmol of **amine 14** and (*R*)-VANOL according to the general procedure. The product was then purified by silica gel column chromatography (2/98 to 8/92 of ethyl acetate/hexanes) to provide ligand **L22** as a white powder (163.9 mg, 0.1970 mmol, 86%).

[α]D^{25} = –278° (c 0.29, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.60 (d, *J* = 8.3 Hz, 1H), 7.93 (d, *J* = 8.3 Hz, 1H), 7.90 (d, *J* = 8.3 Hz, 1H), 7.87 (d, *J* = 8.9 Hz 1H), 7.86 (d, *J* = 8.0 Hz, 1H), 7.81 – 7.76 (m, 2H), 7.71 (d, *J* = 8.6 Hz, 1H), 7.67 – 7.61 (m, 2H), 7.56 – 7.50 (m, 2H), 7.45 (s, 1H), 7.37 – 7.31 (m, 2H), 7.29 (t, *J* = 7.5 Hz, 1H), 7.25 (s, 1H), 7.22 (t, *J* = 7.5 Hz, 1H), 7.13 (t, *J* = 7.4 Hz, 1H), 7.08 – 7.03 (m, 2H), 6.96 (d, *J* = 7.5, 1H), 6.92 – 6.86 (m, 4H), 6.76 (s, 1H), 6.70 (t, *J* = 7.6 Hz, 1H), 6.50 – 6.45 (m, 4H), 6.13 (br s, 2H), 5.18 (dq, *J* = 14.4, 7.2 Hz, 1H), 4.03 (d, *J* = 16.2 Hz, 1H), 3.47 (d, *J* = 16.2 Hz, 1H), 2.00 (s, 6H), 1.94 (d, *J* = 7.1 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 148.1 (d, *J* = 7.5 Hz), 147.7, 142.0, 140.8, 140.8, 140.7, 140.6, 140.3, 140.2, 139.5 (d, *J* = 4.5 Hz), 137.1, 135.7, 134.5, 134.1, 133.8, 131.8, 129.7, 129.3, 129.1, 129.0, 128.3, 128.3, 128.2, 128.1, 127.6, 127.6, 127.4, 127.2, 127.2, 127.1, 127.0, 126.8, 126.7, 126.6, 126.5, 126.3, 126.2, 126.2, 125.8, 125.5, 125.5, 125.4 (d, *J* = 5.2 Hz), 125.0 (d, *J* = 6.7 Hz), 124.5, 123.3 (d, *J* = 3.7 Hz), 122.8 (d, *J* = 2.0 Hz), 122.5, 122.5, 52.2 (d, *J* = 30.9 Hz), 45.4 (d, *J* = 5.0 Hz), 23.3 (d, *J* = 20.7 Hz), 21.4.

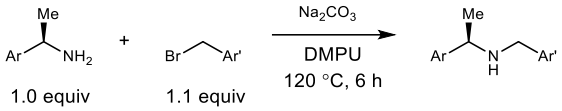
^{31}P NMR (243 MHz, $CDCl_3$) δ 145.9.

HRMS (ESI): *m/z* for $C_{59}H_{47}NO_2P^+$ $[M+H]^+$ calcd.: 832.3339, found: 832.3328.

Synthesis of Amines

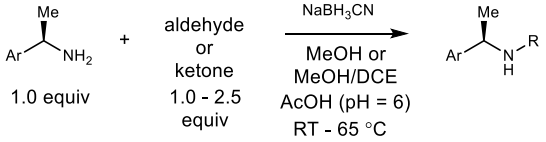
The amine precursors to the ligands were prepared by alkylation with a substituted benzylic bromide (general procedure for S_N2 benzylation) or by reductive amination (general procedure for reductive amination).

General Procedure for S_N2 Benzylation of Amines[19]



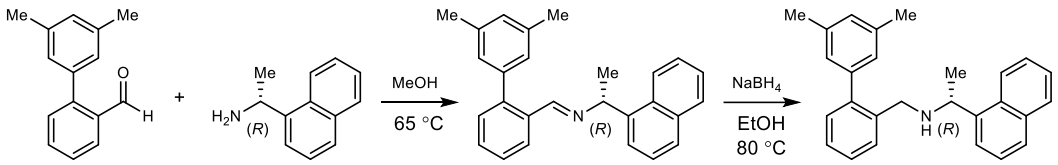
A 20 mL vial equipped with a magnetic stir bar was charged with a chiral amine (1.0 equiv), anhydrous sodium carbonate (2.0 equiv), and anhydrous DMPU (0.25 M in chiral amine). A benzylic bromide (1.1 equiv) was added, the vial was sealed under nitrogen, and the reaction mixture was heated to 120 °C for 4 hours. After this time, the reaction mixture was cooled to ambient temperature, diluted with water (200 mL) and extracted with diethyl ether (4 x 100 mL). The combined organic layers were washed with 3 M NaOH (1 x 100 mL), water (4 x 100 mL), and brine (1 x 100 mL), and finally dried over sodium sulfate and concentrated *in vacuo*. The resulting residue was purified by column chromatography on silica pretreated with the triethylamine/hexanes eluent.

General Procedure for Reductive Amination



A round-bottomed flask equipped with a magnetic stir bar was charged with chiral amine (1.0 equiv), aldehyde or ketone (1.0–2.0 equiv), and methanol (0.25 M in chiral amine). Dichloroethane was added as a cosolvent when the reaction mixtures remained heterogeneous in methanol. Sodium cyanoborohydride (1.2 equiv) was added, and the pH of the reaction mixture was adjusted to ~5 by dropwise addition of glacial acetic acid. The reaction mixture was then stirred at either room temperature or 50 °C. After the reaction reached completion, as judged by TLC analysis, the reaction mixture was concentrated *in vacuo*, diluted with saturated potassium carbonate solution (100 mL), and extracted with dichloromethane (3 x 50 mL). The combined organic layers were washed with brine (50 mL), dried over sodium sulfate, and concentrated *in vacuo*. The resulting residue was purified by column chromatography on silica pretreated with the triethylamine/hexanes eluent.

Gram-scale preparation of Amine 14

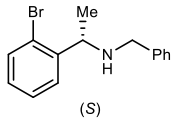


Amine 14
73% overall, *2.54 g*

A 100 mL round bottomed flask with a magnetic stir bar was charged with 3',5'-dimethyl-[1,1'-biphenyl]-2-carbaldehyde[20] (2.000 g, 9.511 mmol, 1 equiv), freshly distilled (*R*)-1-(naphthalen-1-yl)ethan-1-amine (2.350 g, 13.72 1.443 equiv), and methanol (32 mL, 0.30 M in aldehyde). The reaction was stirred at reflux for two hours (until completion, as judged by TLC analysis). At this stage, a significant amount of white precipitate formed. The reaction mixture was transferred to a 250 mL Erlenmeyer flask with anhydrous methanol, heated to boiling, and slowly diluted with anhydrous methanol until all solid material dissolved. The solution was allowed to cool slowly to room temperature for two hours and then was cooled to –10 °C for two hours to provide the imine as colorless needles. After this time, the crystalline material was isolated by vacuum filtration on a glass frit. The resulting crystals were washed twice with cold methanol, dried *in vacuo*, and used immediately for the subsequent step.

Next, a 250 mL round-bottomed flask equipped with a magnetic stir bar was charged with the crystalline imine (2.880 g, 7.923 mmol, 1 equiv) and sodium borohydride (754.2 mg, 19.94 mmol, 2.516 equiv). The flask was evacuated and backfilled with nitrogen three times, and anhydrous ethanol (80 mL, 0.10 M in imine) was added. The reaction mixture was heated at reflux for 7 h. After this time, the reaction had reached completion (as judged by TLC analysis), the reaction mixture was concentrated *in vacuo*, diluted with saturated sodium bicarbonate (100 mL), and extracted with dichloromethane (3 x 50 mL). The combined organic layers were washed with brine (50 mL), dried over sodium sulfate, and concentrated *in vacuo*. The product was purified by silica gel column chromatography (2/98 of triethylamine/hexanes) to provide **Amine 14** as a colorless liquid (2.535 g, 6.935 mmol, 73% over two steps). *Note:* **Amine 15** was prepared in a similar manner.

***ent*-Amine 5**



***ent*-Amine 5** was prepared from 3.549 mmol of (*S*)-1-(2-bromophenyl)ethan-1-amine and benzyl bromide according to the general procedure for the S_N2 benzylation of amines. The product was then purified by silica gel column chromatography (2/98 of triethylamine/hexanes) to provide ***ent*-Amine 5** as a colorless liquid (785.3 mg, 2.706 mmol, 76%).

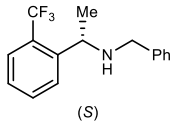
[α]D^{25} = –3.66° (c 0.36, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.65 (dd, *J* = 7.8, 1.7 Hz, 1H), 7.56 (dd, *J* = 8.0, 1.3 Hz, 1H), 7.37 (t, *J* = 7.6, 1.3 Hz, 1H), 7.35 – 7.31 (m, 4H), 7.29 – 7.25 (m, 1H), 7.13 (td, *J* = 7.6, 1.7 Hz, 1H), 4.33 (q, *J* = 6.6 Hz, 1H), 3.65 (AB, *J* = 13.1 Hz, 2H), 1.63 (br s, 1H), 1.37 (d, *J* = 6.6 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 144.1, 140.6, 133.0, 128.5, 128.3, 128.3, 127.9, 127.8, 127.0, 123.9, 56.5, 51.9, 23.1.

HRMS (ESI): *m/z* for $C_{15}H_{17}BrN^+$ $[M+H]^+$ calcd.: 290.0539, found: 290.0526.

***ent*-Amine 6**



***ent*-Amine 6** was prepared from 0.6079 mmol of (*S*)-1-(2-(trifluoromethyl)phenyl)ethan-1-amine and benzyl bromide according to the general procedure for the S_N2 benzylation of amines. The product was then purified by silica gel column chromatography (2/98 of triethylamine/hexanes) to provide ***ent*-Amine 6** as a colorless liquid (133.0 mg, 0.4762 mmol, 78%).

[α]D^{25} = –13.8° (c 0.37, $CHCl_3$).

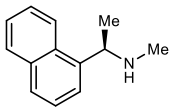
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (d, *J* = 7.9 Hz, 1H), 7.64 (d, *J* = 7.9 Hz, 1H), 7.59 (t, *J* = 7.7 Hz, 1H), 7.39 – 7.20 (m, 6H), 4.37 (q, *J* = 6.3 Hz, 1H), 3.65 (d, *J* = 12.9 Hz, 1H), 3.52 (d, *J* = 12.8 Hz, 1H), 1.57 (br s, 1H), 1.38 (d, *J* = 6.5 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 145.5, 140.7, 132.4, 128.5, 128.3 (q, *J* = 29.9 Hz), 128.2, 127.6, 127.1, 126.8, 125.5 (q, *J* = 6.0 Hz), 124.7 (q, *J* = 274.1 Hz), 53.2 (q, *J* = 1.7 Hz), 52.0, 25.0.

^{19}F NMR (376 MHz, $CDCl_3$) δ -57.3.

HRMS (ESI): *m/z* for $C_{16}H_{17}F_3N^+$ $[M+H]^+$ calcd.: 280.1308, found: 280.1306.

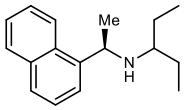
Amine 7



(*R*)

Amine 7 is known, and it was prepared according to a literature procedure.[21]

Amine 8



(*R*)

Amine 8 was prepared from 7.008 mmol of (*R*)-1-(naphthalen-1-yl)ethan-1-amine and 14.02 mmol 3-pentanone according to the general procedure for reductive amination. The reaction was conducted in 28 mL methanol solvent and the reaction was deemed complete after 7 days at room temperature. After extraction, the product was purified by silica gel column chromatography (1.5/98.5 of triethylamine/hexanes) to provide **Amine 8** as a colorless liquid (965.9 mg, 4.002 mmol, 57%).

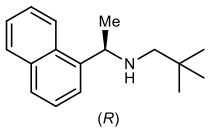
$[\alpha]_D^{25}$ = +56.3° (c 0.43, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.30 (d, *J* = 8.3 Hz, 1H), 7.91 (dd, *J* = 8.0, 1.6 Hz, 1H), 7.78 (d, *J* = 8.1 Hz, 1H), 7.74 (d, *J* = 7.1 Hz, 1H), 7.56 – 7.48 (m, 3H), 4.82 (q, *J* = 6.6 Hz, 1H), 2.42 (p, *J* = 5.7 Hz, 1H), 1.57 – 1.37 (m, 7H), 1.30 (br s, 1H), 0.92 (t, *J* = 7.5 Hz, 3H), 0.90 (t, *J* = 7.5 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 142.3, 134.1, 131.5, 129.0, 127.0, 125.8, 125.7, 125.3, 123.3, 123.1, 56.8 (d, *J* = 3.5 Hz), 50.3, 26.7, 25.5, 24.6, 10.4, 9.3.

HRMS (ESI): *m/z* for $C_{17}H_{24}N^+$ $[M+H]^+$ calcd.: 242.1903, found: 242.1904.

Amine 9



(*R*)

Amine 9 was prepared from 10.00 mmol of (*R*)-1-(naphthalen-1-yl)ethan-1-amine and 25.00 mmol pivaldehyde according to the general procedure for reductive amination. The reaction was conducted in 40 mL methanol solvent and the reaction was deemed complete after 72 h at room temperature. After extraction, the product was purified by silica gel column chromatography (2/98 of triethylamine/hexanes) to provide **Amine 9** as a colorless liquid (1.925 g, 7.975 mmol, 80%).

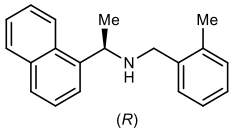
$[\alpha]_D^{25}$ = +96.6° (c 0.31, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.31 (d, *J* = 8.4 Hz, 1H), 7.97 – 7.90 (m, 1H), 7.84 – 7.76 (m, 2H), 7.59 – 7.51 (m, 3H), 4.63 (q, *J* = 6.6 Hz, 1H), 2.44 (d, *J* = 11.2 Hz, 1H), 2.36 (d, *J* = 11.2 Hz, 1H), 1.57 (d, *J* = 6.6 Hz, 3H), 1.32 (br s, 1H), 1.01 (s, 9H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 141.9, 134.1, 131.6, 129.0, 127.1, 125.8, 125.7, 125.3, 123.3, 123.0, 60.5, 54.7, 31.6, 28.0, 24.0.

HRMS (ESI): *m/z* for $C_{17}H_{24}N^+$ $[M+H]^+$ calcd.: 242.1903, found: 242.1902.

Amine 11



Amine 11 was prepared from 2.336 mmol of (*R*)-1-(naphthalen-1-yl)ethan-1-amine and 2.569 mmol 2-methylbenzyl bromide according to the general procedure for the S_N2 benzylation of amines. The product was then purified by silica gel column chromatography (2/98 of triethylamine/hexanes) to provide **Amine 11** as a colorless liquid (419.5 mg, 1.523 mmol, 65%).

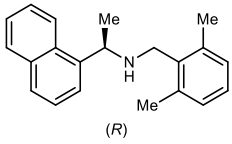
$[\alpha]_D^{25}$ = +5.0° (c 0.24, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.22 (d, *J* = 8.1 Hz, 1H), 7.91 (dd, *J* = 7.8, 1.8 Hz, 1H), 7.82 (d, *J* = 7.2 Hz, 1H), 7.80 (d, *J* = 8.2 Hz, 1H), 7.56 – 7.48 (m, 3H), 7.35 (dd, *J* = 5.2, 3.7 Hz, 1H), 7.23 – 7.15 (m, 3H), 4.75 (q, *J* = 6.6 Hz, 1H), 3.74 (AB, *J* = 13.1 Hz, 2H), 2.31 (s, 3H), 1.58 (br s, 1H), 1.57 (d, *J* = 6.6 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 141.3, 138.8, 136.6, 134.2, 131.5, 130.4, 129.1, 128.7, 127.4, 127.1, 126.0, 125.9, 125.8, 125.4, 123.2, 123.1, 53.8, 50.0, 23.9, 19.1.

HRMS (ESI): *m/z* for $C_{20}H_{22}N^+$ $[M+H]^+$ calcd.: 276.1747, found: 276.1743.

Amine 12



Amine 12 was prepared from 2.336 mmol of (*R*)-1-(naphthalen-1-yl)ethan-1-amine and 2.569 mmol 2,6-dimethylbenzyl bromide according to the general procedure for the S_N2 benzylation of amines. The product was then purified by silica gel column chromatography (2/98 of triethylamine/hexanes) to provide **Amine 12** as a colorless liquid (379.9 mg, 1.313 mmol, 56%).

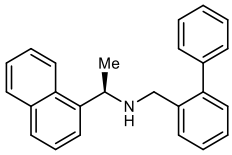
$[\alpha]_D^{25}$ = +24.7° (c 0.36, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.36 (d, *J* = 8.4 Hz, 1H), 7.96 (dd, *J* = 8.0, 1.6 Hz, 1H), 7.89 (d, *J* = 7.1 Hz, 1H), 7.85 (d, *J* = 8.1 Hz, 1H), 7.62 – 7.54 (m, 3H), 7.14 (dd, *J* = 8.4, 6.4 Hz, 1H), 7.09 (d, *J* = 7.4 Hz, 2H), 4.83 (q, *J* = 6.6 Hz, 1H), 3.79 (s, 2H), 2.43 (s, 6H), 1.63 (d, *J* = 6.6 Hz, 3H), 1.42 (br s, 1H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 141.3, 137.2, 137.0, 134.1, 131.5, 129.1, 128.3, 127.4, 127.1, 125.8, 125.8, 125.4, 123.2, 123.1, 54.8, 46.6, 23.7, 19.7.

HRMS (ESI): *m/z* for $C_{21}H_{24}N^+$ $[M+H]^+$ calcd.: 290.1903, found: 290.1903.

Amine 13



(*R*)

Amine 13 was prepared from 2.336 mmol of (*R*)-1-(naphthalen-1-yl)ethan-1-amine and 2.569 mmol 2-phenylbenzyl bromide according to the general procedure for the S_N2 benzylation of amines. The product was then purified by silica gel column chromatography (2/98 of triethylamine/hexanes) to provide **Amine 13** as a colorless liquid (515.3 mg, 1.527 mmol, 65%).

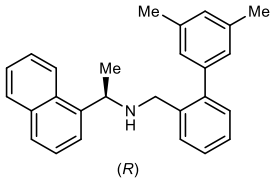
$[\alpha]_D^{25}$ = +22.2° (c 0.34, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.10 – 8.05 (m, 1H), 7.90 – 7.86 (m, 1H), 7.74 (d, *J* = 8.1 Hz, 1H), 7.55 (d, *J* = 7.1 Hz, 1H), 7.51 – 7.45 (m, 3H), 7.43 (dd, *J* = 8.1, 7.2 Hz, 1H), 7.40 – 7.31 (m, 7H), 7.29 – 7.26 (m, 1H), 4.53 (q, *J* = 6.6 Hz, 1H), 3.79 (d, *J* = 12.8 Hz, 1H), 3.66 (d, *J* = 12.8 Hz, 1H), 1.52 (br s, 1H), 1.40 (d, *J* = 6.6 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 142.1, 141.3, 141.0, 138.1, 134.1, 131.4, 130.2, 129.8, 129.2, 129.0, 128.3, 127.6, 127.2, 127.1, 127.1, 125.9, 125.7, 125.3, 123.2, 123.0, 53.5, 49.9, 23.7.

HRMS (ESI): *m/z* for $C_{25}H_{24}N^+$ $[M+H]^+$ calcd.: 338.1903, found: 338.1916.

Amine 14



(*R*)

Amine 14 was prepared from 0.9519 mmol of (*R*)-1-(naphthalen-1-yl)ethan-1-amine and 0.9511 mmol 3',5'-dimethyl-[1,1'-biphenyl]-2-carbaldehyde[20] according to the general procedure for reductive amination. The reaction was conducted in 5.0 mL methanol solvent and the reaction was

deemed complete after 48 h at 65 °C. After extraction, the product was purified by silica gel column chromatography (2/98 of triethylamine/hexanes) to provide **Amine 14** as a colorless liquid (309.7 mg, 0.8473 mmol, 89%). *Note:* **Amine 14** was prepared on a gram scale by a cleaner, stepwise protocol. See above for details.

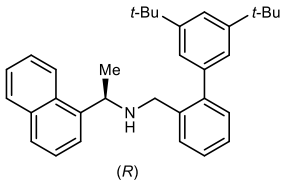
$|[\alpha]_D^{25}| < 2°$ (c 0.15, $CHCl_3$). – The specific rotation for this sample was too small to determine the sign or quantify the absolute rotation.

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.12 – 8.07 (m, 1H), 7.94 – 7.89 (m, 1H), 7.78 (d, *J* = 8.1 Hz, 1H), 7.60 (d, *J* = 7.0 Hz, 1H), 7.55 – 7.48 (m, 2H), 7.50 – 7.44 (m, 2H), 7.39 – 7.34 (m, 2H), 7.33 – 7.28 (m, 1H), 7.06 (s, 1H), 7.02 (s, 2H), 4.57 (q, *J* = 6.6 Hz, 1H), 3.86 (d, *J* = 12.8 Hz, 1H), 3.71 (d, *J* = 12.8 Hz, 1H), 2.38 (s, 6H), 1.60 (br s, 1H), 1.44 (d, *J* = 6.6 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 142.3, 141.3, 141.1, 138.0, 137.7, 134.1, 131.4, 130.2, 129.8, 129.0, 128.7, 127.4, 127.1, 127.0, 127.0, 125.9, 125.7, 125.3, 123.1, 122.9, 53.1, 49.9, 23.7, 21.4.

HRMS (ESI): *m/z* for $C_{27}H_{28}N^+$ $[M+H]^+$ calcd.: 366.2216, found: 366.2213.

Amine 15



Amine 15 was prepared from 4.316 mmol of (*R*)-1-(naphthalen-1-yl)ethan-1-amine and 2.717 mmol 3',5'-di-tert-butyl-[1,1'-biphenyl]-2-carbaldehyde[22] according to the general procedure for reductive amination. The reaction was conducted in a mixture of 9 mL methanol and 3 mL of DCE and the reaction was deemed complete after 48 h at 50 °C. After extraction, the product was purified by silica gel column chromatography (1/99 of triethylamine/hexanes) to provide **Amine 15** as a sticky oil (890.9 mg, 1.981 mmol, 73%). *Note:* **Amine 15** was prepared on a gram scale by a cleaner, stepwise protocol. See above for details.

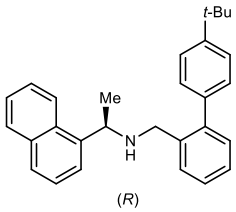
$[\alpha]_D^{25}$ = +13.9° (c 0.13, $CHCl_3$).

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 – 7.95 (m, 1H), 7.89 – 7.82 (m, 1H), 7.72 (d, *J* = 8.0 Hz, 1H), 7.53 – 7.28 (m, 9H), 7.21 (d, *J* = 1.9 Hz, 2H), 4.45 (q, *J* = 6.5 Hz, 1H), 3.77 (d, *J* = 12.8 Hz, 1H), 3.67 (d, *J* = 12.8 Hz, 1H), 1.49 (br s, 1H), 1.35 – 1.30 (m, 21H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 150.7, 143.2, 141.1, 140.5, 138.2, 134.1, 131.4, 130.3, 129.9, 129.0, 127.4, 127.1, 127.0, 125.9, 125.7, 125.3, 123.5, 123.1, 122.9, 121.0, 53.1, 50.2, 35.0, 31.7, 23.7.

HRMS (ESI): *m/z* for $C_{33}H_{40}N^+$ $[M+H]^+$ calcd.: 450.3155, found: 450.3153.

Amine 16



Amine 16 was prepared from 4.028 mmol of (*R*)-1-(naphthalen-1-yl)ethan-1-amine and 2.518 mmol 4'-(tert-butyl)-[1,1'-biphenyl]-2-carbaldehyde[23] according to the general procedure for reductive amination. The reaction was conducted in a mixture of 9.0 mL methanol and 3.0 mL DCE and the reaction was deemed complete after 48 h at 50 °C. After extraction, the product was purified by silica gel column chromatography (1/99 of triethylamine/hexanes) to provide **Amine 16** as a tan solid (535.3 mg, 1.360 mmol, 54%).

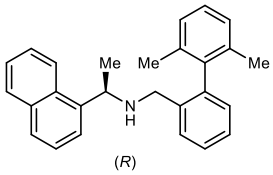
$[\alpha]_D^{25}$ = +21.7° (c 0.33, $CHCl_3$).

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.07 – 7.99 (m, 1H), 7.85 – 7.79 (m, 1H), 7.68 (d, *J* = 8.1 Hz, 1H), 7.53 (d, *J* = 7.0 Hz, 1H), 7.45 – 7.34 (m, 4H), 7.34 – 7.18 (m, 7H), 4.46 (q, *J* = 6.6 Hz, 1H), 3.73 (d, *J* = 12.8 Hz, 1H), 3.61 (d, *J* = 12.7 Hz, 1H), 1.49 (br s, 1H), 1.36 – 1.31 (s, 12H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 149.9, 142.0, 141.0, 138.3, 138.2, 134.1, 131.4, 130.3, 129.8, 129.0, 128.9, 127.4, 127.2, 127.0, 125.9, 125.7, 125.3, 125.1, 123.3, 123.1, 53.5, 49.9, 34.7, 31.6, 23.7.

HRMS (ESI): *m/z* for $C_{29}H_{32}N^+$ $[M+H]^+$ calcd.: 394.2529, found: 394.2544.

Amine 17



Amine 17 was prepared from 0.4759 mmol of (*R*)-1-(naphthalen-1-yl)ethan-1-amine and 0.4756 mmol 2',6'-dimethyl-[1,1'-biphenyl]-2-carbaldehyde[24] according to the general procedure for reductive amination. The reaction was conducted in 2.5 mL methanol solvent and the reaction was

deemed complete after 48 h at 65 °C. After extraction, the product was purified by silica gel column chromatography (2/98 of triethylamine/hexanes) to provide **Amine 17** as a colorless liquid (121.8 mg, 0.3332 mmol, 70%).

$[\alpha]_D^{25}$ = +25.7° (c 0.15, $CHCl_3$).

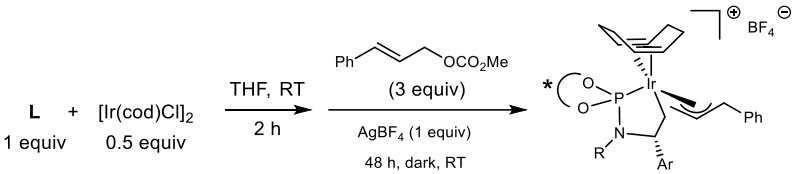
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.08 – 8.04 (m, 1H), 7.89 – 7.86 (m, 1H), 7.74 – 7.70 (m, 1H), 7.52 – 7.45 (m, 3H), 7.40 – 7.33 (m, 4H), 7.23 (t, *J* = 7.6 Hz, 1H), 7.16 (d, *J* = 7.5 Hz, 1H), 7.11 (d, *J* = 7.5 Hz, 1H), 7.10 – 7.06 (m, 1H), 4.52 (q, *J* = 6.6 Hz, 1H), 3.47 (d, *J* = 12.9 Hz, 1H), 3.36 (d, *J* = 12.9 Hz, 1H), 2.03 (s, 3H), 1.92 (s, 3H), 1.41 (br s, 1H), 1.37 (d, *J* = 6.6 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 140.9, 140.4, 140.4, 138.2, 136.3, 136.1, 134.1, 131.4, 129.6, 129.6, 129.0, 127.5, 127.5, 127.5, 127.4, 127.3, 127.1, 126.0, 125.7, 125.3, 123.1, 122.7, 53.4, 49.9, 23.9, 20.9, 20.7.

HRMS (ESI): *m/z* for $C_{27}H_{28}N^+$ $[M+H]^+$ calcd.: 366.2216, found: 366.2212.

2.) Iridium Catalysts

Iridium catalysts **C1**–**C22** were prepared from the corresponding ligands **L1**–**L22** according to the following procedure, which was adapted from the literature.[1,25,26] Similarly, catalyst **C23** was prepared from **L21** and $[Ir(DBCOT)Cl]_2$. The catalysts were synthesized on small scale and used immediately for screening.



In a nitrogen-filled glovebox, a 4 mL vial equipped with a magnetic stir bar was charged with $[Ir(cod)Cl]_2$ (0.01 mmol, 0.5 equiv), ligand **L** (0.02 mmol, 1 equiv), and THF (400 µL). The reaction mixture was stirred at room temperature for 2 hours. Then, cinnamyl methyl carbonate (0.04 mmol, 2 equiv) was added, followed by a solution of $AgBF_4$ (0.02 mmol, 1 equiv) in THF (400 µL). The reaction mixture was protected from light with aluminum foil and was stirred vigorously for 48 hours at room temperature. *Note: Rapid stirring is important.* After this time, the reaction mixture was filtered through a 0.2 µm PTFE syringe filter to afford a yellow solution. Outside of the glovebox and under air, the crude product was concentrated *in vacuo* to afford a tan-colored residue which is further dried under high vacuum (< 1 torr) for one hour. *Note: removal of residual THF is important for the following precipitation.* Anhydrous, unstabilized diethyl ether

was added to the tan-colored residue to form a pale-yellow powder. The resulting powder was washed with diethyl ether several times, until cinnamyl methyl carbonate is no longer observed by TLC of the supernatant solution (typically 5–6 times is sufficient). The resulting powder is concentrated *in vacuo,* dried under high vacuum for 12 hours, and used without further purification. The iridium catalysts are stable under air.

Catalyst **C21** (**Cω**) was prepared according to the procedure given above on a larger scale and at higher concentration, using 0.300 mmol ligand **L21** (**Lω**), 0.150 mmol $[Ir(cod)Cl]_2$, 0.900 mmol cinnamyl methyl carbonate, 0.300 mmol $AgBF_4$, and 3.00 mL THF. Yield: 320.2 mg, 0.269 mmol, 90%.

Catalyst **C21'** (**Cω'**) bears an unsubstituted allyl group instead of a cinnamyl group. Catalyst **C21'** (**Cω'**) was used for substrates in which an impurity arising from attack of a nucleophile on the π-cinnamyl precatalyst complicated product purification. Catalyst **C21'** (**Cω'**) was prepared according to the procedure given above, using 0.0760 mmol ligand **L21**, 0.038 mmol $[Ir(cod)Cl]_2$, 0.230 mmol allyl methyl carbonate, 0.0760 mmol $AgBF_4$, and 0.70 mL THF. Yield: 64.7 mg, 0.0580 mmol, 76%.

Catalyst **C15 (Cγ)** was prepared according to the procedure given above on a larger scale, using 0.200 mmol ligand **L15 (Lγ)**, 0.100 mmol $[Ir(cod)Cl]_2$, 0.600 mmol cinnamyl methyl carbonate, 0.200 mmol $AgBF_4$, and 2.00 mL THF. Yield: 233.7 mg, 0.184 mmol, 92%.

IRIDIUM-CATALYZED ASYMMETRIC ALLYLIC FLUOROALKYLATION

1) General Procedure: Malonates and β-Keto Esters

In a nitrogen-filled glovebox, a 4 mL vial equipped with a stir bar was charged with 3-substituted 3,3-difluoropropene **1** (0.100 mmol) and a 50 μL aliquot of a solution of iridium catalyst **C21** (**Cω**) (40 mM solution, 0.0020 mmol, 2.0 mol%). A solution of the nucleophile **2** and LiO*t*-Bu was prepared in THF (0.15 mmol LiO*t*-Bu and 0.15 mmol nucleophile per 200 μL THF), and the mixture was stirred at room temperature until fully homogeneous (~15 minutes). The solution of the nucleophile and the solution of the catalyst and 3-substituted 3,3-difluoropropene were both cooled to –40 °C in a glovebox freezer for 20 minutes. While keeping both solutions cold, a 200 μL aliquot of the nucleophile solution was added to the vial containing the catalyst and the 3-substituted 3,3-difluoropropene. The reaction vial was quickly sealed, removed from the glovebox, and transferred to a magnetically-stirred cold well maintained at –10 °C. After 72 hours,

the reaction mixture was warmed to room temperature, diluted with DCM, and transferred to a 20 mL vial. The solvent was removed *in vacuo* and the crude reaction mixture was directly subjected to purification by either preparative TLC or silica-gel column chromatography to provide pure allylic fluoride **3**.

Note: The reaction development and catalyst design (outlined in figure S13) was conducted as discussed above with 5.0 mol% of the corresponding catalyst at a 0.02 mmol scale of 3-substituted 3,3-difluoropropene **1**. These reactions were conducted at room temperature for 48 h.

2) General Procedure: Malononitriles

In a nitrogen-filled glovebox, a 4 mL vial equipped with a stir bar was charged with 3-substituted 3,3-difluoropropene **1** (0.100 mmol) and a 250 µL aliquot of a solution of iridium catalyst **C21' (Cω')** (8 mM solution, 0.0020 mmol, 2.0 mol%). Lithium bromide (43.4 mg, 0.500 mmol, 5.00 equiv) was added neat to this solution. In a separate vial, a solution of the nucleophile **2e** and LiO*t*-Bu was prepared in THF (0.20 mmol LiO*t*-Bu and 0.20 mmol nucleophile per 750 µL THF), and the mixture was stirred at room temperature until fully homogeneous (~15 minutes). Then, a 750 µL aliquot of the nucleophile solution was added to the vial containing the catalyst, lithium bromide, and the 3-substituted 3,3-difluoropropene. The reaction vial was sealed and stirred at room temperature for 24 hours. After this time, the solvent was removed *in vacuo* and the crude reaction mixture was directly subjected to purification by either preparative TLC or silica-gel column chromatography to provide pure allylic fluoride **3**.

3) General Procedure: Silyl Ketene Acetals

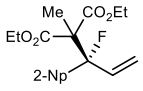
In a nitrogen-filled glovebox, a 4 mL vial equipped with a stir bar was charged with 3-substituted 3,3-difluoropropene **1** (0.100 mmol) and a 120 µL aliquot of a solution of iridium catalyst **C15 (Cγ)** (50 mM solution, 0.0060 mmol, 6.0 mol%). In a separate vial, a solution of diethyl methyl malonate (43.6 mg, 0.250 mmol) in THF (4.00 mL) was treated with dry sodium hydride (12.0 mg, 0.500 mmol) and stirred vigorously for 10 minutes at room temperature. This solution was then passed through a syringe filter to provide a homogeneous solution of sodium diethyl malonate. An 80 µL aliquot of the freshly prepared sodium diethyl methyl malonate solution (0.0050 mmol sodium malonate, 5.0 mol%) was added to the vial containing substrate and catalyst, and the resulting suspension was stirred for 1 minute, followed immediately by the addition of neat silyl ketene acetal **2** (0.200 mmol, 2.00 equiv). The reaction vial was sealed and

stirred at room temperature. After 48 – 96 hours the reaction mixture was diluted with DCM and transferred to a 20 mL vial. The solvent was removed *in vacuo* and resulting residue was directly subjected to purification by preparative TLC to provide pure allylic fluoride **3**.

CHARACTERIZATION OF ALLYLIC FLUOROALKYLATION PRODUCTS – SCOPE OF NUCLEOPHILES

Products from Nucleophiles with Lithium Counterions

diethyl (*R*)-2-(1-fluoro-1-(naphthalen-2-yl)allyl)-2-methylmalonate (3aa)



3aa

98%, 96:4 er

The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.100 mmol scale. Reaction time: 72 h. Reaction temperature: –10 °C. The product was purified by preparative TLC (1/99 of diethyl ether/benzene) to provide allylic fluoride **3aa** as a clear oil (35.2 mg, 0.0982 mmol, 98%).

The **enantiomeric ratio** was determined to be 96:4 by HPLC analysis with t_R = 10.4 min (major) and t_R = 11.5 min (minor) [AD-H, 1.0% *i*PrOH in hexanes, 0.8 mL/min, 268 nm, 25 °C].

[α]$_D^{25}$ = +68.3° (c 0.19, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +74.2° (c 0.19, $CHCl_3$).

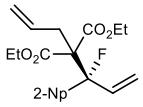
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.98 (s, 1H), 7.87 – 7.77 (m, 3H), 7.65 (dd, *J* = 8.8, 1.9 Hz, 1H), 7.50 – 7.46 (m, 2H), 7.06 (ddd, *J* = 22.0, 17.1, 11.1 Hz, 1H), 5.45 (d, *J* = 17.1 Hz, 1H), 5.34 (d, *J* = 11.1 Hz, 1H), 4.19 (q, *J* = 7.1 Hz, 2H), 4.11 – 4.01 (m, 2H), 1.58 (d, *J* = 1.4 Hz, 3H), 1.23 (t, *J* = 7.1 Hz, 3H), 1.06 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 169.5 (d, *J* = 4.4 Hz), 169.2 (d, *J* = 7.1 Hz), 137.4 (d, *J* = 23.1 Hz), 137.1 (d, *J* = 18.0 Hz), 132.8, 132.7 (d, *J* = 1.5 Hz), 128.6, 127.5, 127.2 (d, *J* = 2.1 Hz), 126.5, 126.2, 126.1 (d, *J* = 11.9 Hz), 124.5 (d, *J* = 10.1 Hz), 115.9 (d, *J* = 14.5 Hz), 97.6 (d, *J* = 189.3 Hz), 62.8 (d, *J* = 26.8 Hz), 61.6, 61.5, 18.2 (d, *J* = 5.5 Hz), 14.1, 13.8.

^{19}F NMR (376 MHz, $CDCl_3$) δ -157.2 (d, *J* = 22.0 Hz).

HRMS (ESI): *m/z* for $C_{21}H_{23}FNaO_4^+$ $[M+Na]^+$ calcd.: 381.1473, found: 381.1474.

diethyl (*R*)-2-allyl-2-(1-fluoro-1-(naphthalen-2-yl)allyl)malonate (3ab)



3ab
78%, 94:6 er

The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.100 mmol scale. Reaction time: 96 h. Reaction temperature: –10 °C. The product was purified by preparative TLC (1/99 of diethyl ether/benzene) to provide allylic fluoride **3ab** as a clear oil (30.1 mg, 0.0783 mmol, 78%).

The **enantiomeric ratio** was determined to be 94:6 by HPLC analysis with t_R = 12.3 min (major) and t_R = 13.3 min (minor) [AD-H, 1.0% *i*PrOH in hexanes, 0.8 mL/min, 210 nm, 25 °C].

[α]$_D^{25}$ = +71.4° (c 0.23, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +81.1° (c 0.23, $CHCl_3$).

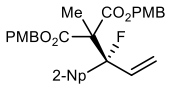
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.92 (s, 1H), 7.86 – 7.77 (m, 3H), 7.57 (dd, *J* = 8.7, 1.9 Hz, 1H), 7.50 – 7.46 (m, 2H), 7.01 (ddd, *J* = 22.2, 17.1, 11.1 Hz, 1H), 5.75 (ddt, *J* = 17.0, 10.0, 7.3 Hz, 1H), 5.46 (d, *J* = 17.1 Hz, 1H), 5.35 (d, *J* = 11.0 Hz, 1H), 5.05 (d, *J* = 17.1 Hz, 1H), 4.98 (d, *J* = 10.0 Hz, 1H), 4.16 (q, *J* = 7.1 Hz, 2H), 4.11 – 3.99 (m, 2H), 2.91 (dd, *J* = 14.1, 7.9 Hz, 1H), 2.81 (dd, *J* = 14.1, 6.5 Hz, 1H), 1.22 (t, *J* = 7.1 Hz, 3H), 1.05 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 168.4 (d, *J* = 4.4 Hz), 168.0 (d, *J* = 6.1 Hz), 137.4 (d, *J* = 23.1 Hz), 137.0 (d, *J* = 18.1 Hz), 133.9, 132.9, 132.7 (d, *J* = 1.5 Hz), 128.6, 127.6, 127.4 (d, *J* = 2.2 Hz), 126.6, 126.3, 125.8 (d, *J* = 11.7 Hz), 124.2 (d, *J* = 10.0 Hz), 118.6, 116.1 (d, *J* = 14.4 Hz), 97.6 (d, *J* = 192.7 Hz), 67.2 (d, *J* = 25.2 Hz), 61.5, 61.4, 36.5 (d, *J* = 5.3 Hz), 14.1, 13.8.

^{19}F NMR (565 MHz, $CDCl_3$) δ -157.1 (d, *J* = 22.3 Hz).

HRMS (ESI): *m/z* for $C_{23}H_{25}FNaO_4^+$ $[M+Na]^+$ calcd.: 407.1629, found: 407.1625.

bis(4-methoxybenzyl) (*R*)-2-(1-fluoro-1-(naphthalen-2-yl)allyl)-2-methylmalonate (3ac)



3ac
84%, 95:5 er

The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.100 mmol scale. Reaction time: 72 h. Reaction temperature: –10 °C. The product was purified by preparative TLC (benzene, run up the plate twice) to provide allylic fluoride **3ac** as a clear oil (45.5 mg, 0.0839 mmol, 84%).

The **enantiomeric ratio** was determined to be 95:5 by HPLC analysis with t_R = 23.0 min (major) and t_R = 24.5 min (minor) [AD-H, 4.0% *i*PrOH in hexanes, 0.8 mL/min, 230 nm, 25 °C].

[α]$_D^{25}$ = +46.5° (c 0.13, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +51.7° (c 0.13, $CHCl_3$).

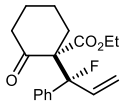
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.92 (s, 1H), 7.82 – 7.73 (m, 2H), 7.70 (d, *J* = 8.7 Hz, 1H), 7.56 (dd, *J* = 8.7, 1.9 Hz, 1H), 7.50 – 7.44 (m, 2H), 7.14 (d, *J* = 8.6 Hz, 2H), 7.00 (ddd, *J* = 22.1, 17.1, 11.1 Hz, 1H), 6.90 (d, *J* = 8.6 Hz, 2H), 6.80 (d, *J* = 8.6 Hz, 2H), 6.68 (d, *J* = 8.6 Hz, 2H), 5.40 (d, *J* = 17.1 Hz, 1H), 5.28 (ddd, *J* = 11.1, 2.4, 1.2 Hz, 1H), 5.03 (s, 2H), 4.90 (AB, *J* = 11.9 Hz, 2H), 3.80 (s, 3H), 3.76 (s, 3H), 1.60 (d, *J* = 1.4 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 169.3 (d, *J* = 4.5 Hz), 168.9 (d, *J* = 6.2 Hz), 159.7, 159.6, 137.3 (d, *J* = 23.1 Hz), 136.9 (d, *J* = 17.7 Hz), 132.8, 132.7 (d, *J* = 1.4 Hz), 130.1, 130.0, 128.7, 127.5, 127.4, 127.3 (d, *J* = 2.0 Hz), 127.1, 126.5, 126.2, 126.0 (d, *J* = 11.6 Hz), 124.4 (d, *J* = 10.0 Hz), 116.1 (d, *J* = 14.4 Hz), 113.9, 113.8, 97.6 (d, *J* = 190.0 Hz), 67.2 (2C), 63.0 (d, *J* = 26.6 Hz), 55.4, 55.3, 18.3 (d, *J* = 5.6 Hz).

^{19}F NMR (376 MHz, $CDCl_3$) δ -157.0 (d, *J* = 22.1 Hz).

HRMS (ESI): *m/z* for $C_{33}H_{31}FNaO_6^+$ $[M+Na]^+$ calcd.: 565.1997, found: 565.1985.

ethyl (*R*)-1-((*R*)-1-fluoro-1-phenylallyl)-2-oxocyclohexane-1-carboxylate (3bd)



3bd

96%, 6:1 dr
(determined by NMR)

79%, 98:2 er
single diastereomer
(after isolation)

The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.400 mmol scale with the catalyst loading increased to 5.00 mol%. Catalyst **C21'** (**Cω'**) was used in place of catalyst **C21** (**Cω**). The reaction temperature was increased to 0 °C for this nucleophile. Reaction time: 72 h. After this time, the reaction mixture was transferred to a separatory funnel with diethyl ether (100 mL) and was washed with water (2 x 50 mL), 1 M HCl (1 x 50 mL), saturated $NaHCO_3$ (2 x 50 mL), and brine (1 x 50 mL). The organic layer was dried over sodium sulfate, filtered, and concentrated *in vacuo* to provide a yellow-brown oil. Trichloroethylene (72.0 µL, 0.802 mmol, 2.01 equiv) was added as an internal standard and the entire mixture was dissolved in $CDCl_3$ (8 mL). An aliquot was removed and was analyzed by ^{1}H NMR to establish a chemical yield of 96% and diastereomeric ratio of 6:1. The NMR sample and bulk sample were combined, dried *in vacuo*, and purified by silica gel column

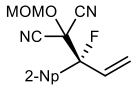
chromatography (2/98 to 15/85 of ethyl acetate/hexanes) to provide allylic fluoride **3bd** as a clear oil and as a single diastereomer (96.5 mg, 0.317 mmol, 79%). Note: the diastereomers do not visibly separate on TLC, so an aliquot of each fraction containing the product was analyzed by ^{1}H NMR prior to combining fractions.

The **enantiomeric ratio** was determined to be 98:2 by HPLC analysis with t_R = 17.39 min (major) and t_R = 19.96 min (minor) [OJ, 0.1% *i*PrOH in hexanes, 1.0 mL/min, 190 nm, 25 °C].

[α]$_D^{25}$ = +134° (c 0.53, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +138° (c 0.53, $CHCl_3$).

All other characterization data matched with the literature, and the absolute configuration is opposite that of our previous work.[2]

(*R*)-2-(1-fluoro-1-(naphthalen-2-yl)allyl)-2-(methoxymethoxy)malononitrile (3ae)



3ae
98%, 94:6 er

The title compound was prepared according to the general procedure for the allylic alkylation of malononitriles on a 0.100 mmol scale. The product was purified by preparative thin-layer chromatography (30/70 of diethyl ether/hexanes) to provide allylic fluoride **3ae** as an amorphous white solid (30.3 mg, 0.0976 mmol, 98%).

The **enantiomeric ratio** was determined to be 94:6 by HPLC analysis with t_R = 12.0 min (minor) and t_R = 12.8 min (major) [OD-H, 1.0% *i*PrOH in hexanes, 0.7 mL/min, 260 nm, 25 °C].

[α]$_D^{25}$ = +52.3° (c 0.61, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +59.8° (c 0.61, $CHCl_3$).

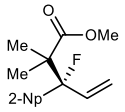
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.10 (s, 1H), 7.96 – 7.85 (m, 3H), 7.64 (dd, *J* = 8.7, 1.9 Hz, 1H), 7.59 – 7.54 (m, 2H), 6.60 (ddd, *J* = 20.5, 17.1, 11.1 Hz, 1H), 5.87 (d, *J* = 17.0 Hz, 1H), 5.71 (dd, *J* = 11.1, 2.3 Hz, 1H), 5.05 (AB, *J* = 7.0 Hz, 2H), 3.43 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 133.7, 132.7 (d, *J* = 1.5 Hz), 131.4 (d, *J* = 21.5 Hz), 130.9 (d, *J* = 17.6 Hz), 128.9, 128.3 (d, *J* = 1.7 Hz), 127.8, 127.6, 126.9, 126.7 (d, *J* = 11.1 Hz), 123.4 (d, *J* = 8.9 Hz), 121.6 (d, *J* = 12.7 Hz), 111.5, 111.1, 97.0, 96.6 (d, *J* = 197.0 Hz), 72.9 (d, *J* = 35.4 Hz), 57.7.

^{19}F NMR (565 MHz, $CDCl_3$) δ -159.0 (d, *J* = 20.5 Hz).

HRMS (EI): *m/z* for $C_{18}H_{15}FN_2O_2$ $[M]^+$ calcd.: 310.1118, found: 310.1120.

methyl (*R*)-3-fluoro-2,2-dimethyl-3-(naphthalen-2-yl)pent-4-enoate (3af)



3af
99%, 90:10 er

The title compound was prepared according to the general procedure for the allylic alkylation of silyl ketene acetals with a reaction time of 48 h and using 21.0 mg (0.103 mmol) of 2-(1,1-difluoroallyl)naphthalene. The product was purified by preparative TLC on silica (7/93 ethyl acetate/hexanes) to provide allylic fluoride **3af** as a clear oil (29.3 mg, 0.102 mmol, 99%).

The **enantiomeric ratio** was determined to be 90:10 by HPLC analysis with t_R = 6.3 min (major) and t_R = 7.1 min (minor) [AD-H, 2.0% *i*PrOH in hexanes, 0.8 mL/min, 278 nm, 25 °C].

$[\alpha]_D^{25}$ = +85.3° (c 0.15, $CHCl_3$). *Corrected for enantiopurity:* **$[\alpha]_D^{25}$** = +107° (c 0.15, $CHCl_3$).

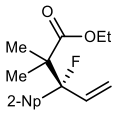
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.87 – 7.78 (m, 4H), 7.53 – 7.45 (m, 2H), 7.41 (dd, *J* = 8.6, 1.9 Hz, 1H), 6.78 (ddd, *J* = 23.0, 17.0, 11.1 Hz, 1H), 5.48 (d, *J* = 17.0 Hz, 1H), 5.34 (d, *J* = 11.1 Hz, 1H), 3.60 (s, 3H), 1.34 (s, 3H), 1.25 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 175.1 (d, *J* = 5.7 Hz), 137.8 (d, *J* = 23.1 Hz), 136.4 (d, *J* = 19.0 Hz), 132.8 (d, *J* = 1.5 Hz), 132.8, 128.5, 127.6, 127.4 (d, *J* = 2.1 Hz), 126.4, 126.4, 125.1 (d, *J* = 11.4 Hz), 123.8 (d, *J* = 9.8 Hz), 115.5 (d, *J* = 14.8 Hz), 98.8 (d, *J* = 190.9 Hz), 52.0, 51.4 (d, *J* = 24.8 Hz), 21.8 (d, *J* = 4.1 Hz), 20.7 (d, *J* = 5.7 Hz).

^{19}F NMR (565 MHz, $CDCl_3$) δ -165.9 (d, *J* = 22.8 Hz).

HRMS (ESI): *m/z* for $C_{18}H_{19}FNaO_2^+$ $[M+Na]^+$ calcd.: 309.1261, found: 309.1262

ethyl (*R*)-3-fluoro-2,2-dimethyl-3-(naphthalen-2-yl)pent-4-enoate (3ag)



3ag
95%, 91:9 er

The title compound was prepared according to the general procedure for the allylic alkylation of silyl ketene acetals with a reaction time of 48 h and using 20.6 mg (0.101 mmol) of 2-(1,1-

difluoroallyl)naphthalene. The product was purified by preparative TLC on silica (7/93 ethyl acetate/hexanes) to provide allylic fluoride **3ag** as a clear oil (28.8 mg, 0.0959 mmol, 95%).

The **enantiomeric ratio** was determined to be 91:9 by HPLC analysis with t_R = 6.0 min (major) and t_R = 6.6 min (minor) [AD-H, 2.0% *i*PrOH in hexanes, 0.8 mL/min, 260 nm, 25 °C].

[α]$_D^{25}$ = +90.1° (c 0.12, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +110° (c 0.12, $CHCl_3$).

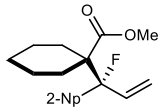
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.86 – 7.78 (m, 4H), 7.51 – 7.46 (m, 2H), 7.44 (dd, *J* = 8.7, 1.9 Hz, 1H), 6.79 (ddd, *J* = 22.9, 17.0, 11.1 Hz, 1H), 5.48 (dd, *J* = 17.0, 1.4 Hz, 1H), 5.33 (ddd, *J* = 11.2, 2.9, 1.4 Hz, 1H), 4.11 – 4.02 (m, 2H), 1.34 (s, 3H), 1.25 (d, *J* = 1.6 Hz, 3H), 1.13 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 174.6 (d, *J* = 5.9 Hz), 137.9 (d, *J* = 23.1 Hz), 136.6 (d, *J* = 19.0 Hz), 132.8 (d, *J* = 1.6 Hz), 132.7, 128.5, 127.6, 127.3 (d, *J* = 2.1 Hz), 126.4, 126.3, 125.1 (d, *J* = 11.5 Hz), 123.9 (d, *J* = 9.6 Hz), 115.4 (d, *J* = 14.6 Hz), 98.8 (d, *J* = 190.5 Hz), 61.0, 51.2 (d, *J* = 24.7 Hz), 21.9 (d, *J* = 4.2 Hz), 20.8 (d, *J* = 5.7 Hz), 14.1.

^{19}F NMR (376 MHz, $CDCl_3$) δ -164.0 (d, *J* = 22.8 Hz).

HRMS (ESI): *m/z* for $C_{19}H_{21}FNaO_2^+$ $[M+Na]^+$ calcd.: 323.1418, found: 323.1418.

methyl (*R*)-1-(1-fluoro-1-(naphthalen-2-yl)allyl)cyclohexane-1-carboxylate (3ah)



3ah
93%, 88:12 er

The title compound was prepared according to the general procedure for the allylic alkylation of silyl ketene acetals with a reaction time of 48 h and using 21.0 mg (0.103 mmol) of 2-(1,1-difluoroallyl)naphthalene. The product was purified by preparative TLC on silica (7/93 ethyl acetate/hexanes) to provide allylic fluoride **3ah** as a clear oil (31.3 mg, 0.0959 mmol, 93%).

The **enantiomeric ratio** was determined to be 88:12 by HPLC analysis with t_R = 6.9 min (major) and t_R = 7.7 min (minor) [AD-H, 2.0% *i*PrOH in hexanes, 0.8 mL/min, 260 nm, 25 °C].

[α]$_D^{25}$ = +59.3° (c 0.10, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +78.0° (c 0.10, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.86 – 7.81 (m, 2H), 7.79 (d, *J* = 8.7 Hz, 1H), 7.75 (s, 1H), 7.51 – 7.46 (m, 2H), 7.35 (dd, *J* = 8t.7, 1.9 Hz, 1H), 6.70 (ddd, *J* = 23.4, 17.0, 11.1 Hz, 1H), 5.45 (dd, *J* = 17.0, 1.4 Hz, 1H), 5.31 (ddd, *J* = 11.1, 3.2, 1.4 Hz, 1H), 3.58 (s, 3H), 2.40 – 2.34 (m, 1H), 2.12 – 2.07 (m, 1H), 1.71 – 1.61 (m, 2H), 1.59 – 1.54 (m, 1H), 1.50 (td, *J* = 13.2, 4.0 Hz, 1H), 1.39 (td,

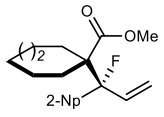
J = 13.2, 3.8 Hz, 1H), 1.22 (qt, *J* = 13.4, 3.8 Hz, 1H), 1.15 (qt, *J* = 13.3, 2.9 Hz, 1H), 1.05 (qt, *J* = 13.1, 3.6 Hz, 1H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 173.5 (d, *J* = 4.7 Hz), 137.7 (d, *J* = 23.5 Hz), 136.2 (d, *J* = 18.8 Hz), 132.7, 128.4, 127.6, 127.2, 127.1, 126.4, 126.4, 125.1 (d, *J* = 11.5 Hz), 124.0 (d, *J* = 9.7 Hz), 115.3 (d, *J* = 15.0 Hz), 98.8 (d, *J* = 192.3 Hz), 56.9 (d, *J* = 23.1 Hz), 51.6, 29.6 (d, *J* = 3.5 Hz), 28.4 (d, *J* = 5.5 Hz), 25.4, 23.7, 23.6.

^{19}F NMR (565 MHz, $CDCl_3$) δ -166.6 (d, *J* = 23.3 Hz).

HRMS (ESI): *m/z* for $C_{21}H_{23}FNaO_2^+$ $[M+Na]^+$ calcd.: 349.1574, found: 349.1570.

methyl (*R*)-1-(1-fluoro-1-(naphthalen-2-yl)allyl)cycloheptane-1-carboxylate (3ai)



3ai
94%, 82:18 er

The title compound was prepared according to the general procedure for the allylic alkylation of silyl ketene acetals with a reaction time of 96 h and using 20.4 mg (0.100 mmol) of 2-(1,1-difluoroallyl)naphthalene. The product was purified by preparative TLC on silica (7/93 ethyl acetate/hexanes) to provide allylic fluoride **3ai** as a clear oil (32.1 mg, 0.0943 mmol, 94%).

The **enantiomeric ratio** was determined to be 82:18 by HPLC analysis with t_R = 9.9 min (minor) and t_R = 10.8 min (major) [OD-H, 0.3% *i*PrOH in hexanes, 0.8 mL/min, 260 nm, 25 °C].

$[\alpha]_D^{25}$ = +56.2° (c 0.11, $CHCl_3$). *Corrected for enantiopurity:* **$[\alpha]_D^{25}$** = +87.8° (c 0.11, $CHCl_3$).

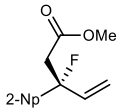
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.86 – 7.79 (m, 2H), 7.79 (d, *J* = 8.7 Hz, 1H), 7.77 (s, 1H), 7.51 – 7.46 (m, 2H), 7.35 (dd, *J* = 8.7, 1.9 Hz, 1H), 6.72 (ddd, *J* = 23.5, 17.0, 11.1 Hz, 1H), 5.44 (dd, *J* = 17.0, 1.4 Hz, 1H), 5.30 (ddd, *J* = 11.2, 3.3, 1.4 Hz, 1H), 3.62 (s, 3H), 2.32 (dd, *J* = 14.6, 8.5 Hz, 1H), 2.12 (dd, *J* = 14.6, 8.2 Hz, 1H), 1.88 (ddd, *J* = 14.8, 10.2, 1.7 Hz, 1H), 1.82 (ddd, *J* = 14.8, 10.0, 1.9 Hz, 1H), 1.62 – 1.51 (m, 2H), 1.50 – 1.26 (m, 6H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 174.8 (d, *J* = 6.6 Hz), 138.1 (d, *J* = 23.1 Hz), 136.9 (d, *J* = 18.8 Hz), 132.8 (d, *J* = 1.5 Hz), 132.7, 128.5, 127.6, 127.3 (d, *J* = 2.1 Hz), 126.4, 126.4, 125.2 (d, *J* = 11.7 Hz), 123.9 (d, *J* = 9.8 Hz), 115.1 (d, *J* = 15.0 Hz), 99.9 (d, *J* = 193.3 Hz), 59.4 (d, *J* = 22.6 Hz), 51.8, 32.3 (d, *J* = 3.0 Hz), 31.4 (d, *J* = 4.4 Hz), 29.6, 29.5, 24.2, 24.0.

^{19}F NMR (565 MHz, $CDCl_3$) δ -165.1 (d, *J* = 23.6 Hz).

HRMS (ESI): *m/z* for $C_{22}H_{25}FNaO_2^+$ $[M+Na]^+$ calcd.: 363.1731, found: 363.1732.

methyl (*R*)-3-fluoro-3-(naphthalen-2-yl)pent-4-enoate (3aj)



3aj
74%, 92:8 er

The title compound was prepared according to the general procedure for the allylic alkylation of silyl ketene acetals with a reaction time of 53 h and using 20.4 mg (0.100 mmol) of 2-(1,1-difluoroallyl)naphthalene. For this silyl ketene acetal, the corresponding TBS-silyl ketene acetal was used instead of the TMS-silyl ketene acetal. Sodium diethyl methyl malonate was not added to this reaction. The product was purified by column chromatography on silica (1/99 to 10/90 ethyl acetate/hexanes) to provide allylic fluoride **3aj** as a clear oil (19.0 mg, 0.0736 mmol, 74%).

The **enantiomeric ratio** was determined to be 92:8 by HPLC analysis with t_R = 13.2 min (minor) and t_R = 16.0 min (major) [OD-H, 2.0% *i*PrOH in hexanes, 0.75 mL/min, 260 nm, 25 °C].

$[\alpha]_D^{25}$ = +19.4° (c 0.38, $CHCl_3$). *Corrected for enantiopurity:* **$[\alpha]_D^{25}$** = +23.1° (c 0.38, $CHCl_3$).

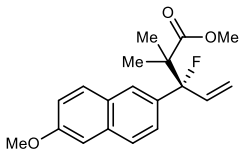
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.88 – 7.76 (m, 4H), 7.51 – 7.41 (m, 3H), 6.34 (td, *J* = 17.2, 11.0 Hz, 1H), 5.40 (dt, *J* = 17.3, 1.2 Hz, 1H), 5.30 (d, *J* = 10.9 Hz, 1H), 3.57 (s, 3H), 3.19 (s, 1H), 3.15 (s, 1H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 169.2 (d, *J* = 3.7 Hz), 138.5 (d, *J* = 22.2 Hz), 138.4 (d, J = 22.3 Hz), 133.1, 133.0, 128.5, 128.4, 127.7, 126.4, 126.5, 123.9 (d, *J* = 9.5 Hz), 122.9 (d, *J* = 7.6 Hz), 115.8 (d, *J* = 11.6 Hz), 95.6 (d, *J* = 180.4 Hz), 51.9, 45.4 (d, *J* = 25.4 Hz).

^{19}F NMR (565 MHz, $CDCl_3$) δ -150.9 (q, *J* = 20.0 Hz).

HRMS (EI): *m/z* for $C_{16}H_{15}FO_2$ $[M]^+$ calcd.: 258.1056, found: 258.1056.

methyl (*R*)-3-fluoro-3-(6-methoxynaphthalen-2-yl)-2,2-dimethylpent-4-enoate (3jf)

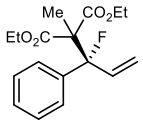


3jf
98%, 92:8 er

The synthesis of compound **3jf** is discussed in the section regarding the synthesis of F-methallenstril.

CHARACTERIZATION OF ALLYLIC FLUOROALKYLATION PRODUCTS – SCOPE OF ELECTROPHILES

diethyl (*R*)-2-(1-fluoro-1-phenylallyl)-2-methylmalonate (3ba)



3ba
84%, 96:4 er

The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.100 mmol scale. Reaction time: 72 h. Reaction temperature: –10 °C. The product was purified by preparative TLC (1/99 of diethyl ether/benzene) to provide allylic fluoride **3ba** as a clear oil (26.0 mg, 0.0843 mmol, 84%).

The **enantiomeric ratio** was determined to be 96:4 by HPLC analysis with t_R = 22.4 min (minor) and t_R = 27.6 min (major) [OD-H, 0.1% *i*PrOH in hexanes, 0.7 mL/min, 214 nm, 25 °C].

[α]$_D^{25}$ = +58.3° (c 0.59, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +63.4° (c 0.59, $CHCl_3$).

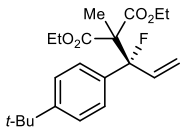
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.52 – 7.49 (m, 2H), 7.33 – 7.25 (m, 3H), 6.93 (ddd, *J* = 22.3, 17.1, 11.1 Hz, 1H), 5.40 (dd, *J* = 17.1, 1.3 Hz, 1H), 5.29 (ddd, *J* = 11.1, 2.6, 1.4 Hz, 1H), 4.17 (q, *J* = 7.1 Hz, 2H), 4.12 – 4.01 (m, 2H), 1.52 (d, *J* = 1.4 Hz, 3H), 1.22 (t, *J* = 7.1 Hz, 3H), 1.11 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 169.5 (d, *J* = 4.3 Hz), 169.1 (d, *J* = 6.9 Hz), 139.9 (d, *J* = 22.8 Hz), 137.1 (d, *J* = 18.0 Hz), 128.0, 127.7 (d, *J* = 2.0 Hz), 126.6 (d, *J* = 11.0 Hz), 115.7 (d, *J* = 14.8 Hz), 97.3 (d, *J* = 189.4 Hz), 62.7 (d, *J* = 26.5 Hz), 61.6, 61.5, 18.1 (d, *J* = 5.8 Hz), 14.1, 13.8.

^{19}F NMR (376 MHz, $CDCl_3$) δ -158.3 (d, *J* = 22.4 Hz).

HRMS (ESI): *m/z* for $C_{17}H_{21}FNaO_4^+$ $[M+Na]^+$ calcd.: 331.1316, found: 331.1317.

diethyl (*R*)-2-(1-(4-(tert-butyl)phenyl)-1-fluoroallyl)-2-methylmalonate (3ca)



3ca
89%, 95:5 er

The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.100 mmol scale. Reaction time: 72 h. Reaction temperature:

–10 °C. The product was purified by preparative TLC (1/99 of diethyl ether/benzene) to provide allylic fluoride **3ca** as a clear oil (32.5 mg, 0.0892 mmol, 89%).

The **enantiomeric ratio** was determined to be 95:5 by HPLC analysis with t_R = 18.2 min (minor) and t_R = 21.4 min (major) [OD-H, 0.1% *i*PrOH in hexanes, 0.7 mL/min, 214 nm, 25 °C].

[α]$_D^{25}$ = +59.1° (c 0.11, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +65.7° (c 0.11, $CHCl_3$).

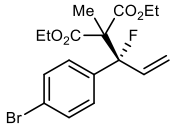
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.42 (d, *J* = 8.7 Hz, 2H), 7.32 (d, *J* = 8.4 Hz, 2H), 6.92 (ddd, *J* = 22.6, 17.2, 11.1 Hz, 1H), 5.40 (dd, *J* = 17.1, 1.4 Hz, 1H), 5.27 (ddd, *J* = 11.1, 2.7, 1.4 Hz, 1H), 4.16 (q, *J* = 7.1 Hz, 2H), 4.10 – 4.00 (m, 2H), 1.53 (d, *J* = 1.4 Hz, 3H), 1.29 (s, 9H), 1.21 (t, *J* = 7.1 Hz, 3H), 1.09 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 169.5 (d, *J* = 4.0 Hz), 169.2 (d, *J* = 6.6 Hz), 150.8, 137.1 (d, *J* = 18.0 Hz), 136.8 (d, *J* = 23.2 Hz), 126.3 (d, *J* = 10.8 Hz), 124.7 (d, *J* = 1.5 Hz), 115.3 (d, *J* = 14.8 Hz), 97.4 (d, *J* = 189.1 Hz), 62.8 (d, *J* = 26.7 Hz), 61.5, 61.4, 34.6, 31.4, 18.0 (d, *J* = 6.0 Hz), 14.1, 13.8.

^{19}F NMR (376 MHz, $CDCl_3$) δ -158.3 (d, *J* = 22.4 Hz).

HRMS (ESI): *m/z* for $C_{21}H_{29}FNaO_4^+$ $[M+Na]^+$ calcd.: 387.1942, found: 387.1944.

diethyl (*R*)-2-(1-(4-bromophenyl)-1-fluoroallyl)-2-methylmalonate (3da)



3da
96%, 96:4 er

The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.100 mmol scale. Reaction time: 72 h. Reaction temperature: –10 °C. The product was purified by preparative TLC (1/99 of diethyl ether/benzene) to provide allylic fluoride **3da** as a clear oil (37.0 mg, 0.0955 mmol, 96%).

The **enantiomeric ratio** was determined to be 96:4 by HPLC analysis with t_R = 11.5 min (major) and t_R = 14.0 min (minor) [OD-H, 1.0% *i*PrOH in hexanes, 0.75 mL/min, 230 nm, 25 °C].

[α]$_D^{25}$ = +61.5° (c 0.16, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +66.8° (c 0.16, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.44 (d, *J* = 8.6 Hz, 2H), 7.40 (d, *J* = 8.8 Hz, 2H), 6.86 (ddd, *J* = 22.3, 17.1, 11.1 Hz, 1H), 5.39 (dd, *J* = 17.1, 1.2 Hz, 1H), 5.30 (ddd, *J* = 11.1, 2.6, 1.2 Hz, 1H),

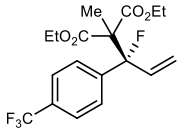
4.16 (q, *J* = 7.1 Hz, 2H), 4.11 – 4.00 (m, 2H), 1.51 (d, *J* = 1.3 Hz, 3H), 1.22 (t, *J* = 7.1 Hz, 3H), 1.12 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 169.3 (d, *J* = 5.0 Hz), 169.0 (d, *J* = 6.6 Hz), 139.1 (d, *J* = 23.4 Hz), 136.5 (d, *J* = 17.9 Hz), 130.8 (d, *J* = 1.9 Hz), 128.6 (d, *J* = 11.0 Hz), 122.3 (d, *J* = 2.0 Hz), 116.1 (d, *J* = 14.7 Hz), 97.2 (d, *J* = 189.3 Hz), 62.5 (d, *J* = 26.6 Hz), 61.7, 61.6, 18.0 (d, *J* = 5.7 Hz), 14.1, 13.9.

^{19}F NMR (376 MHz, $CDCl_3$) δ -158.2 (d, *J* = 22.2 Hz).

HRMS (ESI): *m/z* for $C_{17}H_{20}{}^{79}BrFNaO_4^+$ $[M+Na]^+$ calcd.: 409.0421, found: 409.0425.

diethyl (*R*)-2-(1-fluoro-1-(4-(trifluoromethyl)phenyl)allyl)-2-methylmalonate (3ea)



3ea
96%, 97:3 er

The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.100 mmol scale. Reaction time: 72 h. Reaction temperature: –10 °C. The product was purified by preparative TLC (1/99 of diethyl ether/benzene) to provide allylic fluoride **3ea** as a clear oil (33.1 mg, 0.0880 mmol, 88%).

The **enantiomeric ratio** was determined to be 97:3 by HPLC analysis with t_R = 7.81 min (minor) and t_R = 8.32 min (major) [IA, 0.1% *i*PrOH in hexanes, 1.0 mL/min, 227 nm, 25 °C].

$[\alpha]_D^{25}$ = +64.1° (c 0.18, $CHCl_3$). *Corrected for enantiopurity:* **$[\alpha]_D^{25}$** = +68.2° (c 0.18, $CHCl_3$).

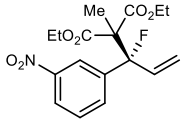
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.67 (d, *J* = 8.4 Hz, 2H), 7.58 (d, *J* = 8.4 Hz, 2H), 6.90 (ddd, *J* = 22.5, 17.1, 11.1 Hz, 1H), 5.41 (d, *J* = 17.1 Hz, 1H), 5.33 (ddd, *J* = 11.1, 2.7, 1.2 Hz, 1H), 4.18 (q, *J* = 7.1 Hz, 2H), 4.11 – 3.98 (m, 2H), 1.53 (d, *J* = 1.4 Hz, 3H), 1.22 (t, *J* = 7.1 Hz, 3H), 1.08 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 169.2 (d, *J* = 6.0 Hz), 168.9 (d, *J* = 6.1 Hz), 144.1 (d, *J* = 23.3 Hz), 136.3 (d, *J* = 17.8 Hz), 130.2 (q, *J* = 32.1 Hz), 127.2 (d, *J* = 11.4 Hz), 124.7 (dq, *J* = 5.9, 2.9 Hz), 124.2 (q, *J* = 272.1 Hz), 116.4 (d, *J* = 14.8 Hz), 97.2 (d, *J* = 189.8 Hz), 62.5 (d, *J* = 26.9 Hz), 61.8, 61.6, 18.1 (d, *J* = 5.6 Hz), 14.1, 13.8.

^{19}F NMR (565 MHz, $CDCl_3$) δ -63.7 (3F), -160.5 (d, *J* = 22.5 Hz, 1F).

HRMS (ESI): *m/z* for $C_{18}H_{20}F_4NaO_4^+$ $[M+Na]^+$ calcd.: 399.1190, found: 399.1190.

diethyl (*R*)-2-(1-fluoro-1-(3-nitrophenyl)allyl)-2-methylmalonate (3fa)



3fa
97%, 96:4 er

The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.100 mmol scale. Reaction time: 72 h. Reaction temperature: –10 °C. The product was purified by preparative TLC (1/99 of diethyl ether/benzene) to provide allylic fluoride **3fa** as a clear oil (34.1 mg, 0.0965 mmol, 97%).

The **enantiomeric ratio** was determined to be 96:4 by HPLC analysis with t_R = 11.2 min (minor) and t_R = 12.8 min (major) [AD-H, 1.0% *i*PrOH in hexanes, 0.8 mL/min, 214 nm, 25 °C].

[α]$_D^{25}$ = +65.9° (c 0.22, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +71.6° (c 0.22, $CHCl_3$).

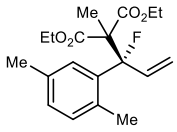
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.41 (t, *J* = 2.1 Hz, 1H), 8.16 (ddd, *J* = 8.2, 2.3, 1.0 Hz, 1H), 7.89 (ddd, *J* = 8.0, 1.8, 1.0 Hz, 1H), 7.51 (t, *J* = 8.1 Hz, 1H), 6.87 (ddd, *J* = 22.6, 17.1, 11.1 Hz, 1H), 5.45 (dd, *J* = 17.1, 1.1 Hz, 1H), 5.37 (ddd, *J* = 11.1, 2.8, 1.1 Hz, 1H), 4.19 (q, *J* = 7.1 Hz, 2H), 4.14 – 4.00 (m, 2H), 1.55 (d, *J* = 1.4 Hz, 3H), 1.22 (t, *J* = 7.2 Hz, 3H), 1.10 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 169.1 (d, *J* = 6.6 Hz), 168.7 (d, *J* = 5.4 Hz), 147.8 (d, *J* = 2.1 Hz), 142.4 (d, *J* = 23.9 Hz), 135.8 (d, *J* = 17.8 Hz), 133.0 (d, *J* = 11.0 Hz), 128.7 (d, *J* = 1.9 Hz), 123.0, 122.2 (d, *J* = 12.0 Hz), 117.0 (d, *J* = 14.6 Hz), 96.9 (d, *J* = 190.7 Hz), 62.5 (d, *J* = 26.5 Hz), 62.0, 61.8, 18.2 (d, *J* = 5.3 Hz), 14.0, 13.8.

^{19}F NMR (376 MHz, $CDCl_3$) δ -158.4 (d, *J* = 22.7 Hz).

HRMS (ESI): *m/z* for $C_{17}H_{20}FNNaO_6^+$ $[M+Na]^+$ calcd.: 376.1167, found: 376.1167.

diethyl (*R*)-2-(1-(2,5-dimethylphenyl)-1-fluoroallyl)-2-methylmalonate (3ga)



3ga
95%, 94:6 er

The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.100 mmol scale. Reaction time: 72 h. Reaction temperature:

–10 °C. The product was purified by preparative TLC (1/99 of diethyl ether/benzene) to provide allylic fluoride **3ga** as a clear oil (32.0 mg, 0.0951 mmol, 95%).

The **enantiomeric ratio** was determined to be 94:6 by HPLC analysis with t_R = 8.9 min (minor) and t_R = 10.3 min (major) [OD-H, 0.3% *i*PrOH in hexanes, 0.8 mL/min, 214 nm, 25 °C].

$[\alpha]_D^{25}$ = +58.9° (c 0.18, $CHCl_3$). *Corrected for enantiopurity:* **$[\alpha]_D^{25}$** = +66.9° (c 0.18, $CHCl_3$).

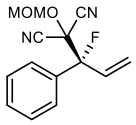
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.06 (s, 1H), 7.00 (d, *J* = 7.8 Hz, 1H), 6.95 (d, *J* = 7.7 Hz, 1H), 6.88 – 6.78 (m, 1H), 5.31 – 5.27 (m, 2H), 4.19 – 4.08 (m, 4H), 2.39 (d, *J* = 7.8 Hz, 3H), 2.26 (s, 3H), 1.61 (d, *J* = 1.3 Hz, 3H), 1.18 (t, *J* = 7.1 Hz, 3H), 1.17 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 169.8 (d, *J* = 3.8 Hz), 169.6 (d, *J* = 7.5 Hz), 138.1 (d, *J* = 20.1 Hz), 137.5 (d, *J* = 22.0 Hz), 134.2 (d, *J* = 1.5 Hz), 133.8, 133.0, 128.6, 128.2 (d, *J* = 8.3 Hz), 115.7 (d, *J* = 13.7 Hz), 100.5 (d, *J* = 190.9 Hz), 63.4 (d, *J* = 25.9 Hz), 61.7, 61.6, 22.7 (d, *J* = 14.1 Hz), 21.2, 18.9 (d, *J* = 5.0 Hz), 14.0, 13.9.

^{19}F NMR (376 MHz, $CDCl_3$) δ -152.2 (br s).

HRMS (ESI): *m/z* for $C_{19}H_{25}FNaO_4^+$ $[M+Na]^+$ calcd.: 359.1629, found: 359.1630.

(*R*)-2-(1-fluoro-1-phenylallyl)-2-(methoxymethoxy)malononitrile (3be)



3be
97%, 93:7 er, *335 mg*

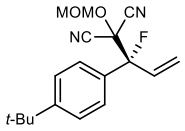
The title compound was prepared according to the general procedure for the allylic alkylation of malononitriles on a 1.332 mmol scale (200.0 mg of $PhCF_2CH{=}CH_2$). The product was purified by silica gel column chromatography (0/100 to 20/80 of ethyl acetate/hexanes) to provide allylic fluoride **3be** as a clear oil (335.3 mg, 1.288 mmol, 97%).

The **enantiomeric ratio** was determined to be 93:7 by HPLC analysis with t_R = 12.8 min (minor) and t_R = 13.6 min (major) [OD-H, 0.3% *i*PrOH in hexanes, 1.0 mL/min, 220 nm, 25 °C].

$[\alpha]_D^{25}$ = +29.6° (c 0.32, $CHCl_3$) *Corrected for enantiopurity:* **$[\alpha]_D^{25}$** = +34.4° (c 0.32, $CHCl_3$).

All other characterization data matched with the literature, and the absolute configuration is opposite that of our previous work.[2]

(*R*)-2-(1-(4-bromophenyl)-1-fluoroallyl)-2-(methoxymethoxy)malononitrile (3ce)



3ce
84%, 94:6 er

The title compound was prepared according to the general procedure for the allylic alkylation of malononitriles on a 0.100 mmol scale. The product was purified by preparative thin-layer chromatography (30/70 of diethyl ether/hexanes) to provide allylic fluoride **3ce** as clear oil (26.5 mg, 0.0838 mmol, 84%).

The **enantiomeric ratio** was determined to be 94:6 by HPLC analysis with t_R = 25.2 min (major) and t_R = 29.2 min (minor) [OD-H, hexanes, 0.8 mL/min, 210 nm, 25 °C].

$[\alpha]_D^{25}$ = +22.5° (c 0.61, $CHCl_3$). *Corrected for enantiopurity:* **$[\alpha]_D^{25}$** = +25.8° (c 0.61, $CHCl_3$).

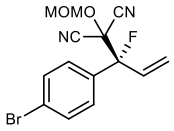
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.50 (d, *J* = 8.7 Hz, 2H), 7.45 (d, *J* = 8.5 Hz, 2H), 6.47 (ddd, *J* = 20.8, 17.1, 11.1 Hz, 1H), 5.80 (d, *J* = 17.1 Hz, 1H), 5.64 (dd, *J* = 11.1, 2.4 Hz, 1H), 5.03 (AB, *J* = 7.2 Hz, 2H), 3.44 (s, 3H), 1.33 (s, 9H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 153.2, 131.0 (d, *J* = 21.9 Hz), 131.0 (d, *J* = 17.5 Hz)126.3 (d, *J* = 9.5 Hz), 125.5 (d, *J* = 1.8 Hz), 121.0 (d, *J* = 12.8 Hz), 111.6, 111.1, 96.9, 96.4 (d, *J* = 196.5 Hz), 72.8 (d, *J* = 35.8 Hz), 57.6, 34.9, 31.3.

^{19}F NMR (565 MHz, $CDCl_3$) -160.02 (d, *J* = 21.1 Hz).

All characterization data matched with the literature, and the absolute configuration is opposite that of our previous work.[2]

(*R*)-2-(1-(4-bromophenyl)-1-fluoroallyl)-2-(methoxymethoxy)malononitrile (3de)



3de
92%, 94:6 er

The title compound was prepared according to the general procedure for the allylic alkylation of malononitriles on a 0.100 mmol scale. The product was purified by preparative thin-layer chromatography (30/70 of diethyl ether/hexanes) to provide allylic fluoride **3de** as clear oil (31.3 mg, 0.0923 mmol, 92%).

The **enantiomeric ratio** was determined to be 94:6 by HPLC analysis with t_R = 13.0 min (major) and t_R = 14.5 min (minor) [AS-H, hexanes, 0.8 mL/min, 210 nm, 25 °C].

[α]$_D^{25}$ = +34.6° (c 0.50, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +39.7° (c 0.50, $CHCl_3$).

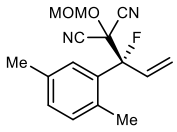
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.59 (d, *J* = 8.3 Hz, 2H), 7.45 (d, *J* = 8.8 Hz, 2H), 6.42 (ddd, *J* = 20.5, 17.0, 11.1 Hz, 1H), 5.82 (d, *J* = 17.0 Hz, 1H), 5.68 (dd, *J* = 11.1, 2.3 Hz, 1H), 5.05 (dd, *J* = 7.0, 0.8 Hz, 1H (leaning)), 5.02 (dd, *J* = 7.0, 0.8 Hz, 1H (leaning)), 3.44 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 133.1 (d, *J* = 22.0 Hz), 131.8 (d, *J* = 2.0 Hz), 130.3 (d, *J* = 17.4 Hz), 128.3 (d, *J* = 9.9 Hz), 124.8 (d, *J* = 1.3 Hz), 121.9 (d, *J* = 12.7 Hz), 111.2, 110.9, 97.0, 96.2 (d, *J* = 197.4 Hz), 72.4 (d, *J* = 35.3 Hz), 57.7.

^{19}F NMR (565 MHz, $CDCl_3$) δ -159.8 (d, *J* = 20.5 Hz).

HRMS (EI): *m/z* for $C_{14}H_{12}{}^{79}BrFN_2O_2$ $[M]^+$ calcd.: 338.0066, found: 338.0059.

(*R*)-2-(1-(2,5-dimethylphenyl)-1-fluoroallyl)-2-(methoxymethoxy)malononitrile (3ge)



3ge
87%, 94:6 er

The title compound was prepared according to the general procedure for the allylic alkylation of malononitriles on a 0.100 mmol scale. The catalyst loading was increased to 5.0 mol% for this substrate, and the reaction time was extended to 48 h. The product was purified by silica gel column chromatography (0/100 to 30/70 of diethyl ether/hexanes) to provide allylic fluoride **3ge** as a clear oil (25.0 mg, 0.0867 mmol, 87%).

The **enantiomeric ratio** was determined to be 94:6 by HPLC analysis with t_R = 26.4 min (minor) and t_R = 27.3 min (major) [AD-H, 1.0% *i*PrOH in hexanes, 0.25 mL/min, 220 nm, 25 °C].

[α]$_D^{25}$ = +15.2° (c 0.60, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +17.3° (c 0.60, $CHCl_3$).

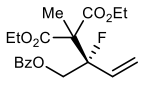
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.34 (s, 1H), 7.15 – 7.08 (m, 2H), 6.48 (ddd, *J* = 18.9, 17.1, 11.0 Hz, 1H), 5.72 (dd, *J* = 17.1, 0.6 Hz, 1H), 5.66 (dd, *J* = 11.1, 2.0 Hz, 1H), 5.09 (s, 2H), 3.50 (s, 3H), 2.47 (d, *J* = 6.4 Hz, 3H), 2.34 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 135.0 (d, *J* = 1.2 Hz), 134.8, 133.3, 132.0 (d, *J* = 19.4 Hz), 131.8 (d, *J* = 20.5 Hz), 130.6, 128.4 (d, *J* = 9.0 Hz), 121.6 (d, *J* = 12.5 Hz), 111.7 (d, *J* = 2.6 Hz), 111.4, 99.0 (d, *J* = 197.4 Hz), 96.9, 73.1 (d, *J* = 34.7 Hz), 57.7, 22.2 (d, *J* = 10.9 Hz), 21.2.

^{19}F NMR (565 MHz, $CDCl_3$) δ -151.1 (br s).

HRMS (EI): *m/z* for $C_{16}H_{17}FN_2O_2$ $[M]^+$ calcd.: 288.1274, found: 288.1270.

diethyl (*S*)-2-(1-(benzoyloxy)-2-fluorobut-3-en-2-yl)-2-methylmalonate (3ha)



3ha
71%, 99:1 er

The title compound was prepared according to the general procedure for the allylic alkylation of malonates and *β*-keto esters on a 0.200 mmol scale. The reaction temperature was increased to +65 °C for this electrophile and the catalyst loading was increased to 5 mol% of **C21** (**Cω**). Reaction time: 96 h. The product was purified by silica gel column chromatography (2/98 to 15/85 of ethyl acetate/hexanes) followed by preparative TLC (1/99 of diethyl ether/benzene, run up the plate twice) to provide allylic fluoride **3ha** as a clear oil (52.3 mg, 0.143 mmol, 71%).

The **enantiomeric ratio** was determined to be 99.3:0.7 by HPLC analysis with t_R = 20.3 min (minor) and t_R = 22.0 min (major) [AD-H, 1.0% *i*PrOH in hexanes, 0.7 mL/min, 230 nm, 25 °C].

$[\alpha]_D^{25}$ = +40.5° (c 0.31, $CHCl_3$). *Corrected for enantiopurity:* **$[\alpha]_D^{25}$** = +41.1° (c 0.31, $CHCl_3$).

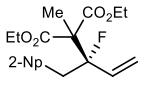
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.02 (d, *J* = 7.6 Hz, 2H), 7.55 (t, *J* = 7.4 Hz, 1H), 7.43 (t, *J* = 7.7 Hz, 2H), 6.11 (ddd, *J* = 23.3, 17.2, 11.2 Hz, 1H), 5.51 (dd, *J* = 17.3, 1.4 Hz, 1H), 5.38 (ddd, *J* = 11.2, 2.9, 1.4 Hz, 1H), 5.03 (dd, *J* = 32.1, 12.2 Hz, 1H), 4.85 (dd, *J* = 14.4, 12.2 Hz, 1H), 4.28 – 4.16 (m, 4H), 1.58 (d, *J* = 1.3 Hz, 3H), 1.29 (t, *J* = 7.1 Hz, 3H), 1.27 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 169.3 (d, *J* = 8.8 Hz), 169.0 (d, *J* = 2.7 Hz), 166.1, 133.2, 133.0 (d, *J* = 19.8 Hz), 130.1, 129.9, 128.5, 118.1 (d, *J* = 13.2 Hz), 96.9 (d, *J* = 192.3 Hz), 65.4 (d, *J* = 21.9 Hz), 62.1, 62.0, 59.6 (d, *J* = 23.3 Hz), 17.7 (d, *J* = 5.3 Hz), 14.1, 14.1.

^{19}F NMR (376 MHz, $CDCl_3$) δ -170.4 (ddd, *J* = 32.1, 23.2, 14.5 Hz).

HRMS (ESI): *m/z* for $C_{19}H_{23}FNaO_6^+$ $[M+Na]^+$ calcd.: 389.1371, found: 389.1365.

diethyl (*S*)-2-(2-fluoro-1-(naphthalen-2-yl)but-3-en-2-yl)-2-methylmalonate (3ia)



3ia
94%, 98:2 er

The title compound was prepared according to a procedure modified from the general procedure for the allylic alkylation of malonates with 2-(2,2-difluorobut-3-en-1-yl)naphthalene (40.0 mg, 0.183 mmol). The reaction was conducted with barium triflate as an additive (3.00 equiv) at a reaction concentration of 0.2 M in THF. The reaction was conducted at room temperature for 19 hours with 2.0 mol% **Cω**. After the reaction reached completion, the mixture was concentrated *in vacuo*, diluted with ethyl acetate, filtered, and concentrated *in vacuo*. The resulting residue was purified by preparative TLC (benzene) to provide allylic fluoride **3ia** as clear oil (64.2 mg, 0.172 mmol, 94%).

The **enantiomeric ratio** was determined to be 98:2 by HPLC analysis with t_R = 11.8 min (major) and t_R = 16.4 min (minor) [AD-H, hexanes, 1.0 mL/min, 220 nm, 25 °C].

[α]$_D^{25}$ = +70.5° (c 0.13, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +73.4° (c 0.13, $CHCl_3$).

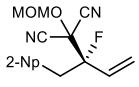
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.81 – 7.76 (m, 2H), 7.72 (d, *J* = 8.4 Hz, 1H), 7.63 (s, 1H), 7.47 – 7.40 (m, 2H), 7.34 (dt, *J* = 8.4, 1.6 Hz, 1H), 6.08 (ddd, *J* = 24.1, 17.3, 11.3 Hz, 1H), 4.99 (ddd, *J* = 11.3, 3.0, 1.4 Hz, 1H), 4.94 (dd, *J* = 17.3, 1.5 Hz, 1H), 4.31 (q, *J* = 7.1 Hz, 2H), 4.27 – 4.20 (m, 2H), 3.61 (dd, *J* = 14.2, 12.7 Hz, 1H), 3.52 (dd, *J* = 39.0, 14.2 Hz, 1H), 1.62 (d, *J* = 1.3 Hz, 3H), 1.34 (t, *J* = 7.1 Hz, 3H), 1.30 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 170.0 (d, *J* = 7.8 Hz), 169.9 (d, *J* = 3.4 Hz), 134.8 (d, *J* = 19.7 Hz), 133.6, 133.3, 132.4, 129.8, 129.6 (d, *J* = 1.9 Hz), 127.8, 127.7, 127.1, 125.8, 125.5, 116.9 (d, *J* = 13.1 Hz), 98.1 (d, *J* = 191.8 Hz), 61.8, 61.6, 61.1 (d, *J* = 23.8 Hz), 41.1 (d, *J* = 21.3 Hz), 17.9 (d, *J* = 5.7 Hz), 14.2, 14.1.

^{19}F NMR (565 MHz, $CDCl_3$) δ -165.2 (ddd, *J* = 37.8, 24.0, 12.6 Hz).

HRMS (EI): *m/z* for $C_{22}H_{25}FO_4^+$ $[M]^+$ calcd.: 372.1737, found: 372.1744.

diethyl (*S*)-2-(2-fluoro-1-(naphthalen-2-yl)but-3-en-2-yl)-2-methylmalonate (3ie)



3ie
89%, 87:13 er

The title compound was prepared according to a procedure modified from the general procedure for the allylic alkylation of malononitriles with 2-(2,2-difluorobut-3-en-1-yl)naphthalene (21.8 mg, 0.100 mmol). The reaction was conducted with barium triflate as an additive instead of lithium bromide (3.00 equiv) at a reaction concentration of 0.1 M in 1,4-dioxane. The reaction was conducted at room temperature for 24 hours with 20.0 mol% **Cω**. After this time, the mixture was concentrated in vacuo, diluted with ethyl acetate, filtered, and concentrated *in vacuo*. The resulting residue was purified by preparative TLC (85/15 of hexanes/diethyl ether) to provide allylic fluoride **3ie** as a clear oil (28.9 mg, 0.0891 mmol, 89%).

The **enantiomeric ratio** was determined to be 87:13 by HPLC analysis with t_R = 12.7 min (minor) and t_R = 15.93 min (major) [IB, 1.0% *i*PrOH in hexanes, 1.0 mL/min, 229 nm, 25 °C].

[α]$_D^{25}$ = +34.7° (c 0.43, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +46.9 (c 0.43, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.85 – 7.80 (m, 2H), 7.78 (d, *J* = 8.5 Hz, 1H), 7.68 (s, 1H), 7.52 – 7.46 (m, 2H), 7.33 (dt, *J* = 8.4, 1.6 Hz, 1H), 5.92 (ddd, *J* = 22.2, 17.2, 11.2 Hz, 1H), 5.45 (d, *J* = 17.2 Hz, 1H), 5.42 (dd, *J* = 11.3, 2.7 Hz, 1H), 5.17 (AB, *J* = 6.6 Hz, 1H), 3.68 (dd, *J* = 14.4, 11.9 Hz, 1H), 3.61 (s, 3H), 3.34 (dd, *J* = 37.5, 14.4 Hz, 1H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 133.3, 132.7, 130.2, 130.0, 129.6 (d, *J* = 19.5 Hz), 128.7 (d, *J* = 1.2 Hz), 128.0, 127.8, 127.8, 126.3, 126.2, 122.5 (d, *J* = 11.2 Hz), 111.4, 111.3 (d, *J* = 1.2 Hz), 97.4 (d, *J* = 200.4 Hz), 97.0, 72.1 (d, *J* = 31.2 Hz), 57.8, 39.6 (d, *J* = 20.0 Hz).

^{19}F NMR (470 MHz, $CDCl_3$) δ -163.3 (ddd, *J* = 35.6, 22.2, 11.9 Hz).

HRMS (EI): *m/z* for $C_{19}H_{17}FN_2O_2^+$ $[M]^+$ calcd.: 324.1274, found: 324.1277.

SYNTHESIS OF FLUORINATED ANALOGS OF TROPIC ACID AND METHALLENESTRIL

To demonstrate the synthetic utility of this method, we prepared fluorinated analogs of two biologically active compounds, tropic acid and methallenestril. The synthesis of the fluorinated derivative of tropic acid was achieved in two steps from compound **3be** via hydrolysis and reductive ozonolysis (Figure S16). Overall, enantioenriched F-Tropic acid was prepared in four steps from commercial materials. Pharmaceuticals with diverse biological activities, including

chronotropic effects (atropine), bronchodilation (ipratropium bromide), antiemetic activity (hyoscine), and a mydriatic activity (tropicamide), are simple esters and amides of tropic acid. Fluorinated analogs of tropic acid derivatives were studied by Novartis in 2019, indicating these compounds are of industrial interest. These compounds were all prepared in racemic form in the patent WO 2019/087146 A1 "Azabicyclo and diazepine derivatives for treating ocular disorders."[27]

Fluorination at the α-position of esters and amides is known to prevent epimerization. Fluorination α to amides (as would be present for the fluorinated analog of Tropicamide) alters the conformation about the amide C–C bond.[28] The lipophilicity of these compounds is affected by fluorination, as the calculated cLogP values indicate. For tropic acid, the pK_a is predicted to decrease by two pK_a units upon fluorination (Figure S16).

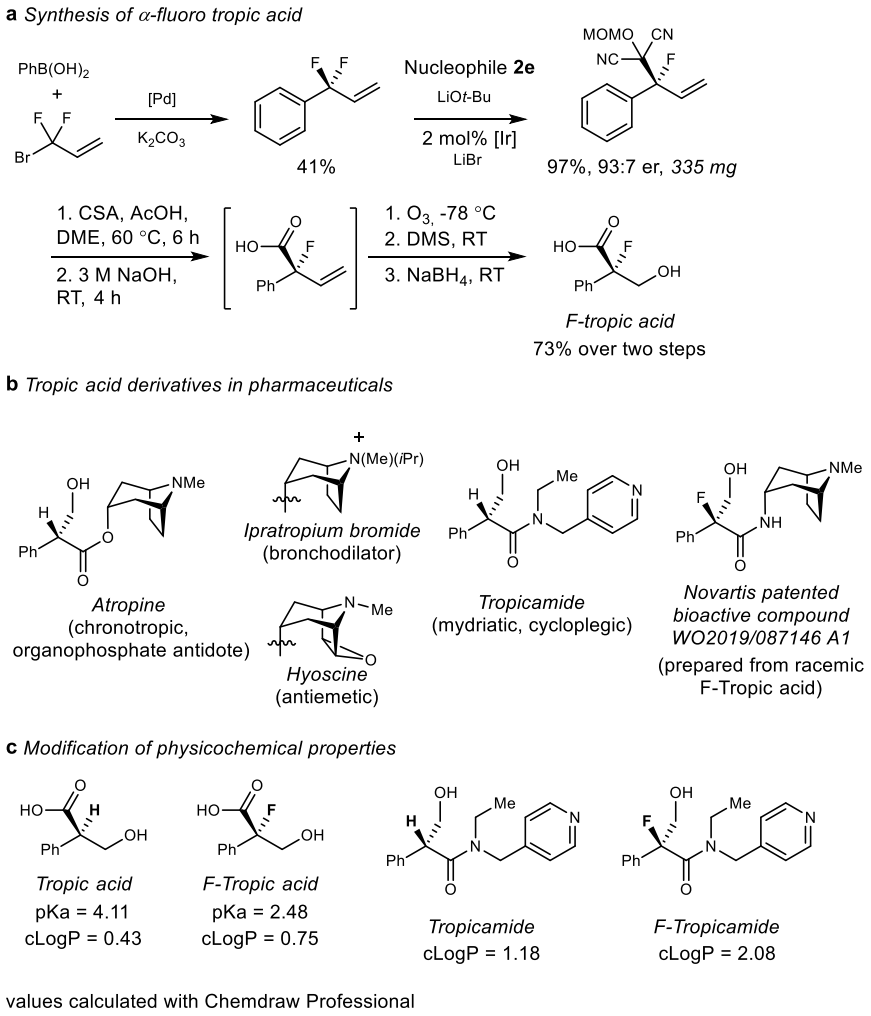


Figure S16. a. Synthesis of a fluorinated analog of tropic acid. **b.** importance of tropic acid derivatives in medicinal chemistry. **c.** Calculated changes in physicochemical properties.

In addition, we prepared in two steps from allylic fluoride **3jf** a fluorinated analog of methallenestril, which is a non-steroidal estrogen (Figure S17). Overall, enantioenriched F-methallenestril was prepared in four steps from commercial materials. The fluorinated derivative we prepared bears two vicinal, fully substituted carbons. The fluorinated analog of methallenestril is predicted to be three times more acidic than the parent compound (0.5 pK_a units).

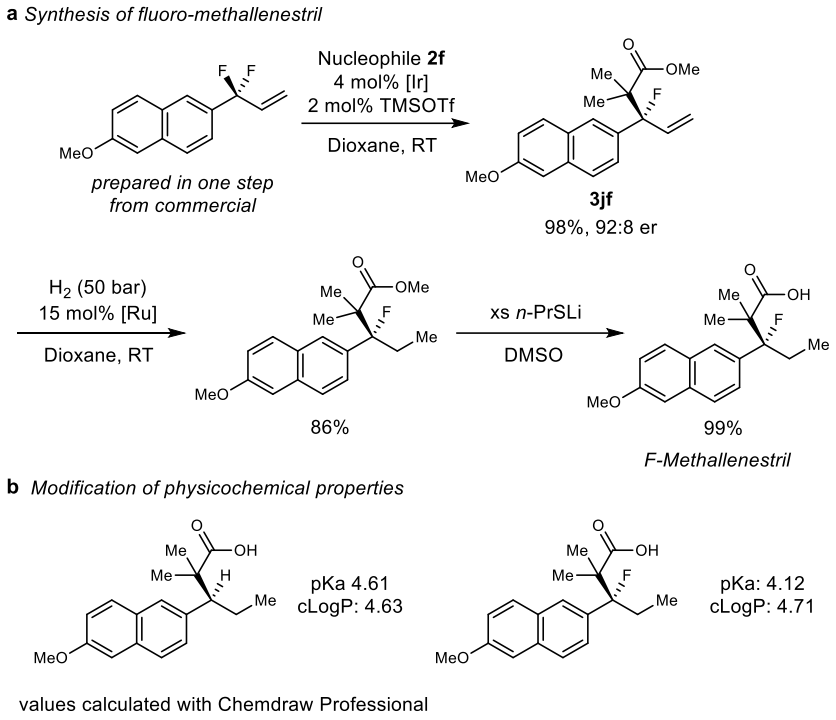
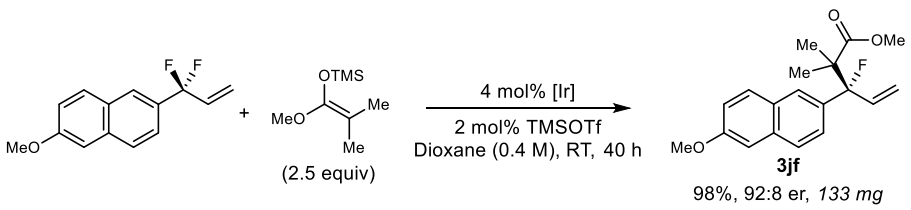


Figure S17. a. Synthesis of a fluorinated analog of methallenestril. **b.** Calculated changes in physicochemical properties.

Synthesis of Fluorinated Analogs of Methallenestril and Tropic Acid

F-Methallenestril

methyl (*R*)-3-fluoro-3-(6-methoxynaphthalen-2-yl)-2,2-dimethylpent-4-enoate (3jf)



Note: We observed that defluorinative alkylation reactions with silyl ketene acetals proceed faster if trimethylsilyl triflate is added as a cocatalyst. This is particularly beneficial for reactions

conducted at larger scales. Under these conditions, reactions in dioxane solvent occurred with the highest enantioselectivities.

In a nitrogen-filled glove box, a 20 mL vial equipped with a magnetic stir bar was charged with 2-(1,1-difluoroallyl)-6-methoxynaphthalene (100.0 mg, 0.4269 mmol, 1 equiv). A solution of **C15 (Cγ)** (21.6 mg, 0.0170 mmol, 4.00 mol%) in dioxane (1.050 mL) was then added. Methyl trimethylsilyl dimethyl ketene acetal (186 mg, 217 µL, 1.07 mmol, 2.50 equiv) was added slowly with stirring. In a separate vial, a solution of trimethylsilyl triflate in dioxane was prepared (15.4 µL TMSOTf in 500 µL dioxane), and an aliquot was added to the reaction mixture (50 µL of this solution added, amounting to 1.54 µmol TMSOTf, 0.0085 mmol, 2.0 mol%). The resulting solution was stirred at room temperature for 40 h, after which time, ^{1}H NMR spectroscopy indicated complete consumption of the starting material. The solvent was removed *in vacuo*, and the product was purified by silica gel column chromatography (4/96 to 12/88 of ethyl acetate/hexanes) to provide allylic fluoride **3jf** as a clear oil (132.5 mg, 0.4188 mmol, 98%).

The **enantiomeric ratio** was determined to be 92:8 by HPLC analysis with t_R = 9.71 min (major) and t_R = 10.9 min (minor) [IC, 1.0% *i*PrOH in hexanes, 1.0 mL/min, 240 nm, 25 °C].

[α]$_D^{25}$ = +65.9° (c 0.31, $CHCl_3$). *Corrected for enantiopurity:* **[α]$_D^{25}$** = +78.5° (c 0.31, $CHCl_3$).

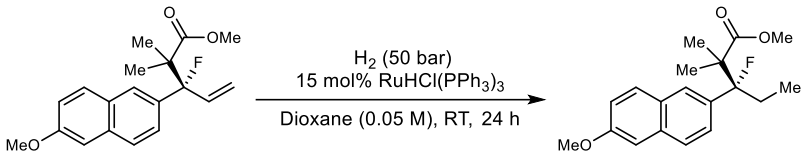
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.75 – 7.71 (m, 2H), 7.69 (d, *J* = 8.7 Hz, 1H), 7.38 (dd, *J* = 8.7, 1.9 Hz, 1H), 7.16 (dd, *J* = 8.9, 2.5 Hz, 1H), 7.12 (d, *J* = 2.5 Hz, 1H), 6.77 (ddd, *J* = 22.9, 17.0, 11.1 Hz, 1H), 5.47 (dd, *J* = 17.0, 1.4 Hz, 1H), 5.32 (ddd, *J* = 11.2, 3.0, 1.4 Hz, 1H), 3.92 (s, 3H), 3.60 (s, 3H), 1.33 (s, 3H), 1.25 (d, *J* = 1.5 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 175.1 (d, *J* = 5.4 Hz), 158.1, 136.5 (d, *J* = 18.8 Hz), 135.4 (d, *J* = 23.2 Hz), 133.9, 129.9, 128.3, 126.2 (d, *J* = 1.9 Hz), 124.9 (d, *J* = 11.4 Hz), 124.3 (d, *J* = 9.8 Hz), 119.3, 115.2 (d, *J* = 14.8 Hz), 105.5, 98.7 (d, *J* = 190.5 Hz), 55.4, 51.9, 51.4 (d, *J* = 24.9 Hz), 21.8 (d, *J* = 4.2 Hz), 20.7 (d, *J* = 5.7 Hz).

^{19}F NMR (565 MHz, $CDCl_3$) δ -164.6 (d, *J* = 22.6 Hz).

HRMS (EI): *m/z* for $C_{19}H_{21}FO_3^+$ $[M]^+$ calcd.: 316.1475, found: 316.1479.

methyl (*R*)-3-fluoro-3-(6-methoxynaphthalen-2-yl)-2,2-dimethylpentanoate (S6)



3jf **S6**

86%, *41.1 mg*

In a nitrogen-filled glove-box, a dry test tube was charged with $RuHCl(PPh_3)_3$ (20.9 mg, 0.0225 mmol, 15.0 mol%) and a solution of allylic fluoride **3jf** (47.5 mg, 0.150 mmol, 1 equiv) in dioxane (3.00 mL). The test tube was loaded into a stainless-steel Parr bomb and the Paar bomb was sealed under nitrogen. The Parr bomb was then pressurized to 50 bar with hydrogen, and the reaction mixture was stirred at room temperature for 24 hours at this pressure. After this time, the Parr bomb was carefully vented, the solvent was removed in vacuo, and the product was purified by silica gel column chromatography (0/100 to 15/85 ethyl acetate/hexanes) to provide tertiary fluoride **S6** as a clear oil (41.1 mg, 0.129 mmol, 86% yield).

$[\alpha]_D^{25}$ = –0.33° (c 0.51, $CHCl_3$). *Corrected for enantiopurity:* **$[\alpha]_D^{25}$** = –0.38° (c 0.51, $CHCl_3$).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.74 (d, *J* = 8.9 Hz, 1H), 7.72 – 7.66 (m, 2H), 7.28 (br d, *J* = 8.7 Hz, 1H), 7.16 (dd, *J* = 8.9, 2.6 Hz, 1H), 7.13 (d, *J* = 2.5 Hz, 1H), 3.93 (s, 3H), 3.62 (s, 3H), 2.37 (ddq, *J* = 42.4, 14.9, 7.4 Hz, 1H), 2.25 (ddq, *J* = 14.5, 9.7, 7.2 Hz, 1H), 1.27 (s, 3H), 1.22 (d, *J* = 1.3 Hz, 3H), 0.71 (t, *J* = 7.3 Hz, 3H).

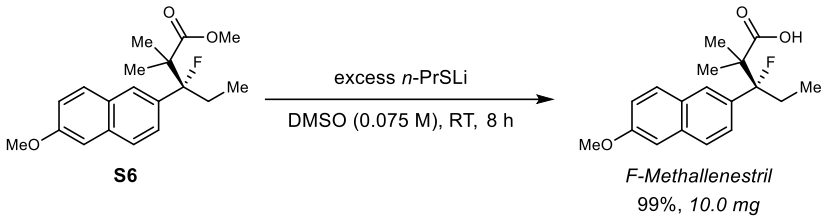
^{13}C NMR (151 MHz, $CDCl_3$) δ 175.7 (d, *J* = 4.5 Hz), 158.0, 134.3 (d, *J* = 22.6 Hz), 133.8, 129.9, 128.4 (d, *J* = 2.0 Hz), 126.1 (d, *J* = 2.1 Hz), 125.5 (d, *J* = 12.5 Hz), 124.8 (d, *J* = 10.0 Hz), 119.1, 105.5, 101.9 (d, *J* = 186.2 Hz), 55.5, 52.0, 51.3 (d, *J* = 24.3 Hz), 27.1 (d, *J* = 22.6 Hz), 21.8 (d, *J* = 4.3 Hz), 21.6 (d, *J* = 6.2 Hz), 8.1 (d, *J* = 4.4 Hz).

^{19}F NMR (565 MHz, $CDCl_3$) δ -165.1 (dd, *J* = 42.8, 9.6 Hz).

HRMS (EI): *m/z* for $C_{19}H_{23}FO_3^+$ $[M]^+$ calcd.: 318.1631, found: 318.1628.

Note: Subjecting allylic fluoride **S6** to HPLC analysis (ADH, 1.0% *i*-PrOH, 1.0 mL/min) indicated a 91:9 ratio of enantiomers: 7.9 min (major) and 9.8 min (minor).

(*R*)-3-fluoro-3-(6-methoxynaphthalen-2-yl)-2,2-dimethylpentanoic acid (*F-Methallenestril*)



S6

F-Methallenestril
99%, *10.0 mg*

In a nitrogen-filled glove-box, a solution of *n*-PrSLi was prepared as follows:

A dry 20 mL vial was charged with lithium hydride powder (25.4 mg, 3.19 mmol) and then dry DMSO (1.07 mL). While stirring the suspension of lithium hydride and DMSO, *n*-propanethiol was added dropwise (150 µL, 1.62 mmol). After the bubbling had ceased (~5 minutes), the vial was sealed and stirred at room temperature for 1 hour. After this time, the resulting suspension was filtered through a 0.2 µm PTFE syringe filter.

The reaction was conducted in a separate vial as follows:

A 4 mL vial was charged with tertiary fluoride **S6** (10.6 mg, 0.0333 mmol, 1 equiv) and a stir bar. An aliquot of the *n*-PrSLi solution (500 µL, ~0.75 mmol, ~23 equiv) was added, the vial was sealed, and the resulting solution was stirred vigorously at room temperature for 8 hours.

After this time, the reaction mixture was transferred to a separatory funnel with water and ethyl acetate. The aqueous layer was acidified with 1 M HCl and extracted with ethyl acetate three times. The combined organic layers were dried over sodium sulfate and concentrated *in vacuo* to provide the crude product as a pale-yellow residue. The crude material was dissolved in benzene (40 mL) and extracted with saturated aqueous $NaHCO_3$ (10 x 15 mL). The combined aqueous layers were carefully acidified with 3 M HCl and then extracted with dichloromethane (3 x 30 mL). The combined DCM layers were dried over sodium sulfate and concentrated *in vacuo* to provide **F-Methallenestril** as a white powder (10.0 mg, 0.329 mmol, 99% yield).

The optical rotation of this compound was too low to quantify.

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.77 – 7.72 (m, 2H), 7.70 (d, J = 8.6 Hz, 1H), 7.35 (br d, J = 8.6 Hz, 1H), 7.16 (dd, J = 8.9, 2.5 Hz, 1H), 7.13 (d, J = 2.5 Hz, 1H), 3.93 (s, 3H), 2.48 – 2.28 (m, 2H), 1.26 (s, 3H), 1.24 (s, 3H), 0.74 (t, J = 7.3 Hz, 3H). *Note:* A broad signal at 12.5–9.0 ppm was observed for the proton of the carboxylic acid.

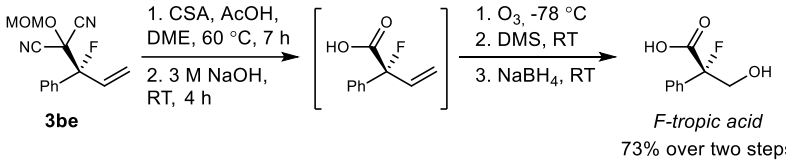
^{13}C NMR (151 MHz, $CDCl_3$) δ 180.4 (d, *J* = 3.2 Hz), 158.1, 133.9, 133.7 (d, *J* = 22.4 Hz), 130.0, 128.3, 126.2 (d, *J* = 2.1 Hz), 125.8 (d, *J* = 12.2 Hz), 124.9 (d, *J* = 10.1 Hz), 119.2, 105.5, 102.0 (d,

J = 185.4 Hz), 55.5, 51.1 (d, *J* = 24.2 Hz), 27.3 (d, *J* = 22.6 Hz), 21.7 (d, *J* = 5.3 Hz), 21.7 (d, *J* = 6.1 Hz), 8.1 (d, *J* = 4.5 Hz).

^{19}F NMR (565 MHz, $CDCl_3$) δ -164.0 (dd, *J* = 41.8, 9.9 Hz).

F-Tropic Acid

(*S*)-2-fluoro-3-hydroxy-2-phenylpropanoic acid (*F-Tropic Acid*)



Step 1: A dry 20 mL vial equipped with a magnetic stir bar was charged with (*R*)-2-(1-fluoro-1-phenylallyl)-2-(methoxymethoxy)malononitrile (**3be**) (75.0 mg, 0.288 mmol, 1 equiv) and dry dimethoxyethane (3.00 mL). Glacial acetic acid (315 µL, 5.50 mmol, 19.1 equiv) was added, followed by (±)-camphor sulfonic acid (80.8 mg, 0.348 mmol, 1.21 equiv). The headspace of the vial was replaced with nitrogen, and the vial was sealed. The vial was heated at 60 °C for 7 hours. After this time, the reaction mixture was cooled to 0 °C and diluted with dimethoxyethane (3.00 mL). While stirring the reaction mixture vigorously at 0 °C, 3 M NaOH (3.00 mL) was added dropwise. After complete addition, the reaction mixture was stirred at room temperature for 4 hours. After this time, the reaction mixture was diluted with water (10 mL) and 3 M NaOH (10 mL). The aqueous layer was washed with DCM (3 x 15 mL, discarded) and then acidified with 1 M HCl. The aqueous layer was then extracted with dichloromethane (3 x 30 mL) and these organic layers were dried over sodium sulfate, filtered, and concentrated in vacuo to provide a pale-yellow oil.

Step 2: The crude carboxylic acid was transferred to a 20 mL vial equipped with a magnetic stir bar. Dry dichloromethane (4.50 mL) and dry methanol (4.50 mL) were added, and the vial was fitted with a septum cap. The reaction mixture was cooled to –78 °C in a dry ice/acetone bath, and ozone was bubbled through the solution until a dark blue color persisted (~ 15 min). After this time, dry nitrogen was bubbled through the reaction mixture to remove excess ozone, and dimethyl sulfide (212 µL, 2.89 mmol, 10.0 equiv) was added while maintaining the reaction mixture at –78 °C. After 5 minutes, the reaction was warmed to room temperature and stirred for an additional 10 minutes. Sodium borohydride (109.2 mg, 2.887 mmol, 10.02 equiv) was added in one portion, and the reaction mixture as stirred at room temperature for 20 minutes. After this time, the reaction was concentrated *in vacuo* and transferred to a separatory funnel with ethyl acetate and water. The

organic phase was extracted with sodium bicarbonate (3 x 20 mL), and the combined aqueous layers were washed once with DCM (40 mL). The combined aqueous layers were then acidified with 1 M HCl, diluted with brine (30 mL), and extracted with ethyl acetate (8 x 50 mL). The combined layers of ethyl acetate were dried over sodium sulfate and concentrated *in vacuo* to provide a colorless residue. The residue was washed with pentane and concentrated under high vacuum to provide α-fluoro tropic acid (***F-Tropic Acid***) as a white powder (38.7 mg, 0.210 mmol, 73% yield).

[α]$_D^{25}$ = –4.4° (c 1.00, MeOH). *Corrected for enantiopurity:* **[α]$_D^{25}$** = –5.0° (c 1.00, MeOH).

^{1}H NMR (600 MHz, d_6-DMSO) δ 7.55 – 7.37 (m, 5H), 4.14 (dd, J = 31.6, 12.4 Hz, 1H), 3.80 (dd, J = 17.3, 12.4 Hz, 1H). *Note:* A broad signal at 14.0–12.0 ppm was observed for the proton of the carboxylic acid.

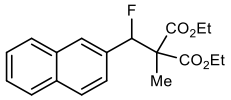
^{13}C NMR (151 MHz, d_6-DMSO) δ 170.2 (d, *J* = 27.5 Hz), 136.0 (d, *J* = 21.9 Hz), 128.6, 128.4, 124.8 (d, *J* = 8.5 Hz), 97.4 (d, *J* = 189.2 Hz), 65.8 (d, *J* = 21.4 Hz).

^{19}F NMR (565 MHz, d_6-DMSO) δ -166.7 (dd, *J* = 31.6, 17.4 Hz).

The NMR data matched with the literature.[27]

BENZYLIC SUBSTITUTION WITH 2-DIFLUOROMETHYL NAPHTHALENE

diethyl 2-(fluoro(naphthalen-2-yl)methyl)-2-methylmalonate (5a)



A 4 mL vial was charged with 2-(difluoromethyl)naphthalene (**4a**) (17.8 mg, 0.100 mmol), DPEphos (2.7 mg, 0.0050 mmol, 5 mol%), and a solution of $[Pd(crotyl)Cl]_2$ (0.98 mg in 40 µL THF, 0.0025 mmol, 2.5 mol%). In a separate vial, a solution of diethyl methyl malonate (2.0 equiv), lithium *tert*-butoxide (2.0 equiv), and lithium triflate (1.0 equiv) per 400 µL THF was prepared. A 400 µL aliquot of this solution was added to the vial containing the catalyst and substrate. The vial was sealed and heated at 65 °C for 22 hours. Analysis of the crude mixture by ^{1}H and ^{19}F NMR spectroscopy with an internal standard (trichloroethylene) indicated >95% yield. The product was purified by column chromatography (97/3 to 93/7 hexanes/ethyl acetate) to provide benzylic fluoride **5a** as a clear oil. The reaction was conducted analogously with 5 mol%

[Pd(crotyl)Cl]$_2$ and 15 mol% (*R*)-BINAP to provide benzylic fluoride **5a** in quantitative yield (>95% yield, 100% conversion) and 82:18 er.

The **enantiomeric ratio** was determined to be 82:18 by HPLC analysis with t_R = 12.8 min (minor) and t_R = 15.9 min (major) [AD-H, 2.0% *i*PrOH in hexanes, 0.75 mL/min, 214 nm, 25 °C].

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.85 – 7.81 (m, 4H), 7.52 – 7.45 (m, 3H), 6.43 (d, *J* = 43.7 Hz, 1H), 4.31 (q, *J* = 7.1 Hz, 2H), 4.14 (q, *J* = 7.1 Hz, 2H), 1.47 (s, 3H), 1.32 (t, *J* = 7.1 Hz, 3H), 1.20 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 169.3, 169.0 (d, *J* = 9.8 Hz), 133.5, 133.1 (d, *J* = 21.2 Hz), 132.8, 128.3, 127.8, 127.8, 126.8 (d, *J* = 8.6 Hz), 126.7, 126.5, 124.4 (d, *J* = 7.5 Hz), 93.9 (d, *J* = 181.1 Hz), 62.1, 61.9, 59.8 (d, *J* = 25.3 Hz), 14.7 (d, *J* = 4.4 Hz), 14.2, 14.0.

^{19}F NMR (565 MHz, $CDCl_3$) δ -185.3 (d, *J* = 43.7 Hz).

HRMS (ESI): *m/z* for $C_{19}H_{21}FNaO_4^+$ $[M+Na]^+$ calcd.: 355.1316, found: 355.1318.

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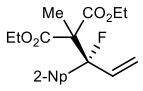
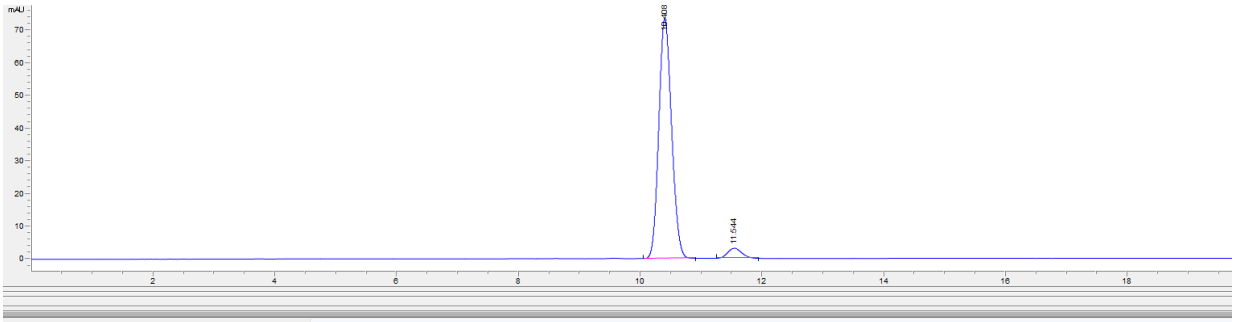
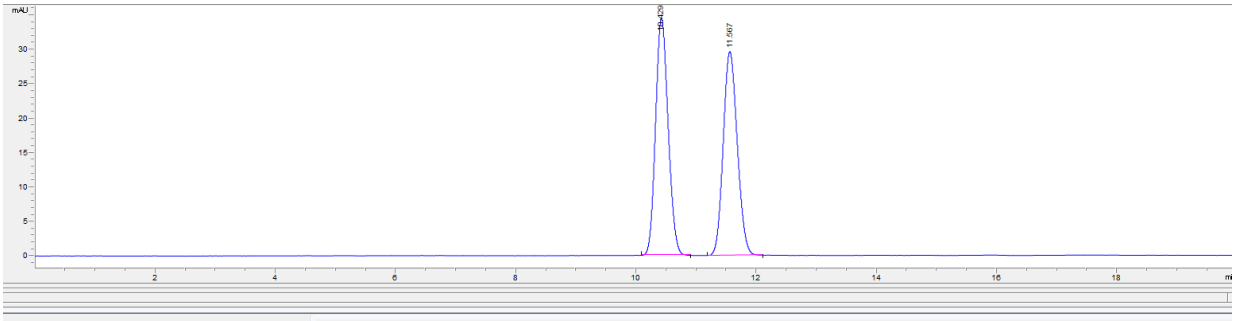
CHIRAL HPLC TRACES



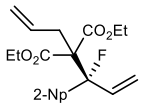
3aa
98%, 96:4 er



#	Time	Type	Area	Height	Width	Area%	Symmetry
1	10.408	BB	1075.1	73.7	0.2238	95.615	0.844
2	11.544	BB	49.3	3.1	0.1876	4.385	0.788

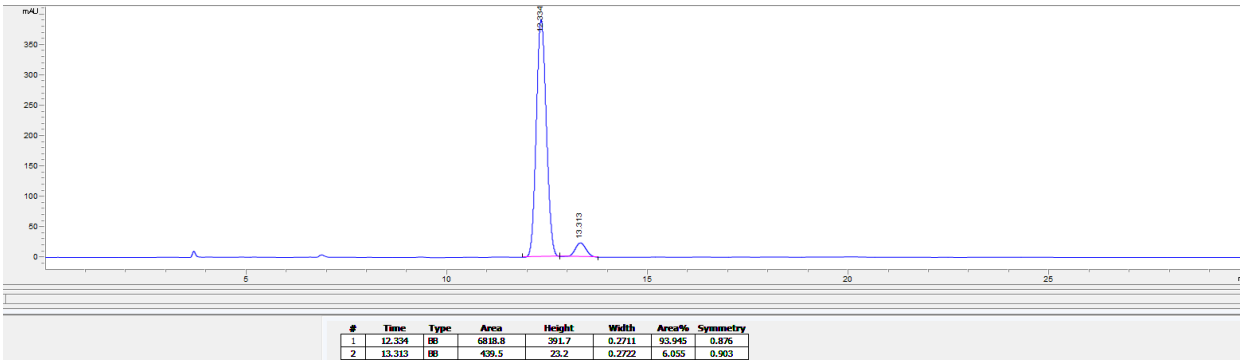


#	Time	Type	Area	Height	Width	Area%	Symmetry
1	10.429	BB	501.8	34.5	0.2193	51.011	0.852
2	11.567	BB	481.9	29.6	0.2409	48.989	0.846

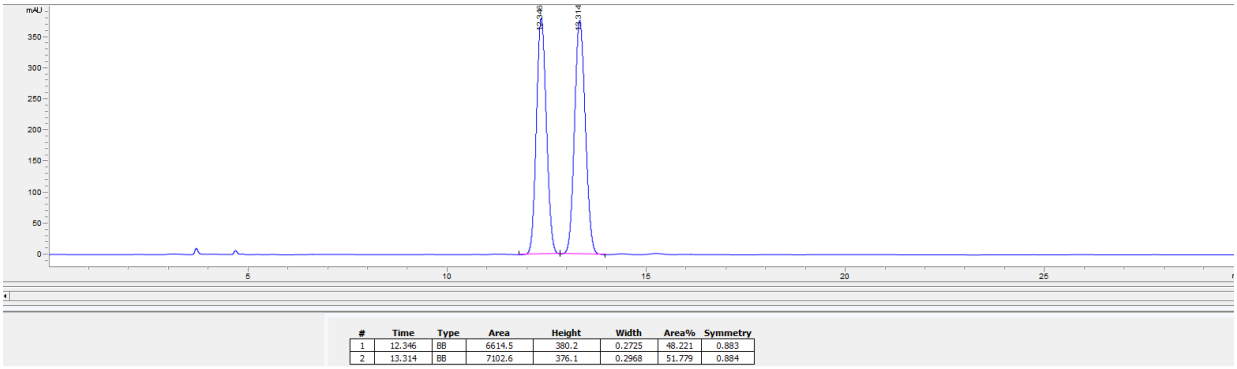


3ab

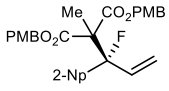
78%, 94:6 er



#	Time	Type	Area	Height	Width	Area%	Symmetry
1	12.334	BB	6818.8	391.7	0.2711	93.945	0.876
2	13.313	BB	439.5	23.2	0.2722	6.055	0.903

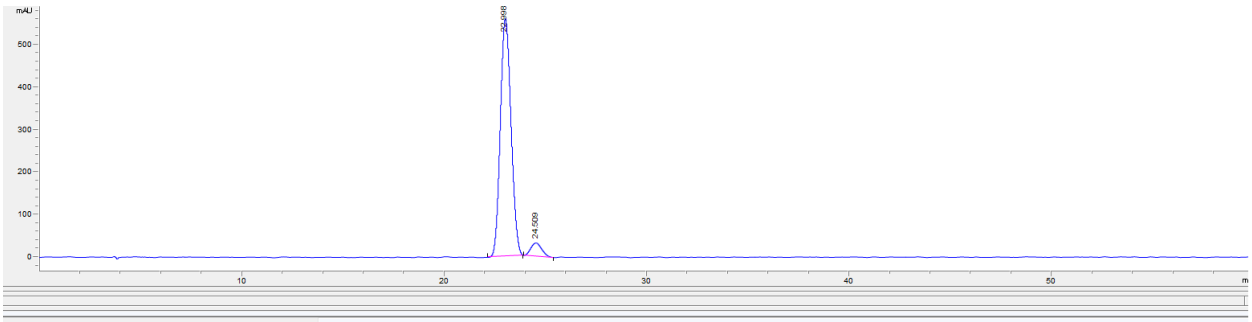


#	Time	Type	Area	Height	Width	Area%	Symmetry
1	12.346	BB	6614.5	380.2	0.2725	48.221	0.883
2	13.314	BB	7102.6	376.1	0.2968	51.779	0.884

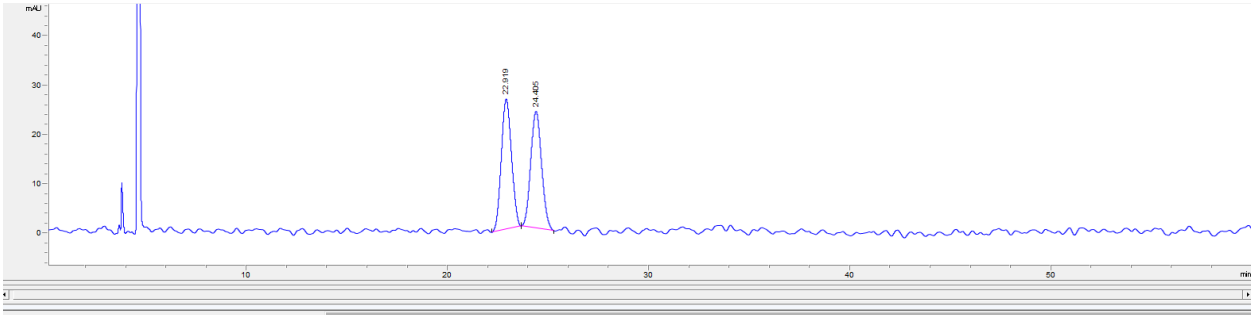


3ac

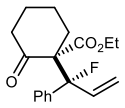
84%, 95:5 er



#	Time	Type	Area	Height	Width	Area%	Symmetry
1	22.998	BB	20591.8	559.8	0.5577	94.546	0.87
2	24.509	BB	1188	31.5	0.4415	5.454	0.865



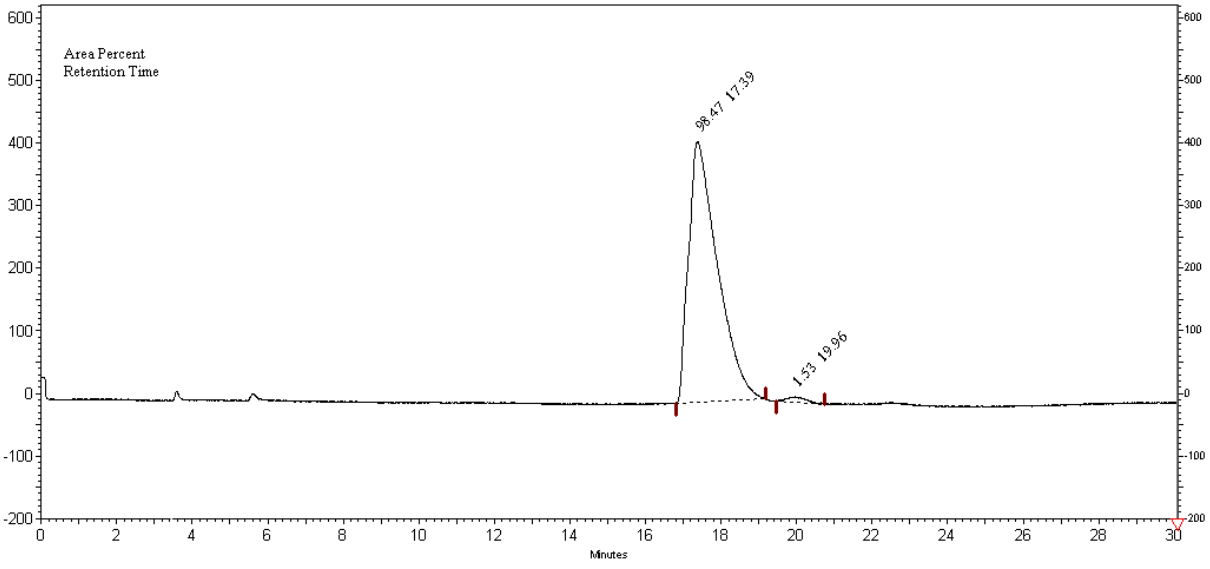
#	Time	Type	Area	Height	Width	Area%	Symmetry
1	22.919	BB	935.4	26.5	0.4213	51.105	0.925
2	24.405	BB	894.9	23.7	0.45	48.895	0.937

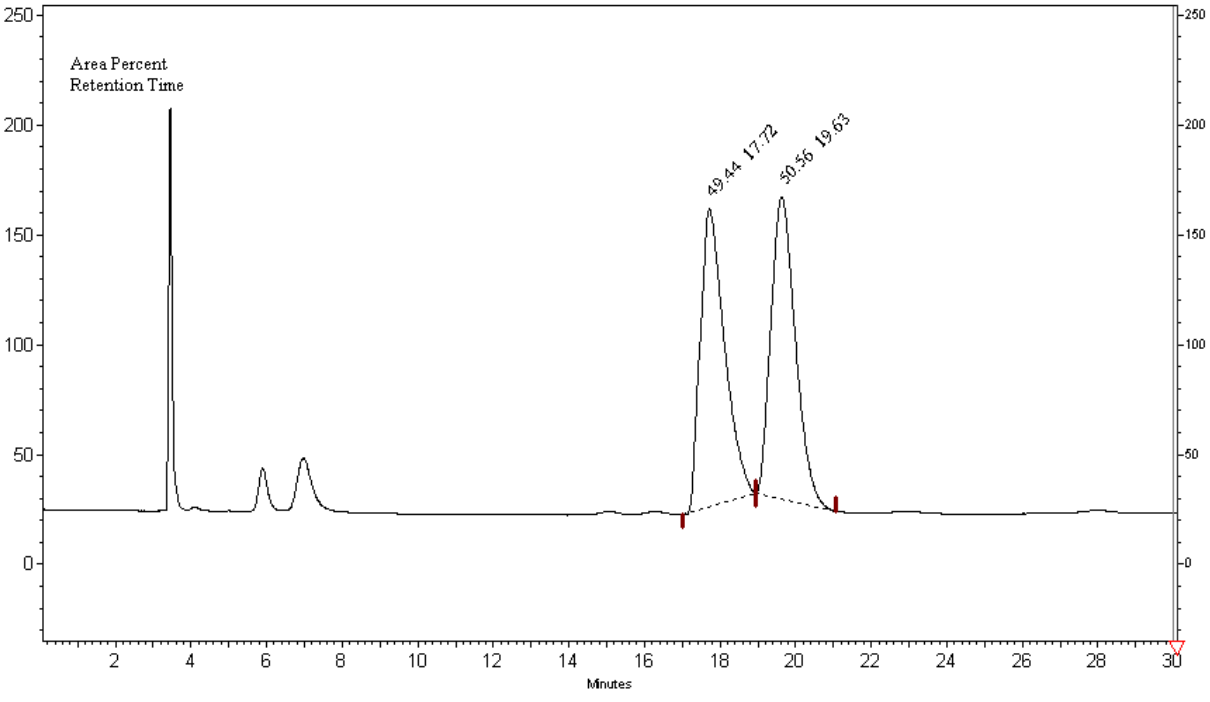


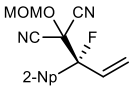
3bd

96%, 6:1 dr
(determined by NMR)

79%, 98:2 er
single diastereomer
(after isolation)

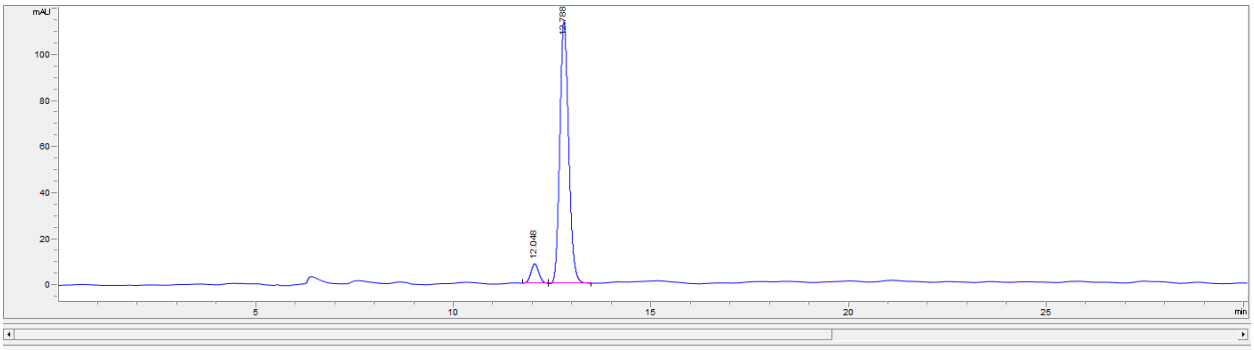




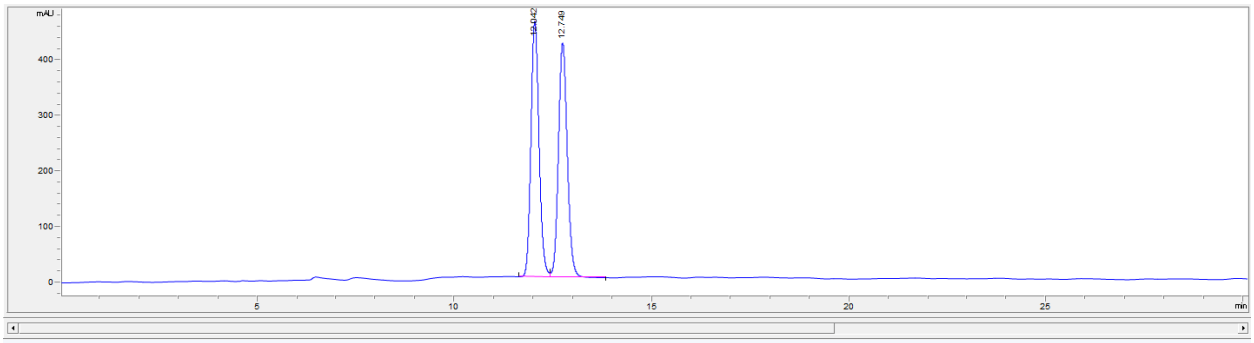


3ae

98%, 94:6 er



#	Time	Type	Area	Height	Width	Area%	Symmetry
1	12.048	BB	119.2	8.5	0.1705	6.276	0.899
2	12.788	BB	1779.7	114.1	0.2405	93.724	0.836



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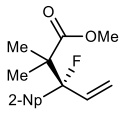
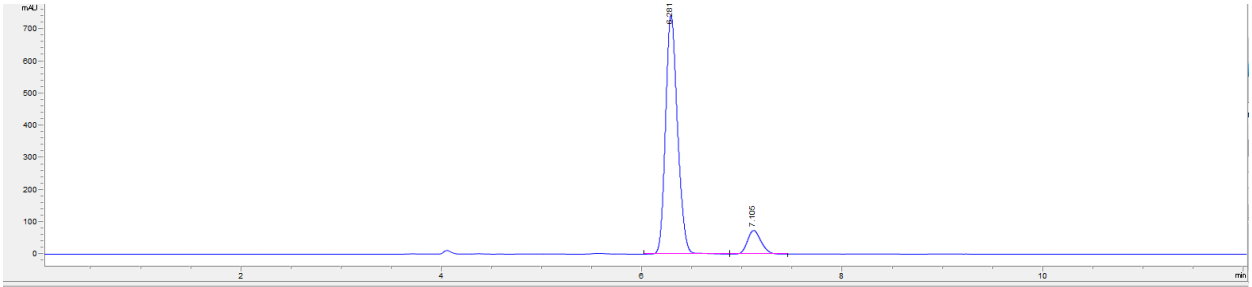
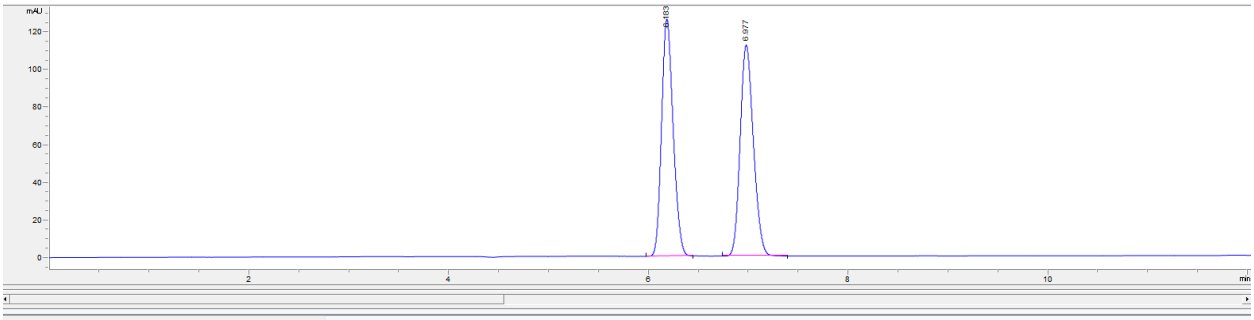
1	12.042	BV	6553.7	458.8	0.2211	49.974	0.852
2	12.749	VB	6560.6	420.8	0.2404	50.026	0.866



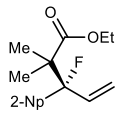
3af
99%, 90:10 er



#	Time	Type	Area	Height	Width	Area%	Symmetry
1	6.281	BB	6148.3	741.2	0.1273	89.898	0.784
2	7.105	BB	690.9	73.4	0.1447	10.102	0.801

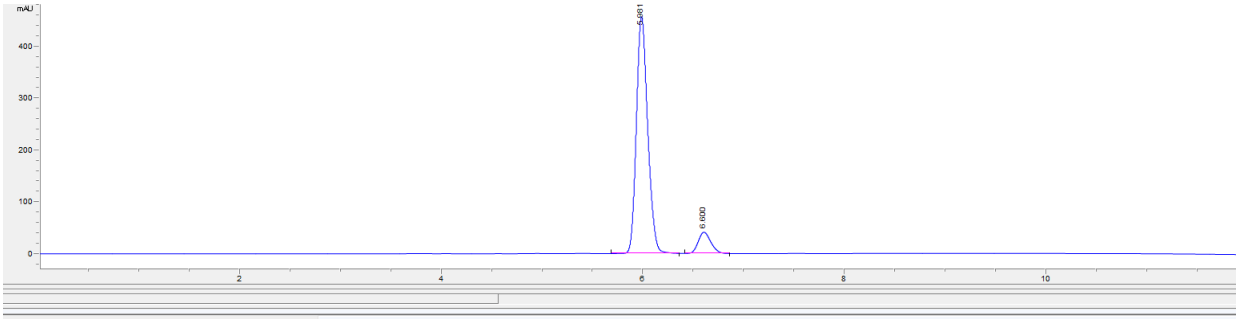


#	Time	Type	Area	Height	Width	Area%	Symmetry
1	6.183	BB	1016.9	126.2	0.1235	49.594	0.793
2	6.977	BB	1033.6	112.3	0.1418	50.406	0.799



3ag

95%, 91:9 er



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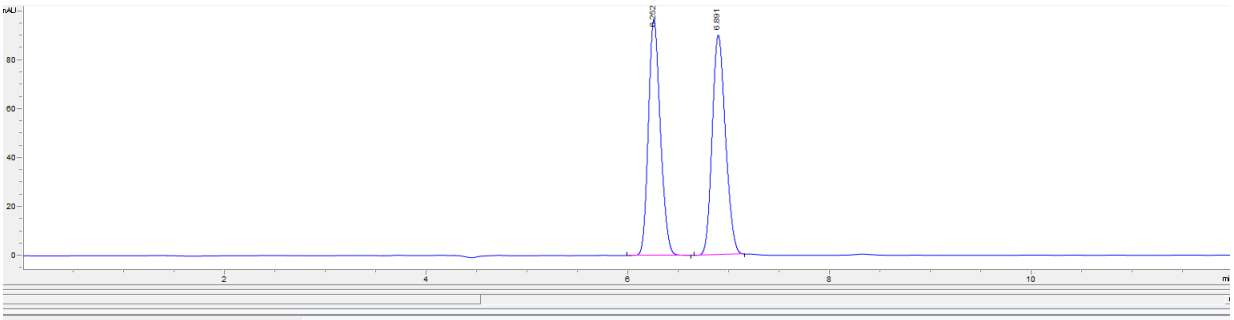
1	5.981	BB	3570.3	457.5	0.1195	90.948	0.789
2	6.6	BB	355.4	41.1	0.1325	9.052	0.801



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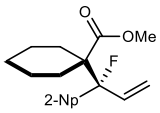
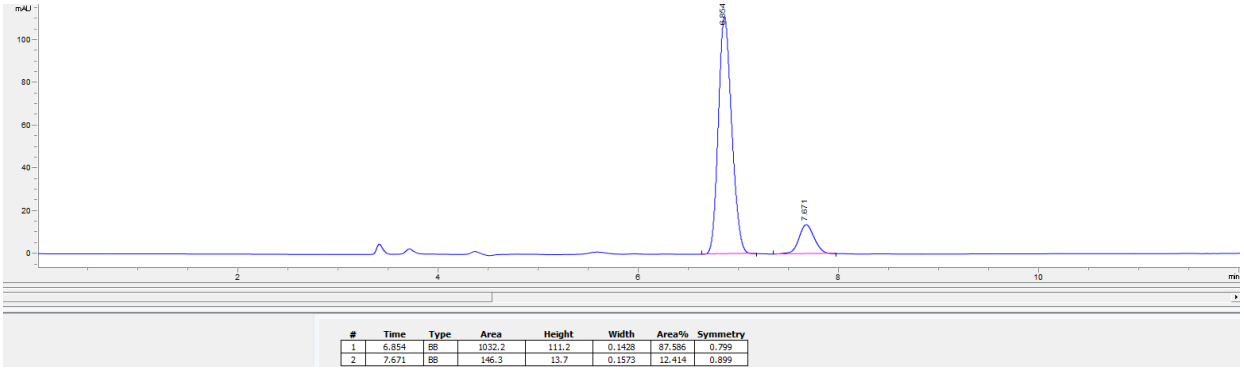
1	6.252	BB	801.4	97	0.1269	49.209	0.793
2	6.891	BB	827.2	90.3	0.1409	50.791	0.807



3ah
93%, 88:12 er



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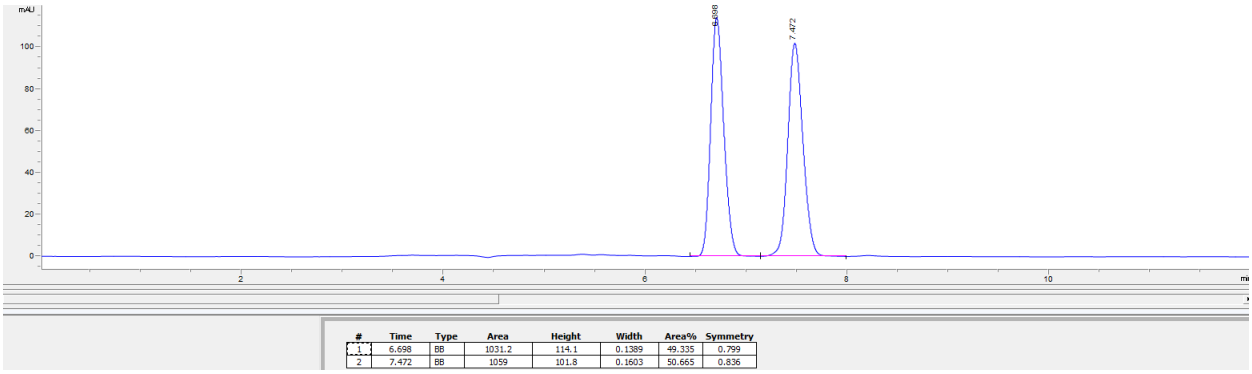
1	6.854	BB	1032.2	111.2	0.1428	87.586	0.799
2	7.671	BB	146.3	13.7	0.1573	12.414	0.899



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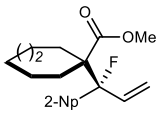
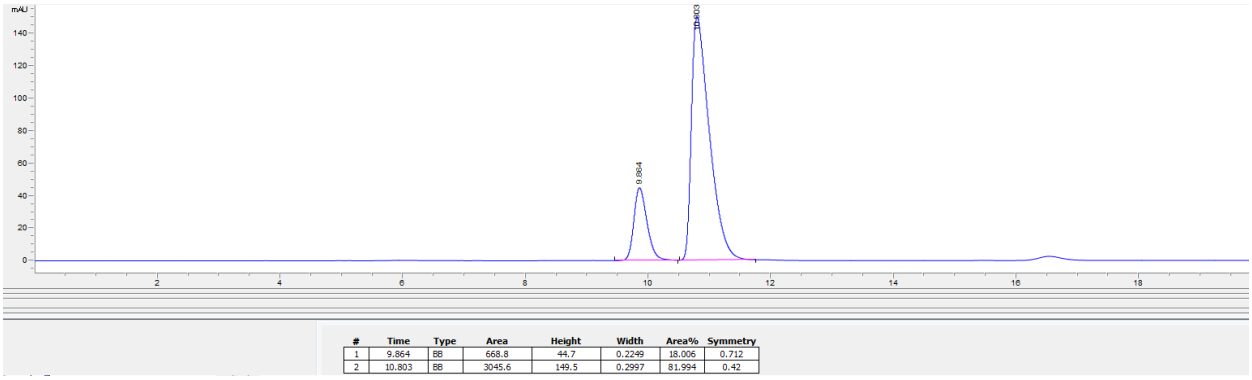
1	6.698	BB	1031.2	114.1	0.1389	49.335	0.799
2	7.472	BB	1059	101.8	0.1603	50.665	0.836



3ai

94%, 82:18 er



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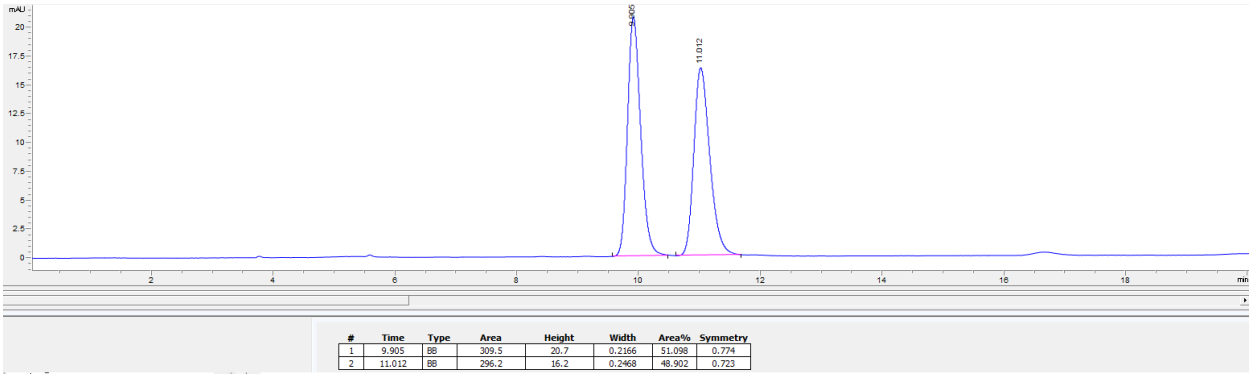
1	9.864	BB	668.8	44.7	0.2249	18.006	0.712
2	10.803	BB	3045.6	149.5	0.2997	81.994	0.42



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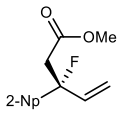
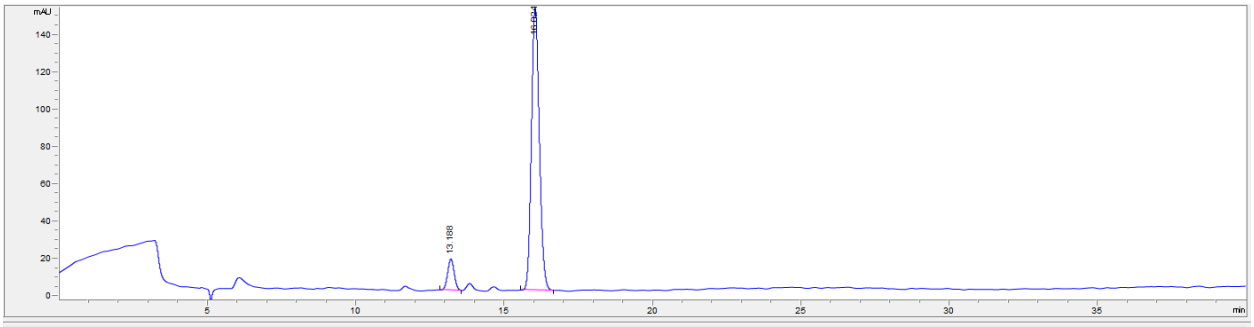
1	9.905	BB	309.5	20.7	0.2166	51.098	0.774
2	11.012	BB	296.2	16.2	0.2468	48.902	0.723



3aj

74%, 92:8 er



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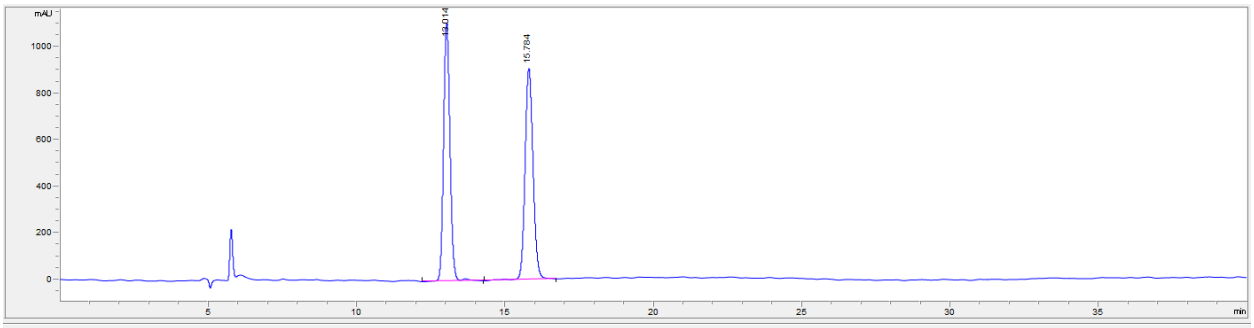
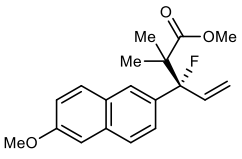
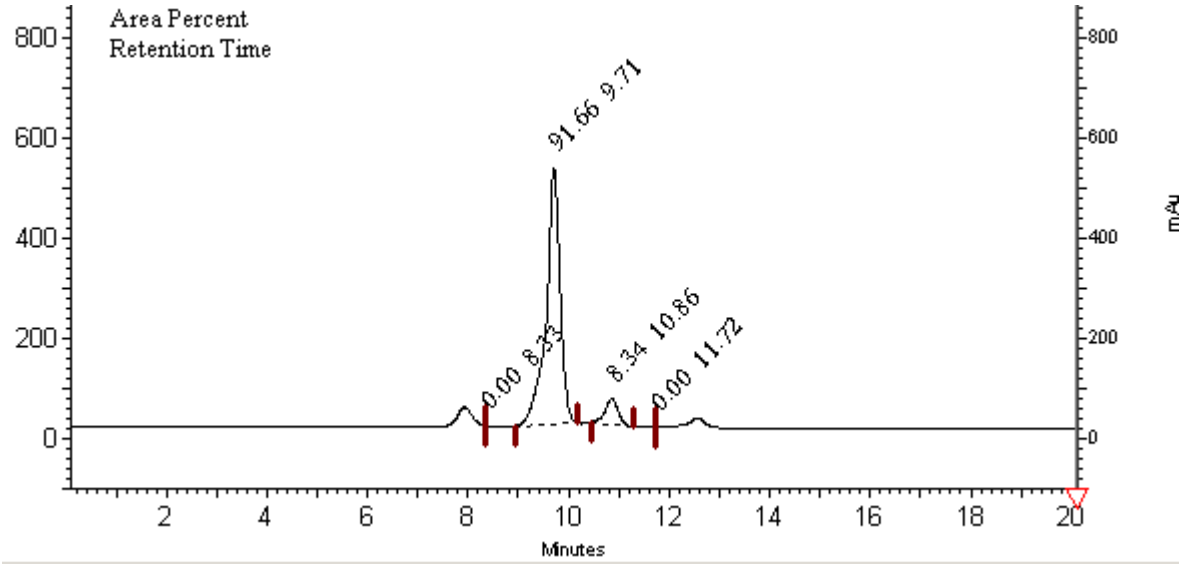
1	13.188	BB	257.9	16.9	0.2159	8.391	0.944
2	16.024	BB	2815.8	151.6	0.2792	91.609	0.836

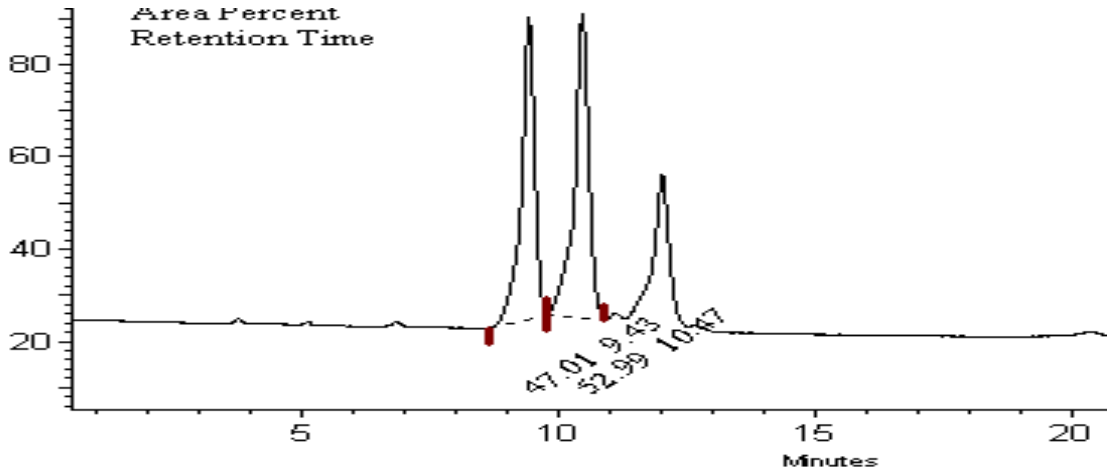


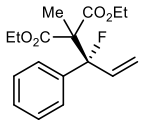
#	Time	Type	Area	Height	Width	Area%	Symmetry
1	13.014	BV R	16943.8	1114	0.2326	49.613	0.873
2	15.784	VB R	17207.9	910.5	0.2806	50.387	0.906


O
Me
OMe
Me
F
MeO

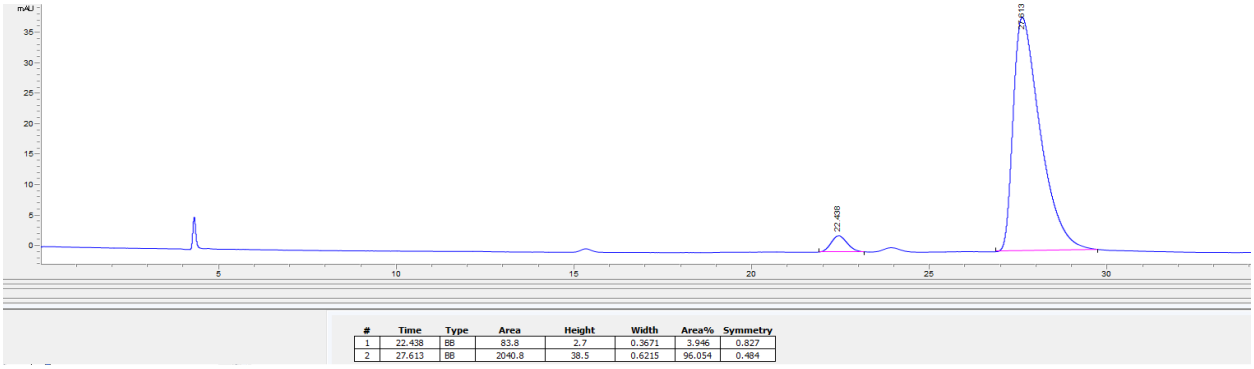
3jf
98%, 92:8 er


Area Percent
Retention Time
91.66 9.71
0.00 8.33
8.34 10.86
0.00 11.72
mAu
Minutes

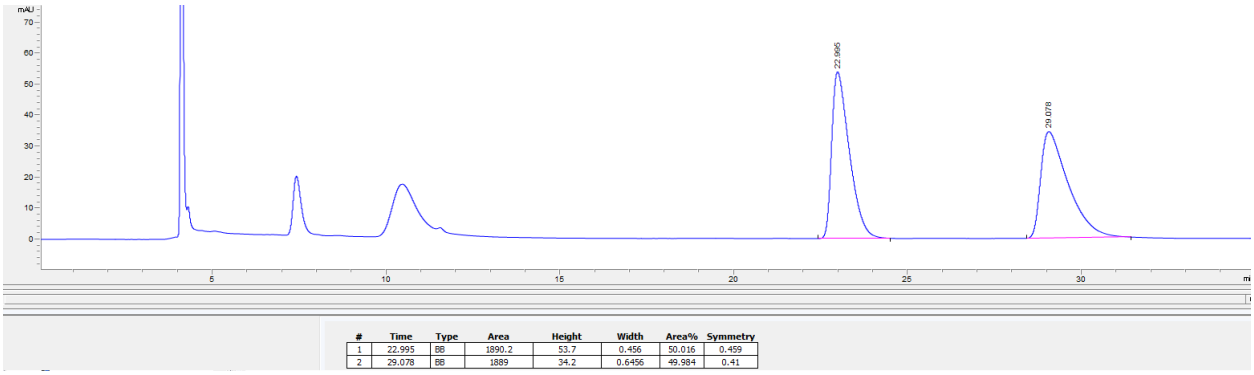

Area Percent
Retention Time
47.01 9.43
52.99 10.67
Minutes



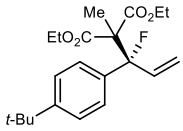
3ba
84%, 96:4 er



#	Time	Type	Area	Height	Width	Area%	Symmetry
1	22.438	BB	83.8	2.7	0.3671	3.946	0.827
2	27.613	BB	2040.8	38.5	0.6215	96.054	0.484

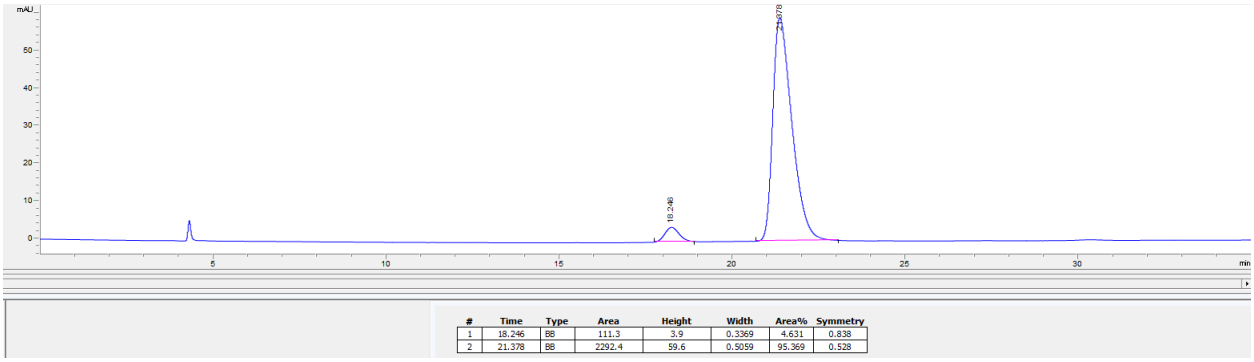


#	Time	Type	Area	Height	Width	Area%	Symmetry
1	22.995	BB	1890.2	53.7	0.456	50.016	0.459
2	29.078	BB	1889	34.2	0.6456	49.984	0.41

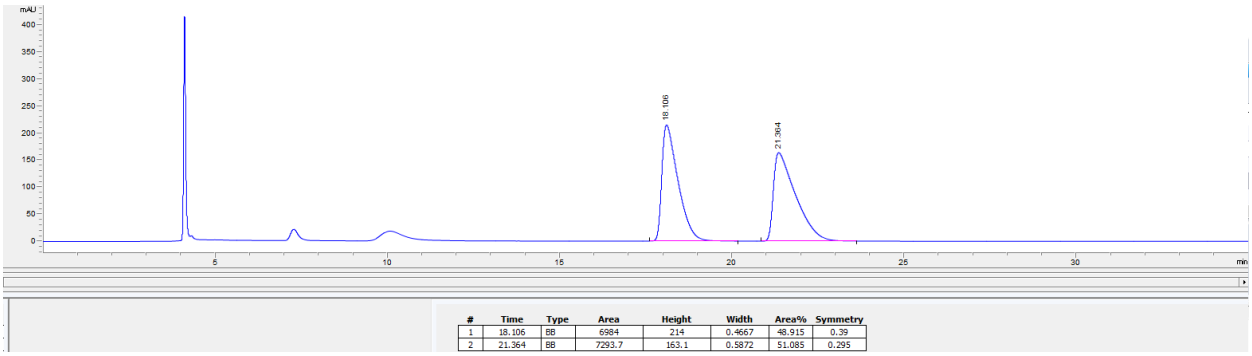


3ca

89%, 95:5 er



#	Time	Type	Area	Height	Width	Area%	Symmetry
1	18.246	BB	111.3	3.9	0.3369	4.631	0.838
2	21.378	BB	2292.4	59.6	0.5059	95.369	0.528



#	Time	Type	Area	Height	Width	Area%	Symmetry
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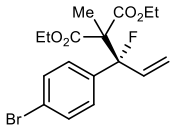
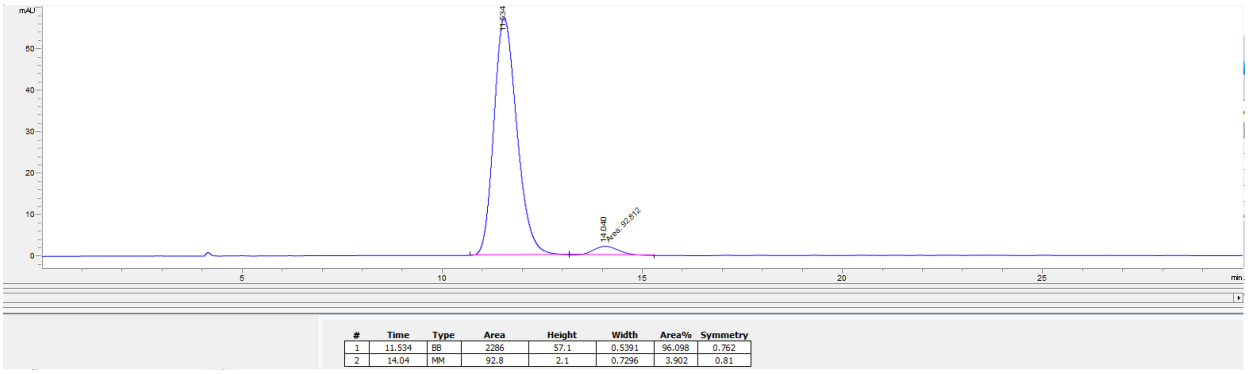
2	21.364	BB	7293.7	163.1	0.5872	51.085	0.295

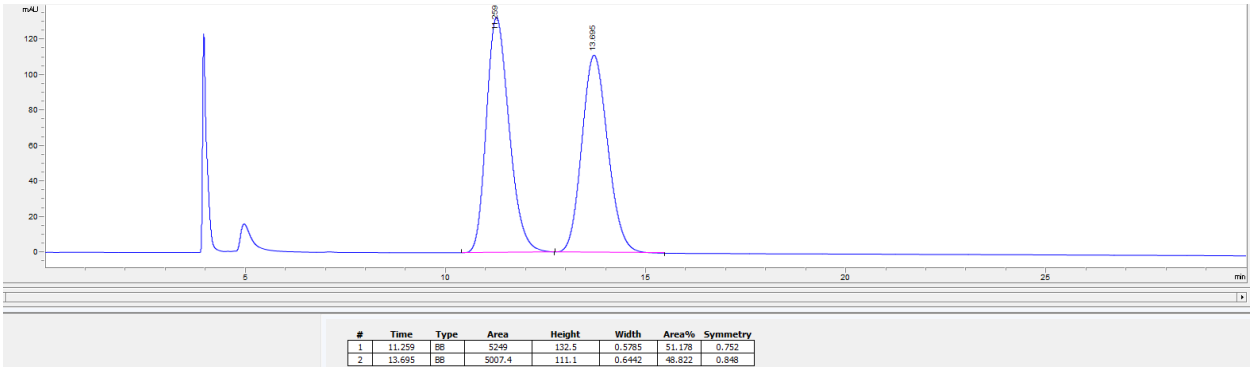


3da

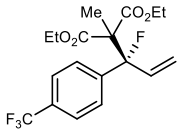
96%, 96:4 er



#	Time	Type	Area	Height	Width	Area%	Symmetry
1	11.534	BB	2286	57.1	0.5391	96.098	0.762
2	14.04	MM	92.8	2.1	0.7296	3.902	0.81

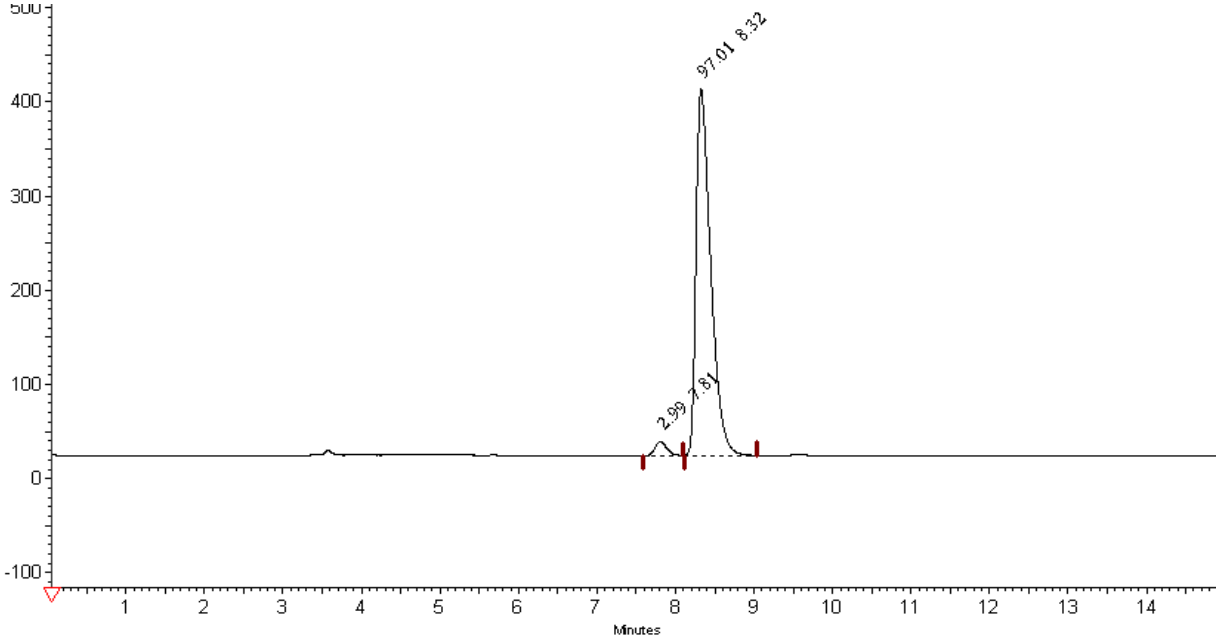


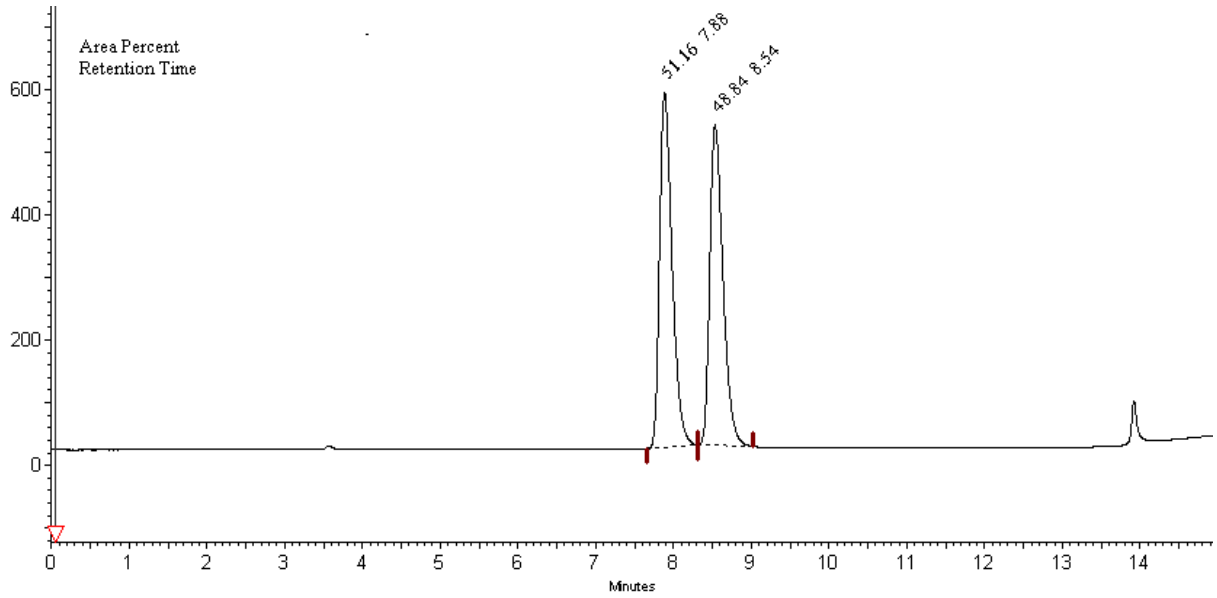
#	Time	Type	Area	Height	Width	Area%	Symmetry
1	11.259	BB	5249	132.5	0.5785	51.178	0.752
2	13.695	BB	5007.4	111.1	0.6442	48.822	0.848

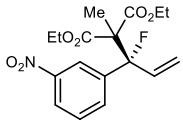

Me
CO2Et
EtO2C
F
F3C

3ea

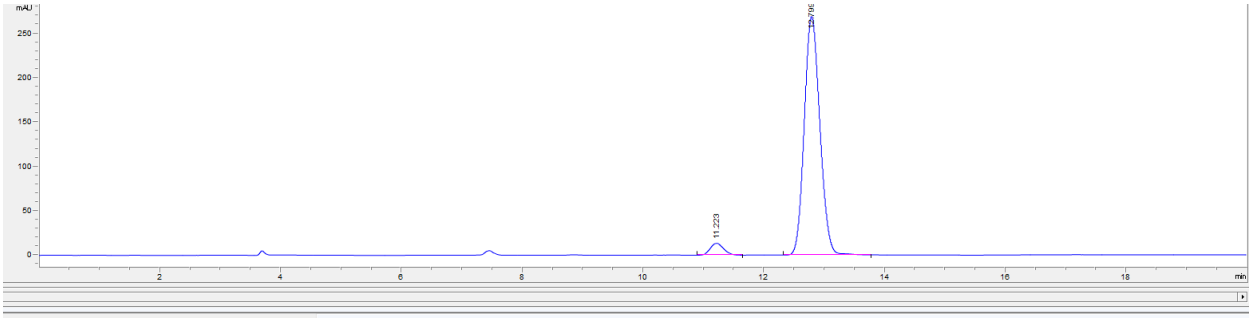
96%, 97:3 er


97.01 8.32
2.99 7.81
Minutes

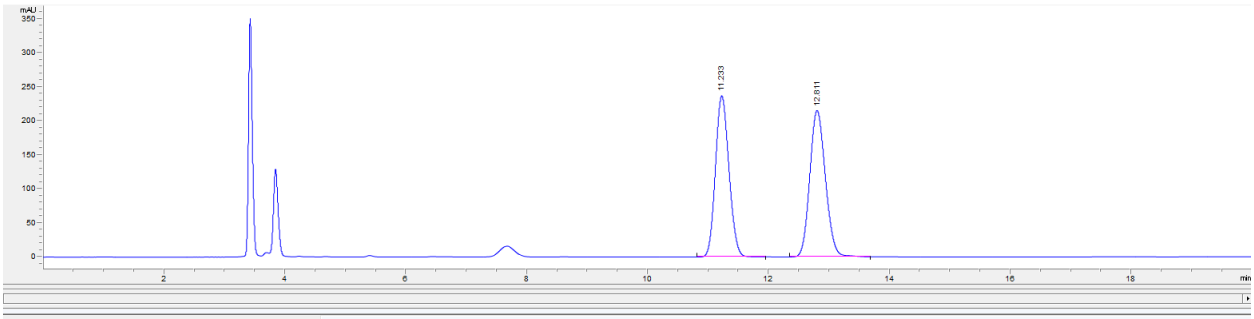

Area Percent
Retention Time
51.16 7.88
48.84 8.54
Minutes



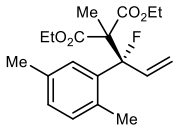
3fa
97%, 96:4 er



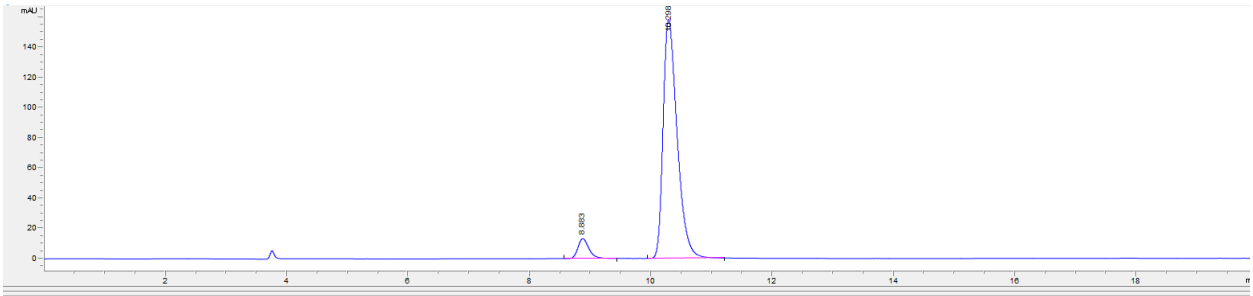
#	Time	Type	Area	Height	Width	Area%	Symmetry
1	11.223	BB	207.1	13.5	0.201	4.108	0.842
2	12.799	BB	4835.5	269.6	0.2757	95.892	0.846



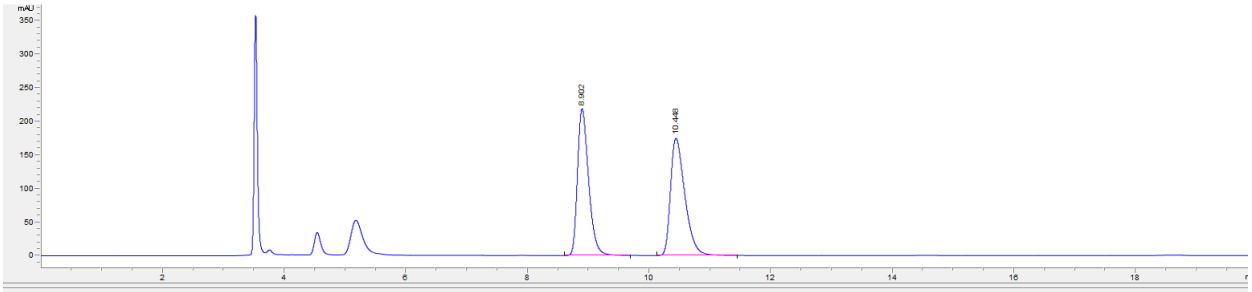
#	Time	Type	Area	Height	Width	Area%	Symmetry
1	11.233	BB	3686.4	237.6	0.238	48.709	0.848
2	12.811	BB	3881.8	215.8	0.2779	51.291	0.839



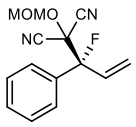
3ga
95%, 94:6 er



#	Time	Type	Area	Height	Width	Area%	Symmetry
1	8.883	BB	166.8	13.3	0.1807	6.147	0.755
2	10.298	BB	2547.3	158.8	0.2412	93.853	0.602

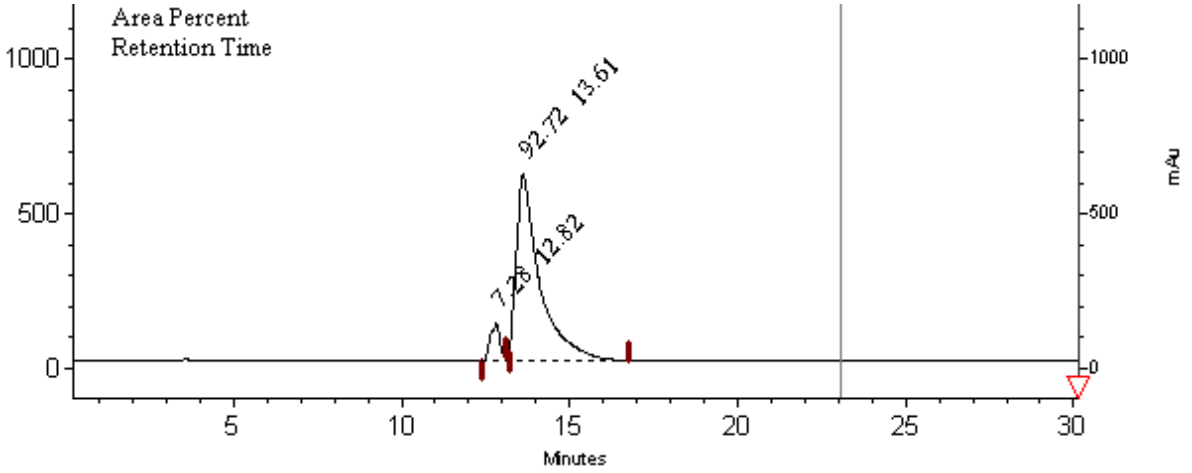


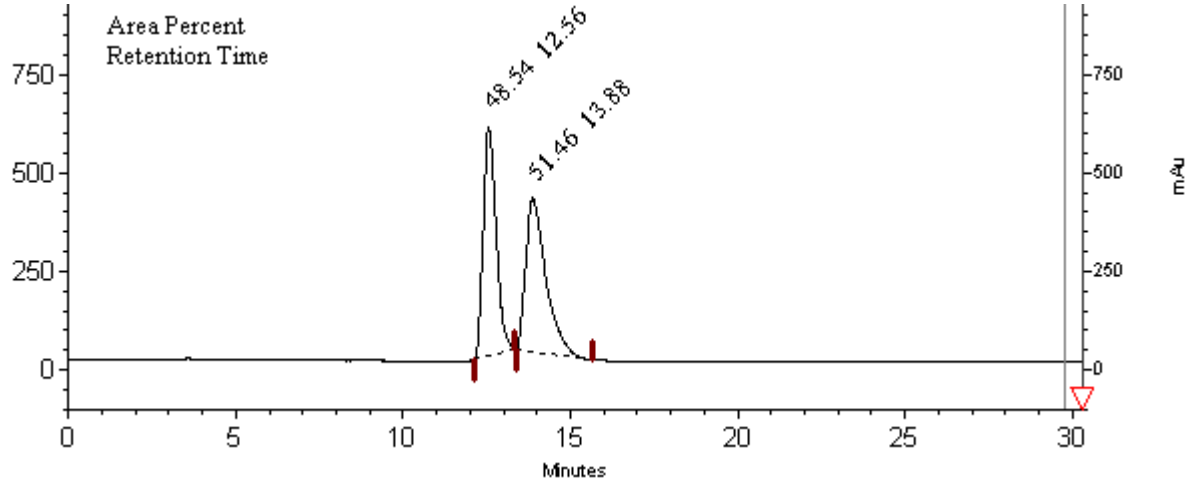
#	Time	Type	Area	Height	Width	Area%	Symmetry
1	8.902	BB	2761.1	218	0.1938	49.189	0.657
2	10.448	BB	2852.2	174.1	0.2487	50.811	0.574

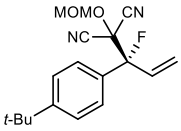


3be

97%, 93:7 er, *335 mg*

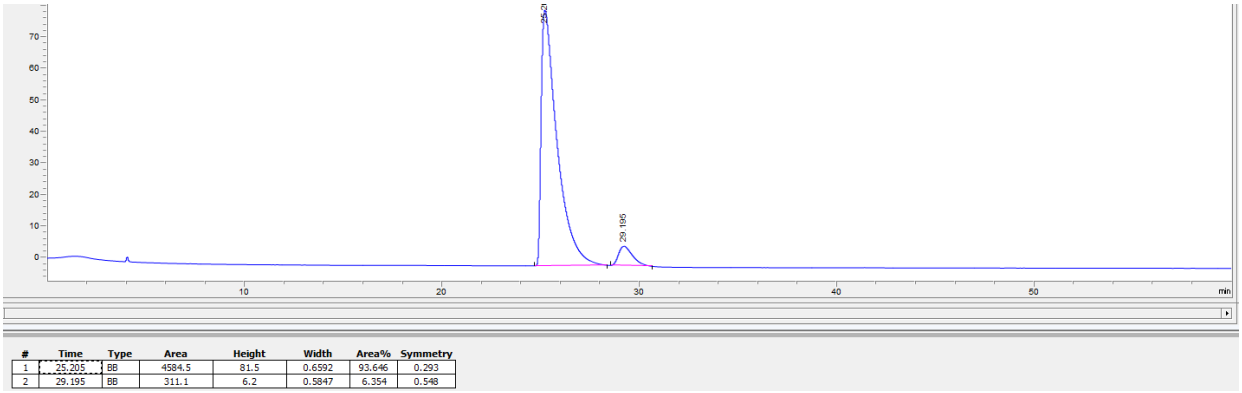




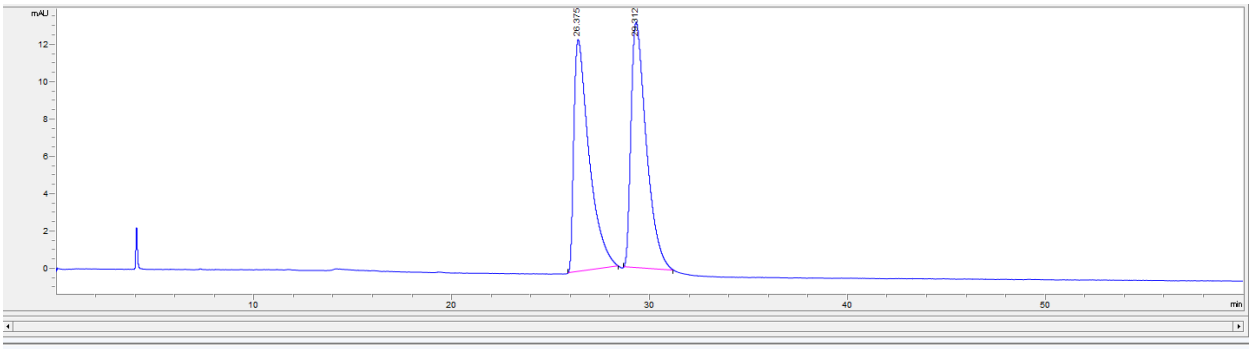


3ce

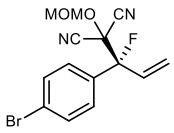
84%, 94:6 er



#	Time	Type	Area	Height	Width	Area%	Symmetry
1	25.205	BB	4584.5	81.5	0.6592	93.646	0.293
2	29.195	BB	311.1	6.2	0.5847	6.354	0.548

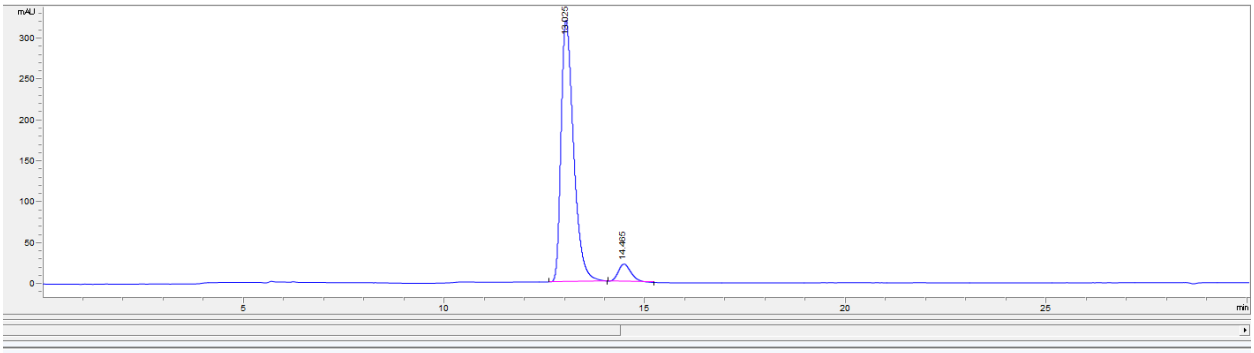


#	Time	Type	Area	Height	Width	Area%	Symmetry
1	26.375	BB	670.7	12.5	0.6297	48.689	0.363
2	29.312	BB	706.8	13.2	0.6305	51.311	0.481

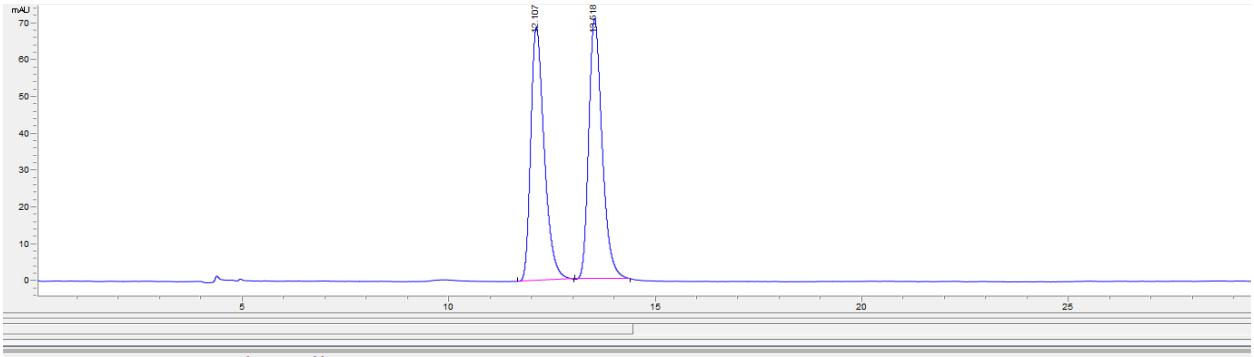


3de

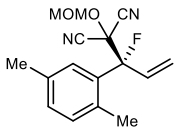
92%, 94:6 er



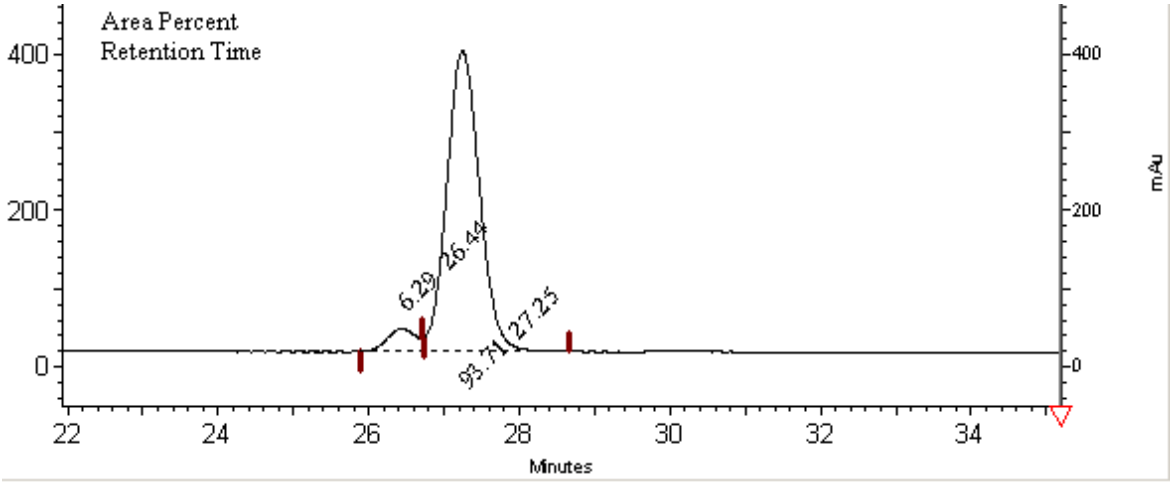
#	Time	Type	Area	Height	Width	Area%	Symmetry
1	13.025	BB	6915.5	319.2	0.3252	93.608	0.607
2	14.465	BB	472.2	21.3	0.2673	6.392	0.724

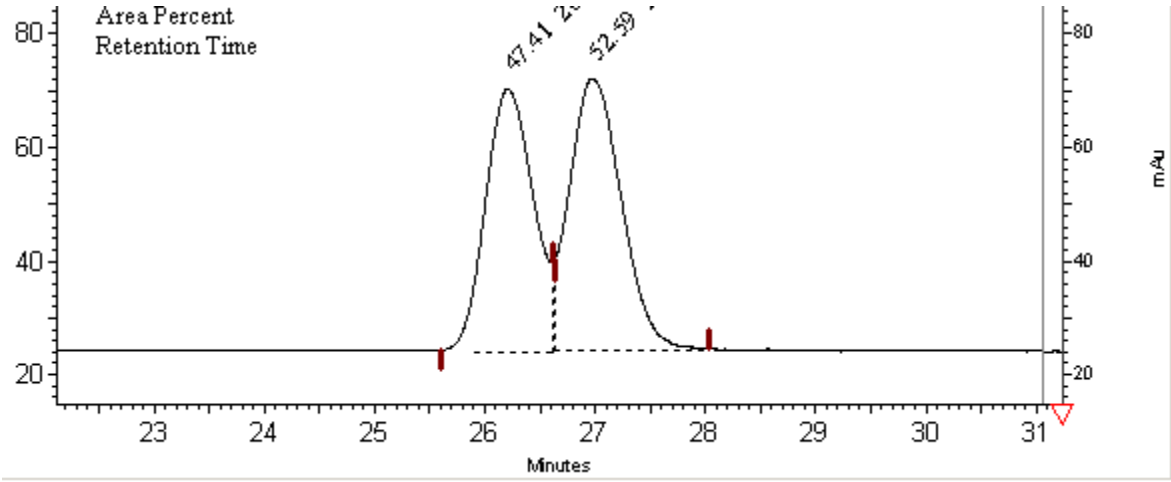


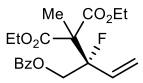
#	Time	Type	Area	Height	Width	Area%	Symmetry
1	12.107	BB	1566.9	68.9	0.3181	49.448	0.661
2	13.518	BB	1601.9	71	0.3148	50.552	0.728


MOMO
CN
NC
F
Me
Me

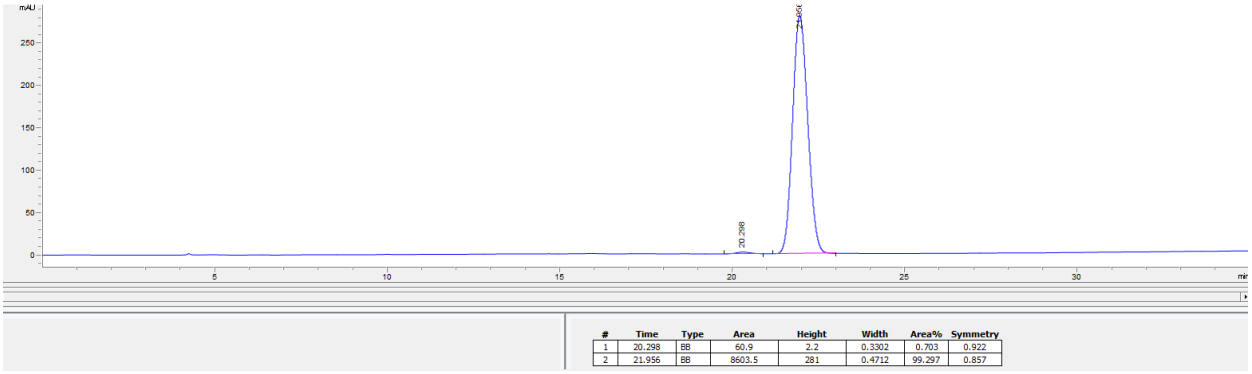
3ge
87%, 94:6 er


Area Percent
Retention Time
400
200
0
6.29
26.44
27.25
93.71
22
24
26
28
30
32
34
Minutes
mAu

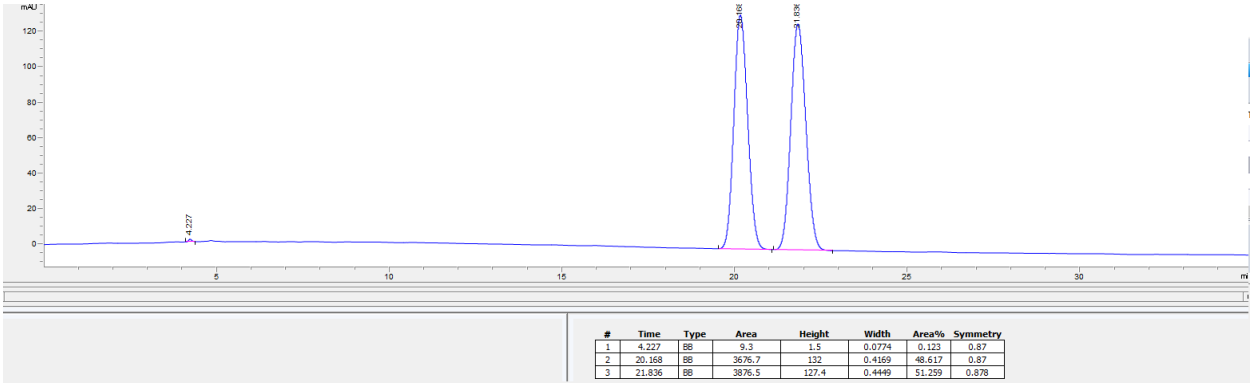

Area Percent
Retention Time
80
60
40
20
47.41
52.59
23
24
25
26
27
28
29
30
31
Minutes
mAu



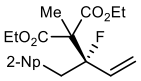
3ha
71%, 99:1 er



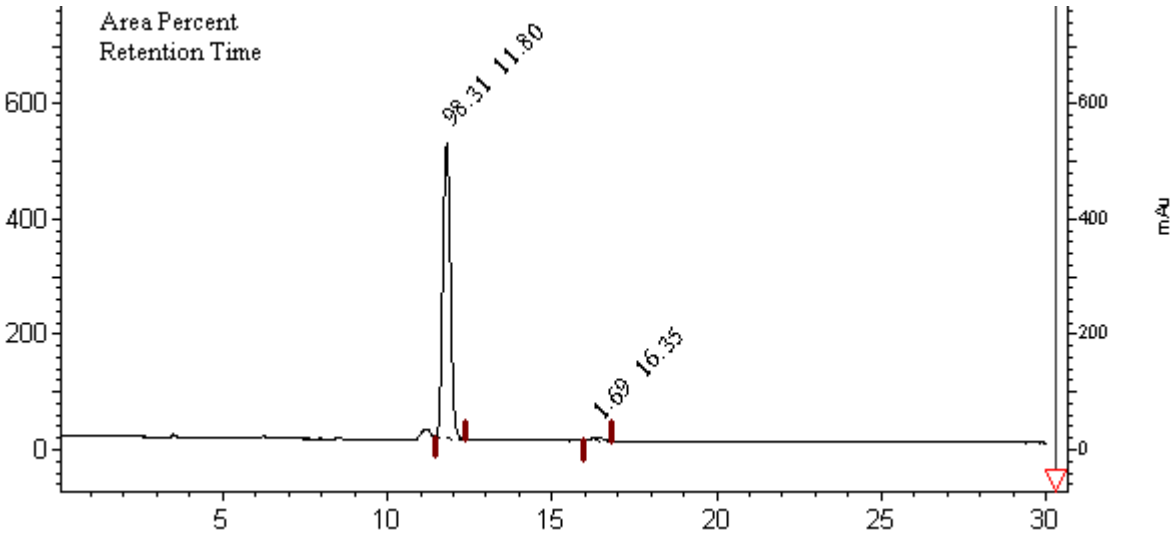
#	Time	Type	Area	Height	Width	Area%	Symmetry
1	20.298	BB	60.9	2.2	0.3302	0.703	0.922
2	21.956	BB	8603.5	281	0.4712	99.297	0.857

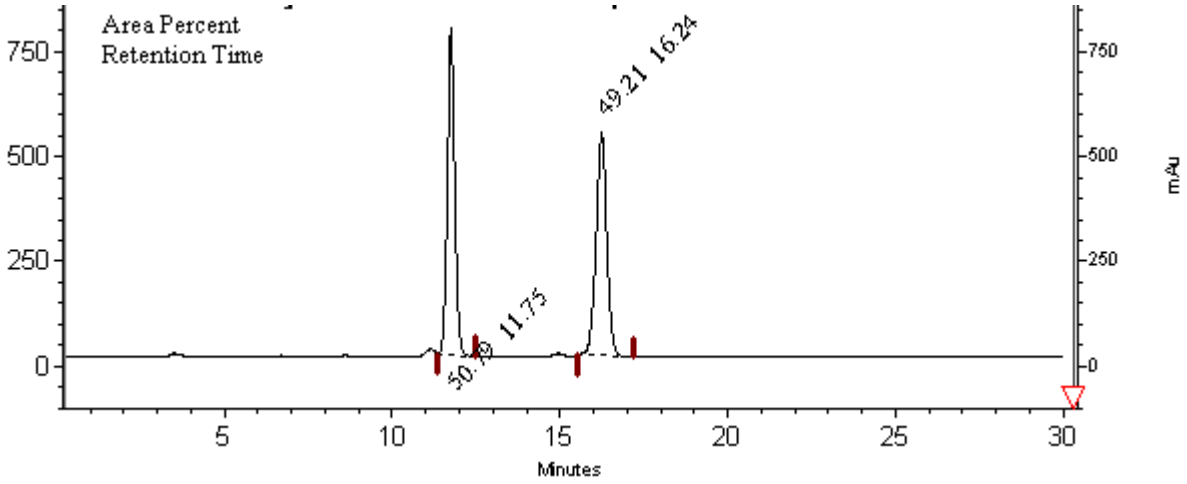


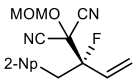
#	Time	Type	Area	Height	Width	Area%	Symmetry
1	4.227	BB	9.3	1.5	0.0774	0.123	0.87
2	20.168	BB	3676.7	132	0.4169	48.617	0.87
3	21.836	BB	3876.5	127.4	0.4449	51.259	0.878


Me
CO2Et
EtO2C
F
2-Np

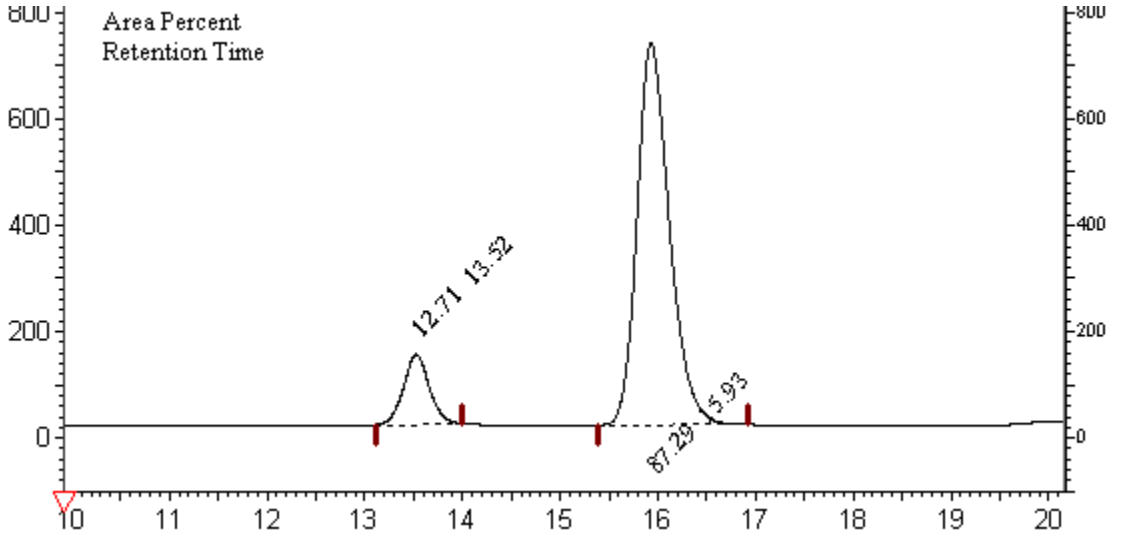
3ia
94%, 98:2 er

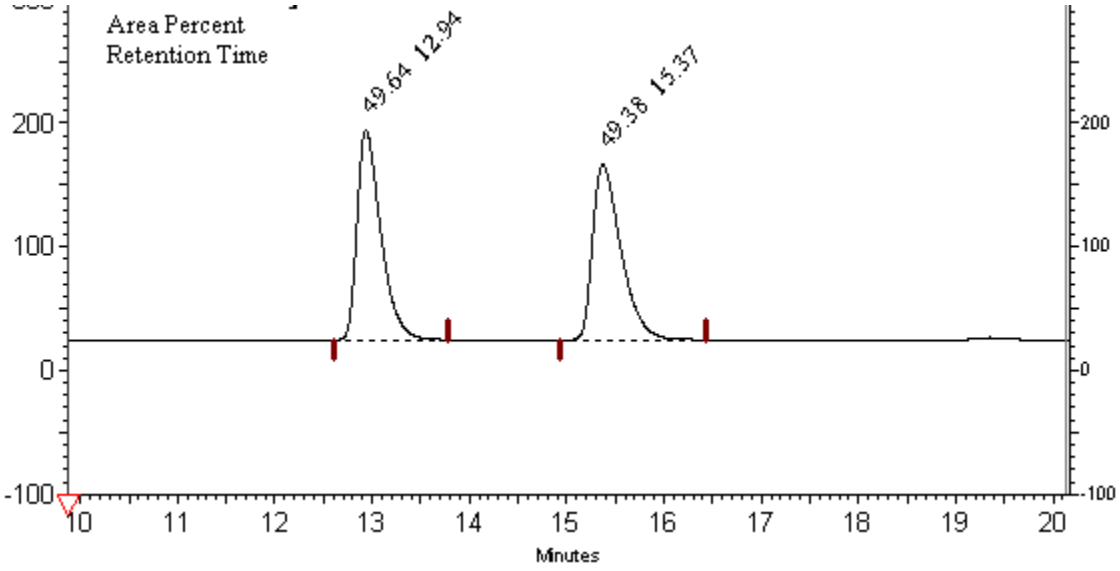

Area Percent
Retention Time
98.31 11.80
1.69 16.35
600
400
200
0
5
10
15
20
25
30
mAu

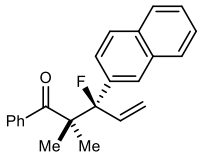

Area Percent
Retention Time
49.21 16.24
50.79 11.75
750
500
250
0
5
10
15
20
25
30
Minutes
mAu



3ie
89%, 87:13 er

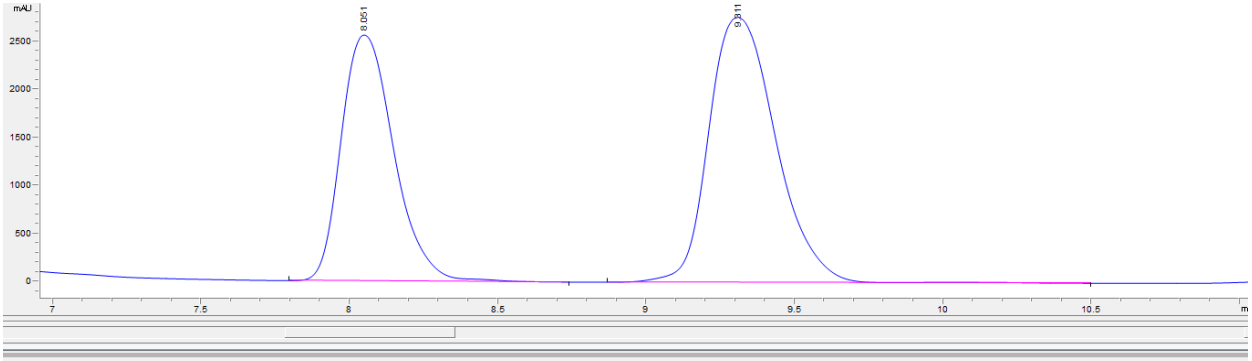




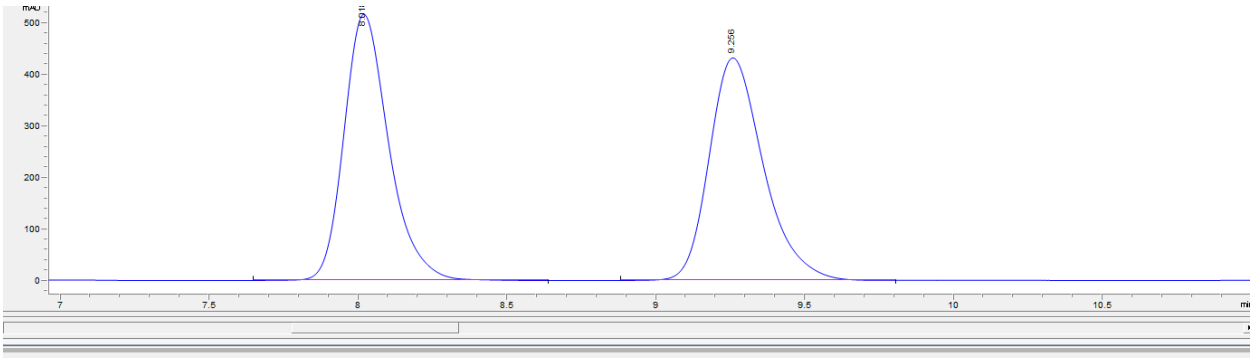


S1

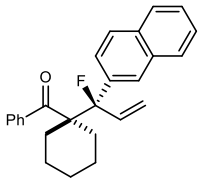
84% (58:42 er)



#	Time	Type	Area	Height	Width	Area%	Symmetry
1	8.051	BB	31614.1	2558.8	0.1936	42.205	0.748
2	9.311	BV R	43291.2	2759.8	0.1859	57.795	0.774

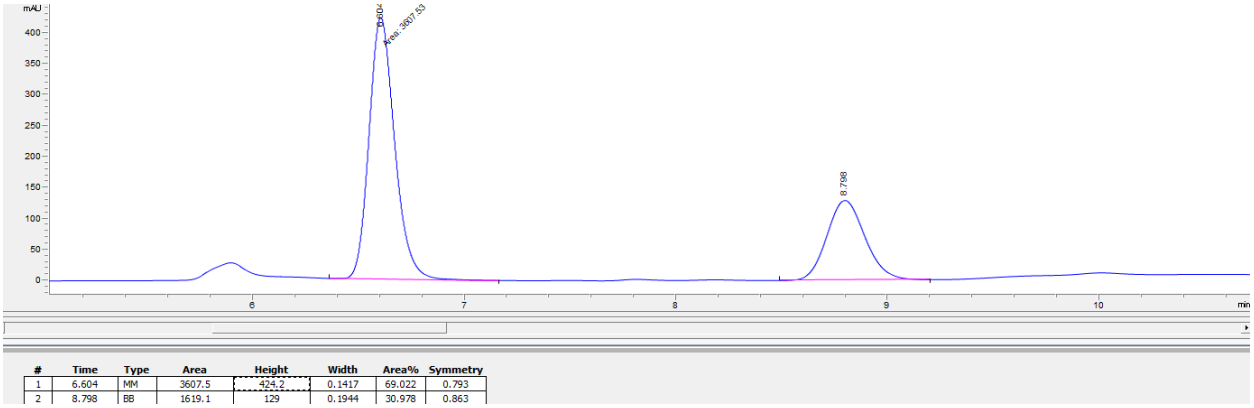


#	Time	Type	Area	Height	Width	Area%	Symmetry
1	8.018	BB	5428.3	518.1	0.1607	49.751	0.754
2	9.256	BB	5482.7	433.1	0.1942	50.249	0.737

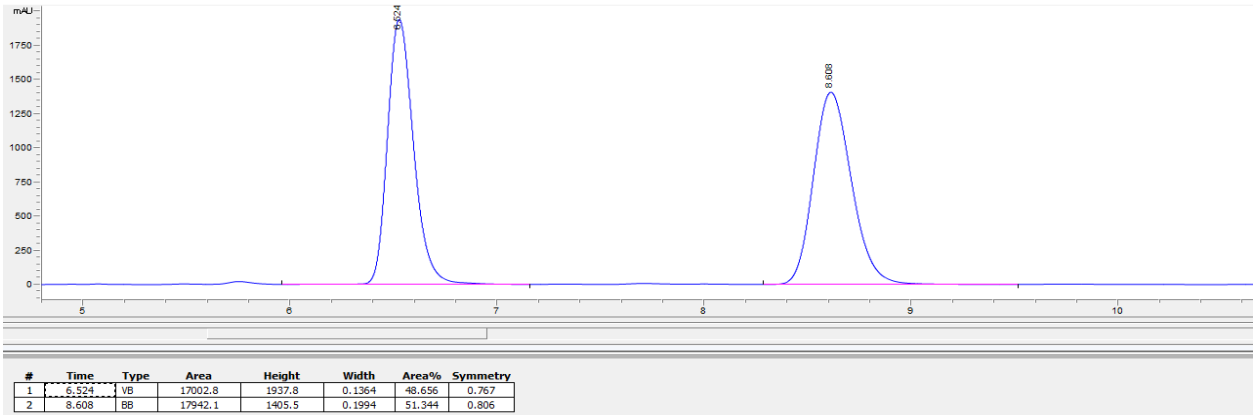


S2

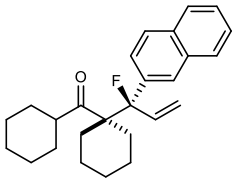
72% (69:31 er)



#	Time	Type	Area	Height	Width	Area%	Symmetry
1	6.604	MM	3607.5	424.2	0.1417	69.022	0.793
2	8.798	BB	1619.1	129	0.1944	30.978	0.863

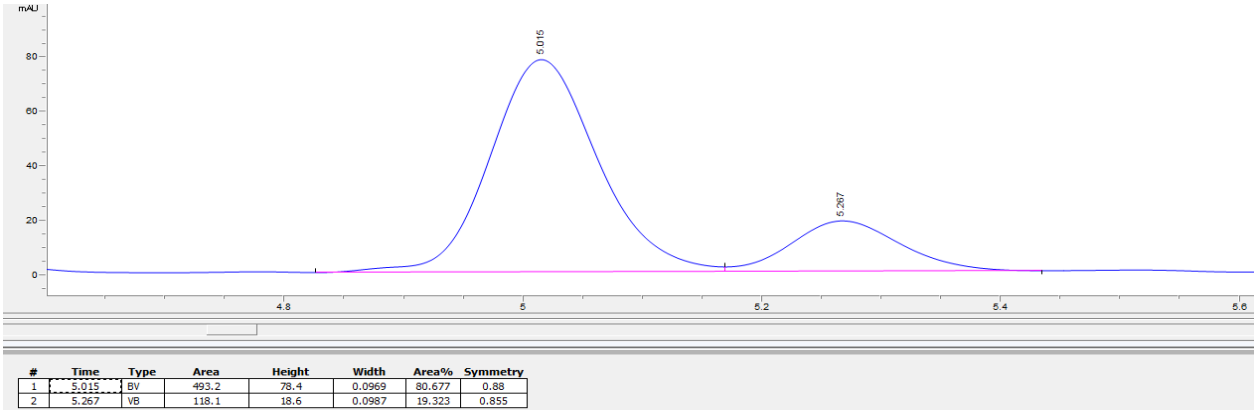


#	Time	Type	Area	Height	Width	Area%	Symmetry
1	6.524	VB	17002.8	1937.8	0.1364	48.656	0.767
2	8.608	BB	17942.1	1405.5	0.1994	51.344	0.806

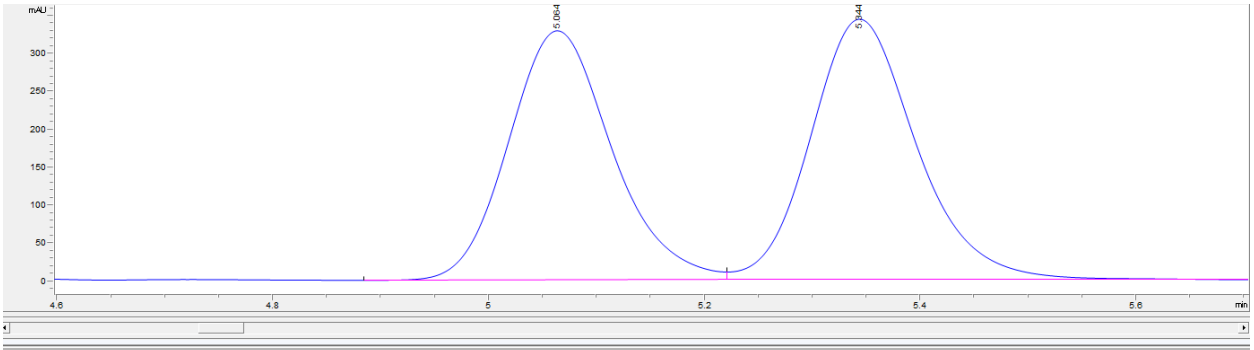


S3

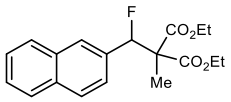
59% (81:19 er)

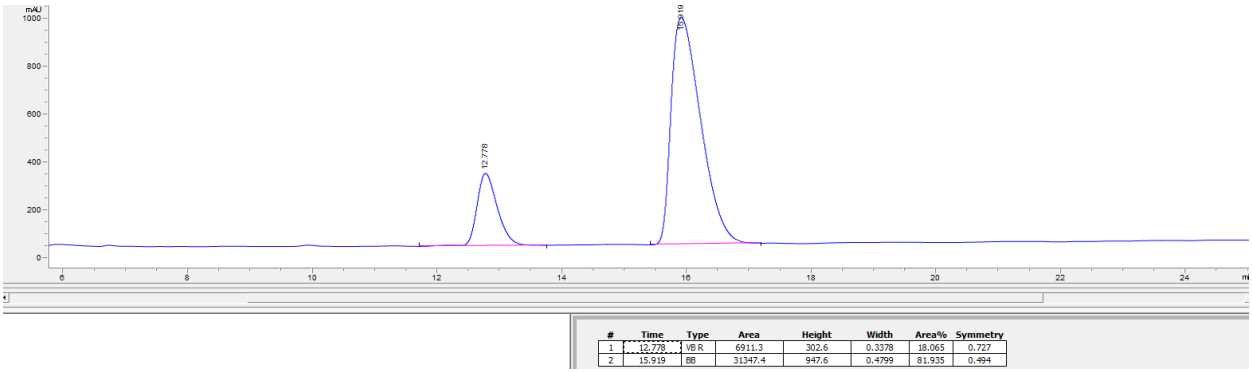


#	Time	Type	Area	Height	Width	Area%	Symmetry
1	5.015	BV	493.2	78.4	0.0969	80.677	0.88
2	5.267	VB	118.1	18.6	0.0987	19.323	0.855

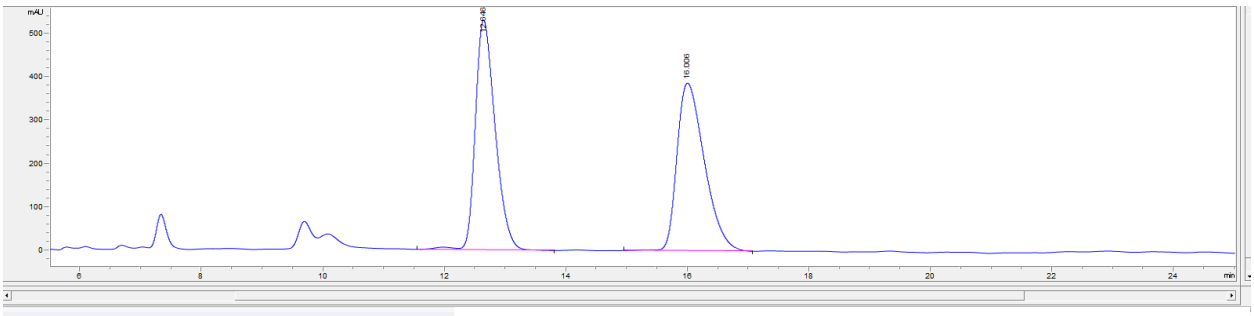


#	Time	Type	Area	Height	Width	Area%	Symmetry
1	5.064	BV	2208	330.7	0.1029	48.187	0.853
2	5.344	VB	2374.1	345.9	0.1051	51.813	0.819



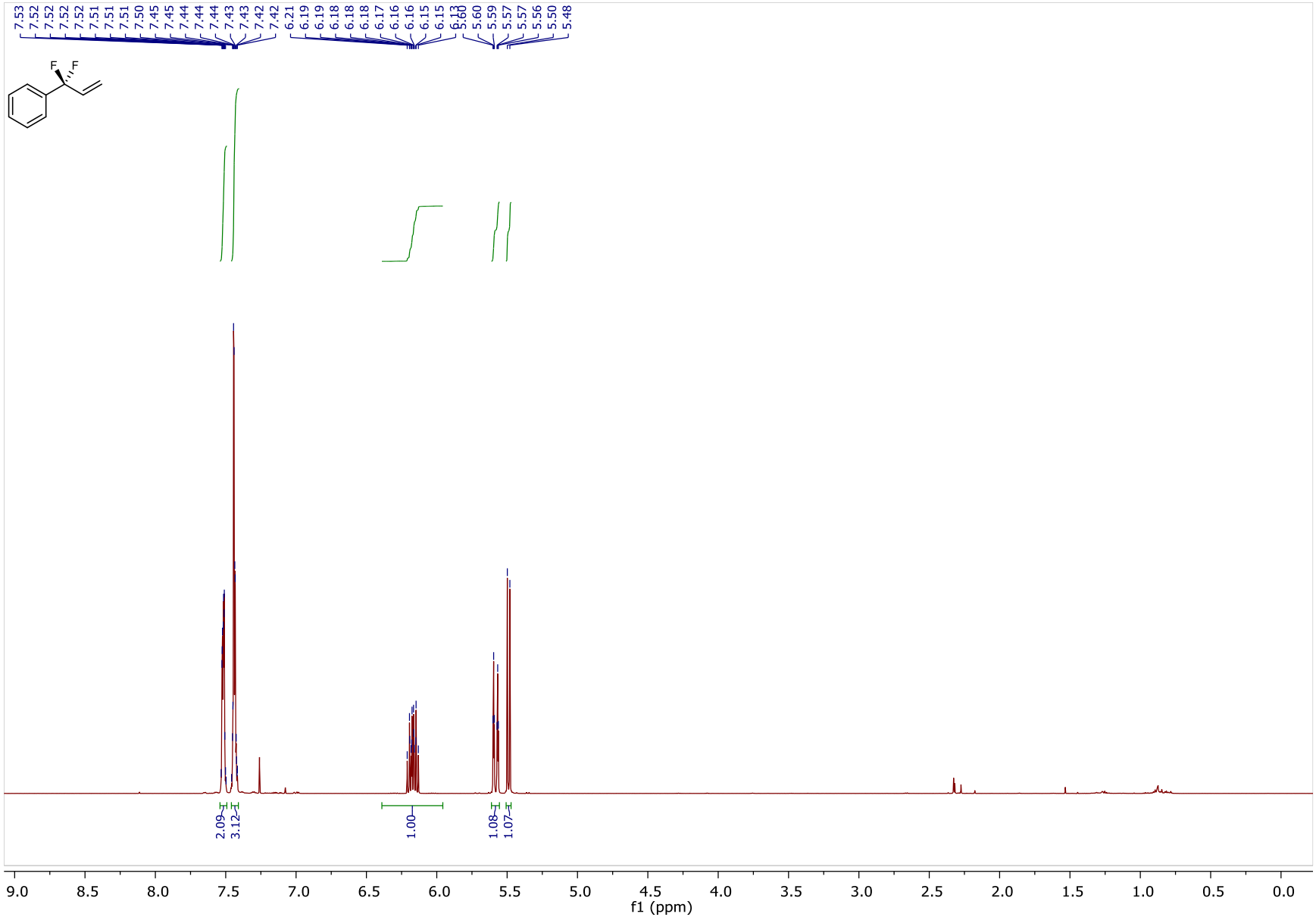


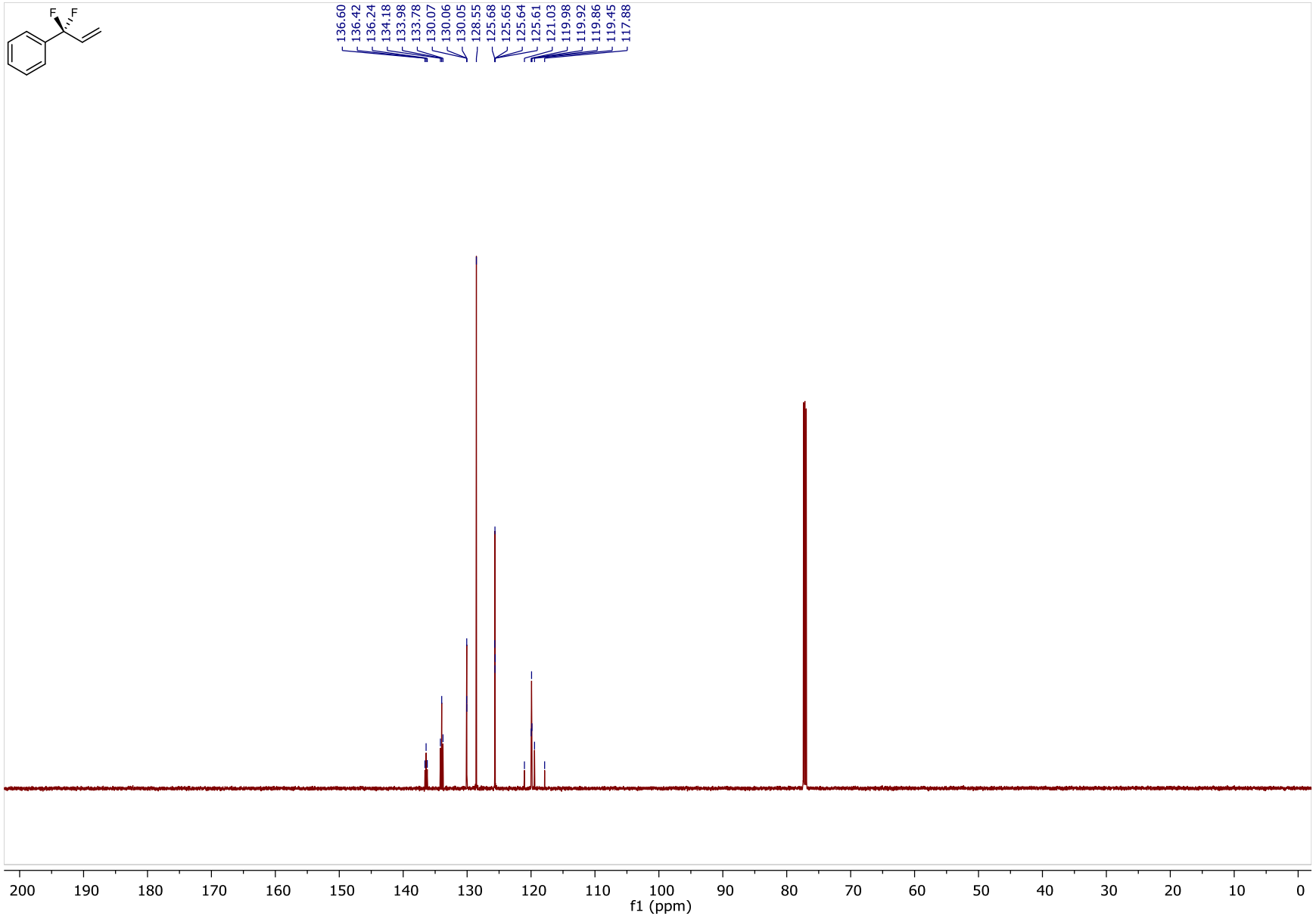
#	Time	Type	Area	Height	Width	Area%	Symmetry
1	12.778	VB R	6911.3	302.6	0.3378	18.065	0.727
2	15.919	BB	31347.4	947.6	0.4799	81.935	0.494

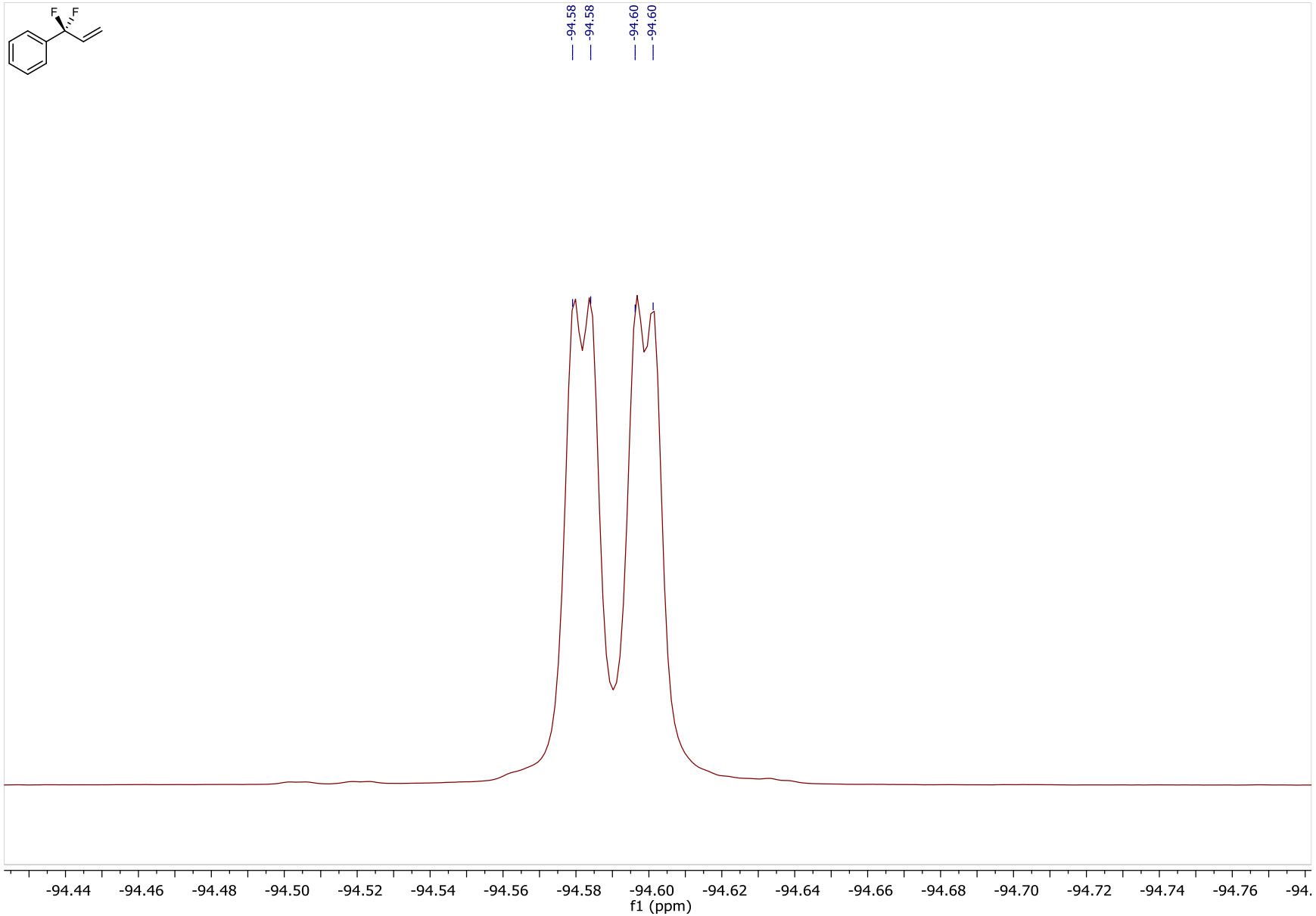


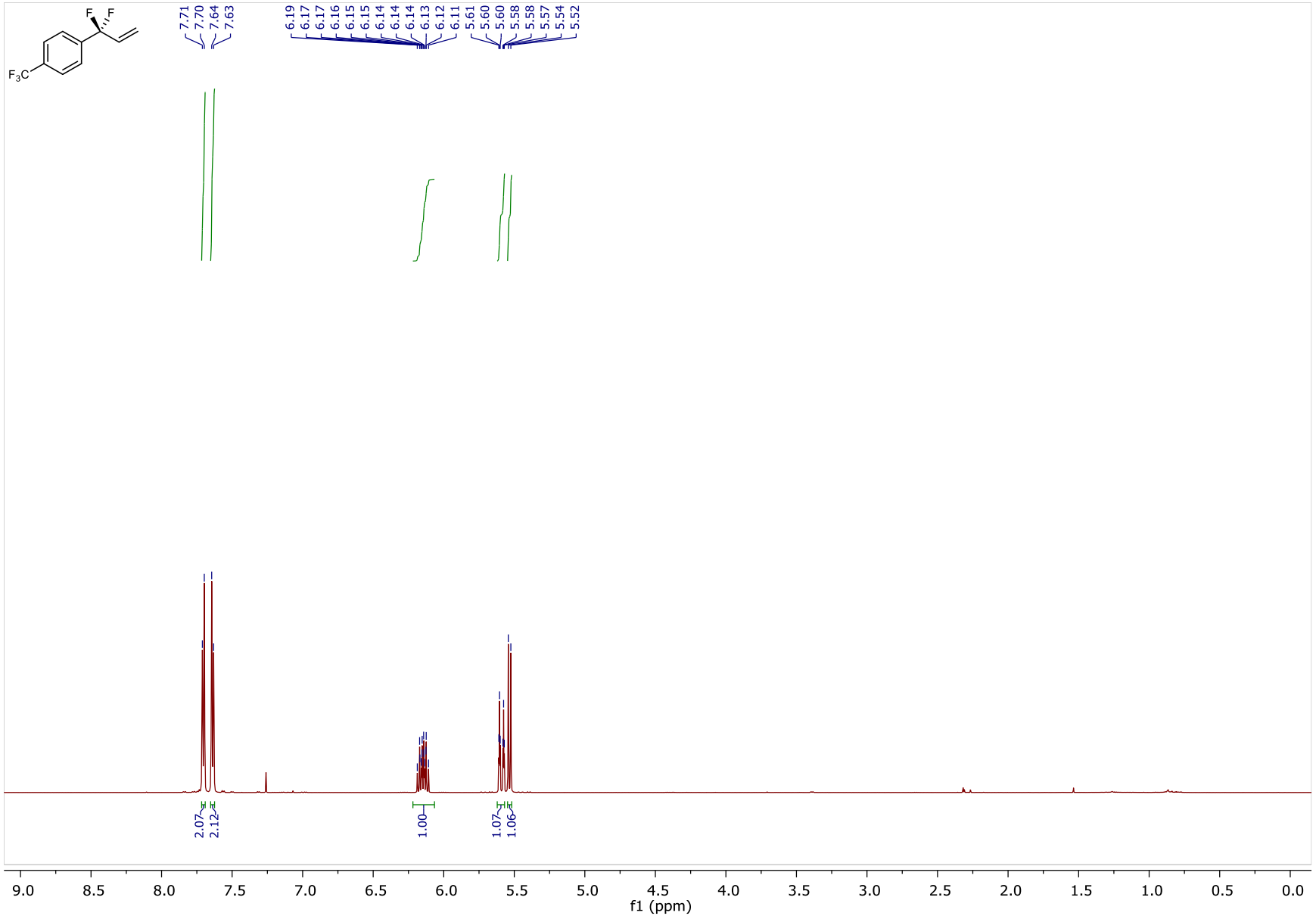
#	Time	Type	Area	Height	Width	Area%	Symmetry
1	12.646	VB R	12062.8	530.2	0.343	49.779	0.703
2	16.006	BB	12169.8	387.2	0.4617	50.221	0.6

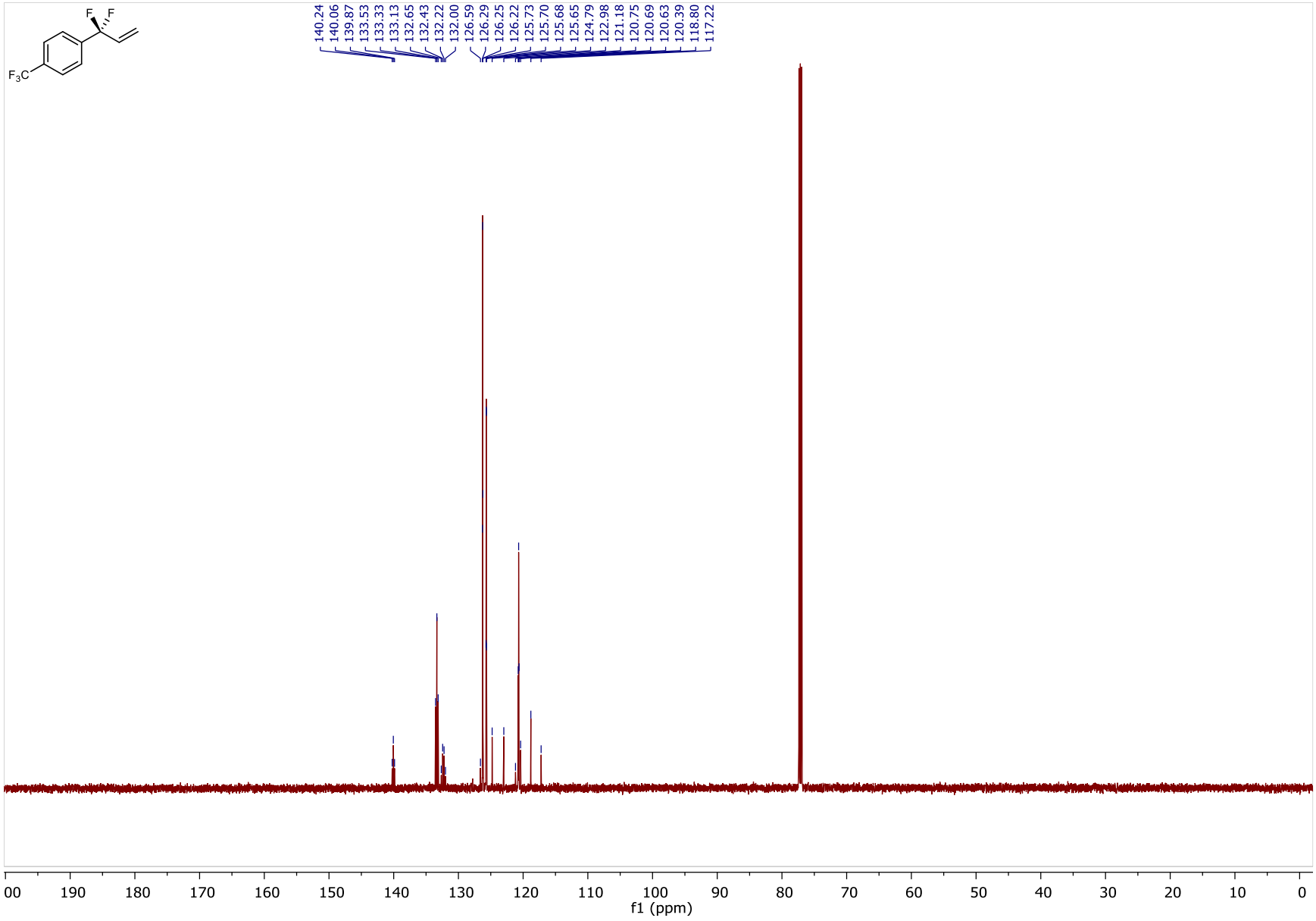
^{1}H, ^{13}C, ^{31}P, AND ^{19}F NMR SPECTRA

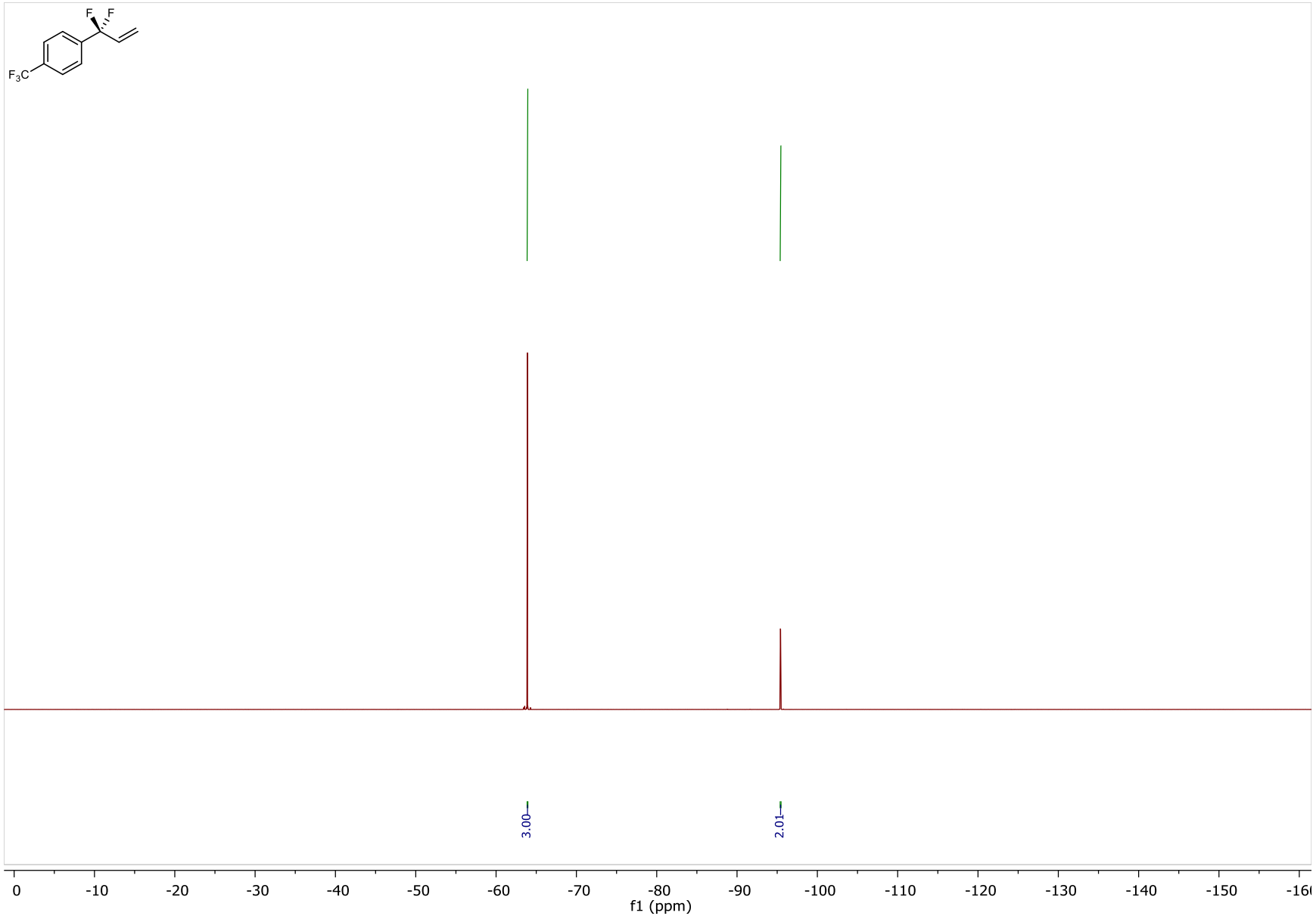

7.53 7.52 7.52 7.52 7.52 7.51 7.51 7.50 7.45 7.45 7.44 7.44 7.44 7.43 7.43 7.42 7.42 6.21 6.19 6.19 6.18 6.18 6.18 6.17 6.16 6.16 6.15 6.15 6.13 5.60 5.60 5.59 5.57 5.57 5.56 5.50 5.48
F F
2.09
3.12
1.00
1.08
1.07
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

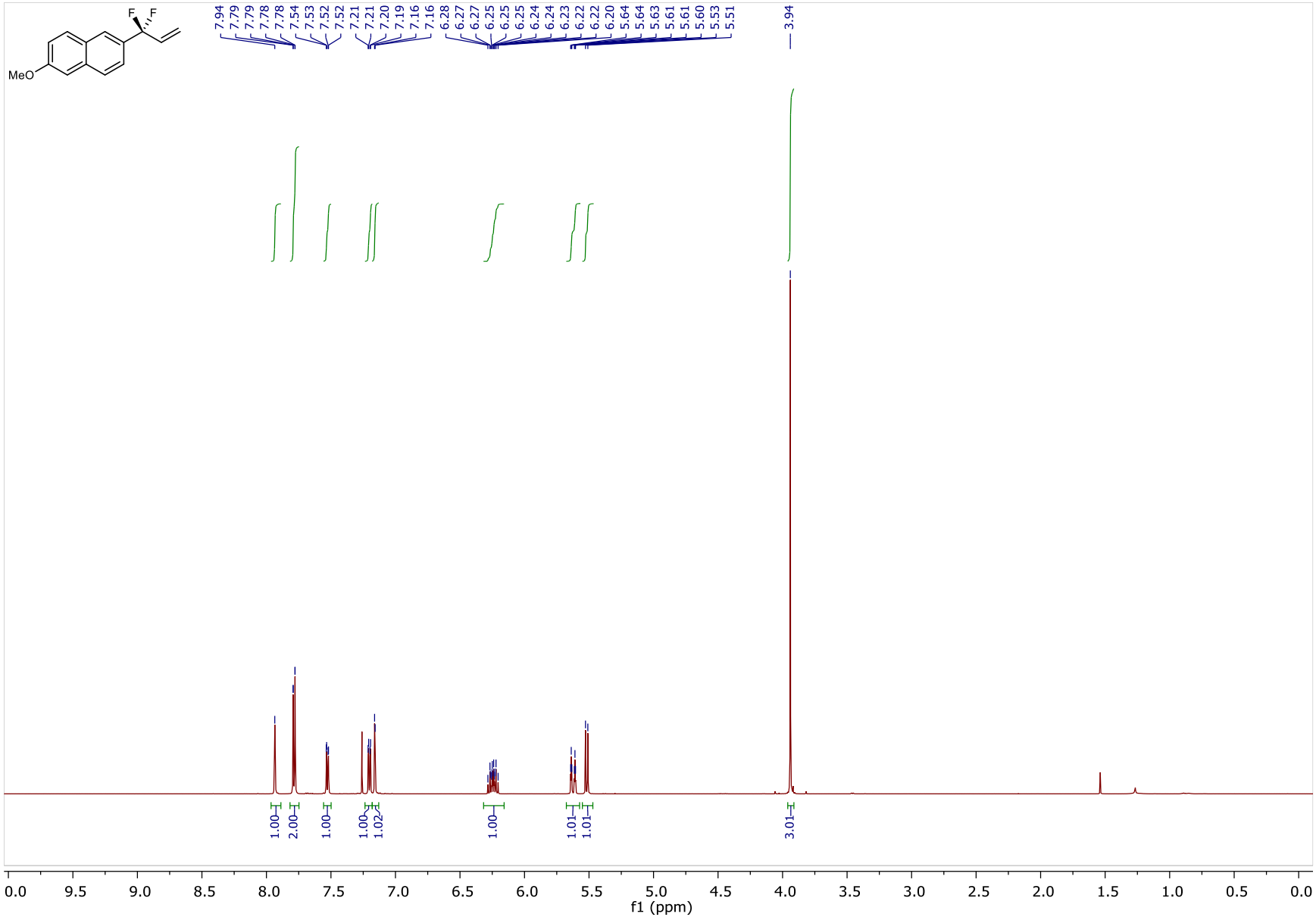

F
F
136.60
136.42
136.24
134.18
133.98
133.78
130.07
130.06
130.05
128.55
125.68
125.65
125.64
125.61
121.03
119.98
119.92
119.86
119.45
117.88
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

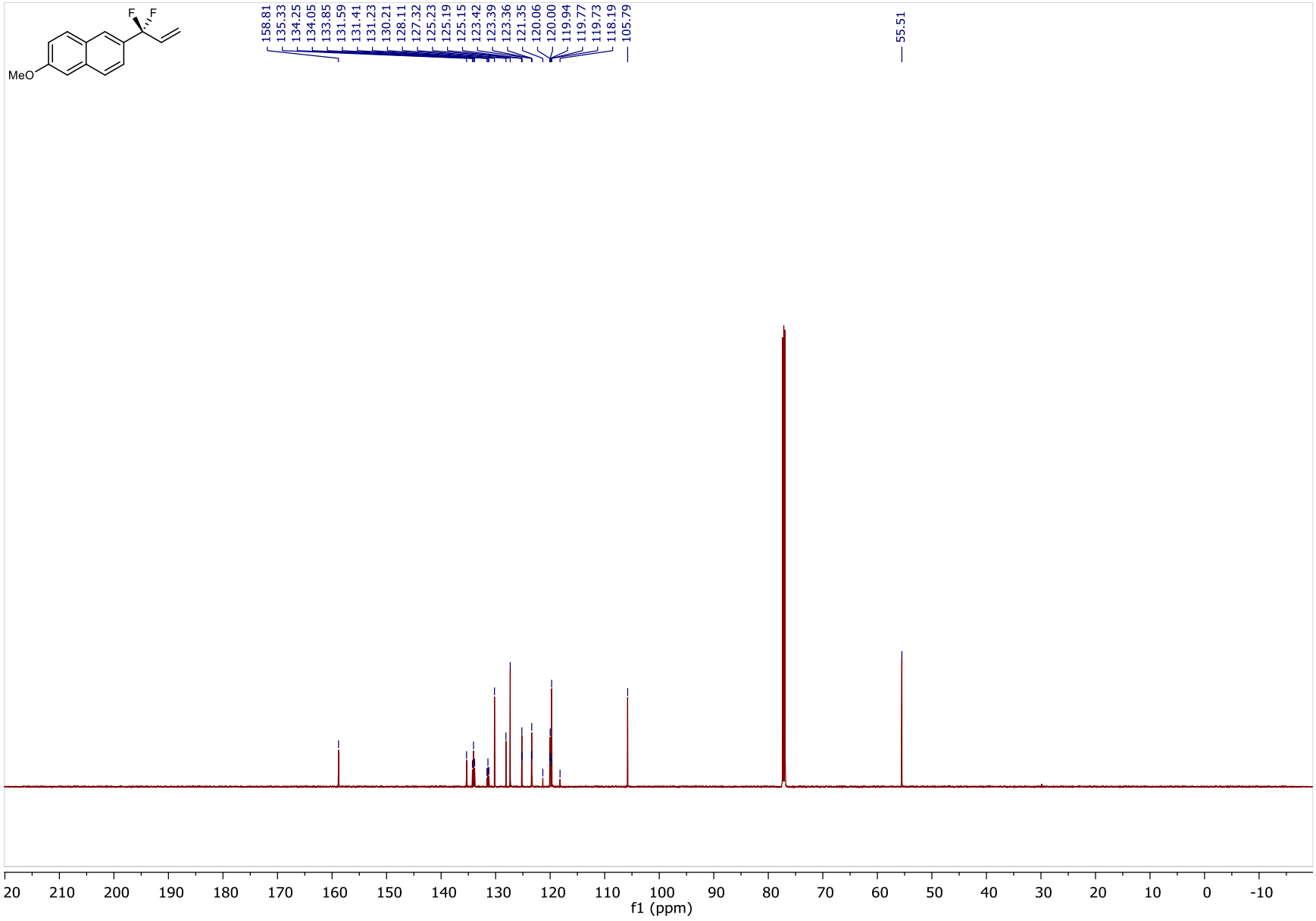

F
F
-94.58
-94.58
-94.60
-94.60
-94.44
-94.46
-94.48
-94.50
-94.52
-94.54
-94.56
-94.58
-94.60
-94.62
-94.64
-94.66
-94.68
-94.70
-94.72
-94.74
-94.76
f1 (ppm)

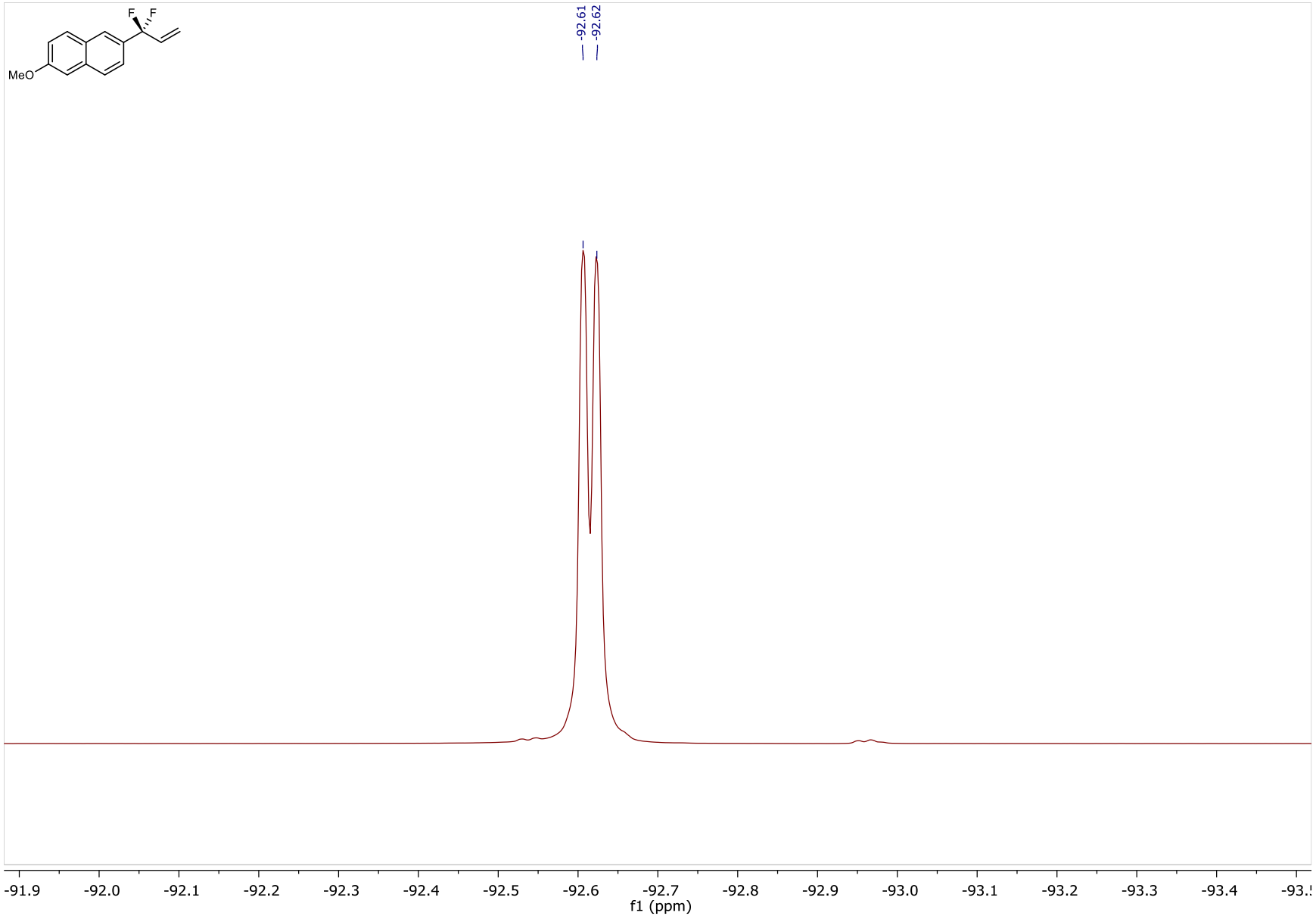

F
F
F3C
7.71
7.70
7.64
7.63
6.19
6.17
6.17
6.16
6.15
6.15
6.14
6.14
6.14
6.13
6.12
6.11
5.61
5.60
5.60
5.58
5.58
5.57
5.54
5.52
2.07
2.12
1.00
1.07
1.06
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

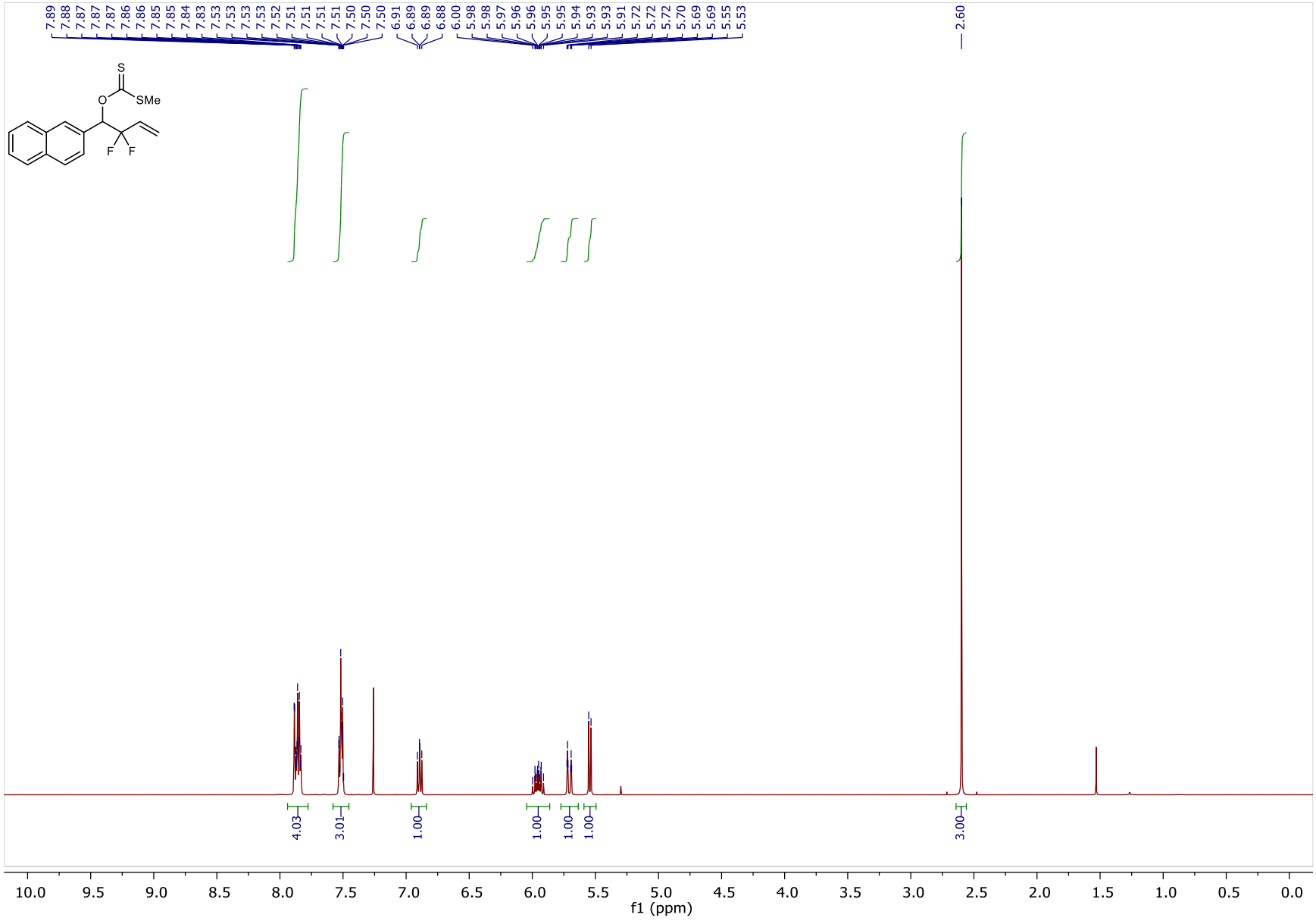

F
F
F3C
140.24
140.06
139.87
133.53
133.33
133.13
132.65
132.43
132.22
132.00
126.59
126.29
126.25
126.22
125.73
125.70
125.68
125.65
124.79
122.98
121.18
120.75
120.69
120.63
120.39
118.80
117.22
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

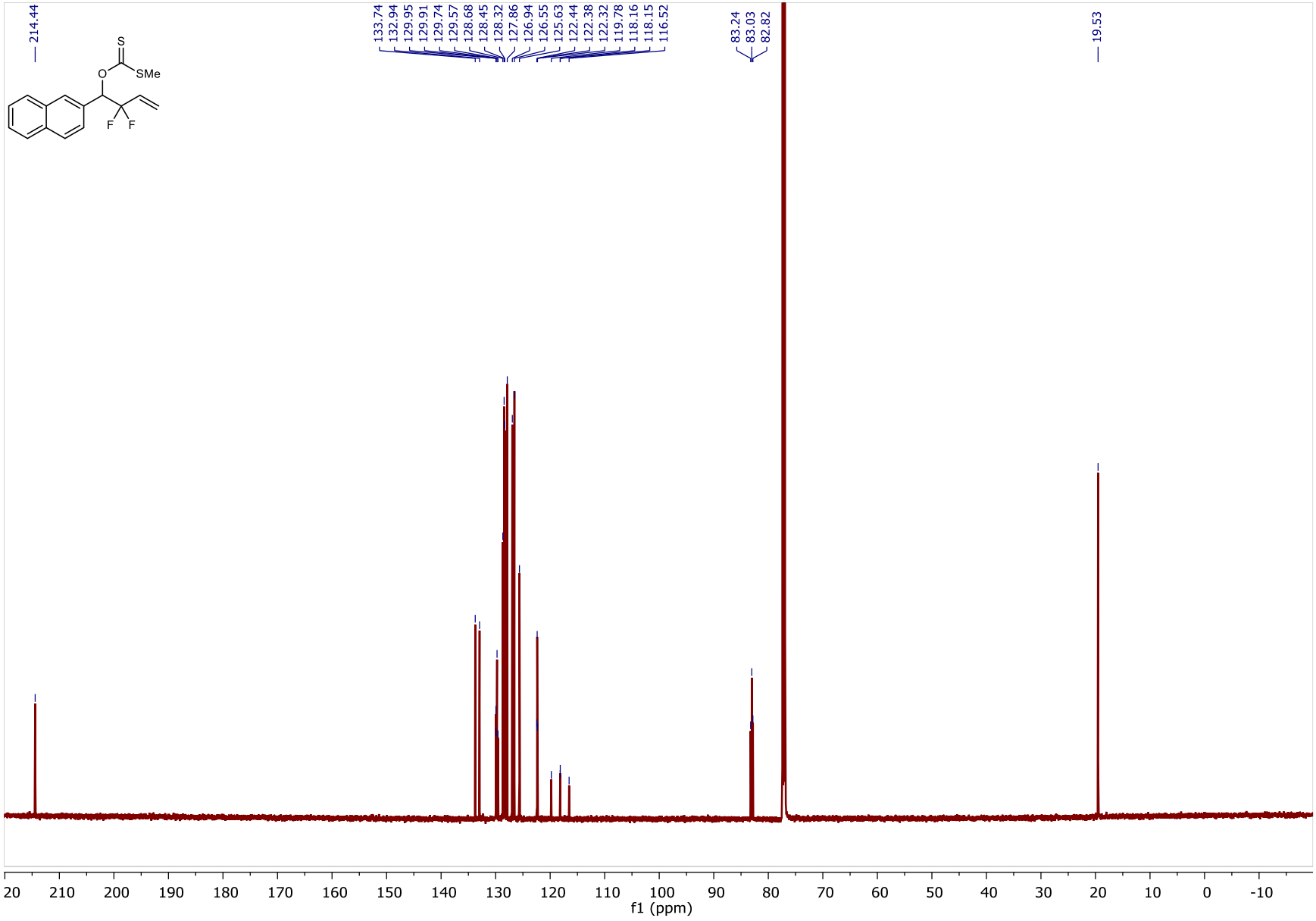

F
F
F3C
3.00
2.01
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
f1 (ppm)

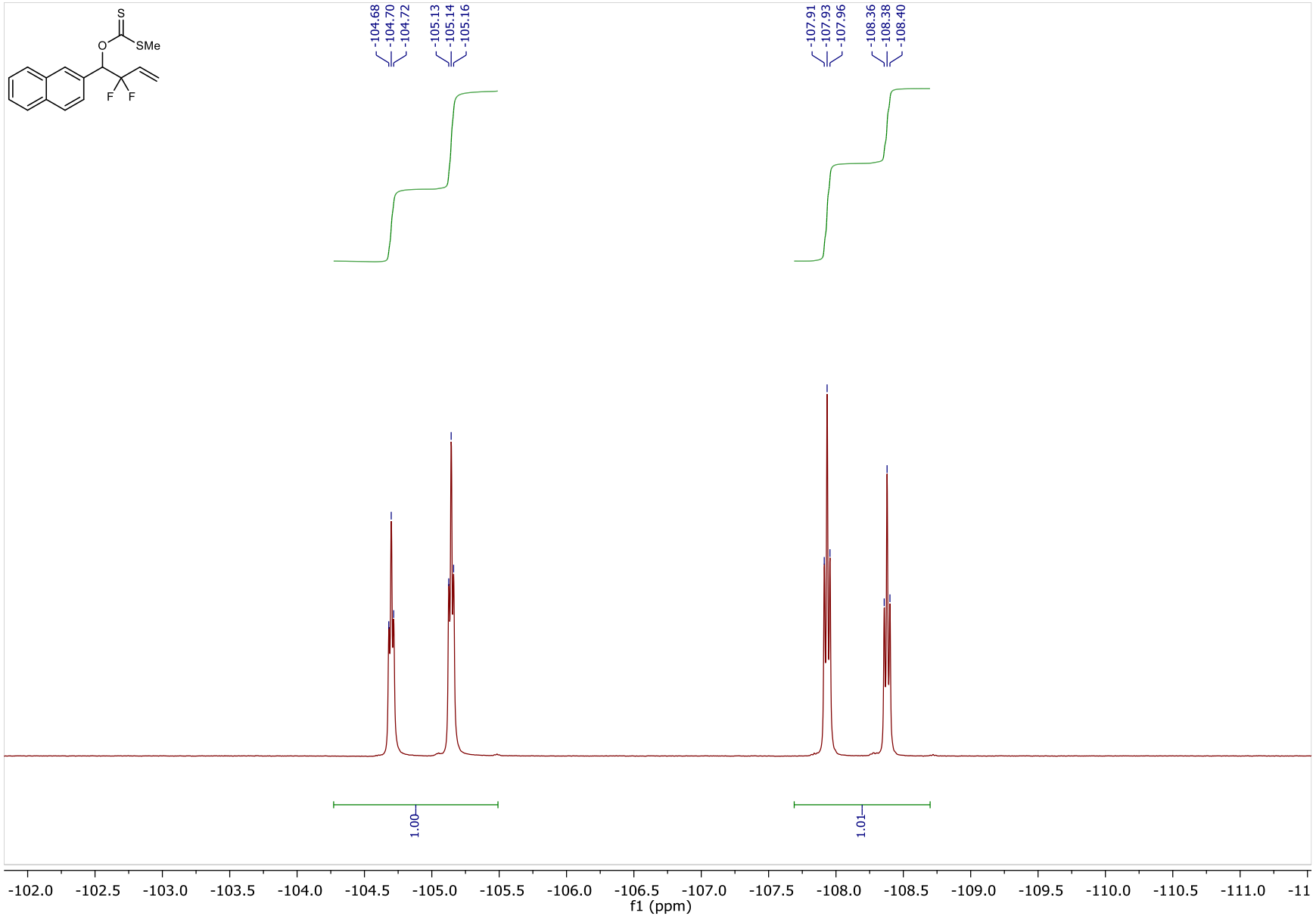

F
F
MeO
7.94
7.79
7.79
7.78
7.78
7.54
7.53
7.52
7.52
7.21
7.21
7.20
7.19
7.16
7.16
6.28
6.27
6.27
6.25
6.25
6.25
6.24
6.24
6.23
6.22
6.22
6.20
5.64
5.64
5.63
5.61
5.61
5.60
5.53
5.51
3.94
1.00
2.00
1.00
1.00
1.02
1.00
1.01
1.01
3.01
0.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

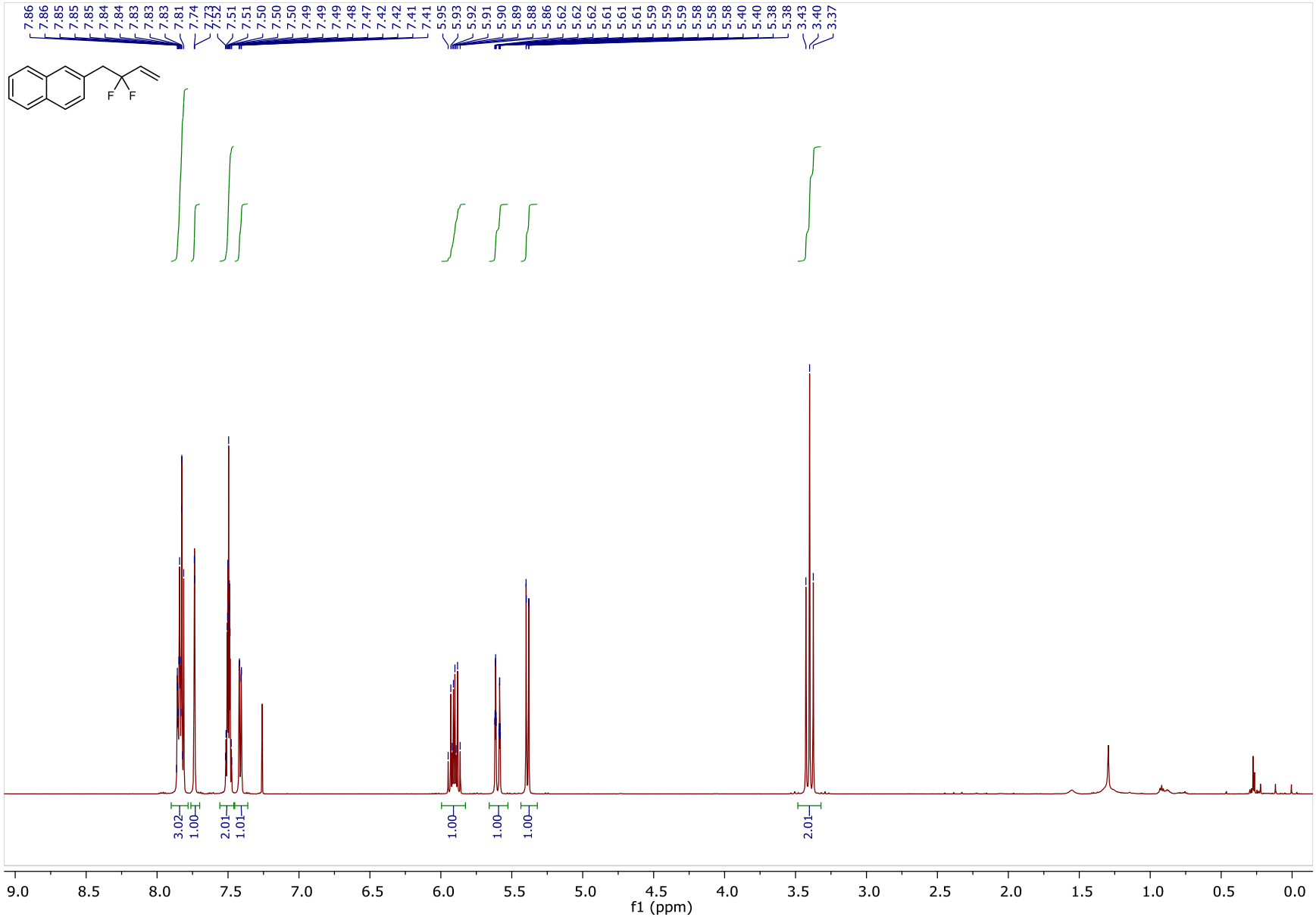

F
F
MeO
158.81
135.33
134.25
134.05
133.85
131.59
131.41
131.23
130.21
128.11
127.32
125.23
125.19
125.15
123.42
123.39
123.36
121.35
120.06
120.00
119.94
119.77
119.73
118.19
105.79
55.51
20
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

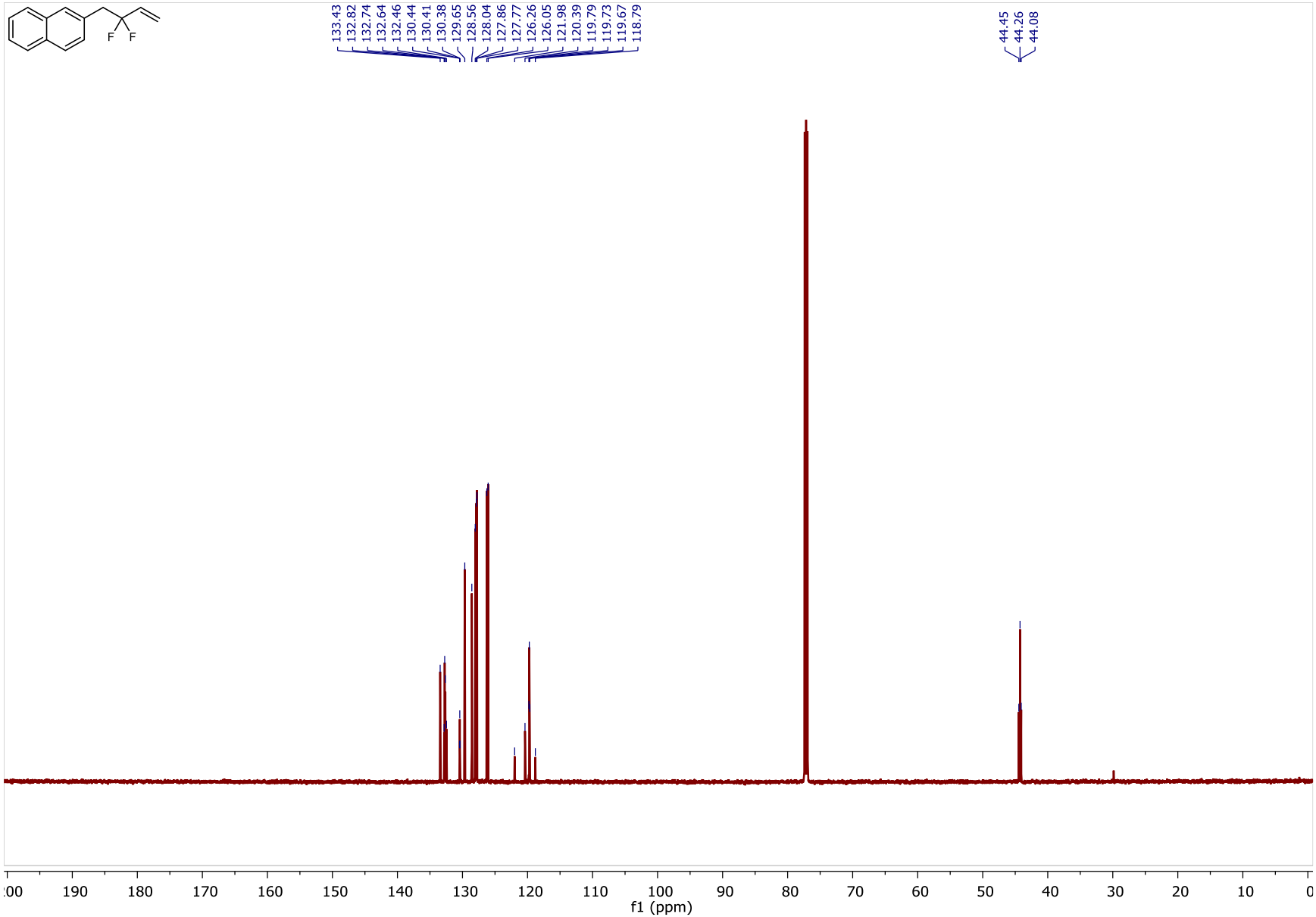

F
F
MeO
-92.61
-92.62
-91.9
-92.0
-92.1
-92.2
-92.3
-92.4
-92.5
-92.6
-92.7
-92.8
-92.9
-93.0
-93.1
-93.2
-93.3
-93.4
f1 (ppm)

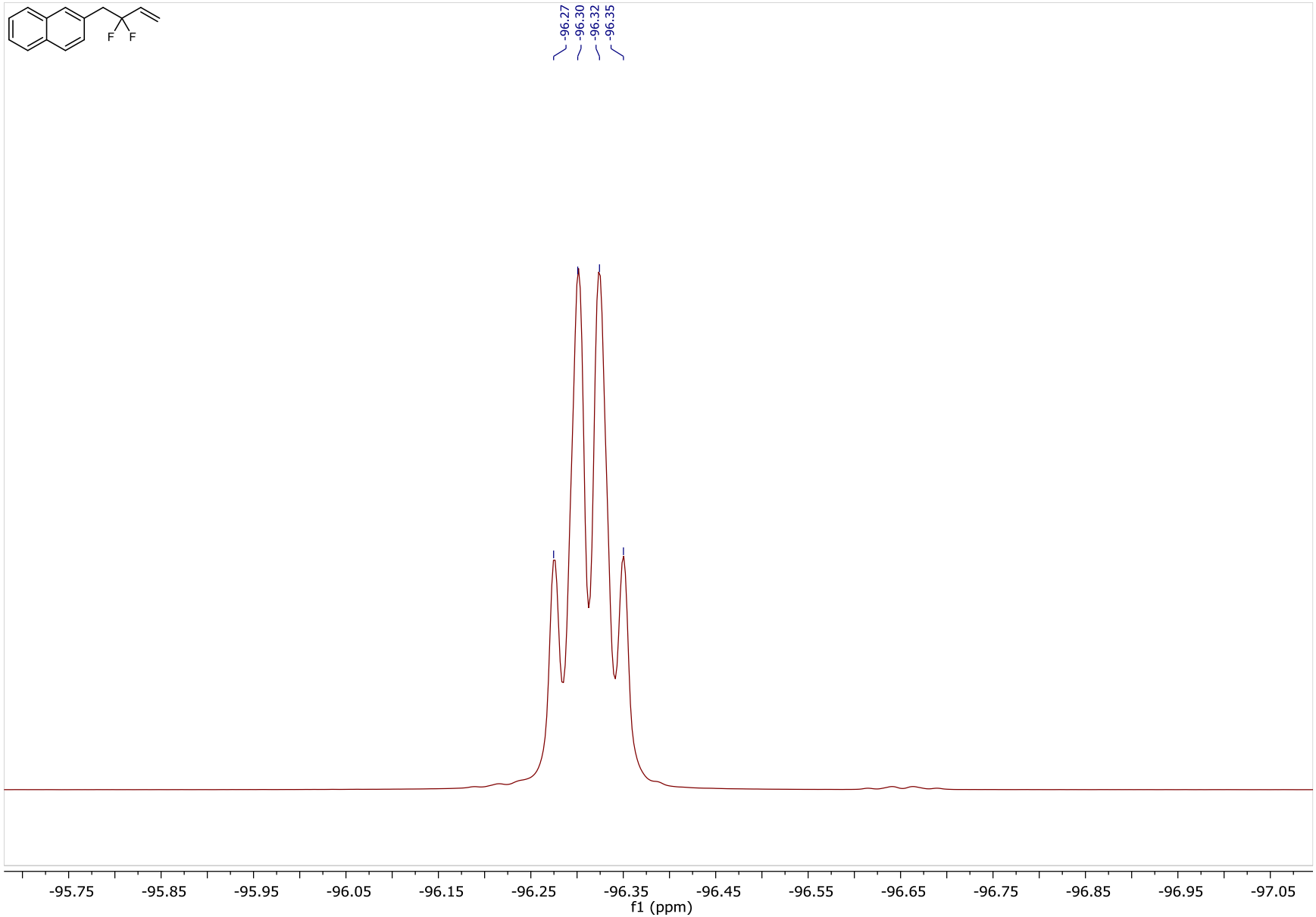

7.89
7.88
7.87
7.87
7.87
7.86
7.86
7.85
7.85
7.84
7.83
7.53
7.53
7.53
7.52
7.51
7.51
7.51
7.50
7.50
7.50
6.91
6.89
6.89
6.88
6.00
5.98
5.98
5.97
5.96
5.96
5.95
5.95
5.94
5.93
5.93
5.91
5.72
5.72
5.70
5.69
5.69
5.55
5.53
2.60
S
O
SMe
F
F
4.03
3.01
1.00
1.00
1.00
1.00
3.00
10.0
9.5
9.0
8.5
8.0
7.5
7.0
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
0.0
f1 (ppm)

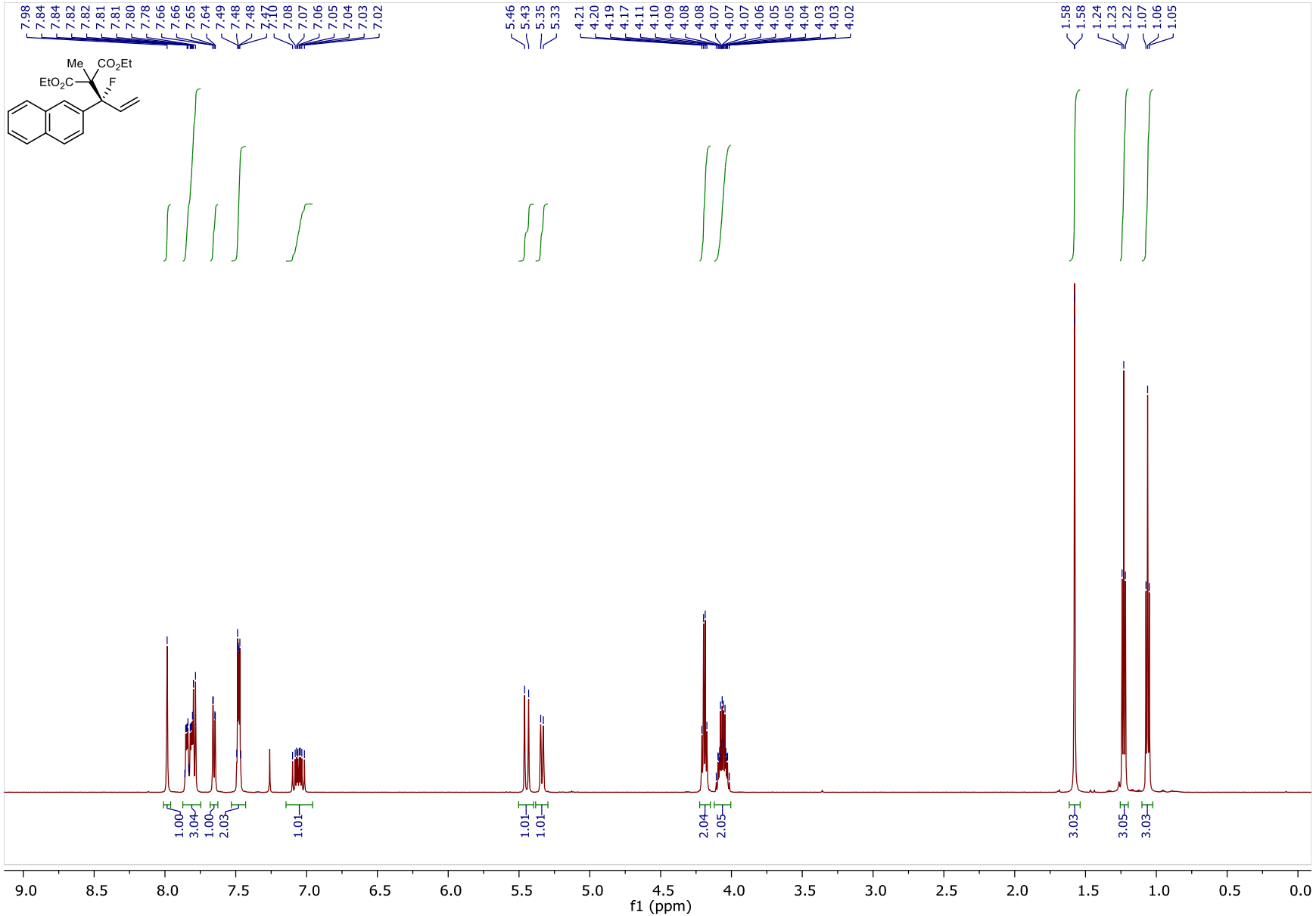

214.44
133.74
132.94
129.95
129.91
129.74
129.57
128.68
128.45
128.32
127.86
126.94
126.55
125.63
122.44
122.38
122.32
119.78
118.16
118.15
116.52
83.24
83.03
82.82
19.53
S
O
SMe
F
F
20
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

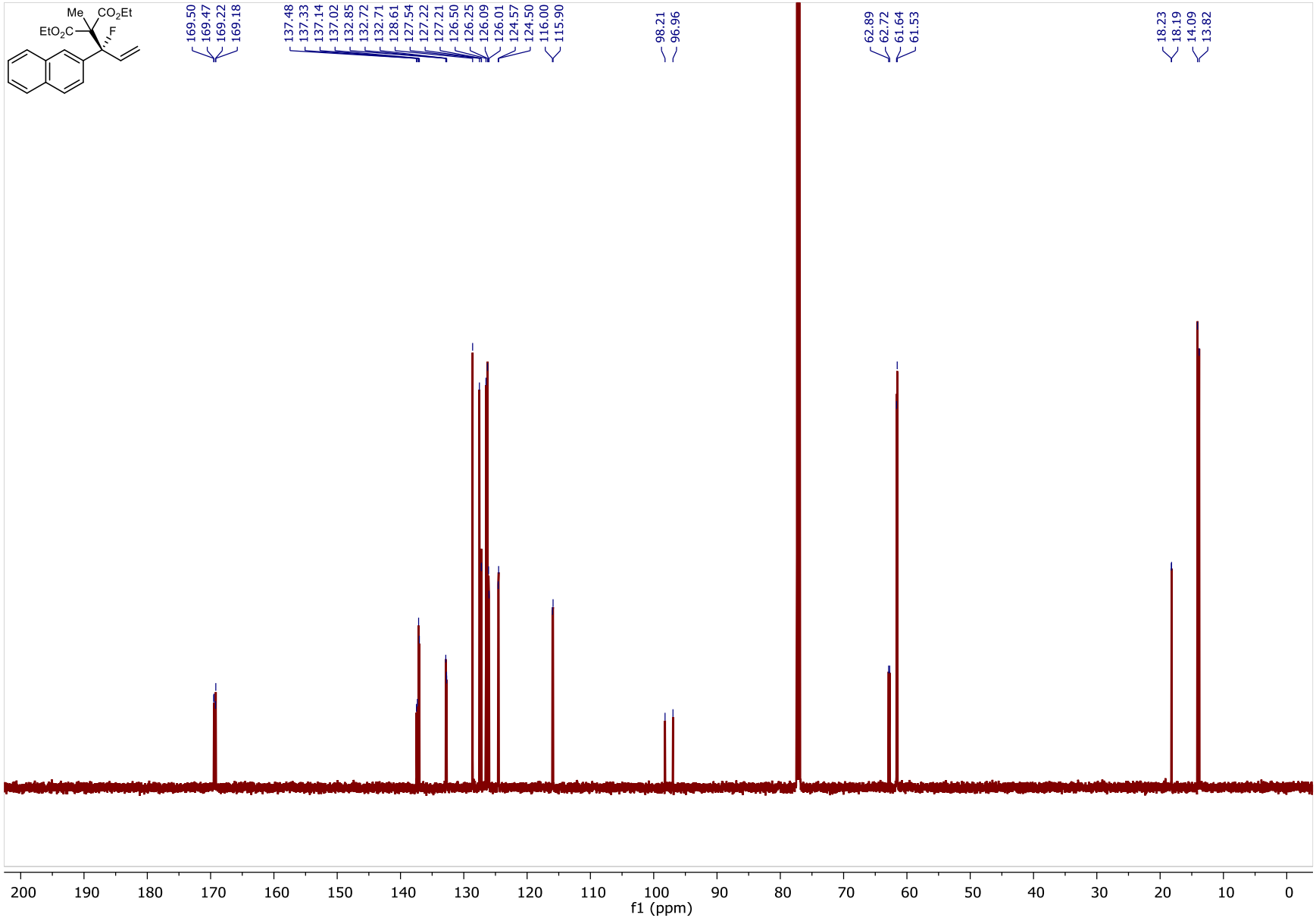

S
O
SMe
F
F
-104.68
-104.70
-104.72
-105.13
-105.14
-105.16
-107.91
-107.93
-107.96
-108.36
-108.38
-108.40
1.00
1.01
-102.0
-102.5
-103.0
-103.5
-104.0
-104.5
-105.0
-105.5
-106.0
-106.5
-107.0
-107.5
-108.0
-108.5
-109.0
-109.5
-110.0
-110.5
-111.0
-11
f1 (ppm)

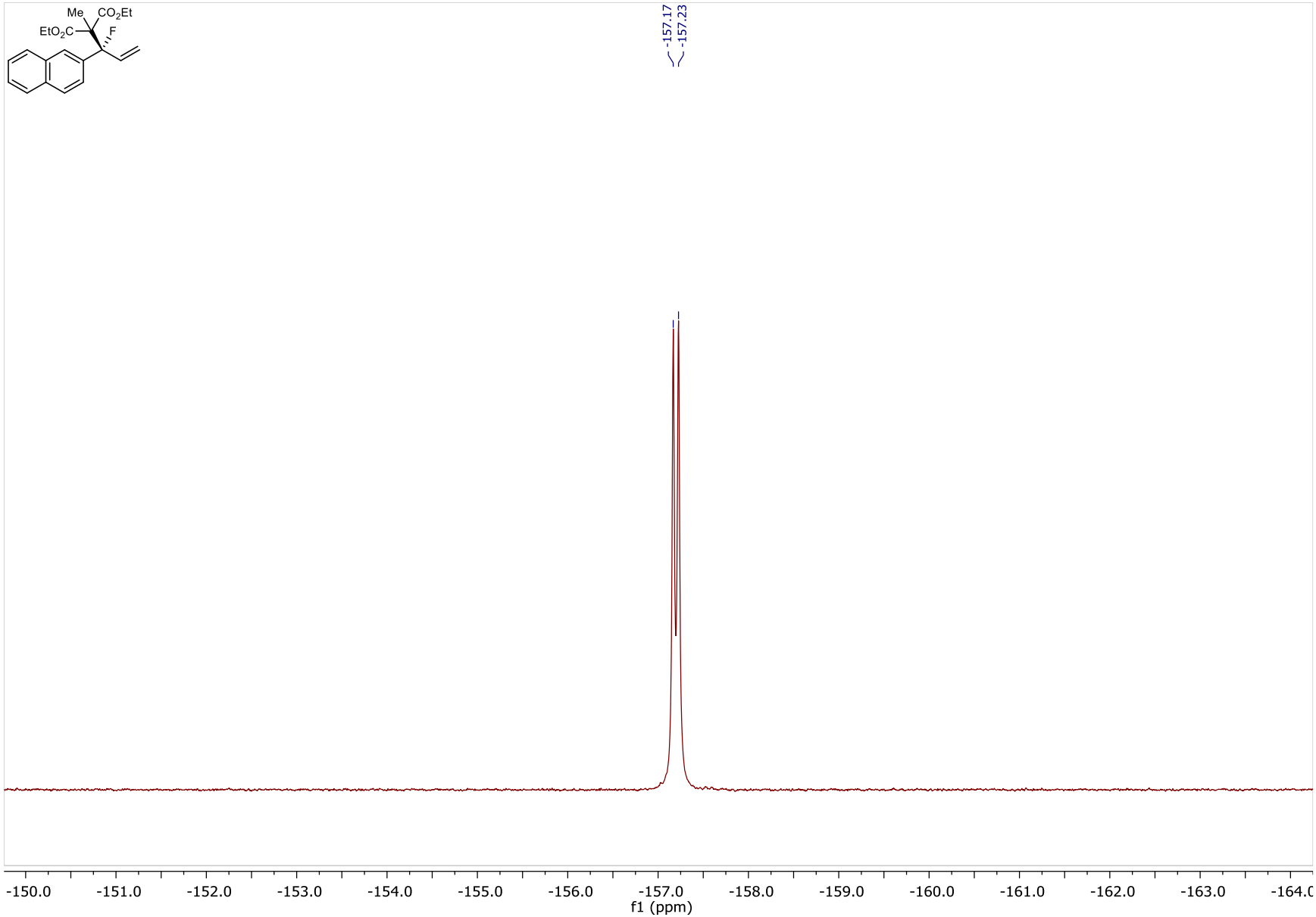

7.86 7.86 7.85 7.85 7.85 7.84 7.84 7.83 7.83 7.83 7.81 7.74 7.73 7.72 7.51 7.51 7.50 7.50 7.50 7.49 7.49 7.49 7.48 7.47 7.42 7.42 7.41 7.41 5.95 5.93 5.92 5.91 5.90 5.89 5.88 5.86 5.62 5.62 5.62 5.61 5.61 5.61 5.59 5.59 5.59 5.58 5.58 5.58 5.40 5.40 5.38 5.38 3.43 3.40 3.37
F F
3.02 1.00 2.01 1.01 1.00 1.00 1.00 2.01
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 0.0
f1 (ppm)

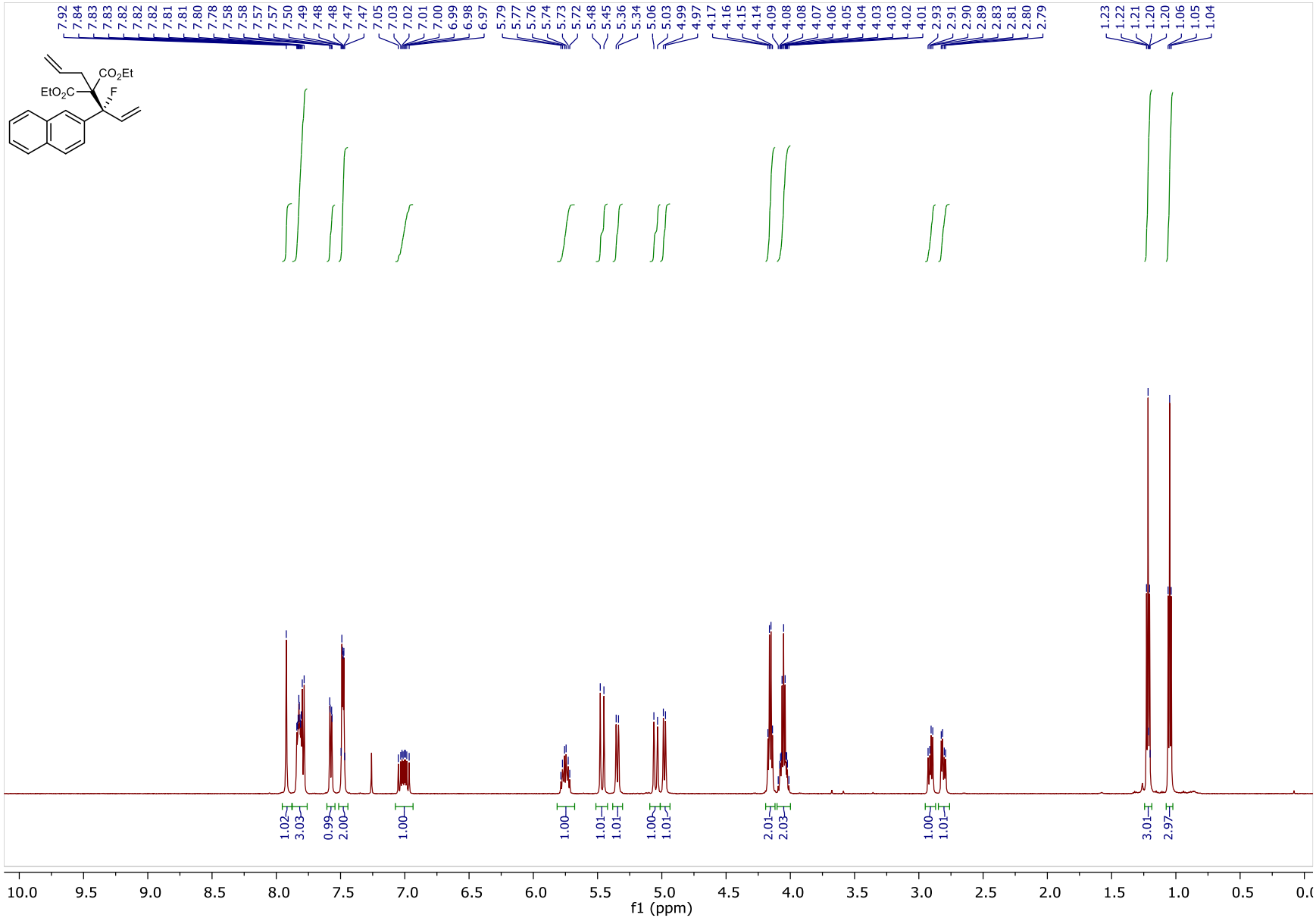

F
F
133.43
132.82
132.74
132.64
132.46
130.44
130.41
130.38
129.65
128.56
128.04
127.86
127.77
126.26
126.05
121.98
120.39
119.79
119.73
119.67
118.79
44.45
44.26
44.08
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

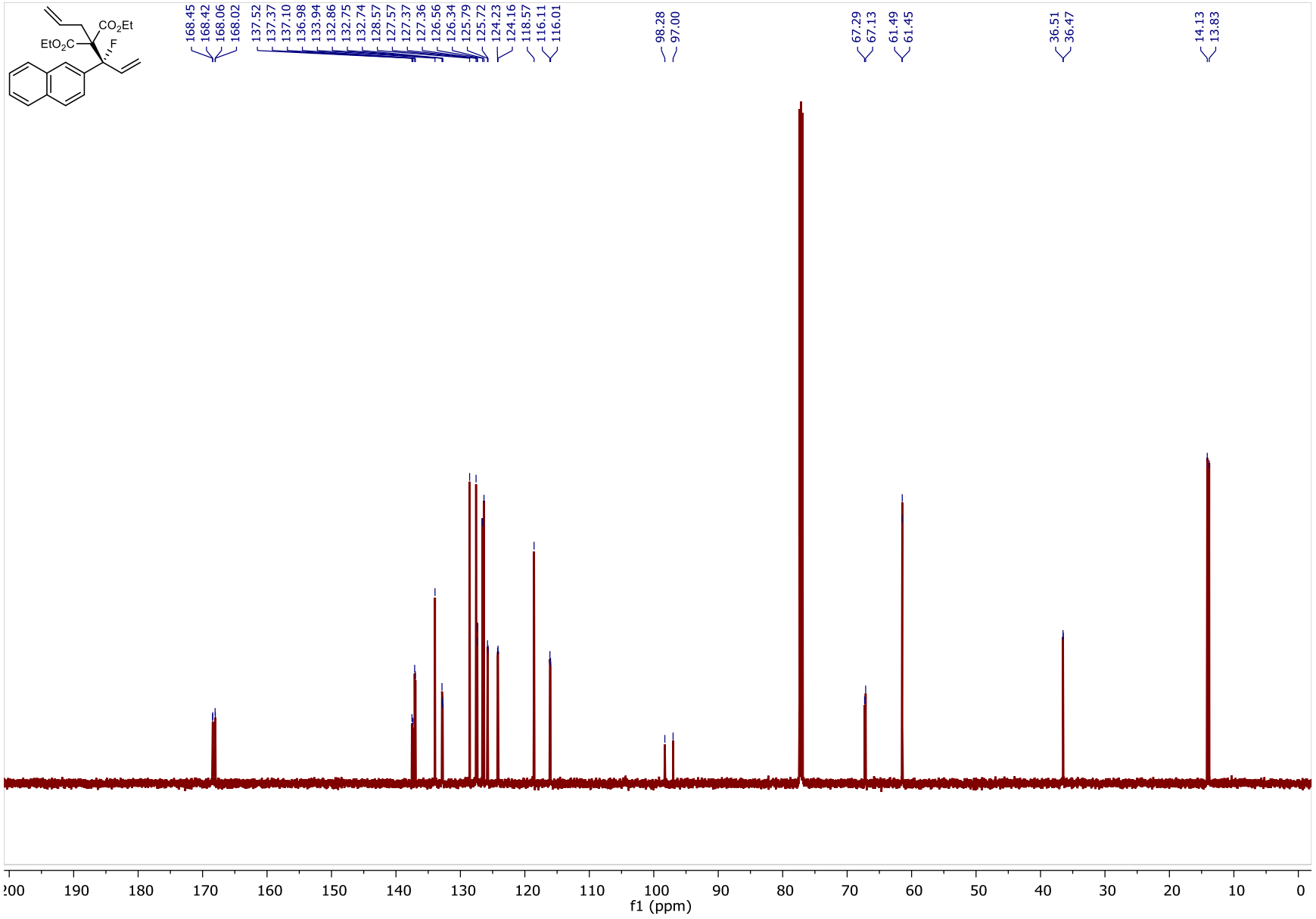

F
F
-96.27
-96.30
-96.32
-96.35
-95.75
-95.85
-95.95
-96.05
-96.15
-96.25
-96.35
-96.45
-96.55
-96.65
-96.75
-96.85
-96.95
-97.05
f1 (ppm)

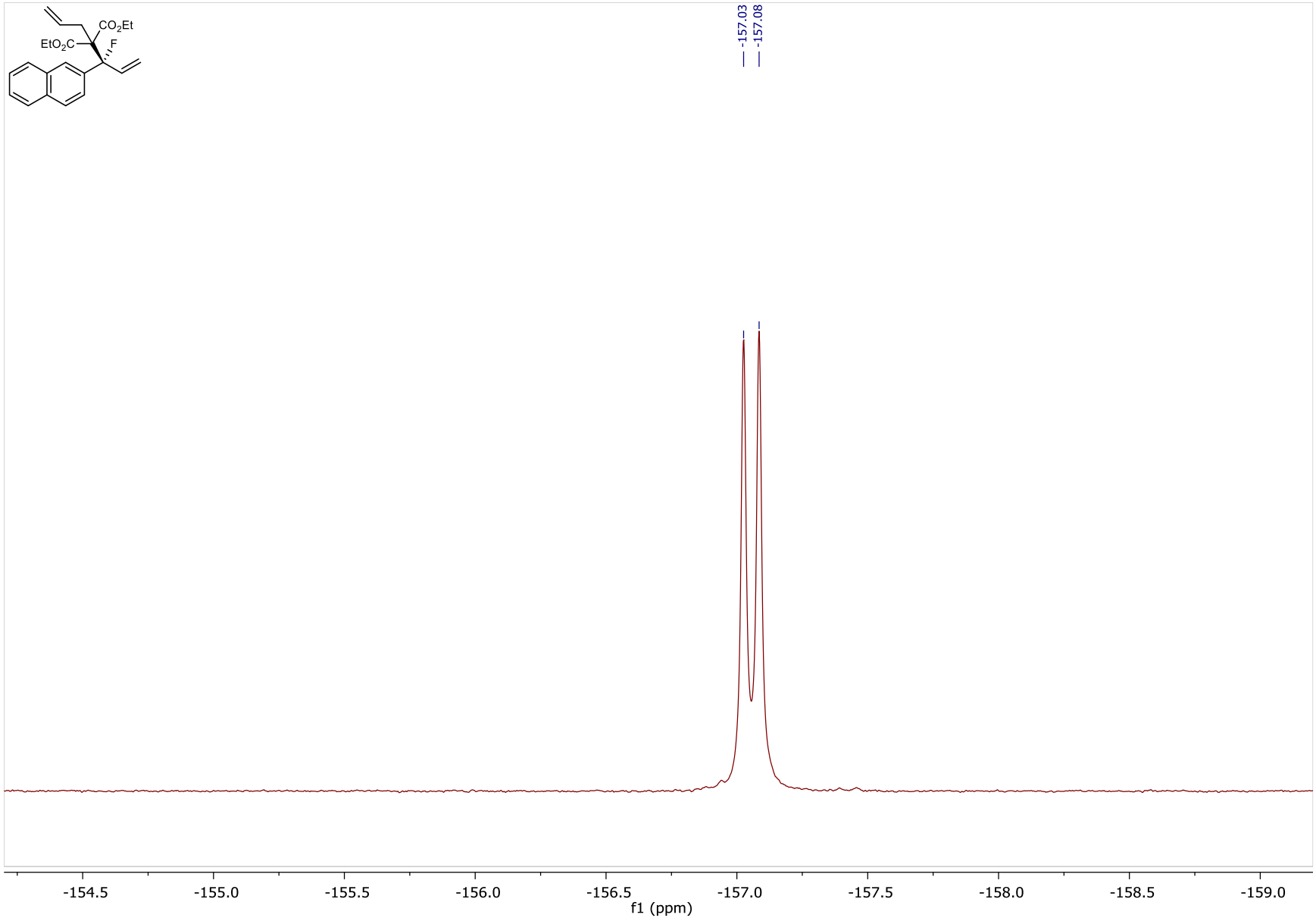

7.98
7.84
7.84
7.82
7.82
7.81
7.81
7.80
7.78
7.66
7.66
7.65
7.64
7.49
7.48
7.48
7.10
7.08
7.07
7.06
7.05
7.04
7.03
7.02
5.46
5.43
5.35
5.33
4.21
4.20
4.19
4.17
4.11
4.10
4.09
4.08
4.08
4.07
4.07
4.07
4.06
4.05
4.05
4.04
4.03
4.03
4.02
1.58
1.58
1.24
1.23
1.22
1.07
1.06
1.05
Me
CO2Et
EtO2C
F
1.00
3.04
1.00
2.03
1.01
1.01
1.01
2.04
2.05
3.03
3.05
3.03
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
0.0
f1 (ppm)

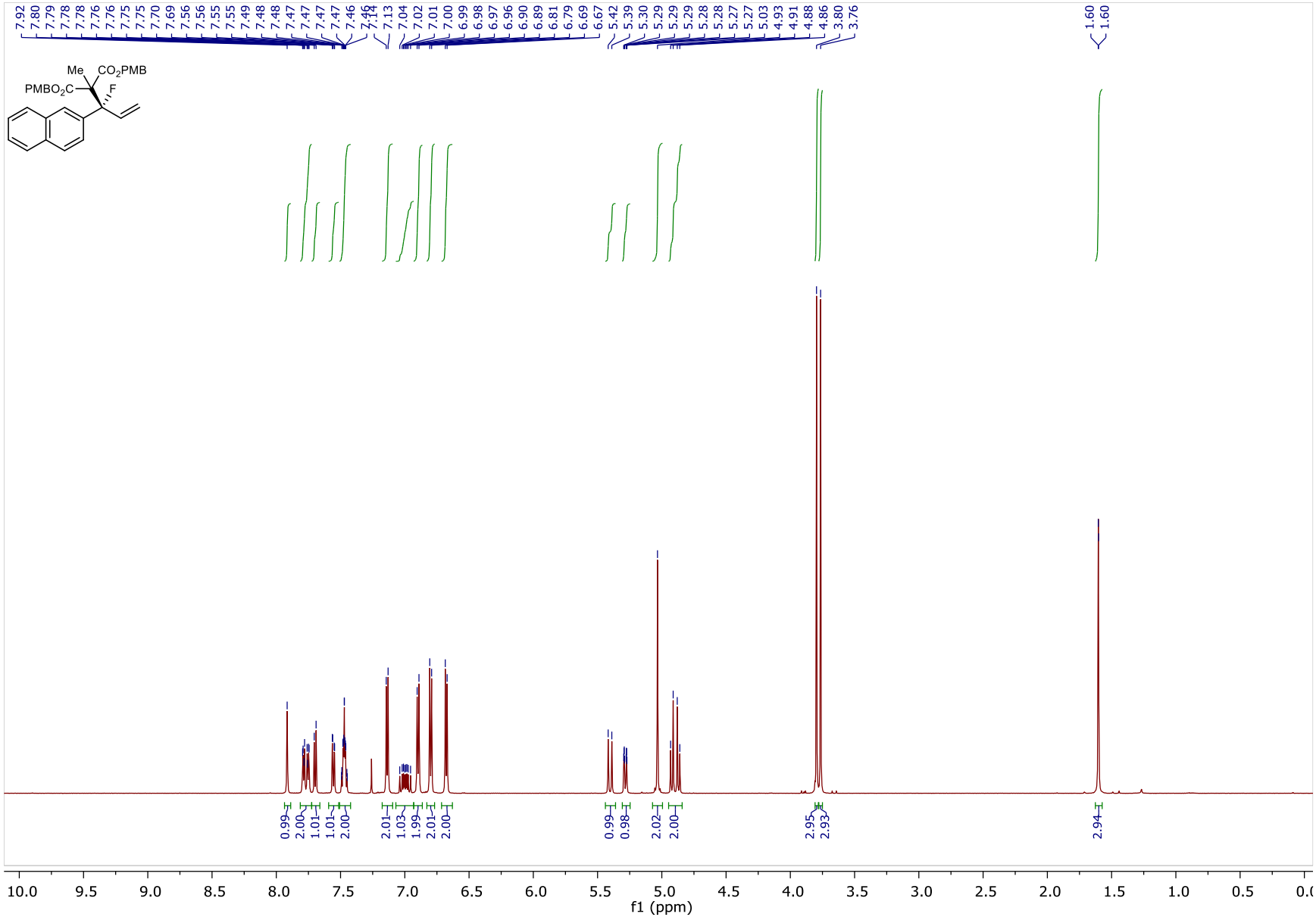

Me
CO2Et
EtO2C
F
169.50
169.47
169.22
169.18
137.48
137.33
137.14
137.02
132.85
132.72
132.71
128.61
127.54
127.22
127.21
126.50
126.25
126.09
126.01
124.57
124.50
116.00
115.90
98.21
96.96
62.89
62.72
61.64
61.53
18.23
18.19
14.09
13.82
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

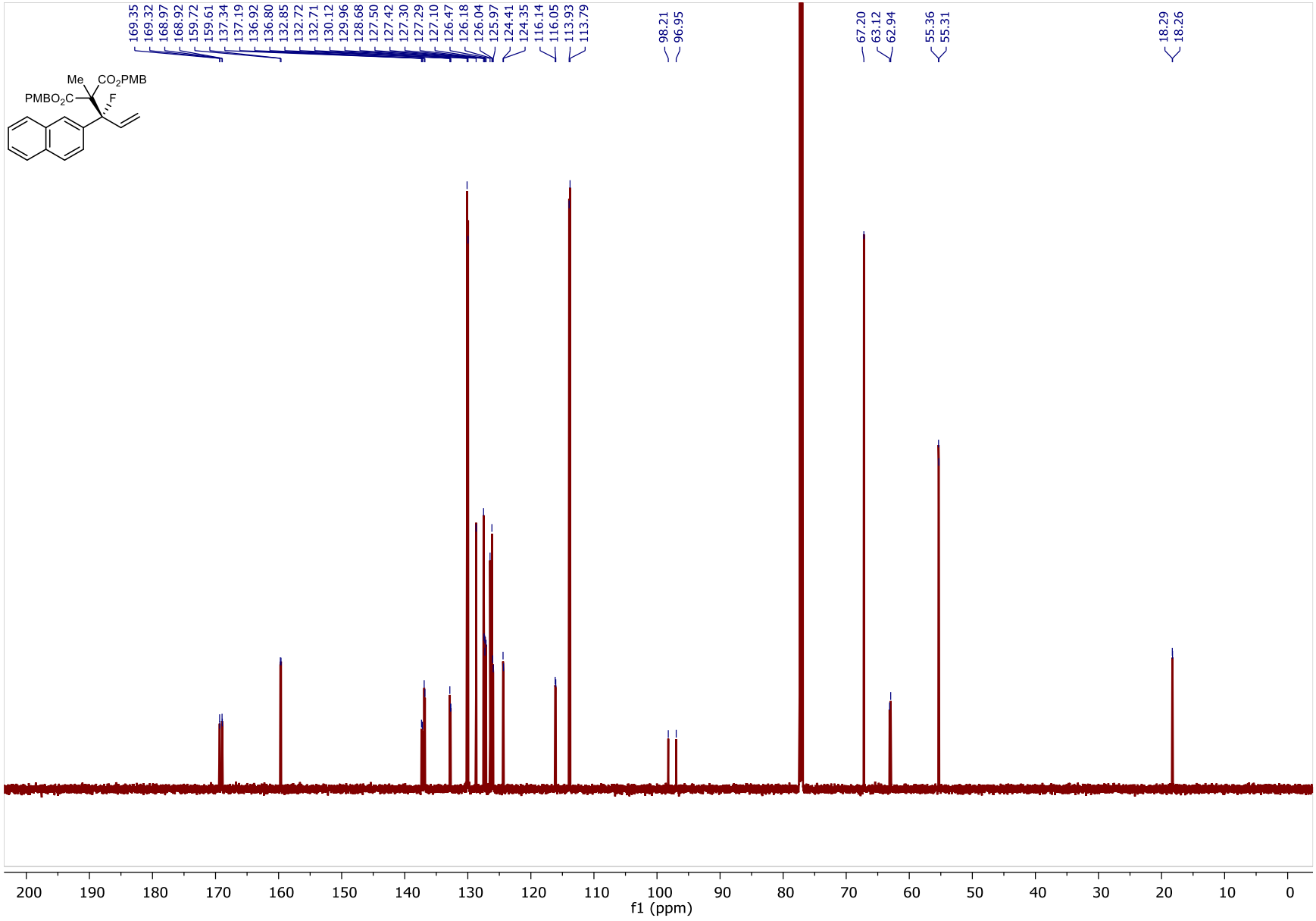

Me
CO2Et
EtO2C
F
-157.17
-157.23
-150.0
-151.0
-152.0
-153.0
-154.0
-155.0
-156.0
-157.0
-158.0
-159.0
-160.0
-161.0
-162.0
-163.0
f1 (ppm)

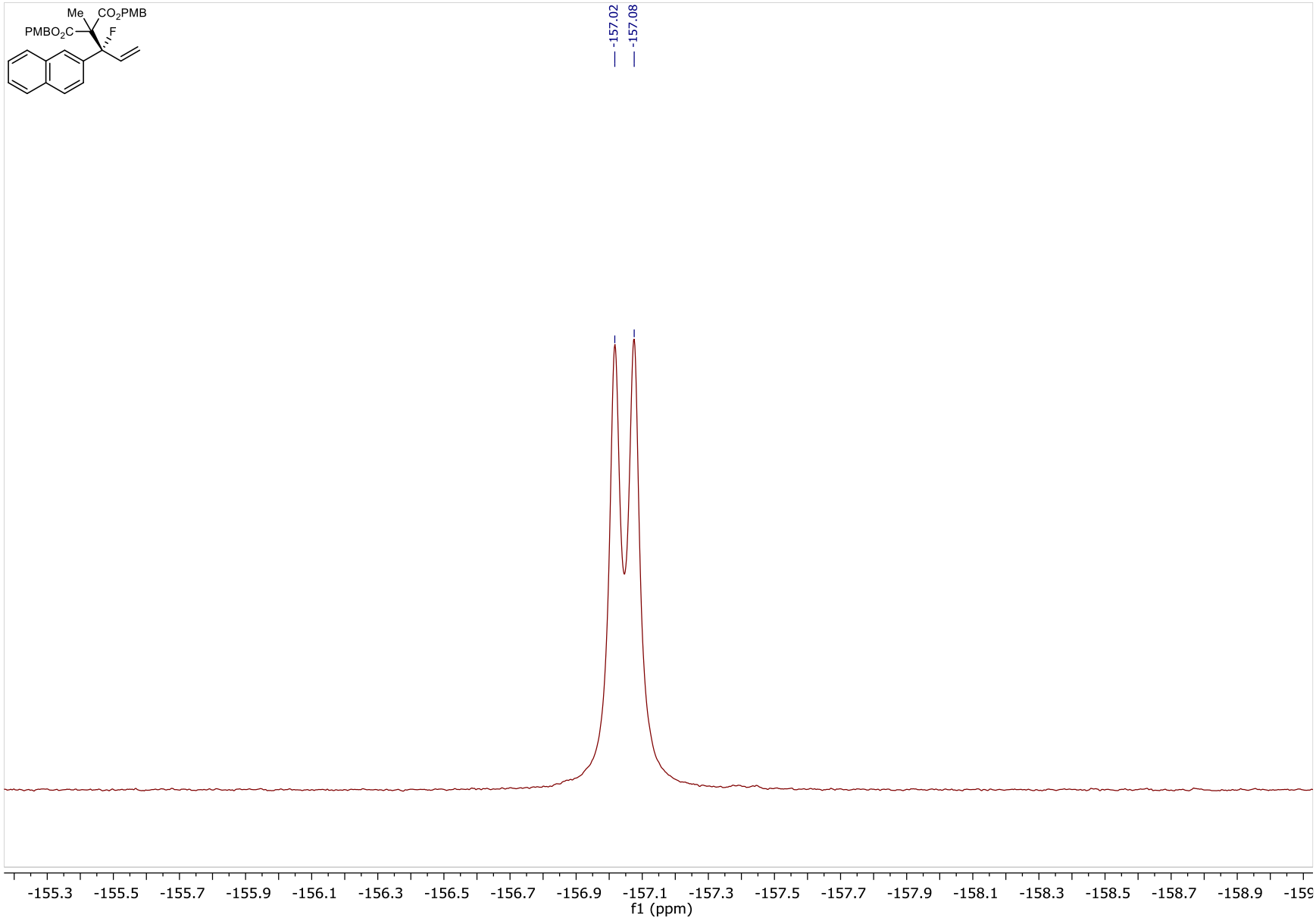

7.92 7.84 7.83 7.83 7.82 7.82 7.82 7.81 7.81 7.80 7.78 7.58 7.58 7.57 7.57 7.50 7.49 7.48 7.48 7.47 7.47 7.05 7.03 7.02 7.01 7.00 6.99 6.98 6.97
5.79 5.77 5.76 5.74 5.73 5.72 5.48 5.45 5.36 5.34 5.06 5.03 4.99 4.97
4.17 4.16 4.15 4.14 4.09 4.08 4.08 4.07 4.06 4.05 4.04 4.03 4.03 4.02 4.01
2.93 2.91 2.90 2.89 2.83 2.81 2.80 2.79
1.23 1.22 1.21 1.20 1.20 1.06 1.05 1.04
CO2Et
EtO2C
F
1.02 3.03 0.99 2.00 1.00 1.00 1.01 1.01 1.00 1.01 2.01 2.03 1.00 1.01 3.01 2.97
10.0 9.5 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
f1 (ppm)

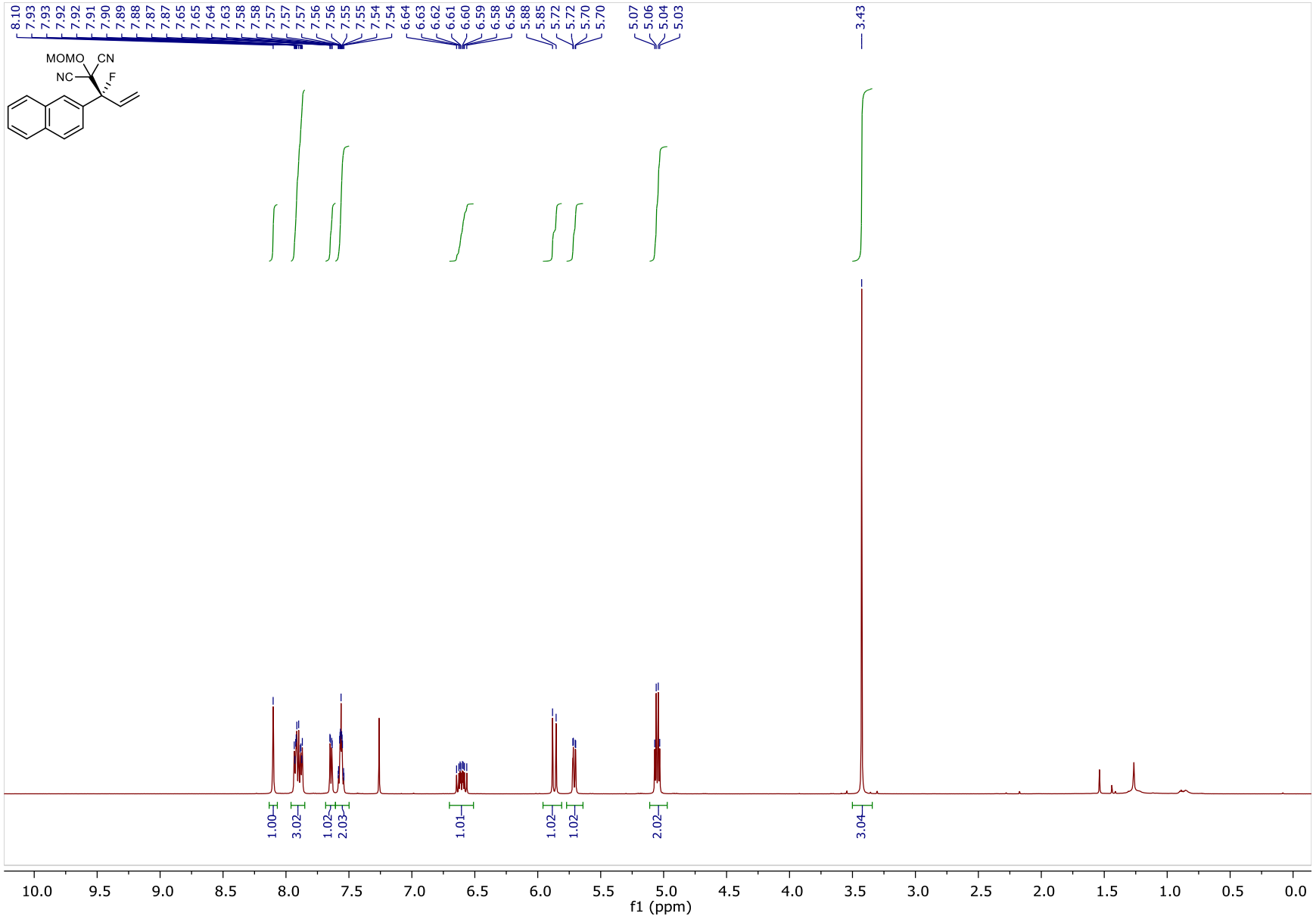

CO2Et
EtO2C
F
168.45
168.42
168.06
168.02
137.52
137.37
137.10
136.98
133.94
132.86
132.75
132.74
128.57
127.57
127.37
127.36
126.56
126.34
125.79
125.72
124.23
124.16
118.57
116.11
116.01
98.28
97.00
67.29
67.13
61.49
61.45
36.51
36.47
14.13
13.83
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

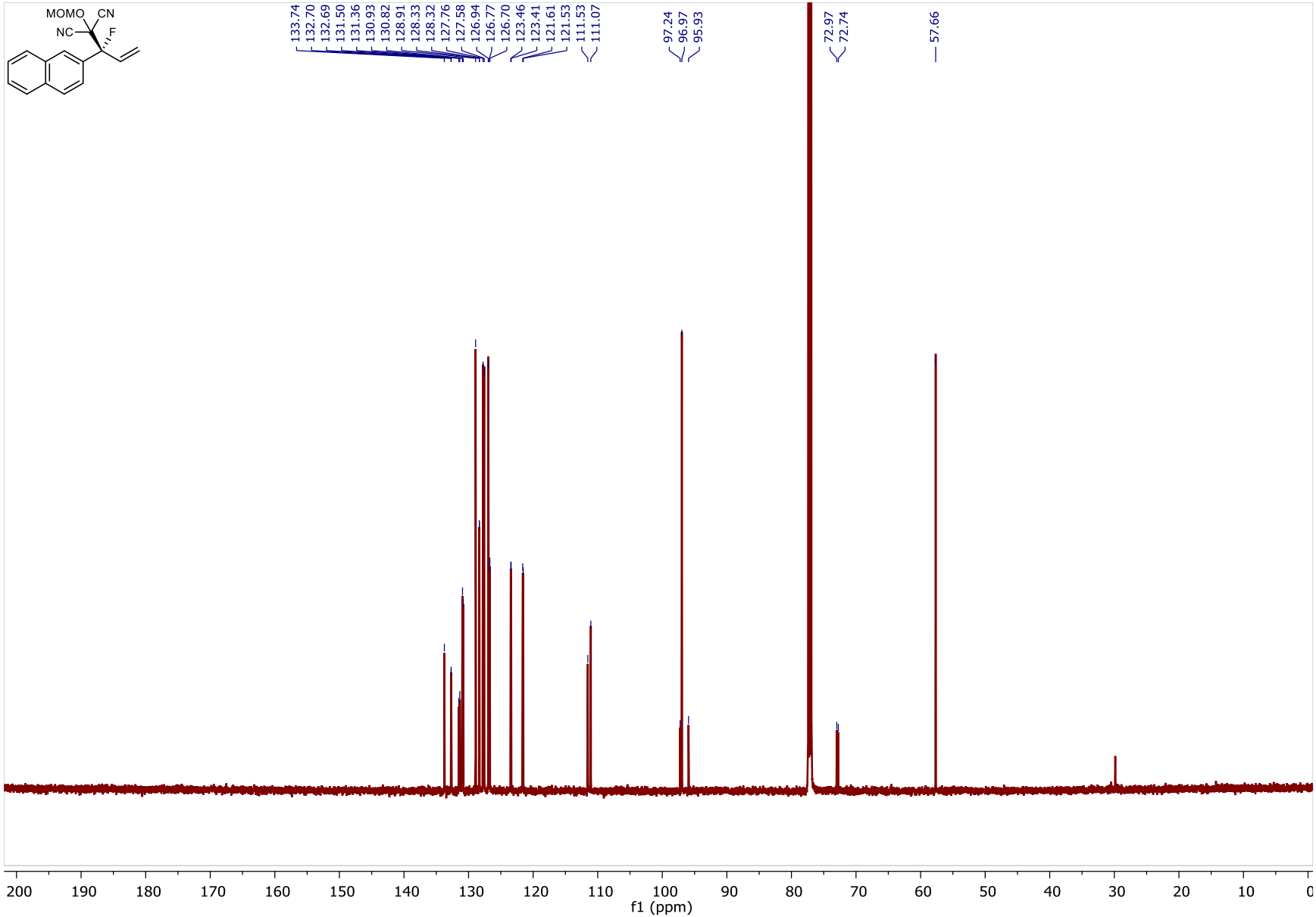

CO2Et
EtO2C
F
-157.03
-157.08
-154.5
-155.0
-155.5
-156.0
-156.5
-157.0
-157.5
-158.0
-158.5
-159.0
f1 (ppm)

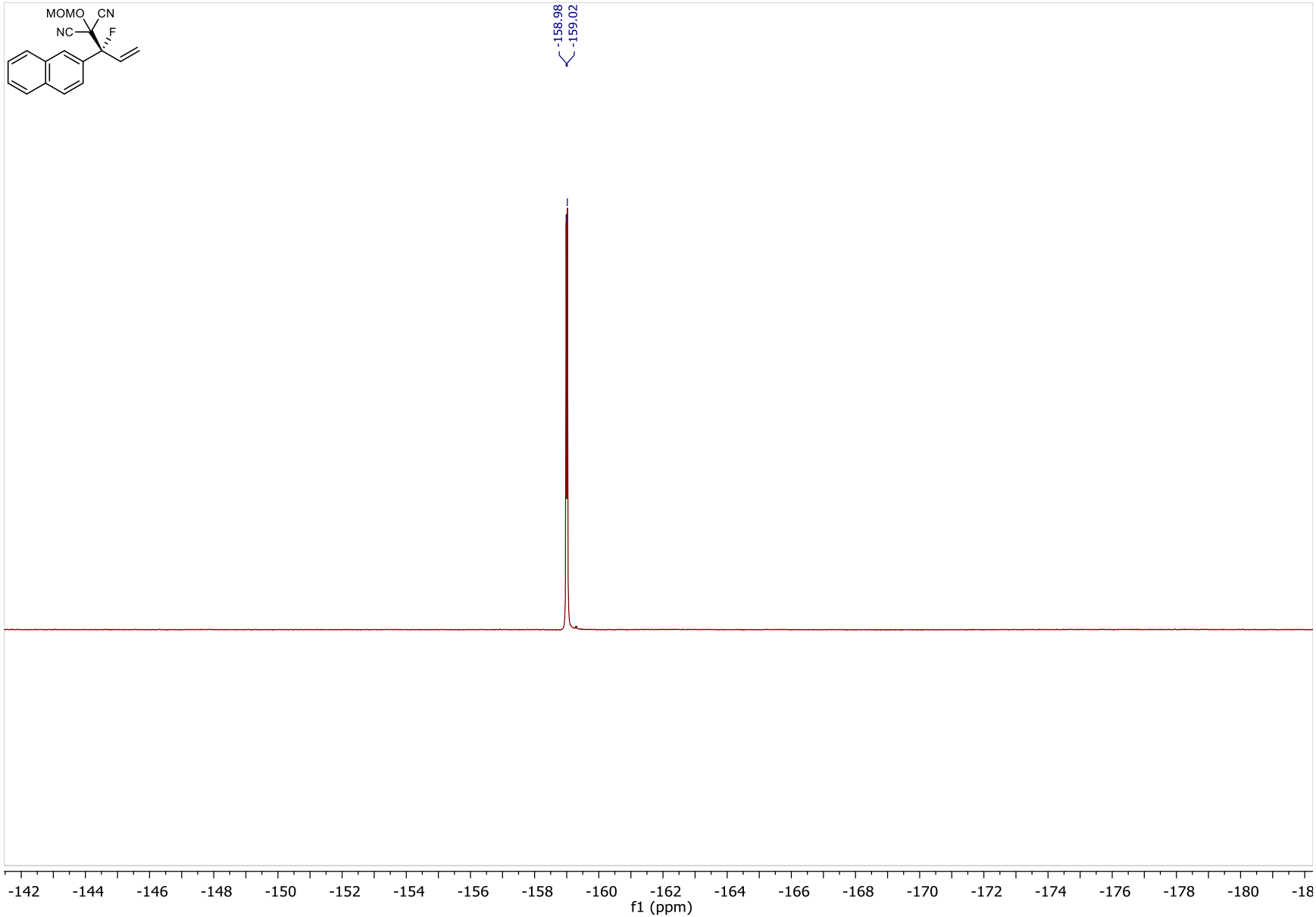

Me
CO2PMB
PMBO2C
F
7.92 7.80 7.79 7.78 7.78 7.76 7.76 7.75 7.75 7.70 7.69 7.56 7.56 7.55 7.55 7.49 7.48 7.48 7.47 7.47 7.47 7.46 7.46 7.14 7.13 7.04 7.02 7.01 7.00 6.99 6.98 6.97 6.96 6.90 6.89 6.81 6.79 6.69 6.67 5.42 5.39 5.30 5.29 5.29 5.29 5.28 5.28 5.27 5.27 5.03 4.93 4.91 4.88 4.86 3.80 3.76
1.60 1.60
0.99 2.00 1.01 1.01 2.00 2.01 1.03 1.99 2.01 2.00 0.99 0.98 2.02 2.00 2.95 2.93 2.94
10.0 9.5 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
f1 (ppm)

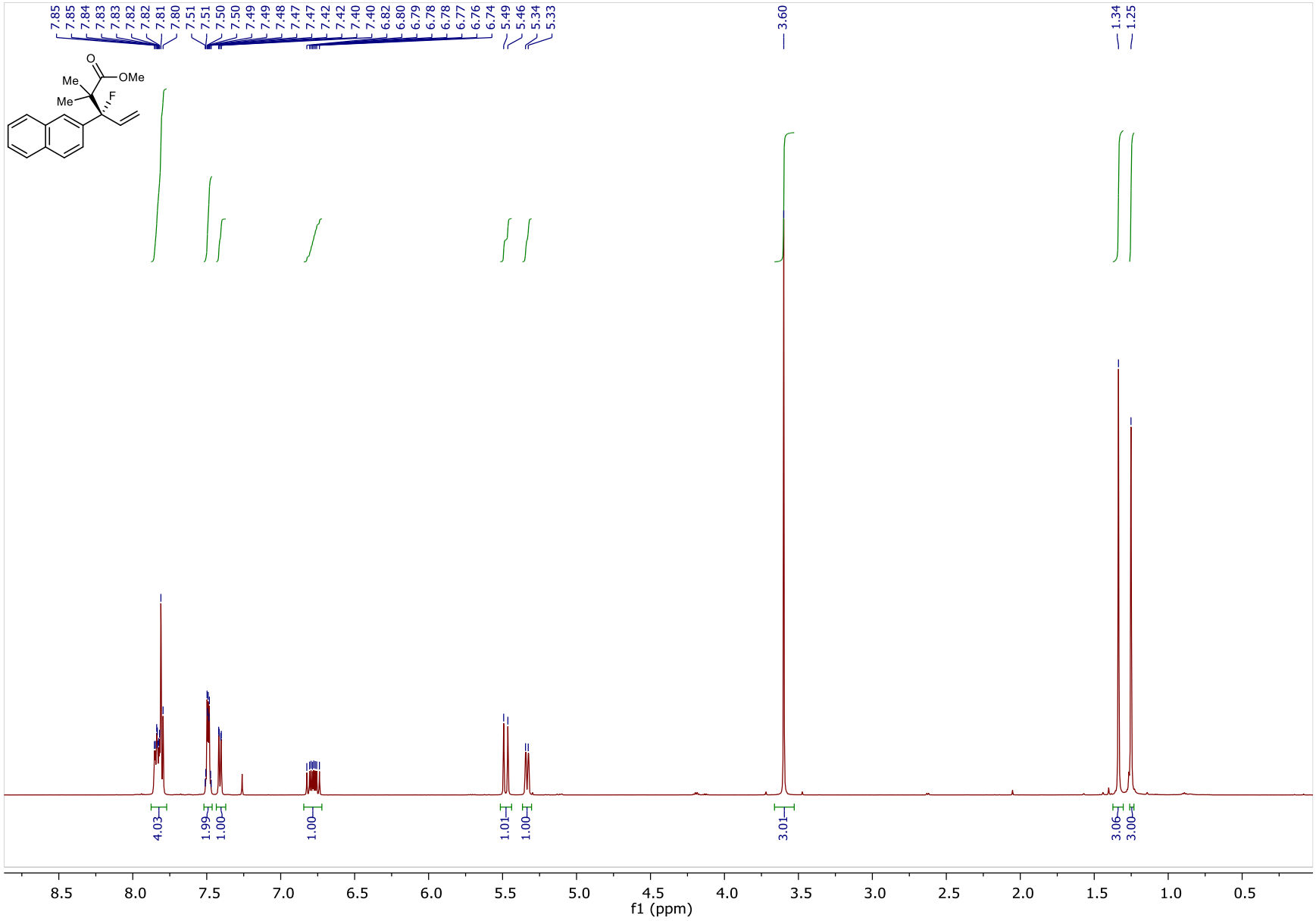

169.35
169.32
168.97
168.92
159.72
159.61
137.34
137.19
136.92
136.80
132.85
132.72
132.71
130.12
129.96
128.68
127.50
127.42
127.30
127.29
127.10
126.47
126.18
126.04
125.97
124.41
124.35
116.14
116.05
113.93
113.79
98.21
96.95
67.20
63.12
62.94
55.36
55.31
18.29
18.26
Me
CO2PMB
PMBO2C
F
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

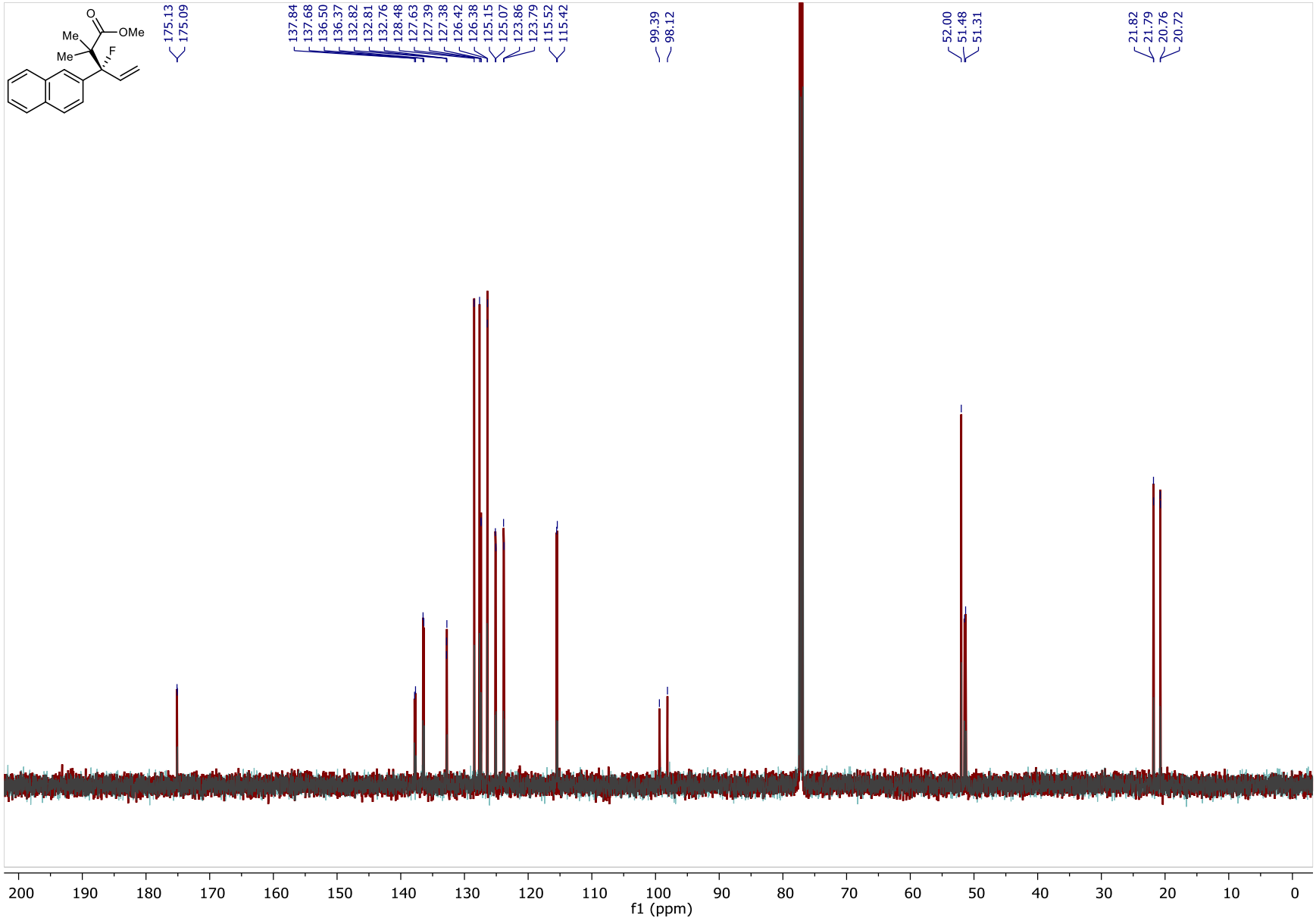

Me
CO2PMB
PMBO2C
F
-157.02
-157.08
-155.3
-155.5
-155.7
-155.9
-156.1
-156.3
-156.5
-156.7
-156.9
-157.1
-157.3
-157.5
-157.7
-157.9
-158.1
-158.3
-158.5
-158.7
-158.9
f1 (ppm)

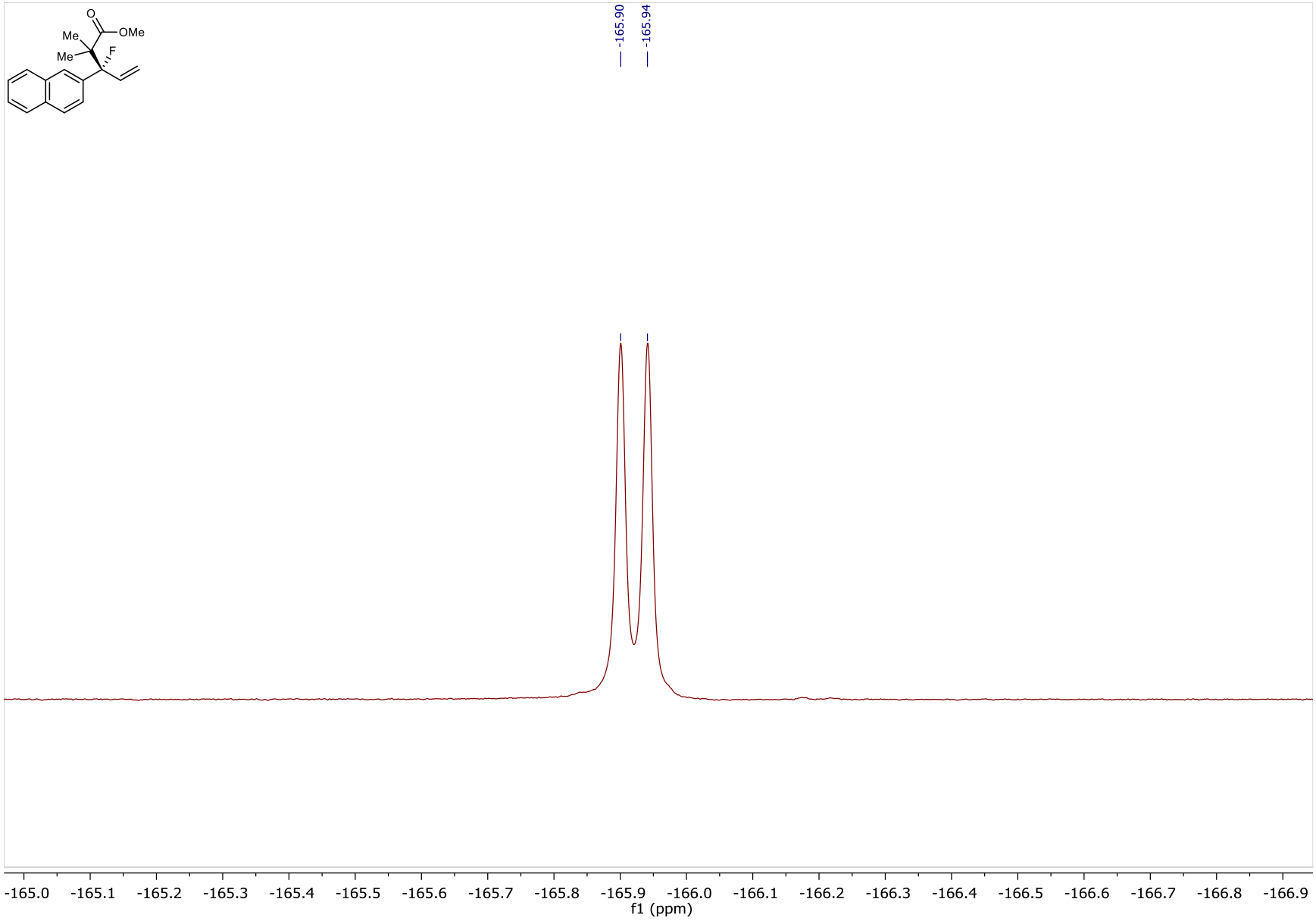

8.10
7.93
7.93
7.92
7.92
7.91
7.90
7.89
7.88
7.87
7.87
7.65
7.65
7.64
7.63
7.58
7.58
7.57
7.57
7.57
7.56
7.56
7.55
7.55
7.54
7.54
6.64
6.63
6.62
6.61
6.60
6.59
6.58
6.56
5.88
5.85
5.72
5.72
5.70
5.70
5.07
5.06
5.04
5.03
3.43
MOMO
CN
NC
F
1.00
3.02
1.02
2.03
1.01
1.02
1.02
2.02
3.04
10.0
9.5
9.0
8.5
8.0
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
0.0
f1 (ppm)

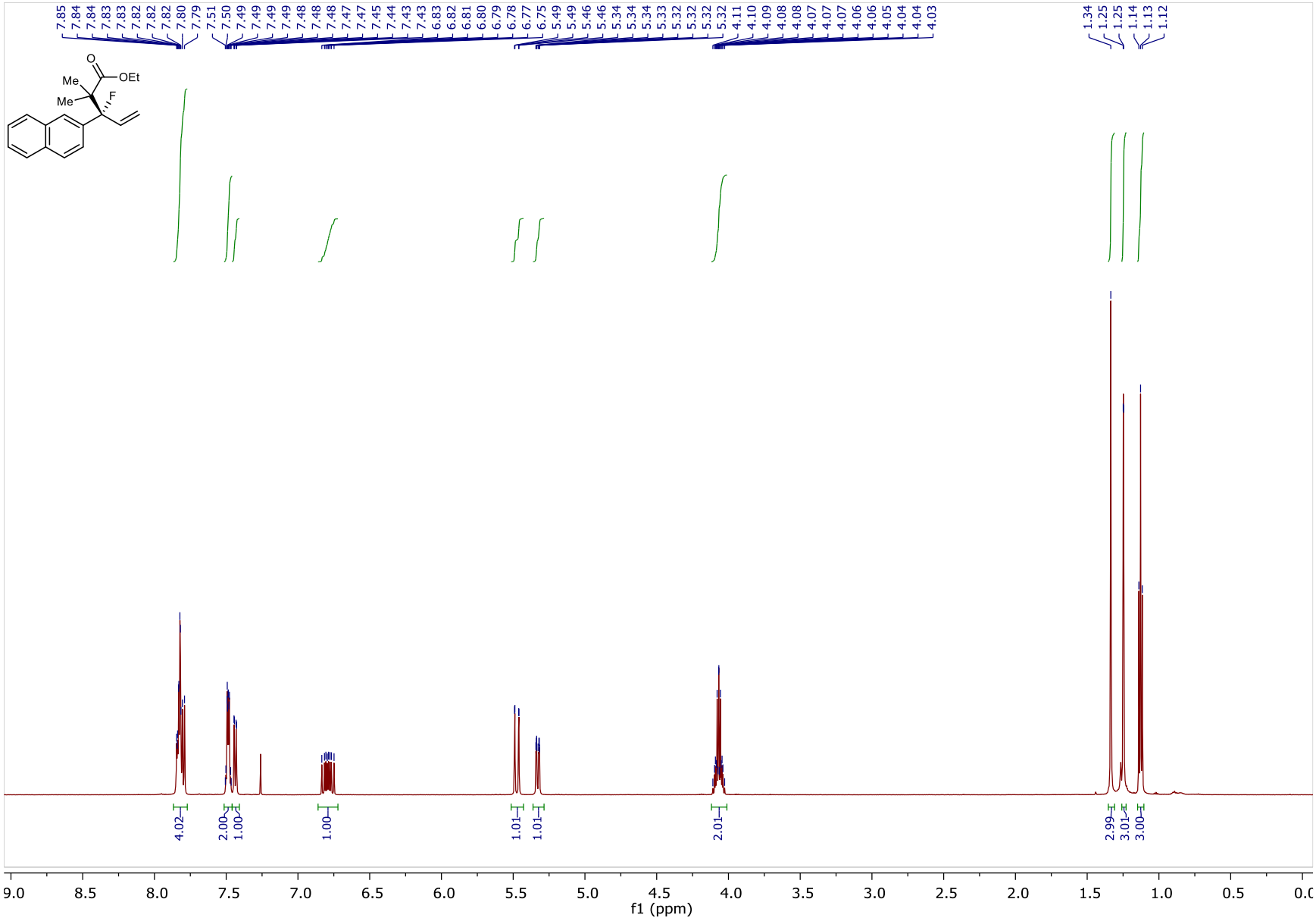

MOMO
CN
NC
F
133.74
132.70
132.69
131.50
131.36
130.93
130.82
128.91
128.33
128.32
127.76
127.58
126.94
126.77
126.70
123.46
123.41
121.61
121.53
111.53
111.07
97.24
96.97
95.93
72.97
72.74
57.66
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

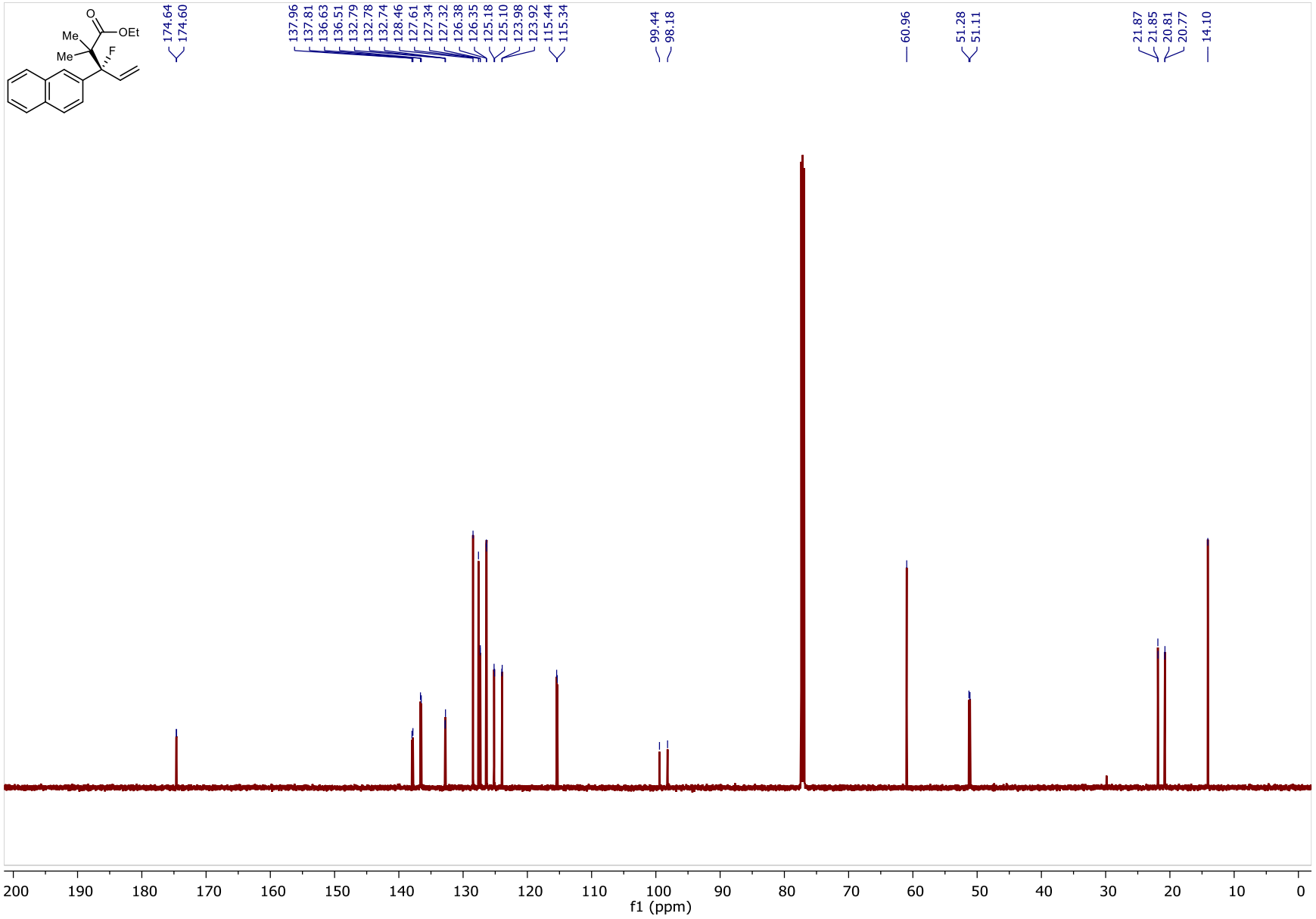

MOMO
CN
NC
F
-158.98
-159.02
-142
-144
-146
-148
-150
-152
-154
-156
-158
-160
-162
-164
-166
-168
-170
-172
-174
-176
-178
-180
-18
f1 (ppm)

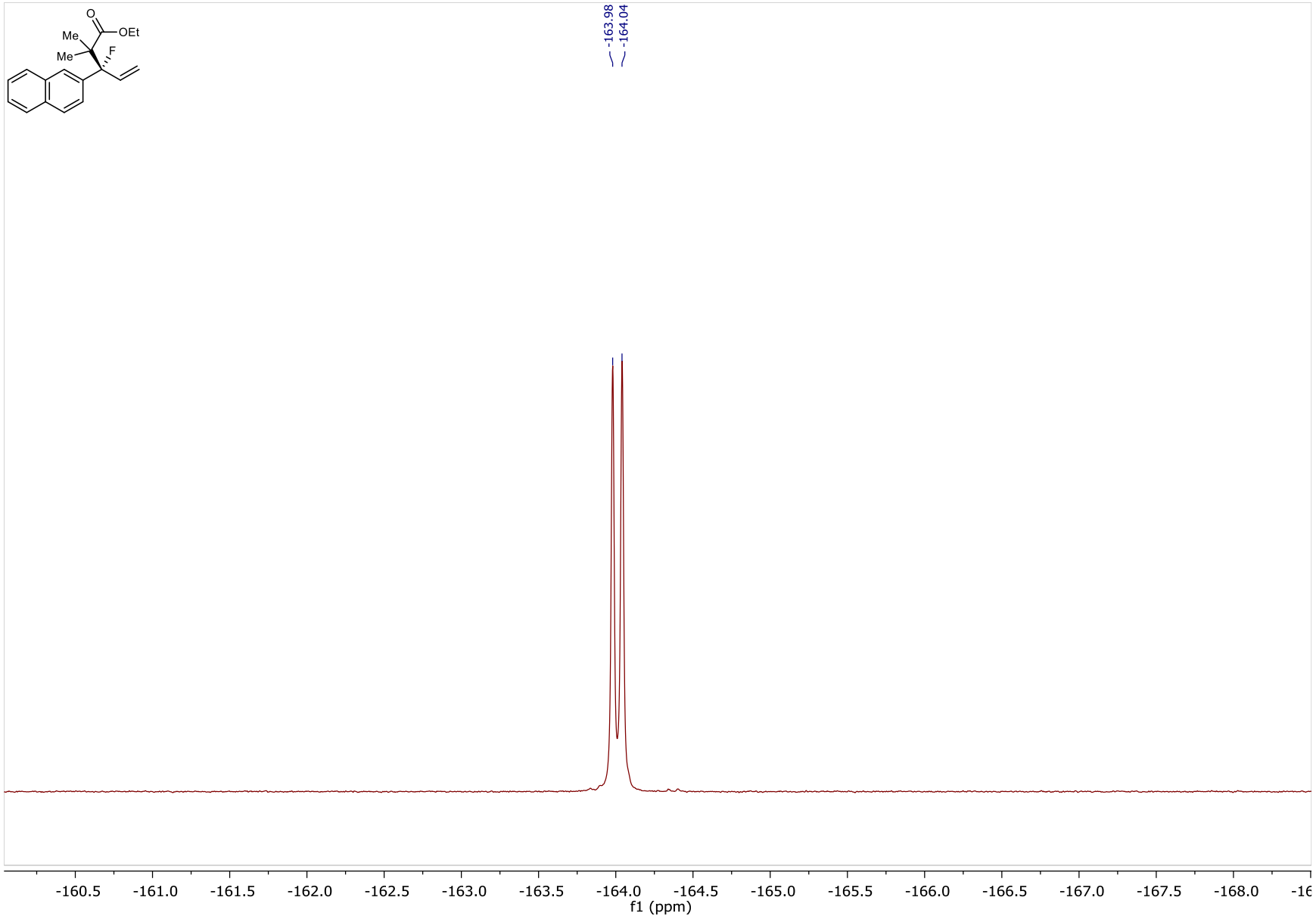

7.85
7.85
7.84
7.83
7.83
7.82
7.82
7.81
7.80
7.51
7.51
7.50
7.50
7.49
7.49
7.48
7.47
7.47
7.42
7.42
7.40
7.40
6.82
6.80
6.79
6.78
6.78
6.77
6.76
6.74
5.49
5.46
5.34
5.33
3.60
1.34
1.25
O
OMe
Me
Me
F
4.03
1.99
1.00
1.00
1.01
1.00
3.01
3.06
3.00
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

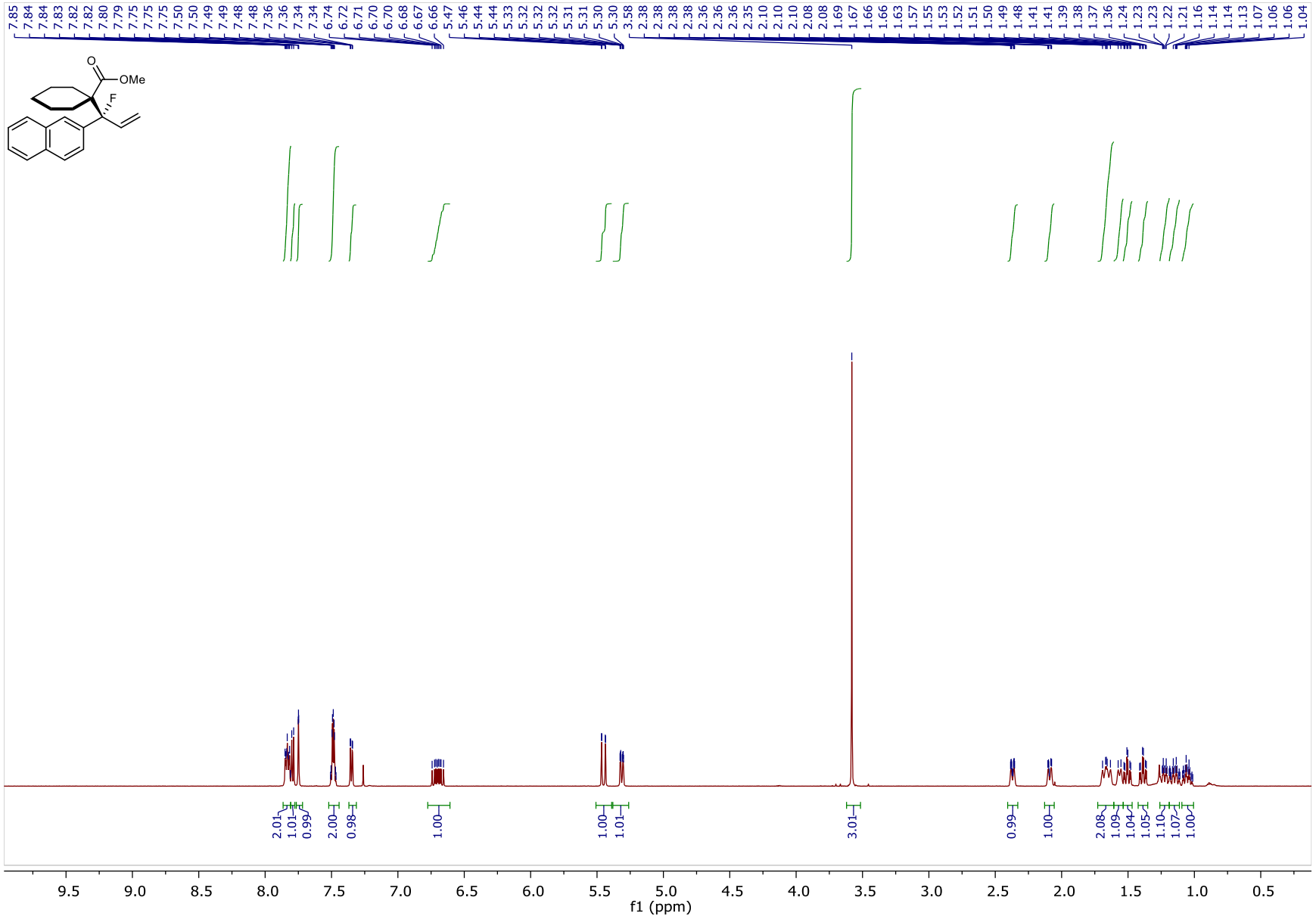

O
OMe
Me
Me
F
175.13
175.09
137.84
137.68
136.50
136.37
132.82
132.81
132.76
128.48
127.63
127.39
127.38
126.42
126.38
125.15
125.07
123.86
123.79
115.52
115.42
99.39
98.12
52.00
51.48
51.31
21.82
21.79
20.76
20.72
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

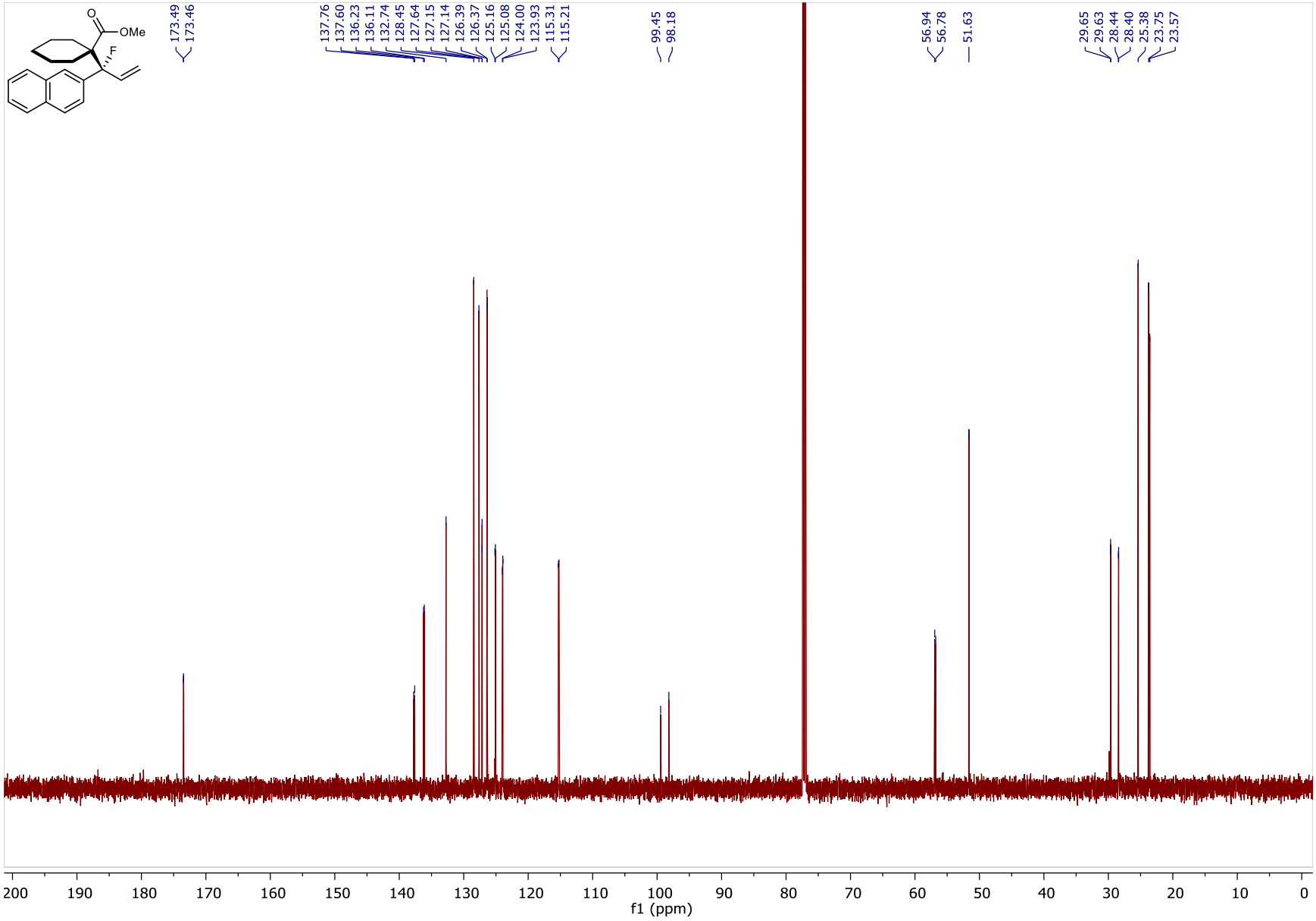

O
OMe
Me
Me
F
-165.90
-165.94
-165.0
-165.1
-165.2
-165.3
-165.4
-165.5
-165.6
-165.7
-165.8
-165.9
-166.0
-166.1
-166.2
-166.3
-166.4
-166.5
-166.6
-166.7
-166.8
-166.9
f1 (ppm)

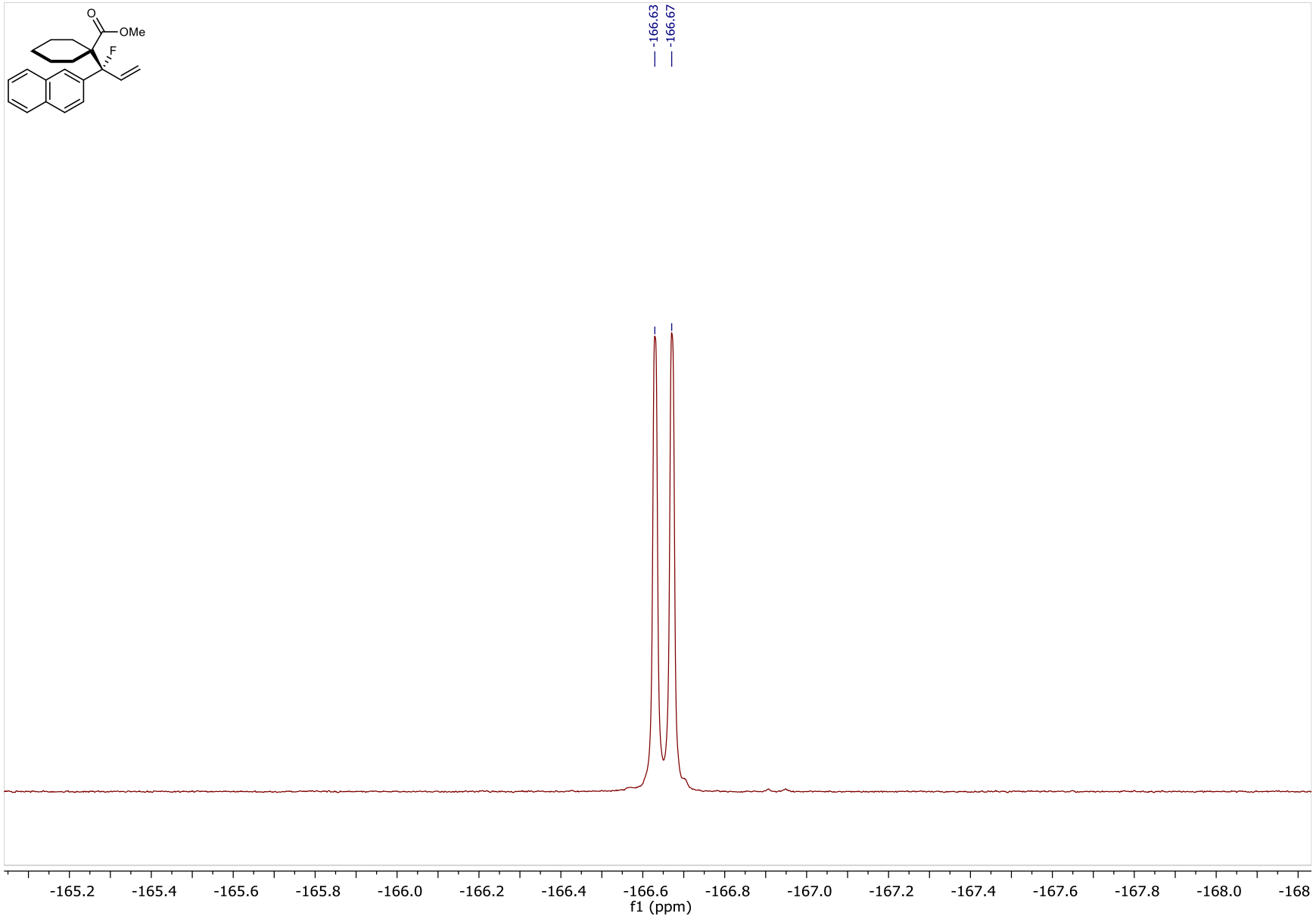

7.85 7.84 7.84 7.83 7.83 7.82 7.82 7.82 7.80 7.79 7.51 7.50 7.49 7.49 7.49 7.49 7.48 7.48 7.48 7.47 7.47 7.45 7.44 7.43 7.43 6.83 6.82 6.81 6.80 6.79 6.78 6.77 6.75 5.49 5.49 5.46 5.46 5.34 5.34 5.34 5.33 5.32 5.32 5.32 5.32 4.11 4.10 4.09 4.08 4.08 4.07 4.07 4.07 4.06 4.06 4.05 4.04 4.04 4.03
1.34 1.25 1.25 1.14 1.13 1.12
O
OEt
Me
Me
F
4.02 2.00 1.00 1.00 1.01 1.01 2.01 2.99 3.01 3.00
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 0.0
f1 (ppm)

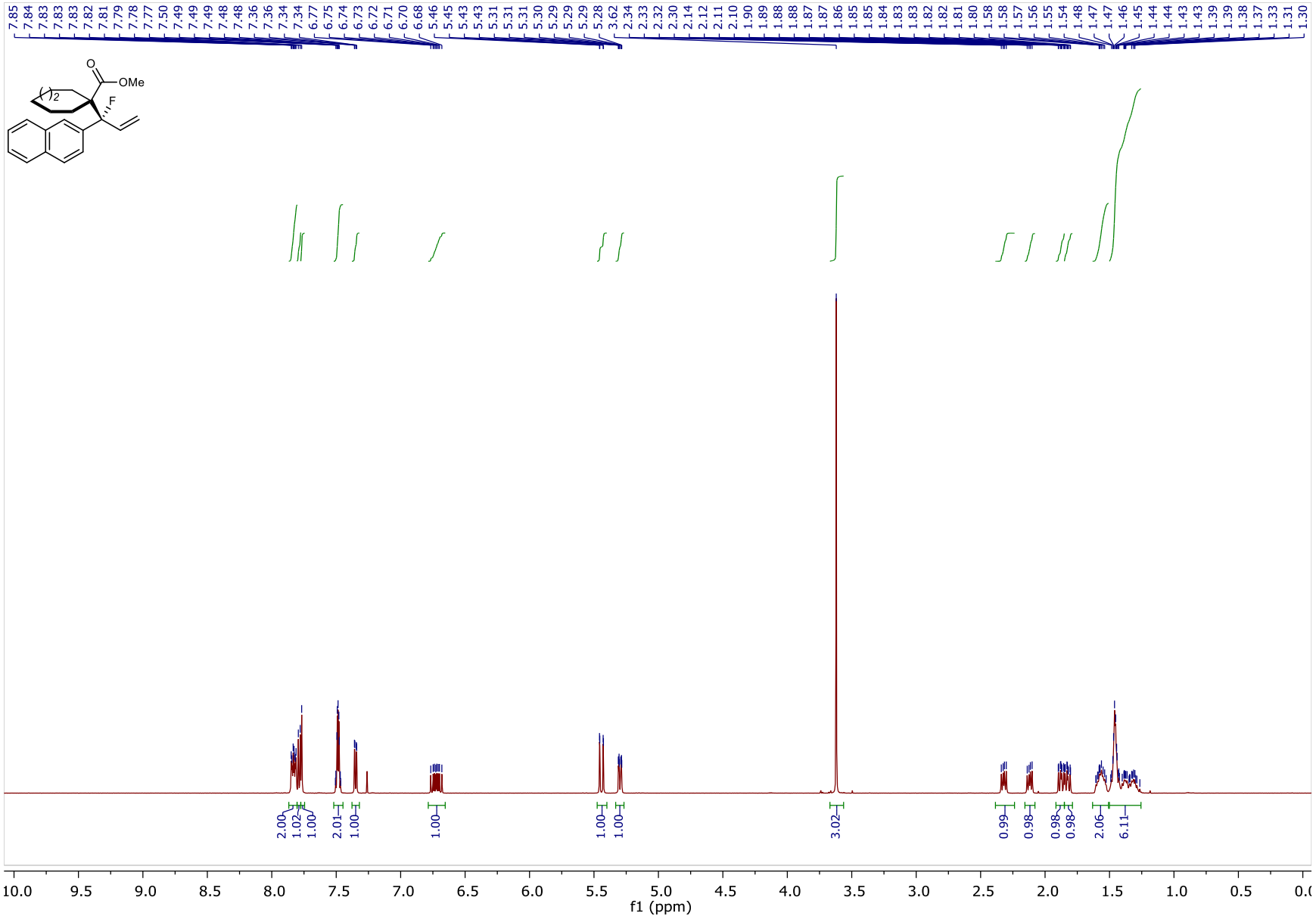

O
OEt
Me
Me
F
174.64
174.60
137.96
137.81
136.63
136.51
132.79
132.78
132.74
128.46
127.61
127.34
127.32
126.38
126.35
125.18
125.10
123.98
123.92
115.44
115.34
99.44
98.18
60.96
51.28
51.11
21.87
21.85
20.81
20.77
14.10
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

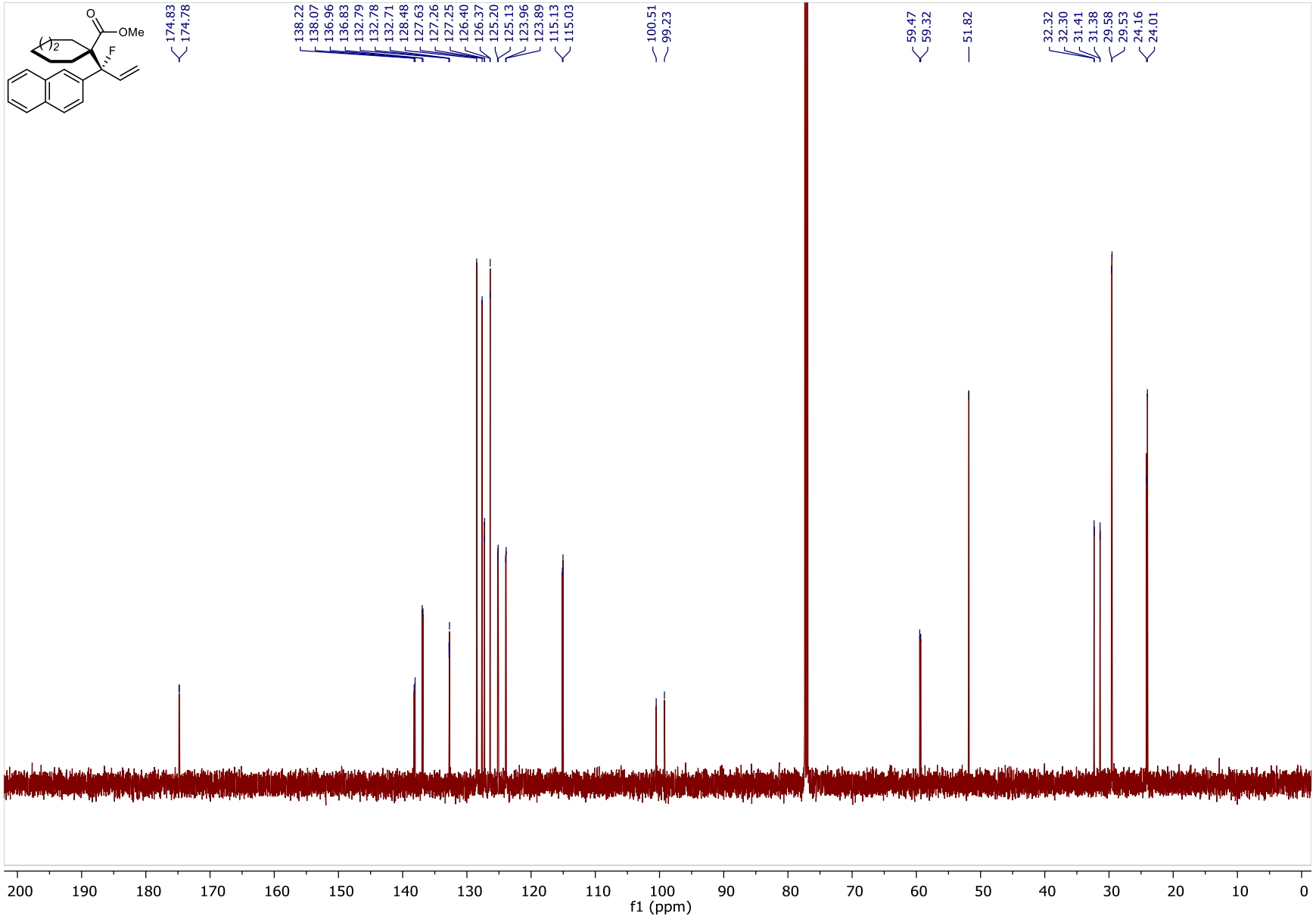

O
OEt
Me
Me
F
-163.98
-164.04
-160.5
-161.0
-161.5
-162.0
-162.5
-163.0
-163.5
-164.0
-164.5
-165.0
-165.5
-166.0
-166.5
-167.0
-167.5
-168.0
f1 (ppm)

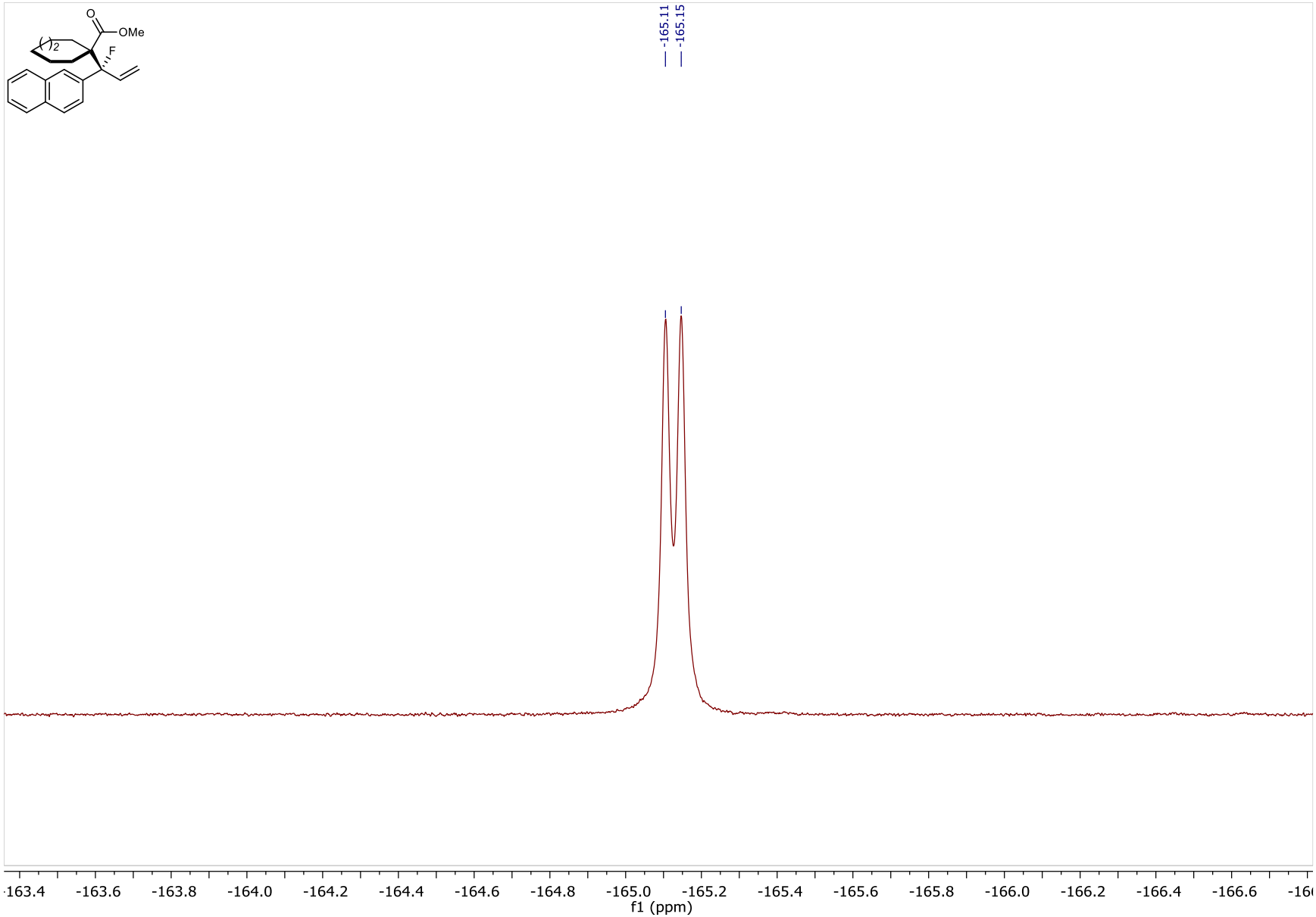

7.85 7.84 7.84 7.83 7.82 7.82 7.80 7.79 7.75 7.75 7.75 7.50 7.50 7.49 7.49 7.48 7.48 7.36 7.36 7.34 7.34 6.74 6.72 6.71 6.70 6.70 6.68 6.67 6.66 5.47 5.46 5.44 5.44 5.33 5.32 5.32 5.31 5.31 5.30 5.30 3.58 2.38 2.38 2.38 2.36 2.36 2.36 2.35 2.10 2.10 2.08 2.08 1.69 1.67 1.66 1.66 1.63 1.57 1.55 1.53 1.52 1.51 1.50 1.49 1.48 1.41 1.41 1.39 1.38 1.37 1.36 1.24 1.23 1.23 1.22 1.21 1.16 1.14 1.14 1.13 1.07 1.06 1.06 1.04
O
OMe
F
2.01 1.01 0.99 2.00 0.98 1.00 1.00 1.01 3.01 0.99 1.00 2.08 1.09 1.04 1.05 1.10 1.07 1.00
9.5 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
f1 (ppm)

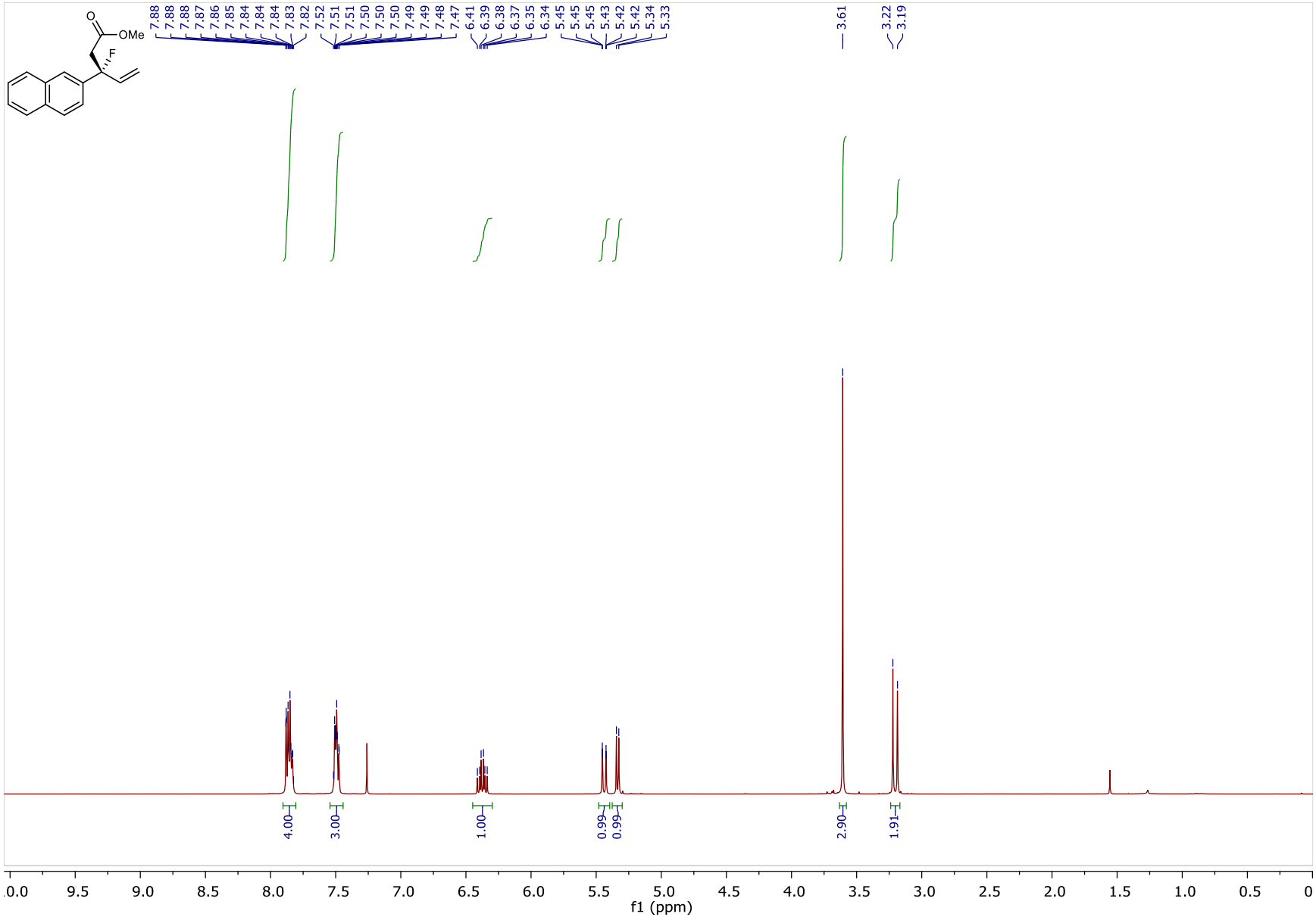

O
OMe
F
173.49
173.46
137.76
137.60
136.23
136.11
132.74
128.45
127.64
127.15
127.14
126.39
126.37
125.16
125.08
124.00
123.93
115.31
115.21
99.45
98.18
56.94
56.78
51.63
29.65
29.63
28.44
28.40
25.38
23.75
23.57
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

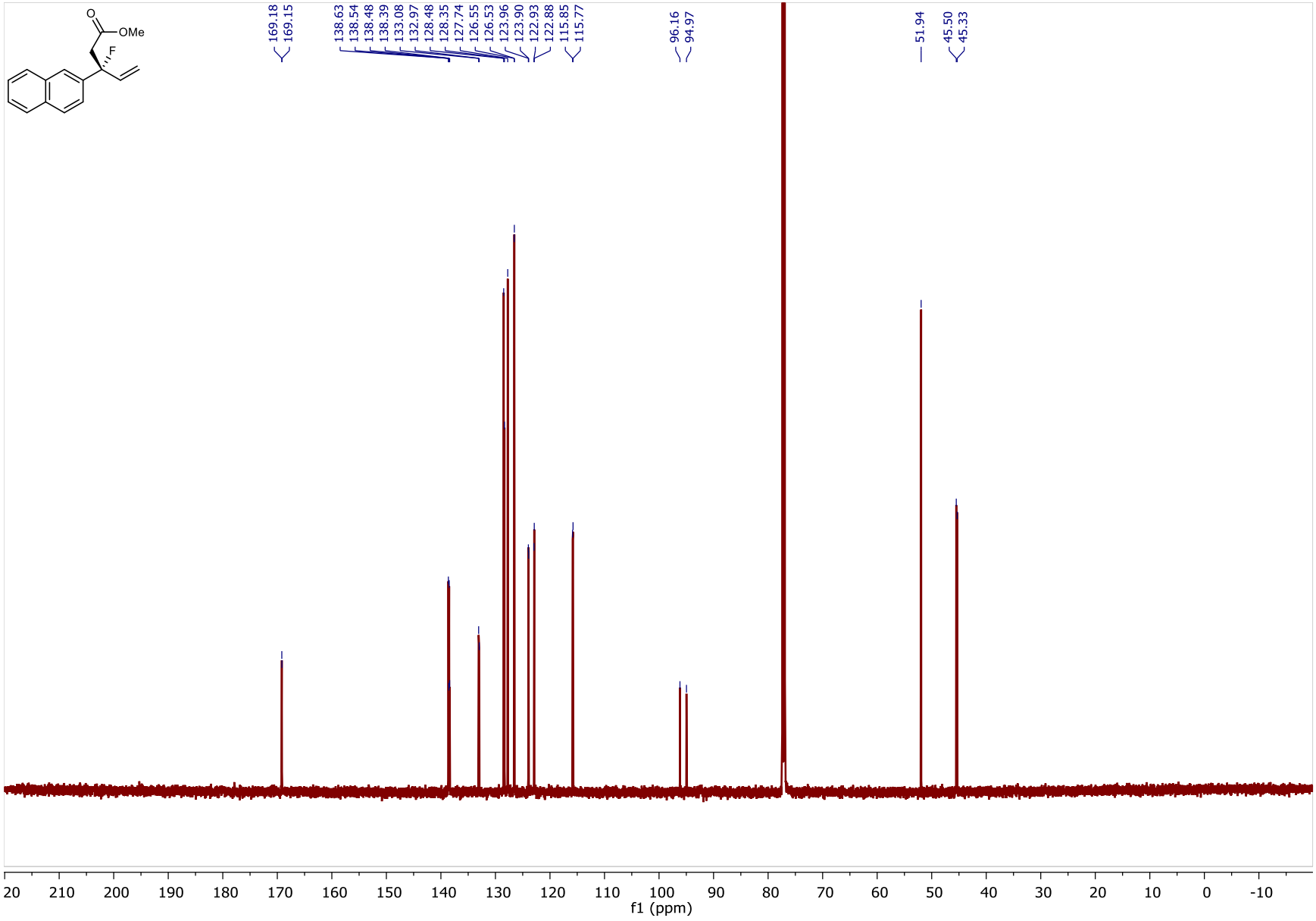

O
OMe
F
-166.63
-166.67
-165.2
-165.4
-165.6
-165.8
-166.0
-166.2
-166.4
-166.6
-166.8
-167.0
-167.2
-167.4
-167.6
-167.8
-168.0
-168
f1 (ppm)

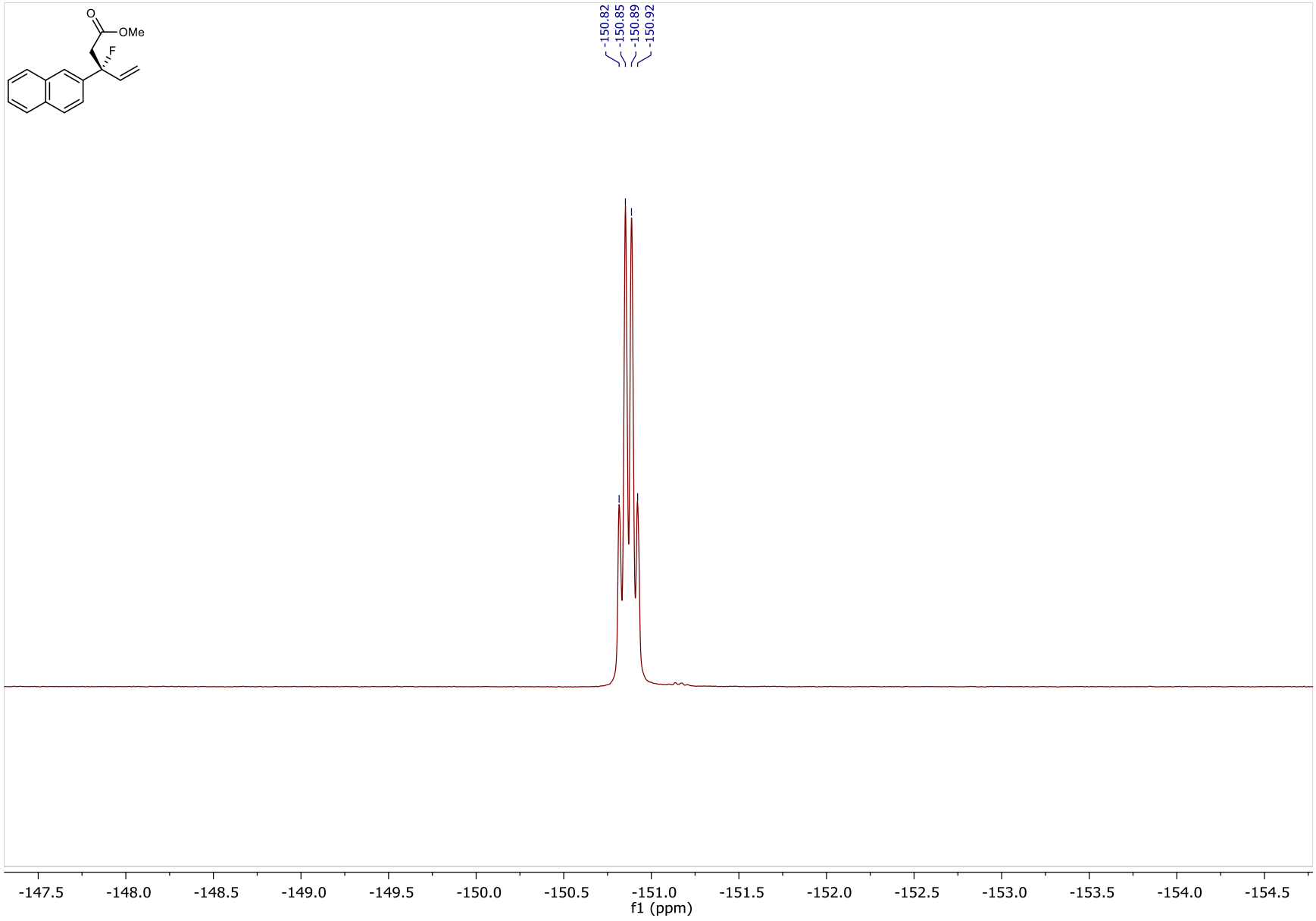

7.85 7.84 7.83 7.83 7.83 7.82 7.81 7.79 7.78 7.77 7.50 7.49 7.49 7.49 7.48 7.48 7.36 7.36 7.34 7.34 6.77 6.75 6.74 6.73 6.72 6.71 6.70 6.68 5.46 5.45 5.43 5.43 5.31 5.31 5.31 5.30 5.29 5.29 5.29 5.28 3.62 2.34 2.33 2.32 2.30 2.14 2.12 2.11 2.10 1.90 1.89 1.88 1.88 1.87 1.87 1.86 1.85 1.85 1.84 1.83 1.83 1.82 1.82 1.81 1.80 1.58 1.58 1.57 1.56 1.55 1.54 1.48 1.47 1.47 1.46 1.45 1.44 1.44 1.43 1.43 1.39 1.39 1.38 1.37 1.33 1.31 1.30
O
OMe
F
2.00 1.02 1.00 2.01 1.00 1.00 1.00 1.00 3.02 0.99 0.98 0.98 0.98 2.06 6.11
10.0 9.5 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
f1 (ppm)

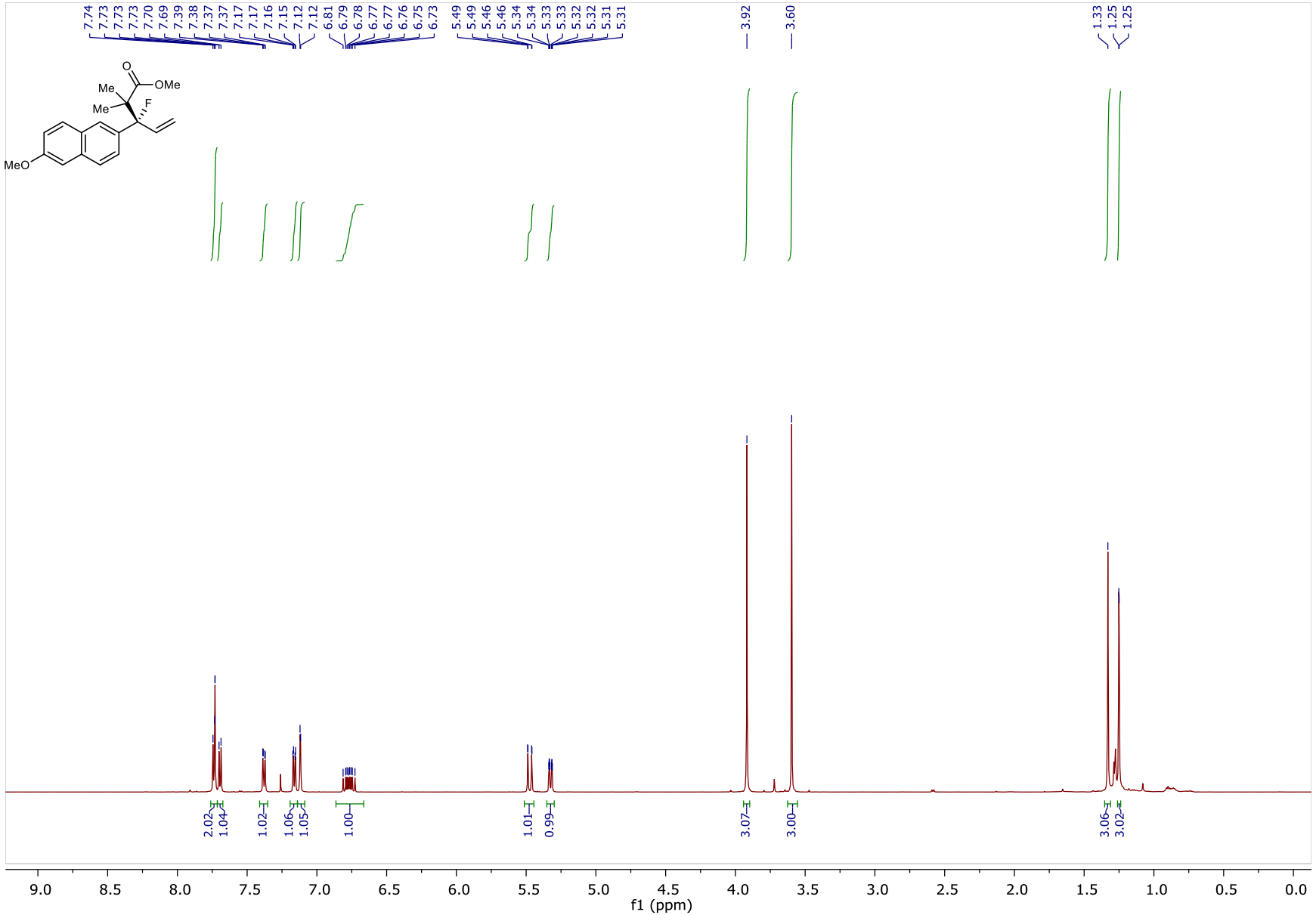

O
OMe
2
F
174.83
174.78
138.22
138.07
136.96
136.83
132.79
132.78
132.71
128.48
127.63
127.26
127.25
126.40
126.37
125.20
125.13
123.96
123.89
115.13
115.03
100.51
99.23
59.47
59.32
51.82
32.32
32.30
31.41
31.38
29.58
29.53
24.16
24.01
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

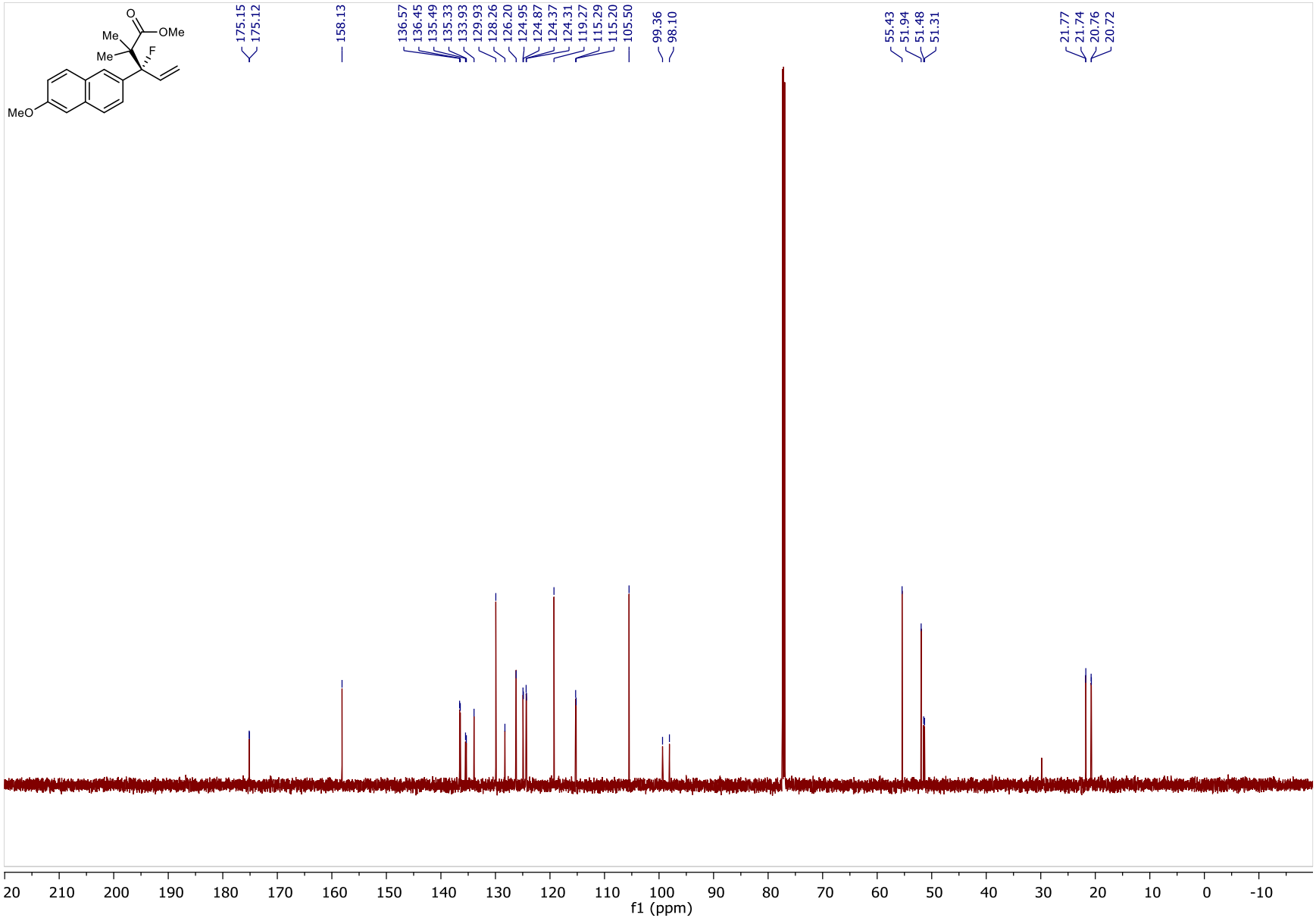

O
OMe
2
F
-165.11
-165.15
-163.4
-163.6
-163.8
-164.0
-164.2
-164.4
-164.6
-164.8
-165.0
-165.2
-165.4
-165.6
-165.8
-166.0
-166.2
-166.4
-166.6
f1 (ppm)

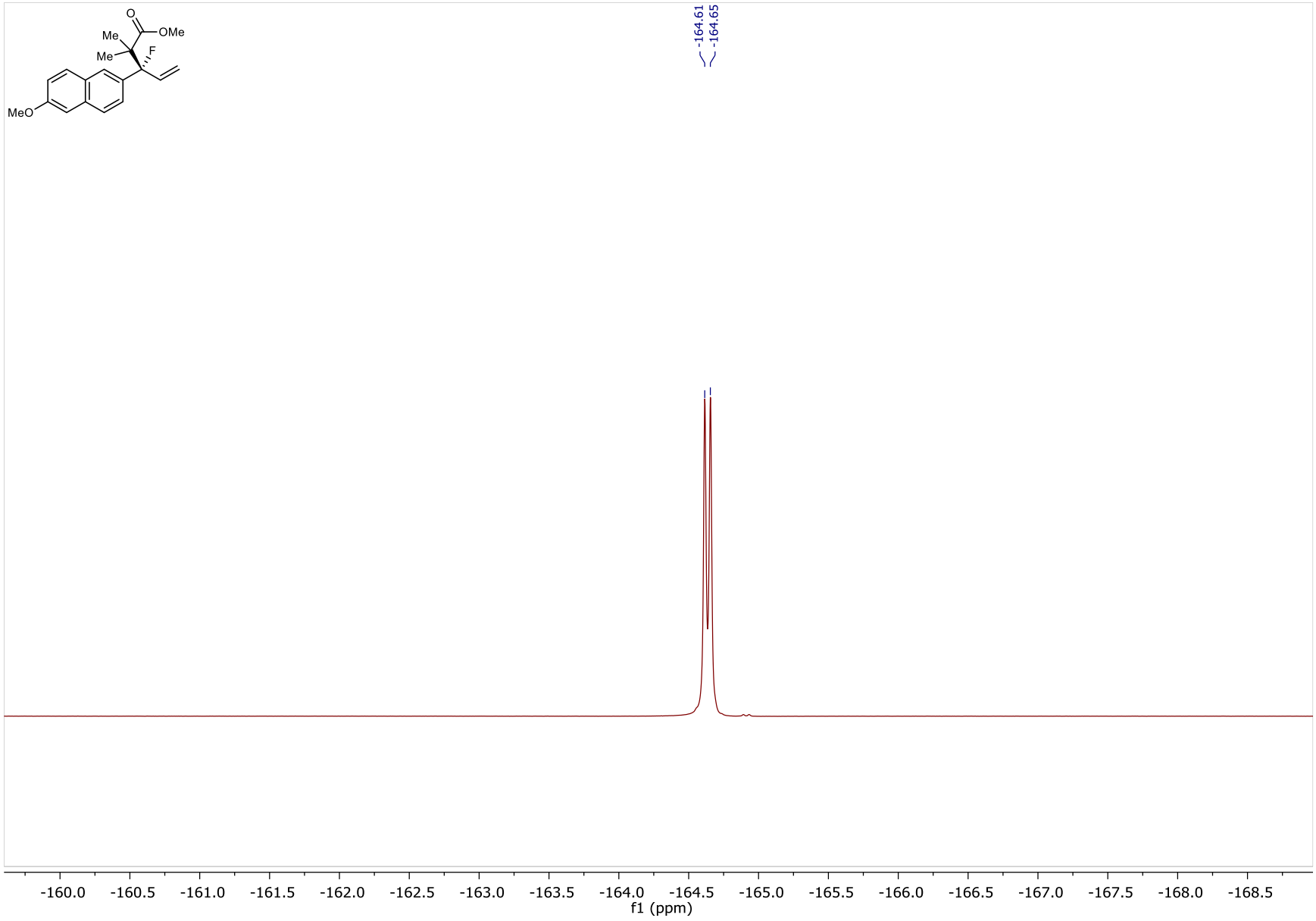

O
OMe
F
7.88
7.88
7.88
7.87
7.86
7.85
7.84
7.84
7.84
7.83
7.82
7.52
7.51
7.51
7.50
7.50
7.50
7.49
7.49
7.48
7.47
6.41
6.39
6.38
6.37
6.35
6.34
5.45
5.45
5.43
5.42
5.42
5.34
5.33
3.61
3.22
3.19
4.00
3.00
1.00
0.99
0.99
2.90
1.91
f1 (ppm)

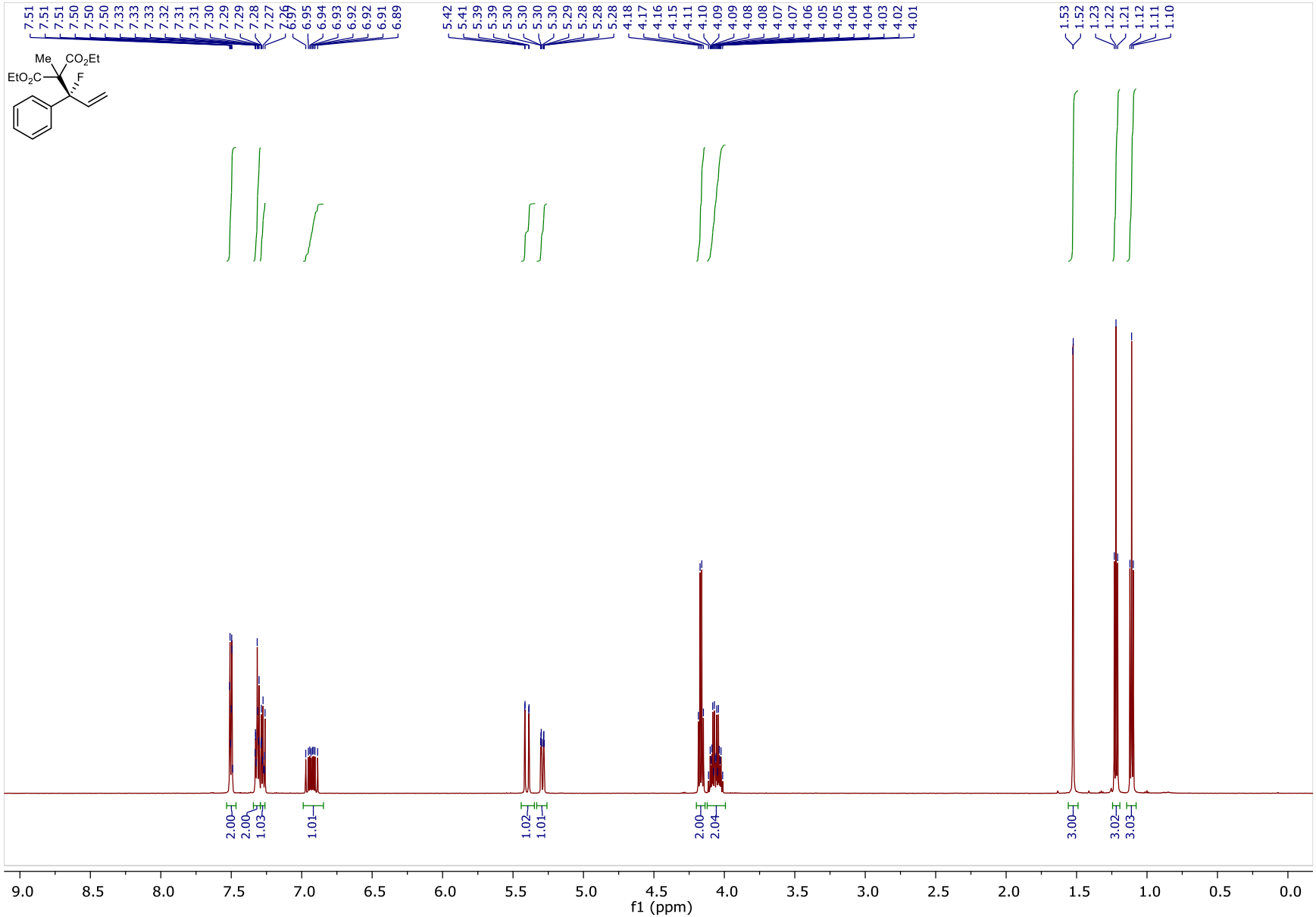

O
OMe
F
169.18
169.15
138.63
138.54
138.48
138.39
133.08
132.97
128.48
128.35
127.74
126.55
126.53
123.96
123.90
122.93
122.88
115.85
115.77
96.16
94.97
51.94
45.50
45.33
20
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

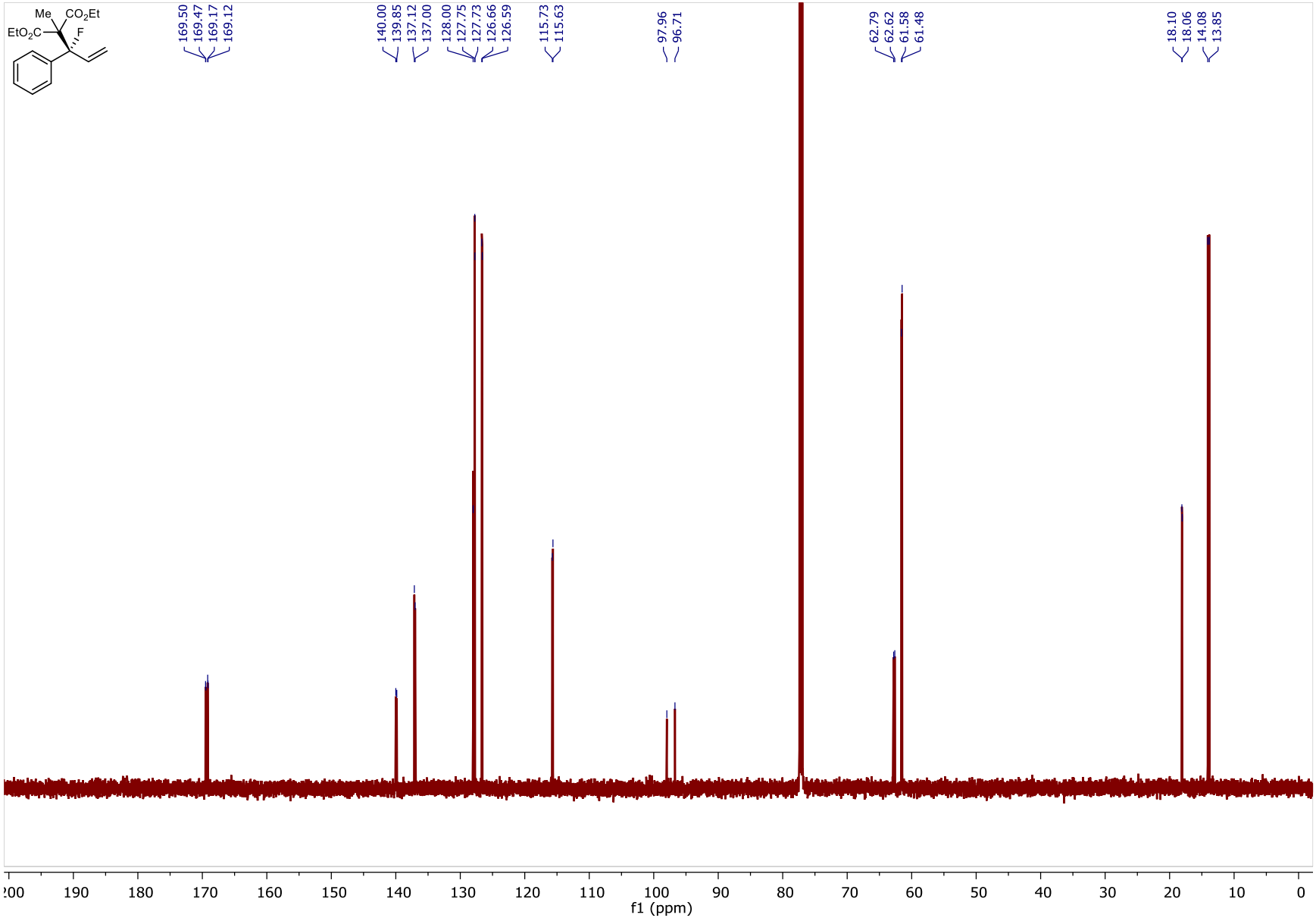

O
OMe
F
-150.82
-150.85
-150.89
-150.92
-147.5
-148.0
-148.5
-149.0
-149.5
-150.0
-150.5
-151.0
-151.5
-152.0
-152.5
-153.0
-153.5
-154.0
-154.5
f1 (ppm)

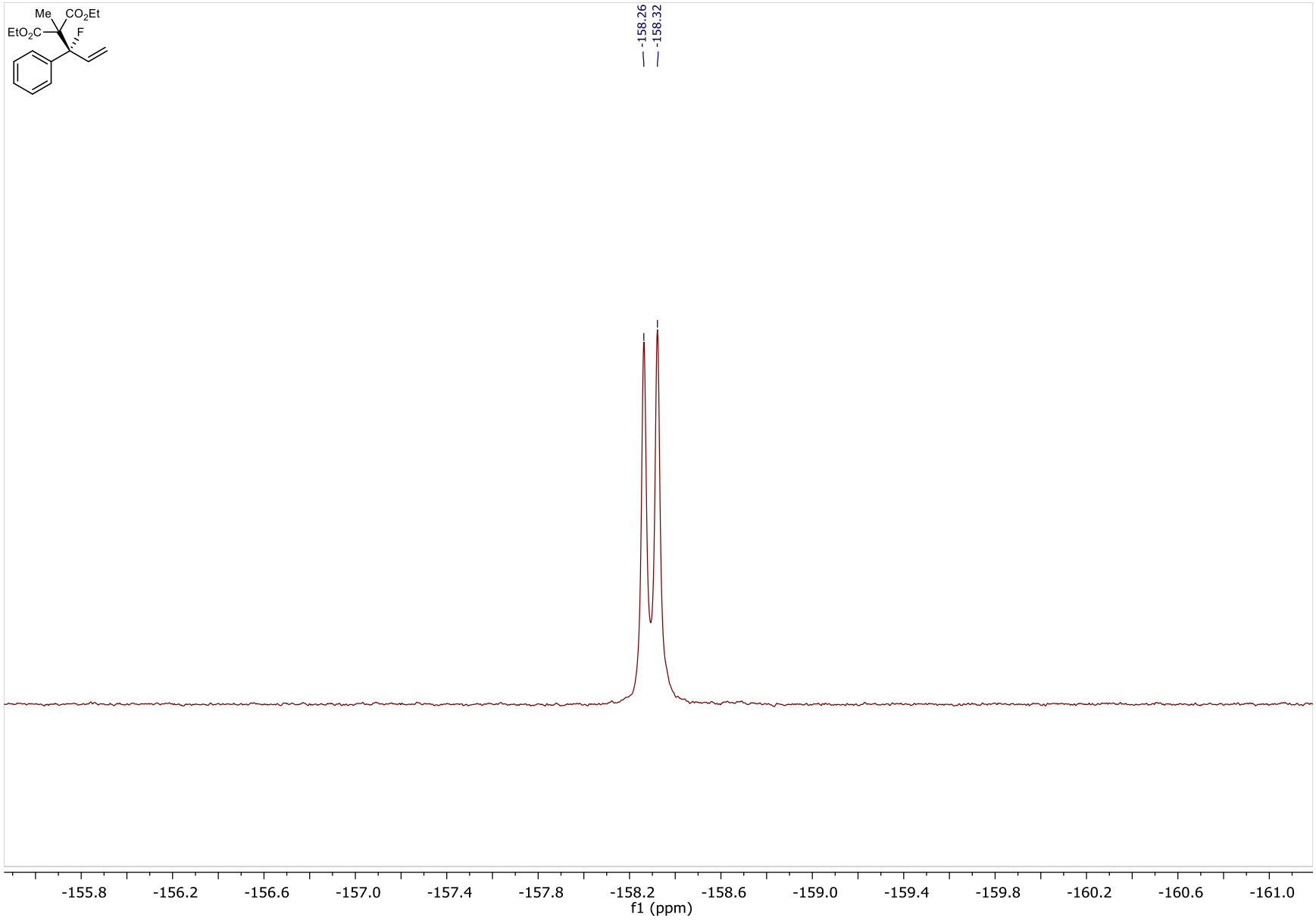

7.74
7.73
7.73
7.73
7.70
7.69
7.39
7.38
7.37
7.37
7.17
7.17
7.16
7.15
7.12
7.12
6.81
6.79
6.78
6.77
6.77
6.76
6.75
6.73
5.49
5.49
5.46
5.46
5.34
5.34
5.33
5.33
5.32
5.32
5.31
5.31
3.92
3.60
1.33
1.25
1.25
O
OMe
Me
Me
F
MeO
2.02
1.04
1.02
1.06
1.05
1.00
1.01
0.99
3.07
3.00
3.06
3.02
9.0
8.5
8.0
7.5
7.0
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
0.0
f1 (ppm)

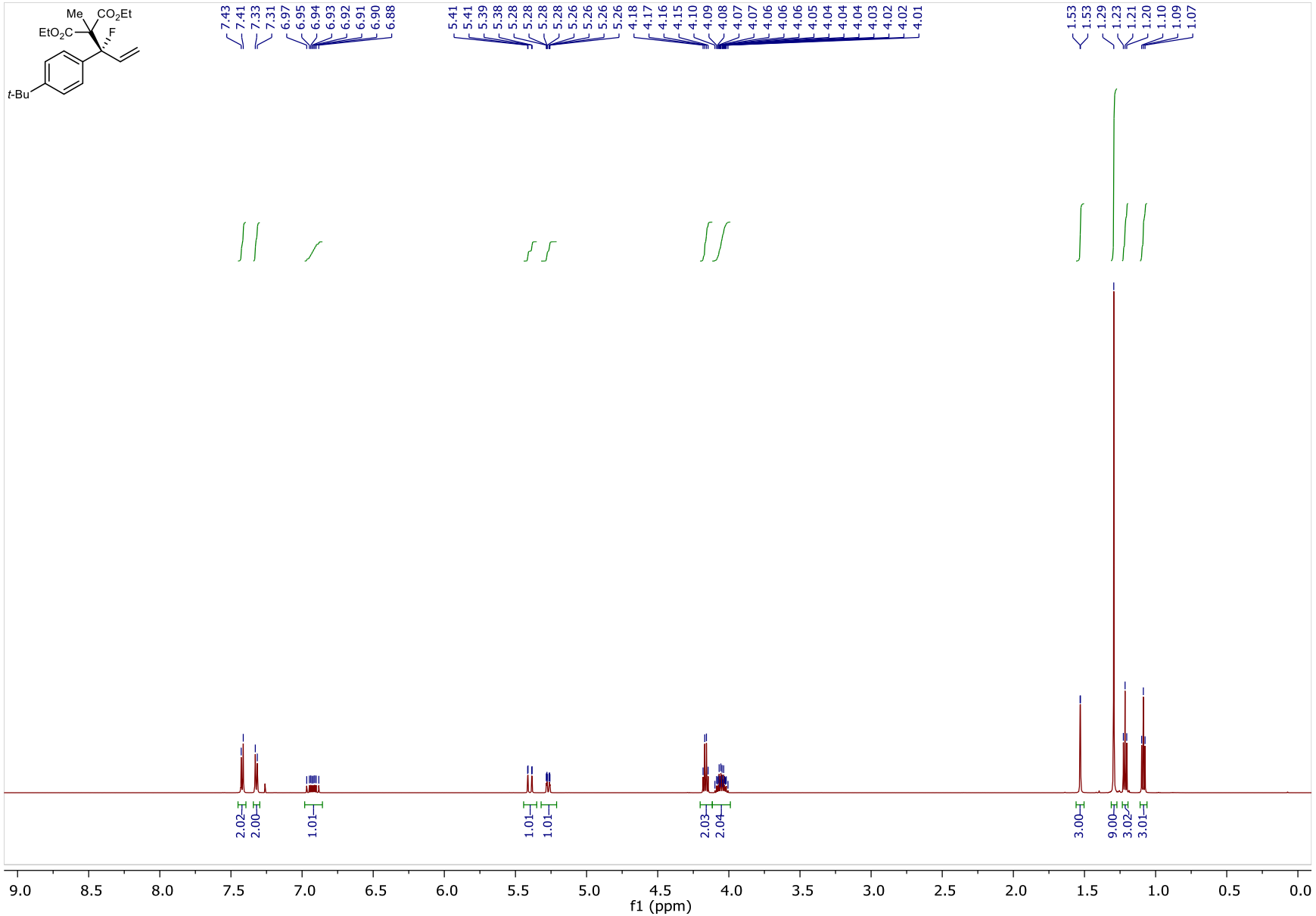

O
OMe
Me
Me
F
MeO
175.15
175.12
158.13
136.57
136.45
135.49
135.33
133.93
129.93
128.26
126.20
124.95
124.87
124.37
124.31
119.27
115.29
115.20
105.50
99.36
98.10
55.43
51.94
51.48
51.31
21.77
21.74
20.76
20.72
20 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

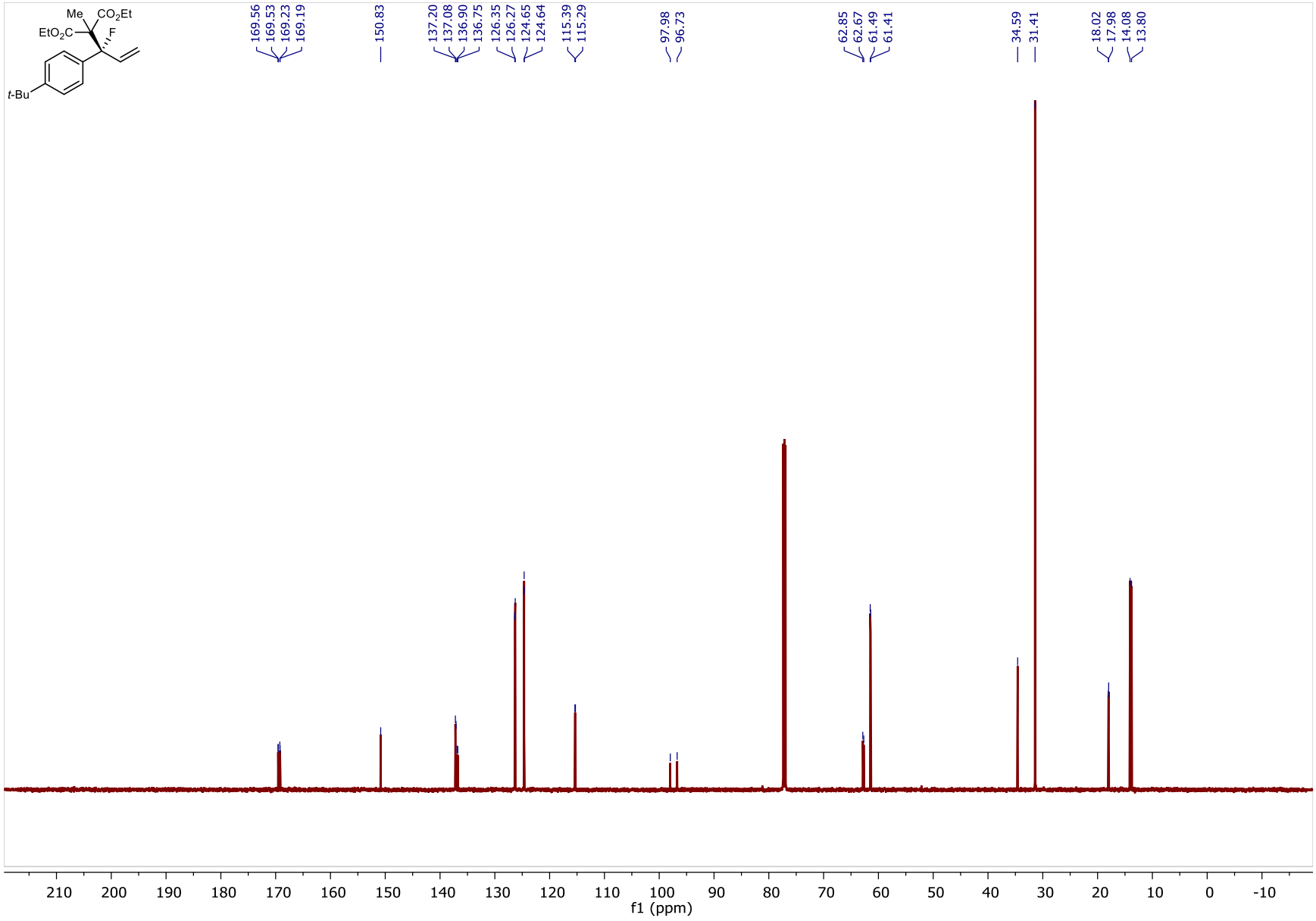

O
OMe
Me
Me
F
MeO
-164.61
-164.65
-160.0
-160.5
-161.0
-161.5
-162.0
-162.5
-163.0
-163.5
-164.0
-164.5
-165.0
-165.5
-166.0
-166.5
-167.0
-167.5
-168.0
-168.5
f1 (ppm)

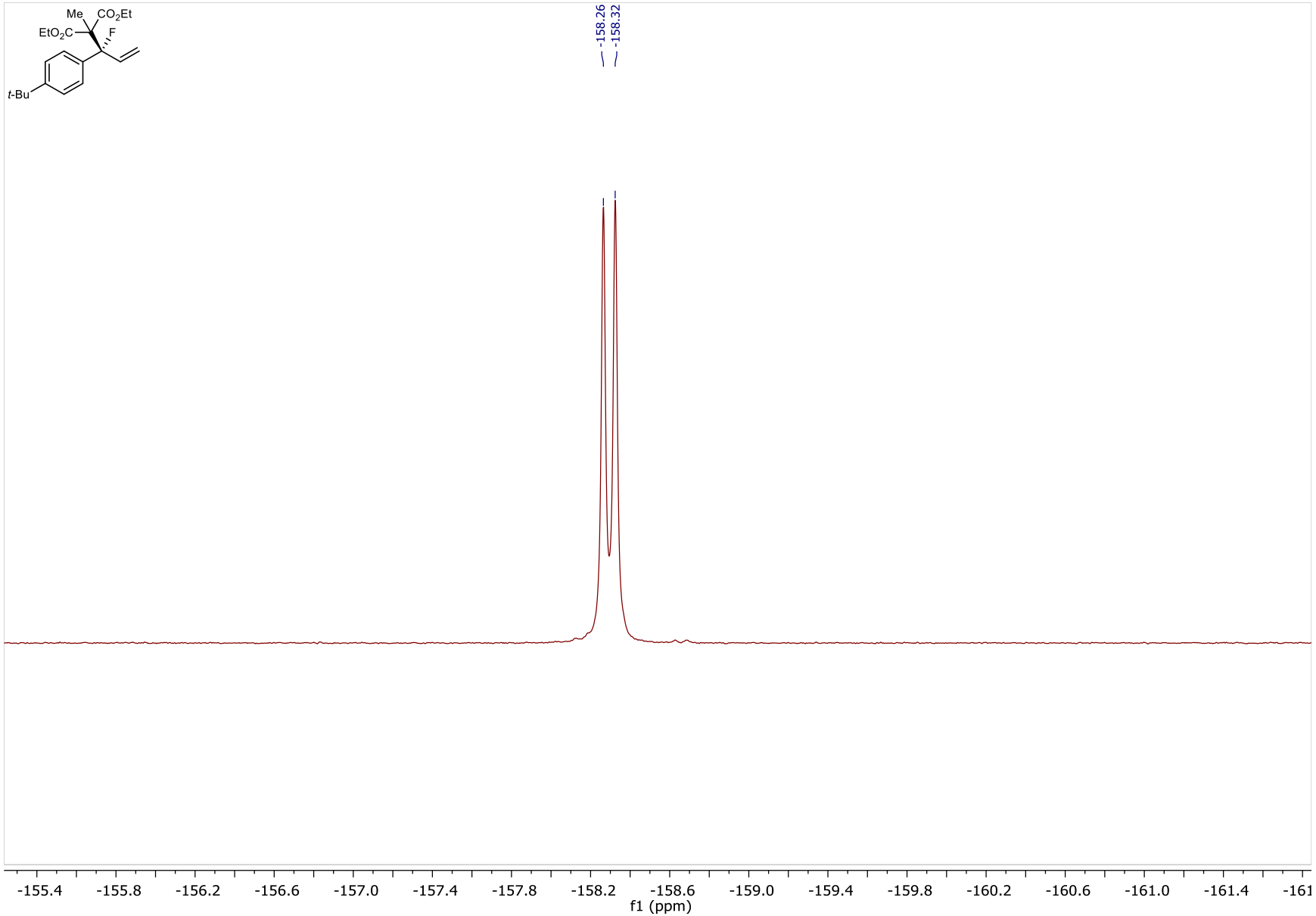

7.51 7.51 7.51 7.50 7.50 7.50 7.33 7.33 7.32 7.31 7.31 7.30 7.29 7.29 7.28 7.27 6.95 6.94 6.93 6.92 6.92 6.91 6.89
5.42 5.41 5.39 5.39 5.30 5.30 5.30 5.29 5.28 5.28 4.18 4.17 4.16 4.15 4.11 4.10 4.09 4.09 4.08 4.08 4.07 4.07 4.06 4.05 4.05 4.04 4.04 4.03 4.02 4.01
1.53 1.52 1.23 1.22 1.21 1.12 1.11 1.10
Me
CO2Et
EtO2C
F
2.00 2.00 1.03 1.01 1.02 1.01 2.00 2.04 3.00 3.02 3.03
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 0.0
f1 (ppm)

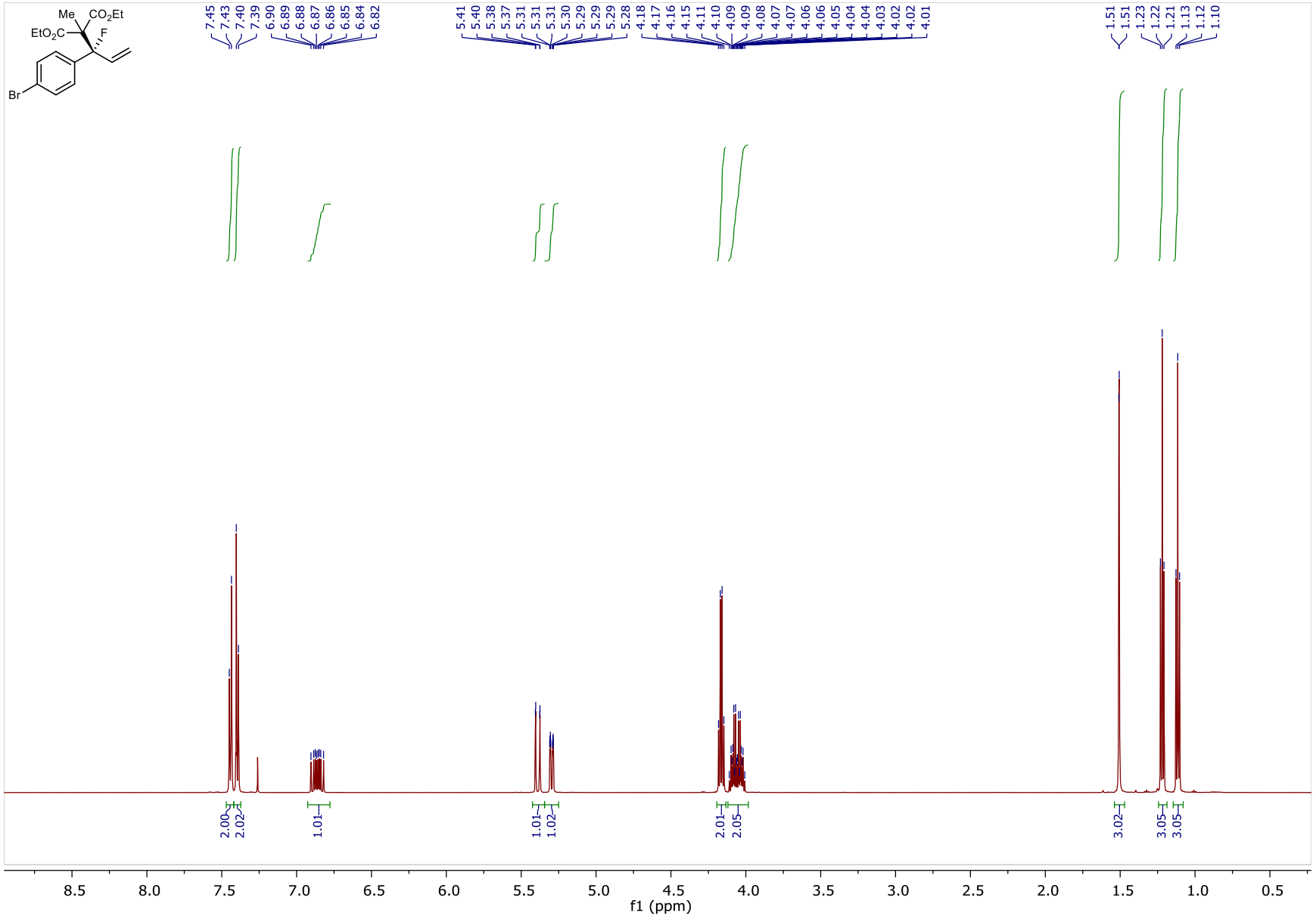

Me
CO2Et
EtO2C
F
169.50
169.47
169.17
169.12
140.00
139.85
137.12
137.00
128.00
127.75
127.73
126.66
126.59
115.73
115.63
97.96
96.71
62.79
62.62
61.58
61.48
18.10
18.06
14.08
13.85
f1 (ppm)

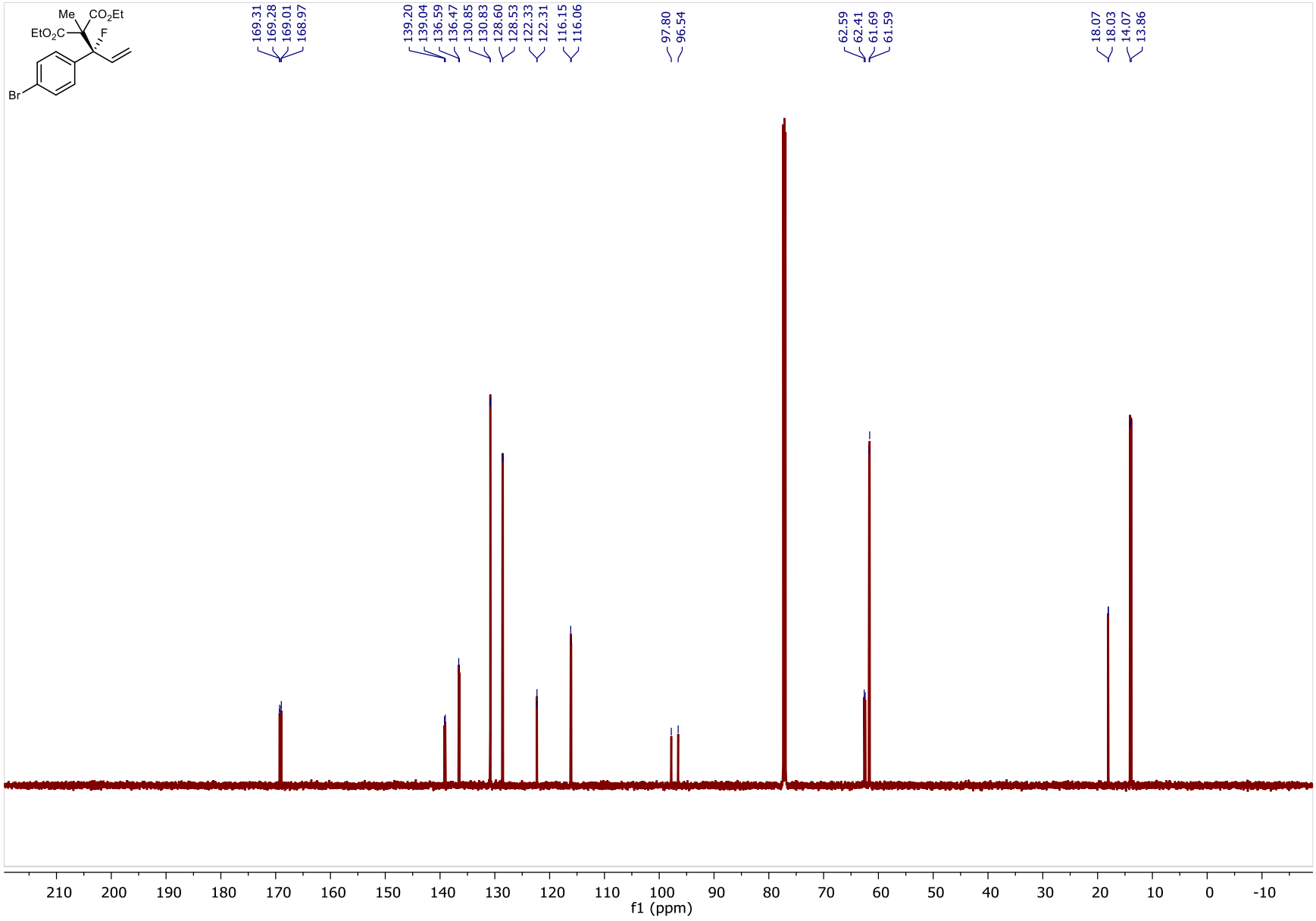

Me
CO2Et
EtO2C
F
-158.26
-158.32
-155.8
-156.2
-156.6
-157.0
-157.4
-157.8
-158.2
-158.6
-159.0
-159.4
-159.8
-160.2
-160.6
-161.0
f1 (ppm)

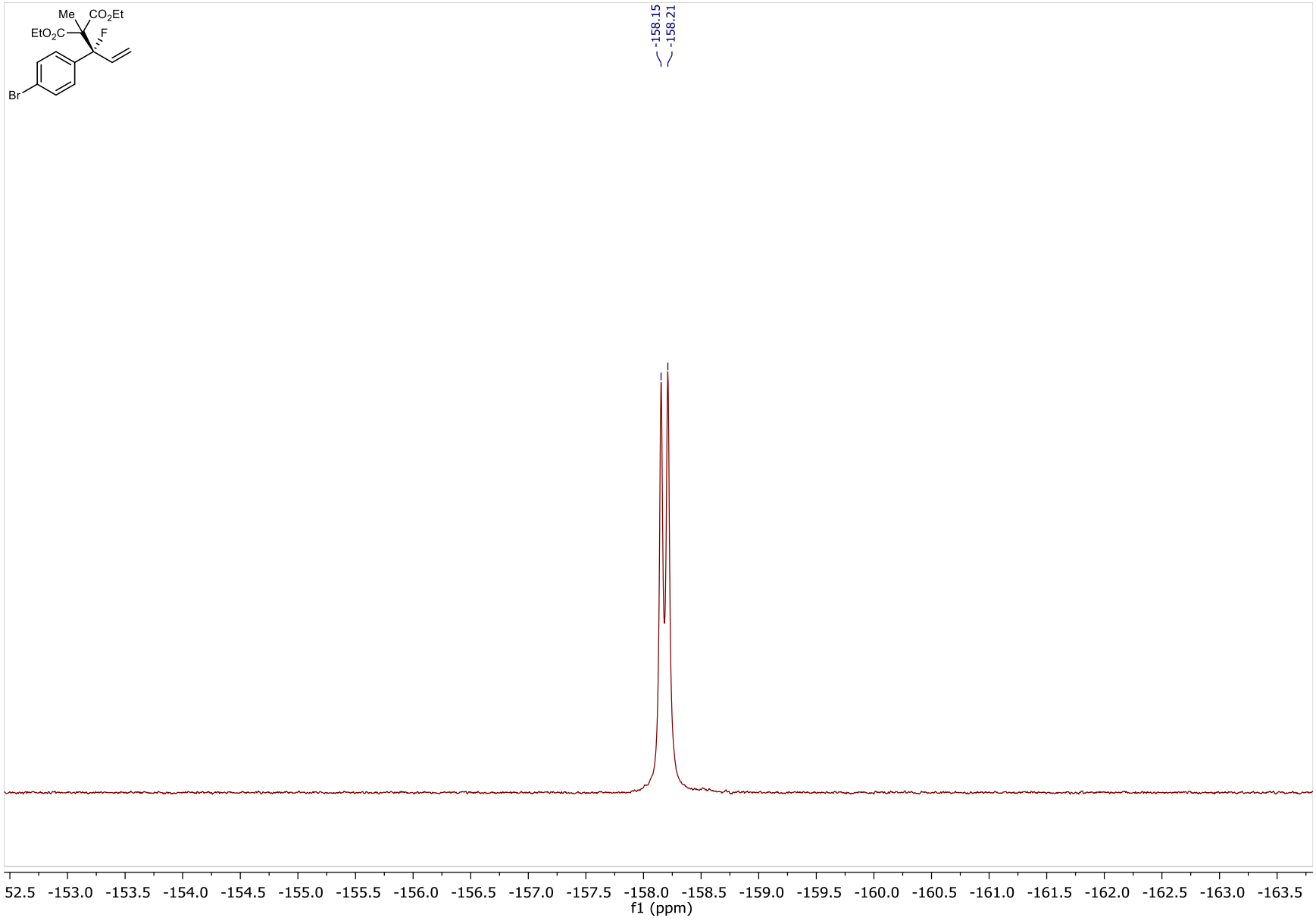

Me
CO2Et
EtO2C
F
t-Bu
7.43
7.41
7.33
7.31
6.97
6.95
6.94
6.93
6.92
6.91
6.90
6.88
5.41
5.41
5.39
5.38
5.28
5.28
5.28
5.26
5.26
5.26
5.26
4.18
4.17
4.16
4.15
4.10
4.09
4.08
4.07
4.07
4.06
4.06
4.06
4.05
4.04
4.04
4.04
4.03
4.02
4.02
4.01
1.53
1.53
1.29
1.23
1.21
1.20
1.10
1.09
1.07
2.02
2.00
1.01
1.01
1.01
2.03
2.04
3.00
9.00
3.02
3.01
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
0.0
f1 (ppm)

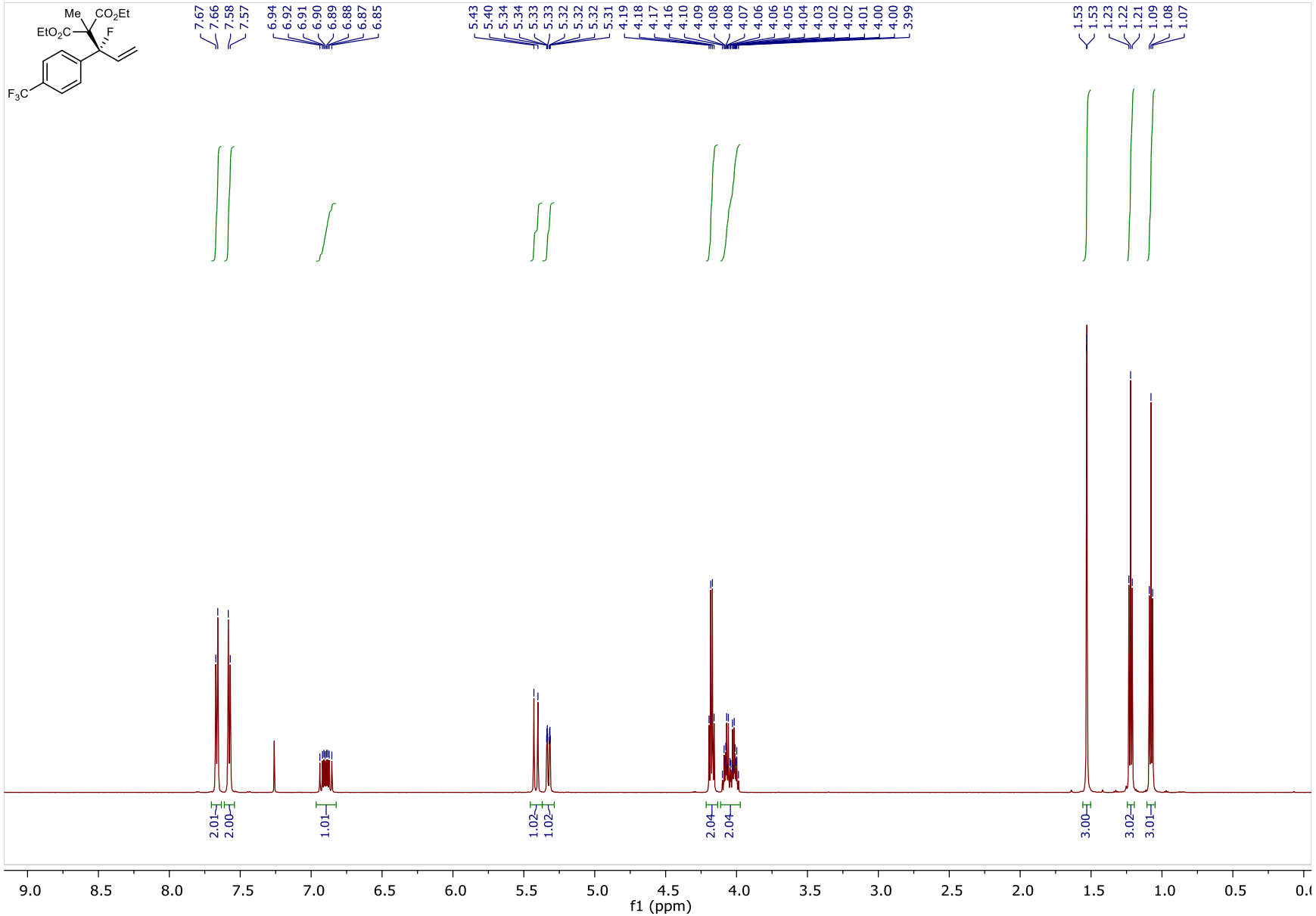

Me
CO2Et
EtO2C
F
t-Bu
169.56
169.53
169.23
169.19
150.83
137.20
137.08
136.90
136.75
126.35
126.27
124.65
124.64
115.39
115.29
97.98
96.73
62.85
62.67
61.49
61.41
34.59
31.41
18.02
17.98
14.08
13.80
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

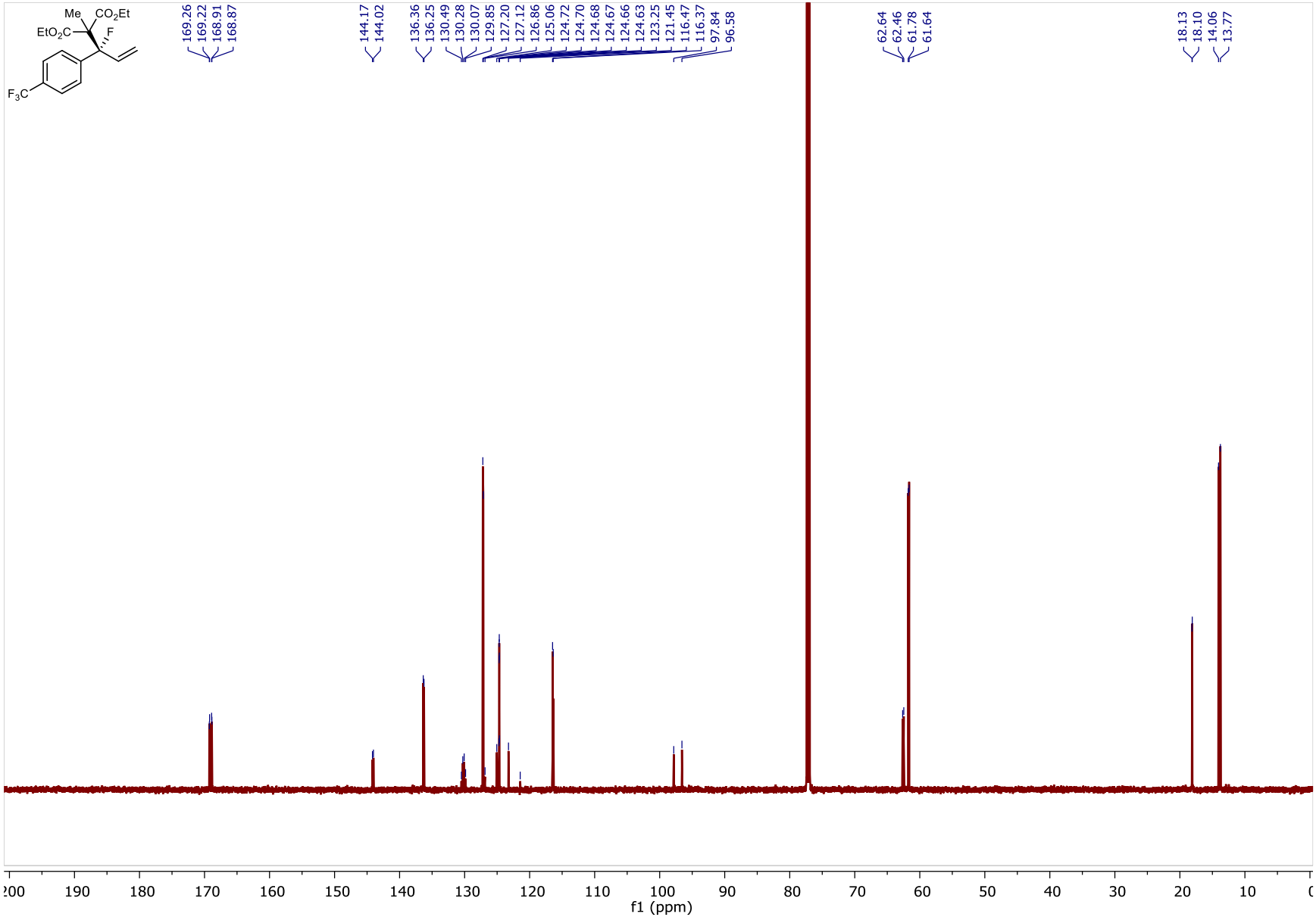

Me
CO2Et
EtO2C
F
t-Bu
-158.26
-158.32
-155.4
-155.8
-156.2
-156.6
-157.0
-157.4
-157.8
-158.2
-158.6
-159.0
-159.4
-159.8
-160.2
-160.6
-161.0
-161.4
f1 (ppm)

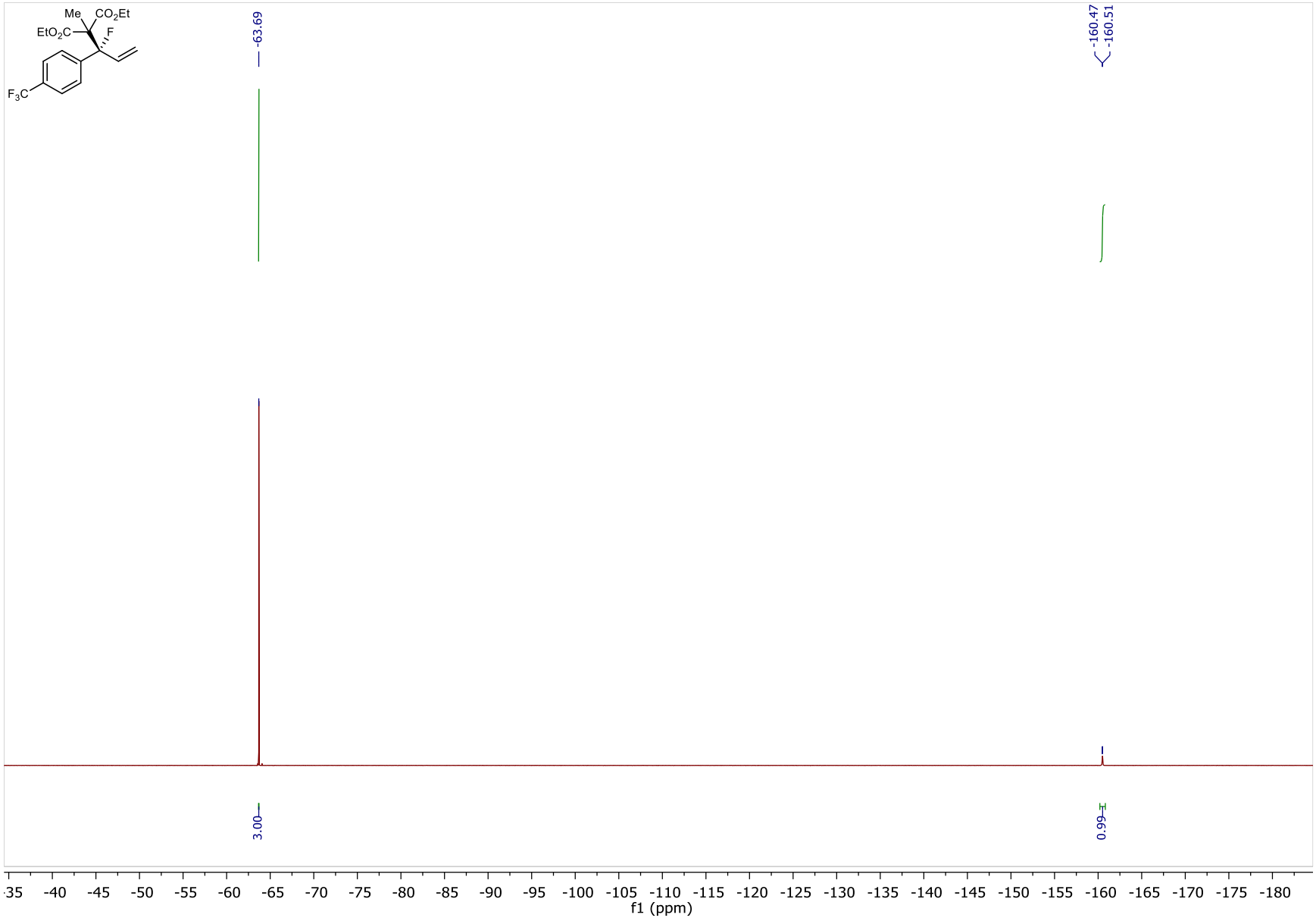

Me
CO2Et
EtO2C
F
Br
7.45
7.43
7.40
7.39
6.90
6.89
6.88
6.87
6.86
6.85
6.84
6.82
5.41
5.40
5.38
5.37
5.31
5.31
5.31
5.30
5.29
5.29
5.29
5.28
4.18
4.17
4.16
4.15
4.11
4.10
4.09
4.09
4.08
4.07
4.07
4.06
4.06
4.05
4.04
4.04
4.03
4.02
4.02
4.01
1.51
1.51
1.23
1.22
1.21
1.13
1.12
1.10
2.00
2.02
1.01
1.01
1.02
2.01
2.05
3.02
3.05
3.05
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
f1 (ppm)

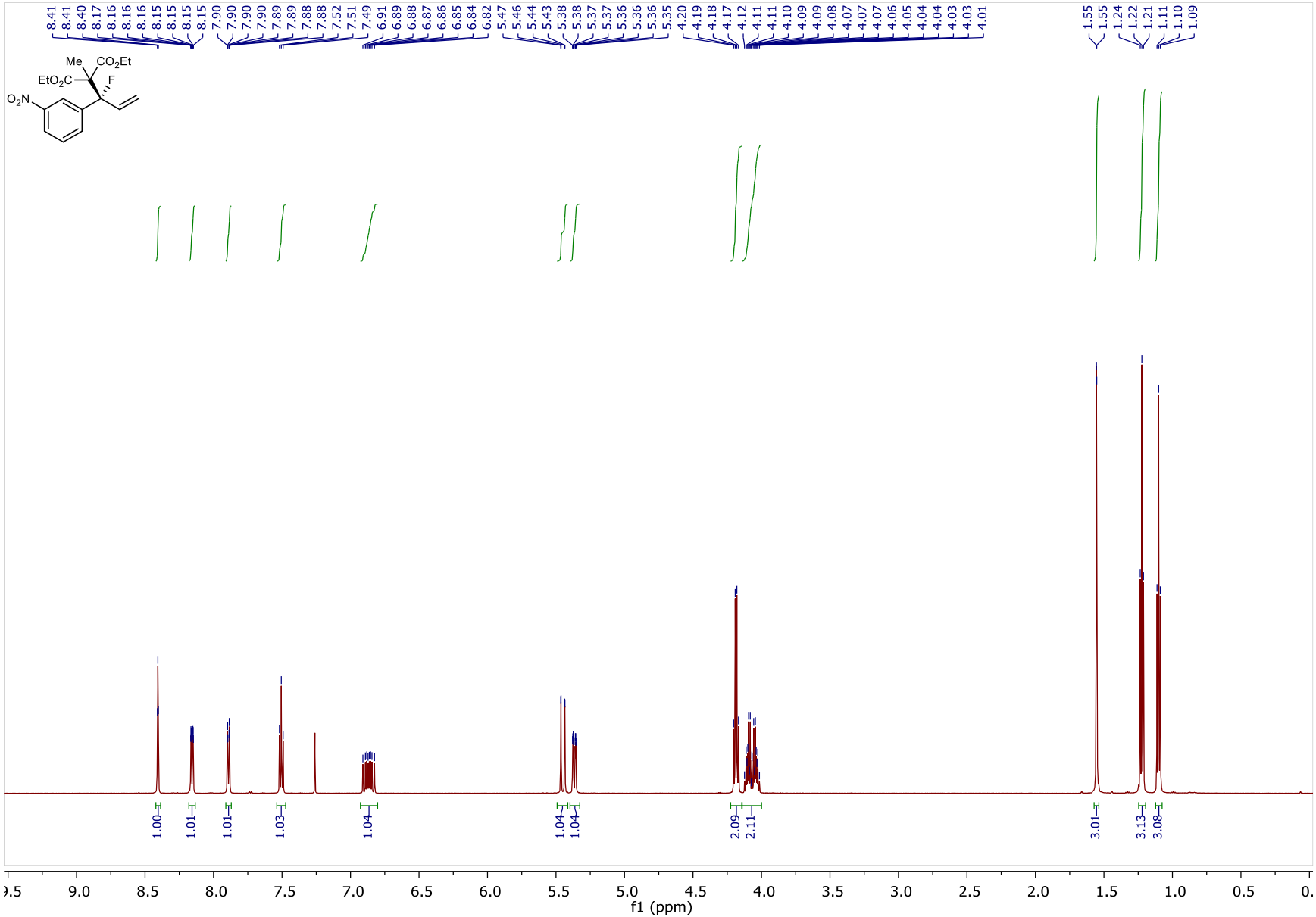

Me
CO2Et
EtO2C
F
Br
169.31
169.28
169.01
168.97
139.20
139.04
136.59
136.47
130.85
130.83
128.60
128.53
122.33
122.31
116.15
116.06
97.80
96.54
62.59
62.41
61.69
61.59
18.07
18.03
14.07
13.86
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

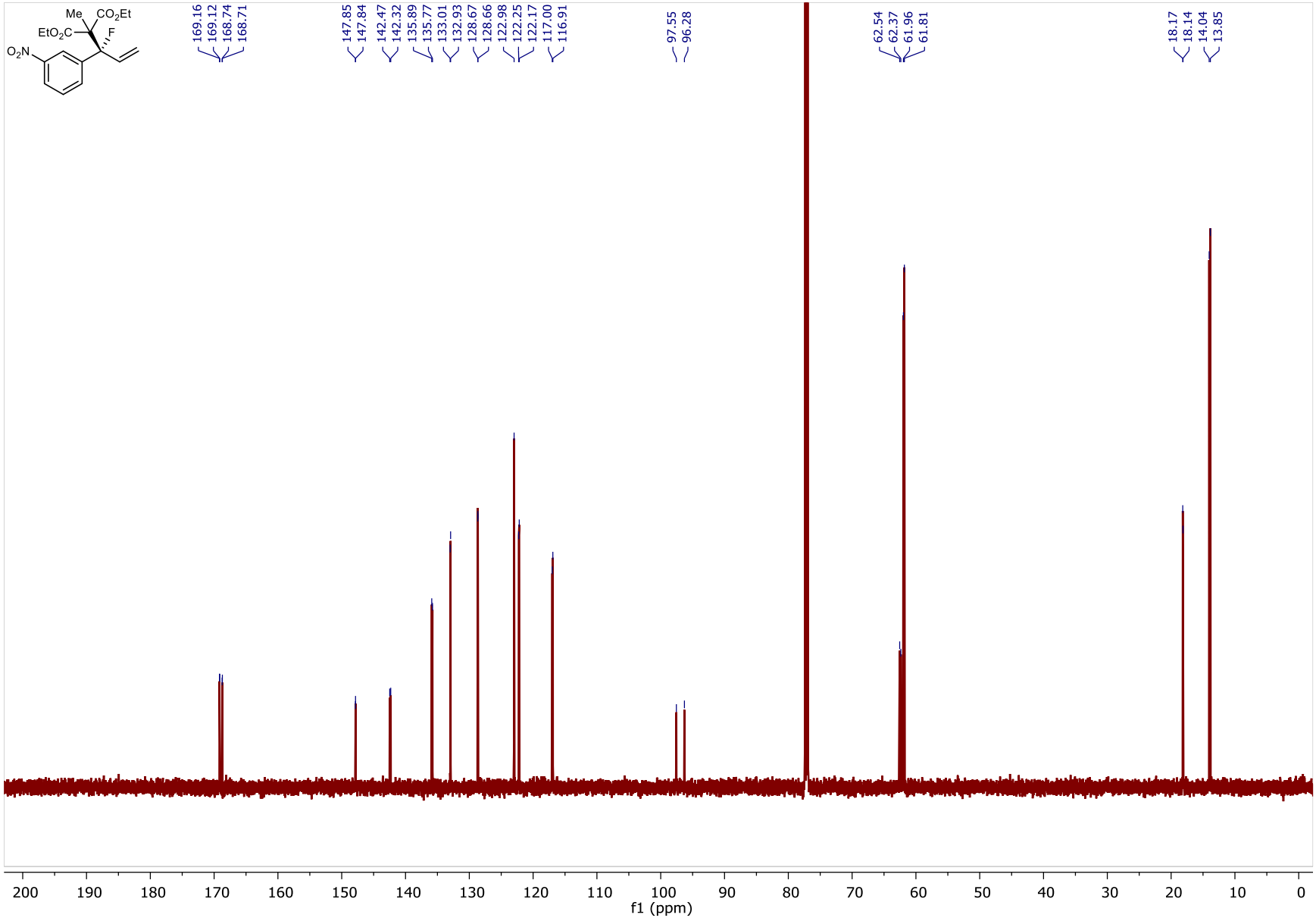

Me
CO2Et
EtO2C
F
Br
-158.15
-158.21
52.5 -153.0 -153.5 -154.0 -154.5 -155.0 -155.5 -156.0 -156.5 -157.0 -157.5 -158.0 -158.5 -159.0 -159.5 -160.0 -160.5 -161.0 -161.5 -162.0 -162.5 -163.0 -163.5
f1 (ppm)

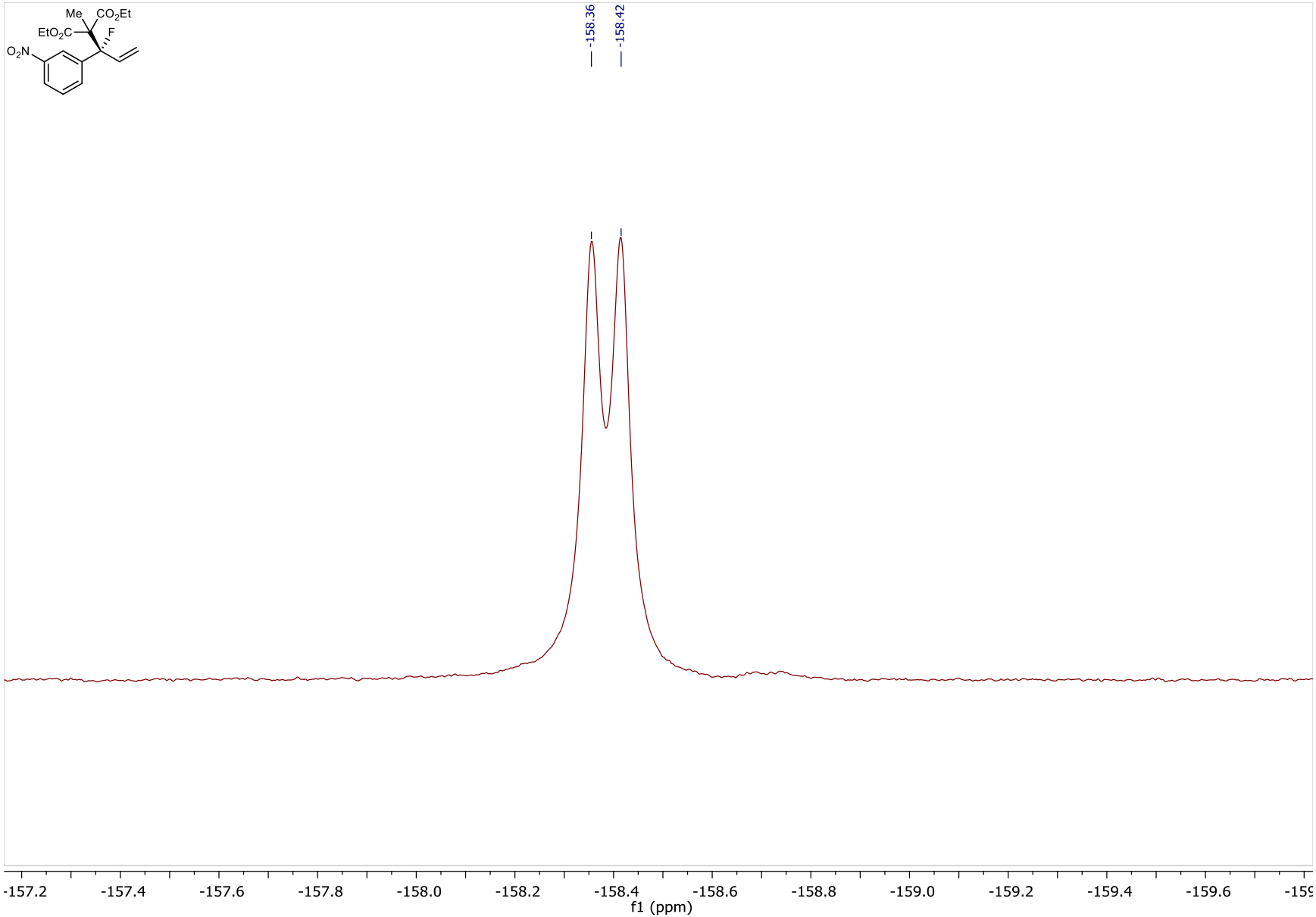

Me
CO2Et
EtO2C
F
F3C
7.67
7.66
7.58
7.57
6.94
6.92
6.91
6.90
6.89
6.88
6.87
6.85
5.43
5.40
5.34
5.34
5.33
5.33
5.32
5.32
5.32
5.31
4.19
4.18
4.17
4.16
4.10
4.09
4.08
4.08
4.07
4.06
4.06
4.05
4.04
4.03
4.02
4.02
4.01
4.00
4.00
3.99
1.53
1.53
1.23
1.22
1.21
1.09
1.08
1.07
2.01
2.00
1.01
1.02
1.02
2.04
2.04
3.00
3.02
3.01
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
f1 (ppm)

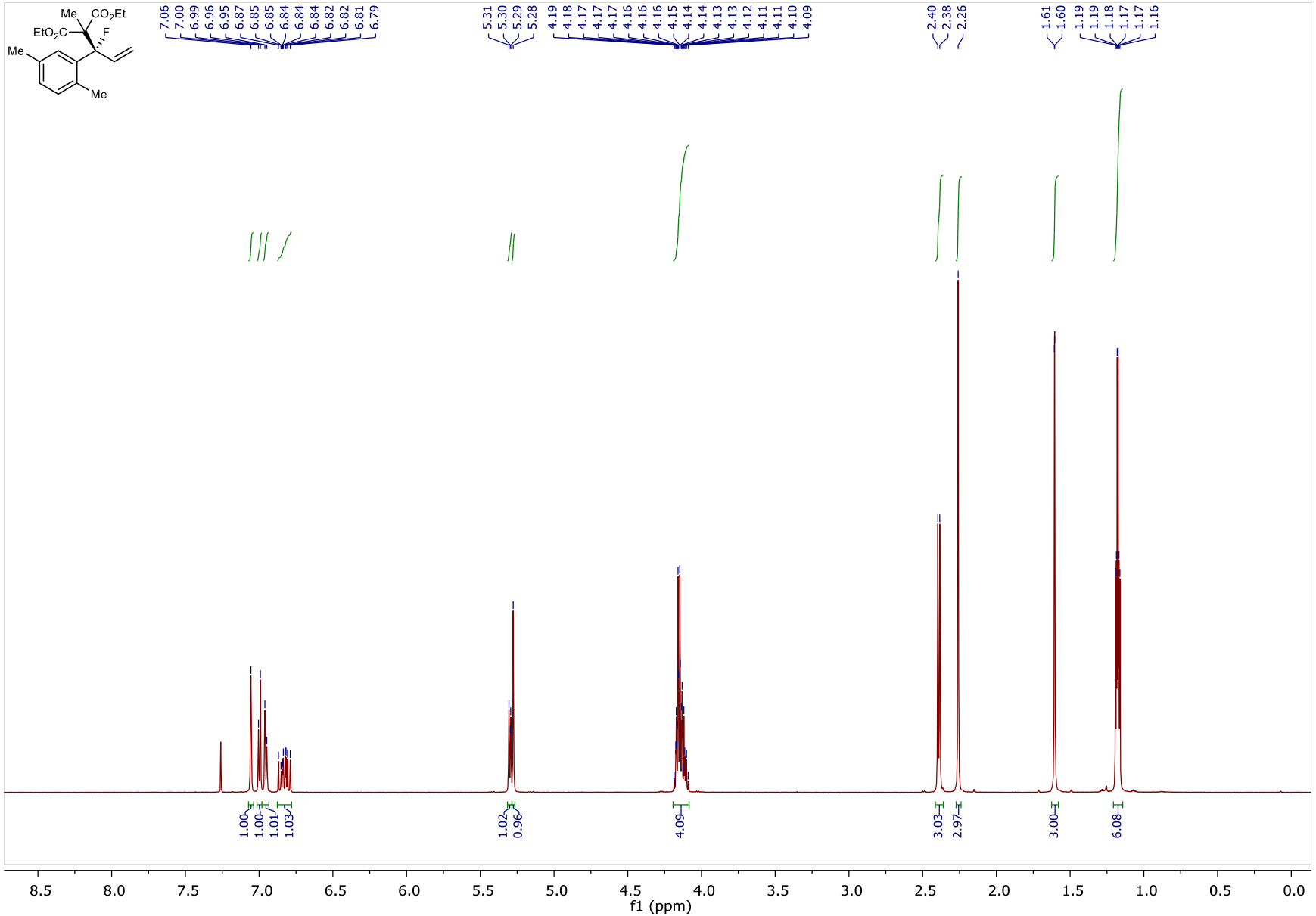

Me
CO2Et
EtO2C
F
F3C
169.26
169.22
168.91
168.87
144.17
144.02
136.36
136.25
130.49
130.28
130.07
129.85
127.20
127.12
126.86
125.06
124.72
124.70
124.68
124.67
124.66
124.63
123.25
121.45
116.47
116.37
97.84
96.58
62.64
62.46
61.78
61.64
18.13
18.10
14.06
13.77
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

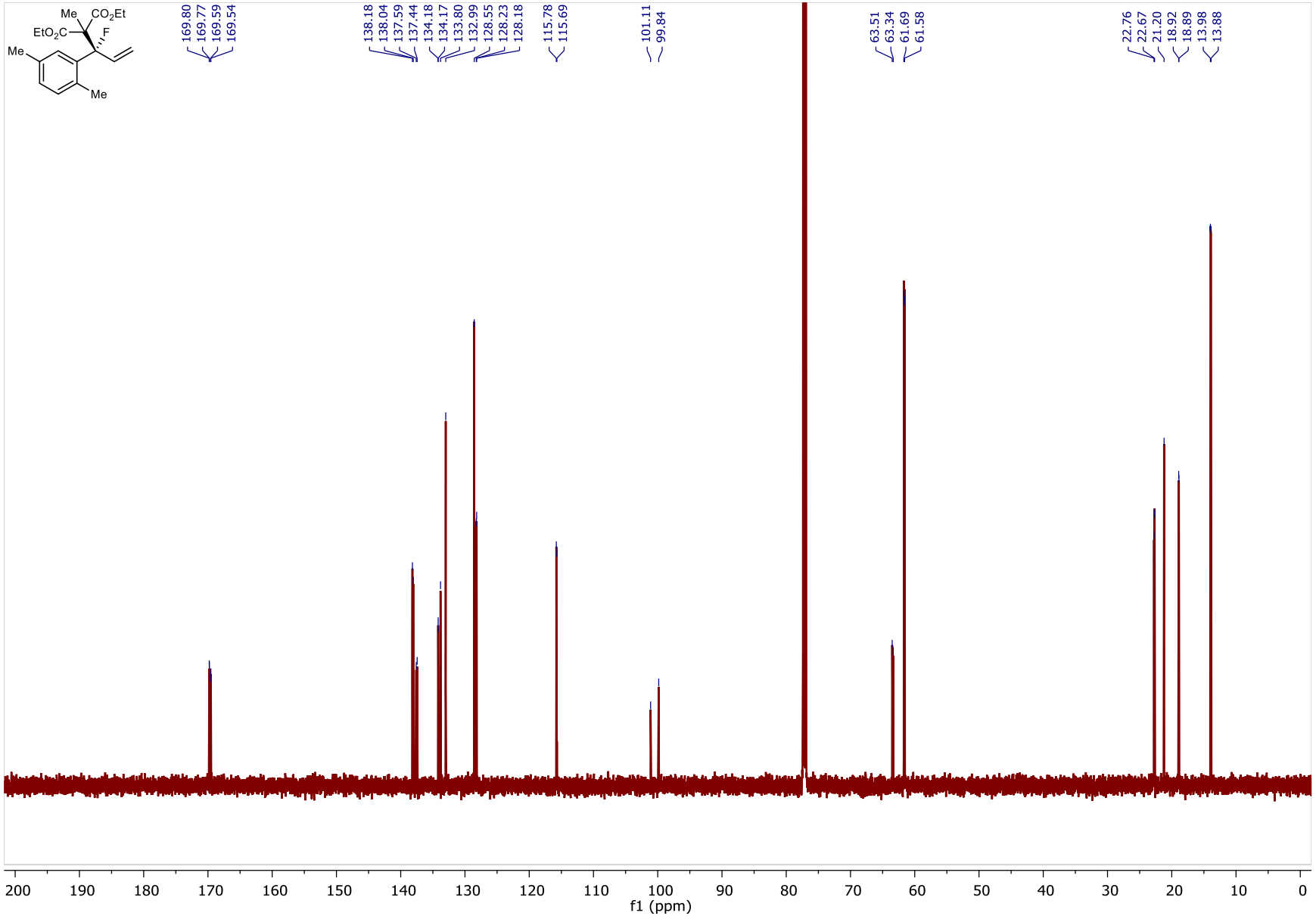

Me
CO2Et
EtO2C
F
F3C
-63.69
-160.47
-160.51
3.00
0.99
f1 (ppm)

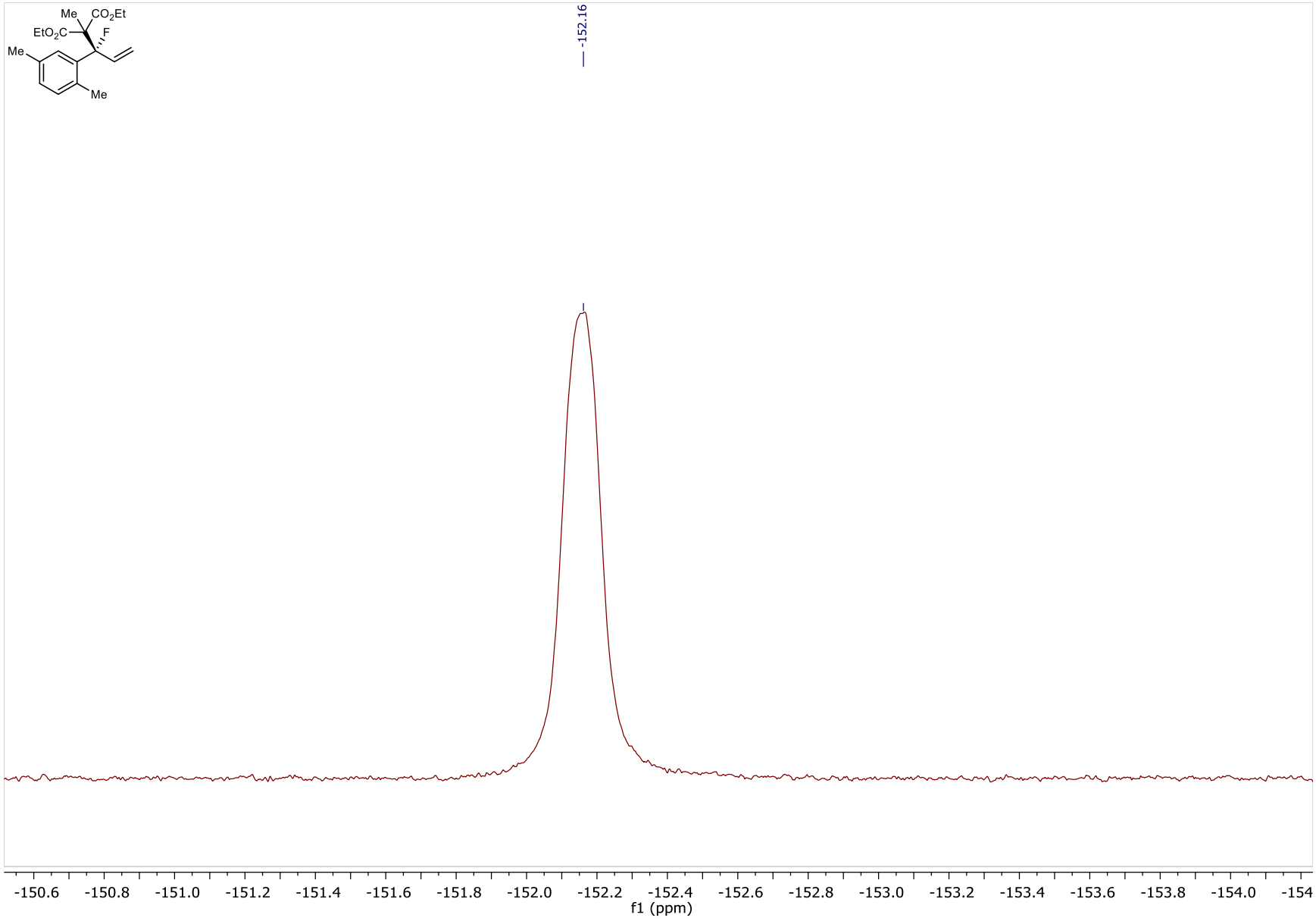

Me
CO2Et
EtO2C
F
O2N
f1 (ppm)

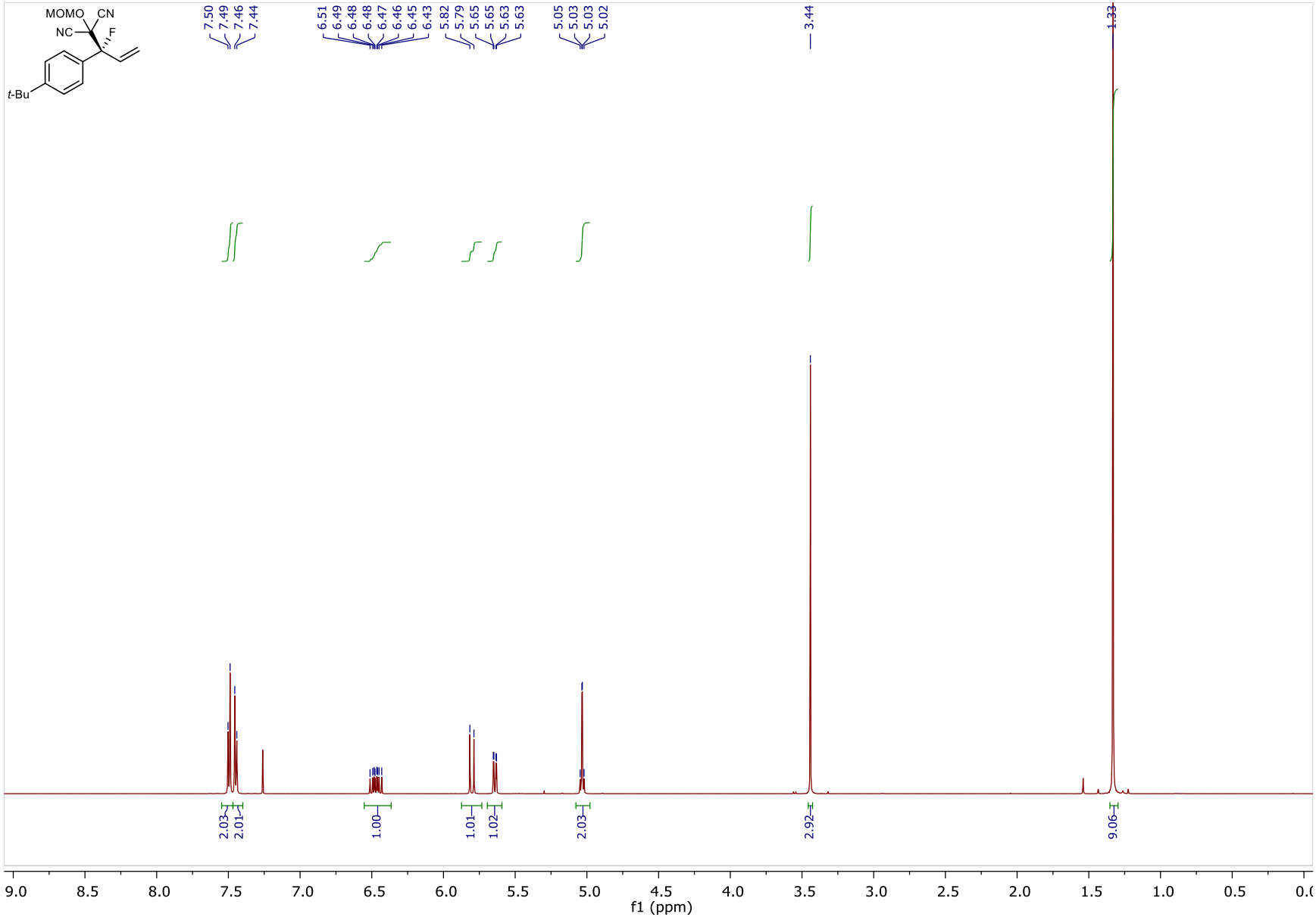

Me
CO2Et
EtO2C
F
O2N
169.16
169.12
168.74
168.71
147.85
147.84
142.47
142.32
135.89
135.77
133.01
132.93
128.67
128.66
122.98
122.25
122.17
117.00
116.91
97.55
96.28
62.54
62.37
61.96
61.81
18.17
18.14
14.04
13.85
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

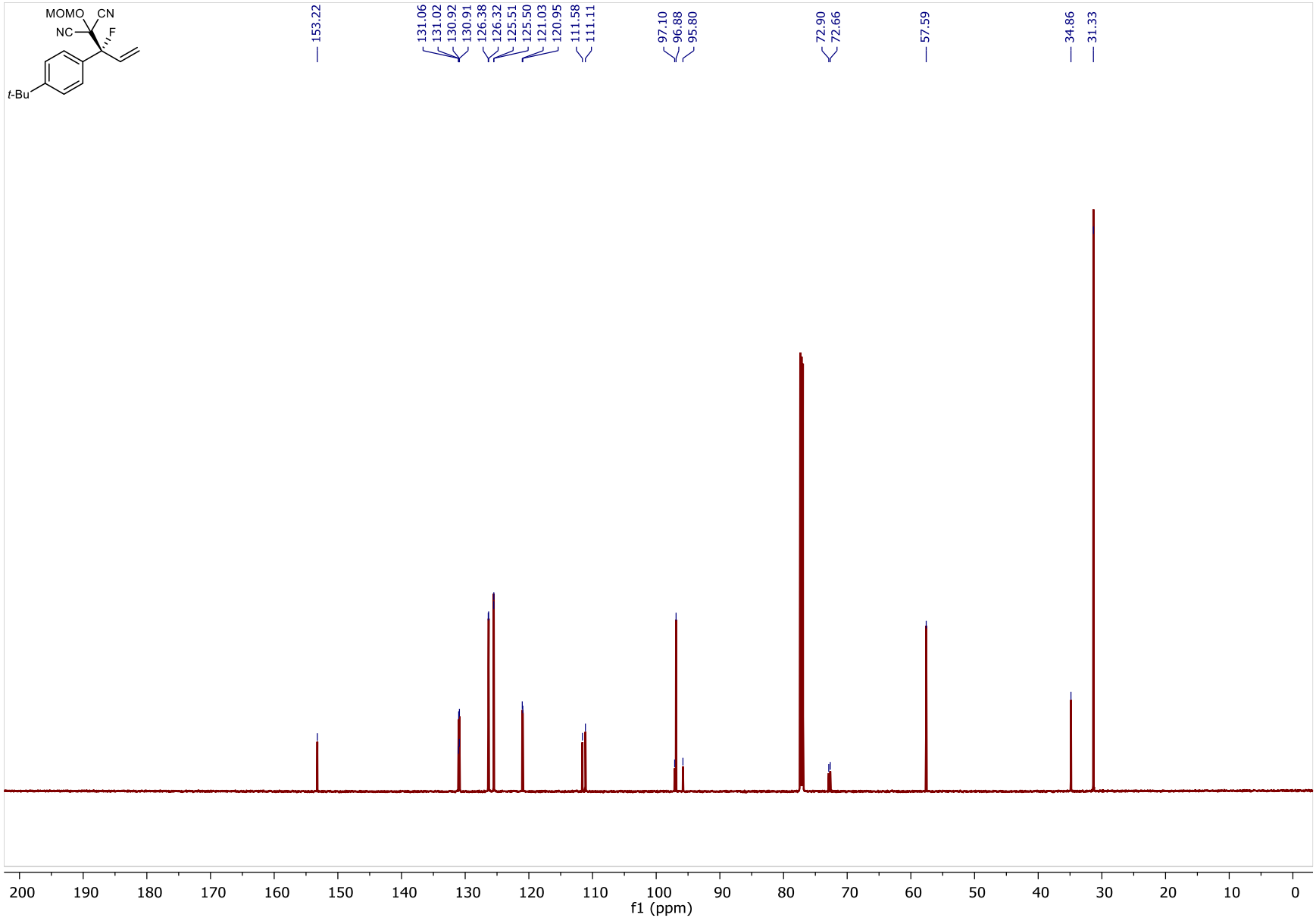

Me
CO2Et
EtO2C
F
O2N
-158.36
-158.42
-157.2
-157.4
-157.6
-157.8
-158.0
-158.2
-158.4
-158.6
-158.8
-159.0
-159.2
-159.4
-159.6
f1 (ppm)

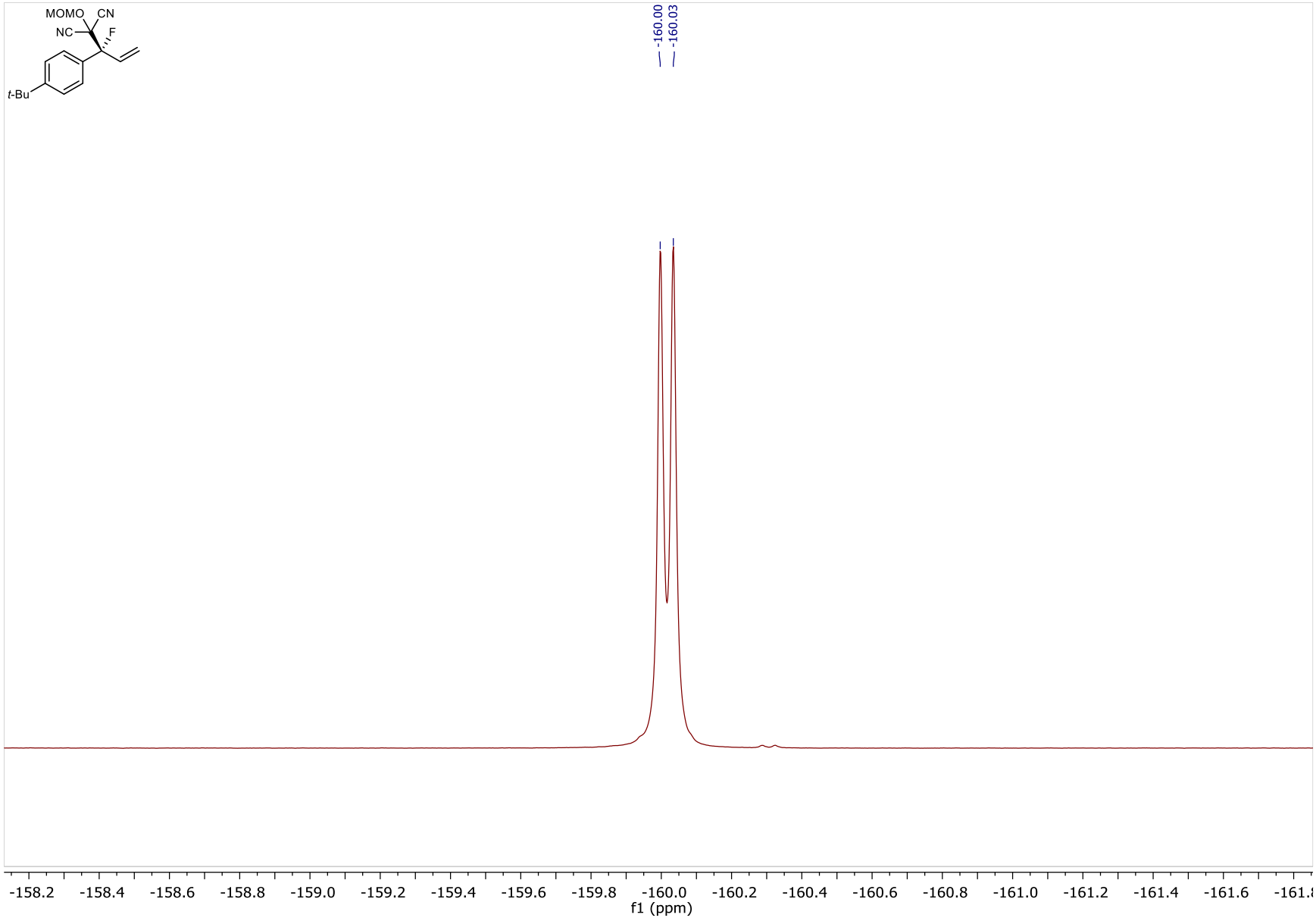

Me
CO2Et
EtO2C
F
Me
Me
7.06
7.00
6.99
6.96
6.95
6.87
6.85
6.85
6.84
6.84
6.84
6.82
6.82
6.81
6.79
5.31
5.30
5.29
5.28
4.19
4.18
4.17
4.17
4.17
4.16
4.16
4.16
4.15
4.14
4.14
4.13
4.13
4.12
4.11
4.11
4.10
4.09
2.40
2.38
2.26
1.61
1.60
1.19
1.19
1.18
1.17
1.17
1.16
1.00
1.00
1.01
1.03
1.02
0.96
4.09
3.03
2.97
3.00
6.08
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
0.0
f1 (ppm)

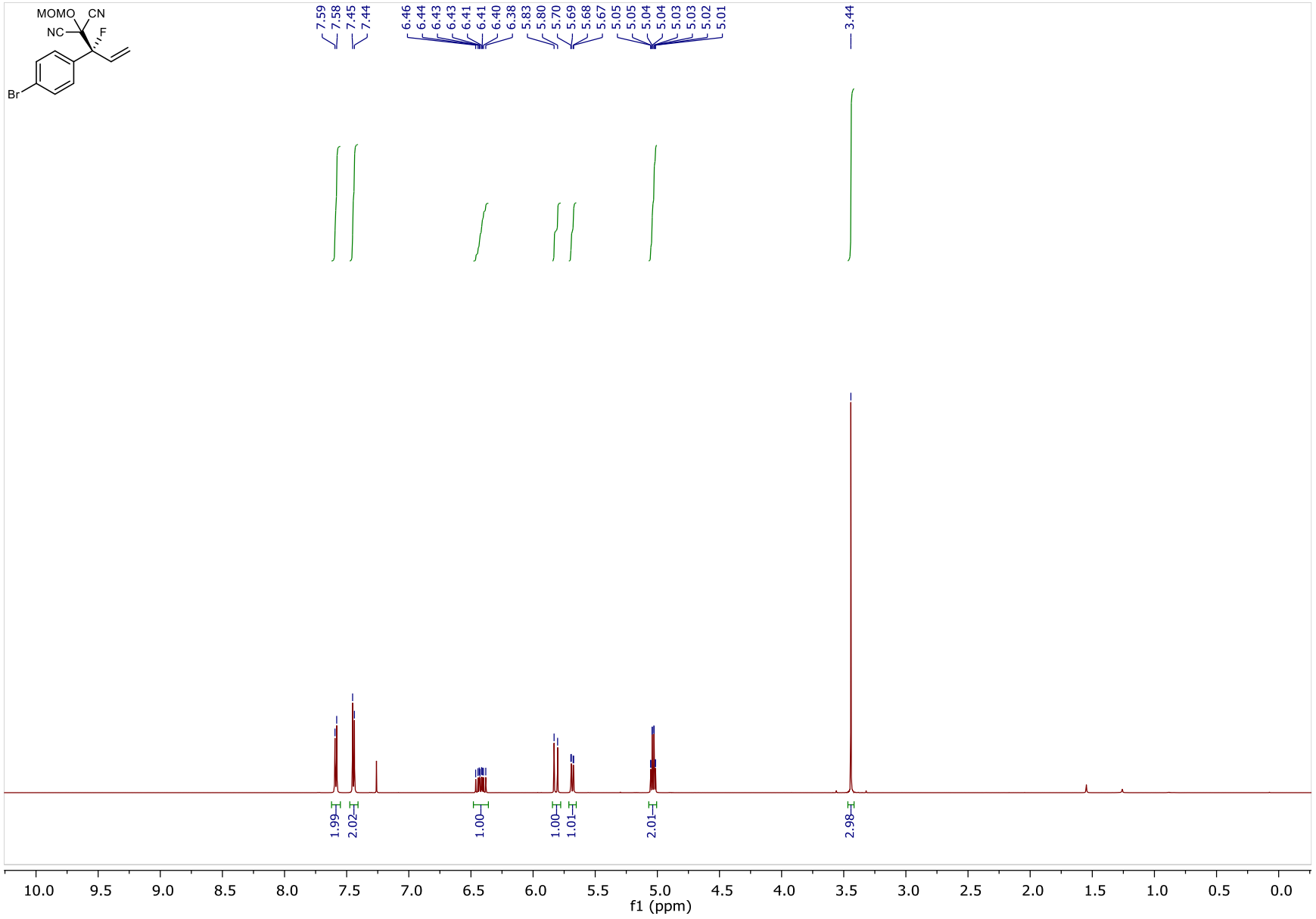

Me
CO2Et
EtO2C
F
Me
Me
169.80
169.77
169.59
169.54
138.18
138.04
137.59
137.44
134.18
134.17
133.80
132.99
128.55
128.23
128.18
115.78
115.69
101.11
99.84
63.51
63.34
61.69
61.58
22.76
22.67
21.20
18.92
18.89
13.98
13.88
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

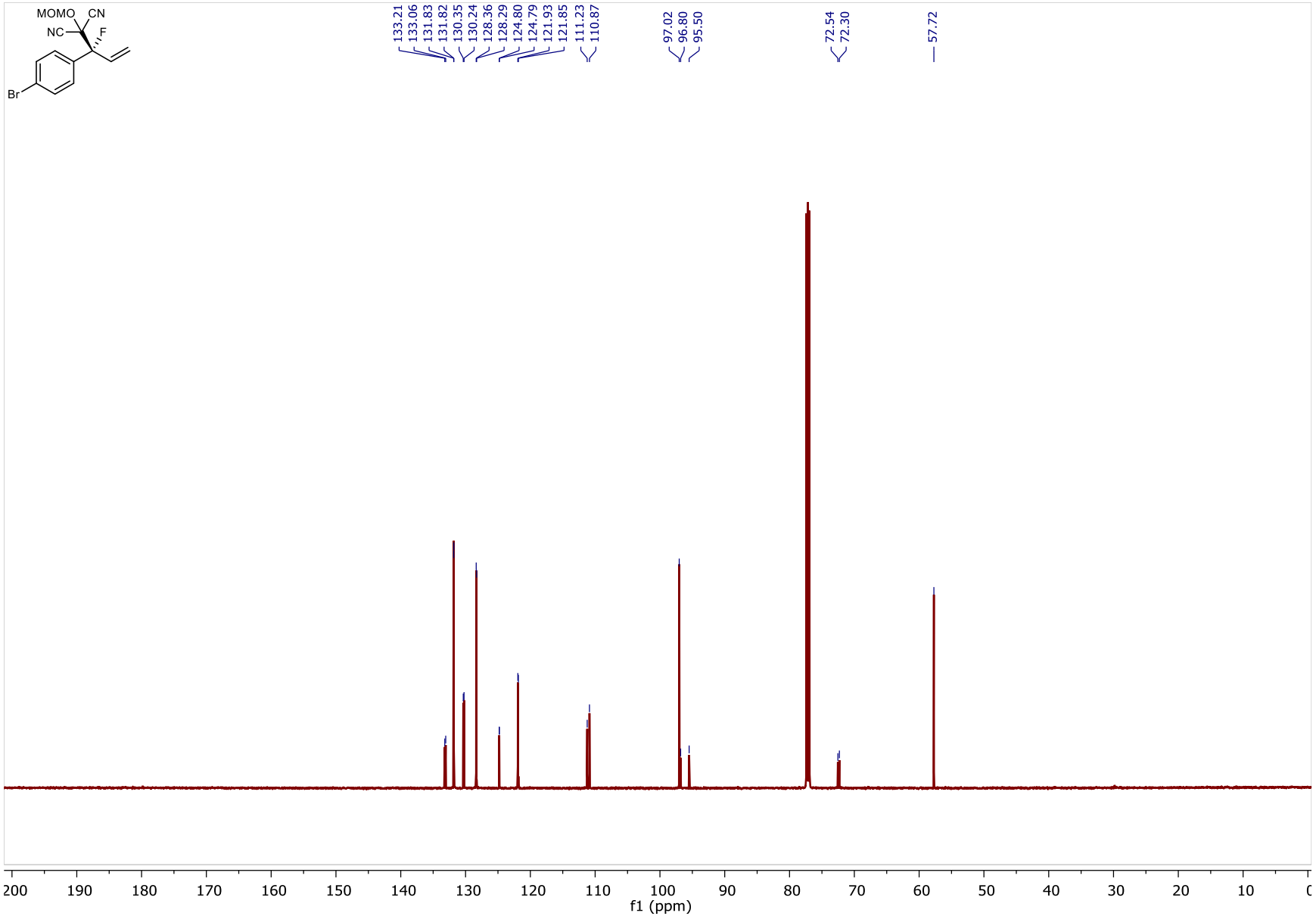

Me
CO2Et
EtO2C
F
Me
Me
-152.16
-150.6
-150.8
-151.0
-151.2
-151.4
-151.6
-151.8
-152.0
-152.2
-152.4
-152.6
-152.8
-153.0
-153.2
-153.4
-153.6
-153.8
-154.0
-154
f1 (ppm)

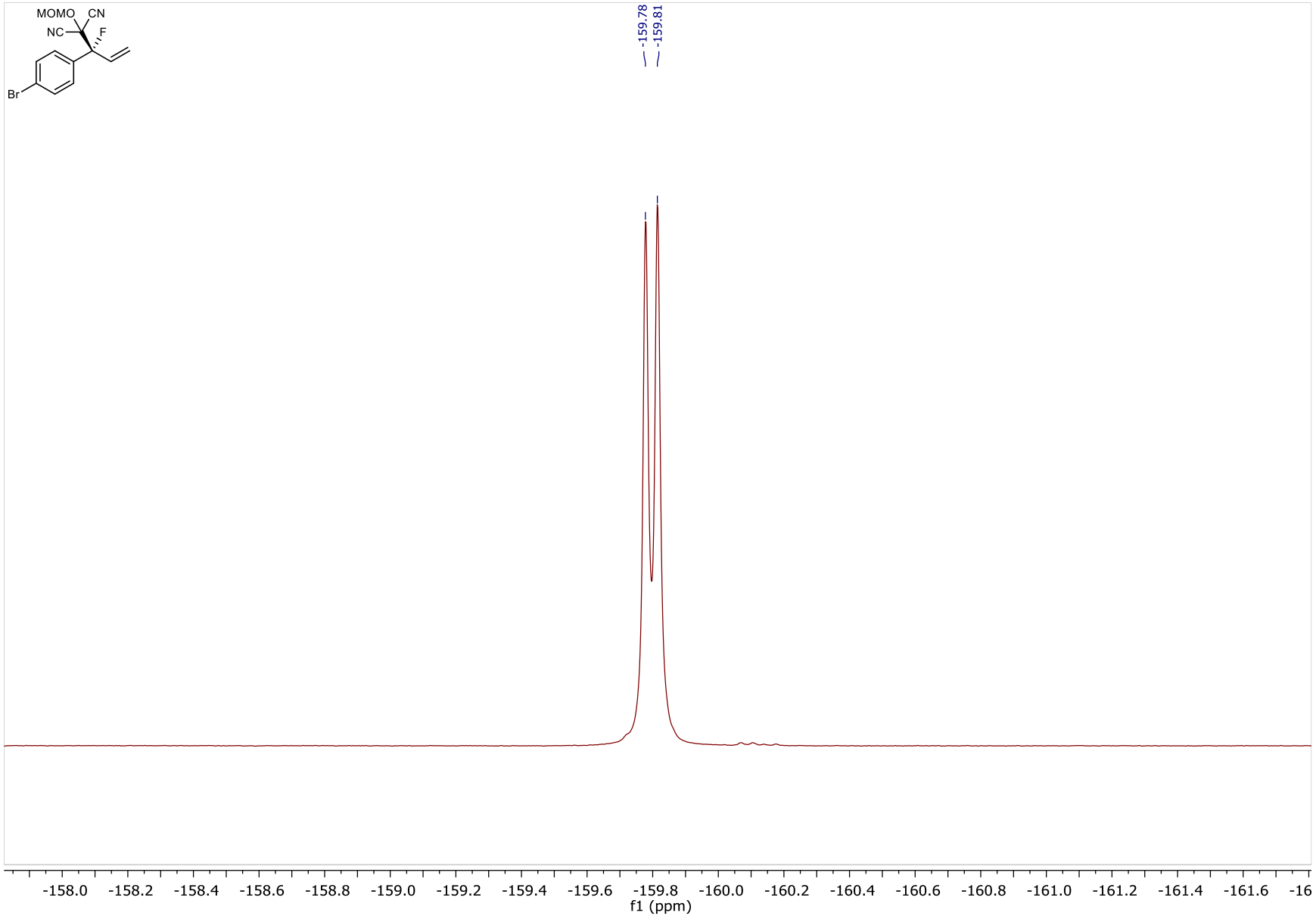

MOMO
CN
NC
F
t-Bu
7.50
7.49
7.46
7.44
6.51
6.49
6.48
6.48
6.47
6.46
6.45
6.43
5.82
5.79
5.65
5.65
5.63
5.63
5.05
5.03
5.03
5.02
3.44
1.33
2.03
2.01
1.00
1.01
1.02
2.03
2.92
9.06
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

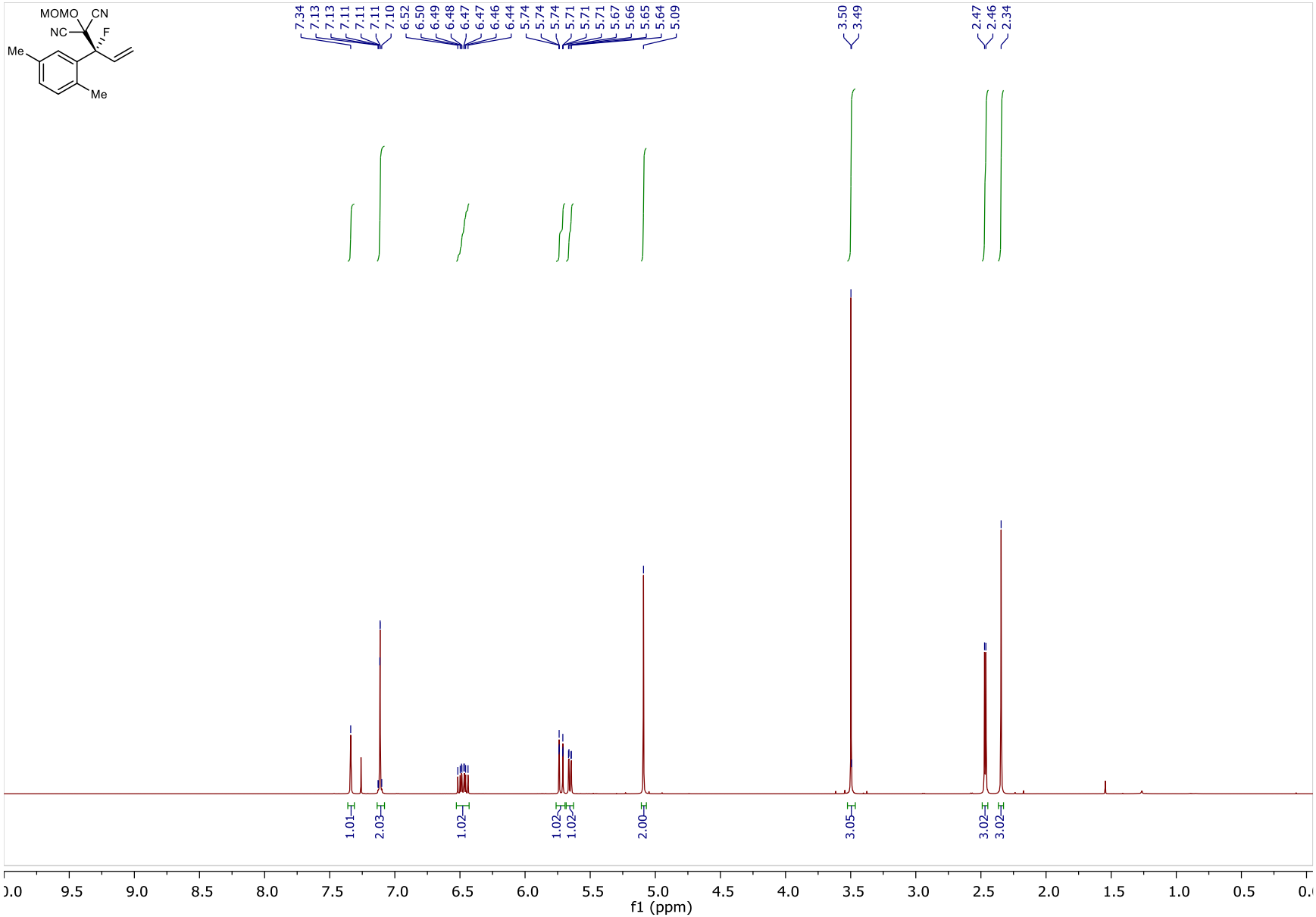

MOMO
CN
NC
F
t-Bu
153.22
131.06
131.02
130.92
130.91
126.38
126.32
125.51
125.50
121.03
120.95
111.58
111.11
97.10
96.88
95.80
72.90
72.66
57.59
34.86
31.33
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

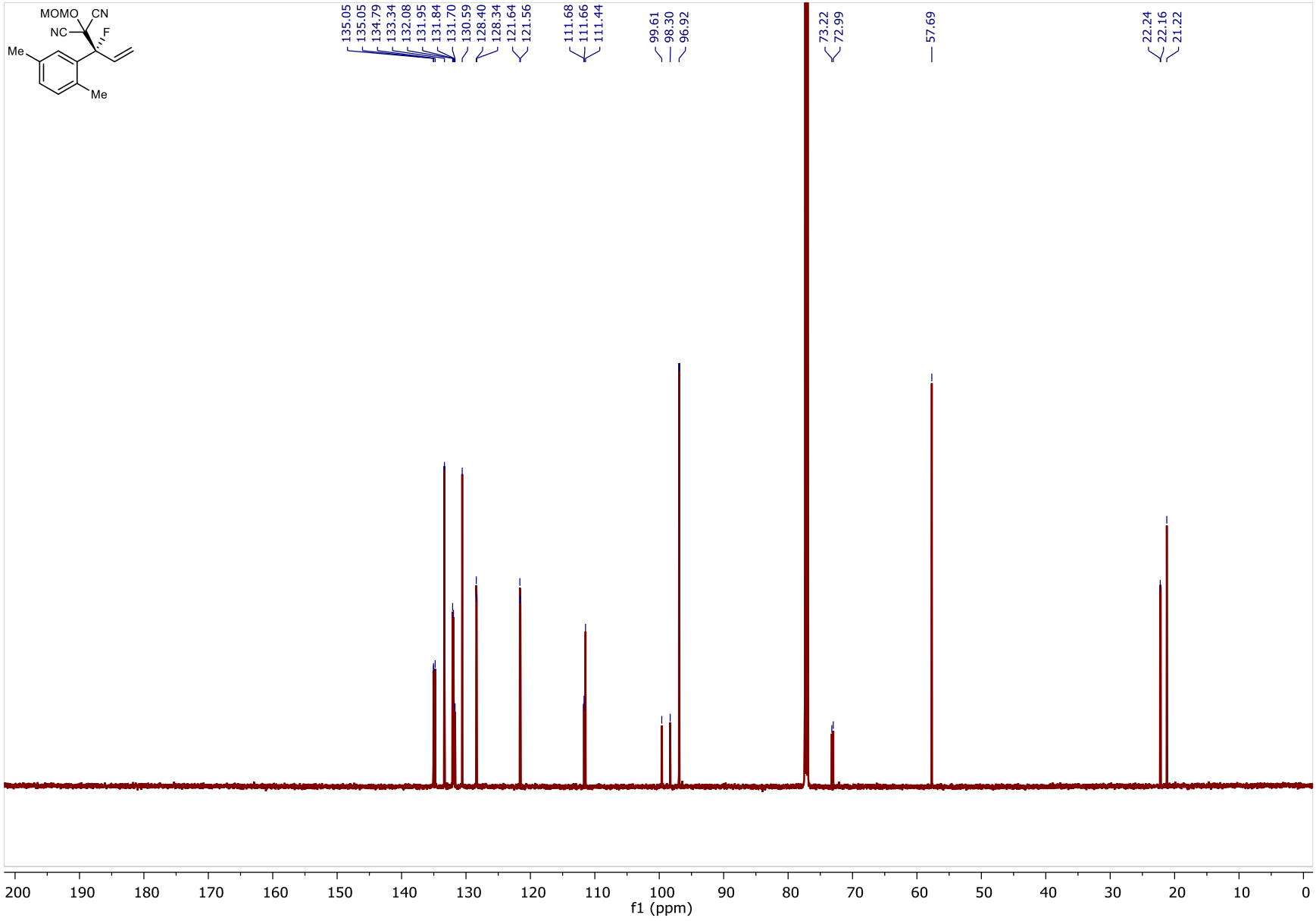

MOMO
CN
NC
F
t-Bu
-160.00
-160.03
-158.2
-158.4
-158.6
-158.8
-159.0
-159.2
-159.4
-159.6
-159.8
-160.0
-160.2
-160.4
-160.6
-160.8
-161.0
-161.2
-161.4
-161.6
f1 (ppm)

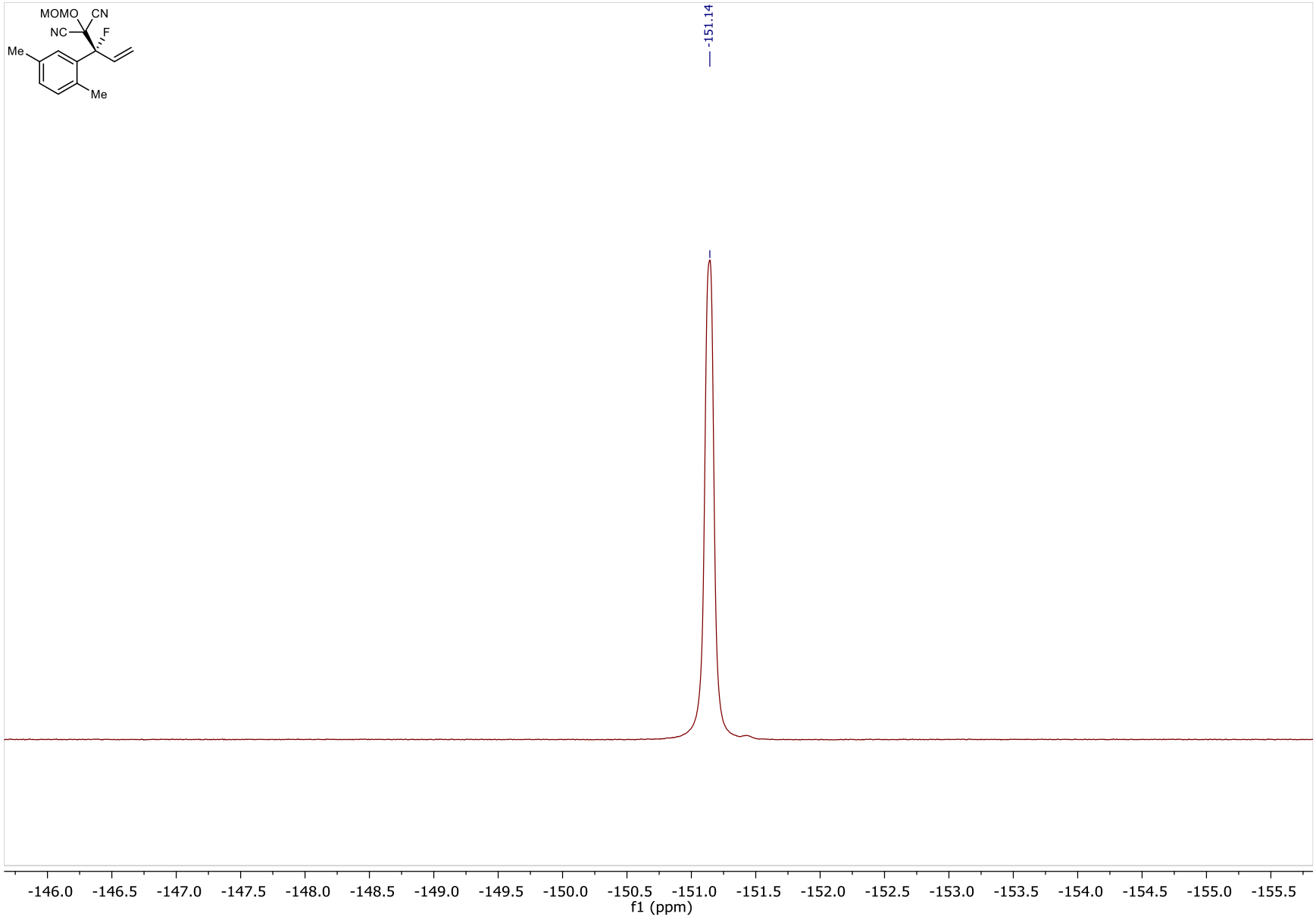

MOMO
CN
NC
F
Br
7.59
7.58
7.45
7.44
6.46
6.44
6.43
6.43
6.41
6.41
6.40
6.38
5.83
5.80
5.70
5.69
5.68
5.67
5.05
5.05
5.04
5.04
5.03
5.03
5.02
5.01
3.44
1.99
2.02
1.00
1.00
1.01
2.01
2.98
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

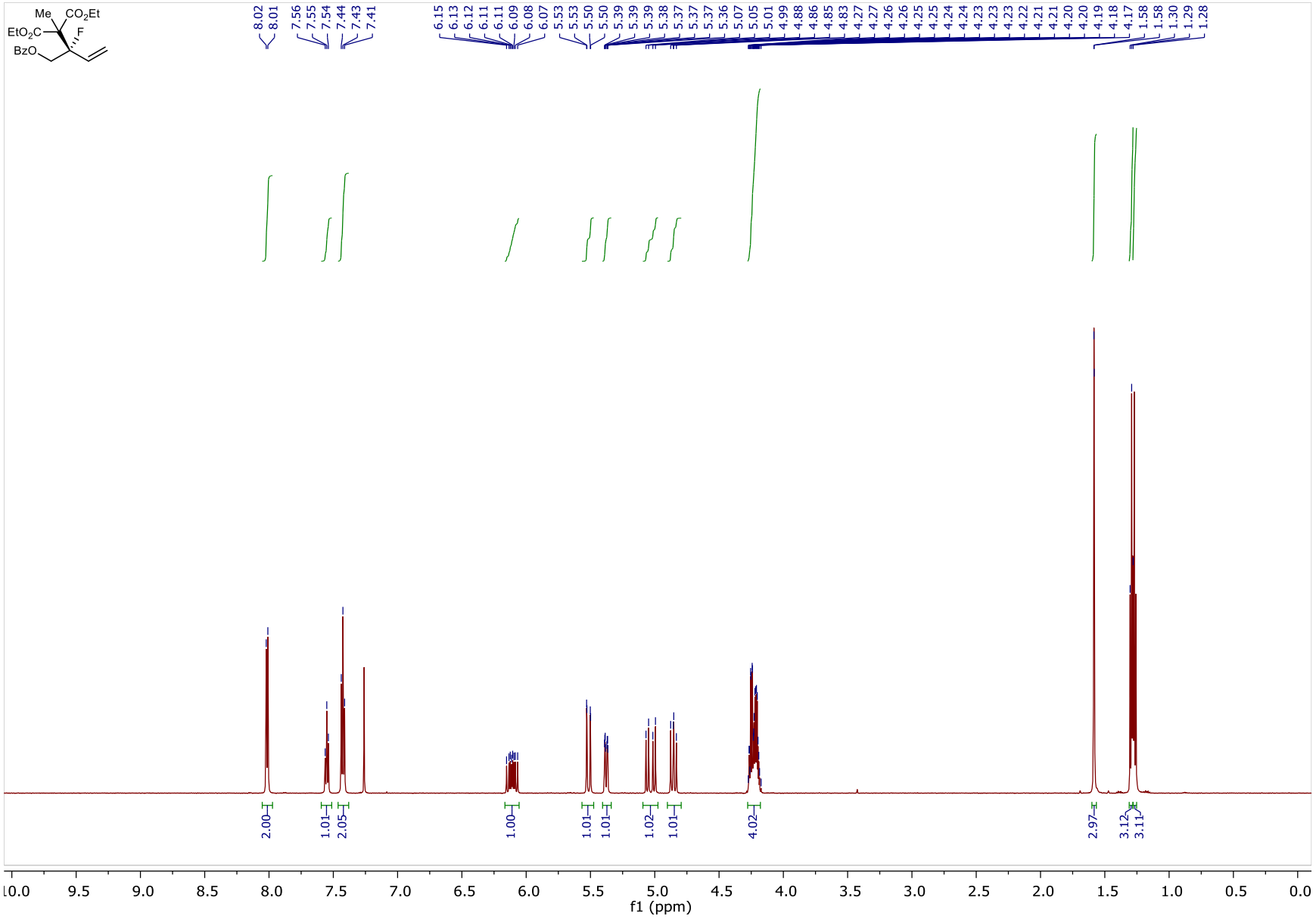

MOMO
CN
NC
F
Br
133.21
133.06
131.83
131.82
130.35
130.24
128.36
128.29
124.80
124.79
121.93
121.85
111.23
110.87
97.02
96.80
95.50
72.54
72.30
57.72
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

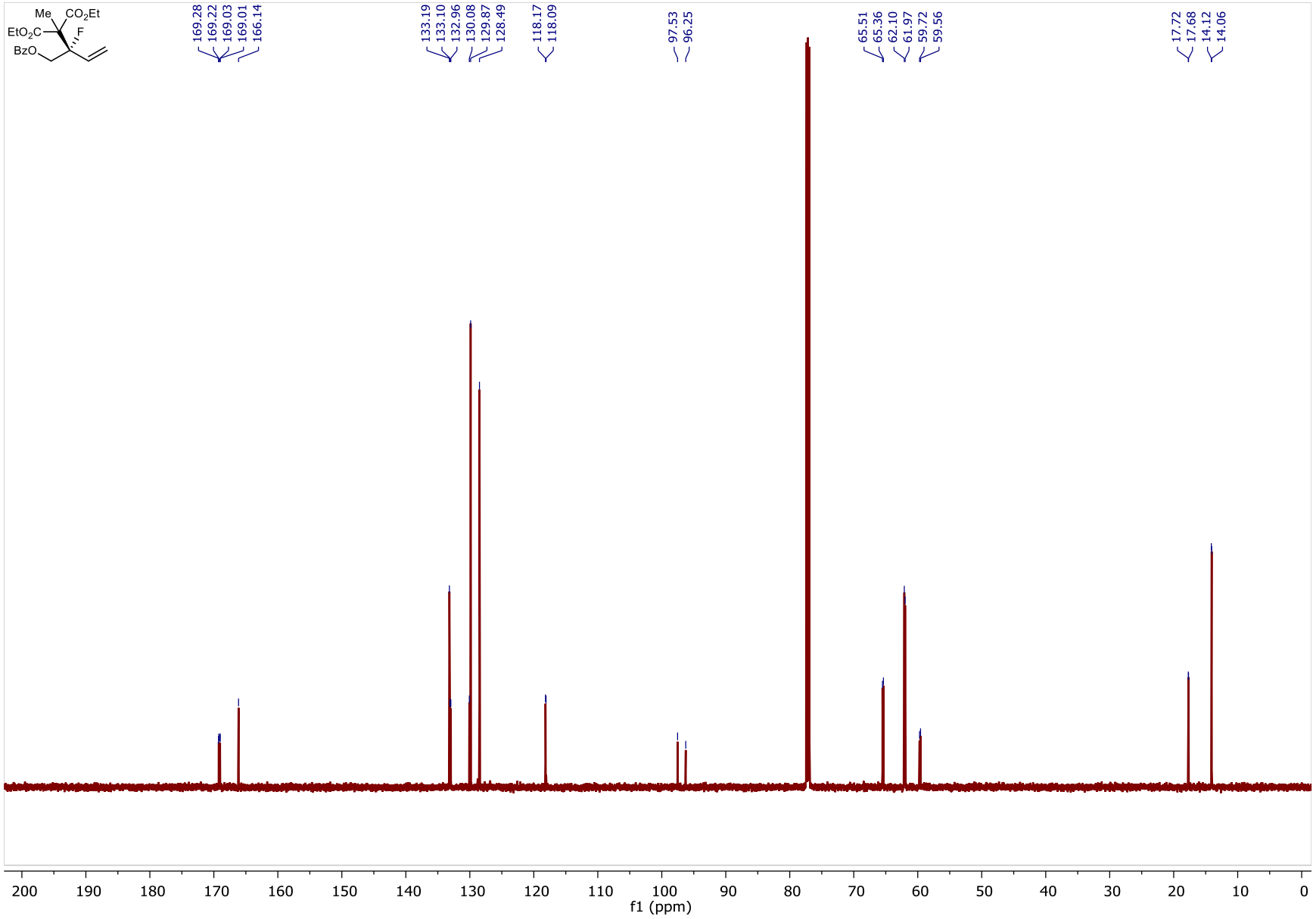

MOMO
CN
NC
F
Br
-159.78
-159.81
-158.0
-158.2
-158.4
-158.6
-158.8
-159.0
-159.2
-159.4
-159.6
-159.8
-160.0
-160.2
-160.4
-160.6
-160.8
-161.0
-161.2
-161.4
-161.6
-16
f1 (ppm)

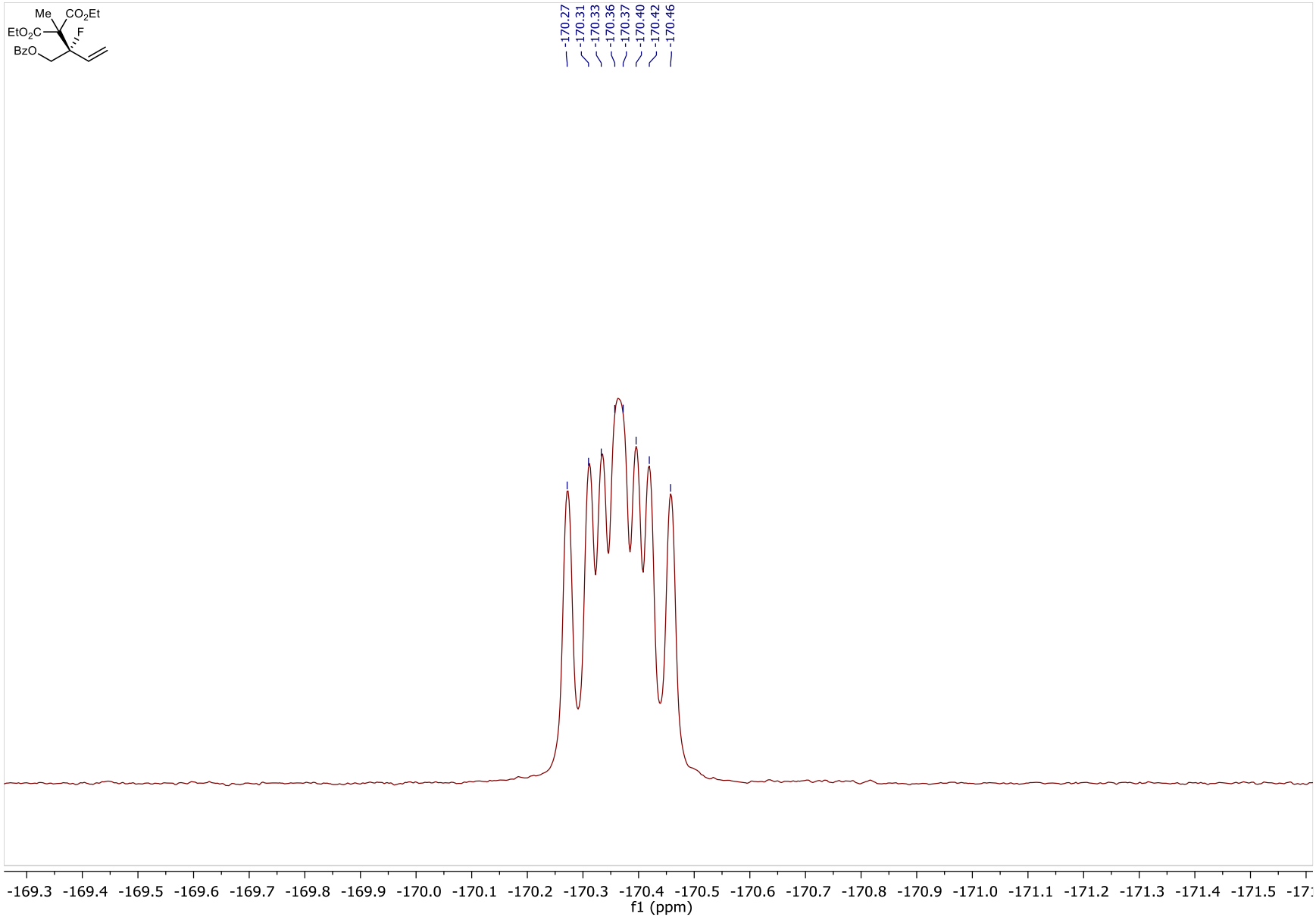

MOMO
CN
NC
F
Me
Me
7.34
7.13
7.13
7.11
7.11
7.11
7.10
6.52
6.50
6.49
6.48
6.47
6.47
6.46
6.44
5.74
5.74
5.74
5.71
5.71
5.71
5.67
5.66
5.65
5.64
5.09
3.50
3.49
2.47
2.46
2.34
1.01
2.03
1.02
1.02
1.02
2.00
3.05
3.02
3.02
f1 (ppm)

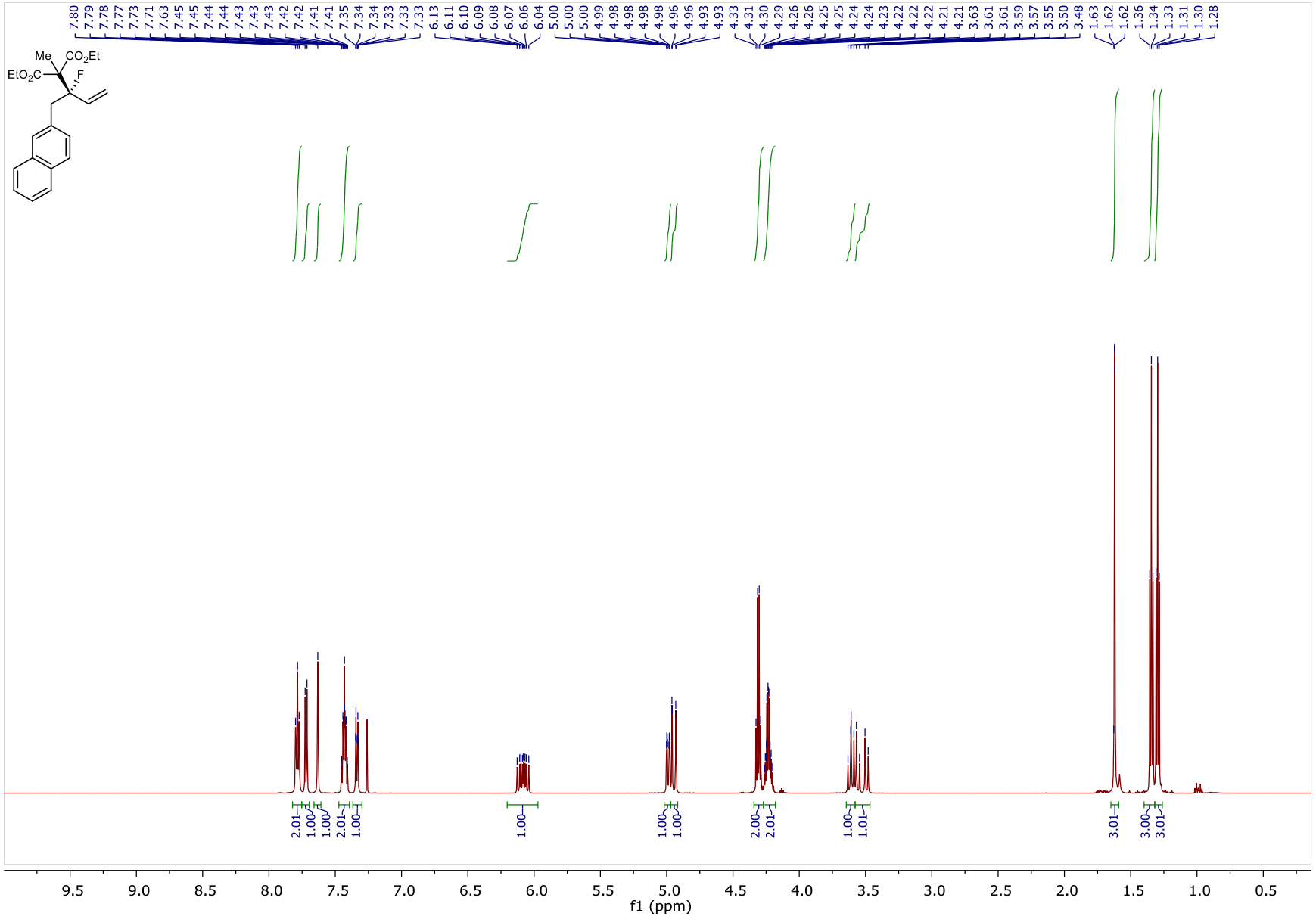

MOMO
CN
NC
F
Me
Me
135.05
135.05
134.79
133.34
132.08
131.95
131.84
131.70
130.59
128.40
128.34
121.64
121.56
111.68
111.66
111.44
99.61
98.30
96.92
73.22
72.99
57.69
22.24
22.16
21.22
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

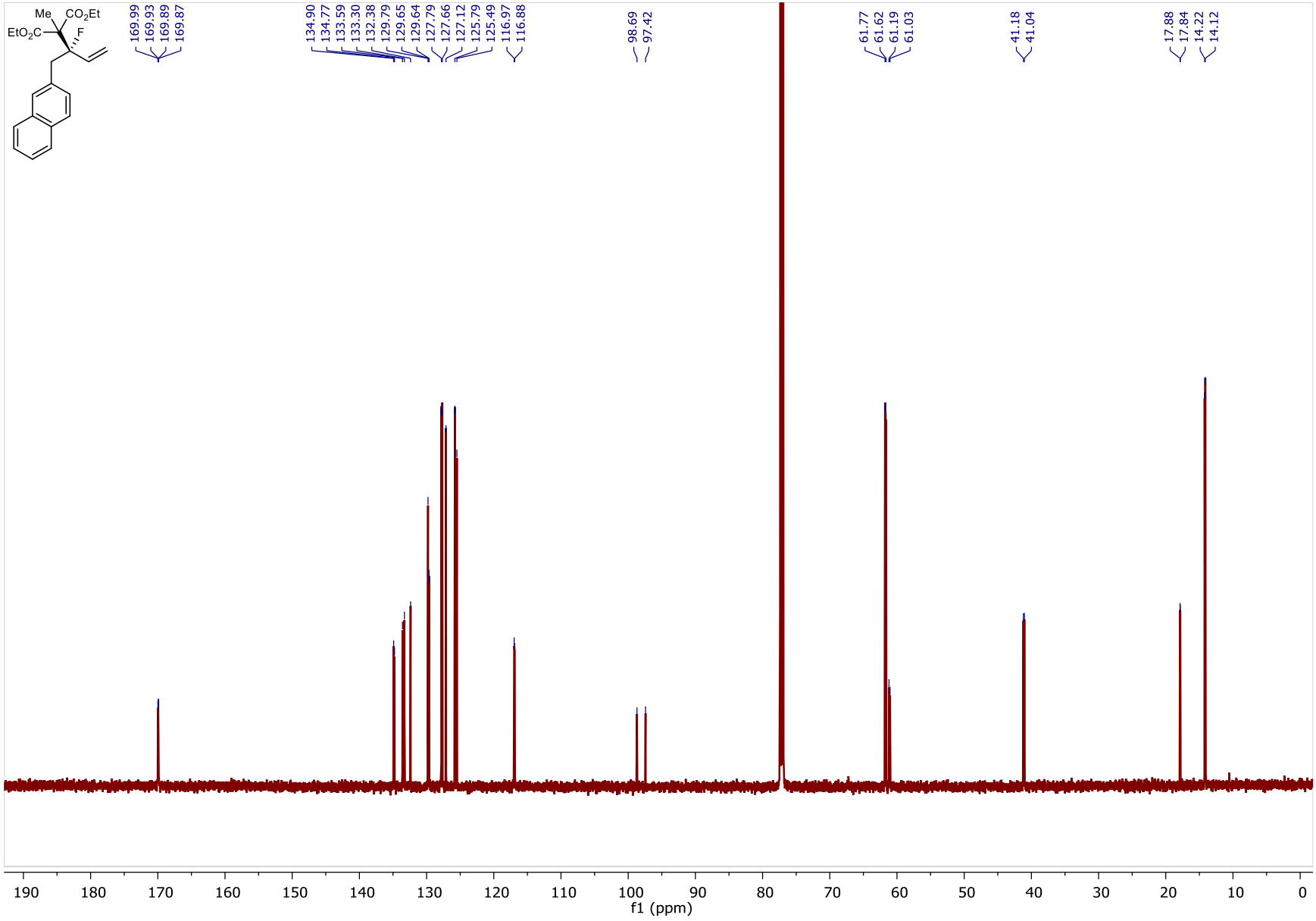

MOMO
CN
NC
F
Me
Me
-151.14
-146.0
-146.5
-147.0
-147.5
-148.0
-148.5
-149.0
-149.5
-150.0
-150.5
-151.0
-151.5
-152.0
-152.5
-153.0
-153.5
-154.0
-154.5
-155.0
-155.5
f1 (ppm)

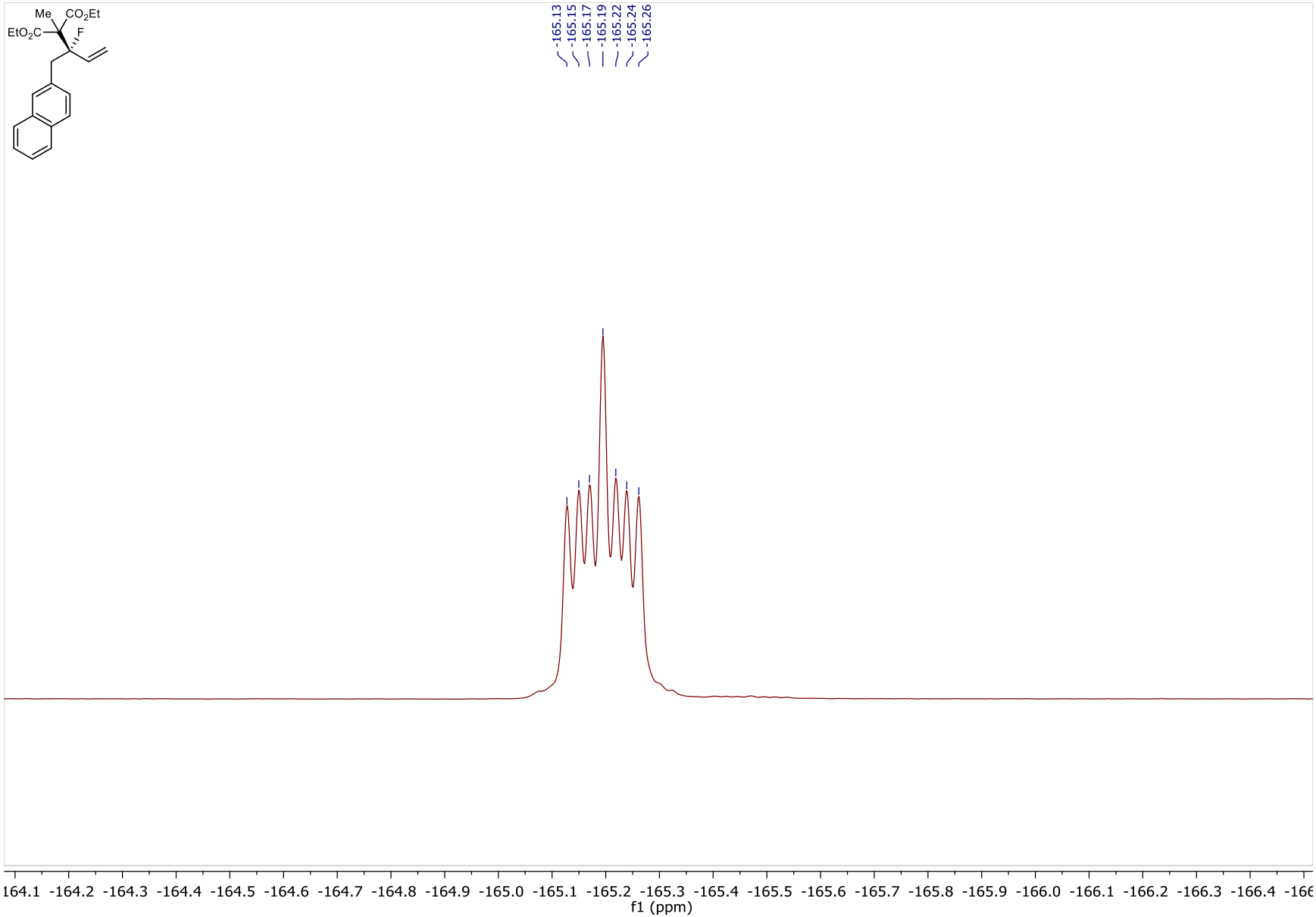

Me
CO2Et
EtO2C
F
BzO
8.02
8.01
7.56
7.55
7.54
7.44
7.43
7.41
6.15
6.13
6.12
6.11
6.11
6.09
6.08
6.07
5.53
5.53
5.50
5.50
5.39
5.39
5.39
5.38
5.37
5.37
5.37
5.36
5.07
5.05
5.01
4.99
4.88
4.86
4.85
4.83
4.27
4.27
4.26
4.26
4.25
4.25
4.24
4.24
4.23
4.23
4.23
4.22
4.21
4.21
4.20
4.20
4.19
4.18
4.17
1.58
1.58
1.30
1.29
1.28
2.00
1.01
2.05
1.00
1.01
1.01
1.02
1.01
4.02
2.97
3.12
3.11
10.0
9.5
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
0.0
f1 (ppm)

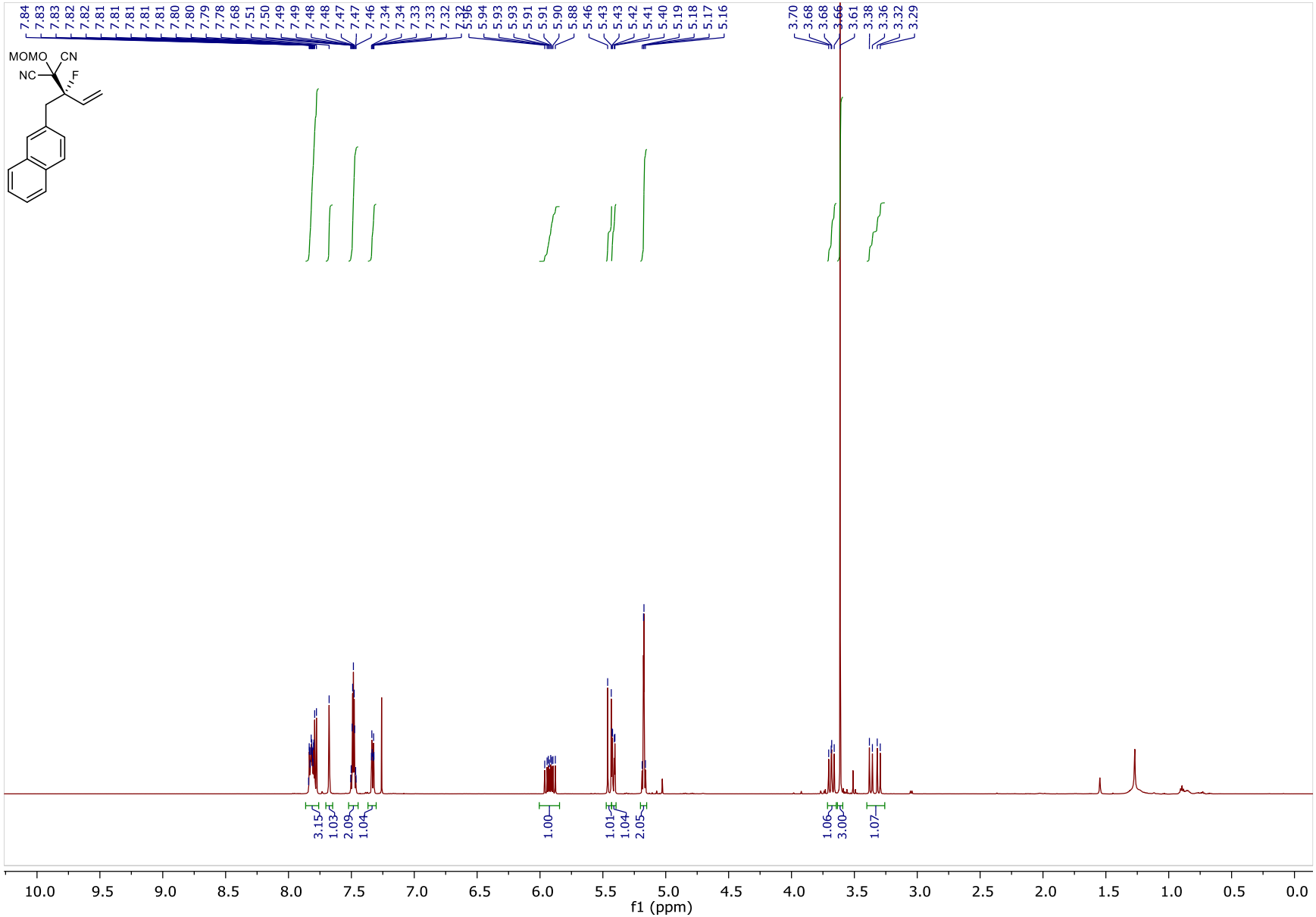

Me
CO2Et
EtO2C
F
BzO
169.28
169.22
169.03
169.01
166.14
133.19
133.10
132.96
130.08
129.87
128.49
118.17
118.09
97.53
96.25
65.51
65.36
62.10
61.97
59.72
59.56
17.72
17.68
14.12
14.06
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

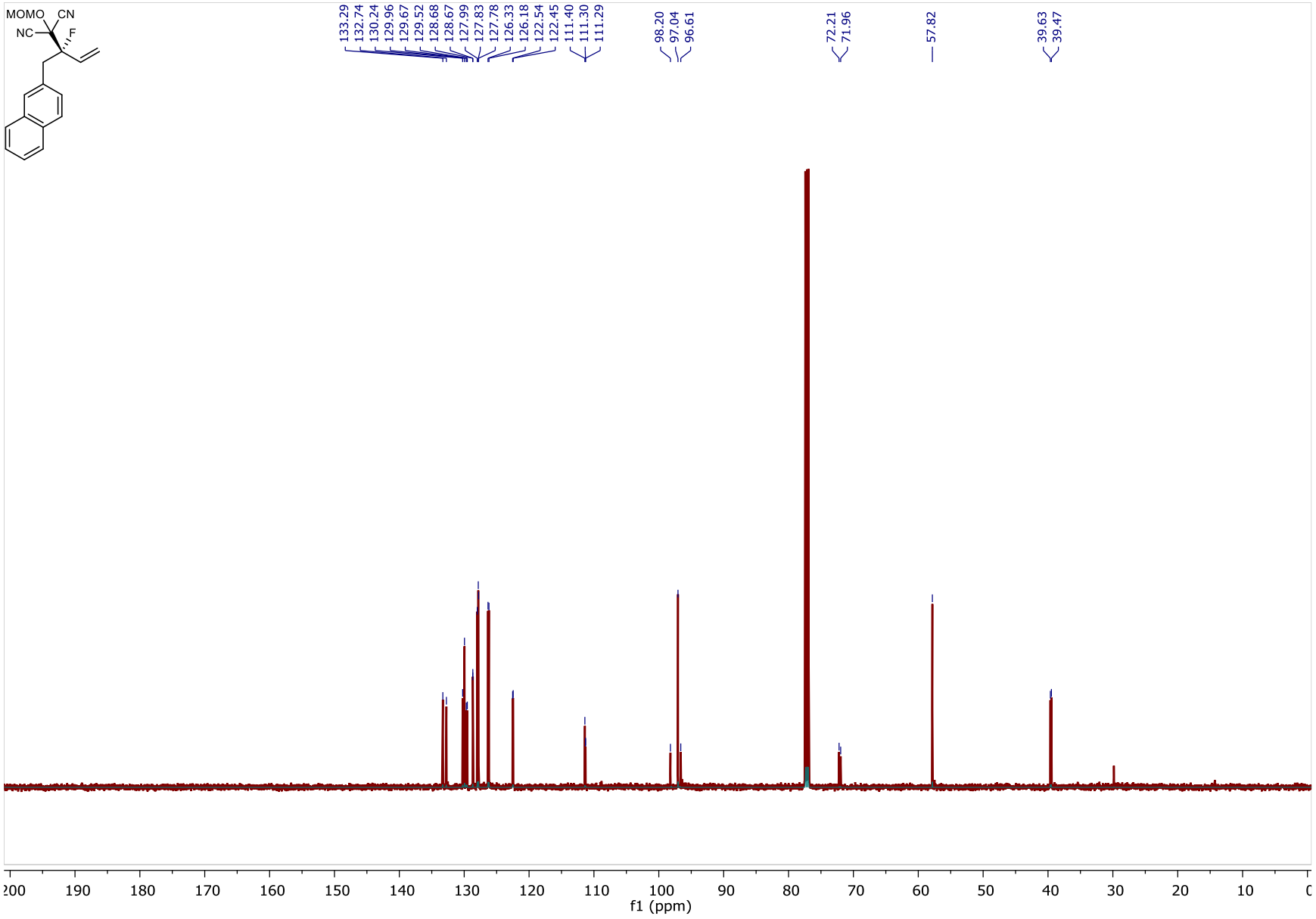

Me
CO2Et
EtO2C
F
BzO
-170.27
-170.31
-170.33
-170.36
-170.37
-170.40
-170.42
-170.46
-169.3 -169.4 -169.5 -169.6 -169.7 -169.8 -169.9 -170.0 -170.1 -170.2 -170.3 -170.4 -170.5 -170.6 -170.7 -170.8 -170.9 -171.0 -171.1 -171.2 -171.3 -171.4 -171.5
f1 (ppm)

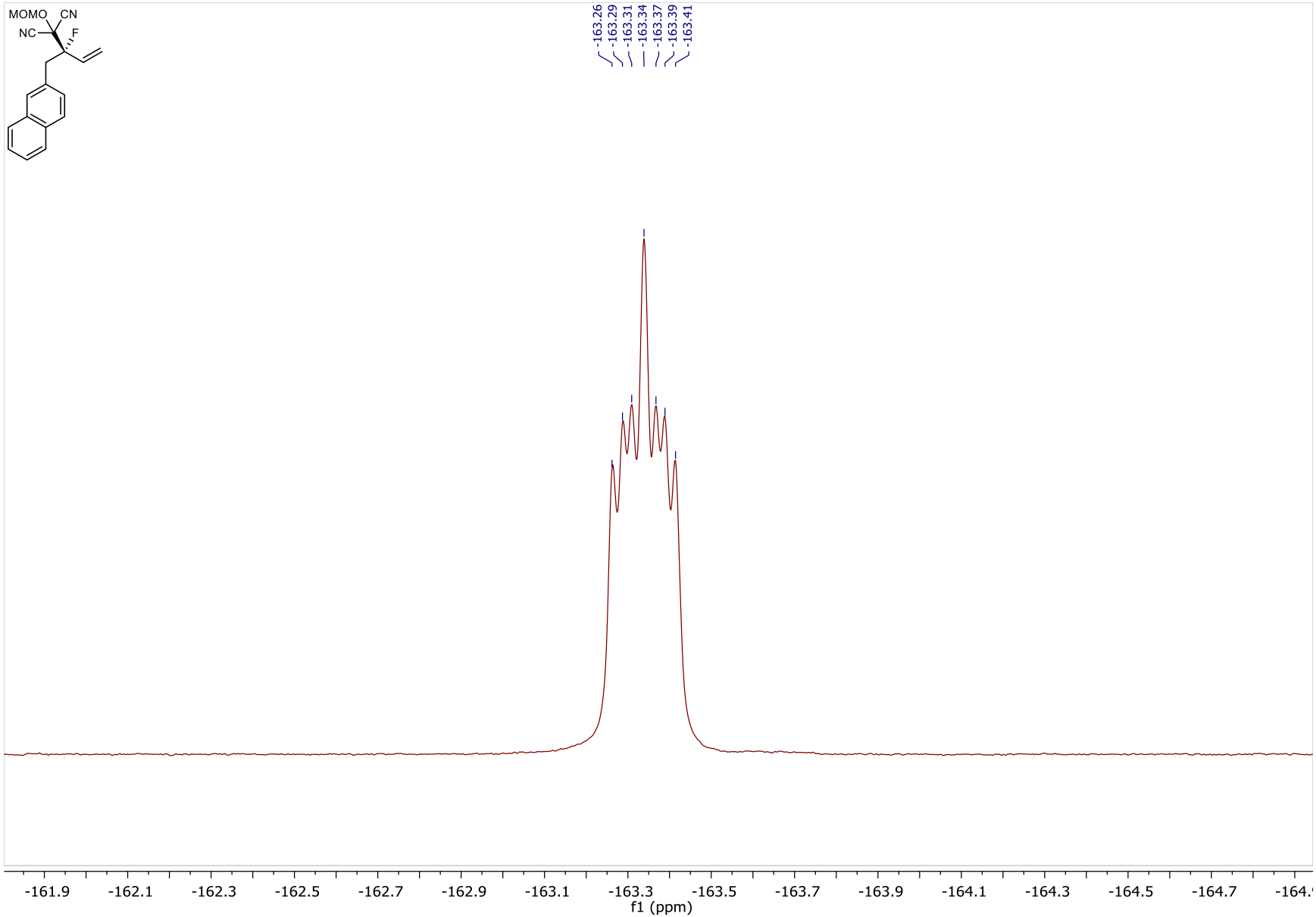

Me
CO2Et
EtO2C
F
7.80 7.79 7.78 7.77 7.73 7.71 7.63 7.45 7.45 7.44 7.44 7.43 7.43 7.43 7.42 7.42 7.41 7.41 7.35 7.34 7.34 7.33 7.33 7.33 6.13 6.11 6.10 6.09 6.08 6.07 6.06 6.04 5.00 5.00 5.00 4.99 4.98 4.98 4.98 4.98 4.96 4.96 4.93 4.93 4.33 4.31 4.30 4.29 4.26 4.26 4.25 4.25 4.24 4.24 4.23 4.22 4.22 4.22 4.21 4.21 3.63 3.61 3.61 3.59 3.57 3.55 3.50 3.48 1.63 1.62 1.62 1.36 1.34 1.33 1.31 1.30 1.28
2.01 1.00 1.00 2.01 1.00 1.00 1.00 1.00 2.00 2.01 1.00 1.01 3.01 3.00 3.01
9.5 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
f1 (ppm)


Me
CO2Et
EtO2C
F
169.99
169.93
169.89
169.87
134.90
134.77
133.59
133.30
132.38
129.79
129.65
129.64
127.79
127.66
127.12
125.79
125.49
116.97
116.88
98.69
97.42
61.77
61.62
61.19
61.03
41.18
41.04
17.88
17.84
14.22
14.12
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


Me
CO2Et
EtO2C
F
-165.13
-165.15
-165.17
-165.19
-165.22
-165.24
-165.26
164.1 -164.2 -164.3 -164.4 -164.5 -164.6 -164.7 -164.8 -164.9 -165.0 -165.1 -165.2 -165.3 -165.4 -165.5 -165.6 -165.7 -165.8 -165.9 -166.0 -166.1 -166.2 -166.3 -166.4 -166
f1 (ppm)


MOMO
CN
NC
F
7.84 7.83 7.83 7.82 7.82 7.81 7.81 7.81 7.81 7.81 7.80 7.80 7.79 7.78 7.68 7.51 7.50 7.49 7.49 7.48 7.48 7.47 7.47 7.46 7.34 7.34 7.33 7.33 7.32 5.96 5.94 5.93 5.93 5.91 5.91 5.90 5.88 5.46 5.43 5.43 5.42 5.41 5.40 5.19 5.18 5.17 5.16
3.70 3.68 3.68 3.66 3.61 3.38 3.36 3.32 3.29
3.15 1.03 2.09 1.04 1.00 1.01 1.04 2.05 1.06 3.00 1.07
10.0 9.5 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 0.0
f1 (ppm)


MOMO
CN
NC
F
133.29
132.74
130.24
129.96
129.67
129.52
128.68
128.67
127.99
127.83
127.78
126.33
126.18
122.54
122.45
111.40
111.30
111.29
98.20
97.04
96.61
72.21
71.96
57.82
39.63
39.47
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


MOMO
CN
NC
F
-163.26
-163.29
-163.31
-163.34
-163.37
-163.39
-163.41
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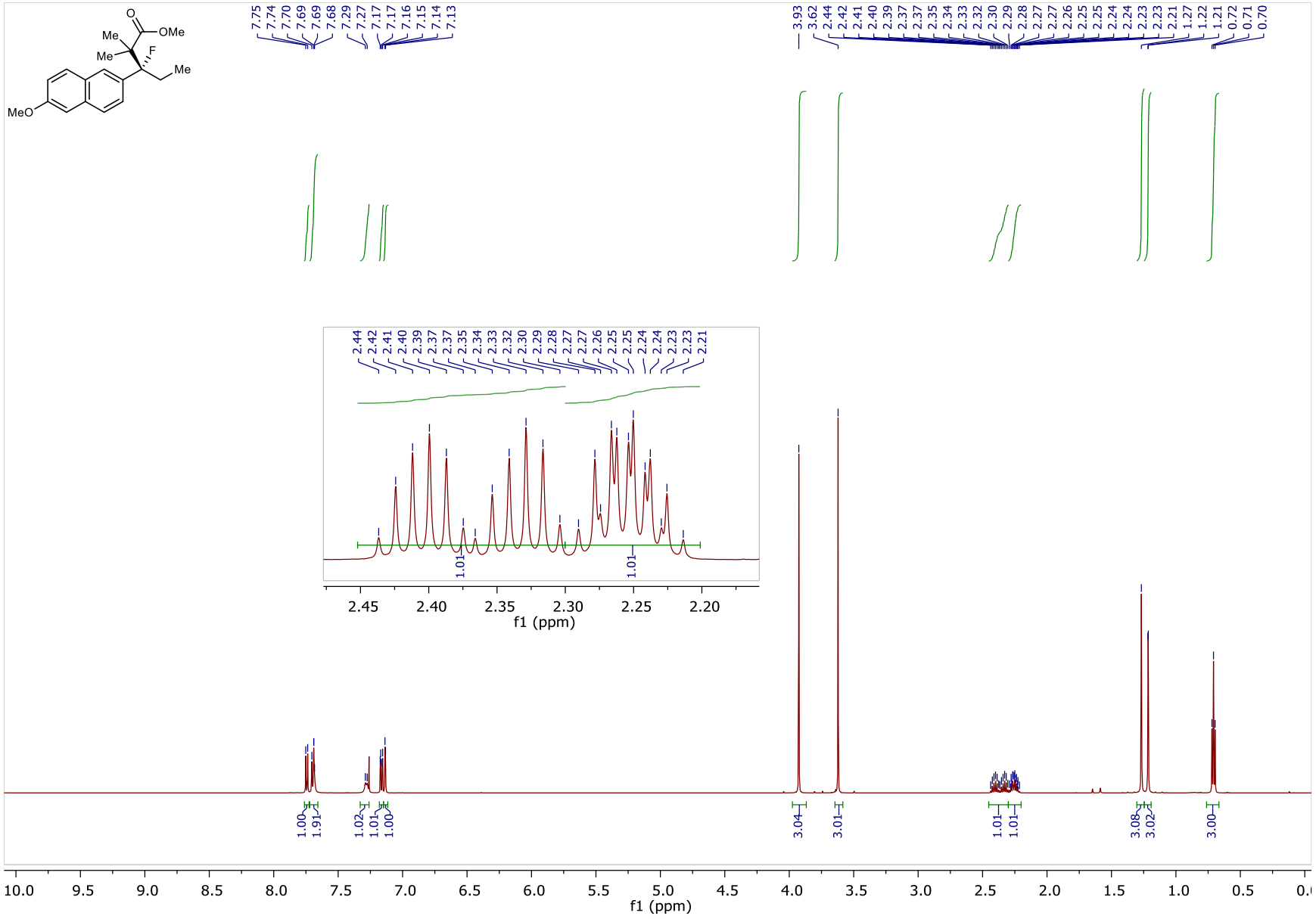
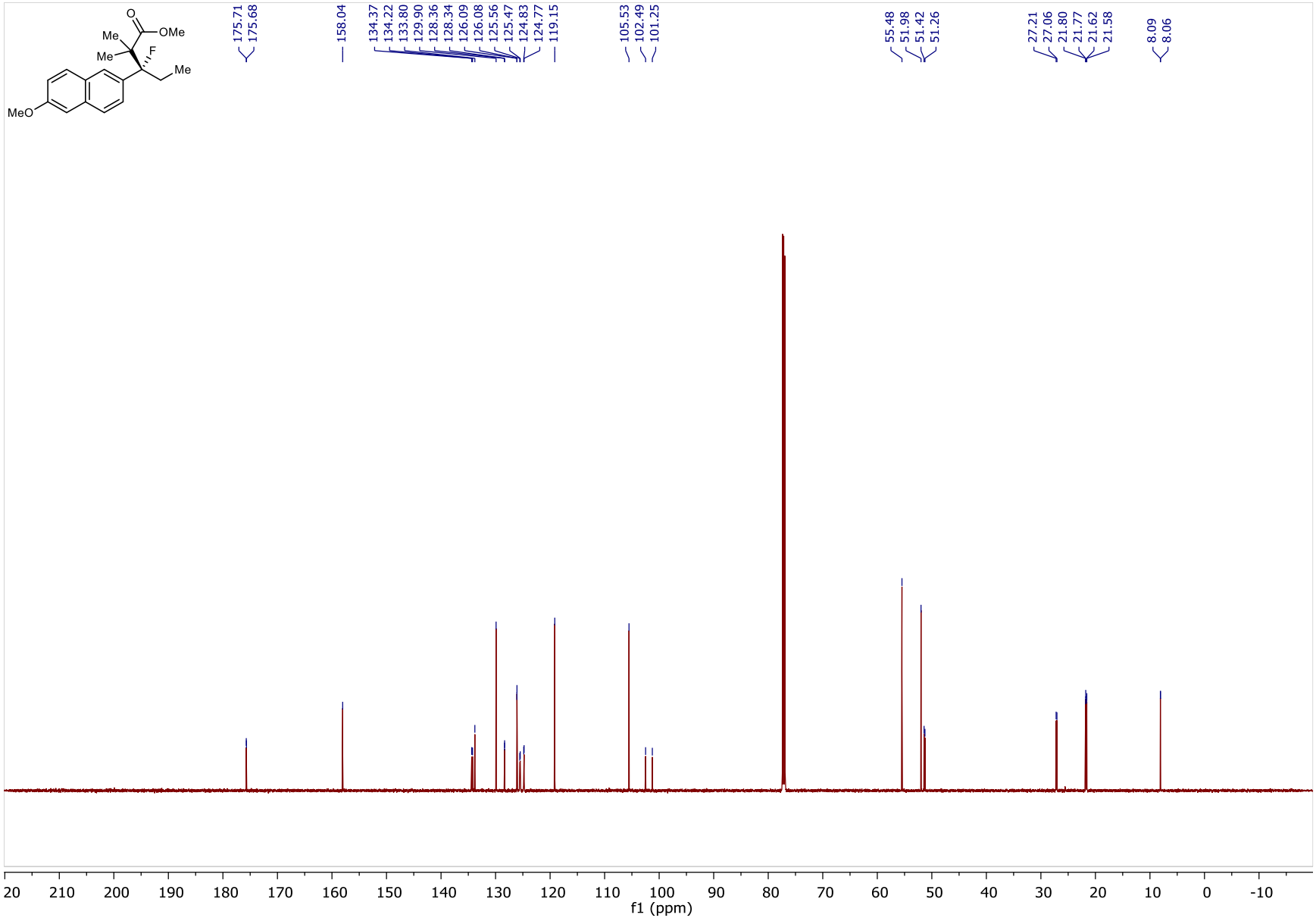
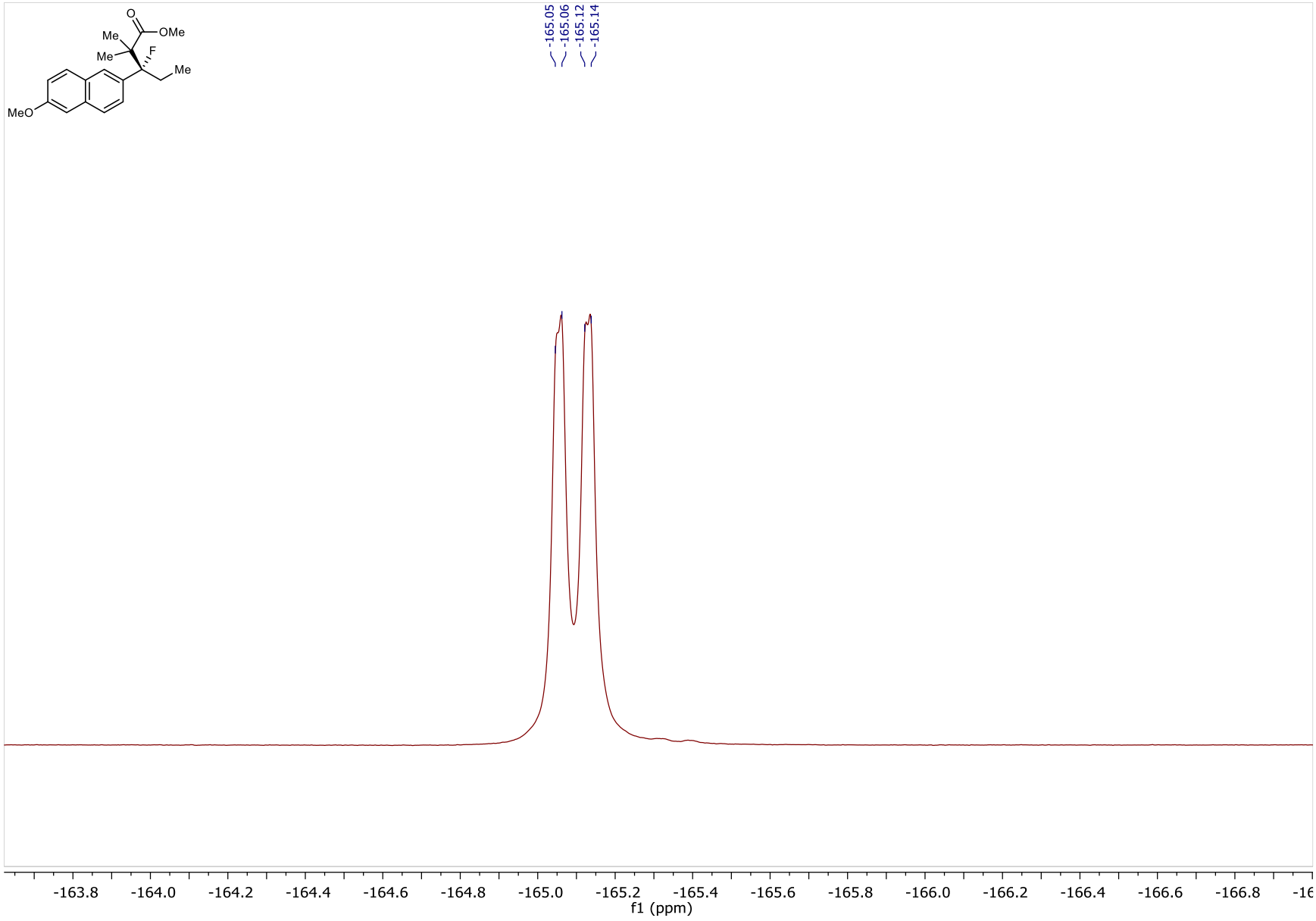
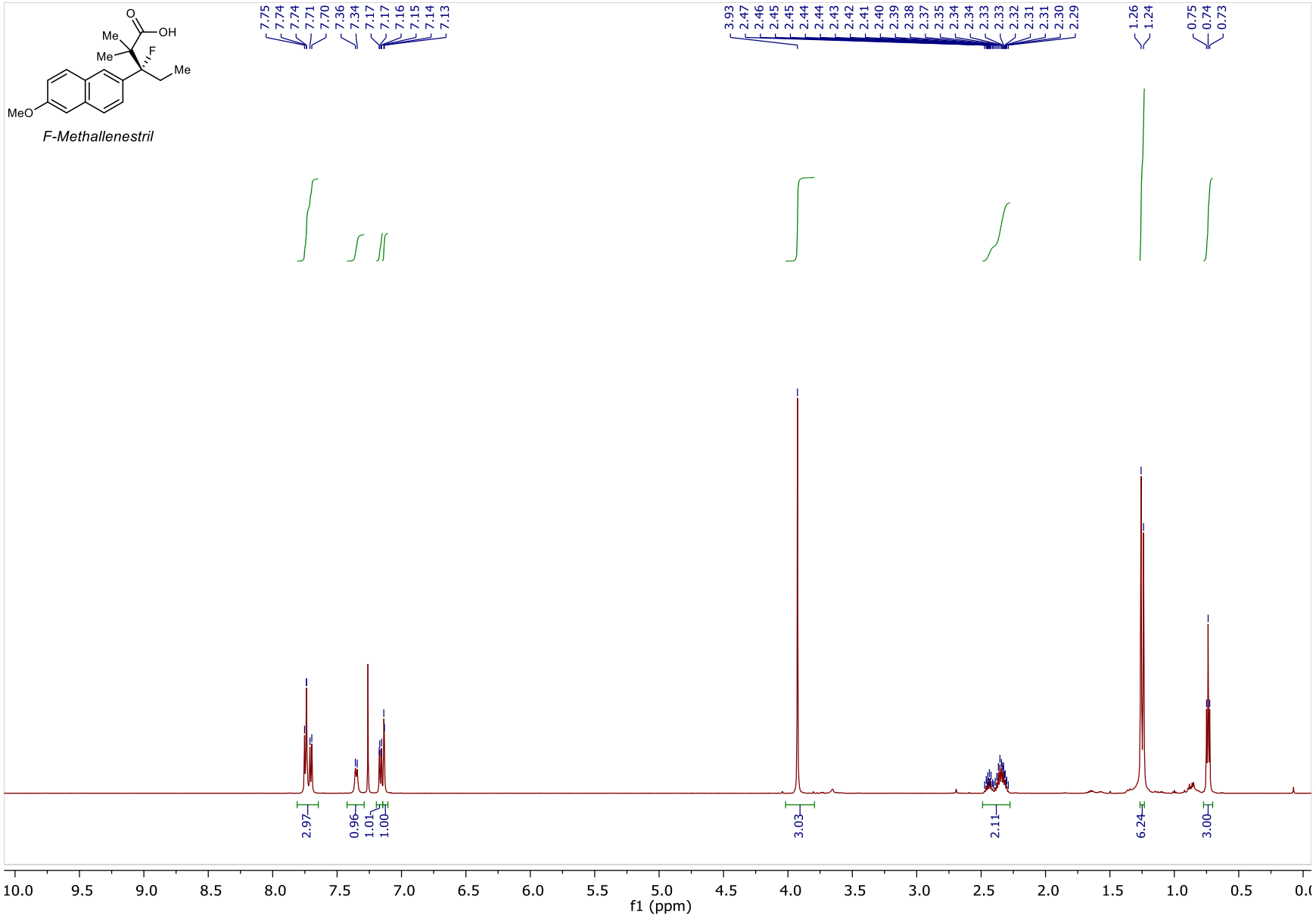
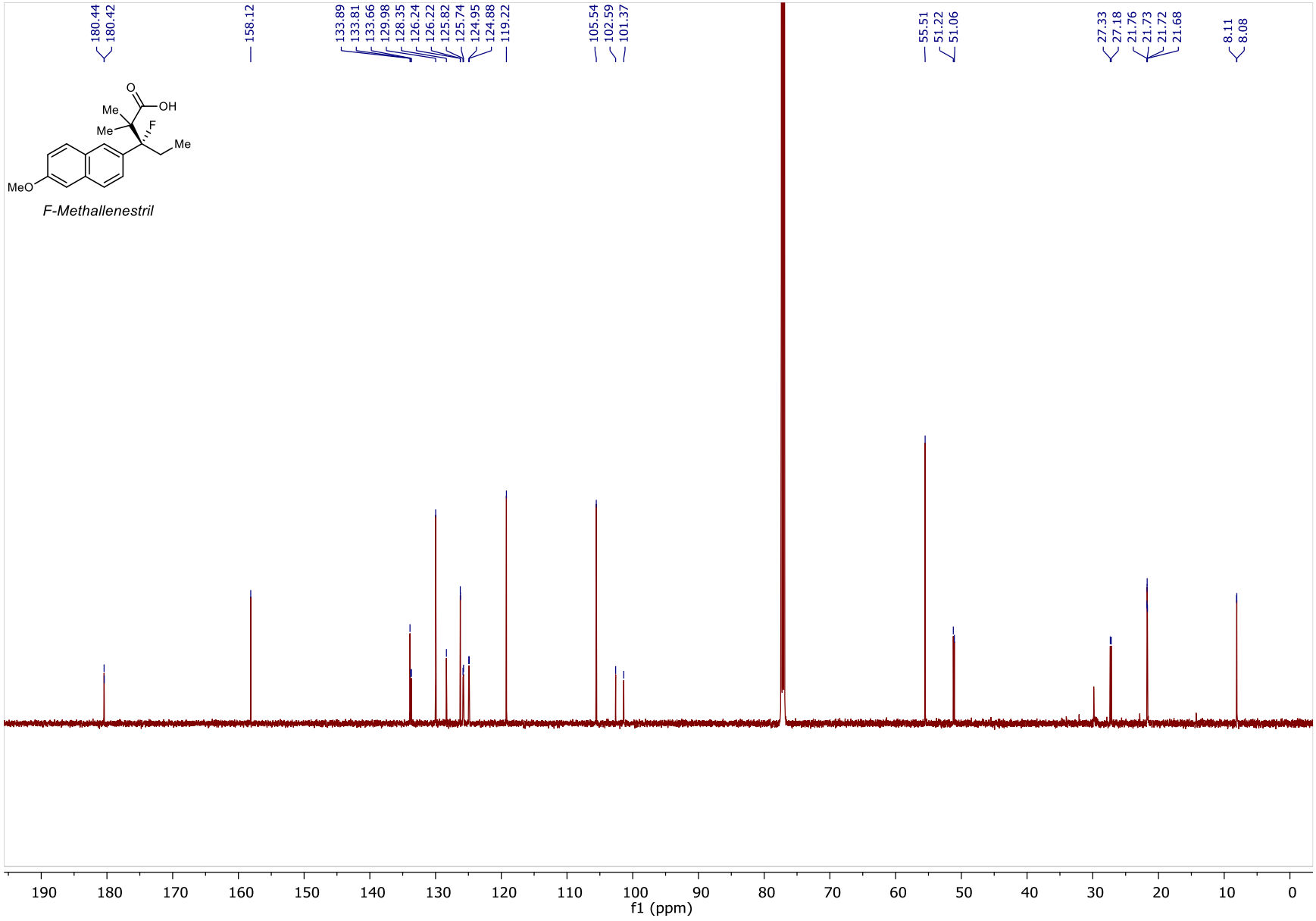
-162.1
-162.3
-162.5
-162.7
-162.9
-163.1
-163.3
-163.5
-163.7
-163.9
-164.1
-164.3
-164.5
-164.7
f1 (ppm)

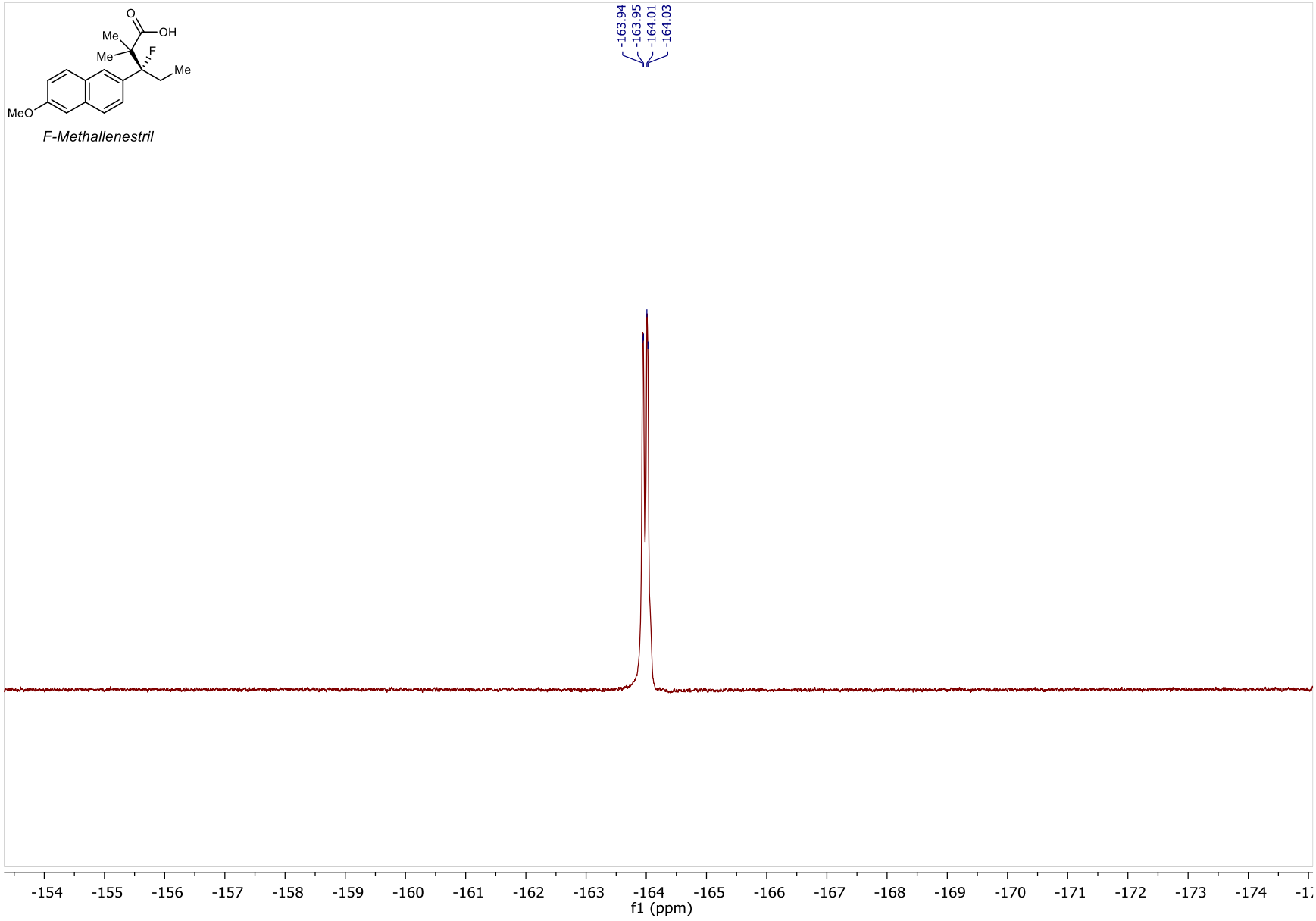

O
OMe
Me
Me
F
Me
MeO
7.75 7.74 7.70 7.69 7.69 7.68 7.29 7.27 7.17 7.17 7.16 7.15 7.14 7.13
3.93 3.62 2.44 2.42 2.41 2.40 2.39 2.37 2.35 2.34 2.33 2.32 2.30 2.29 2.28 2.27 2.27 2.26 2.25 2.25 2.24 2.24 2.23 2.23 2.21 1.27 1.22 1.21 0.72 0.71 0.70
2.44 2.42 2.41 2.40 2.39 2.37 2.37 2.35 2.34 2.33 2.32 2.30 2.29 2.28 2.27 2.27 2.26 2.25 2.25 2.24 2.24 2.23 2.23 2.21
1.01
1.01
2.45 2.40 2.35 2.30 2.25 2.20
f1 (ppm)
1.00 1.91 1.02 1.01 1.00 3.04 3.01 1.01 1.01 3.08 3.02 3.00
10.0 9.5 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
f1 (ppm)

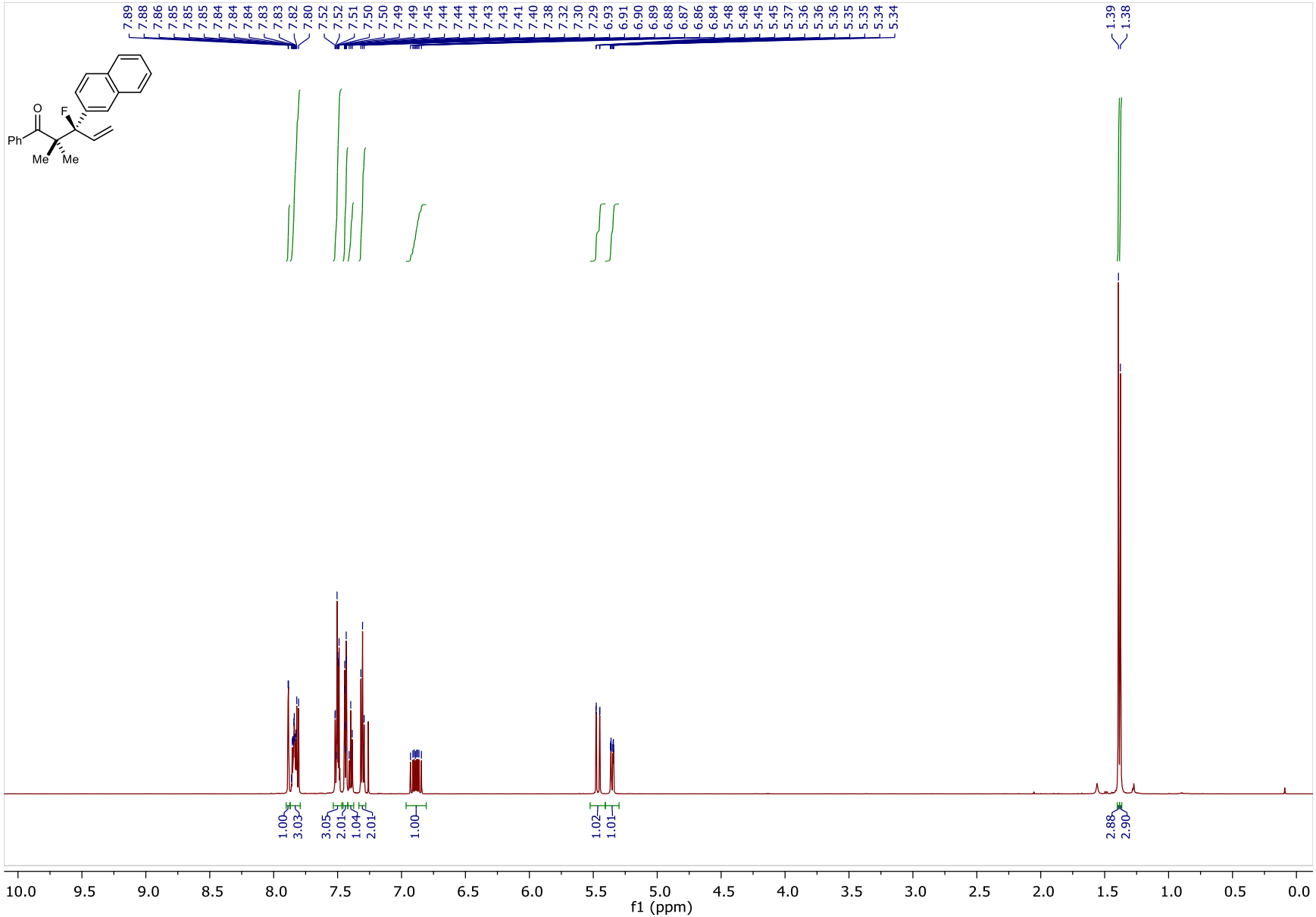

O
OMe
Me
Me
F
Me
MeO
175.71
175.68
158.04
134.37
134.22
133.80
129.90
128.36
128.34
126.09
126.08
125.56
125.47
124.83
124.77
119.15
105.53
102.49
101.25
55.48
51.98
51.42
51.26
27.21
27.06
21.80
21.77
21.62
21.58
8.09
8.06
20
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

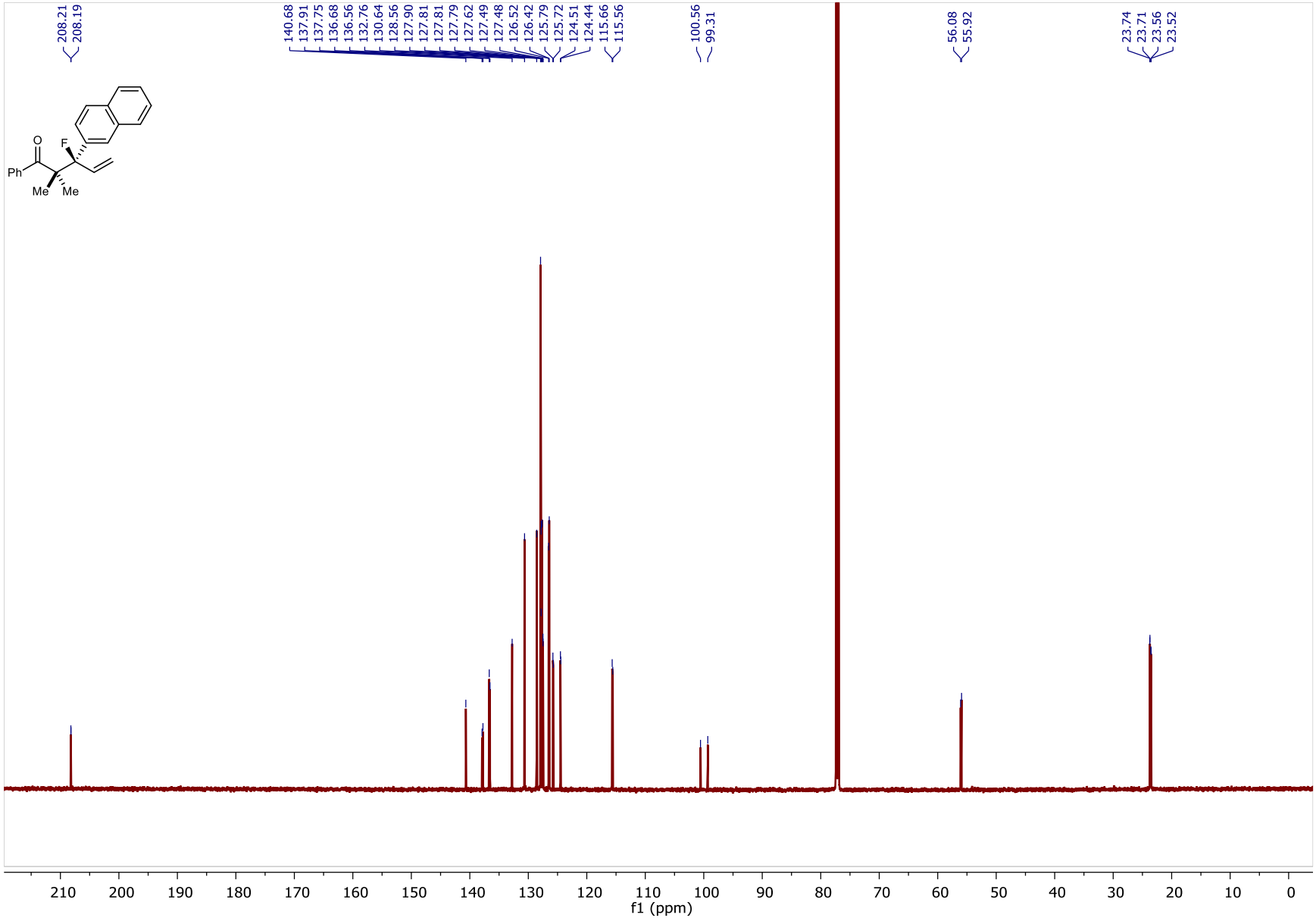

-165.05
-165.06
-165.12
-165.14
O
OMe
Me
Me
F
Me
MeO
-163.8
-164.0
-164.2
-164.4
-164.6
-164.8
-165.0
-165.2
-165.4
-165.6
-165.8
-166.0
-166.2
-166.4
-166.6
-166.8
f1 (ppm)

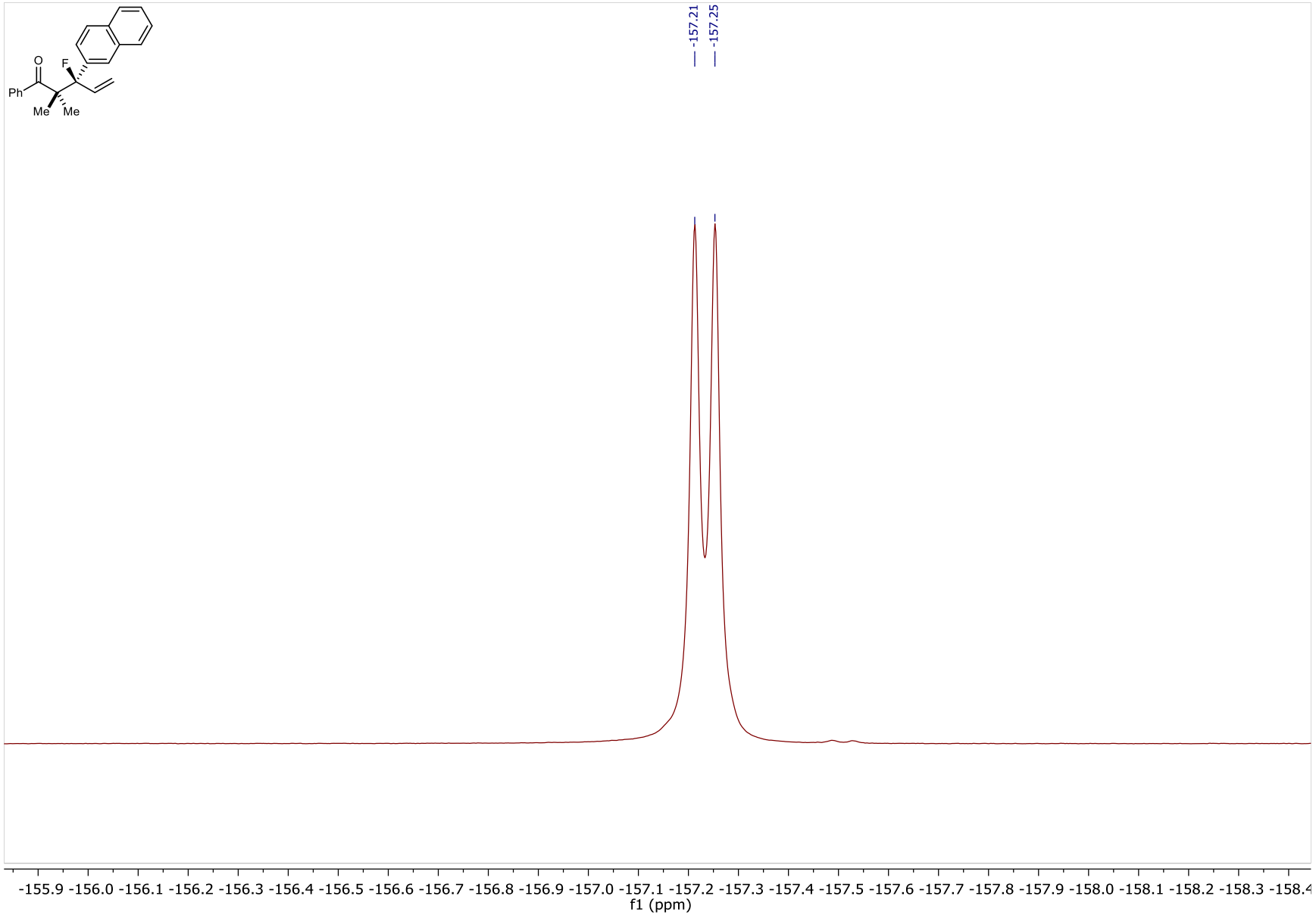

F-Methallenestril
7.75 7.74 7.74 7.71 7.70 7.36 7.34 7.17 7.17 7.16 7.15 7.14 7.13
3.93 2.47 2.46 2.45 2.45 2.44 2.44 2.43 2.42 2.41 2.40 2.39 2.38 2.37 2.35 2.34 2.34 2.33 2.32 2.31 2.31 2.30 2.29
1.26 1.24
0.75 0.74 0.73
2.97 0.96 1.01 1.00 3.03 2.11 6.24 3.00
f1 (ppm)

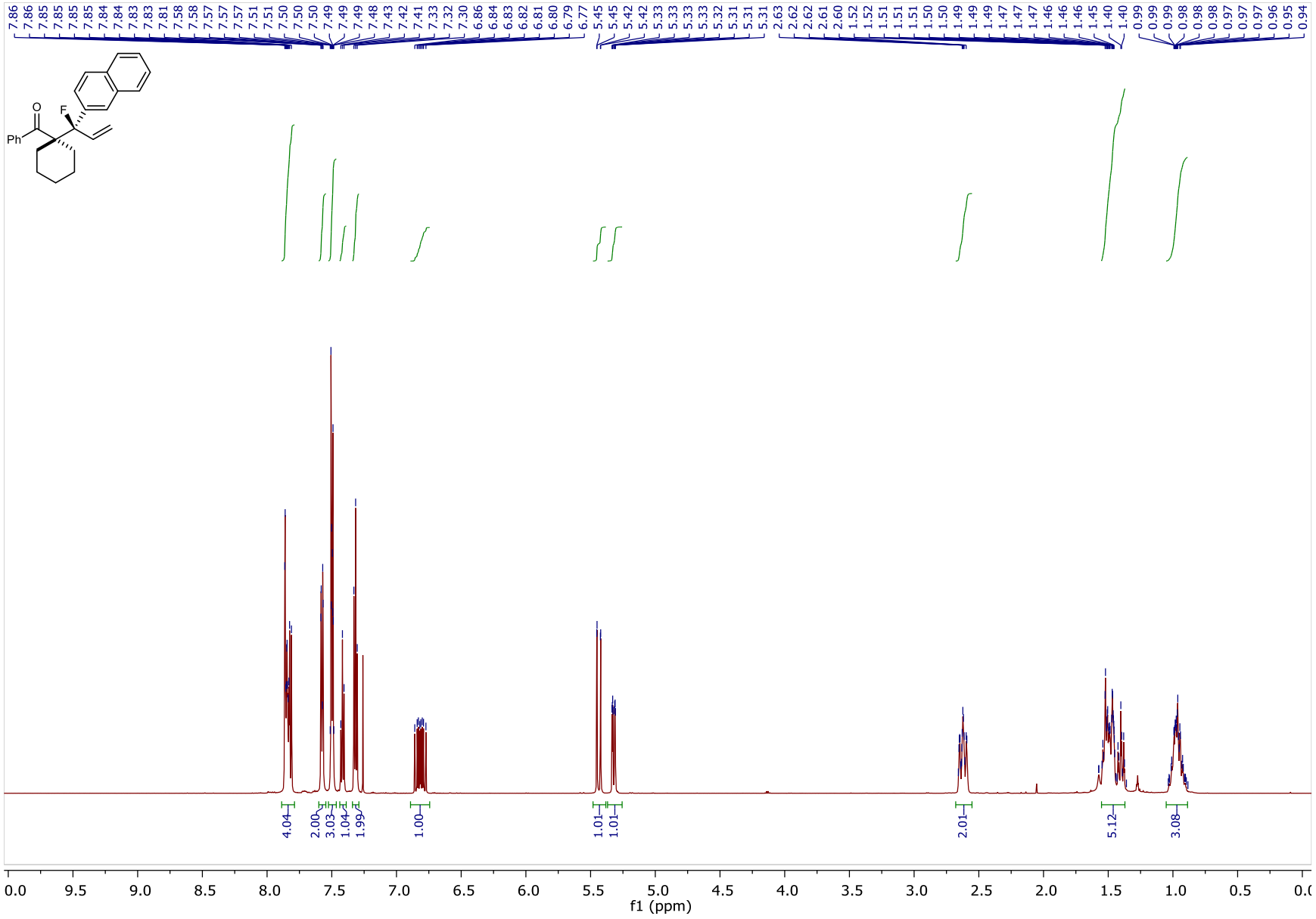

180.44
180.42
158.12
133.89
133.81
133.66
129.98
128.35
126.24
126.22
125.82
125.74
124.95
124.88
119.22
105.54
102.59
101.37
55.51
51.22
51.06
27.33
27.18
21.76
21.73
21.72
21.68
8.11
8.08
O
OH
Me
Me
F
Me
MeO
F-Methallenestril
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

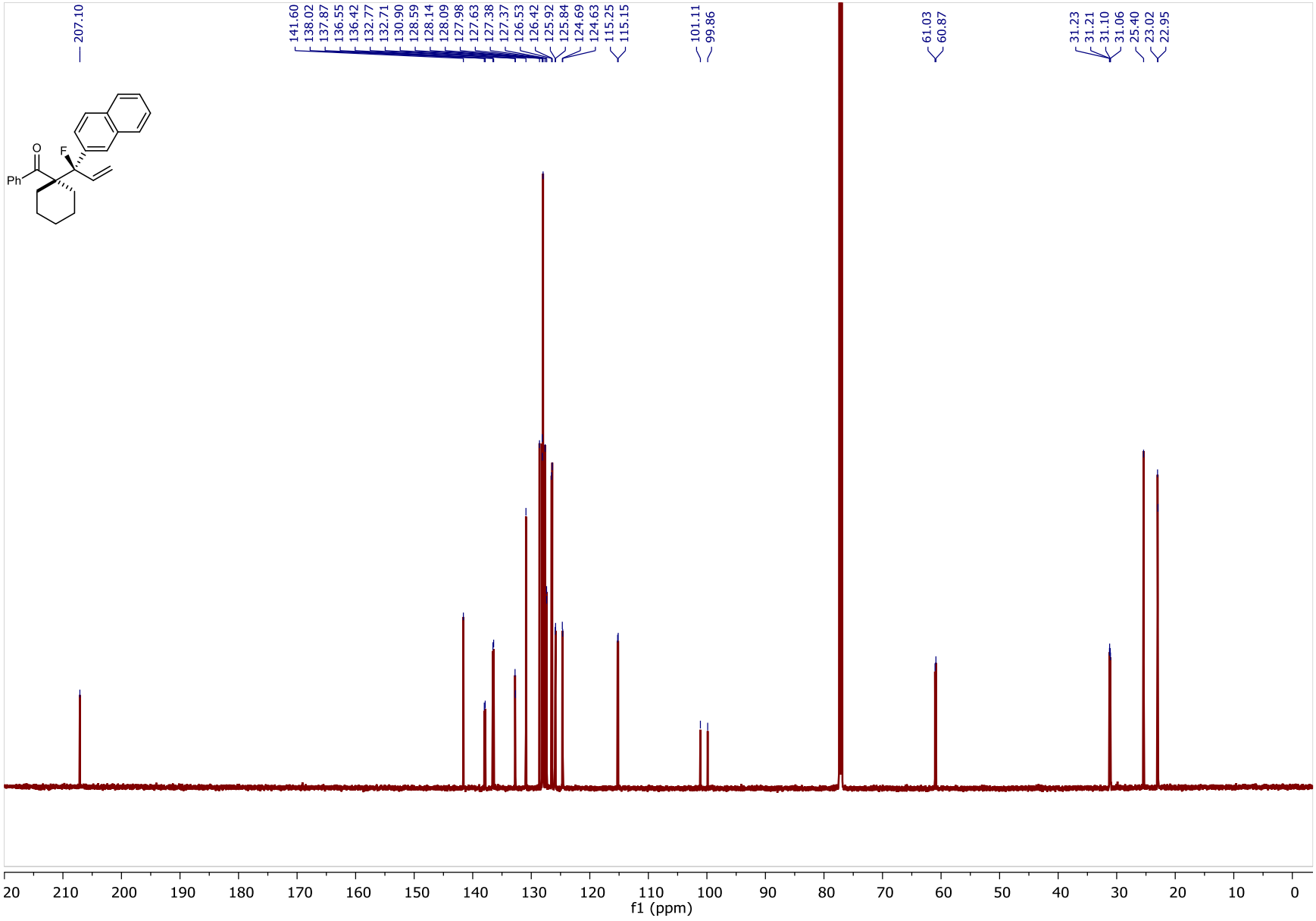

O
OH
Me
Me
F
Me
MeO
F-Methallenestril
-163.94
-163.95
-164.01
-164.03
-154
-155
-156
-157
-158
-159
-160
-161
-162
-163
-164
-165
-166
-167
-168
-169
-170
-171
-172
-173
-174
f1 (ppm)

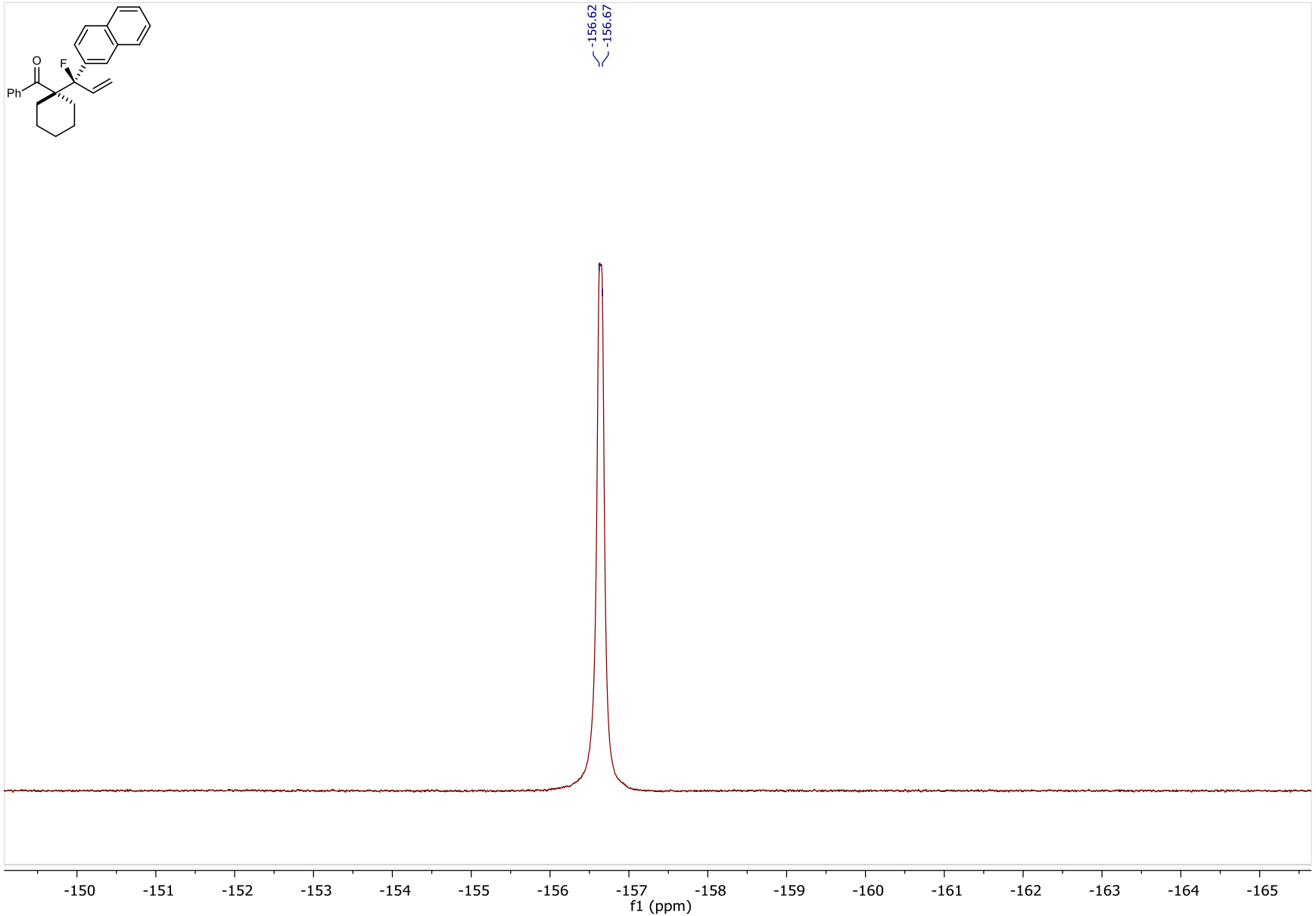

7.89 7.88 7.86 7.85 7.85 7.85 7.84 7.84 7.84 7.83 7.83 7.82 7.80 7.52 7.52 7.51 7.50 7.50 7.49 7.49 7.45 7.44 7.44 7.44 7.43 7.43 7.41 7.40 7.38 7.32 7.30 7.29 6.93 6.91 6.90 6.89 6.88 6.87 6.86 6.84 5.48 5.48 5.45 5.45 5.37 5.36 5.36 5.36 5.35 5.35 5.34 5.34
1.39 1.38
O
F
Ph
Me
Me
1.00 3.03 3.05 2.01 1.04 2.01 1.00 1.02 1.01 2.88 2.90
10.0 9.5 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 0.0
f1 (ppm)

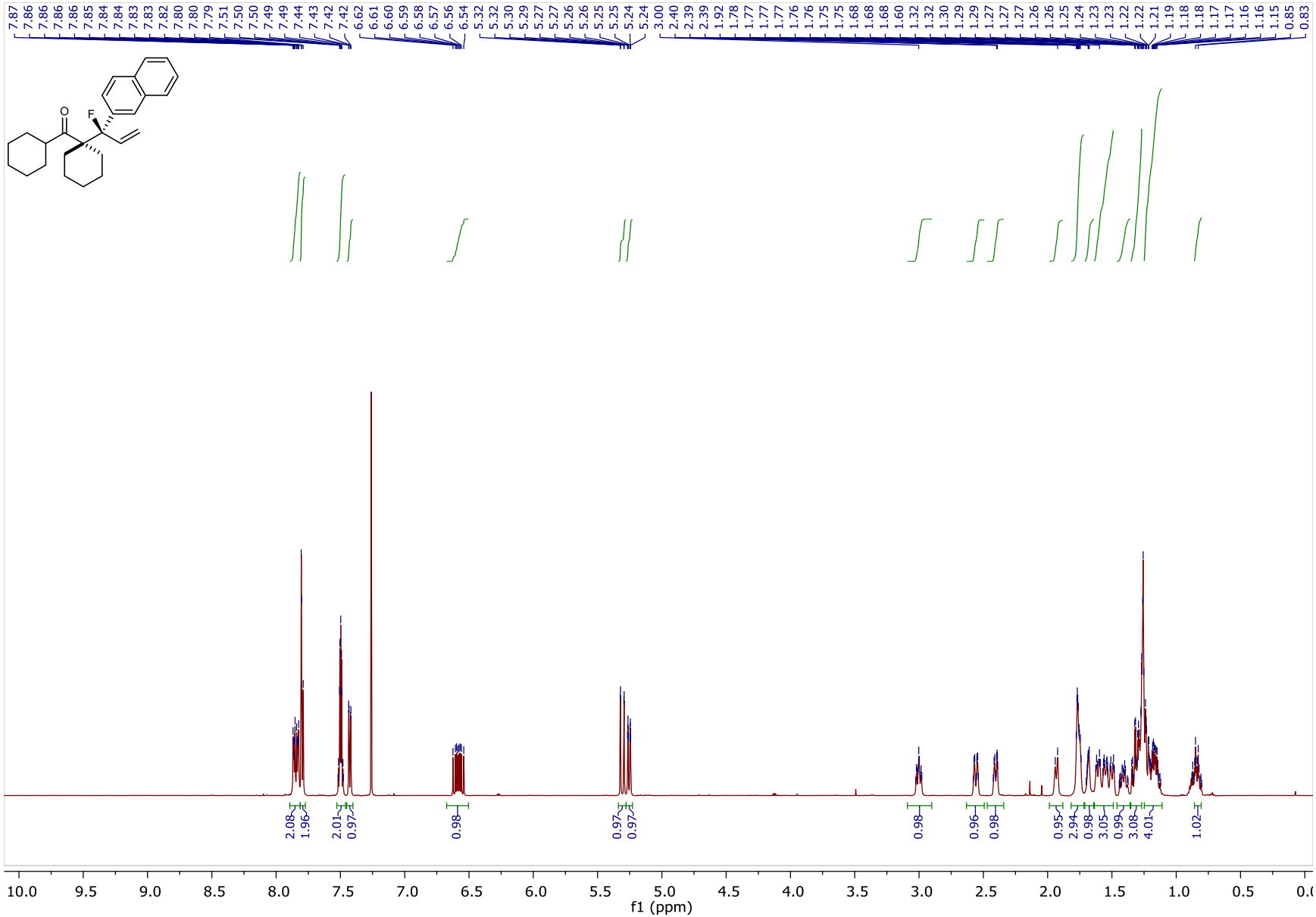

208.21
208.19
140.68
137.91
137.75
136.68
136.56
132.76
130.64
128.56
127.90
127.81
127.81
127.79
127.62
127.49
127.48
126.52
126.42
125.79
125.72
124.51
124.44
115.66
115.56
100.56
99.31
56.08
55.92
23.74
23.71
23.56
23.52
O
F
Ph
Me
Me
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

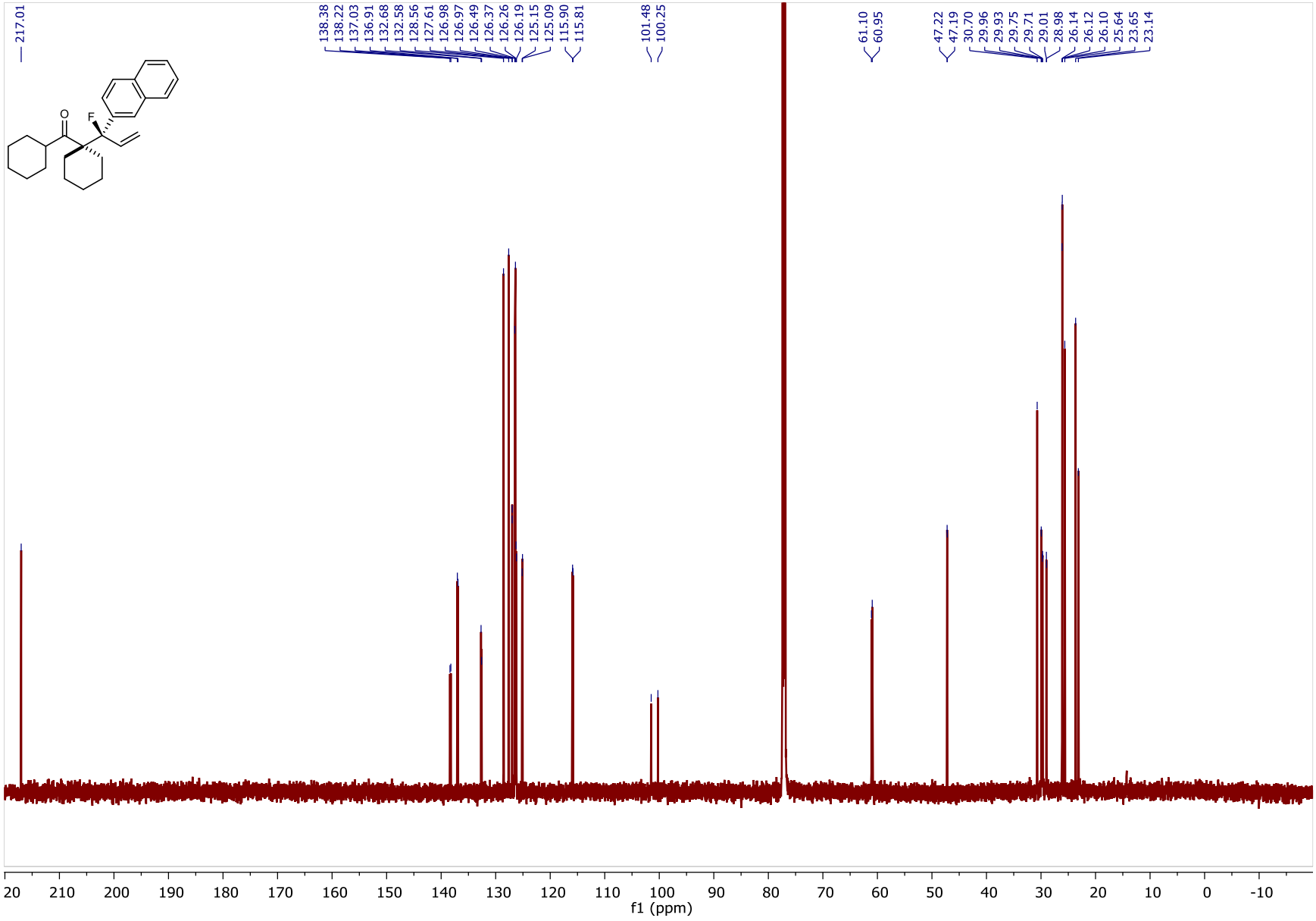

O
F
Ph
Me
Me
-157.21
-157.25
-155.9 -156.0 -156.1 -156.2 -156.3 -156.4 -156.5 -156.6 -156.7 -156.8 -156.9 -157.0 -157.1 -157.2 -157.3 -157.4 -157.5 -157.6 -157.7 -157.8 -157.9 -158.0 -158.1 -158.2 -158.3 -158.4
f1 (ppm)

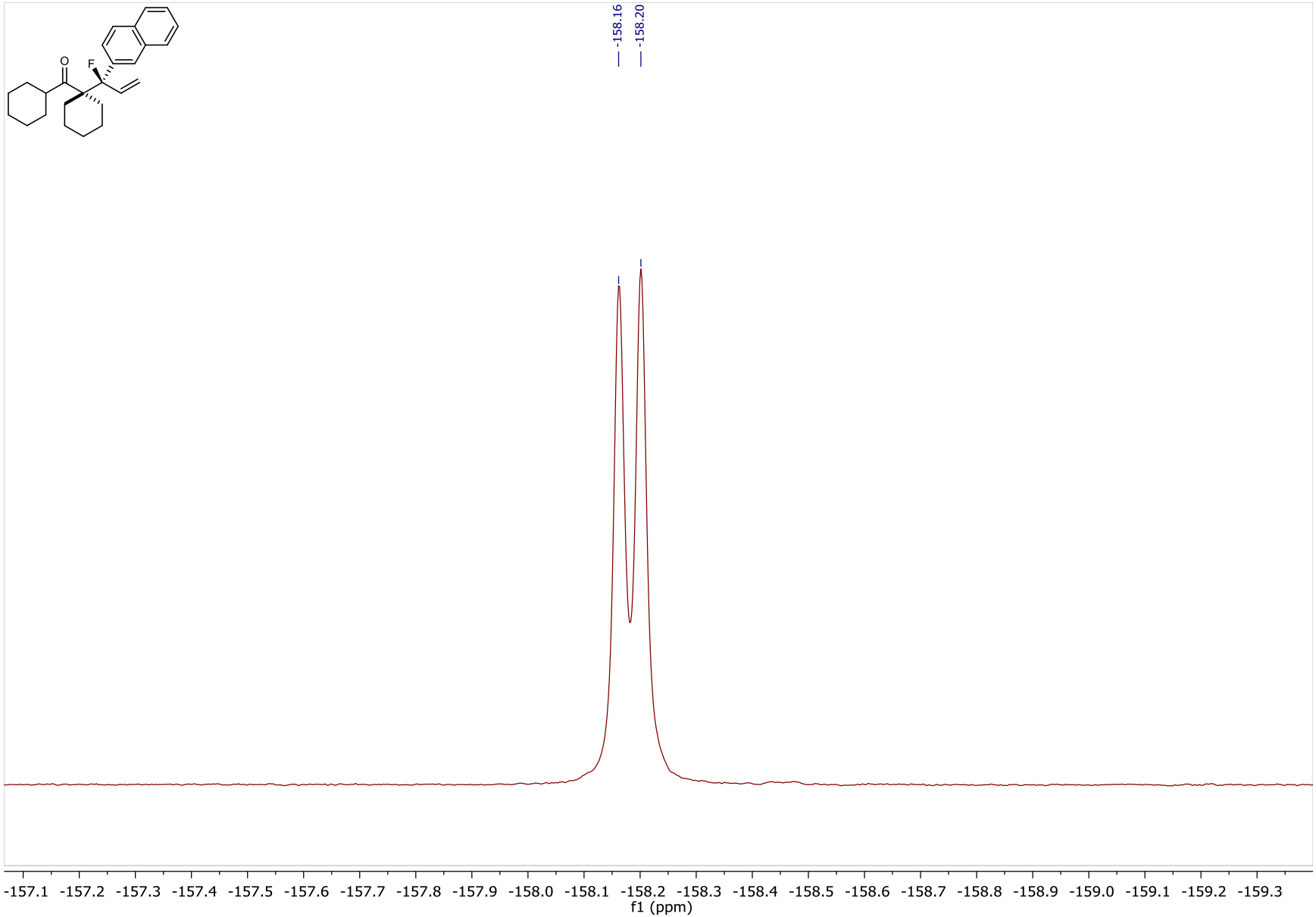

O
F
Ph
4.04
2.00
3.03
1.04
1.99
1.00
1.01
1.01
2.01
5.12
3.08
f1 (ppm)

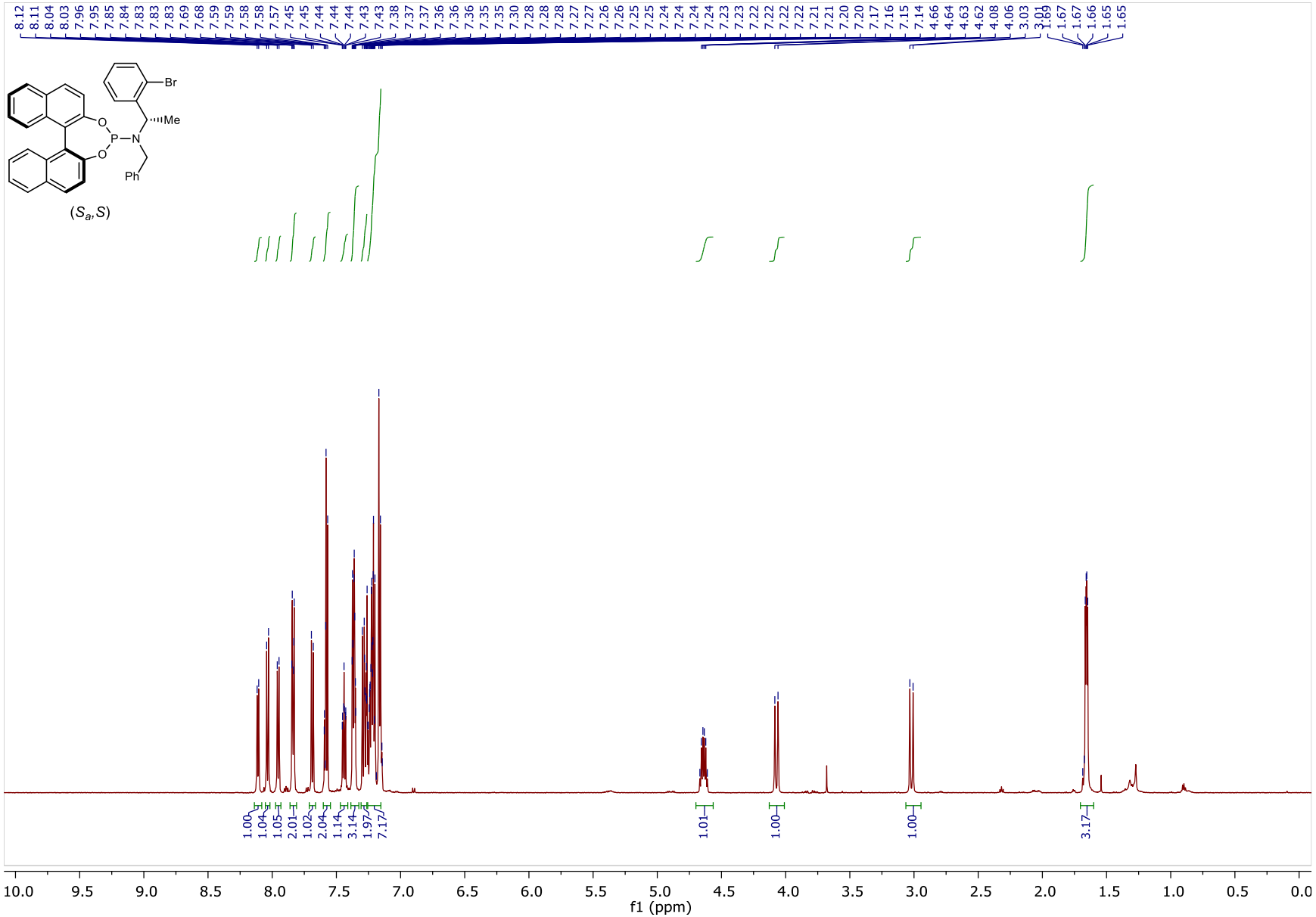

207.10
141.60
138.02
137.87
136.55
136.42
132.77
132.71
130.90
128.59
128.14
128.09
127.98
127.63
127.38
127.37
126.53
126.42
125.92
125.84
124.69
124.63
115.25
115.15
101.11
99.86
61.03
60.87
31.23
31.21
31.10
31.06
25.40
23.02
22.95
O
F
Ph
20
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

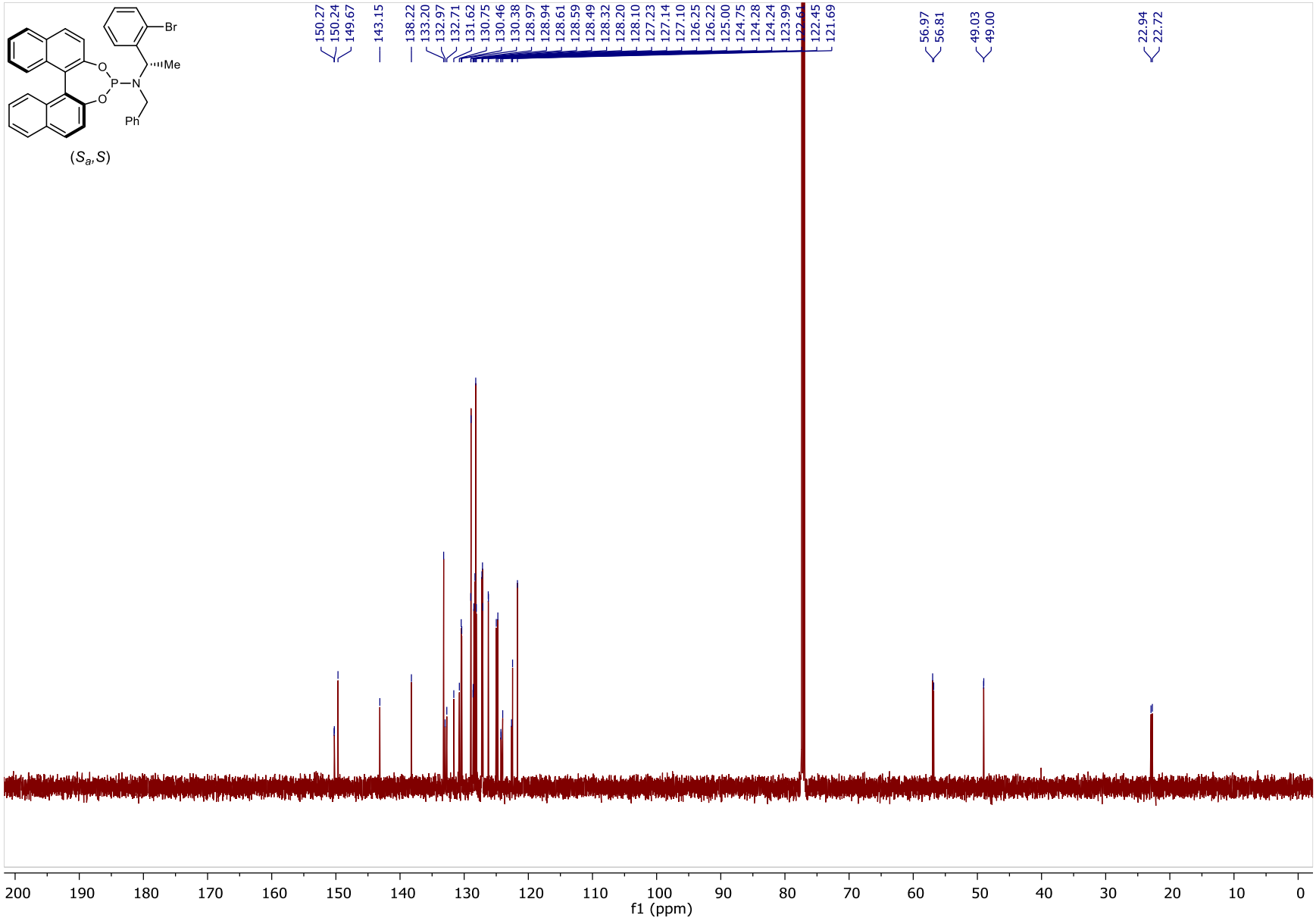

-156.62
-156.67
O
F
Ph
-150
-151
-152
-153
-154
-155
-156
-157
-158
-159
-160
-161
-162
-163
-164
-165
f1 (ppm)

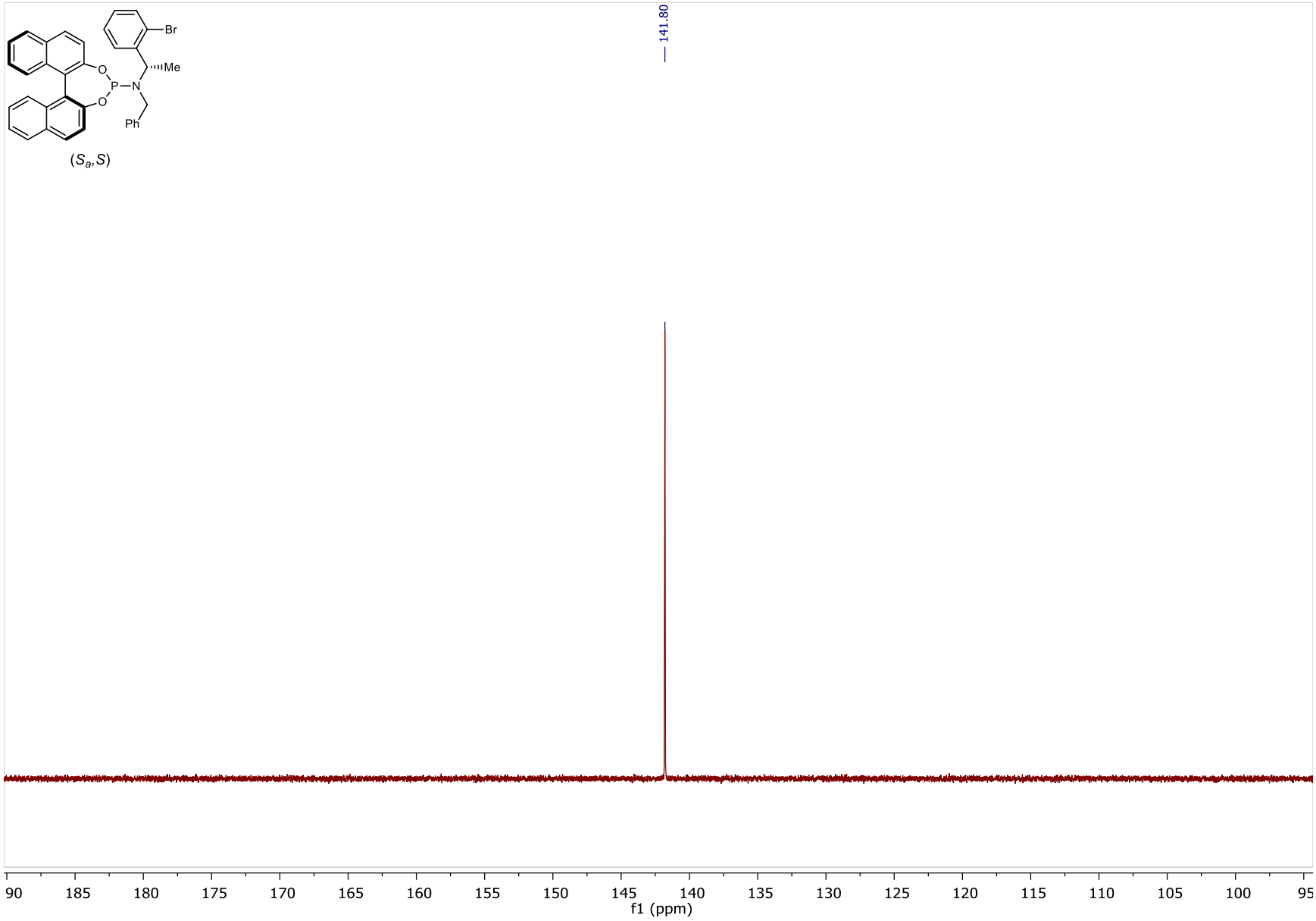

7.87 7.86 7.86 7.86 7.86 7.85 7.84 7.84 7.83 7.83 7.82 7.80 7.80 7.79 7.51 7.50 7.50 7.49 7.49 7.44 7.43 7.42 7.42 6.62 6.61 6.60 6.59 6.58 6.57 6.56 6.54 5.32 5.30 5.29 5.27 5.27 5.26 5.26 5.25 5.25 5.24 5.24 3.00 2.40 2.39 2.39 1.92 1.78 1.77 1.77 1.77 1.76 1.76 1.75 1.75 1.68 1.68 1.68 1.60 1.32 1.32 1.30 1.29 1.29 1.27 1.27 1.27 1.26 1.26 1.25 1.24 1.23 1.23 1.22 1.22 1.21 1.19 1.18 1.18 1.17 1.17 1.16 1.16 1.15 0.85 0.83
O
F
2.08 1.96 2.01 0.97 0.98 0.97 0.97 0.98 0.96 0.98 0.95 2.94 0.98 3.05 0.99 3.08 4.01 1.02
10.0 9.5 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
f1 (ppm)

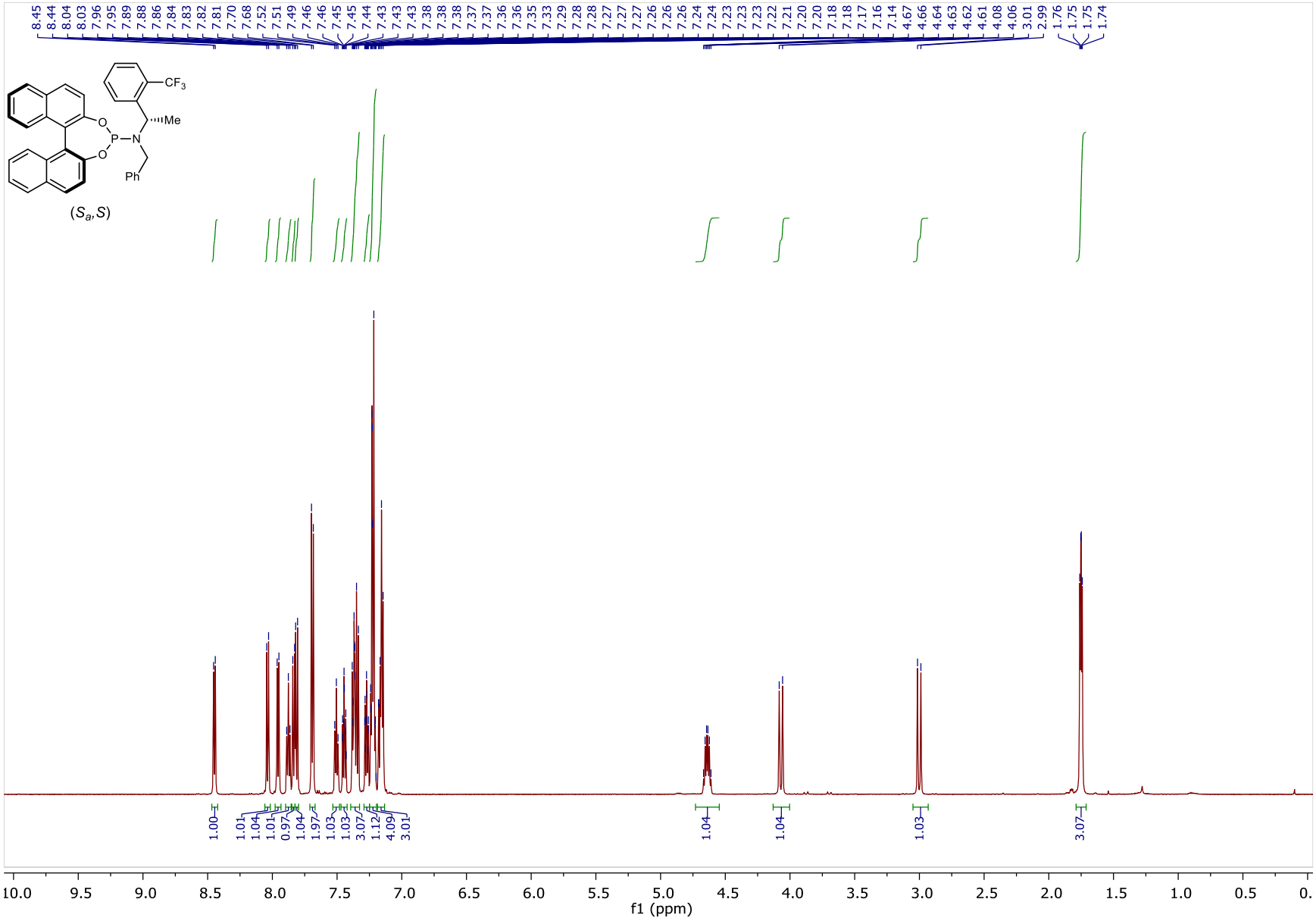

217.01
138.38
138.22
137.03
136.91
132.68
132.58
128.56
127.61
126.98
126.97
126.49
126.37
126.26
126.19
125.15
125.09
115.90
115.81
101.48
100.25
61.10
60.95
47.22
47.19
30.70
29.96
29.93
29.75
29.71
29.01
28.98
26.14
26.12
26.10
25.64
23.65
23.14
O
F
20
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

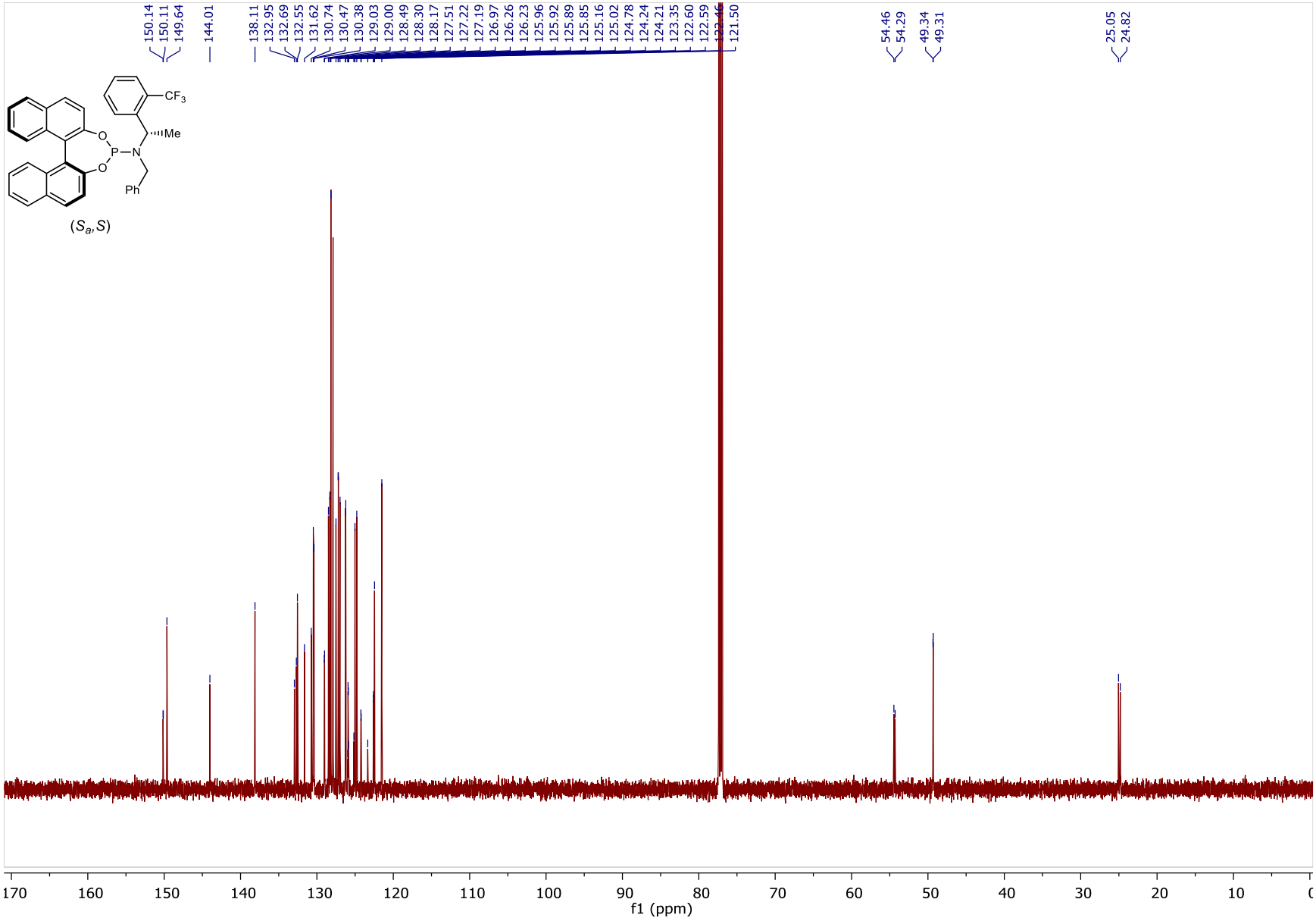

O
F
-158.16
-158.20
-157.1 -157.2 -157.3 -157.4 -157.5 -157.6 -157.7 -157.8 -157.9 -158.0 -158.1 -158.2 -158.3 -158.4 -158.5 -158.6 -158.7 -158.8 -158.9 -159.0 -159.1 -159.2 -159.3
f1 (ppm)

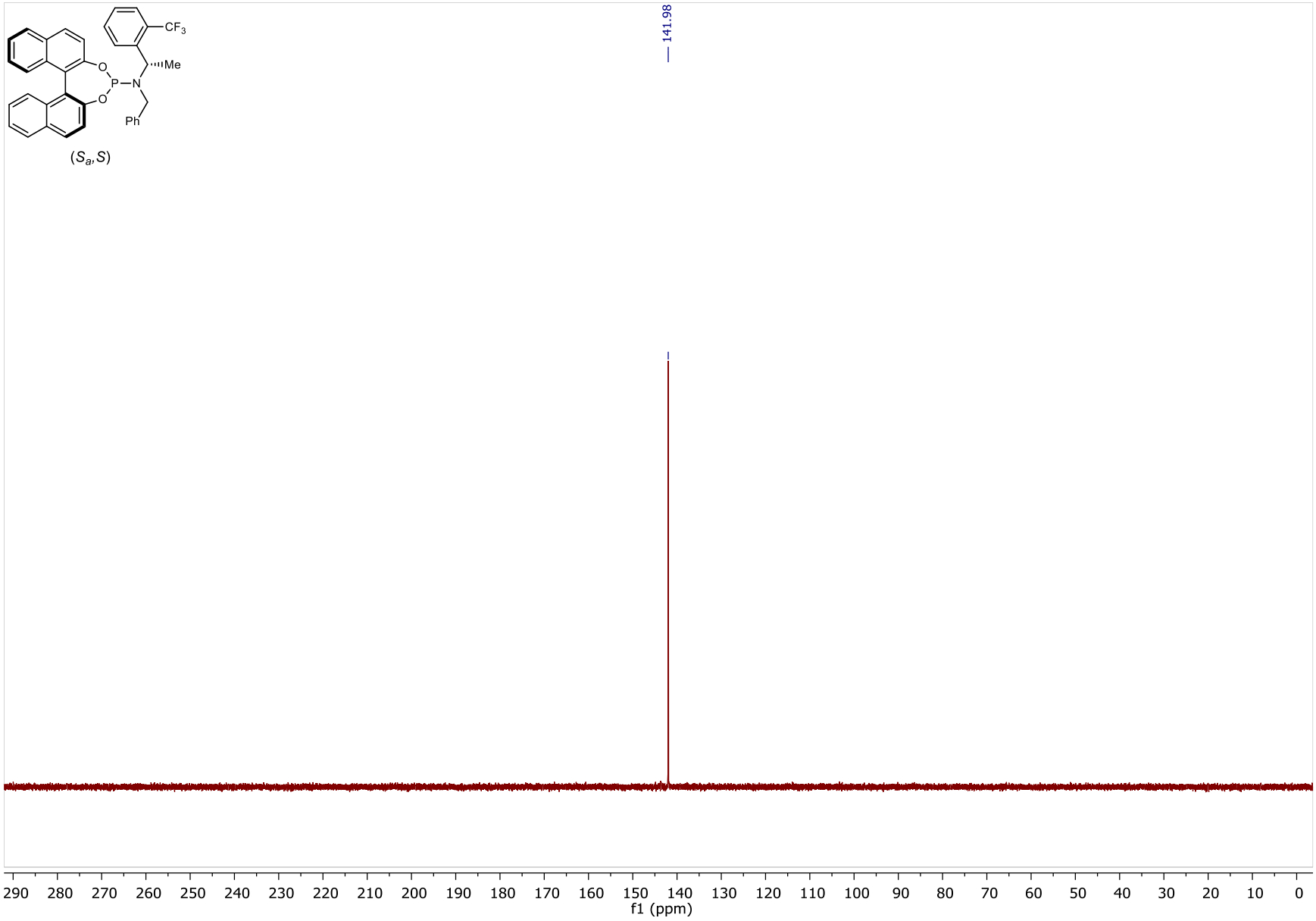

Br
Me
O
P
N
O
Ph
(S_a,S)
f1 (ppm)

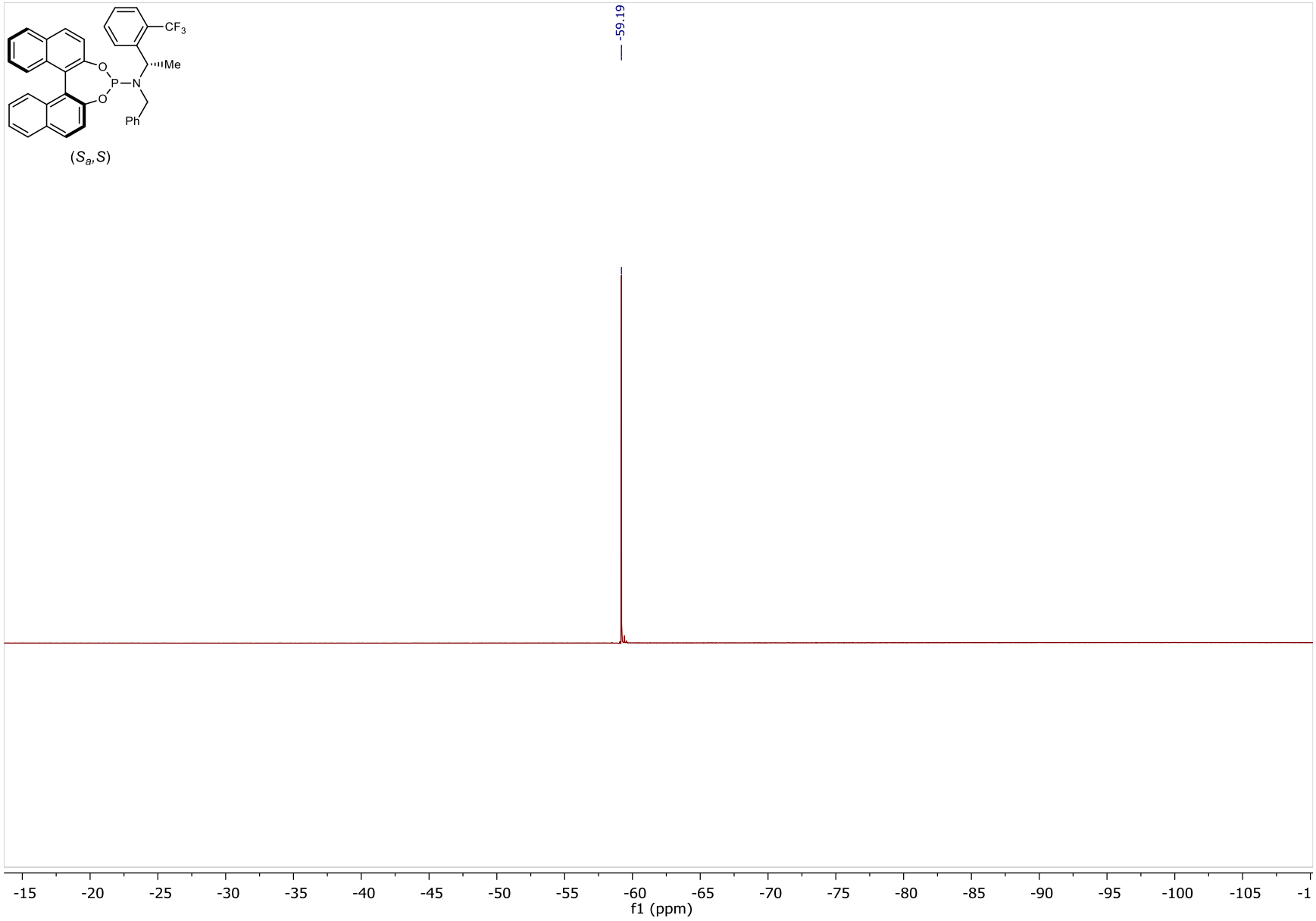

Br
Me
O
P
N
O
Ph
(S_a,S)
150.27
150.24
149.67
143.15
138.22
133.20
132.97
132.71
131.62
130.75
130.46
130.38
128.97
128.94
128.61
128.59
128.49
128.32
128.20
128.10
127.23
127.14
127.10
126.25
126.22
125.00
124.75
124.28
124.24
123.99
122.61
122.45
121.69
56.97
56.81
49.03
49.00
22.94
22.72
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

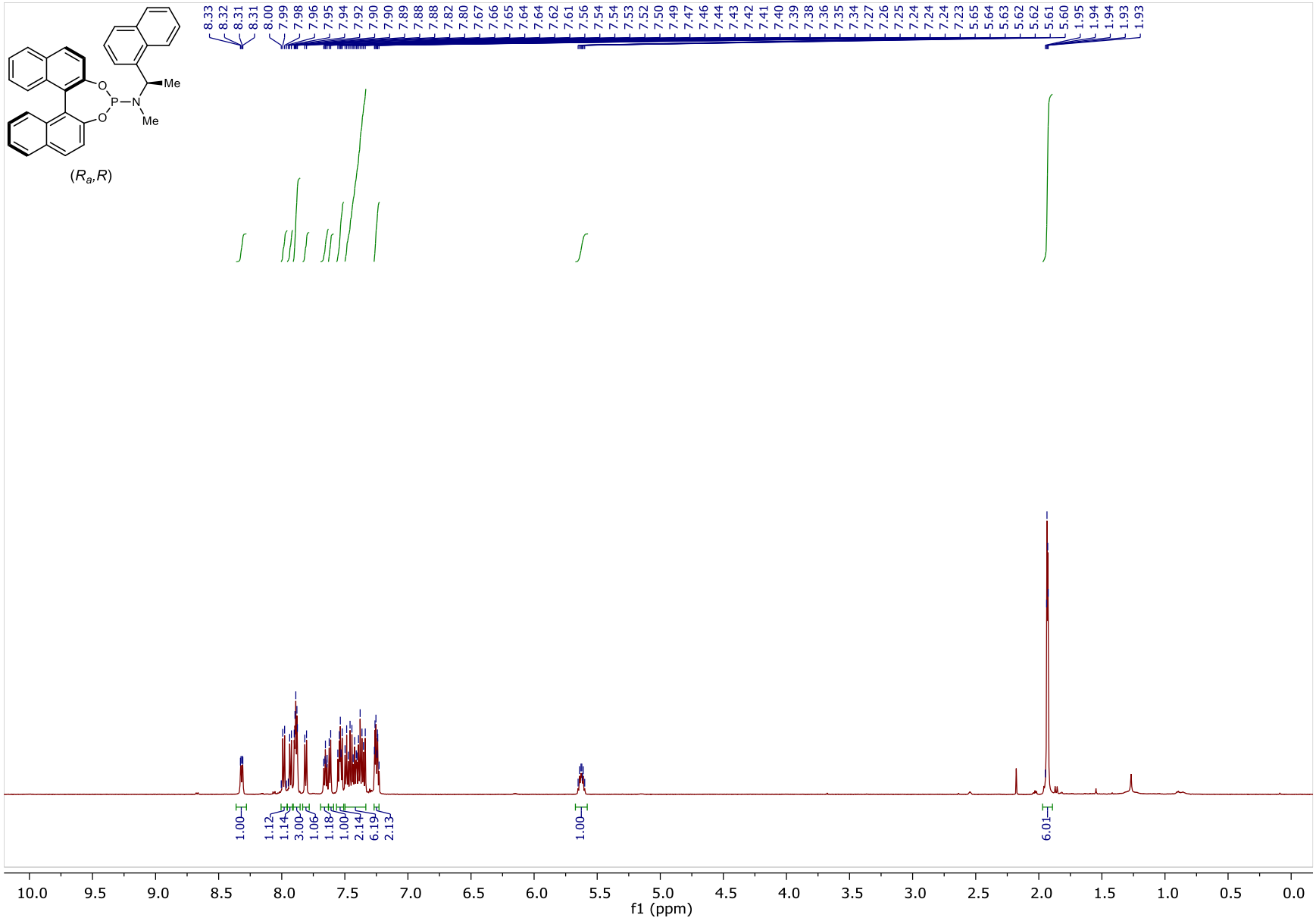

Br
Me
O
P
N
O
Ph
(S_a,S)
141.80
90
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
f1 (ppm)

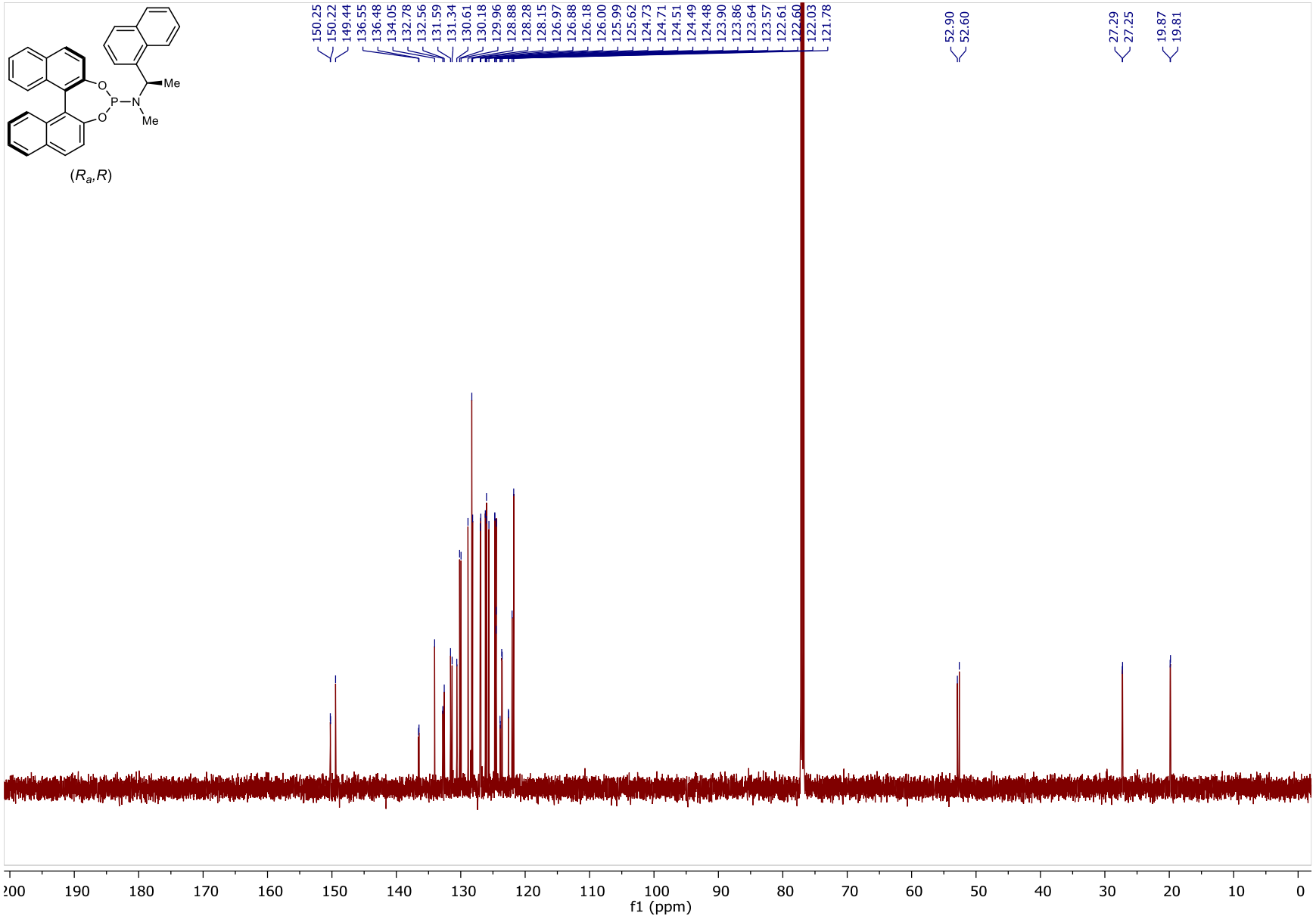

8.45 8.44 8.04 8.03 7.96 7.95 7.89 7.88 7.86 7.84 7.83 7.82 7.81 7.70 7.68 7.52 7.51 7.49 7.46 7.46 7.45 7.45 7.44 7.43 7.43 7.38 7.38 7.38 7.37 7.37 7.36 7.36 7.35 7.33 7.29 7.28 7.28 7.27 7.27 7.27 7.26 7.26 7.26 7.24 7.24 7.23 7.23 7.22 7.21 7.20 7.20 7.18 7.18 7.17 7.16 7.14 4.67 4.66 4.64 4.63 4.62 4.61 4.08 4.06 3.01 2.99 1.76 1.75 1.75 1.74
CF3
Me
O
P
N
O
Ph
(Sa,S)
1.00 1.01 1.04 1.01 0.97 1.04 1.97 1.03 1.03 3.07 1.12 4.09 3.01
1.04
1.04
1.03
3.07
10.0 9.5 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.
f1 (ppm)

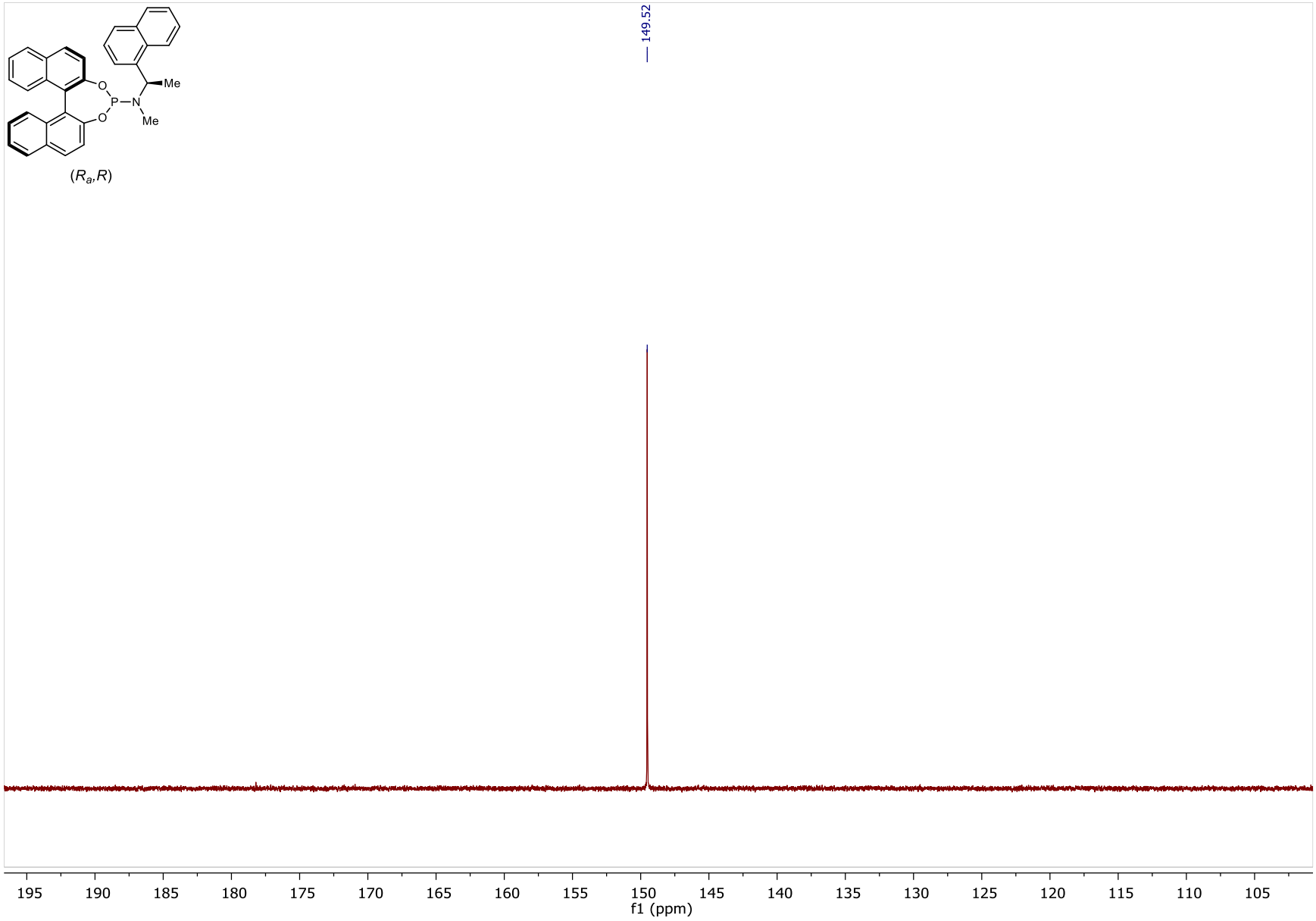

150.14
150.11
149.64
144.01
138.11
132.95
132.69
132.55
131.62
130.74
130.47
130.38
129.03
129.00
128.49
128.30
128.17
127.51
127.22
127.19
126.97
126.26
126.23
125.96
125.92
125.89
125.85
125.16
125.02
124.78
124.24
124.21
123.35
122.60
122.59
122.46
121.50
54.46
54.29
49.34
49.31
25.05
24.82
CF3
Me
O
P
N
O
Ph
(Sa,S)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

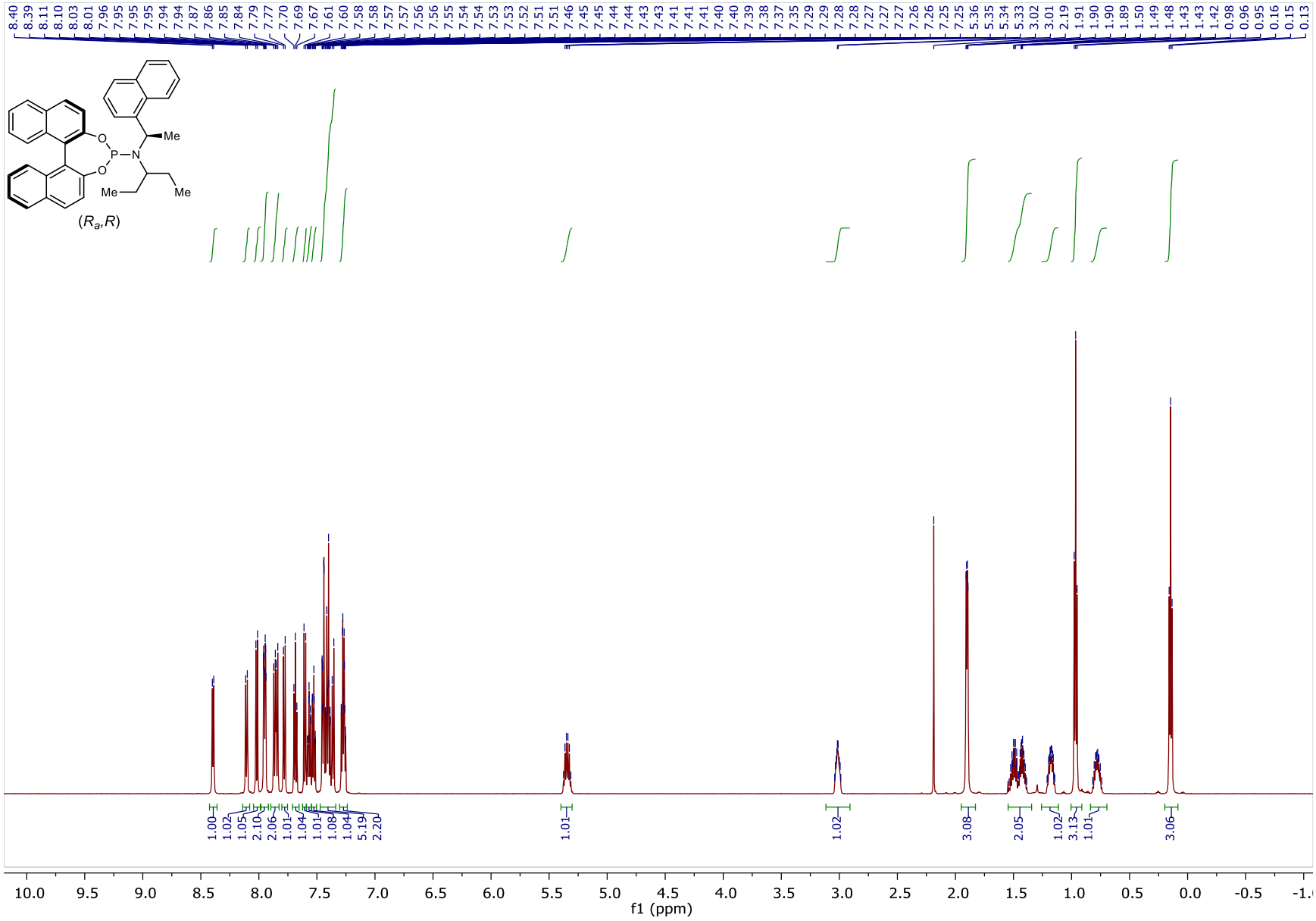

141.98
CF3
Me
O
P
N
O
Ph
(Sa,S)
290 280 270 260 250 240 230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

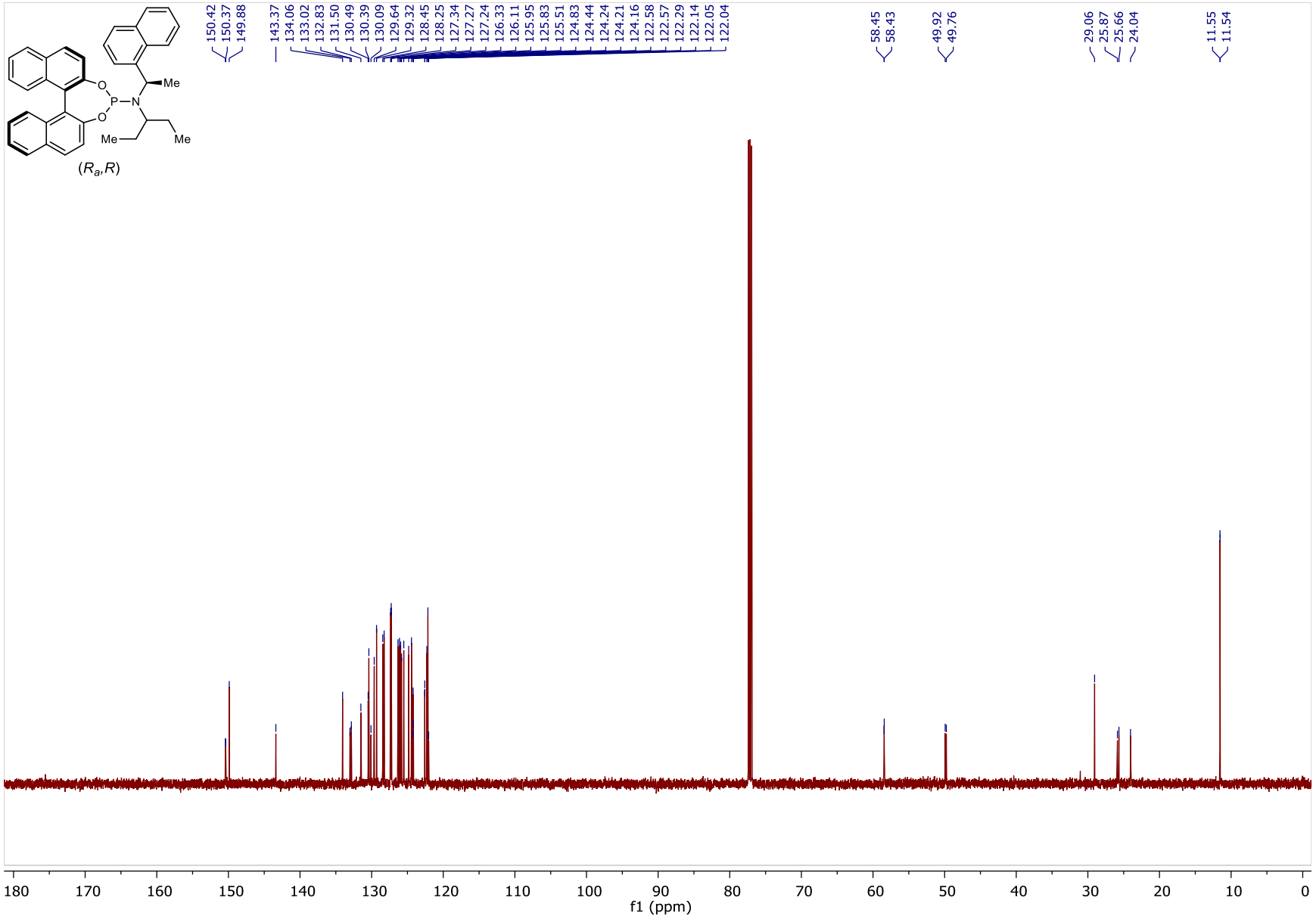

CF3
Me
O
P
N
O
Ph
(Sa,S)
-59.19
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
-105
-1
f1 (ppm)

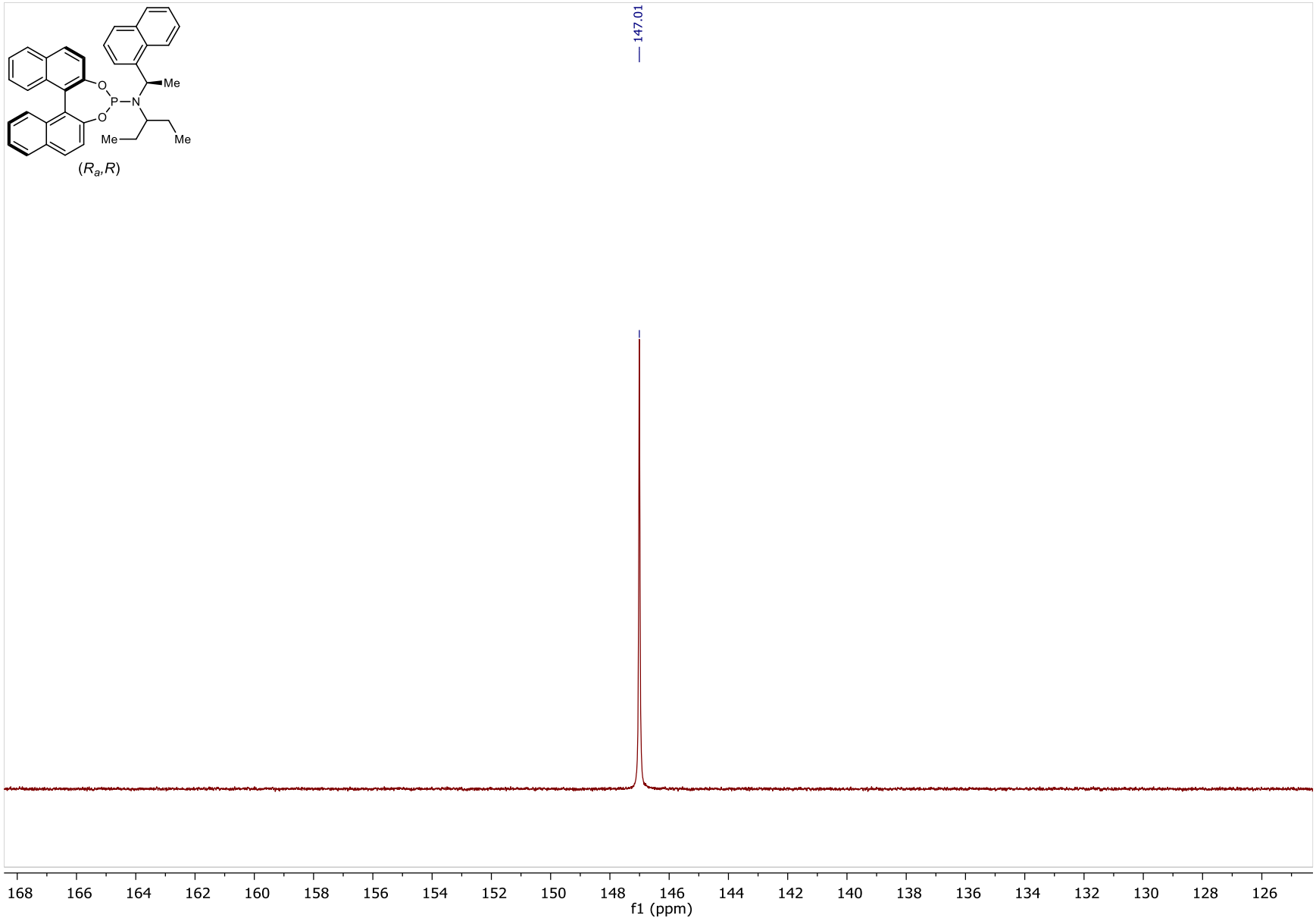

Me
O
P
N
O
Me
(R_a,R)
8.33 8.32 8.31 8.31 8.00 7.99 7.98 7.96 7.95 7.94 7.92 7.90 7.90 7.89 7.88 7.88 7.82 7.80 7.67 7.66 7.65 7.64 7.64 7.62 7.61 7.56 7.54 7.54 7.53 7.52 7.50 7.49 7.47 7.46 7.44 7.43 7.42 7.41 7.40 7.39 7.38 7.36 7.35 7.34 7.27 7.26 7.25 7.24 7.24 7.24 7.23 5.65 5.64 5.63 5.62 5.62 5.61 5.60 1.95 1.94 1.94 1.93 1.93
1.00 1.12 1.14 3.00 1.06 1.18 1.00 2.14 6.19 2.13 1.00 6.01
10.0 9.5 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 0.0
f1 (ppm)

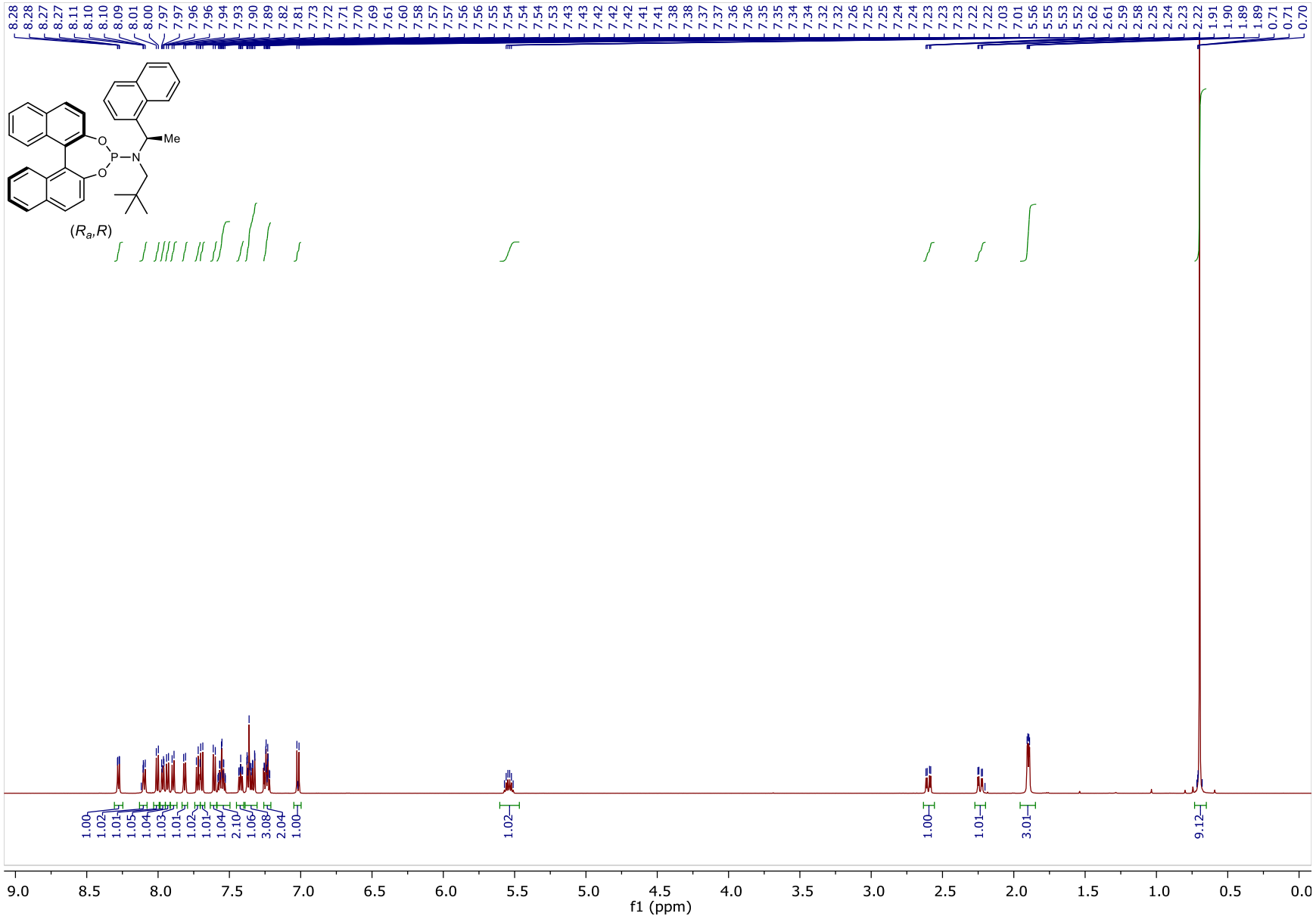

Me
O
P
N
O
Me
(R_a,R)
150.25
150.22
149.44
136.55
136.48
134.05
132.78
132.56
131.59
131.34
130.61
130.18
129.96
128.88
128.28
128.15
126.97
126.88
126.18
126.00
125.99
125.62
124.73
124.71
124.51
124.49
124.48
123.90
123.86
123.64
123.57
122.61
122.60
122.03
121.78
52.90
52.60
27.29
27.25
19.87
19.81
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

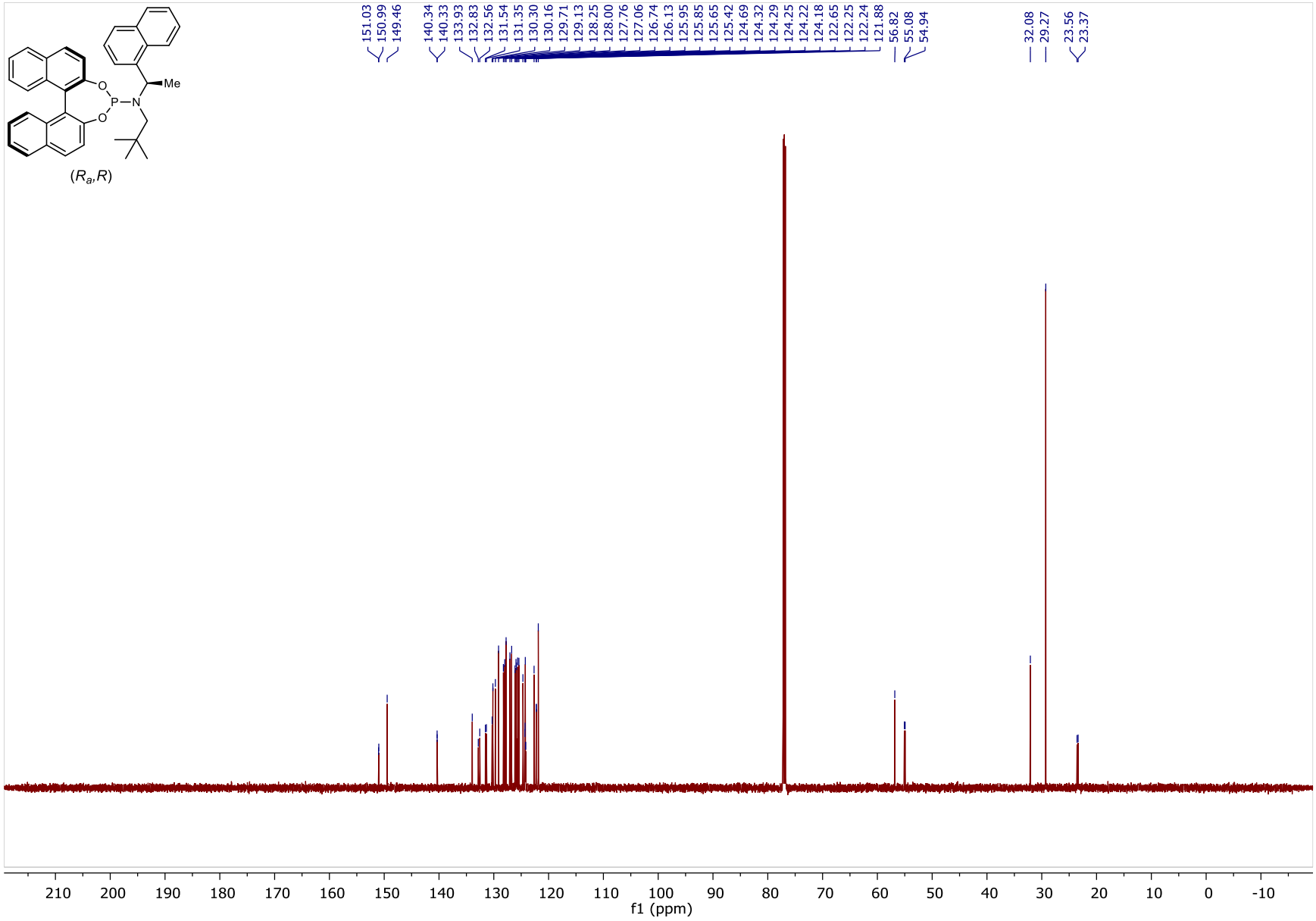

149.52
Me
O
P
N
O
Me
(R_a,R)
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
f1 (ppm)

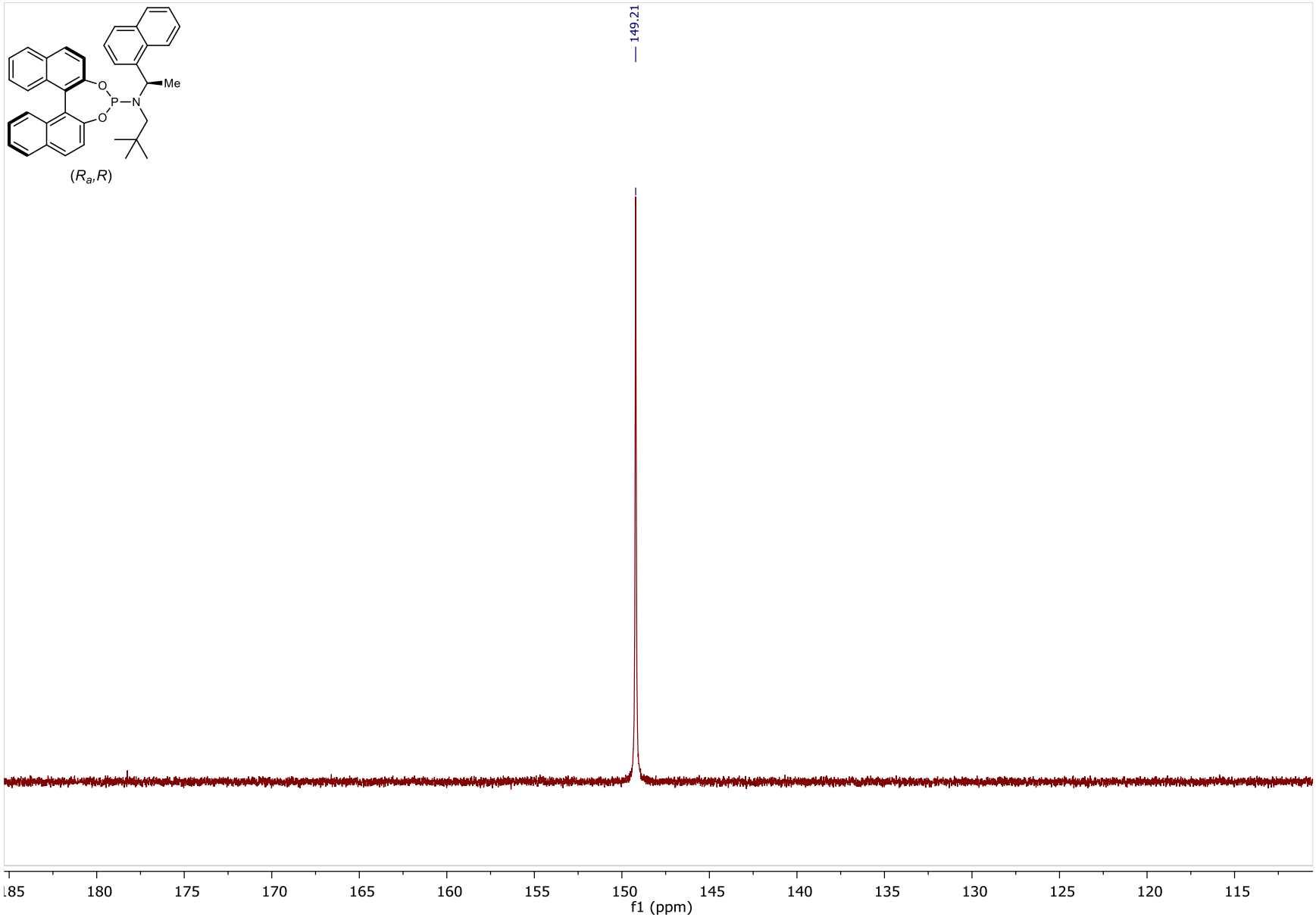

8.40 8.39 8.11 8.10 8.03 8.01 7.96 7.95 7.95 7.94 7.94 7.87 7.86 7.85 7.84 7.79 7.77 7.70 7.69 7.67 7.61 7.60 7.58 7.58 7.57 7.57 7.56 7.56 7.55 7.54 7.54 7.53 7.53 7.52 7.51 7.51 7.46 7.45 7.45 7.44 7.44 7.43 7.43 7.41 7.41 7.40 7.40 7.39 7.38 7.37 7.35 7.29 7.29 7.28 7.28 7.27 7.27 7.26 7.26 7.25 7.25 5.36 5.35 5.34 5.33 3.02 3.01 2.19 1.91 1.90 1.90 1.89 1.50 1.49 1.48 1.43 1.43 1.42 0.98 0.96 0.95 0.16 0.15 0.13
Me
O
P
N
O
Me
Me
(Ra,R)
1.00 1.02 1.05 2.10 2.06 1.01 1.04 1.01 1.08 1.04 5.19 2.20
1.01
1.02
3.08
2.05
1.02
3.13
1.01
3.06
10.0 9.5 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 0.0 -0.5
f1 (ppm)

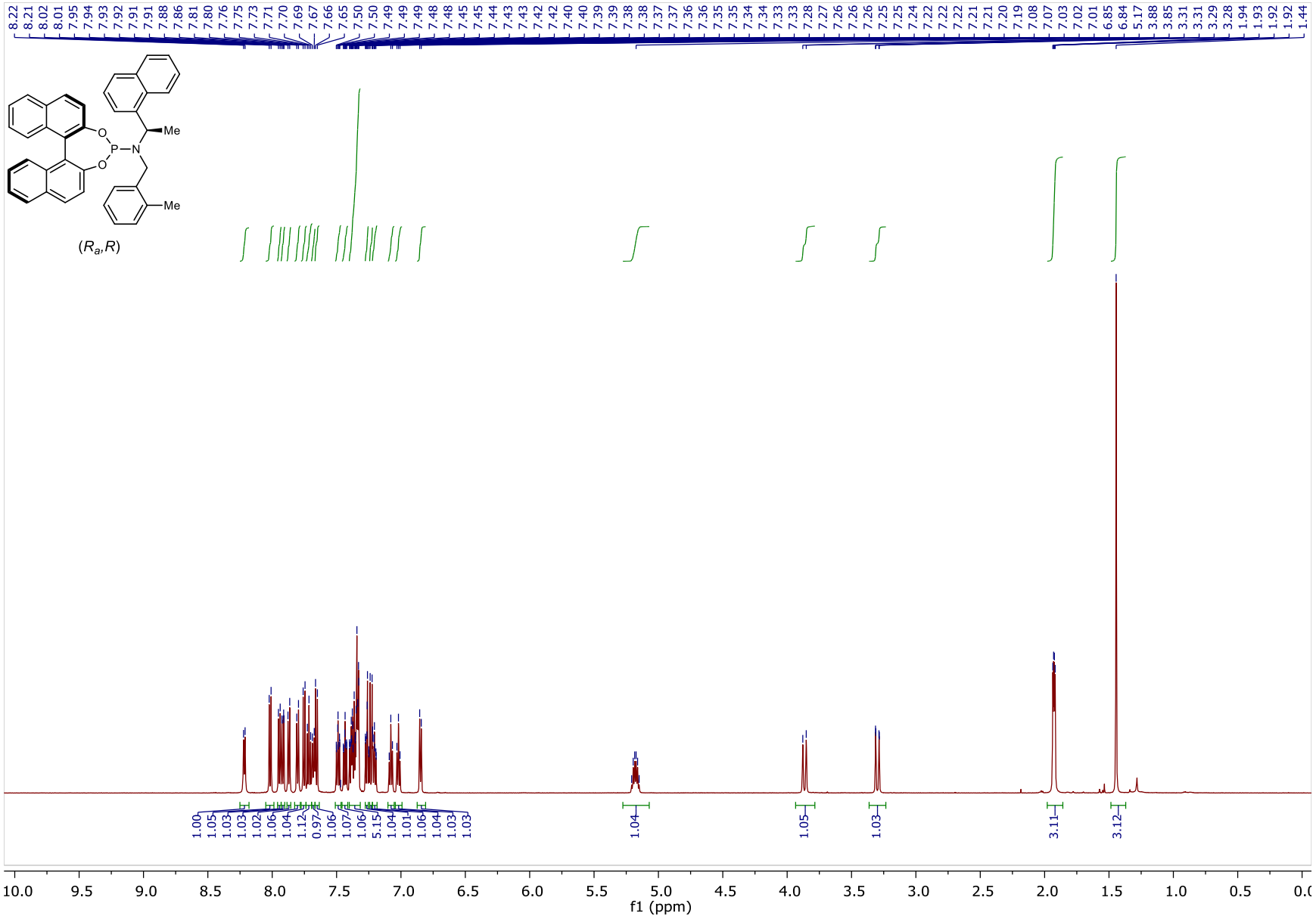

150.42
150.37
149.88
143.37
134.06
133.02
132.83
131.50
130.49
130.39
130.09
129.64
129.32
128.45
128.25
127.34
127.27
127.24
126.33
126.11
125.95
125.83
125.51
124.83
124.44
124.24
124.21
124.16
122.58
122.57
122.29
122.14
122.05
122.04
58.45
58.43
49.92
49.76
29.06
25.87
25.66
24.04
11.55
11.54
Me
Me
Me
O
P
N
O
(R_a,R)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

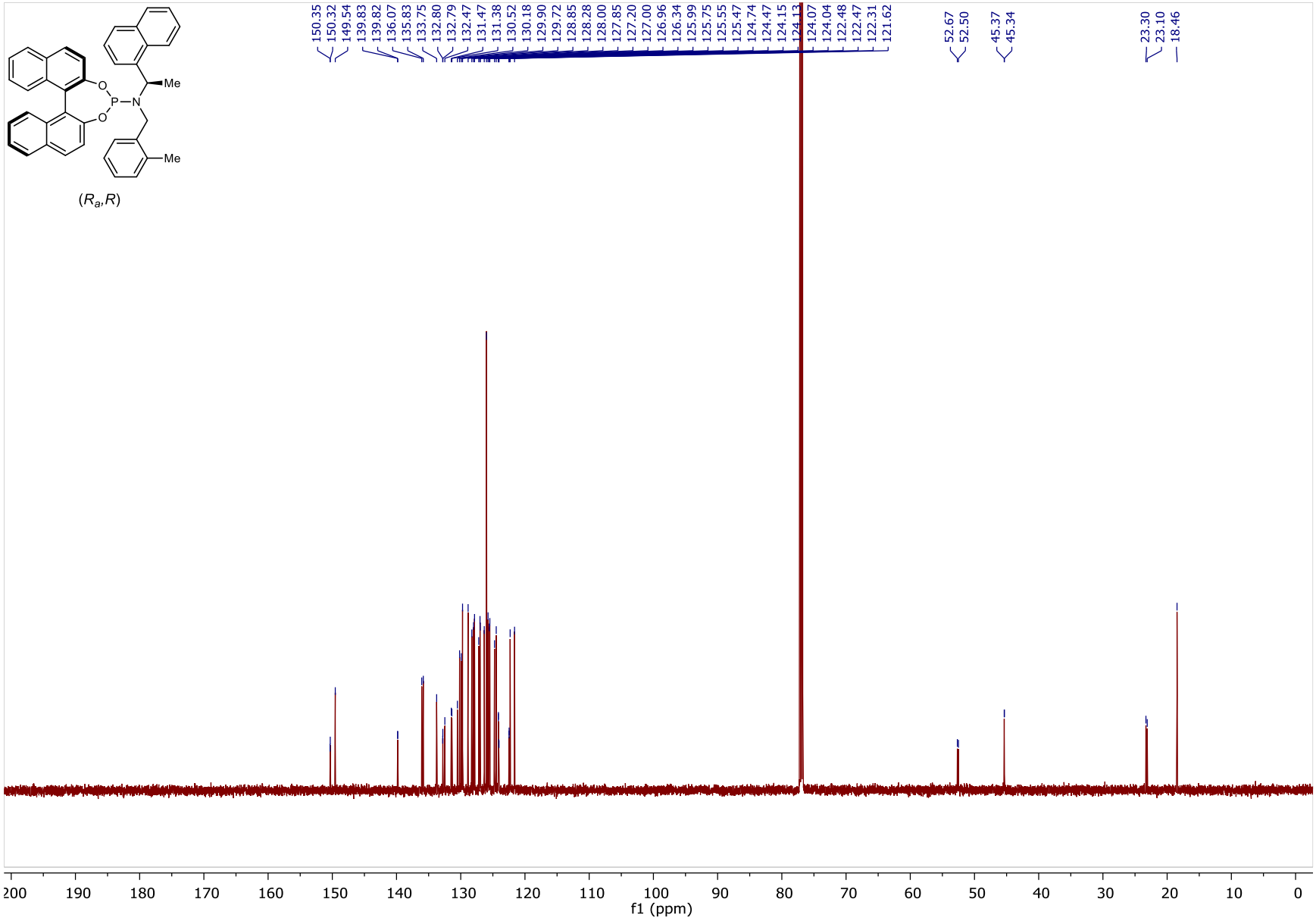

147.01
Me
O
P
N
O
Me
Me
(Ra,R)
168
166
164
162
160
158
156
154
152
150
148
146
144
142
140
138
136
134
132
130
128
126
f1 (ppm)

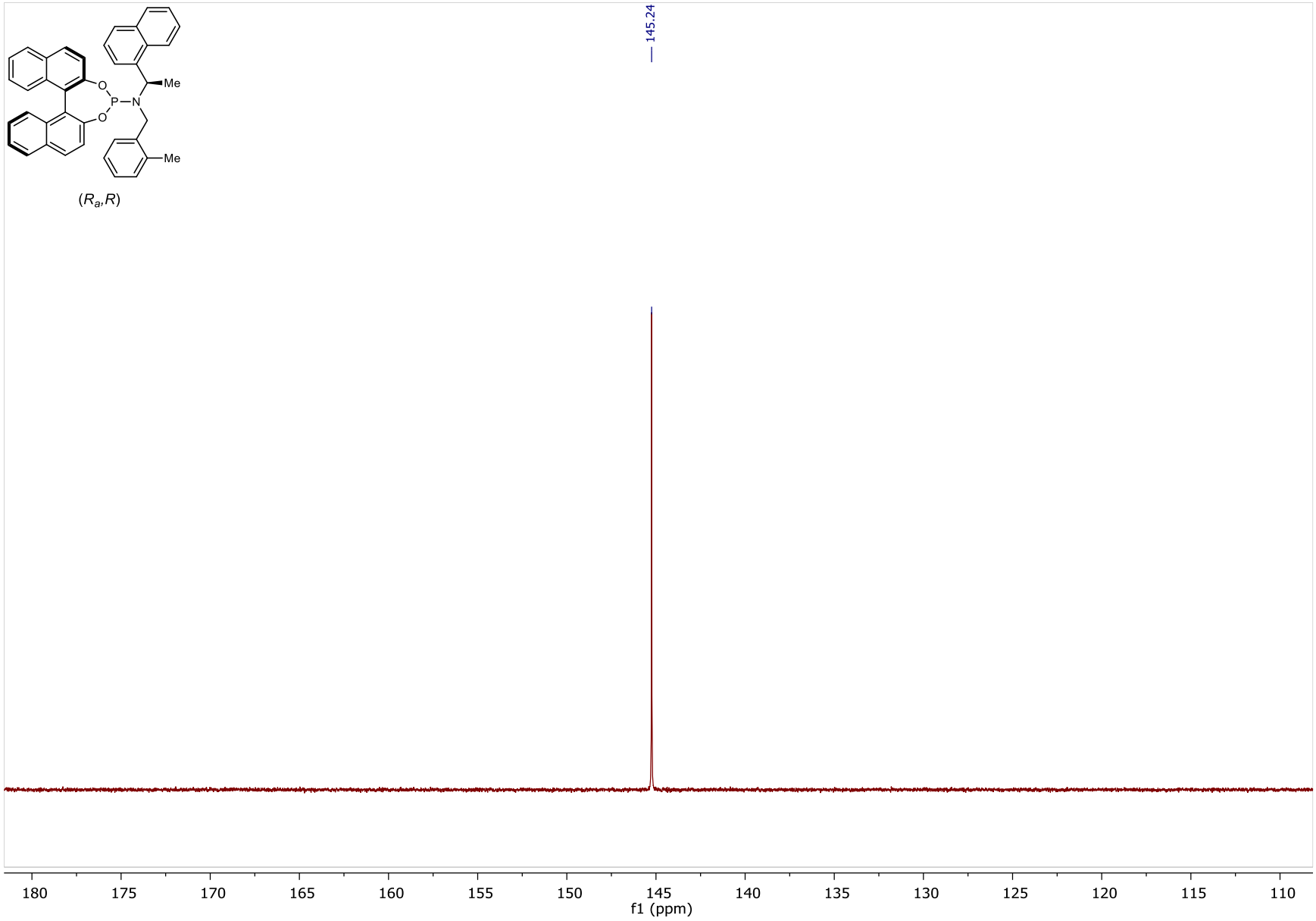

8.28 8.28 8.27 8.27 8.11 8.10 8.10 8.09 8.01 8.00 7.97 7.97 7.96 7.96 7.94 7.93 7.90 7.89 7.82 7.81 7.73 7.72 7.71 7.70 7.69 7.61 7.60 7.58 7.57 7.57 7.56 7.56 7.55 7.54 7.54 7.54 7.53 7.43 7.43 7.42 7.42 7.42 7.41 7.41 7.38 7.38 7.37 7.37 7.36 7.36 7.35 7.35 7.34 7.34 7.32 7.32 7.26 7.25 7.25 7.24 7.24 7.23 7.23 7.23 7.22 7.22 7.03 7.01 5.56 5.55 5.53 5.52 2.62 2.61 2.59 2.58 2.25 2.24 2.23 2.22 1.91 1.90 1.89 1.89 0.71 0.71 0.70
Me
O
P
N
O
O
(R_a,R)
1.00 1.02 1.01 1.05 1.04 1.03 1.01 1.02 1.01 1.04 2.10 1.06 3.08 2.04 1.00
1.02
1.00
1.01
3.01
9.12
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 0.0
f1 (ppm)

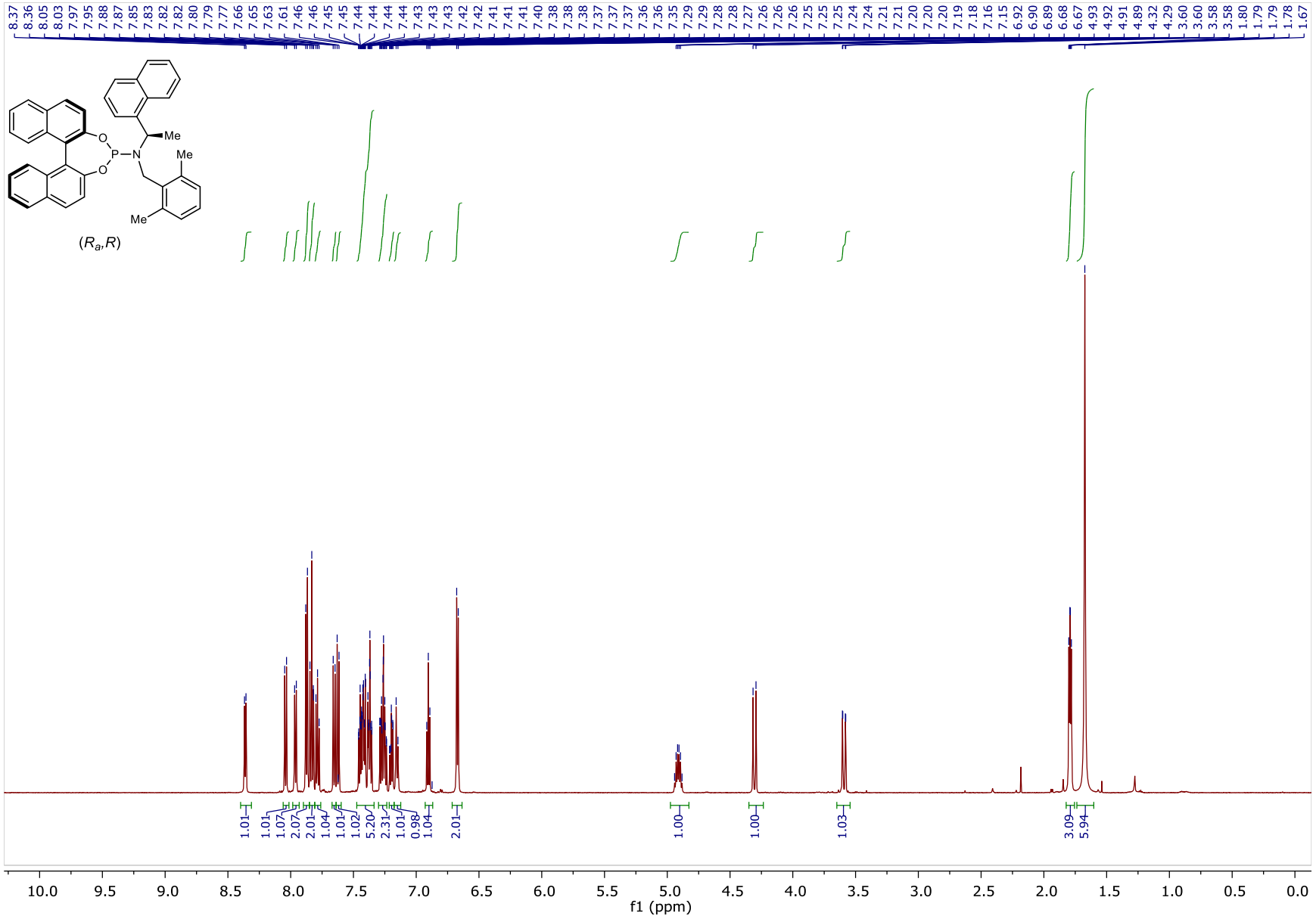

151.03
150.99
149.46
140.34
140.33
133.93
132.83
132.56
131.54
131.35
130.30
130.16
129.71
129.13
128.25
128.00
127.76
127.06
126.74
126.13
125.95
125.85
125.65
125.42
124.69
124.32
124.29
124.25
124.22
124.18
122.65
122.25
122.24
121.88
56.82
55.08
54.94
32.08
29.27
23.56
23.37
Me
O
P
N
O
(Ra,R)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

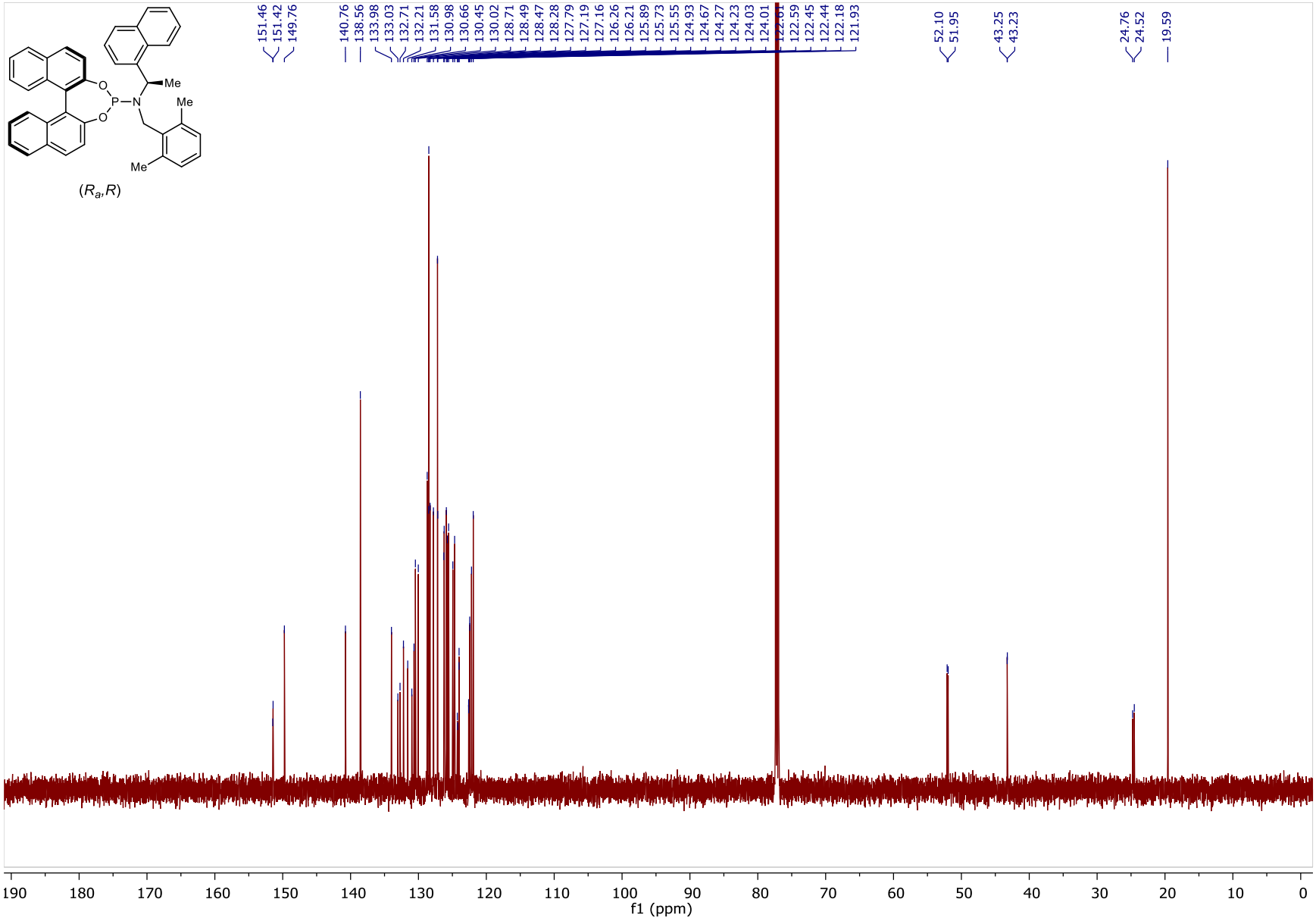

149.21
Me
O
P
N
O
(R_a,R)
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
f1 (ppm)

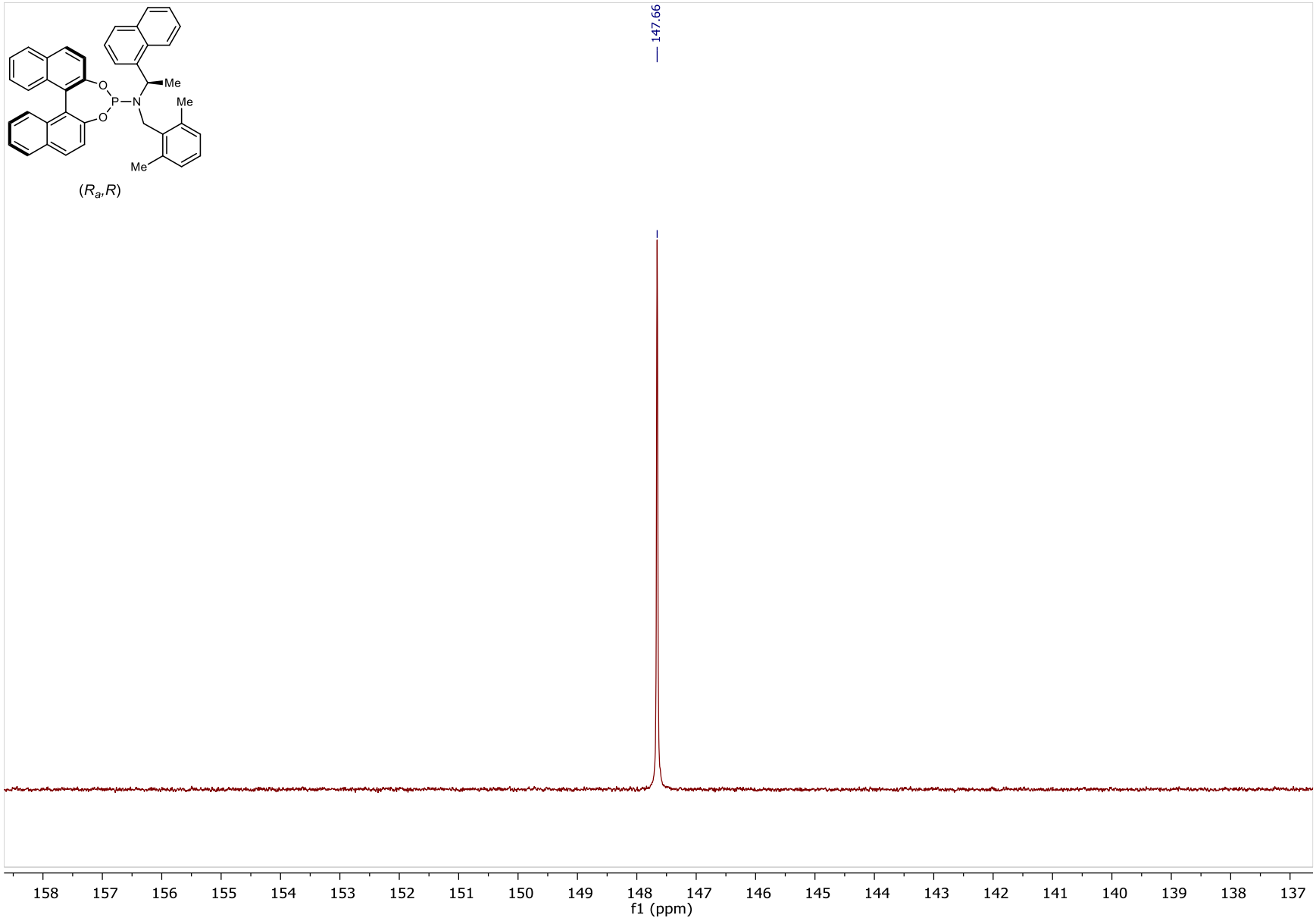

8.22 8.21 8.02 8.01 7.95 7.94 7.93 7.92 7.91 7.91 7.88 7.86 7.81 7.80 7.76 7.75 7.73 7.71 7.70 7.69 7.67 7.66 7.65 7.50 7.50 7.49 7.49 7.49 7.48 7.48 7.45 7.45 7.44 7.43 7.43 7.42 7.42 7.40 7.40 7.39 7.39 7.38 7.38 7.37 7.37 7.36 7.36 7.35 7.35 7.34 7.34 7.33 7.33 7.28 7.27 7.26 7.26 7.26 7.25 7.25 7.24 7.22 7.22 7.22 7.21 7.21 7.20 7.19 7.08 7.07 7.03 7.02 7.01 6.85 6.84 5.17 3.88 3.85 3.31 3.31 3.29 3.28 1.94 1.93 1.92 1.92 1.44
Me
Me
O
P
N
O
(R_a,R)
1.00 1.05 1.03 1.03 1.02 1.06 1.04 1.12 0.97 1.06 1.07 1.06 5.15 1.04 1.01 1.06 1.04 1.03 1.03
1.04
1.05
1.03
3.11
3.12
10.0 9.5 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
f1 (ppm)

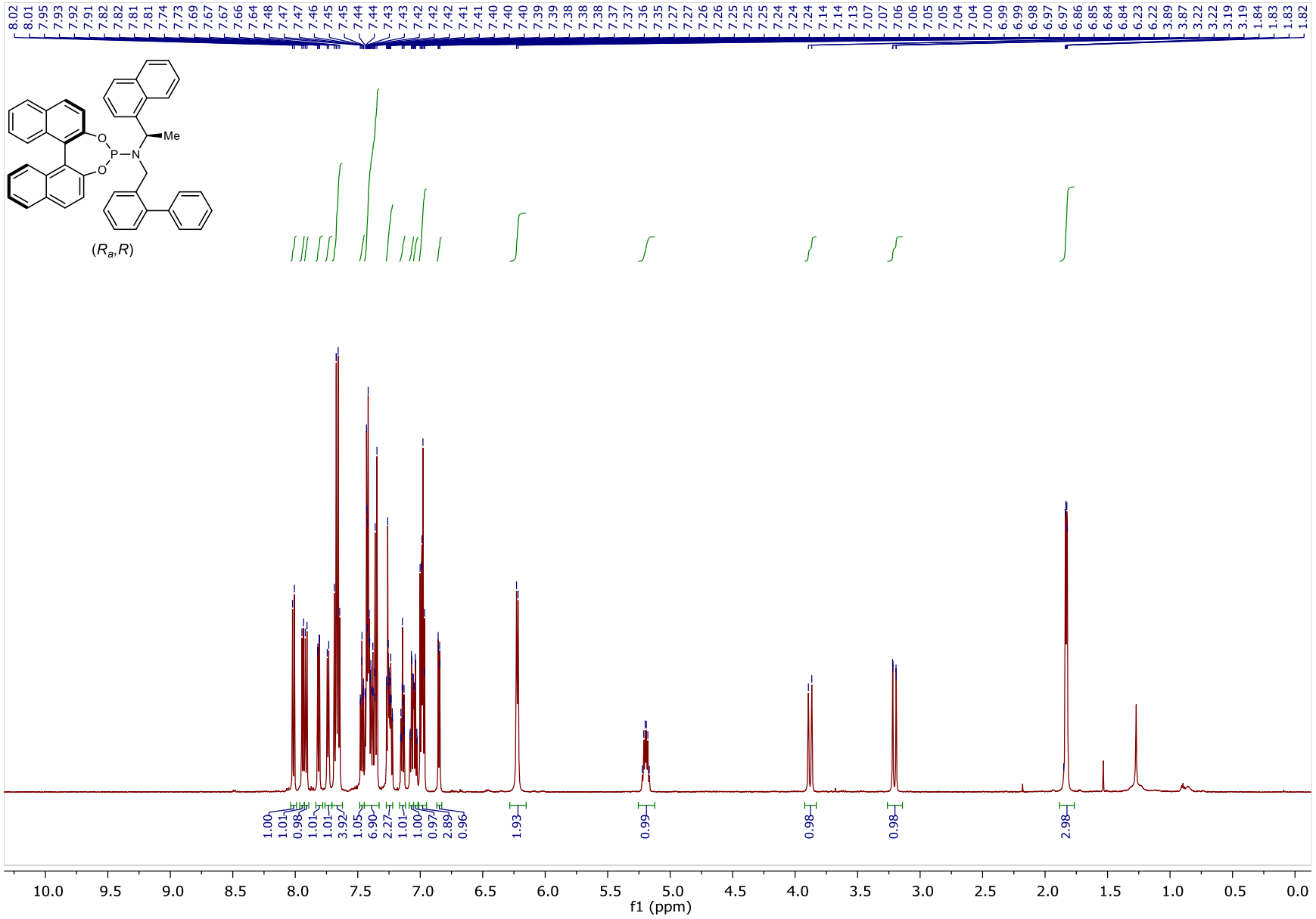

Me
Me
O
P
N
O
(R_a,R)
150.35
150.32
149.54
139.83
139.82
136.07
135.83
133.75
132.80
132.79
132.47
131.47
131.38
130.52
130.18
129.90
129.72
128.85
128.28
128.00
127.85
127.20
127.00
126.96
126.34
125.99
125.75
125.55
125.47
124.74
124.47
124.15
124.13
124.07
124.04
122.48
122.47
122.31
121.62
52.67
52.50
45.37
45.34
23.30
23.10
18.46
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

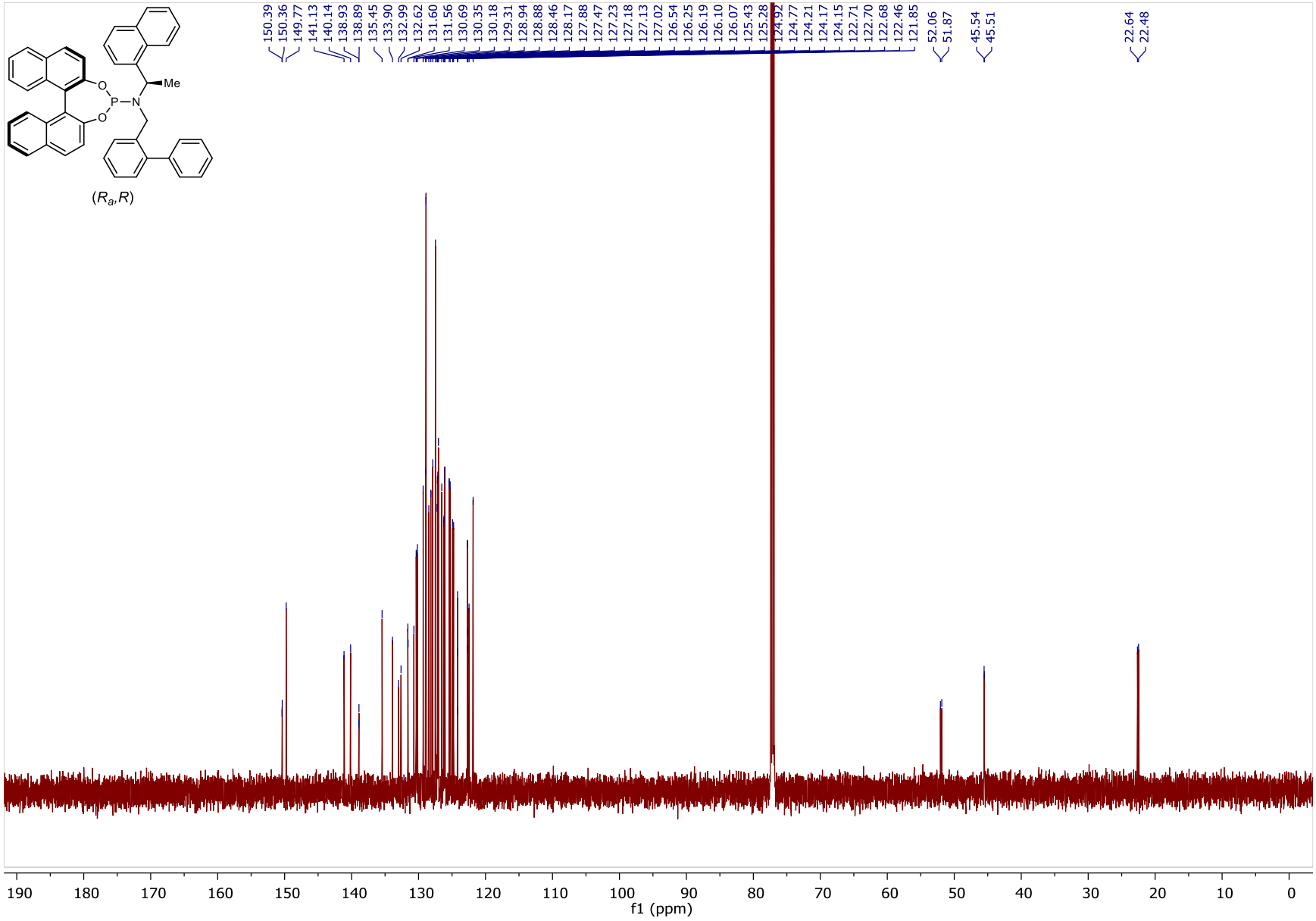

145.24
Me
Me
O
P
N
O
(R_a,R)
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
f1 (ppm)

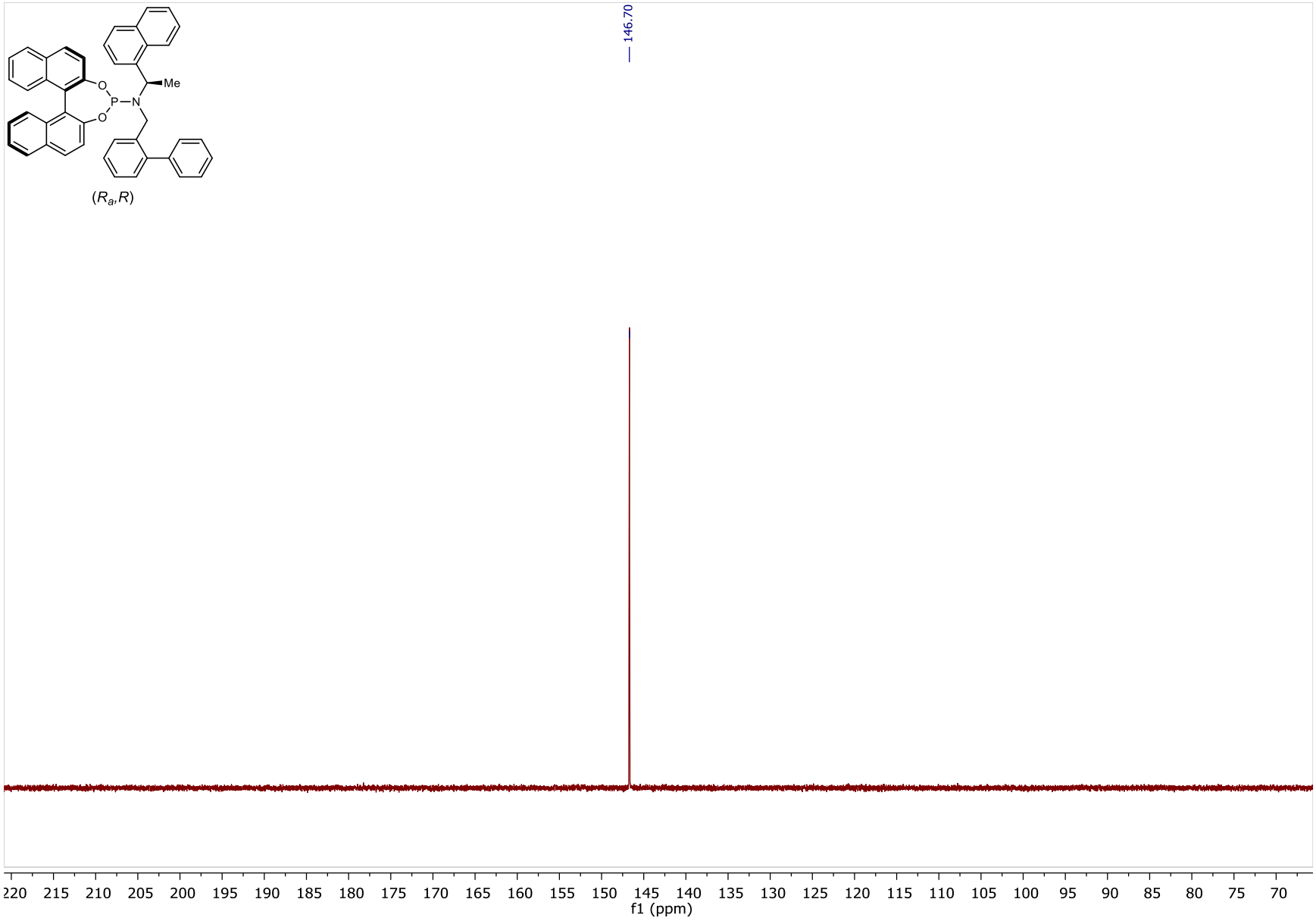

8.37 8.36 8.05 8.03 7.97 7.95 7.88 7.87 7.85 7.83 7.82 7.82 7.80 7.79 7.77 7.66 7.65 7.63 7.61 7.46 7.46 7.45 7.45 7.44 7.44 7.44 7.44 7.43 7.43 7.43 7.42 7.42 7.41 7.41 7.41 7.40 7.38 7.38 7.38 7.37 7.37 7.37 7.36 7.36 7.35 7.29 7.29 7.28 7.28 7.27 7.26 7.26 7.26 7.25 7.25 7.25 7.24 7.24 7.24 7.21 7.20 7.20 7.20 7.19 7.18 7.16 7.15 6.92 6.90 6.89 6.68 6.67 4.93 4.92 4.91 4.89 4.32 4.29 3.60 3.60 3.58 3.58 1.80 1.79 1.79 1.78 1.67
Me
Me
Me
O
O
P
N
(R_a,R)
1.01 1.01 1.07 2.07 2.01 1.04 1.01 1.02 5.20 2.31 1.01 0.98 1.04 2.01 1.00 1.00 1.03 3.09 5.94
10.0 9.5 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 0.0
f1 (ppm)

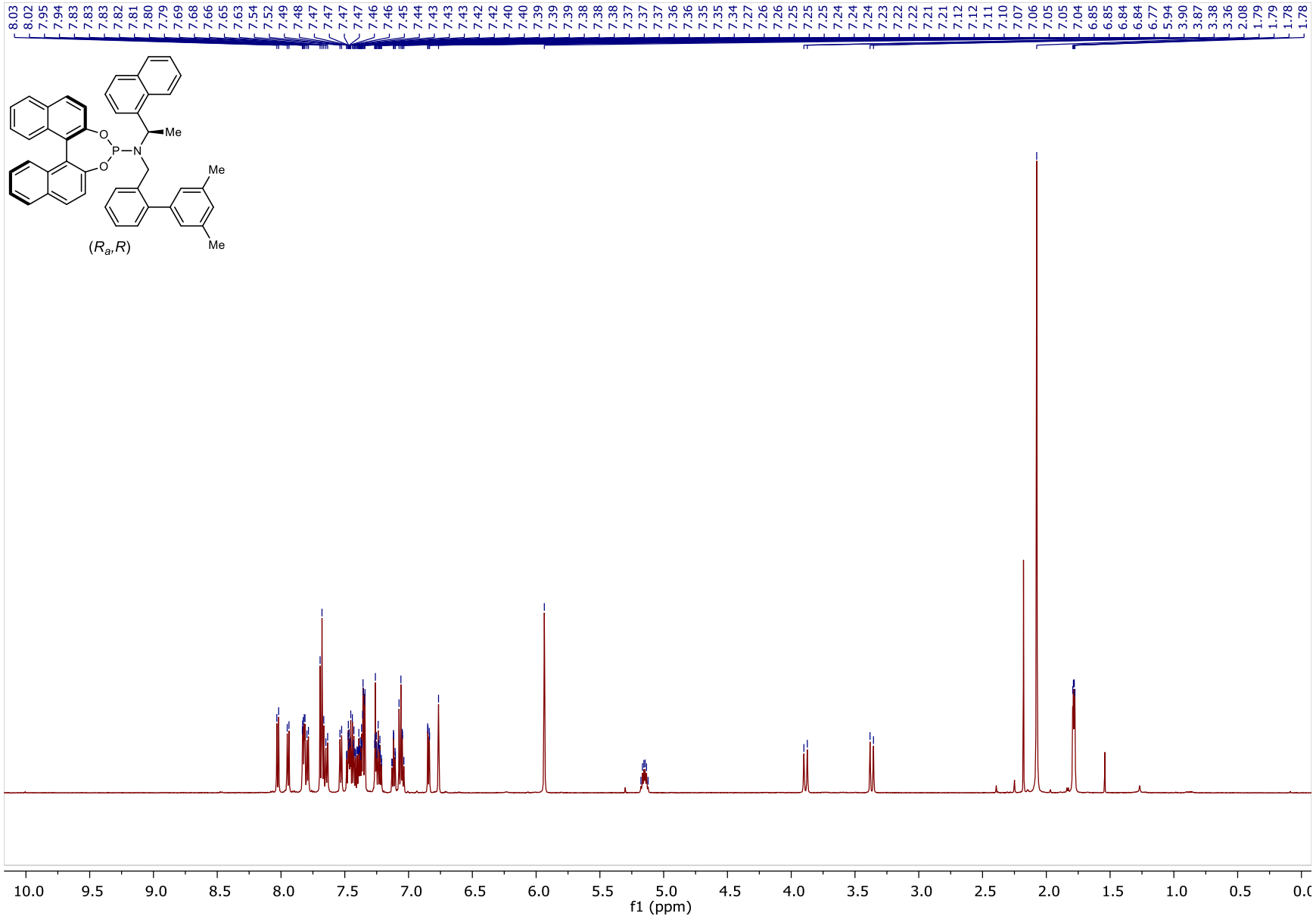

Me
Me
Me
O
O
P
N
(R_a,R)
151.46
151.42
149.76
140.76
138.56
133.98
133.03
132.71
132.21
131.58
130.98
130.66
130.45
130.02
128.71
128.49
128.47
128.28
127.79
127.19
127.16
126.26
126.21
125.89
125.73
125.55
124.93
124.67
124.27
124.23
124.03
124.01
122.61
122.59
122.45
122.44
122.18
121.93
52.10
51.95
43.25
43.23
24.76
24.52
19.59
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

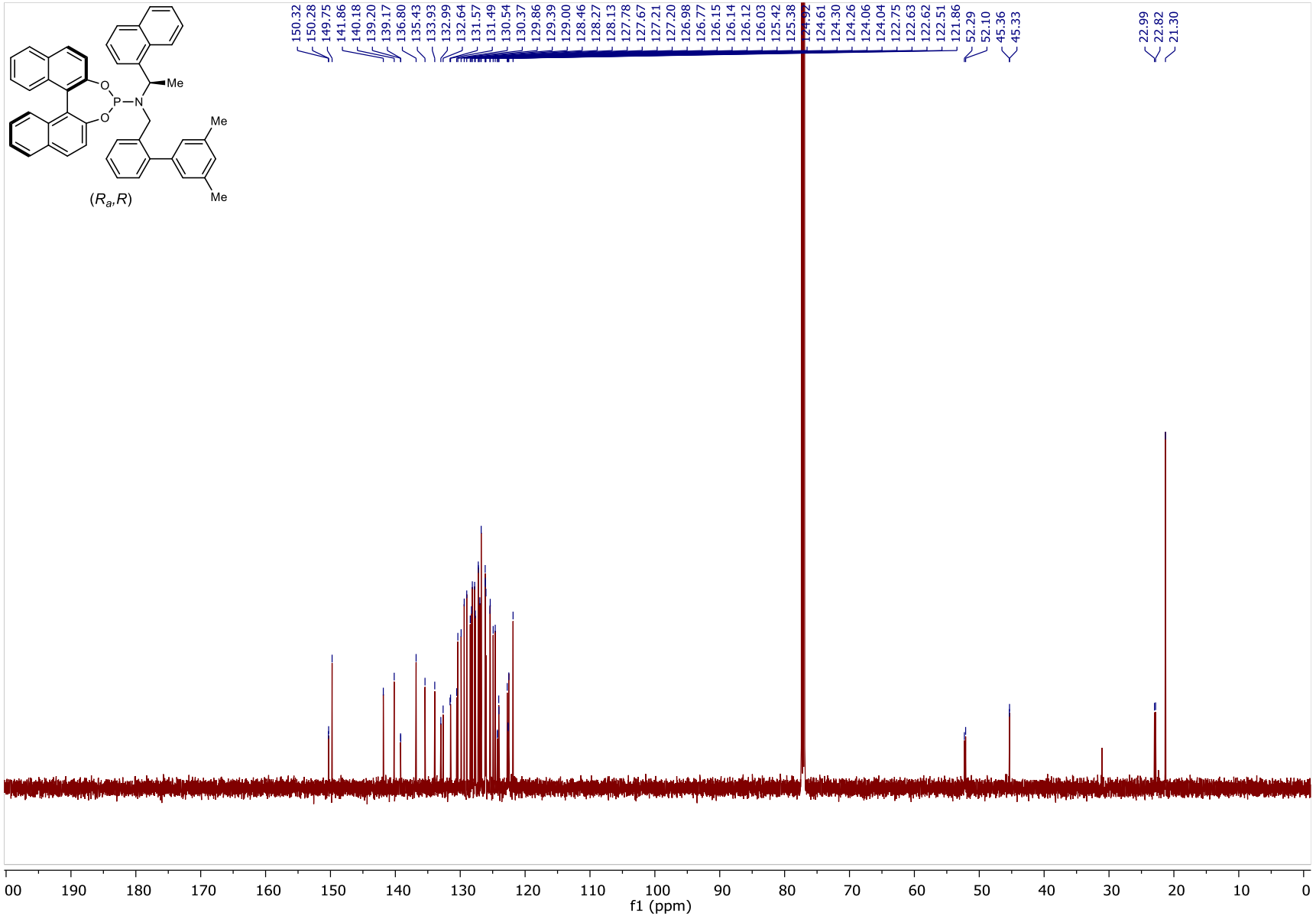

147.66
Me
Me
Me
O
P
N
O
(R_a,R)
158
157
156
155
154
153
152
151
150
149
148
147
146
145
144
143
142
141
140
139
138
137
f1 (ppm)

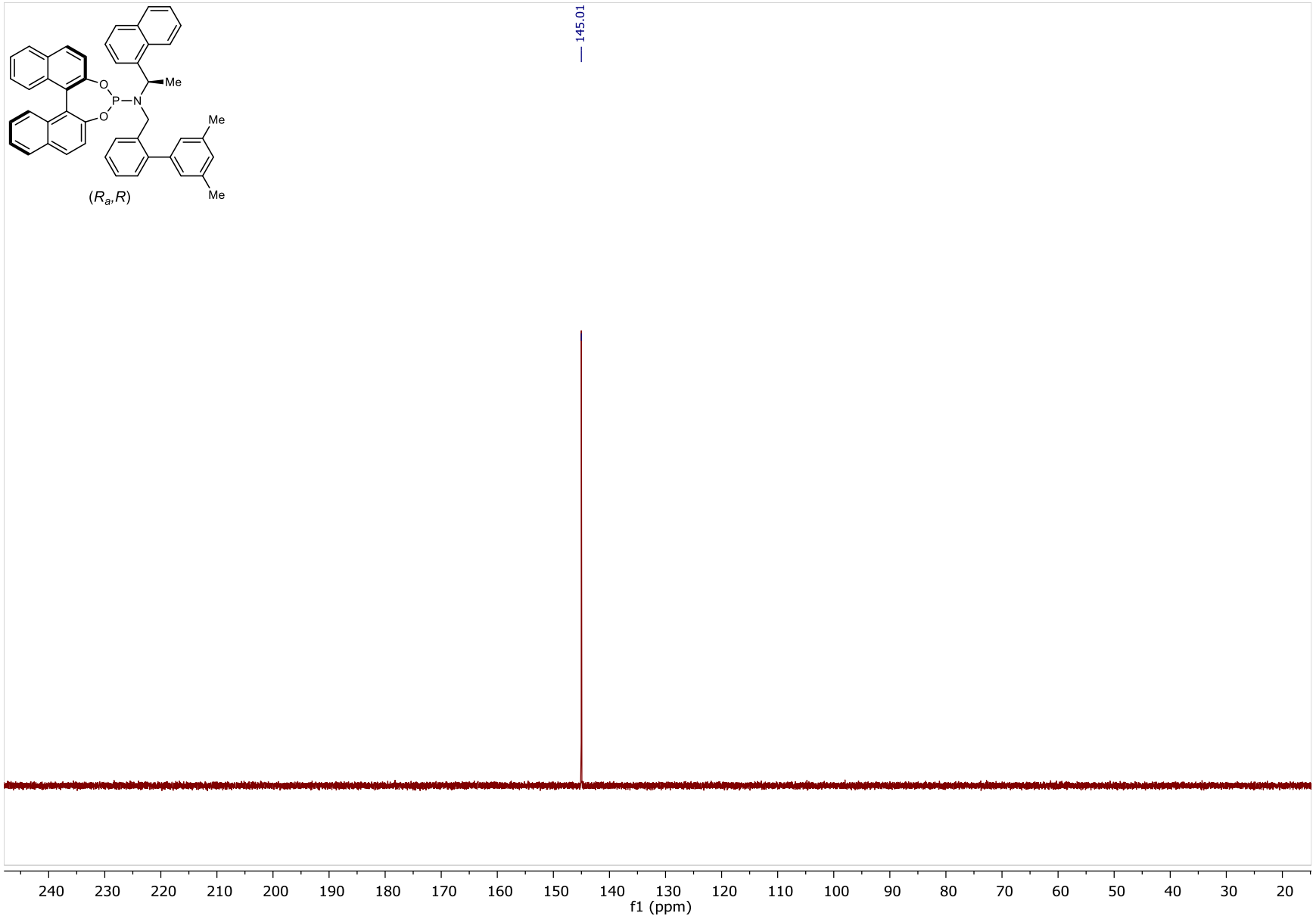

Me
O
P
N
O
(R_a,R)
f1 (ppm)

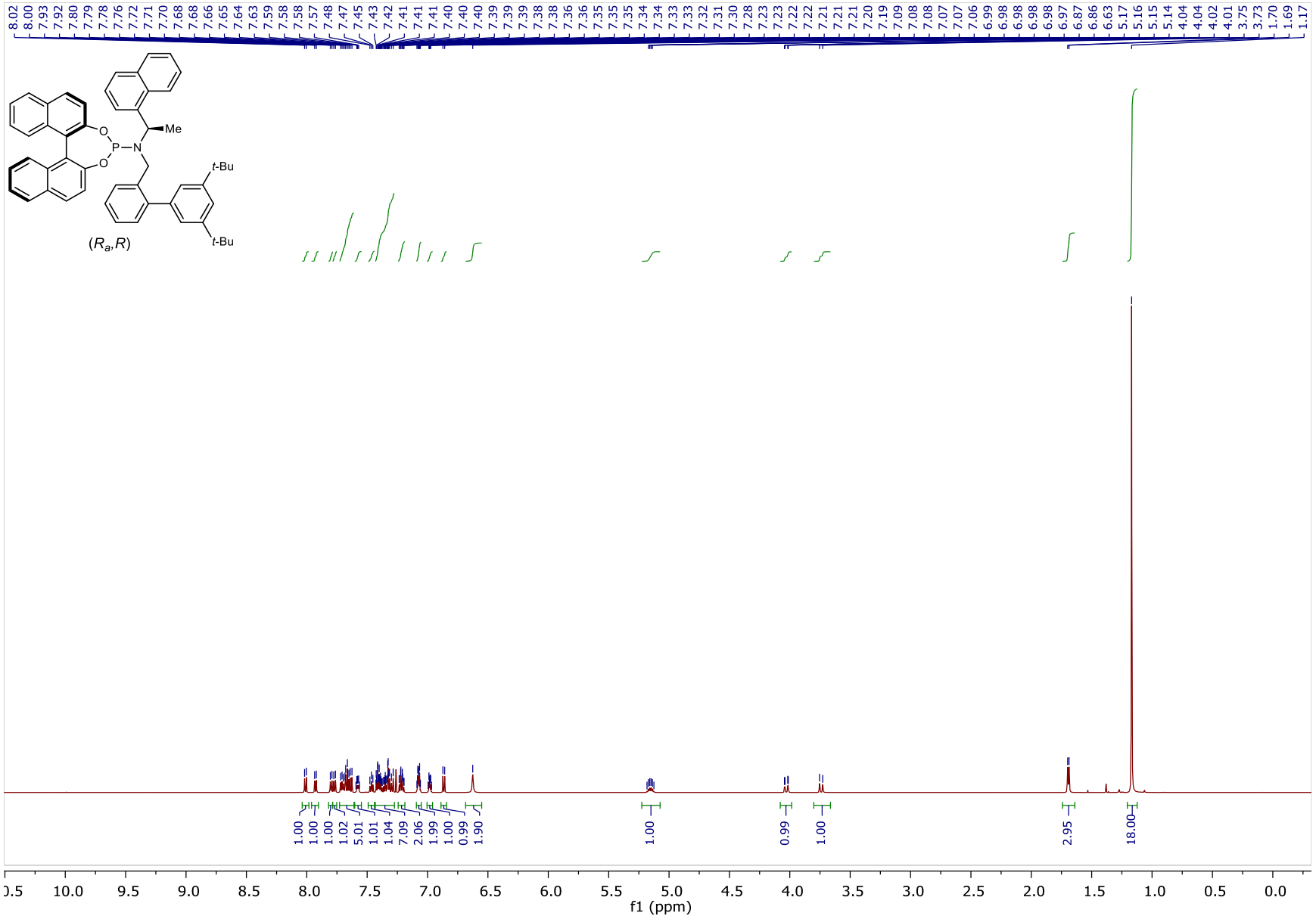

150.39
150.36
149.77
141.13
140.14
138.93
138.89
135.45
133.90
132.99
132.62
131.60
131.56
130.69
130.35
130.18
129.31
128.94
128.88
128.46
128.17
127.88
127.47
127.23
127.18
127.13
127.02
126.54
126.25
126.19
126.10
126.07
125.43
125.28
124.92
124.77
124.21
124.17
124.15
122.71
122.70
122.68
122.46
121.85
52.06
51.87
45.54
45.51
22.64
22.48
Me
O
P
N
O
(R_a,R)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

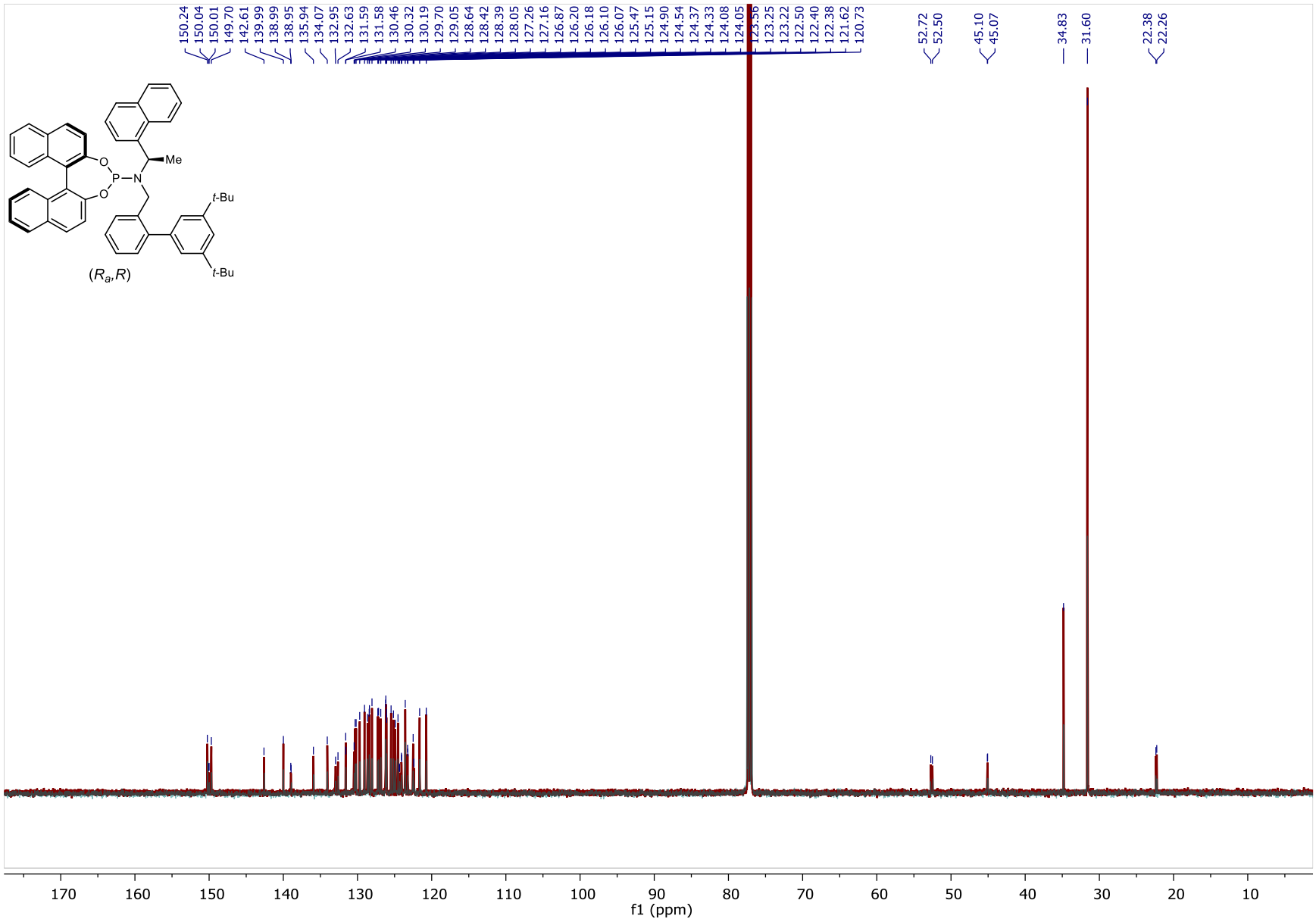

146.70
Me
O
P
N
O
(R_a,R)
220 215 210 205 200 195 190 185 180 175 170 165 160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70
f1 (ppm)

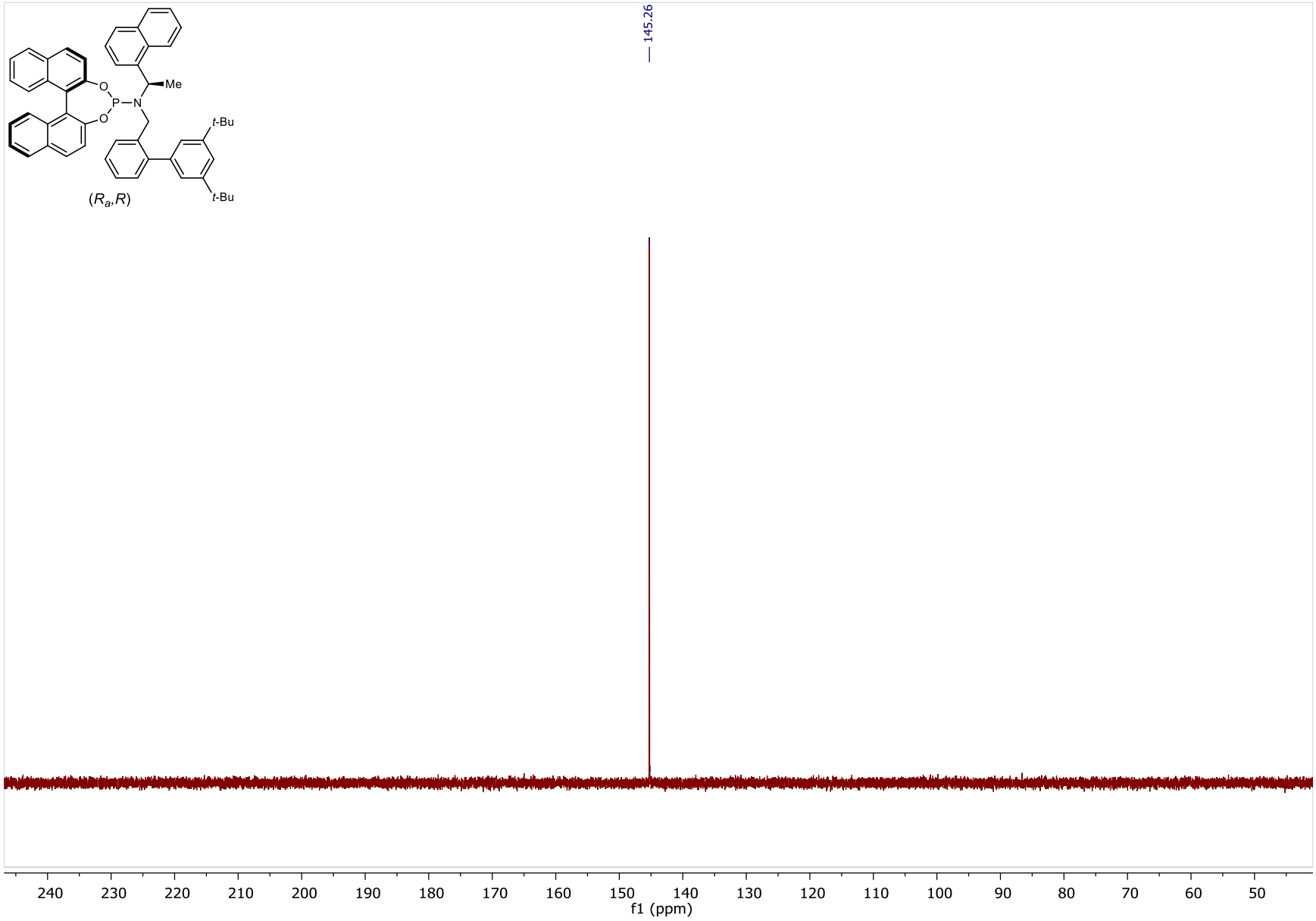

8.03 8.02 7.95 7.94 7.83 7.83 7.83 7.82 7.81 7.80 7.79 7.69 7.68 7.66 7.65 7.63 7.54 7.52 7.49 7.48 7.47 7.47 7.47 7.47 7.46 7.46 7.45 7.44 7.43 7.43 7.43 7.42 7.42 7.40 7.40 7.39 7.39 7.39 7.38 7.38 7.38 7.37 7.37 7.37 7.36 7.36 7.35 7.35 7.34 7.27 7.26 7.26 7.25 7.25 7.25 7.24 7.24 7.24 7.24 7.23 7.22 7.22 7.21 7.21 7.12 7.12 7.11 7.10 7.07 7.06 7.05 7.05 7.04 6.85 6.84 6.84 6.77 5.94 3.90 3.87 3.38 3.36 2.08 1.79 1.79 1.78 1.78
Me
O
P
N
O
Me
Me
(R_a,R)
10.0 9.5 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
f1 (ppm)

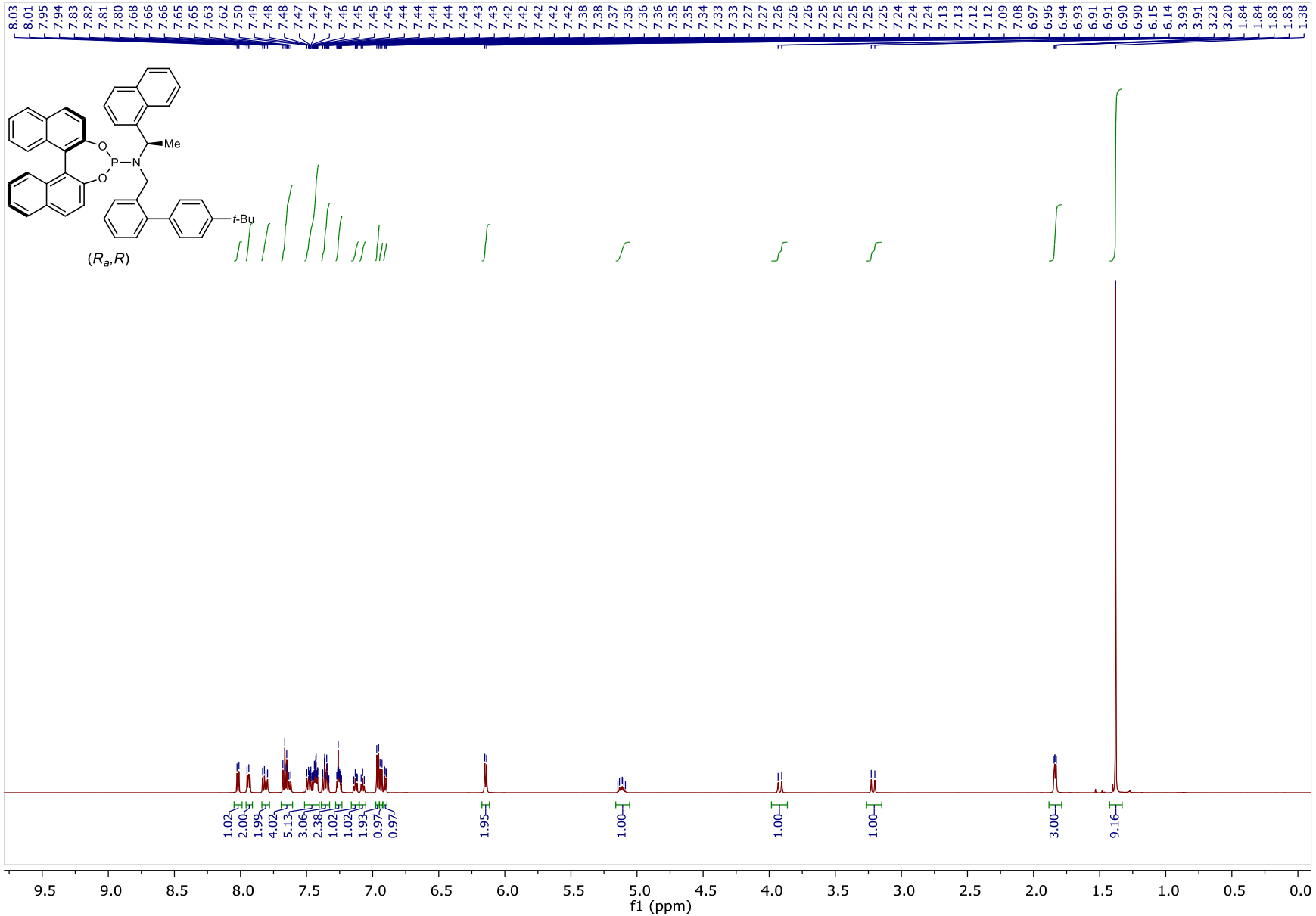

Me
O
P
N
O
Me
Me
(R_a,R)
150.32
150.28
149.75
141.86
140.18
139.20
139.17
136.80
135.43
133.93
132.99
132.64
131.57
131.49
130.54
130.37
129.86
129.39
129.00
128.46
128.27
128.13
127.78
127.67
127.21
127.20
126.98
126.77
126.15
126.14
126.12
126.03
125.42
125.38
124.92
124.61
124.30
124.26
124.06
124.04
122.75
122.63
122.62
122.51
121.86
52.29
52.10
45.36
45.33
22.99
22.82
21.30
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

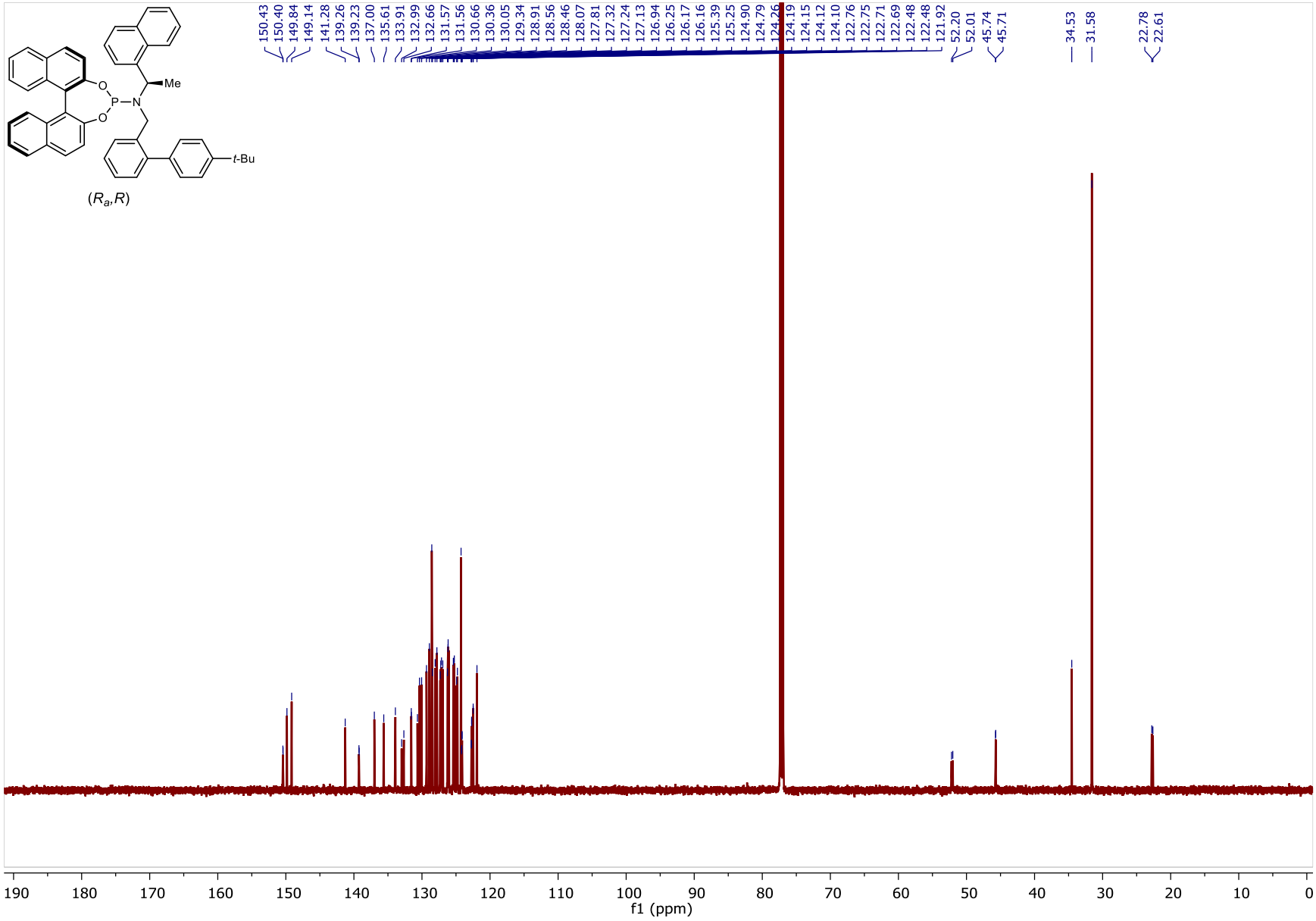

145.01
Me
O
P
N
O
Me
Me
(R_a,R)
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
f1 (ppm)

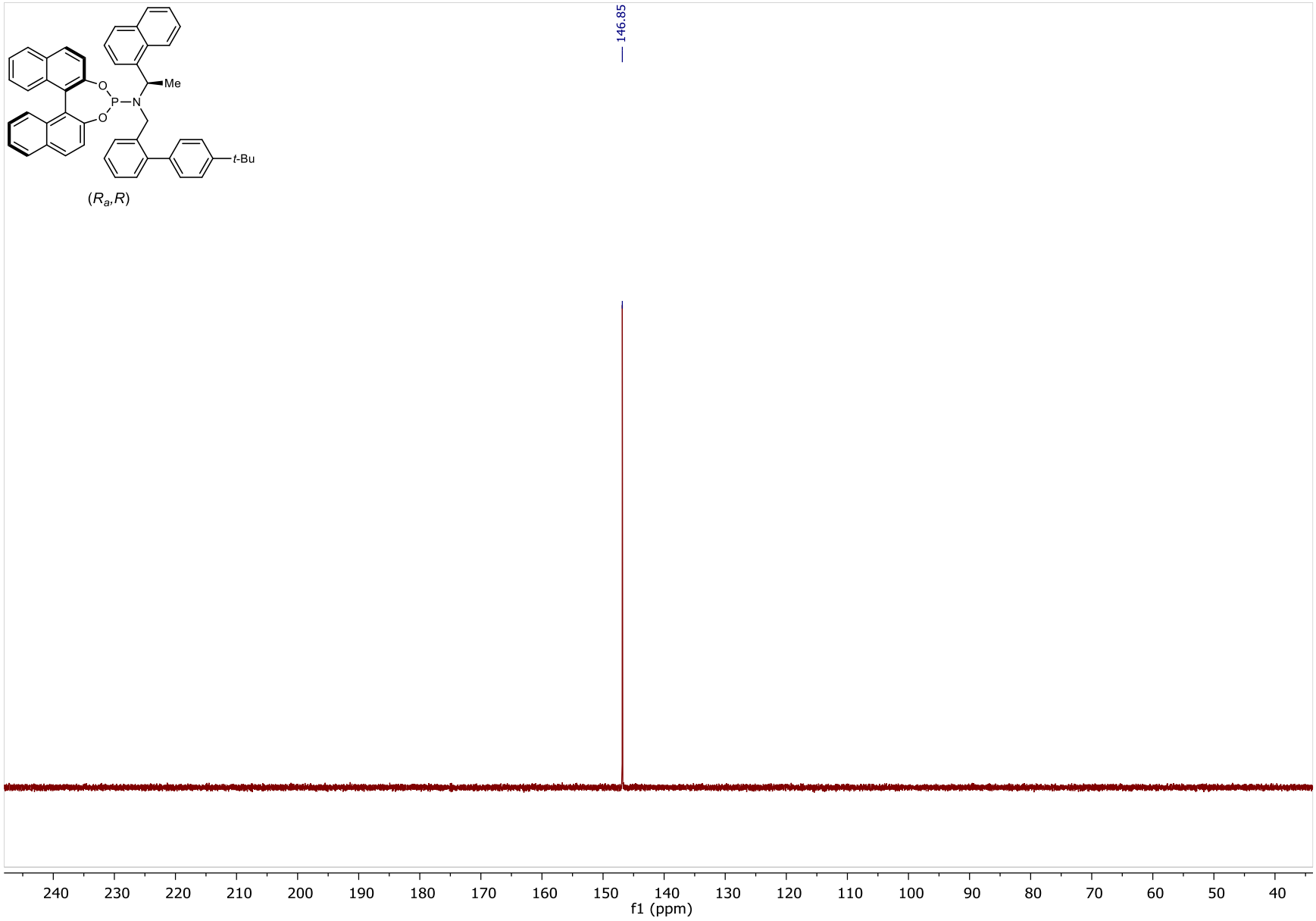

Me
t-Bu
t-Bu
(R_a,R)
f1 (ppm)

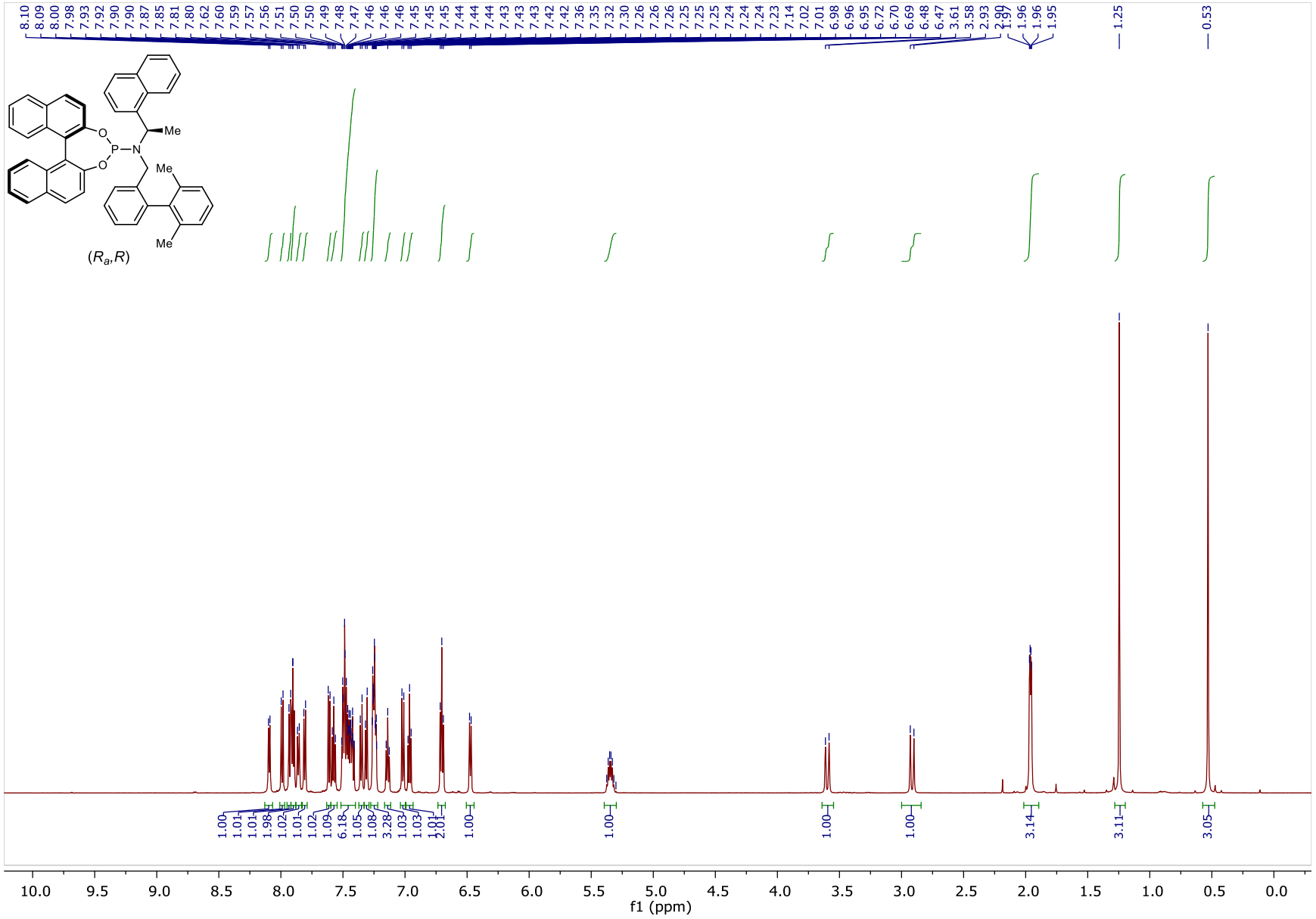

150.24
150.04
150.01
149.70
142.61
139.99
138.99
138.95
135.94
134.07
132.95
132.63
131.59
131.58
130.46
130.32
130.19
129.70
129.05
128.64
128.42
128.39
128.05
127.26
127.16
126.87
126.20
126.18
126.10
126.07
125.47
125.15
124.90
124.54
124.37
124.33
124.08
124.05
123.56
123.25
123.22
122.50
122.40
122.38
121.62
120.73
52.72
52.50
45.10
45.07
34.83
31.60
22.38
22.26
Me
t-Bu
t-Bu
(R_a,R)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

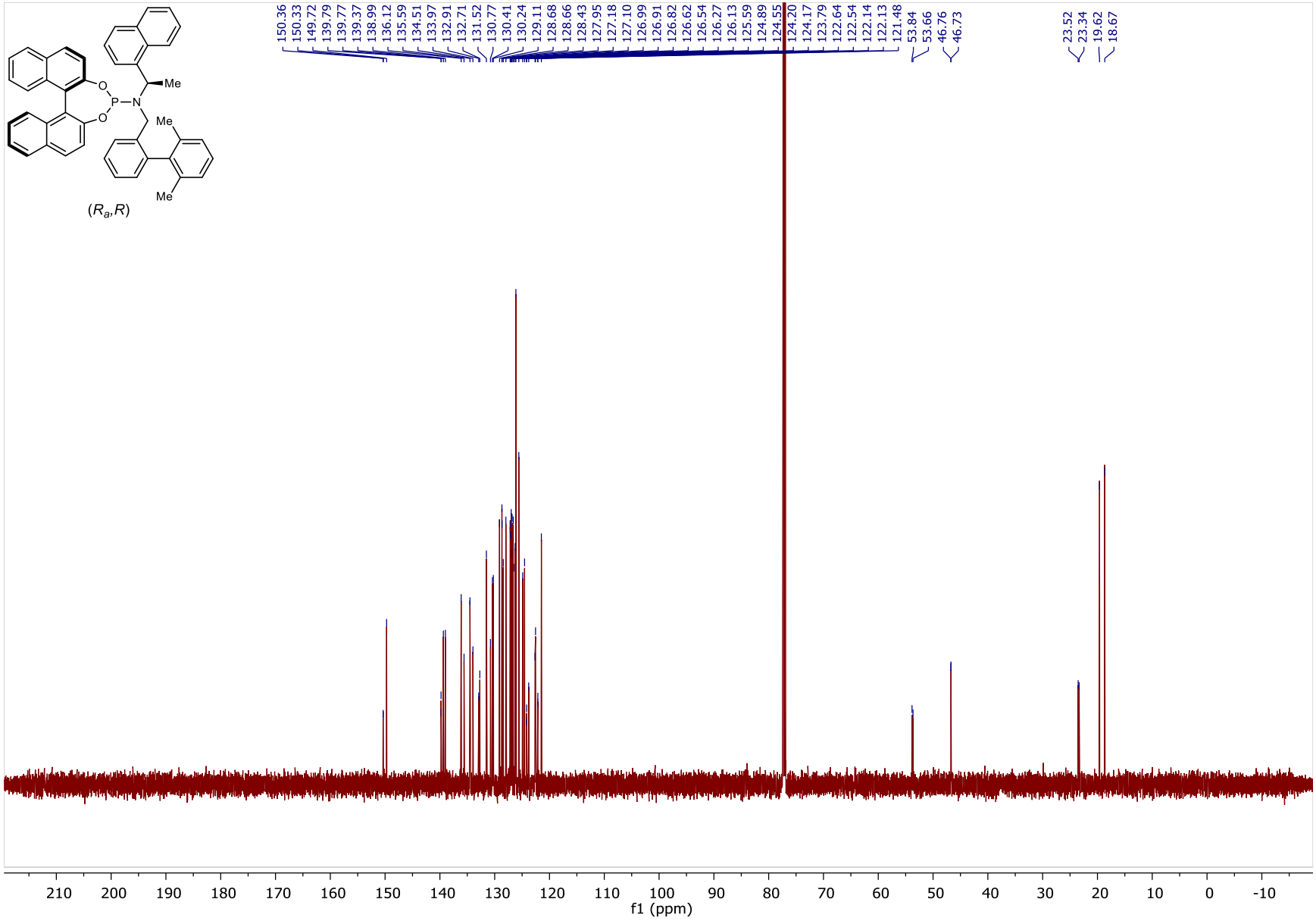

145.26
Me
O
P
N
O
t-Bu
t-Bu
(Ra,R)
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
f1 (ppm)

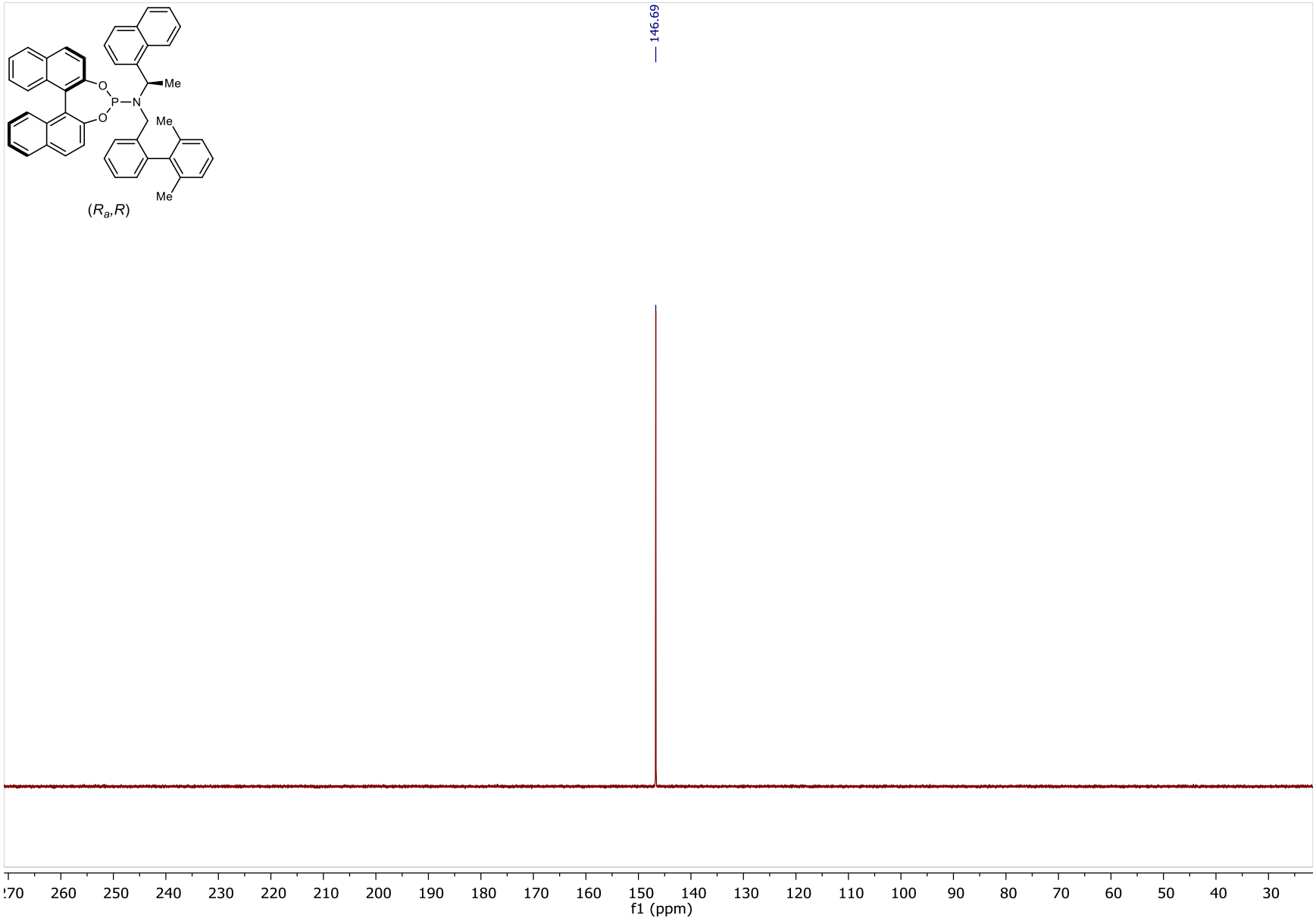

8.03 8.01 7.95 7.94 7.83 7.82 7.81 7.80 7.68 7.66 7.66 7.65 7.65 7.63 7.62 7.50 7.49 7.48 7.48 7.47 7.47 7.47 7.46 7.45 7.45 7.45 7.44 7.44 7.44 7.44 7.43 7.43 7.43 7.42 7.42 7.42 7.42 7.42 7.38 7.38 7.37 7.36 7.36 7.36 7.35 7.35 7.34 7.33 7.33 7.27 7.27 7.26 7.26 7.26 7.25 7.25 7.25 7.25 7.25 7.24 7.24 7.24 7.13 7.13 7.12 7.12 7.09 7.08 6.97 6.96 6.94 6.93 6.91 6.91 6.90 6.90 6.90 6.15 6.14 3.93 3.91 3.23 3.20 1.84 1.84 1.83 1.83 1.38
Me
P
N
O
O
t-Bu
(Ra,R)
1.02 2.00 1.99 4.02 5.13 3.06 2.38 1.02 1.02 1.93 0.97 0.97
1.95
1.00
1.00
1.00
3.00
9.16
9.5 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 0.0
f1 (ppm)

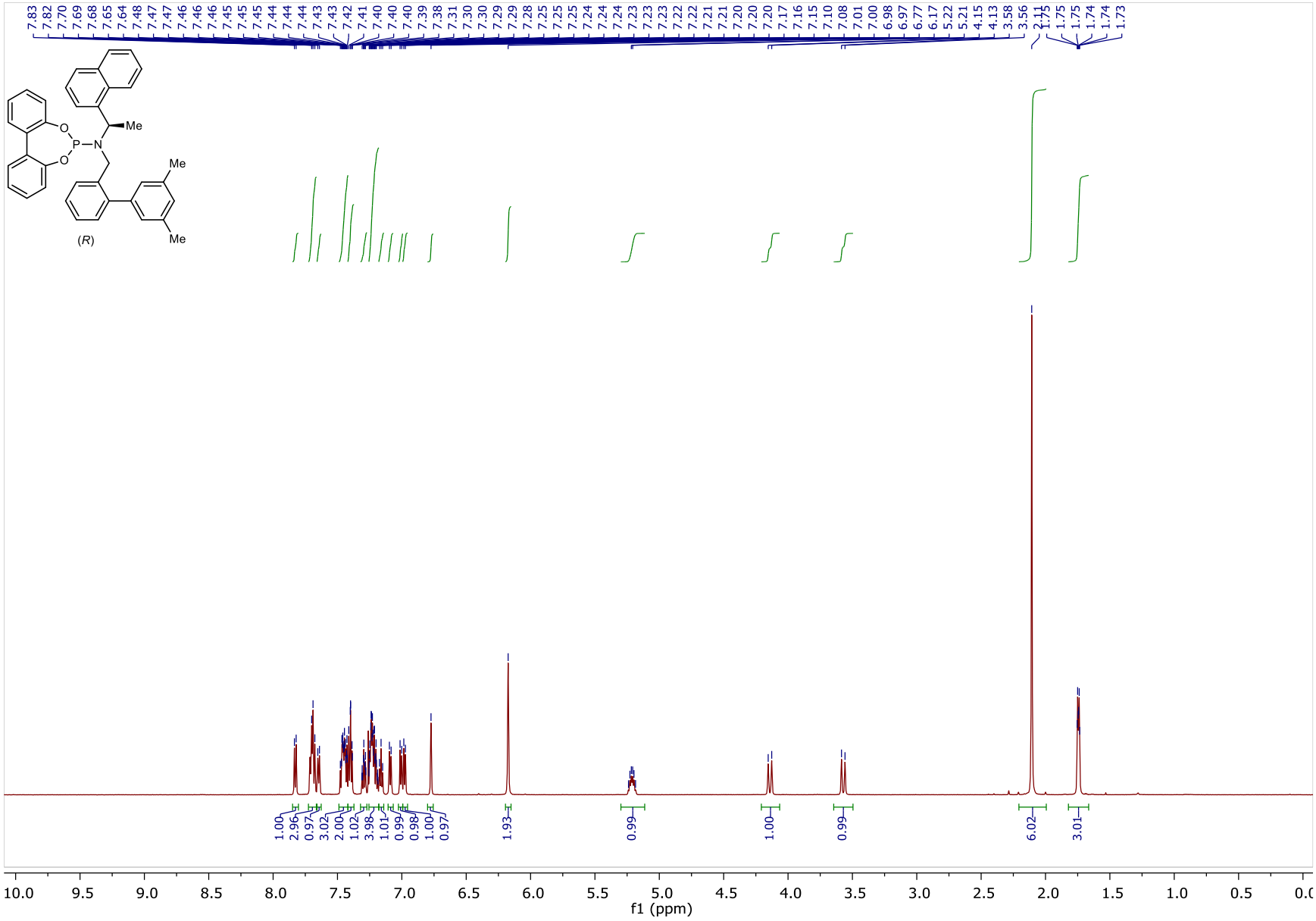

Me
O
P
N
O
t-Bu
(R_a,R)
150.43
150.40
149.84
149.14
141.28
139.26
139.23
137.00
135.61
133.91
132.99
132.66
131.57
131.56
130.66
130.36
130.05
129.34
128.91
128.56
128.46
128.07
127.81
127.32
127.24
127.13
126.94
126.25
126.17
126.16
125.39
125.25
124.90
124.79
124.26
124.19
124.15
124.12
124.10
122.76
122.75
122.71
122.69
122.48
122.48
121.92
52.20
52.01
45.74
45.71
34.53
31.58
22.78
22.61
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

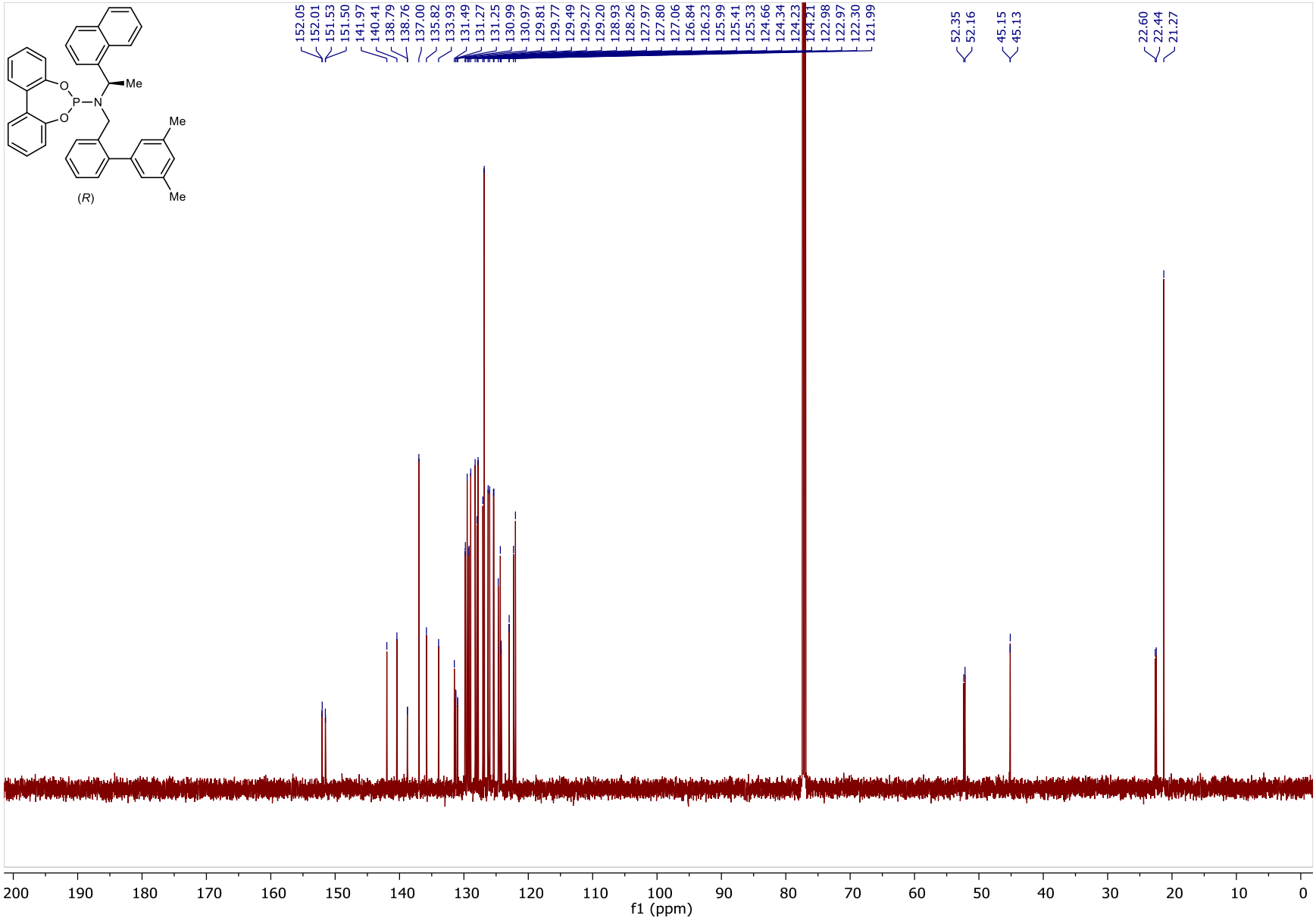

146.85
Me
O
P
N
O
t-Bu
(Ra,R)
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
f1 (ppm)

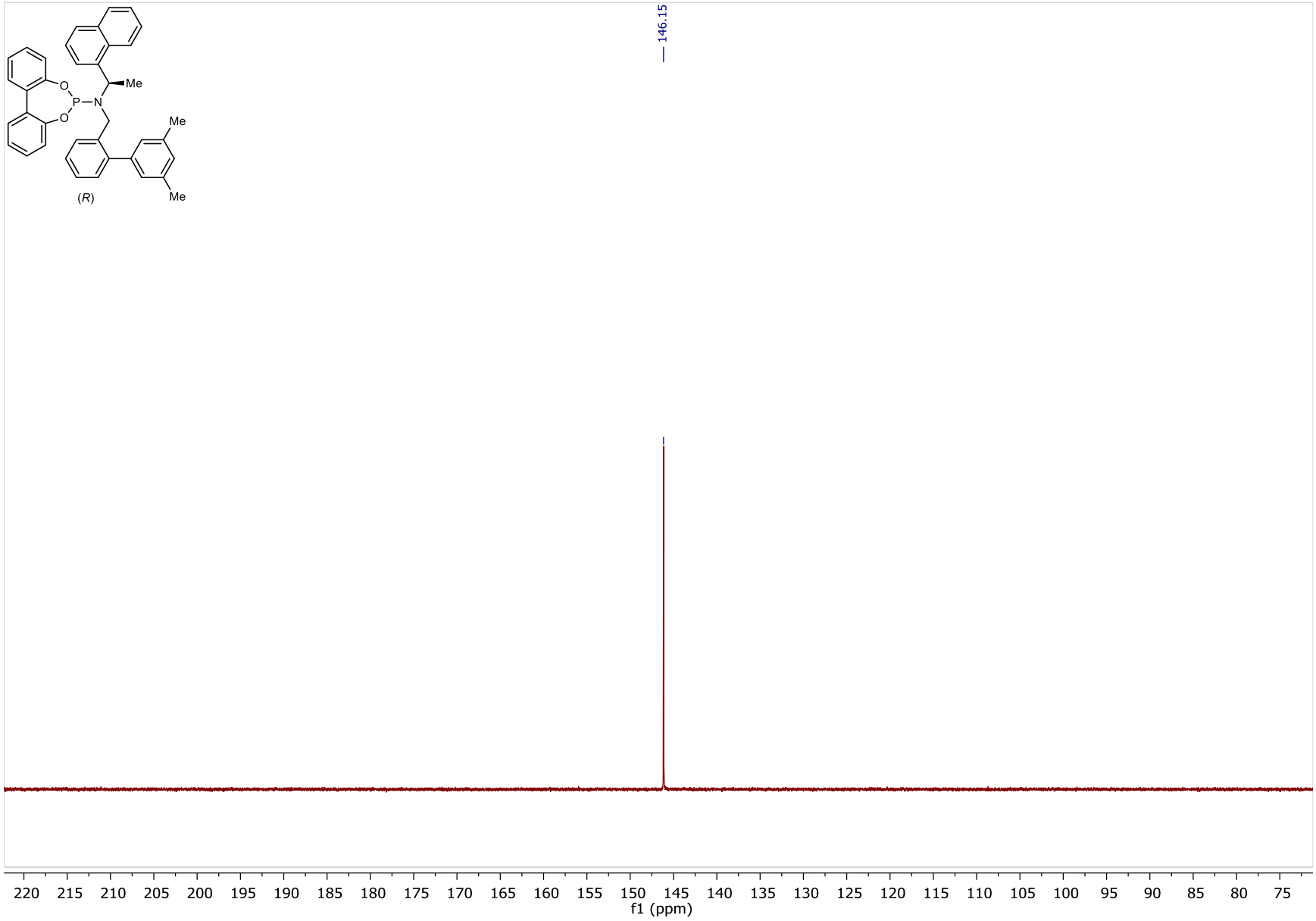

8.10 8.09 8.00 7.98 7.93 7.92 7.90 7.90 7.87 7.85 7.81 7.80 7.62 7.60 7.59 7.57 7.56 7.51 7.50 7.50 7.49 7.48 7.47 7.46 7.46 7.46 7.45 7.45 7.45 7.44 7.44 7.44 7.43 7.43 7.43 7.42 7.42 7.36 7.35 7.32 7.30 7.26 7.26 7.26 7.25 7.25 7.25 7.24 7.24 7.24 7.23 7.14 7.02 7.01 6.98 6.96 6.95 6.72 6.70 6.69 6.48 6.47 3.61 3.58 2.93 2.90 1.97 1.96 1.96 1.95
1.25
0.53
Me
Me
Me
O
P
N
O
(Ra,R)
1.00 1.01 1.01 1.98 1.02 1.01 1.02 1.09 6.18 1.05 1.08 3.28 1.03 1.03 1.01 2.01 1.00
1.00
1.00
1.00
3.14
3.11
3.05
10.0 9.5 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 0.0
f1 (ppm)

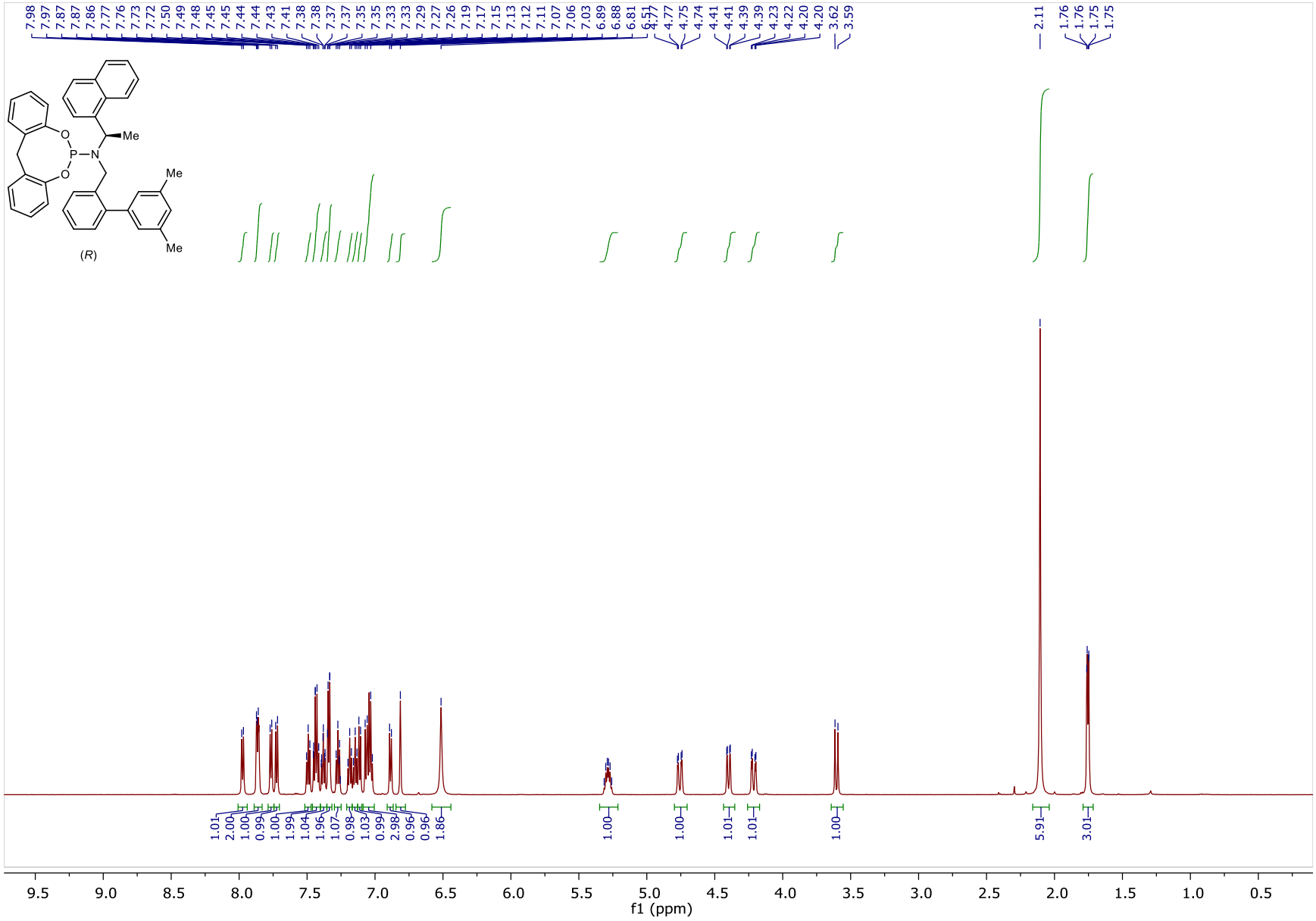

150.36
150.33
149.72
139.79
139.77
139.37
138.99
136.12
135.59
134.51
133.97
132.91
132.71
131.52
130.77
130.41
130.24
129.11
128.68
128.66
128.43
127.95
127.18
127.10
126.99
126.91
126.82
126.62
126.54
126.27
126.13
125.59
124.89
124.55
124.20
124.17
123.79
122.64
122.54
122.14
122.13
121.48
53.84
53.66
46.76
46.73
23.52
23.34
19.62
18.67
O
P
N
O
Me
Me
Me
(R_a,R)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

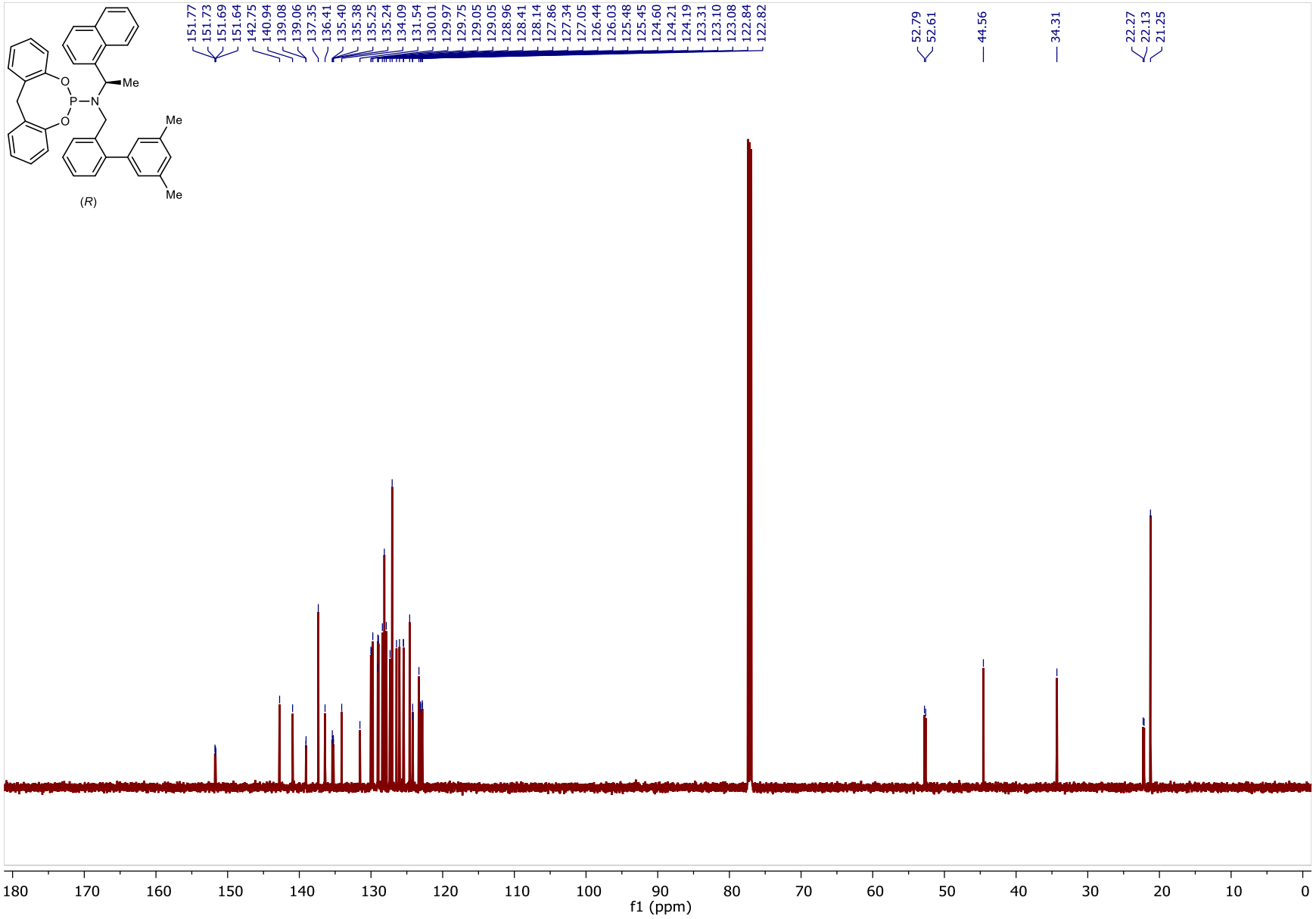

146.69
Me
O
P
N
O
Me
Me
(R_a,R)
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
f1 (ppm)

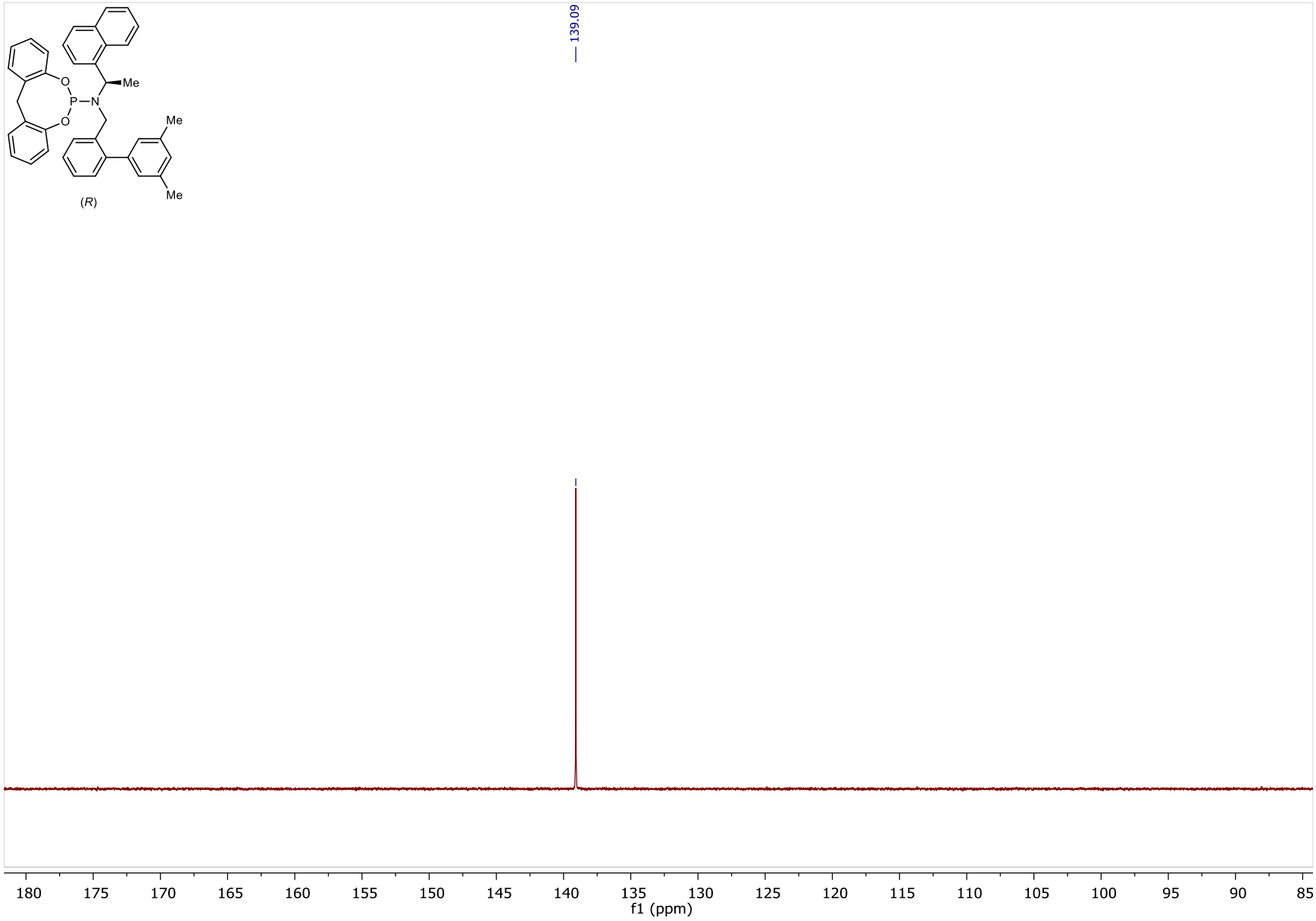

7.83 7.82 7.70 7.69 7.68 7.65 7.64 7.48 7.47 7.47 7.46 7.46 7.46 7.45 7.45 7.45 7.44 7.44 7.44 7.43 7.43 7.42 7.41 7.40 7.40 7.40 7.39 7.38 7.31 7.30 7.30 7.29 7.29 7.28 7.25 7.25 7.24 7.24 7.24 7.23 7.23 7.23 7.22 7.22 7.21 7.21 7.20 7.20 7.20 7.17 7.16 7.15 7.10 7.08 7.01 7.00 6.98 6.97 6.77 6.17 5.22 5.21 4.15 4.13 3.58 3.56 2.11 1.75 1.75 1.74 1.74 1.73
Me
O
P
N
O
Me
Me
(R)
1.00 2.96 0.97 3.02 2.00 1.02 3.98 1.01 0.99 0.98 1.00 0.97 1.93 0.99 1.00 0.99 6.02 3.01
10.0 9.5 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
f1 (ppm)

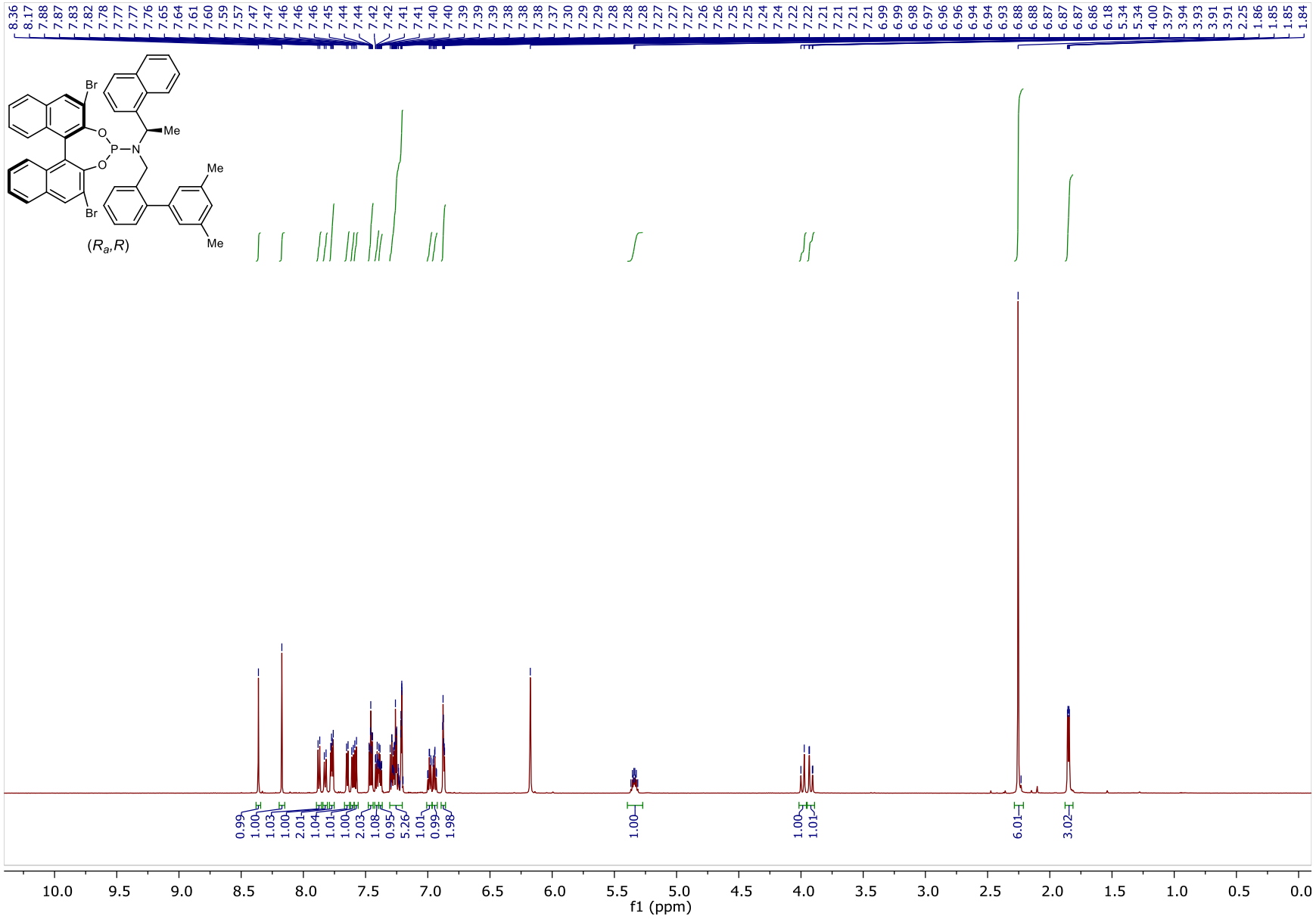

152.05
152.01
151.53
151.50
141.97
140.41
138.79
138.76
137.00
135.82
133.93
131.49
131.27
131.25
130.99
130.97
129.81
129.77
129.49
129.27
129.20
128.93
128.26
127.97
127.80
127.06
126.84
126.23
125.99
125.41
125.33
124.66
124.34
124.23
124.21
122.98
122.97
122.30
121.99
52.35
52.16
45.15
45.13
22.60
22.44
21.27
Me
Me
Me
(R)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

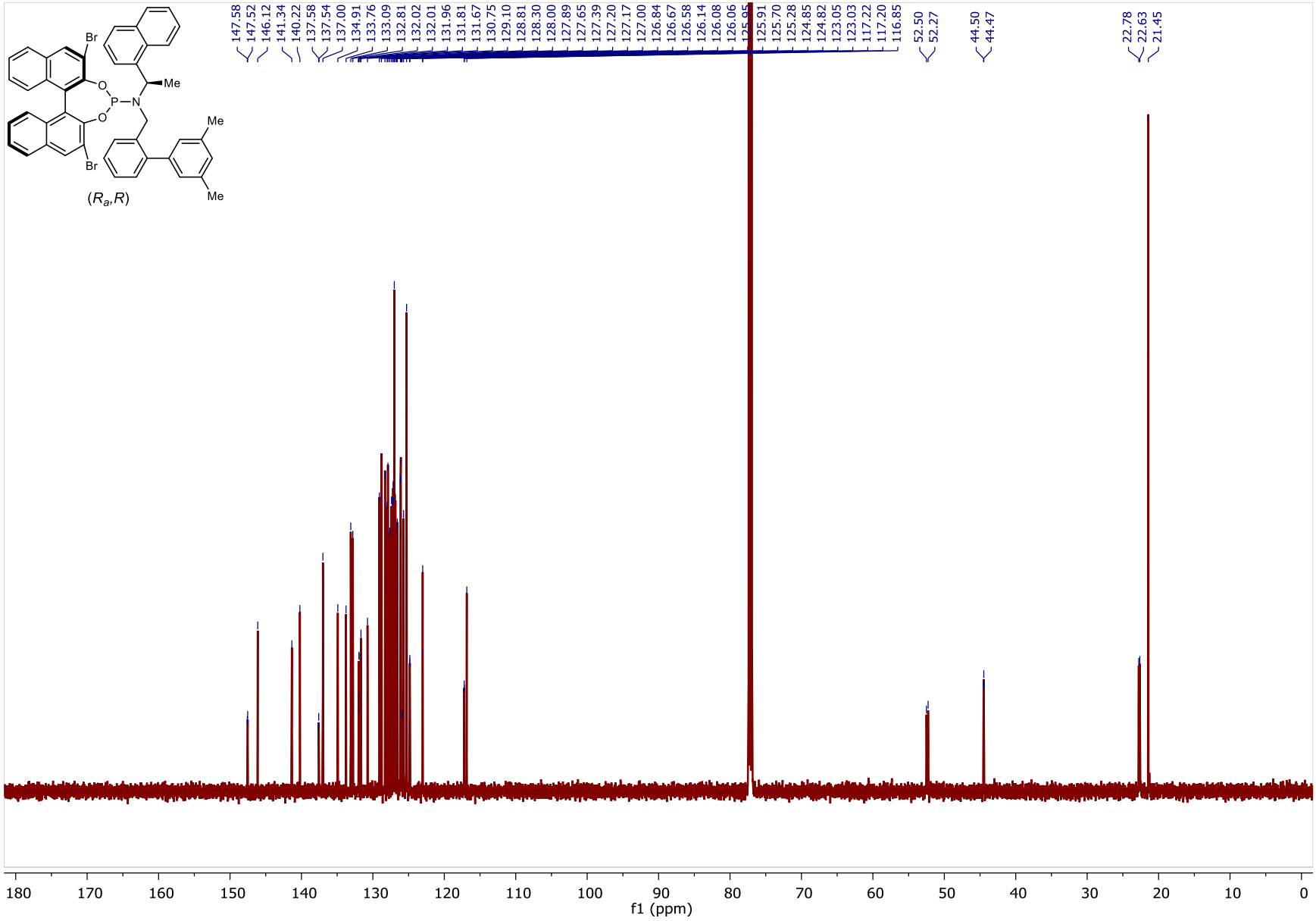

146.15
Me
O
P
N
O
Me
Me
(R)
220 215 210 205 200 195 190 185 180 175 170 165 160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75
f1 (ppm)

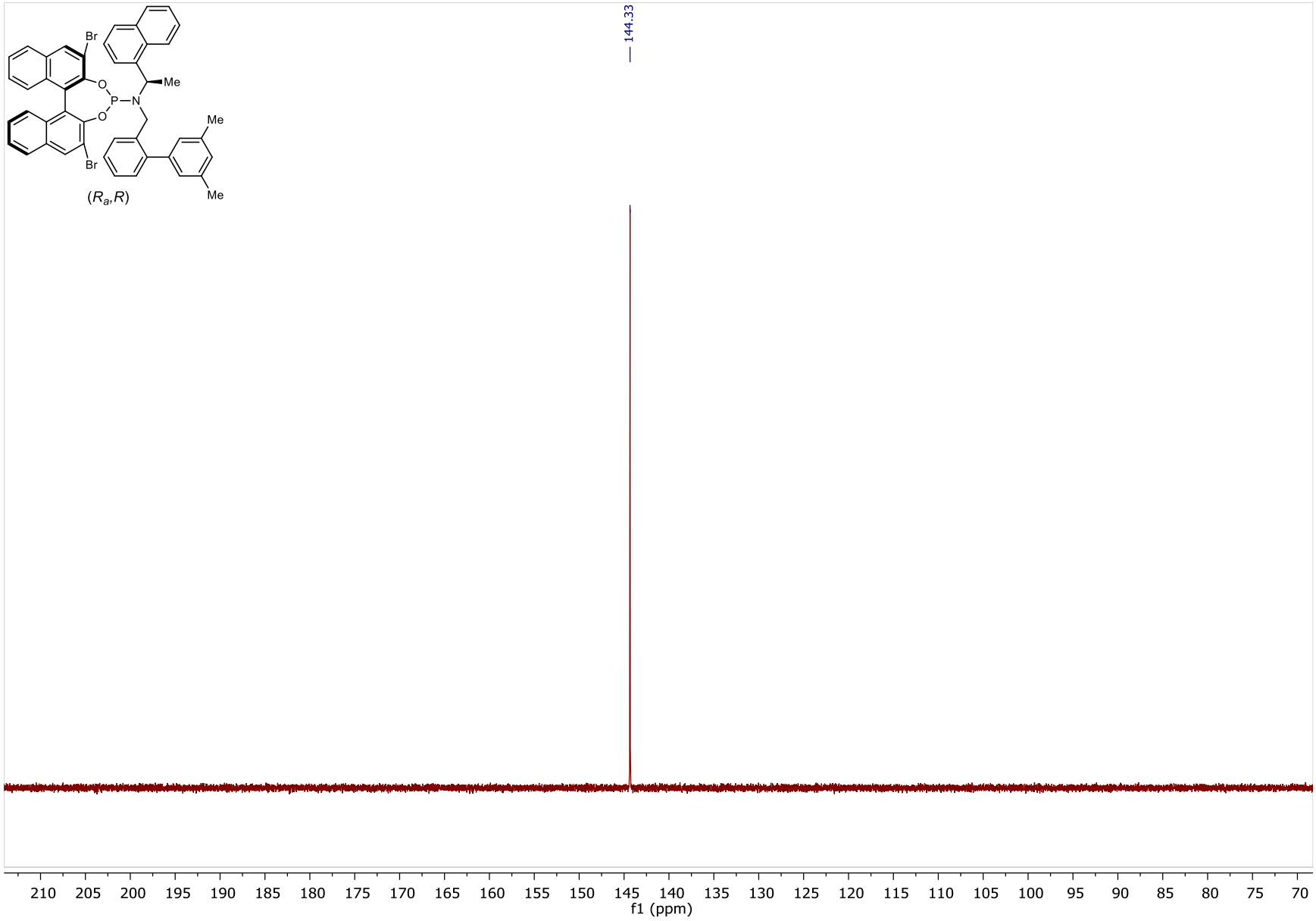

7.98 7.97 7.87 7.87 7.86 7.77 7.76 7.73 7.72 7.50 7.49 7.48 7.45 7.45 7.44 7.44 7.43 7.41 7.38 7.38 7.37 7.37 7.35 7.35 7.33 7.29 7.27 7.26 7.19 7.17 7.15 7.13 7.12 7.11 7.07 7.06 7.03 6.89 6.88 6.81 6.51 4.77 4.75 4.74 4.41 4.41 4.39 4.39 4.23 4.22 4.20 4.20 3.62 3.59
2.11 1.76 1.76 1.75 1.75
Me
Me
Me
(R)
1.01 2.00 1.00 0.99 1.00 1.99 1.04 1.96 1.07 0.98 1.03 0.99 2.98 0.96 0.96 1.86
1.00 1.00 1.01 1.01 1.00
5.91 3.01
9.5 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
f1 (ppm)

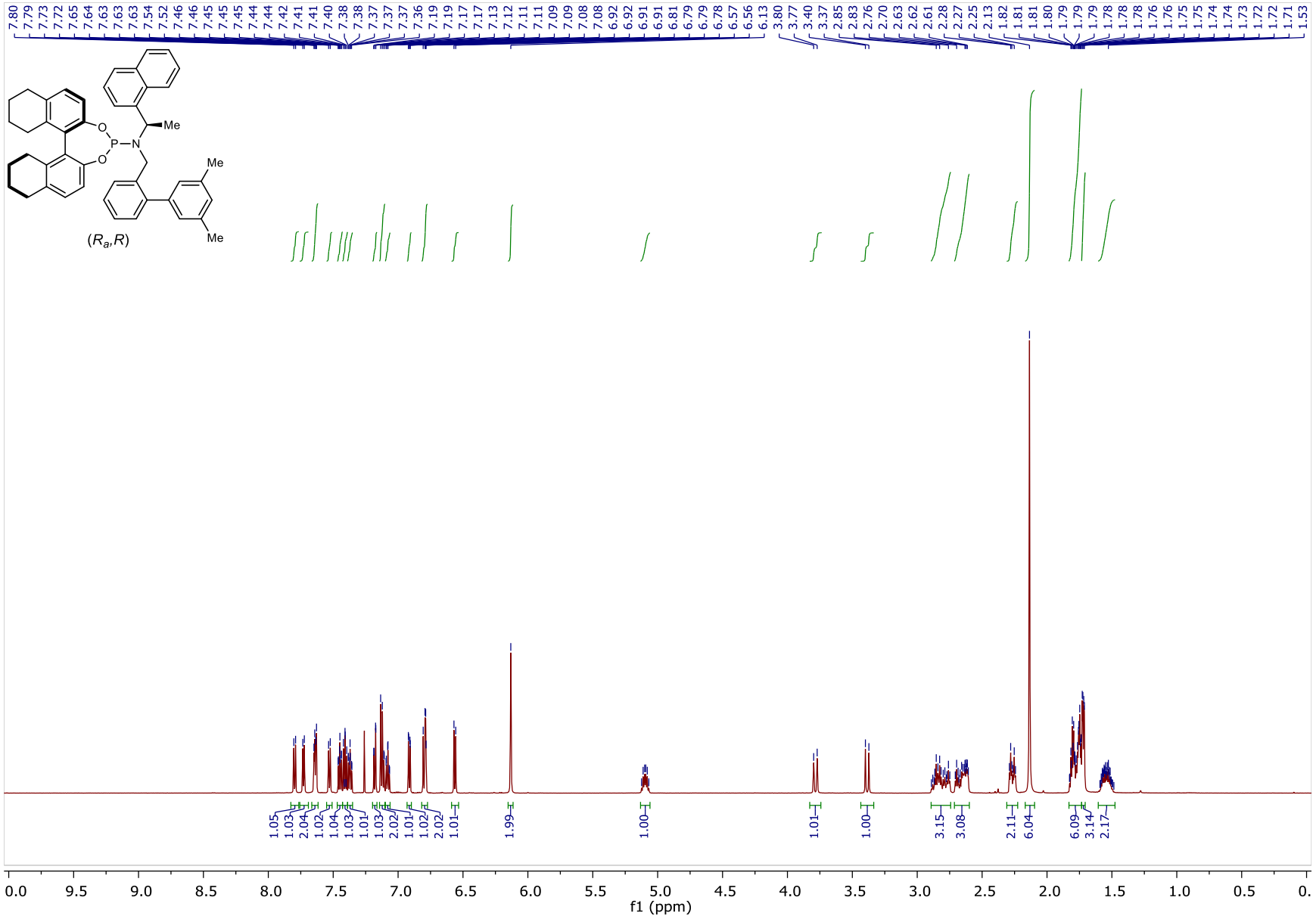

151.77
151.73
151.69
151.64
142.75
140.94
139.08
139.06
137.35
136.41
135.40
135.38
135.25
135.24
134.09
131.54
130.01
129.97
129.75
129.05
129.05
128.96
128.41
128.14
127.86
127.34
127.05
126.44
126.03
125.48
125.45
124.60
124.21
124.19
123.31
123.10
123.08
122.84
122.82
52.79
52.61
44.56
34.31
22.27
22.13
21.25
Me
Me
Me
(R)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

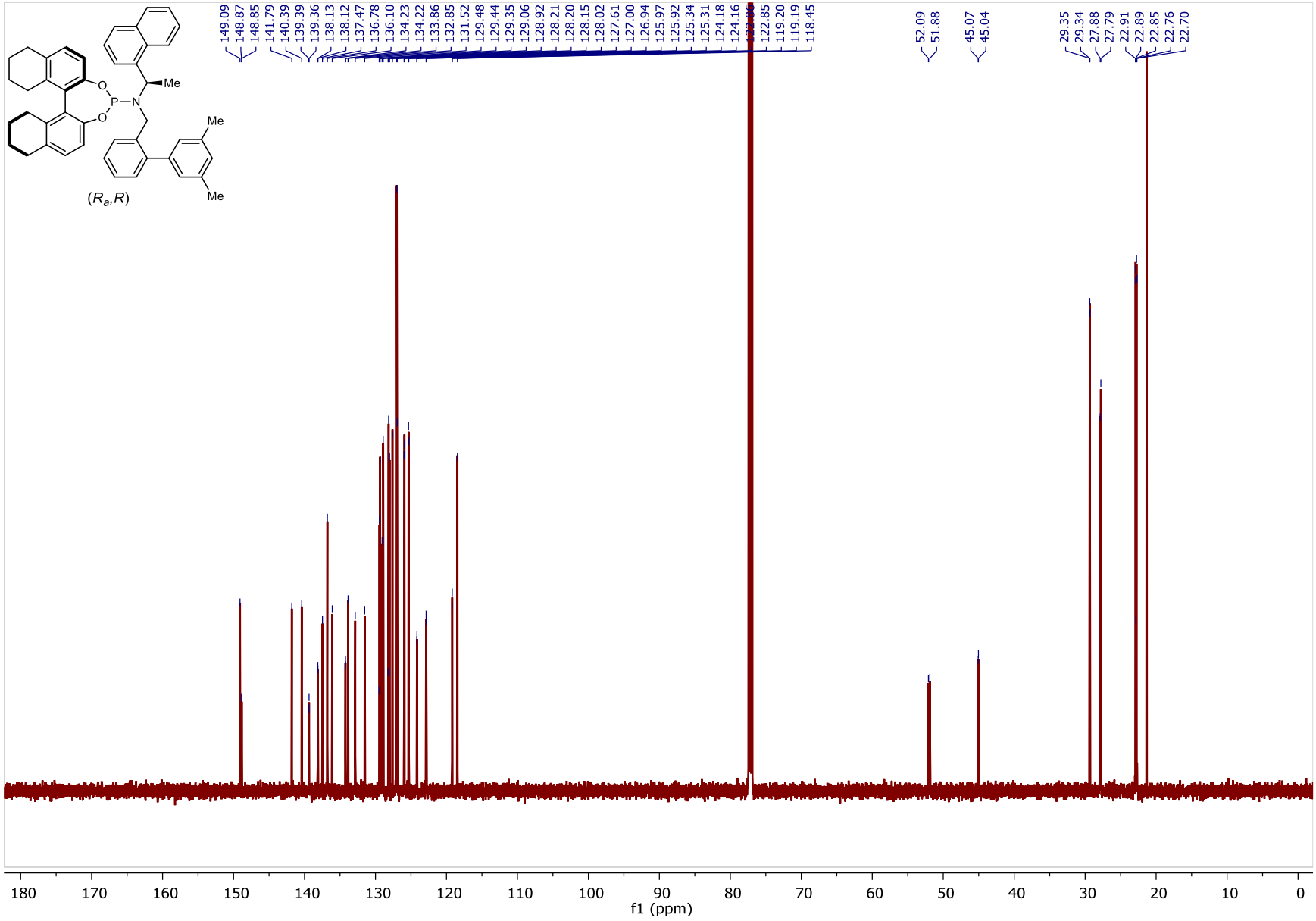

139.09
Me
O
P
N
O
Me
Me
(R)
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
f1 (ppm)

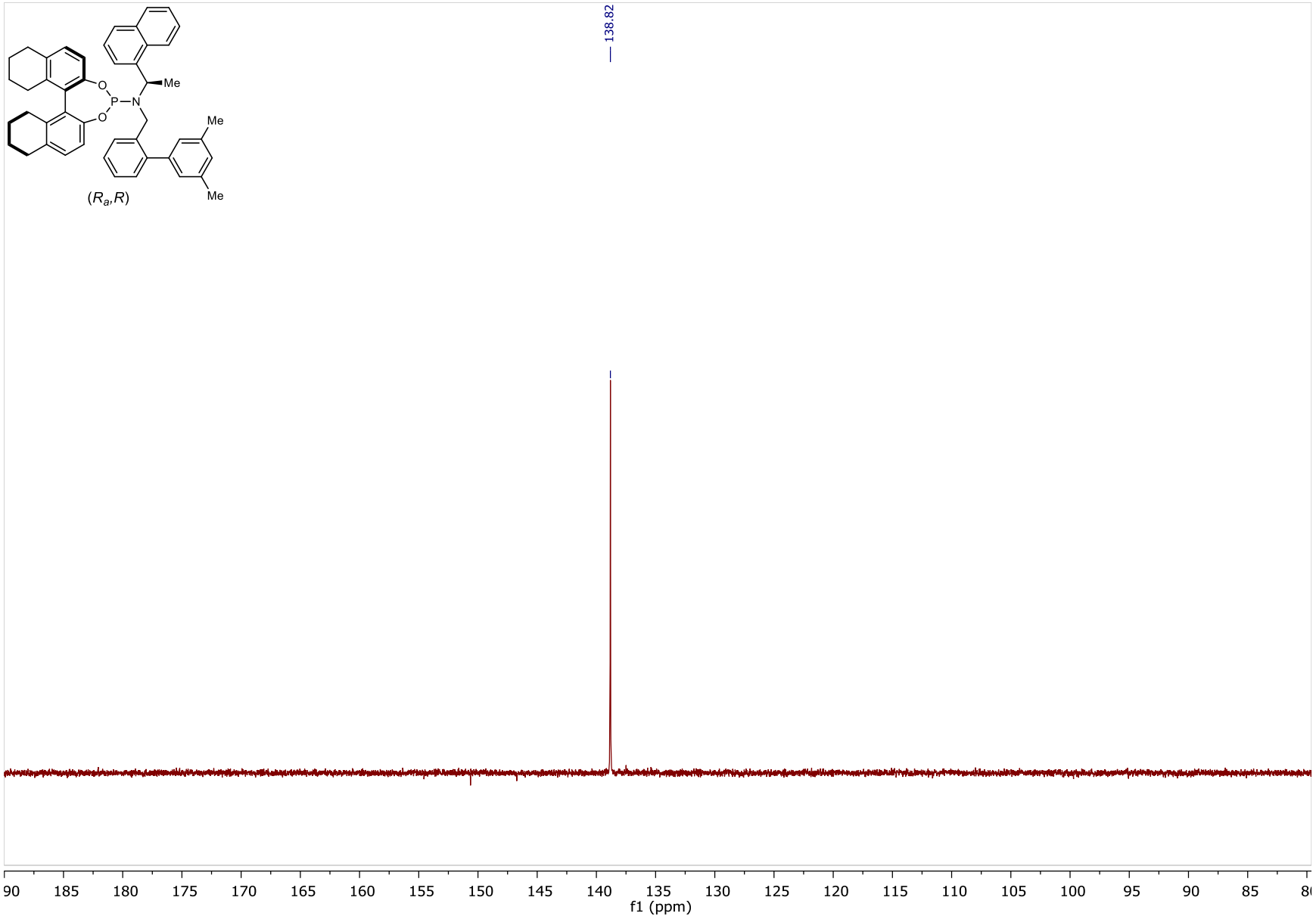

Br
Me
O
P
N
O
Br
Me
Me
(R_a,R)
f1 (ppm)

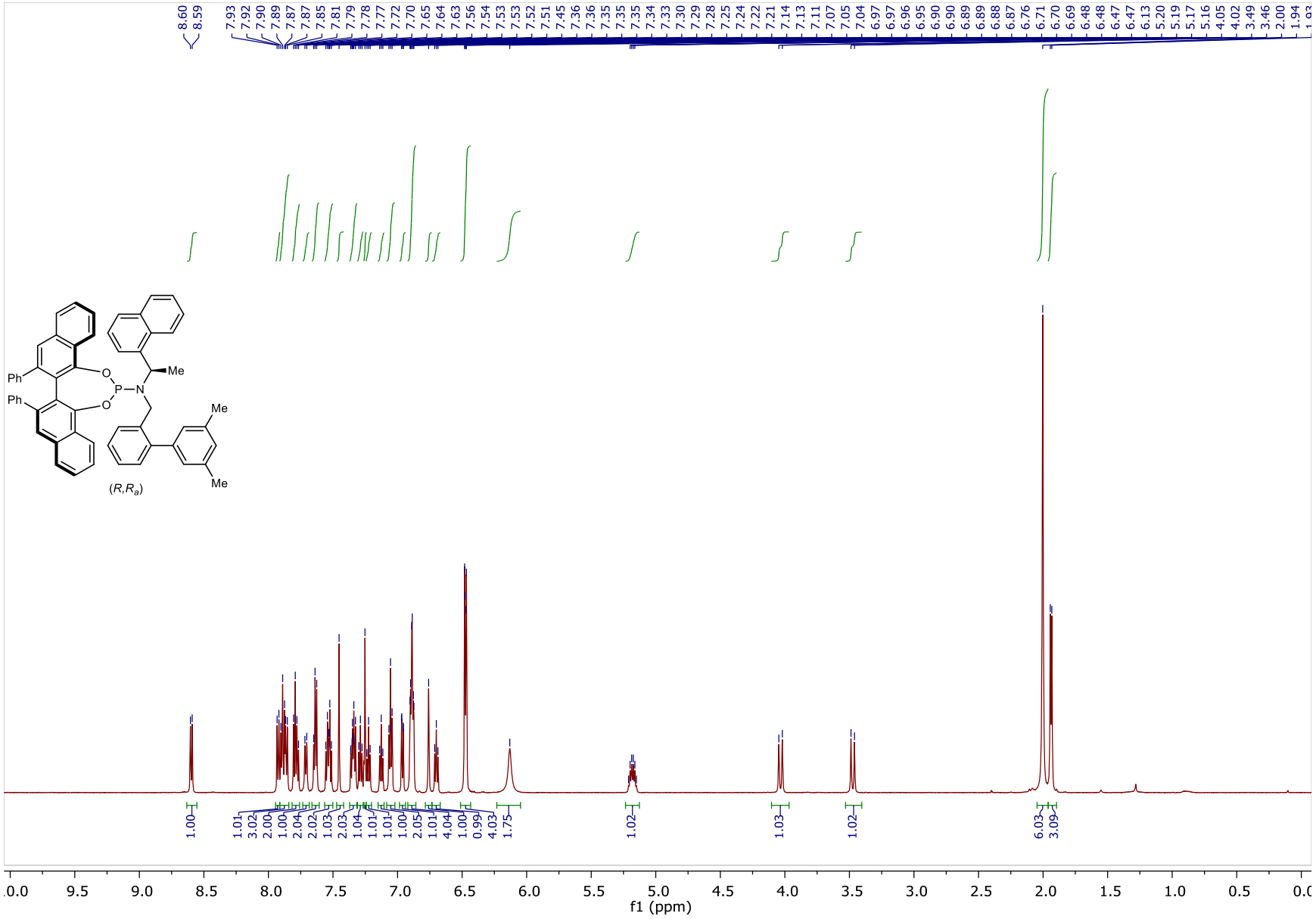

Br
O
P
N
O
Me
Br
Me
Me
(R_a,R)
147.58
147.52
146.12
141.34
140.22
137.58
137.54
137.00
134.91
133.76
133.09
132.81
132.02
132.01
131.96
131.81
131.67
130.75
129.10
128.81
128.30
128.00
127.89
127.65
127.39
127.20
127.17
127.00
126.84
126.67
126.58
126.14
126.08
126.06
125.95
125.91
125.70
125.28
124.85
124.82
123.05
123.03
117.22
117.20
116.85
52.50
52.27
44.50
44.47
22.78
22.63
21.45
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

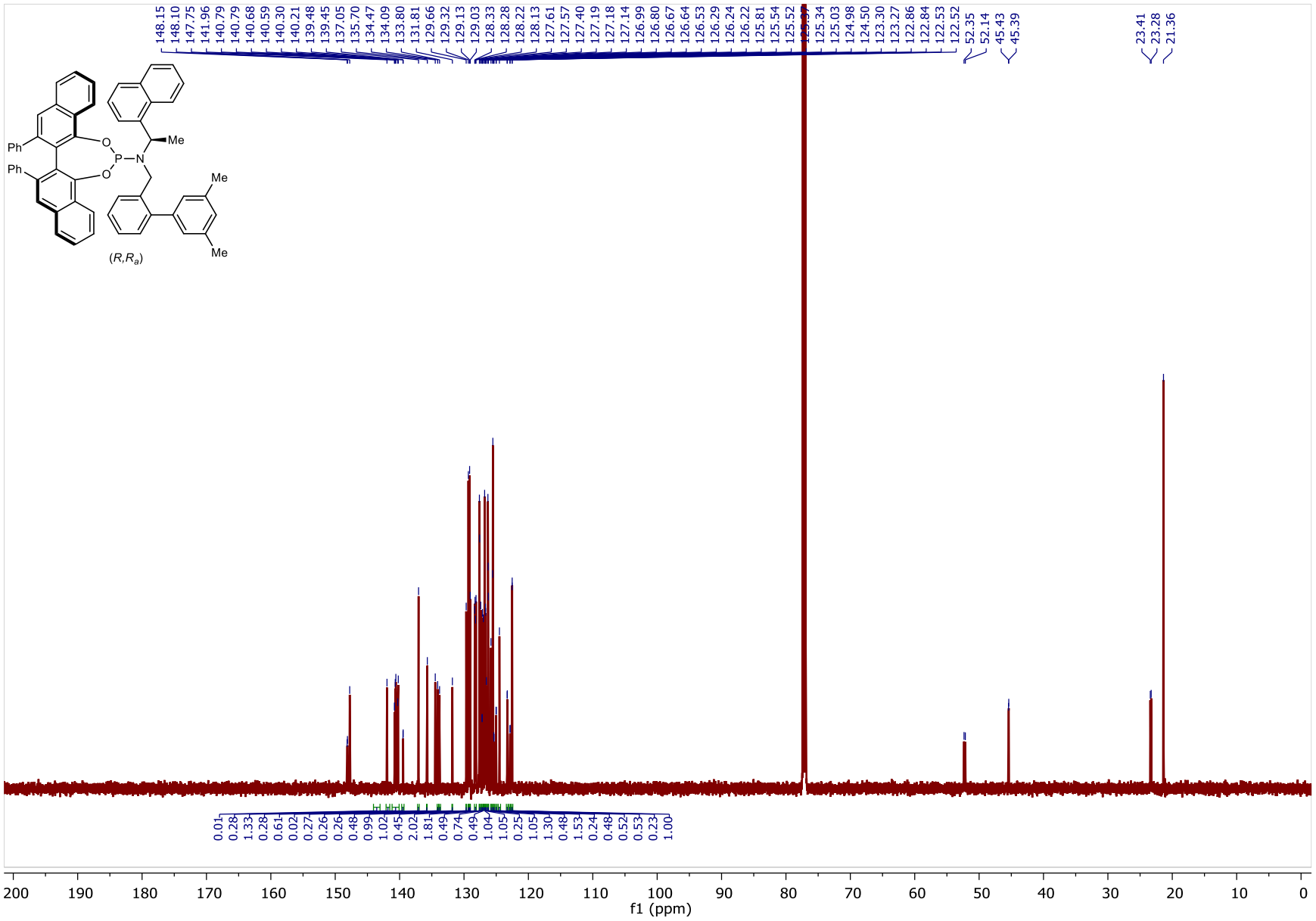

144.33
Br
Me
O
P
N
O
Me
Br
Me
(R_a,R)
210 205 200 195 190 185 180 175 170 165 160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70
f1 (ppm)

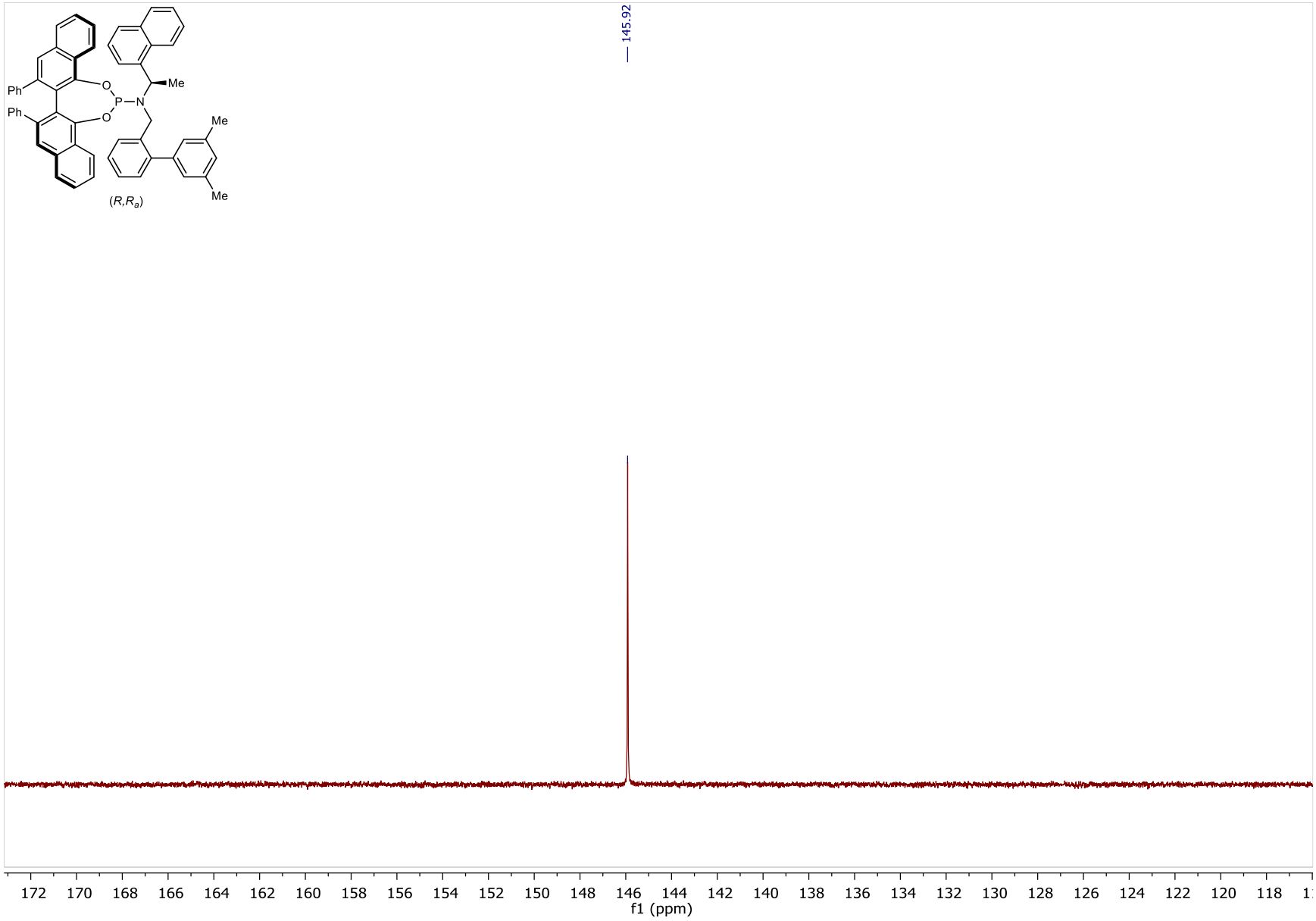

7.80 7.79 7.73 7.72 7.65 7.64 7.63 7.63 7.63 7.54 7.52 7.46 7.46 7.45 7.45 7.45 7.44 7.44 7.42 7.41 7.41 7.40 7.38 7.38 7.37 7.37 7.37 7.36 7.19 7.19 7.17 7.17 7.13 7.12 7.11 7.11 7.09 7.09 7.08 7.08 6.92 6.92 6.91 6.91 6.81 6.79 6.79 6.78 6.57 6.56 6.13 3.80 3.77 3.40 3.37 2.85 2.83 2.76 2.70 2.63 2.62 2.61 2.28 2.27 2.25 2.13 1.82 1.81 1.81 1.80 1.79 1.79 1.78 1.78 1.78 1.76 1.76 1.75 1.75 1.74 1.74 1.73 1.72 1.72 1.71 1.53
Me
Me
Me
O
P
N
O
(R_a,R)
1.05 1.03 2.04 1.02 1.04 1.03 1.01 1.03 2.02 1.01 1.02 2.02 1.01 1.99 1.00 1.01 1.00 3.15 3.08 2.11 6.04 6.09 3.14 2.17
0.0 9.5 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.
f1 (ppm)

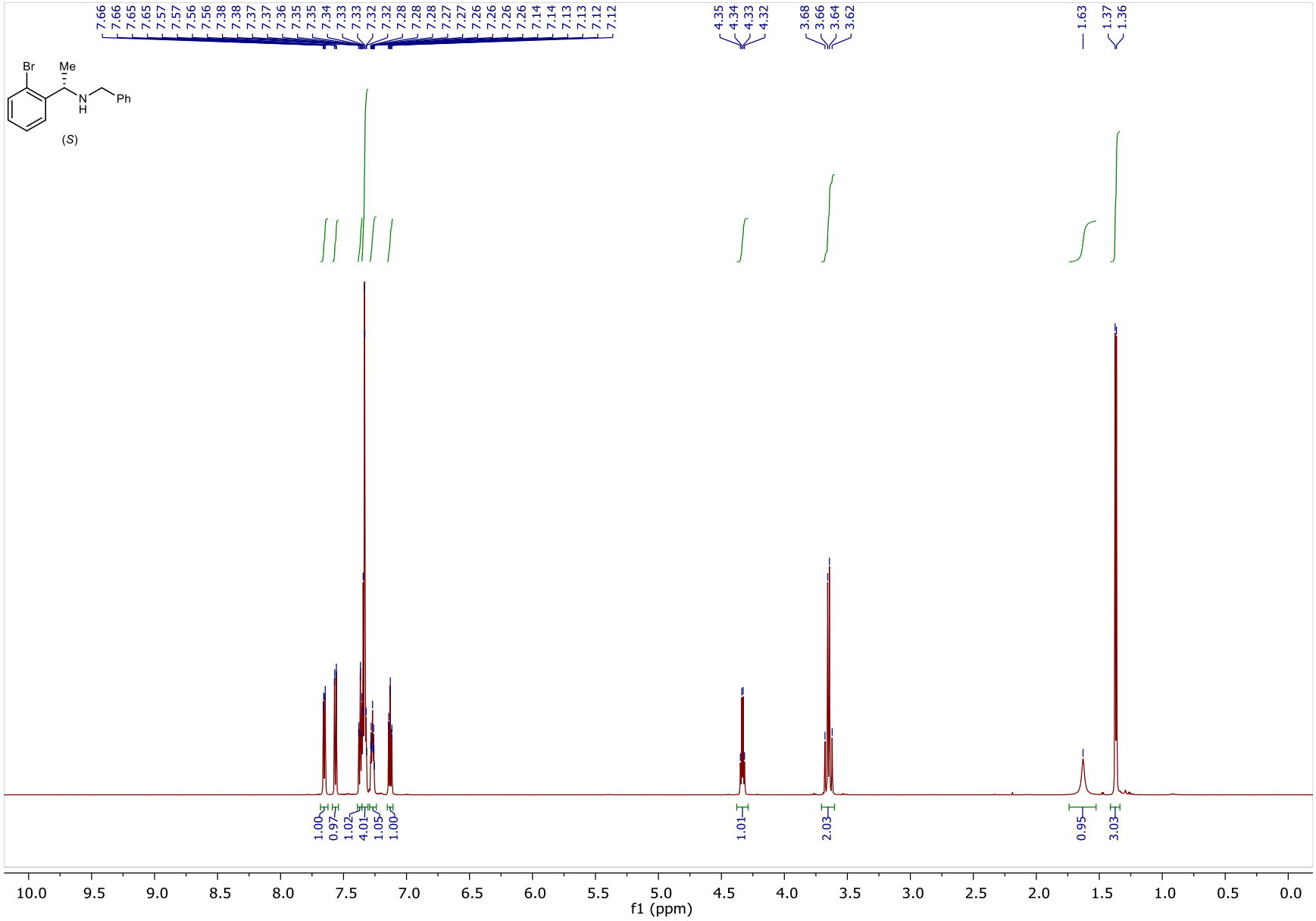

149.09
148.87
148.85
141.79
140.39
139.39
139.36
138.13
138.12
137.47
136.78
136.10
134.23
134.22
133.86
132.85
131.52
129.48
129.44
129.35
129.06
128.92
128.21
128.20
128.15
128.02
127.61
127.00
126.94
125.97
125.92
125.34
125.31
124.18
124.16
122.85
119.20
119.19
118.45
52.09
51.88
45.07
45.04
29.35
29.34
27.88
27.79
22.91
22.89
22.85
22.76
22.70
Me
Me
Me
O
P
N
O
(R_a,R)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

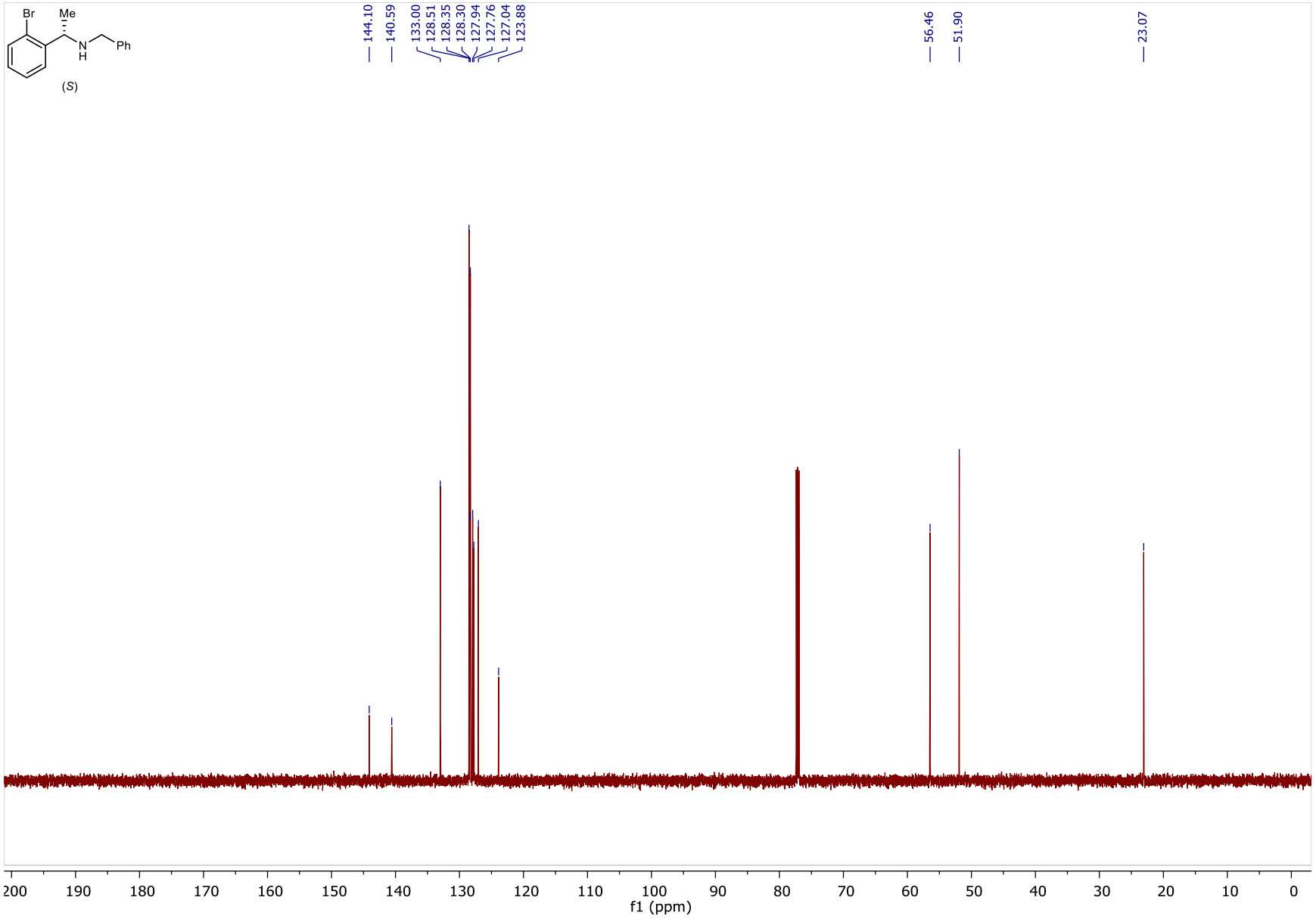

138.82
Me
O
P
N
O
Me
Me
(R_a,R)
90
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
f1 (ppm)

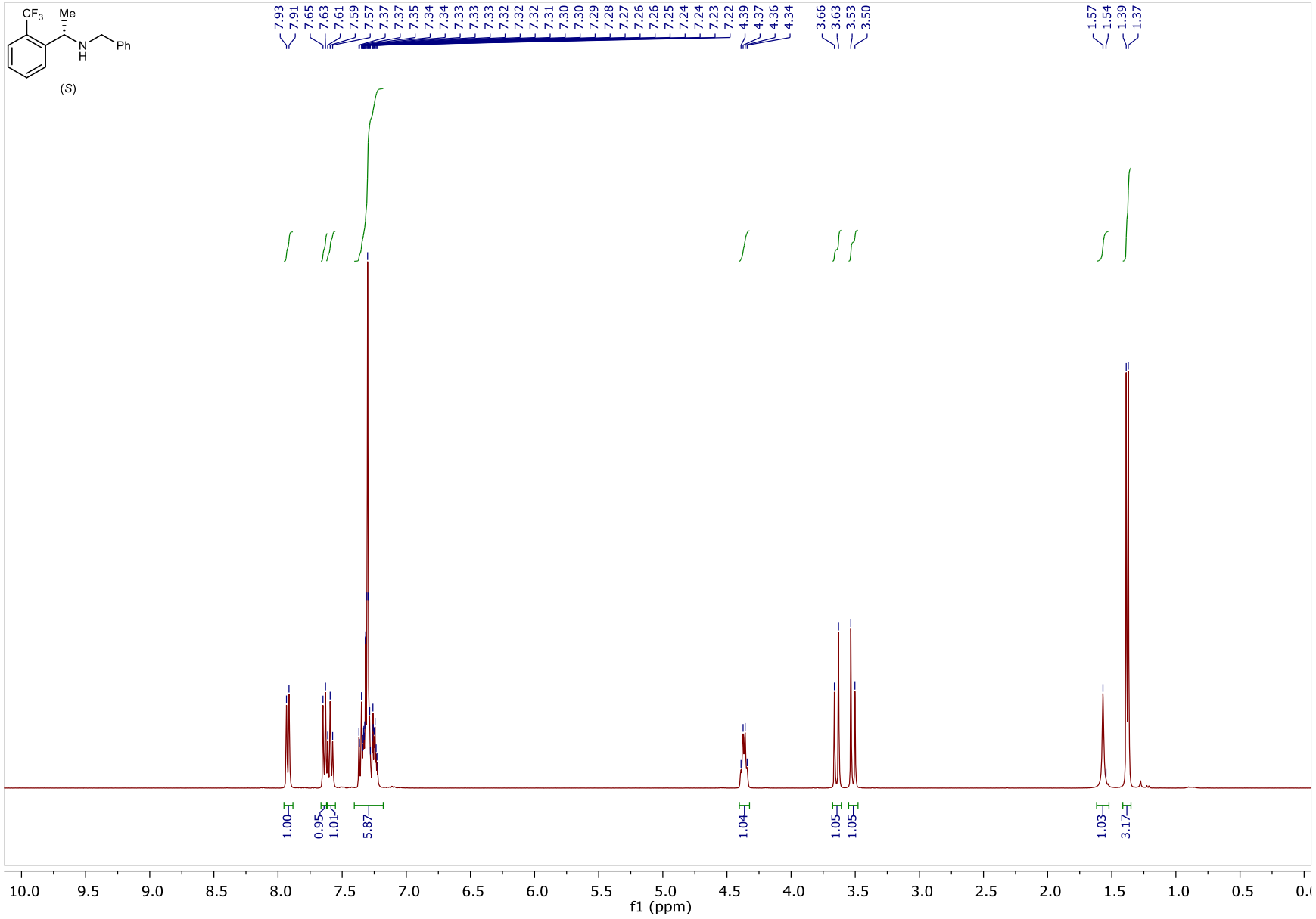

Ph
Ph
O
O
P
N
Me
Me
Me
(R,Ra)
f1 (ppm)

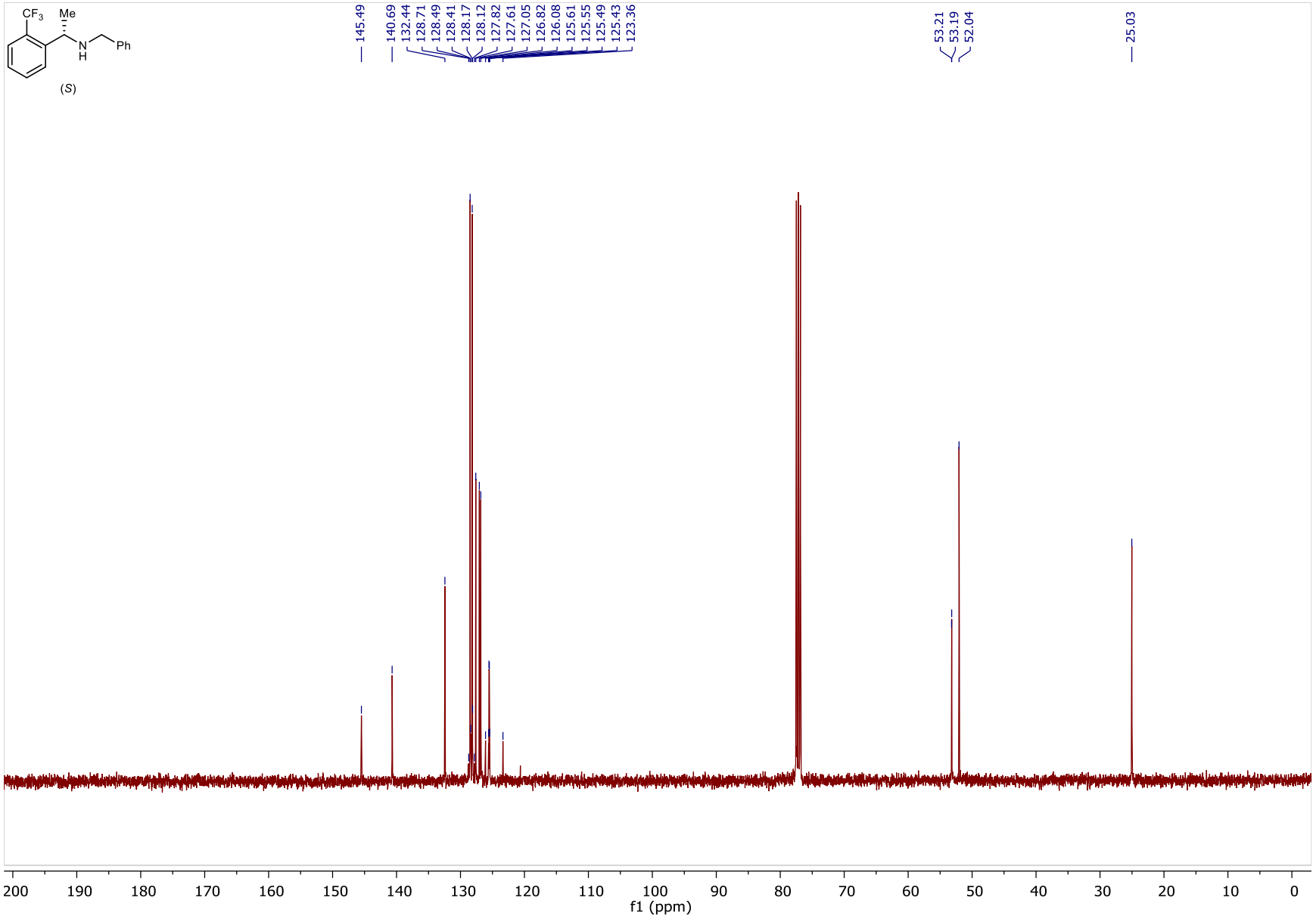

148.15
148.10
147.75
141.96
140.79
140.79
140.68
140.59
140.30
140.21
139.48
139.45
137.05
135.70
134.47
134.09
133.80
131.81
129.66
129.32
129.13
129.03
128.33
128.28
128.22
128.13
127.61
127.57
127.40
127.19
127.18
127.14
126.99
126.80
126.67
126.64
126.53
126.29
126.24
126.22
125.81
125.54
125.52
125.34
125.03
124.98
124.50
123.30
123.27
122.86
122.84
122.53
122.52
52.35
52.14
45.43
45.39
23.41
23.28
21.36
Ph
Ph
O
O
P
N
Me
Me
Me
(R,Ra)
0.01
0.28
1.33
0.28
0.61
0.02
0.27
0.26
0.26
0.48
0.99
1.02
0.45
2.02
1.81
0.49
0.74
0.49
1.04
1.05
0.25
1.05
1.30
0.48
1.53
0.24
0.48
0.52
0.53
0.23
1.00
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

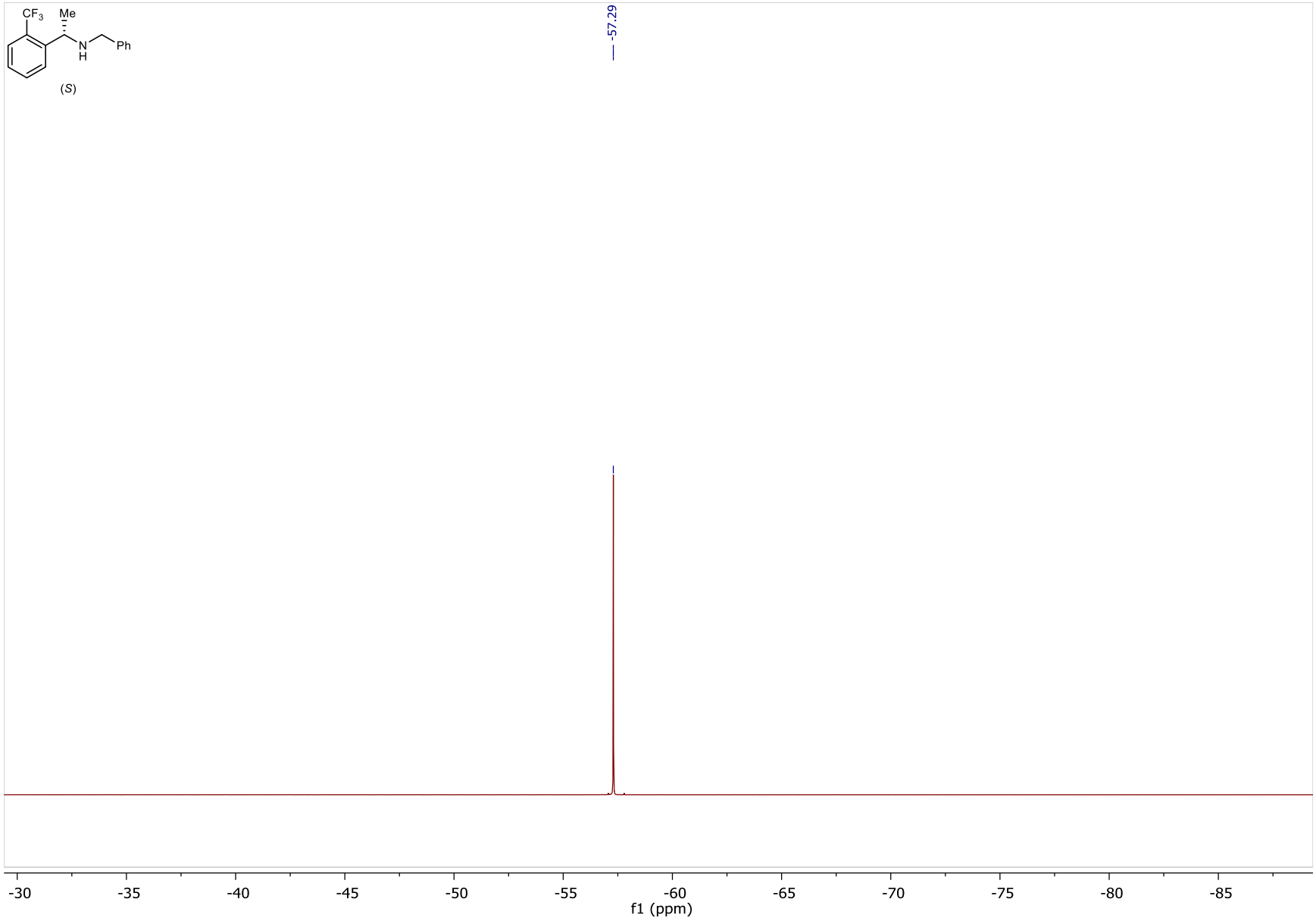

145.92
Ph
Ph
O
O
P
N
Me
Me
Me
(R,Ra)
172 170 168 166 164 162 160 158 156 154 152 150 148 146 144 142 140 138 136 134 132 130 128 126 124 122 120 118
f1 (ppm)

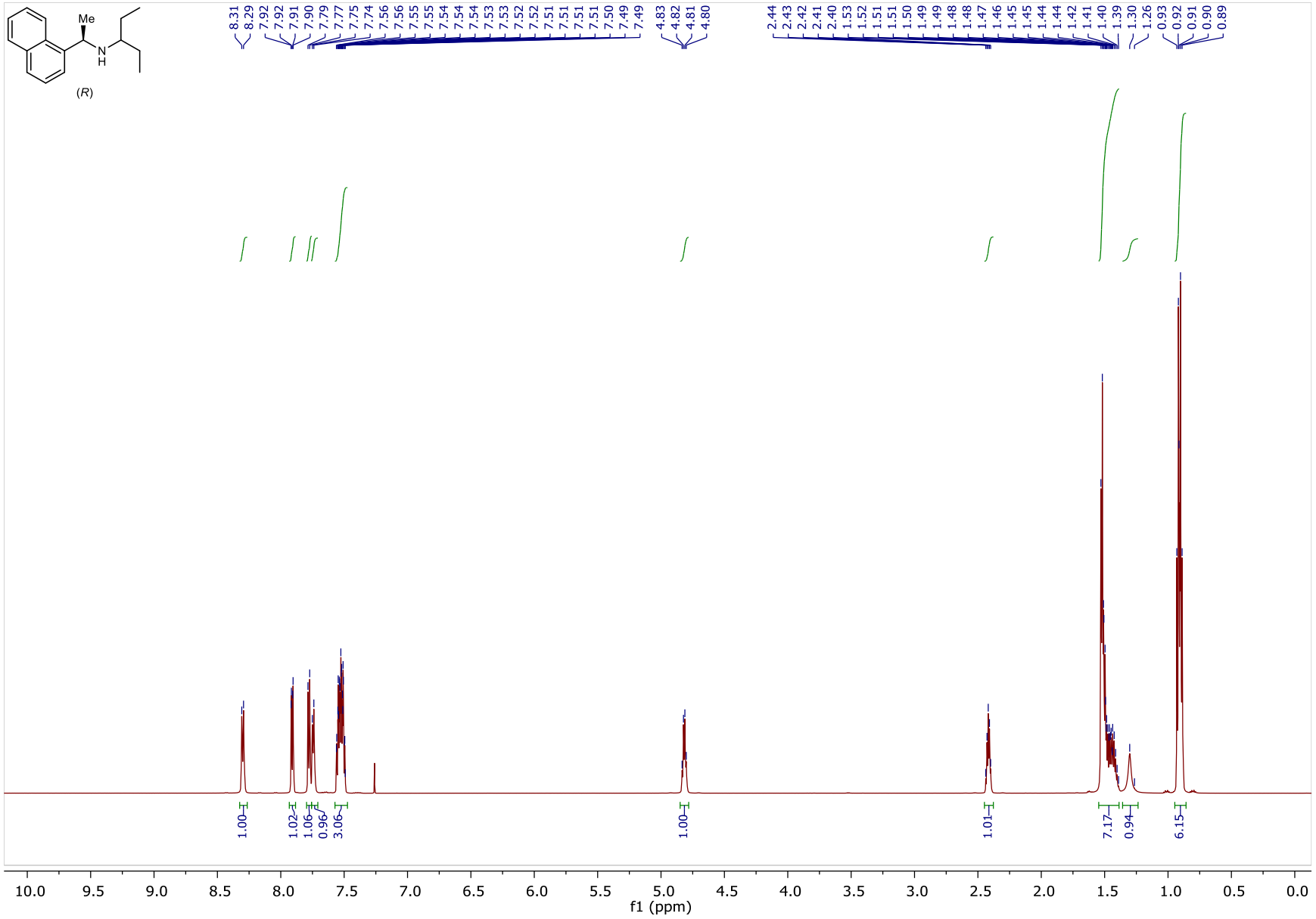

7.66 7.66 7.65 7.65 7.57 7.57 7.56 7.56 7.38 7.38 7.37 7.37 7.36 7.35 7.35 7.34 7.33 7.33 7.32 7.32 7.28 7.28 7.28 7.27 7.27 7.26 7.26 7.26 7.14 7.14 7.13 7.12 7.12
4.35 4.34 4.33 4.32
3.68 3.66 3.64 3.62
1.63
1.37 1.36
Br
Me
N
H
Ph
(S)
1.00 0.97 1.02 4.01 1.05 1.00
1.01
2.03
0.95
3.03
10.0 9.5 9.0 8.5 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 0.0
f1 (ppm)

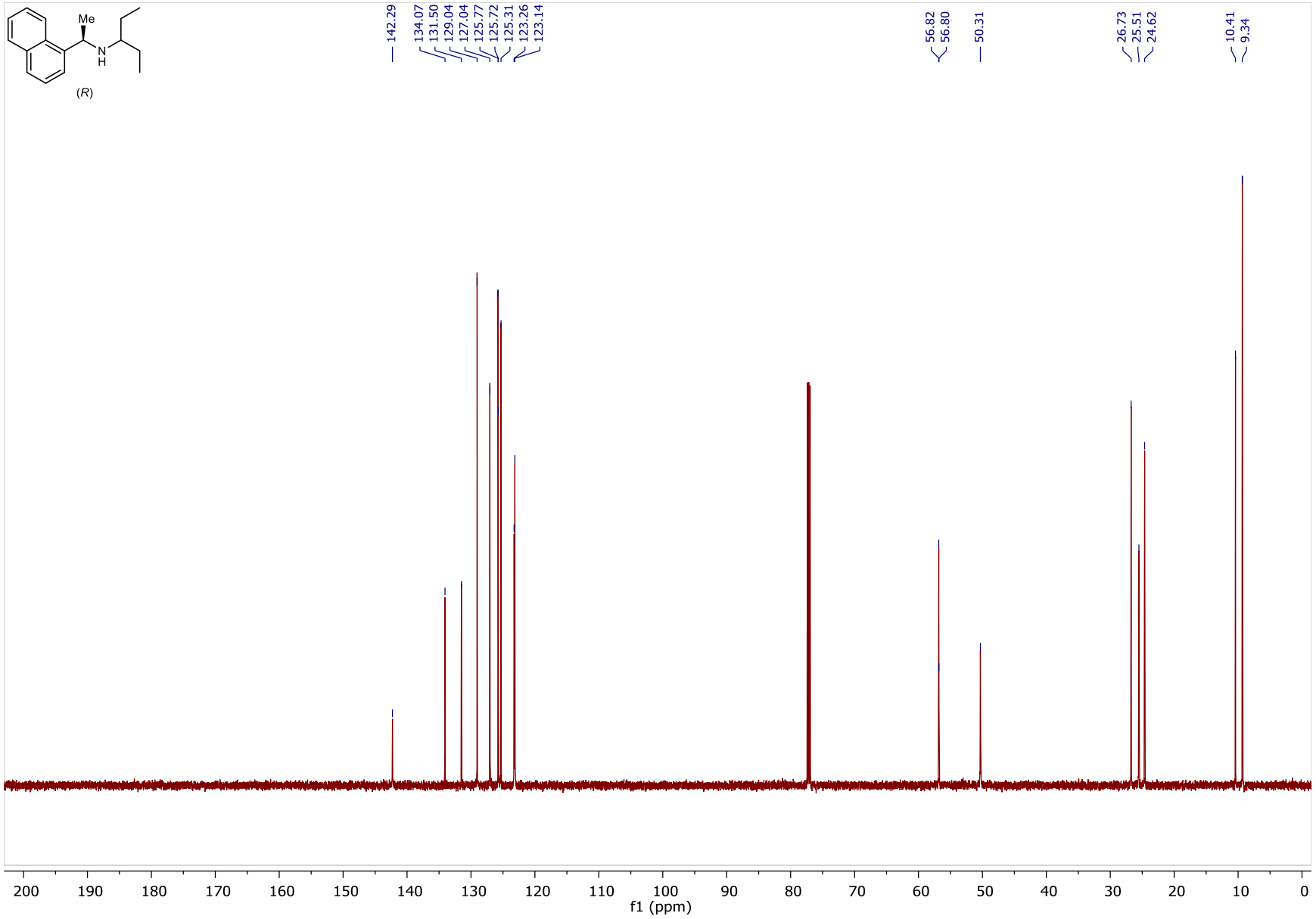

Br
Me
N
H
Ph
(S)
144.10
140.59
133.00
128.51
128.35
128.30
127.94
127.76
127.04
123.88
56.46
51.90
23.07
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

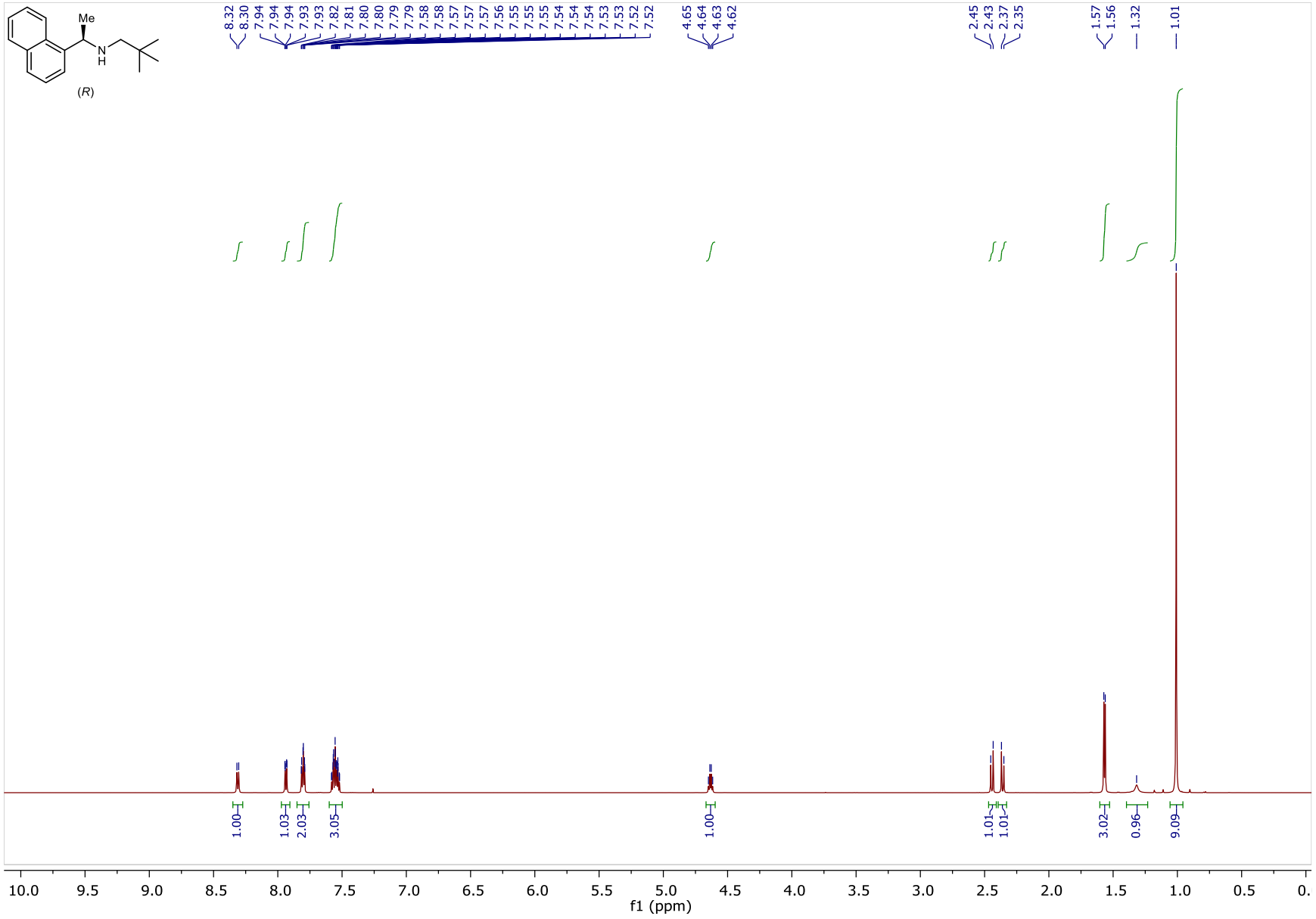

CF3
Me
N
H
Ph
(S)
7.93
7.91
7.65
7.63
7.61
7.59
7.57
7.37
7.37
7.35
7.34
7.34
7.33
7.33
7.32
7.32
7.32
7.31
7.30
7.30
7.29
7.28
7.27
7.26
7.26
7.25
7.24
7.24
7.23
7.22
4.39
4.37
4.36
4.34
3.66
3.63
3.53
3.50
1.57
1.54
1.39
1.37
1.00
0.95
1.01
5.87
1.04
1.05
1.05
1.03
3.17
10.0
9.5
9.0
8.5
8.0
7.5
7.0
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
f1 (ppm)

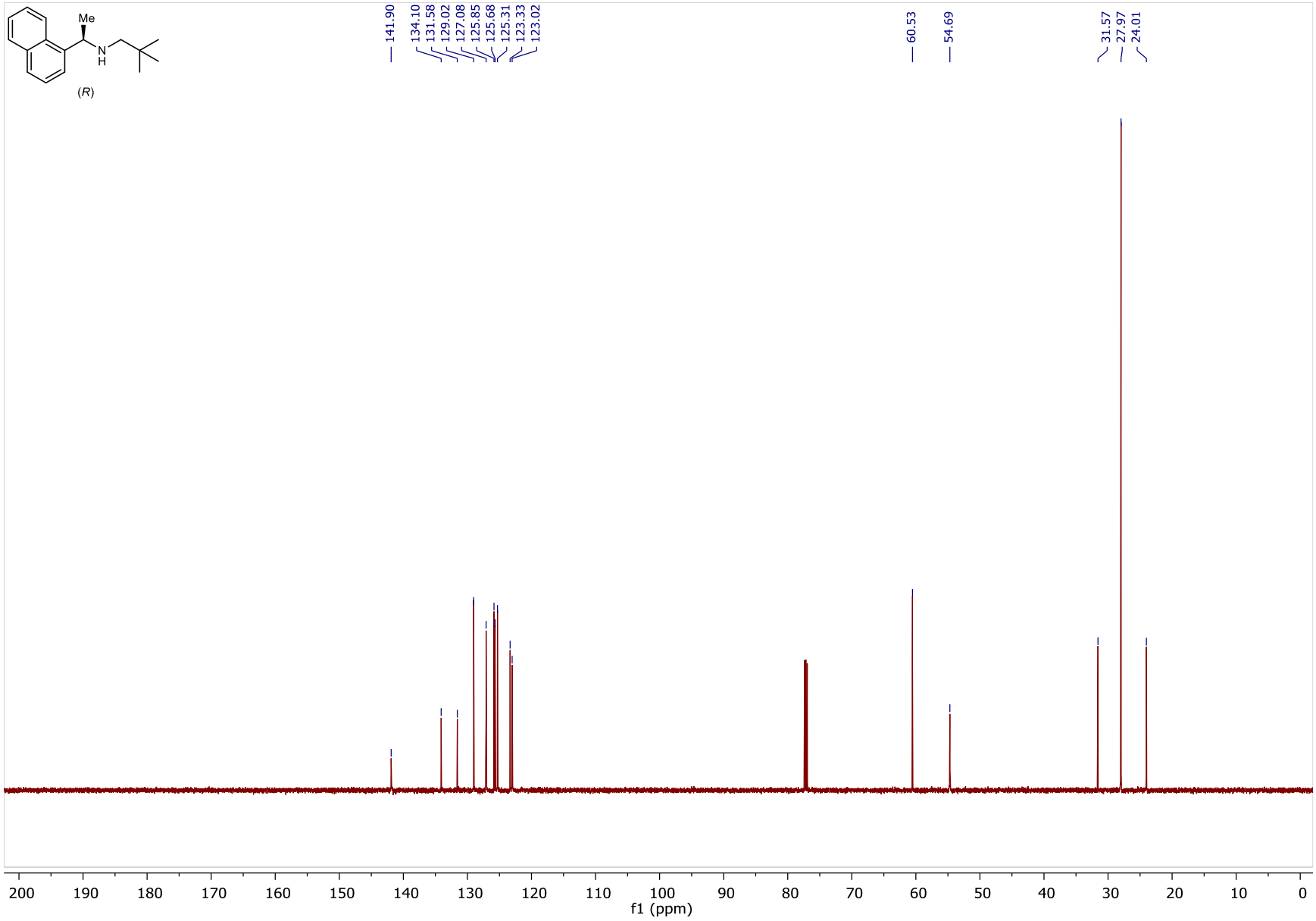

CF3
Me
N
H
Ph
(S)
145.49
140.69
132.44
128.71
128.49
128.41
128.17
128.12
127.82
127.61
127.05
126.82
126.08
125.61
125.55
125.49
125.43
123.36
53.21
53.19
52.04
25.03
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

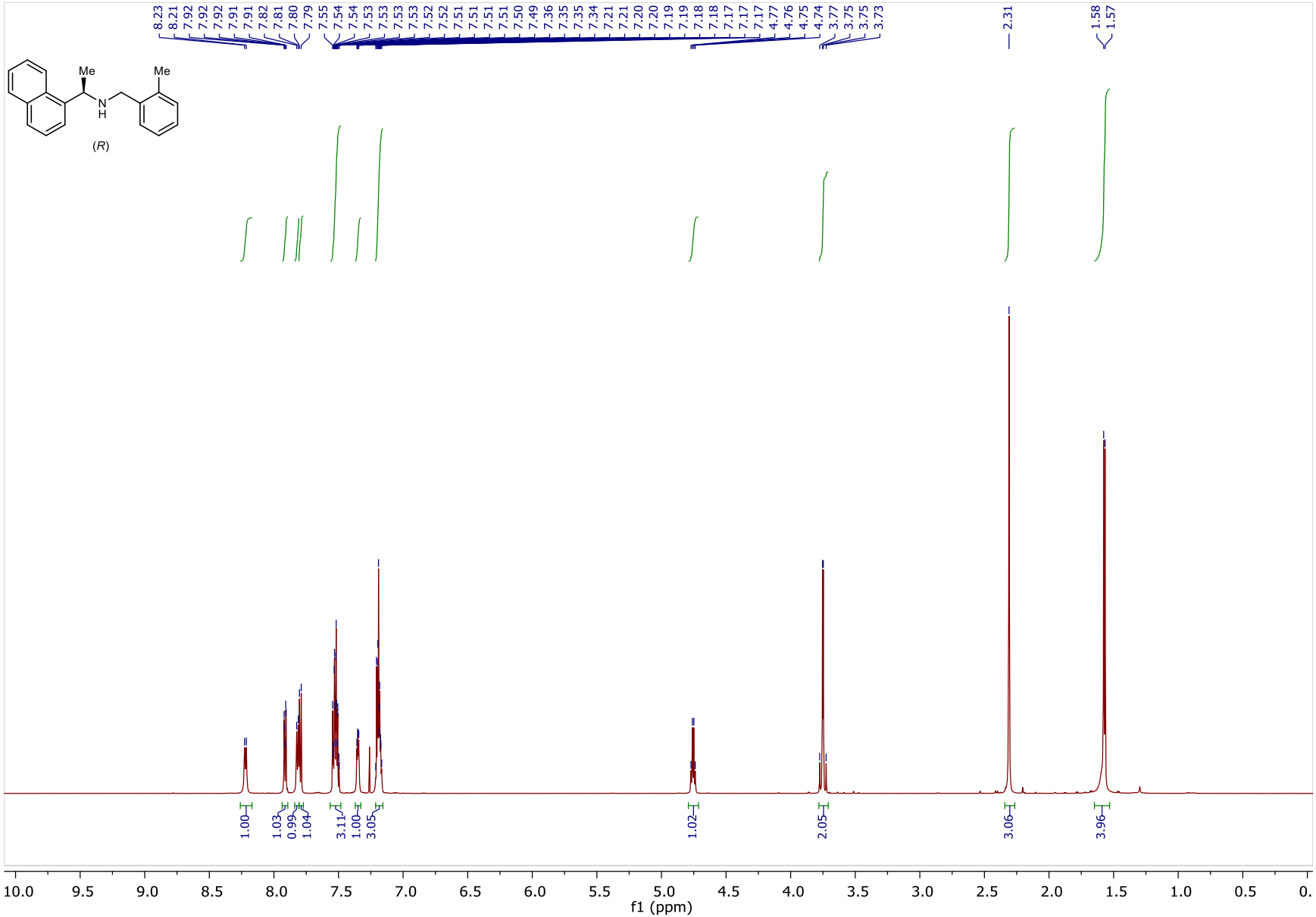

CF3
Me
N
H
Ph
(S)
-57.29
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
f1 (ppm)

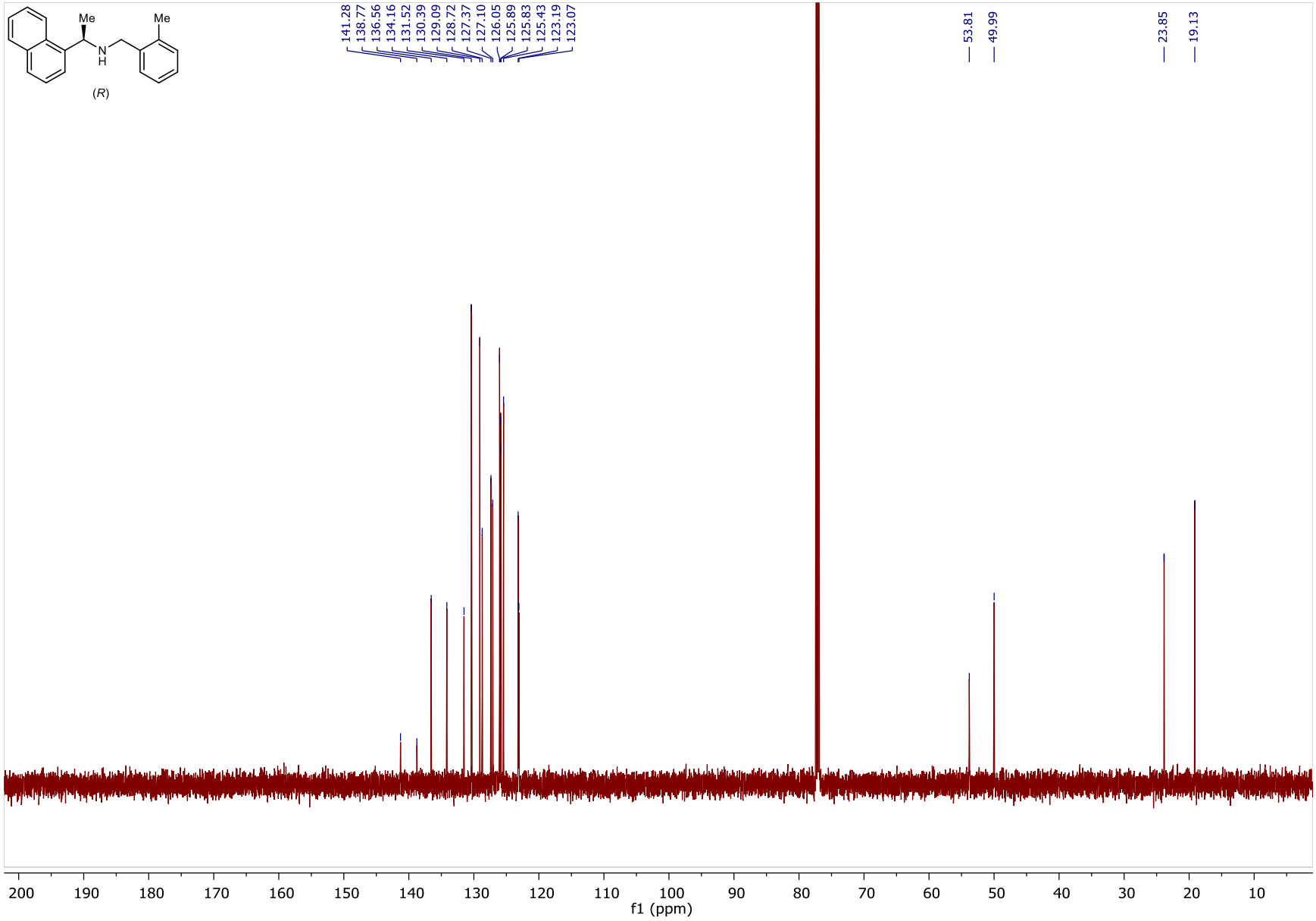

Me
N
H
(R)
8.31 8.29 7.92 7.92 7.91 7.90 7.79 7.77 7.75 7.74 7.56 7.56 7.55 7.55 7.54 7.54 7.54 7.53 7.53 7.52 7.52 7.51 7.51 7.51 7.51 7.50 7.49 7.49
4.83 4.82 4.81 4.80
2.44 2.43 2.42 2.41 2.40 1.53 1.52 1.51 1.51 1.50 1.49 1.49 1.48 1.48 1.47 1.46 1.45 1.45 1.44 1.44 1.42 1.41 1.40 1.39 1.30 1.26 0.93 0.92 0.91 0.90 0.89
1.00 1.02 1.06 0.96 3.06 1.00 1.01 7.17 0.94 6.15
10.0 9.5 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 0.0
f1 (ppm)

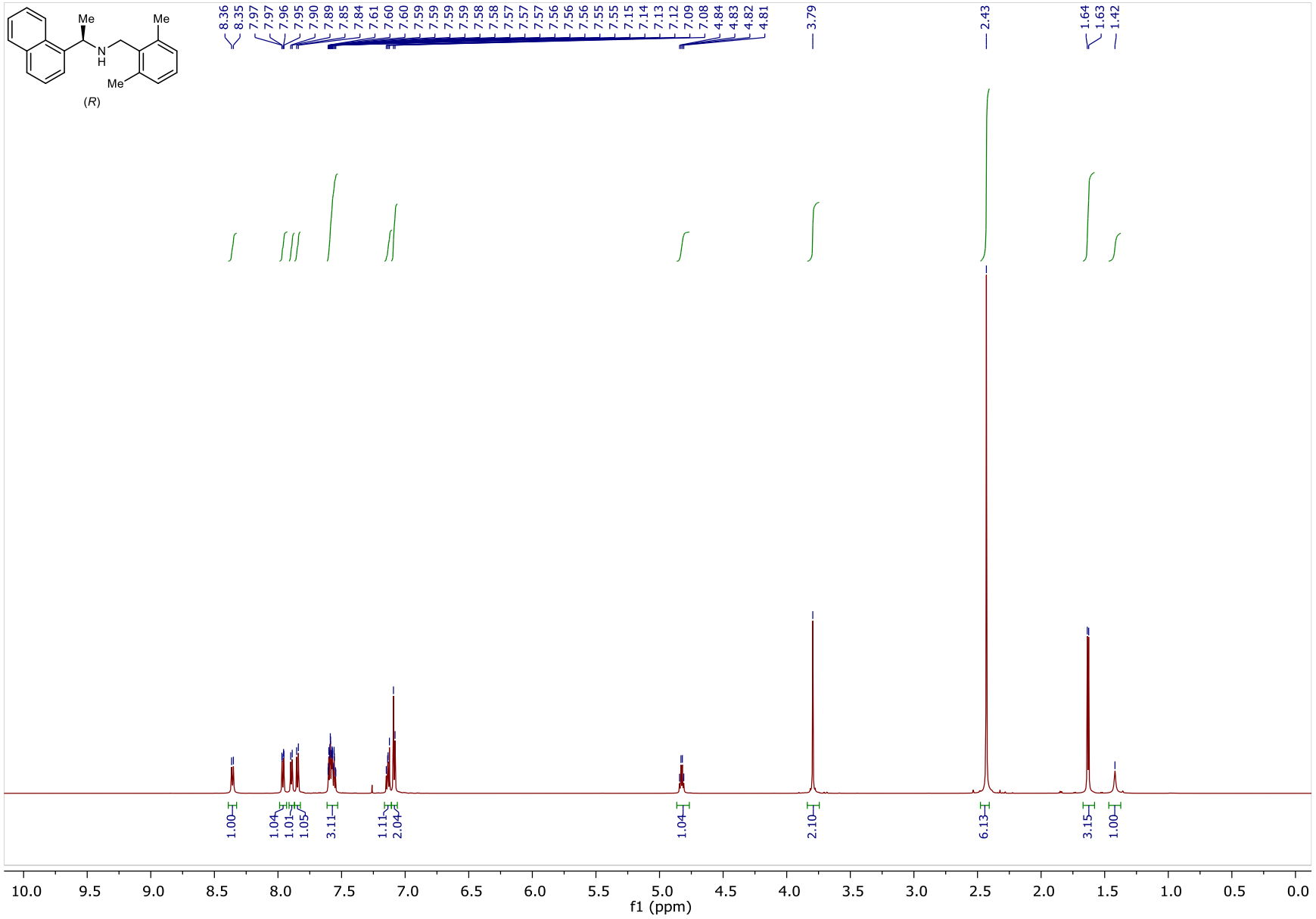

Me
N
H
(R)
142.29
134.07
131.50
129.04
127.04
125.77
125.72
125.31
123.26
123.14
56.82
56.80
50.31
26.73
25.51
24.62
10.41
9.34
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

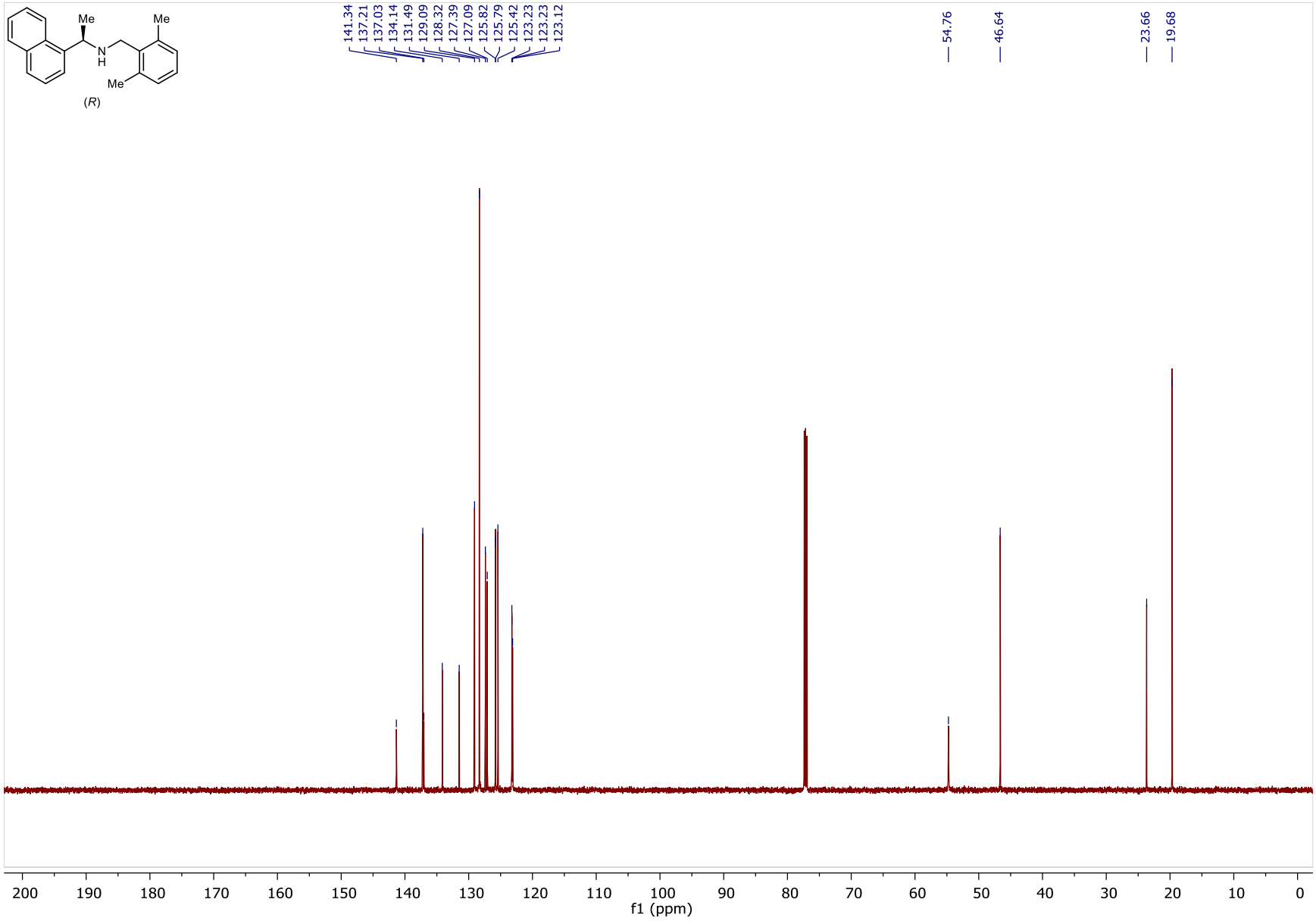

Me
N
H
(R)
8.32
8.30
7.94
7.94
7.94
7.93
7.93
7.82
7.81
7.80
7.80
7.79
7.79
7.58
7.58
7.57
7.57
7.57
7.56
7.55
7.55
7.55
7.54
7.54
7.54
7.53
7.53
7.52
7.52
4.65
4.64
4.63
4.62
2.45
2.43
2.37
2.35
1.57
1.56
1.32
1.01
1.00
1.03
2.03
3.05
1.00
1.01
1.01
3.02
0.96
9.09
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

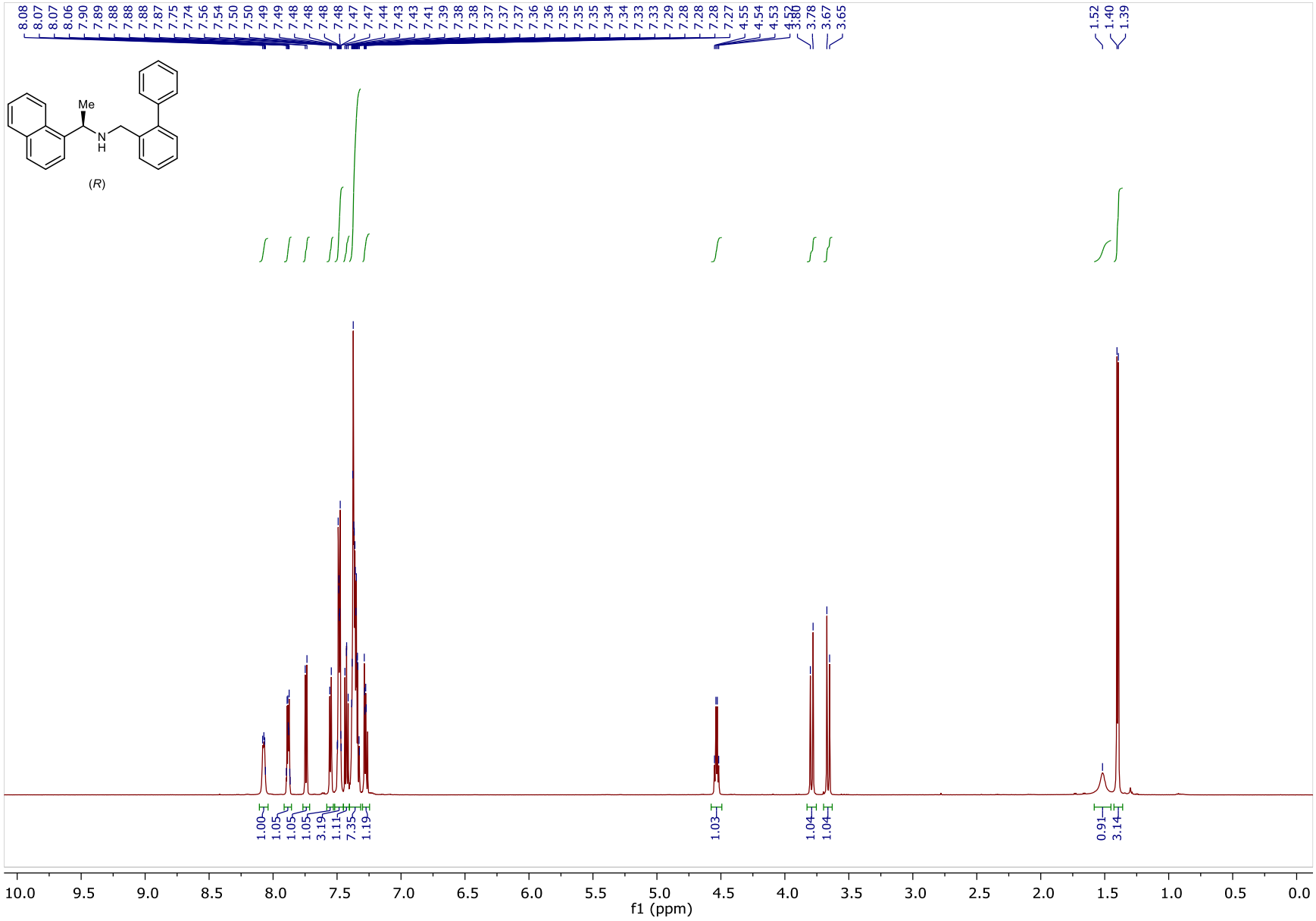

Me
N
H
(R)
141.90
134.10
131.58
129.02
127.08
125.85
125.68
125.31
123.33
123.02
60.53
54.69
31.57
27.97
24.01
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

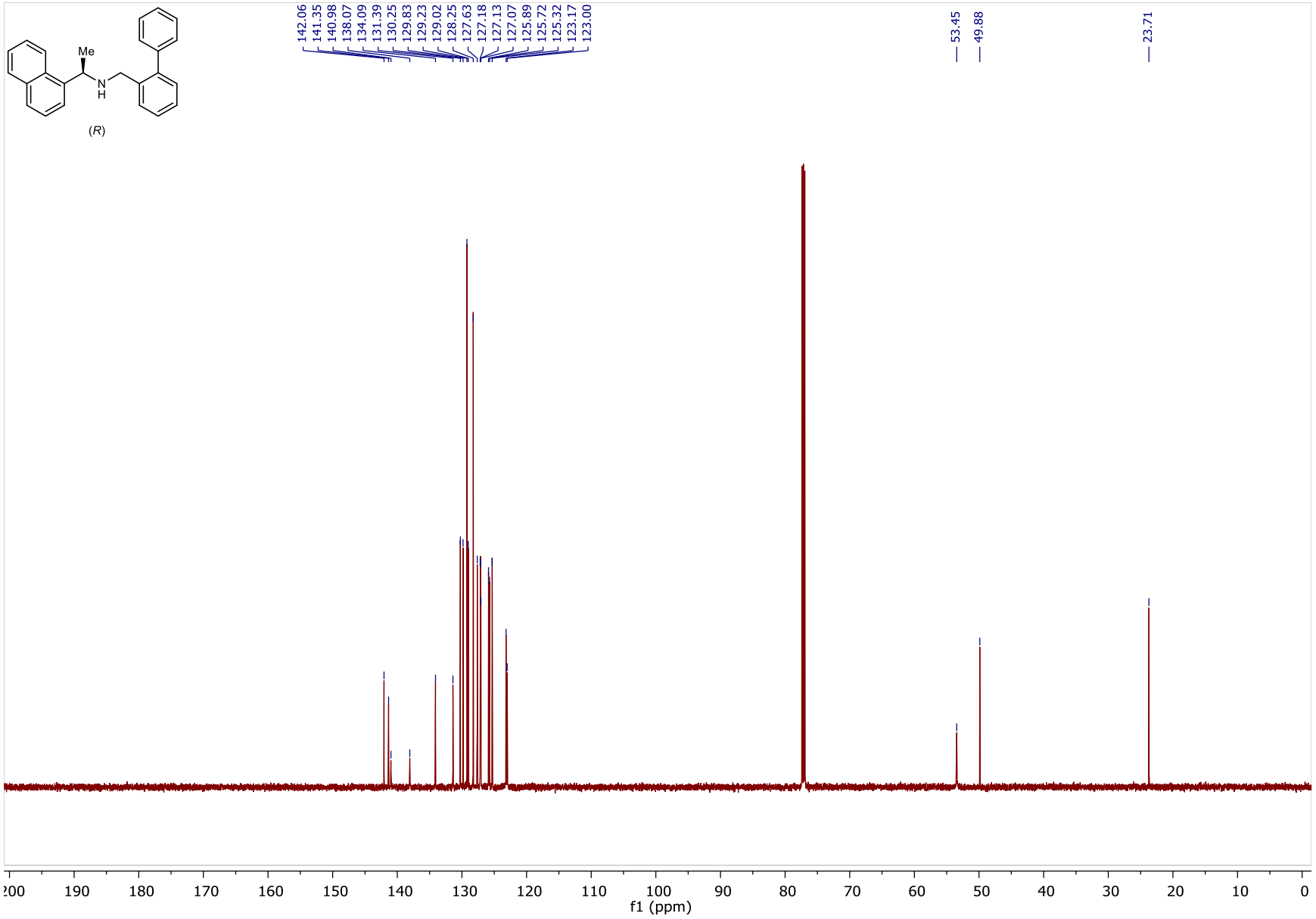

8.23
8.21
7.92
7.92
7.92
7.91
7.91
7.82
7.81
7.80
7.79
7.55
7.54
7.54
7.53
7.53
7.53
7.53
7.52
7.52
7.51
7.51
7.51
7.51
7.50
7.49
7.36
7.35
7.35
7.34
7.21
7.21
7.20
7.20
7.19
7.19
7.18
7.18
7.17
7.17
7.17
4.77
4.76
4.75
4.74
3.77
3.75
3.75
3.73
2.31
1.58
1.57
Me
Me
N
H
(R)
1.00
1.03
0.99
1.04
3.11
1.00
3.05
1.02
2.05
3.06
3.96
10.0
9.5
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
f1 (ppm)

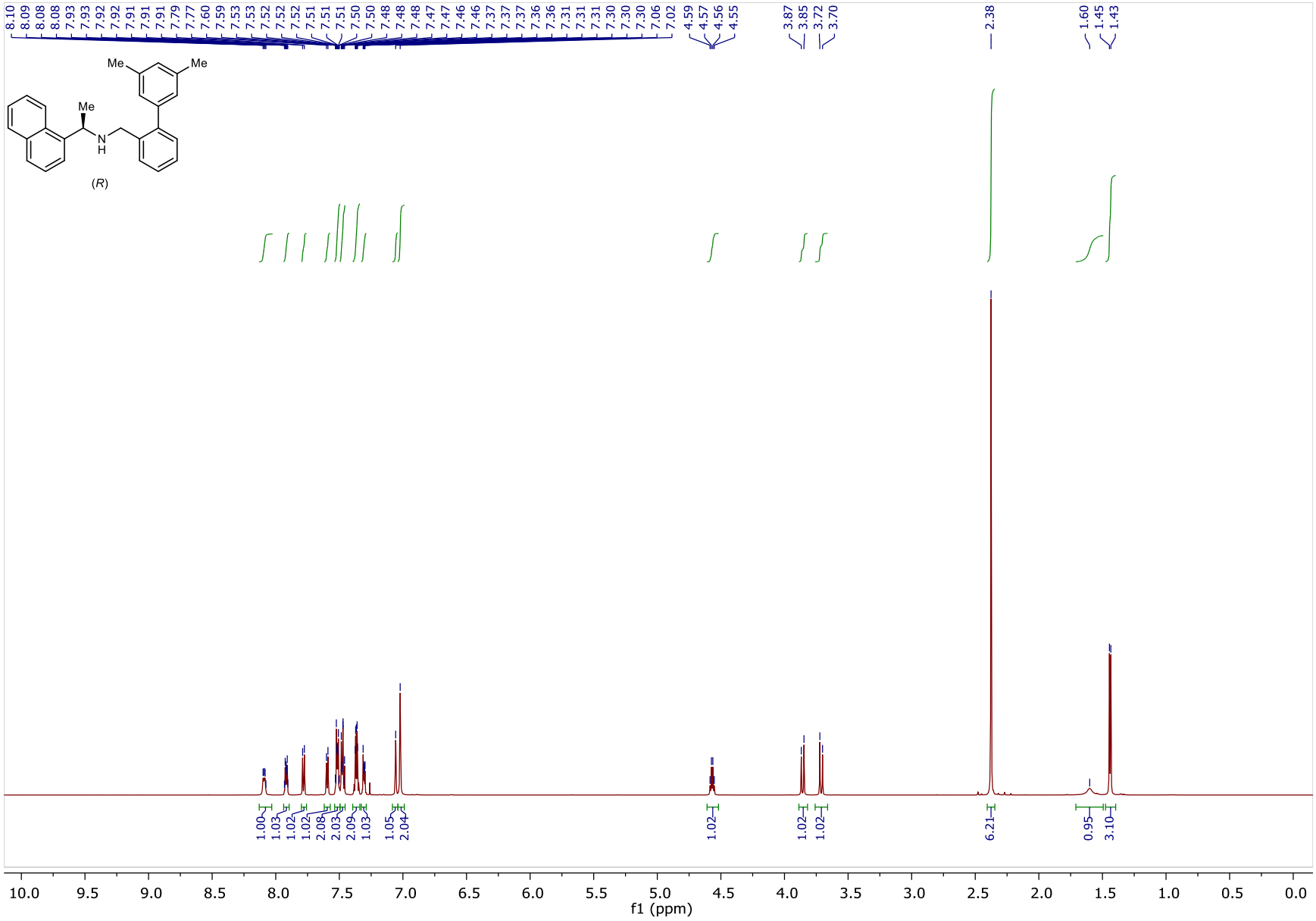

Me
Me
N
H
(R)
141.28
138.77
136.56
134.16
131.52
130.39
129.09
128.72
127.37
127.10
126.05
125.89
125.83
125.43
123.19
123.07
53.81
49.99
23.85
19.13
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

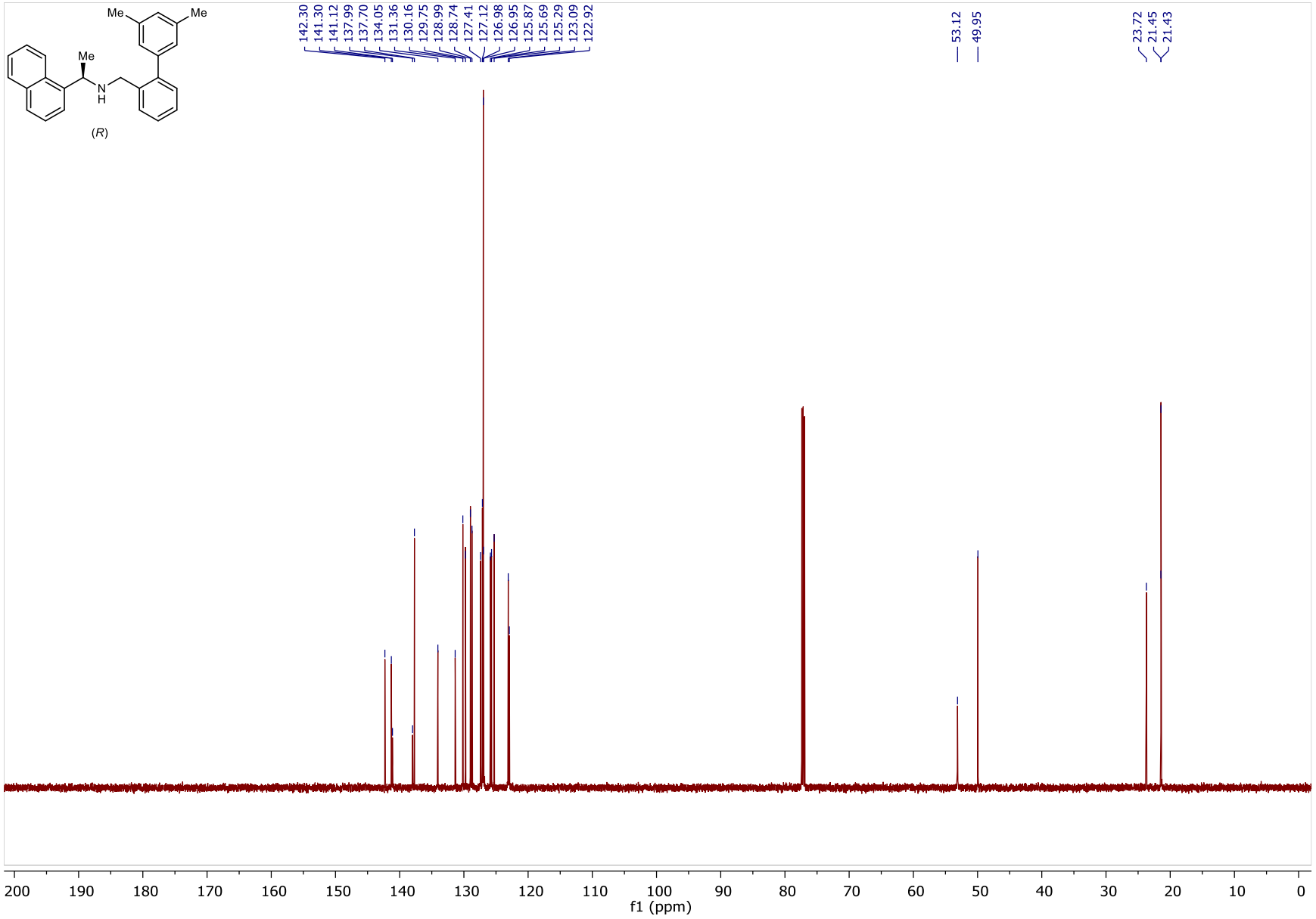

Me
Me
N
H
Me
(R)
8.36
8.35
7.97
7.97
7.96
7.96
7.95
7.90
7.89
7.85
7.84
7.61
7.60
7.60
7.59
7.59
7.59
7.59
7.58
7.58
7.57
7.57
7.57
7.56
7.56
7.56
7.55
7.55
7.15
7.14
7.13
7.12
7.09
7.08
4.84
4.83
4.82
4.81
3.79
2.43
1.64
1.63
1.42
1.00
1.04
1.01
1.05
3.11
1.11
2.04
1.04
2.10
6.13
3.15
1.00
10.0
9.5
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
0.0
f1 (ppm)

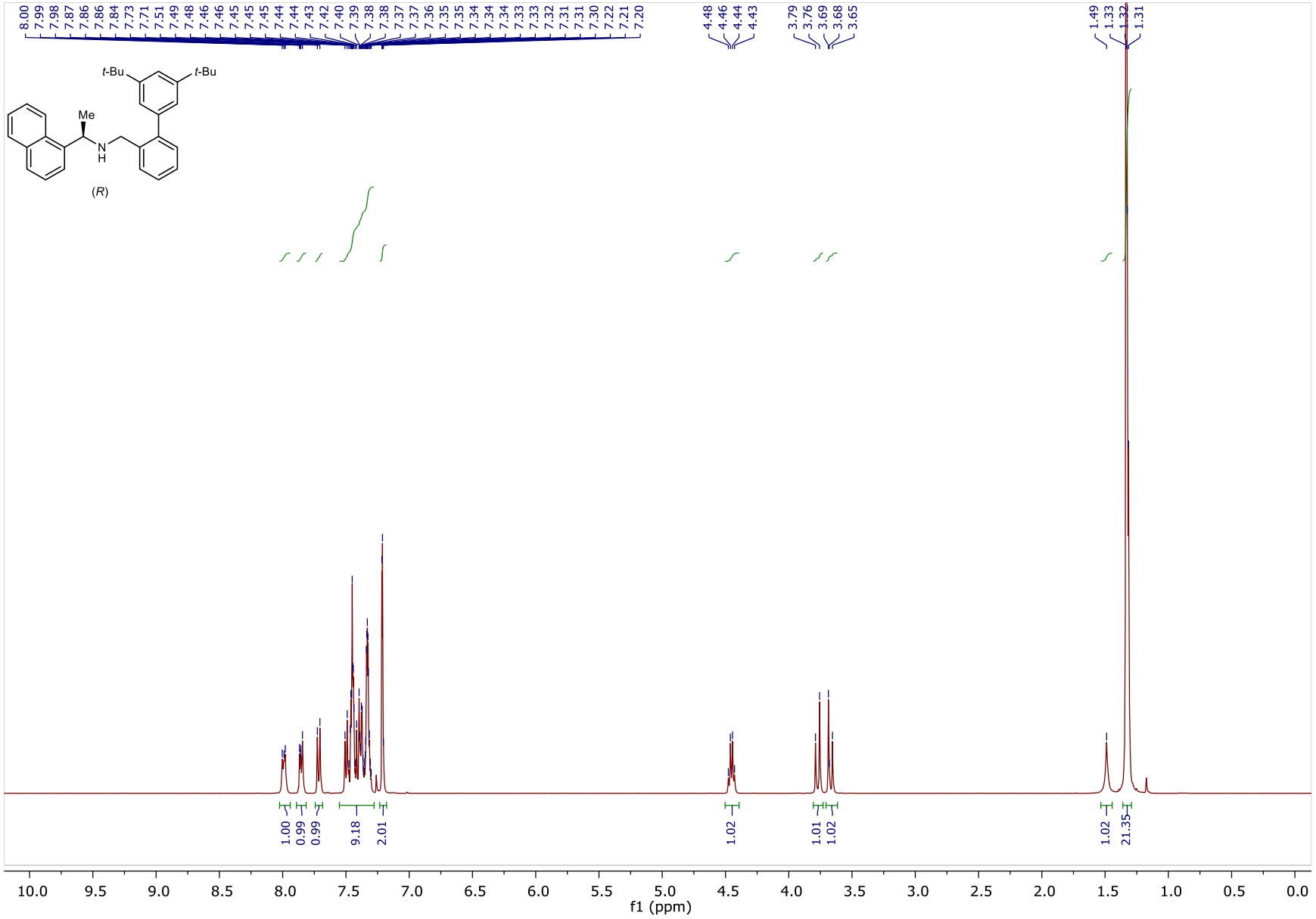

Me
Me
N
H
Me
(R)
141.34
137.21
137.03
134.14
131.49
129.09
128.32
127.39
127.09
125.82
125.79
125.42
123.23
123.23
123.12
54.76
46.64
23.66
19.68
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

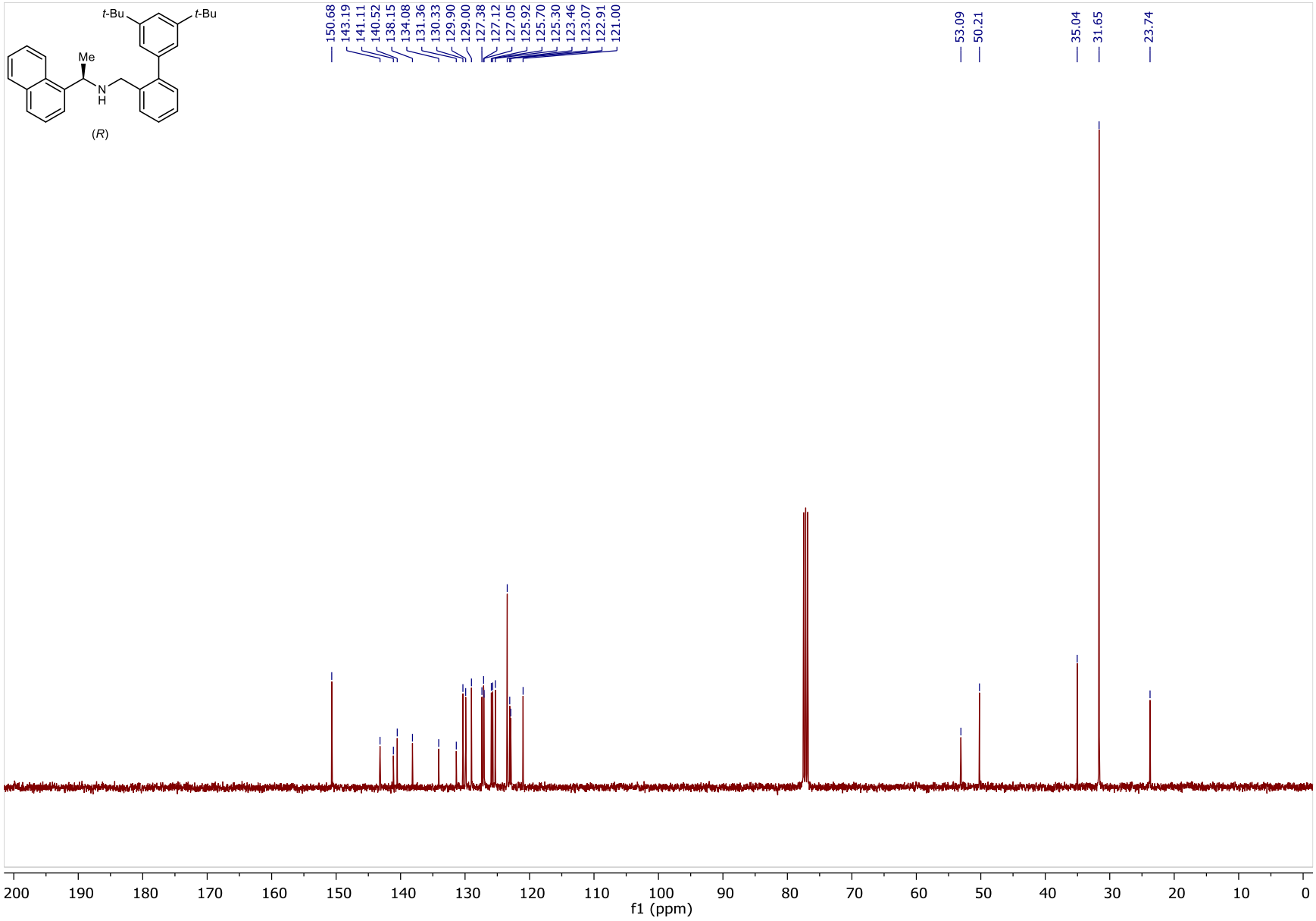

8.08 8.07 8.07 8.06 7.90 7.89 7.88 7.88 7.88 7.87 7.75 7.74 7.56 7.54 7.50 7.50 7.49 7.49 7.48 7.48 7.48 7.48 7.47 7.47 7.44 7.43 7.43 7.41 7.39 7.38 7.38 7.37 7.37 7.37 7.36 7.36 7.35 7.35 7.35 7.34 7.34 7.33 7.33 7.29 7.28 7.28 7.28 7.27 4.55 4.54 4.53 4.52 3.80 3.78 3.67 3.65
1.52 1.40 1.39
Me
N
H
(R)
1.00 1.05 1.05 1.05 3.19 1.11 7.35 1.19
1.03
1.04 1.04
0.91 3.14
10.0 9.5 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 0.0
f1 (ppm)

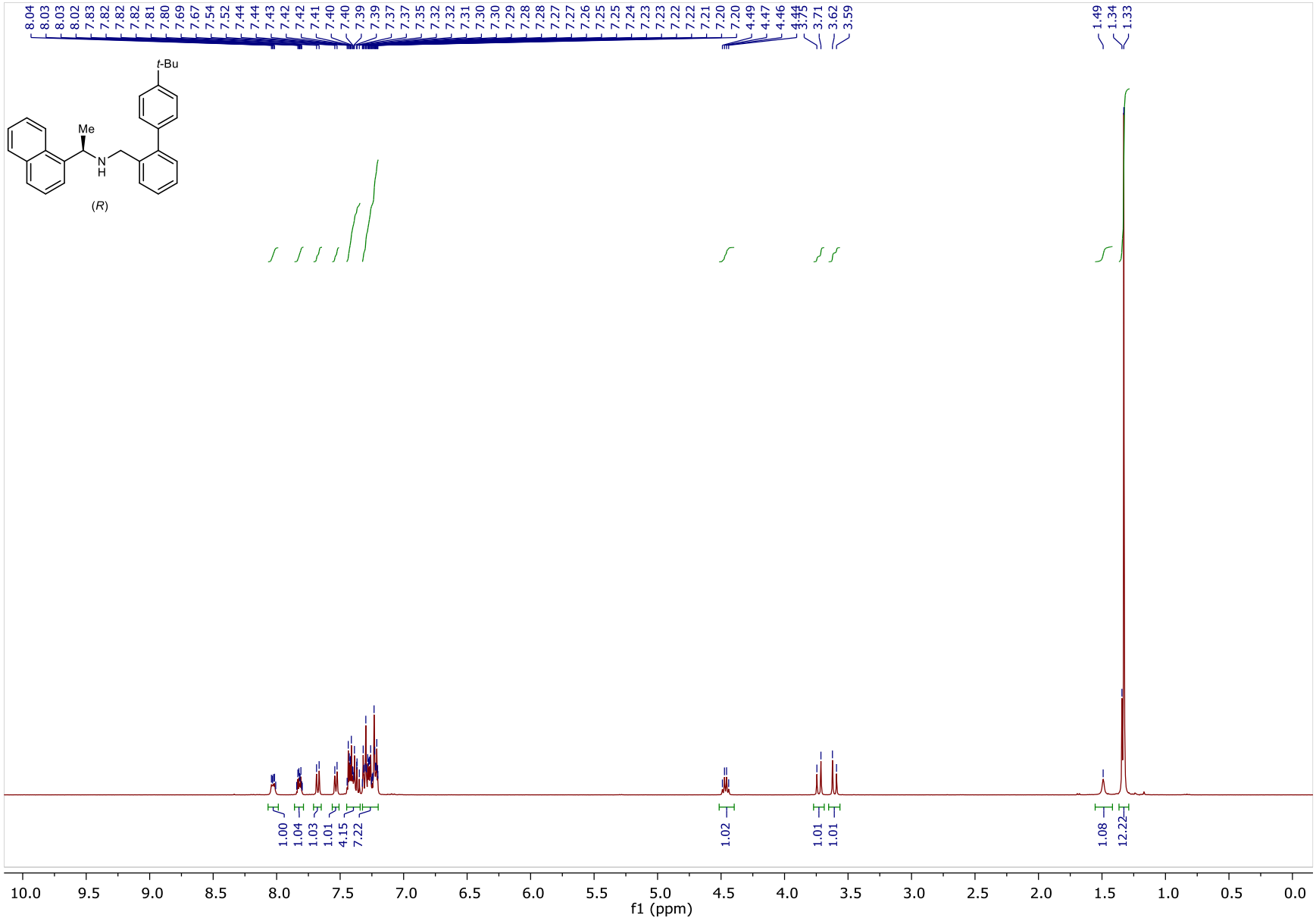

Me
N
H
(R)
142.06
141.35
140.98
138.07
134.09
131.39
130.25
129.83
129.23
129.02
128.25
127.63
127.18
127.13
127.07
125.89
125.72
125.32
123.17
123.00
53.45
49.88
23.71
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

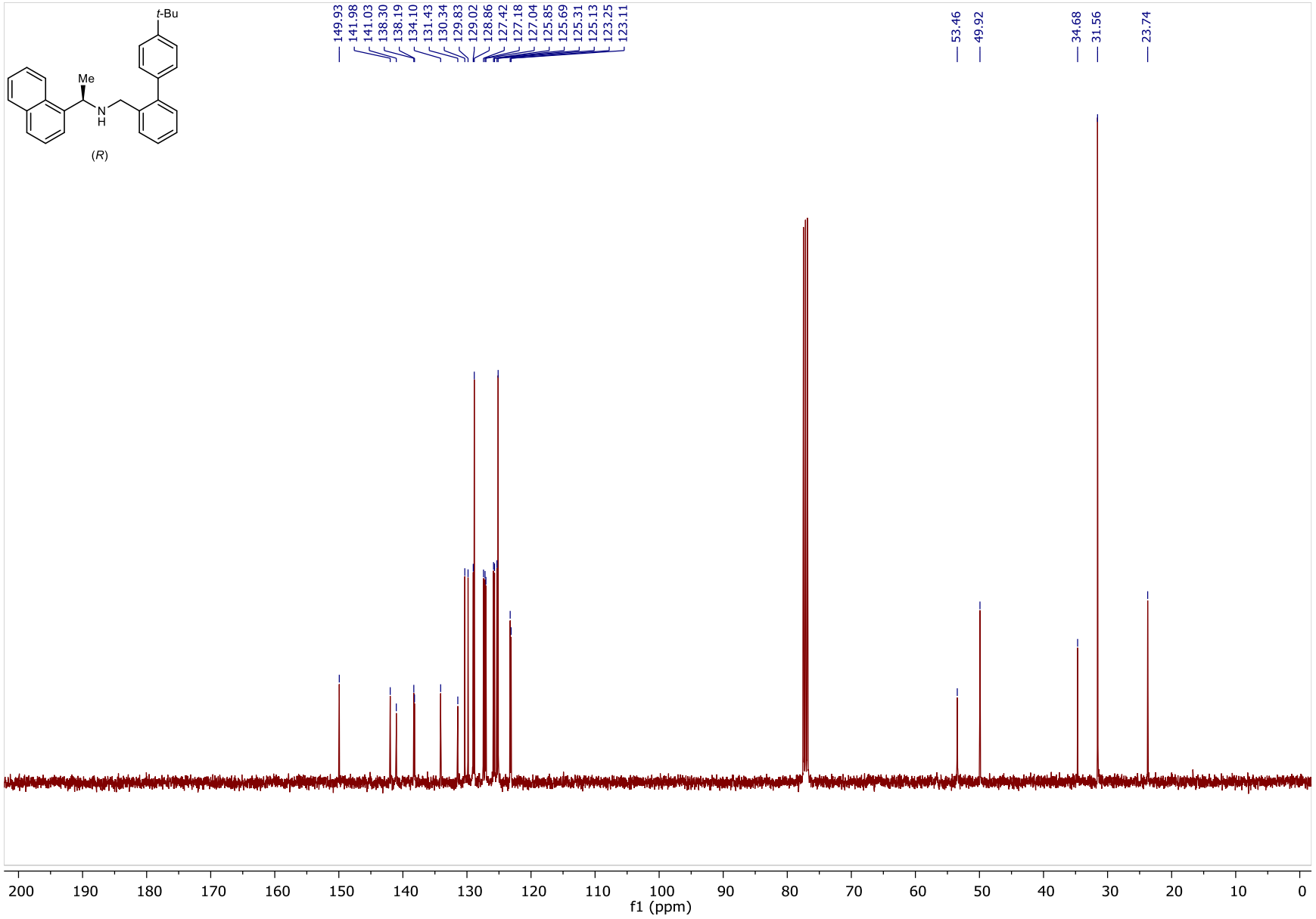

8.10 8.09 8.08 8.08 7.93 7.93 7.92 7.92 7.91 7.91 7.91 7.79 7.77 7.60 7.59 7.53 7.53 7.52 7.52 7.52 7.51 7.51 7.51 7.50 7.50 7.48 7.48 7.48 7.47 7.47 7.46 7.46 7.37 7.37 7.37 7.36 7.36 7.31 7.31 7.31 7.30 7.30 7.30 7.06 7.02 4.59 4.57 4.56 4.55 3.87 3.85 3.72 3.70 2.38 1.60 1.45 1.43
Me
Me
Me
N
H
(R)
1.00 1.03 1.02 1.02 2.08 2.03 2.09 1.03 1.05 2.04 1.02 1.02 1.02 6.21 0.95 3.10
10.0 9.5 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 0.0
f1 (ppm)

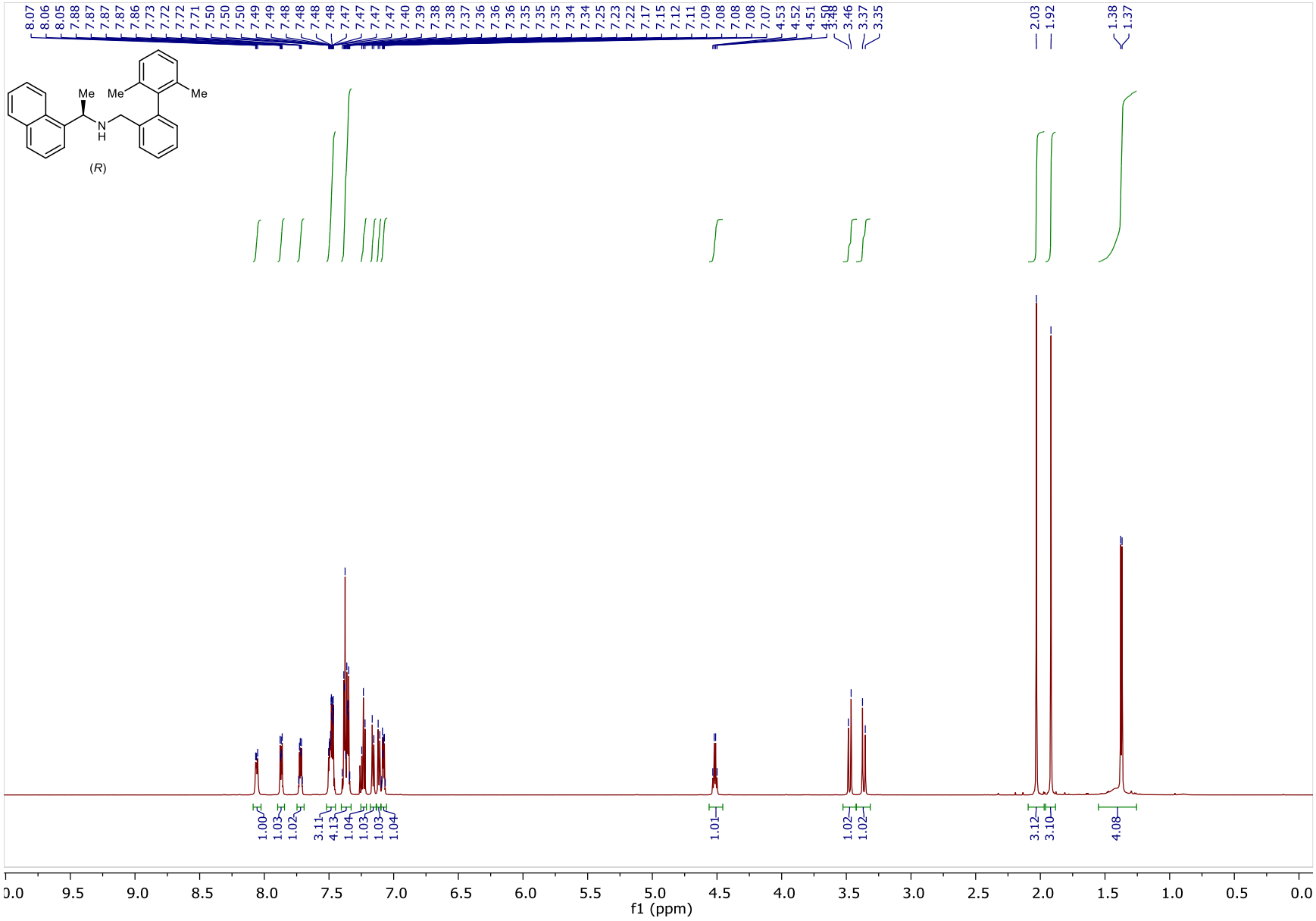

Me
Me
Me
N
H
(R)
142.30
141.30
141.12
137.99
137.70
134.05
131.36
130.16
129.75
128.99
128.74
127.41
127.12
126.98
126.95
125.87
125.69
125.29
123.09
122.92
53.12
49.95
23.72
21.45
21.43
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

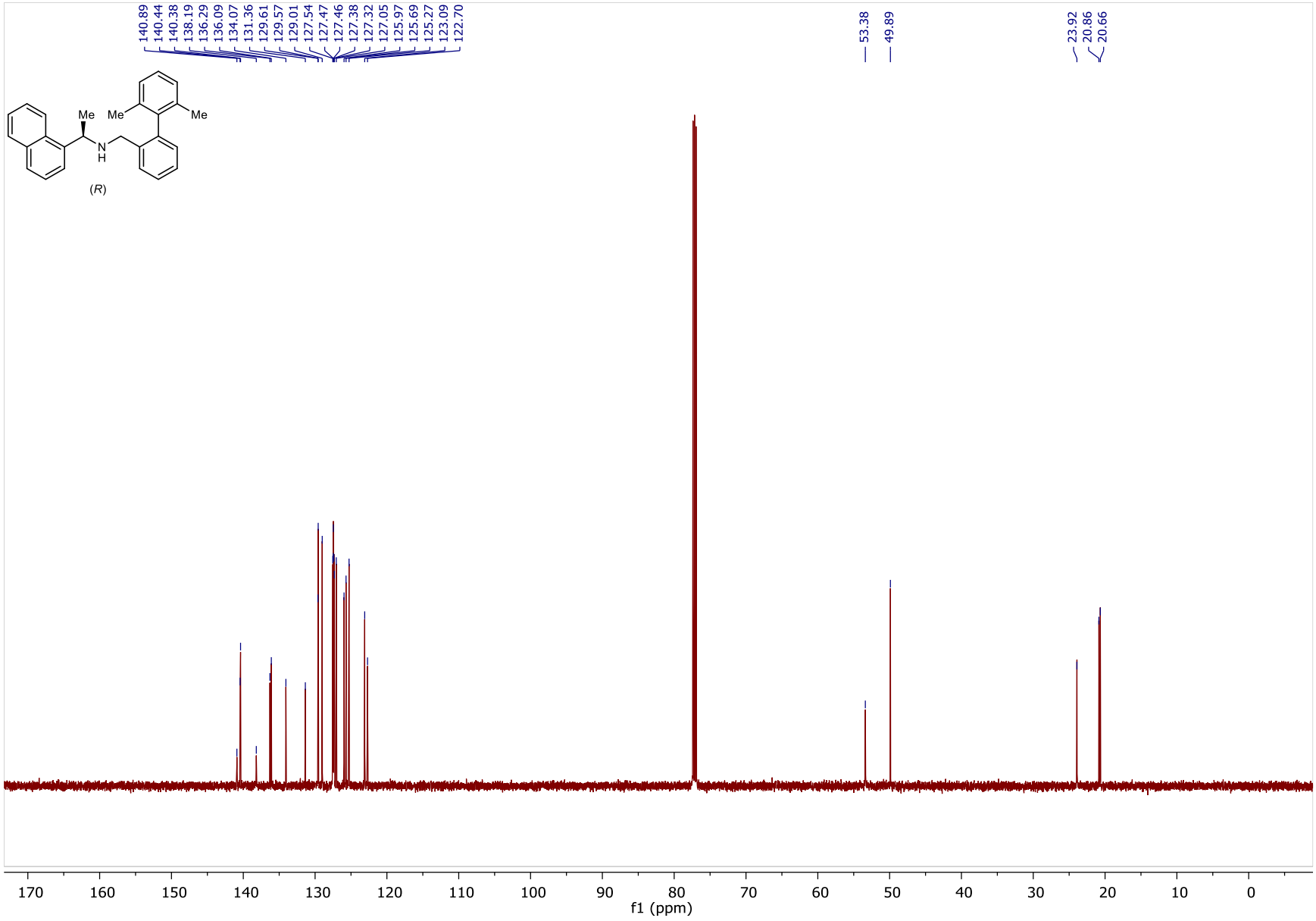

8.00 7.99 7.98 7.87 7.86 7.86 7.84 7.73 7.71 7.51 7.49 7.48 7.46 7.46 7.45 7.45 7.45 7.44 7.44 7.43 7.42 7.40 7.39 7.38 7.38 7.37 7.37 7.36 7.35 7.35 7.34 7.34 7.34 7.33 7.33 7.32 7.31 7.31 7.30 7.22 7.21 7.20
4.48 4.46 4.44 4.43
3.79 3.76 3.69 3.68 3.65
1.49 1.33 1.32 1.31
t-Bu
t-Bu
Me
N
H
(R)
1.00 0.99 0.99 9.18 2.01
1.02
1.01 1.02
1.02 21.35
10.0 9.5 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 0.0
f1 (ppm)

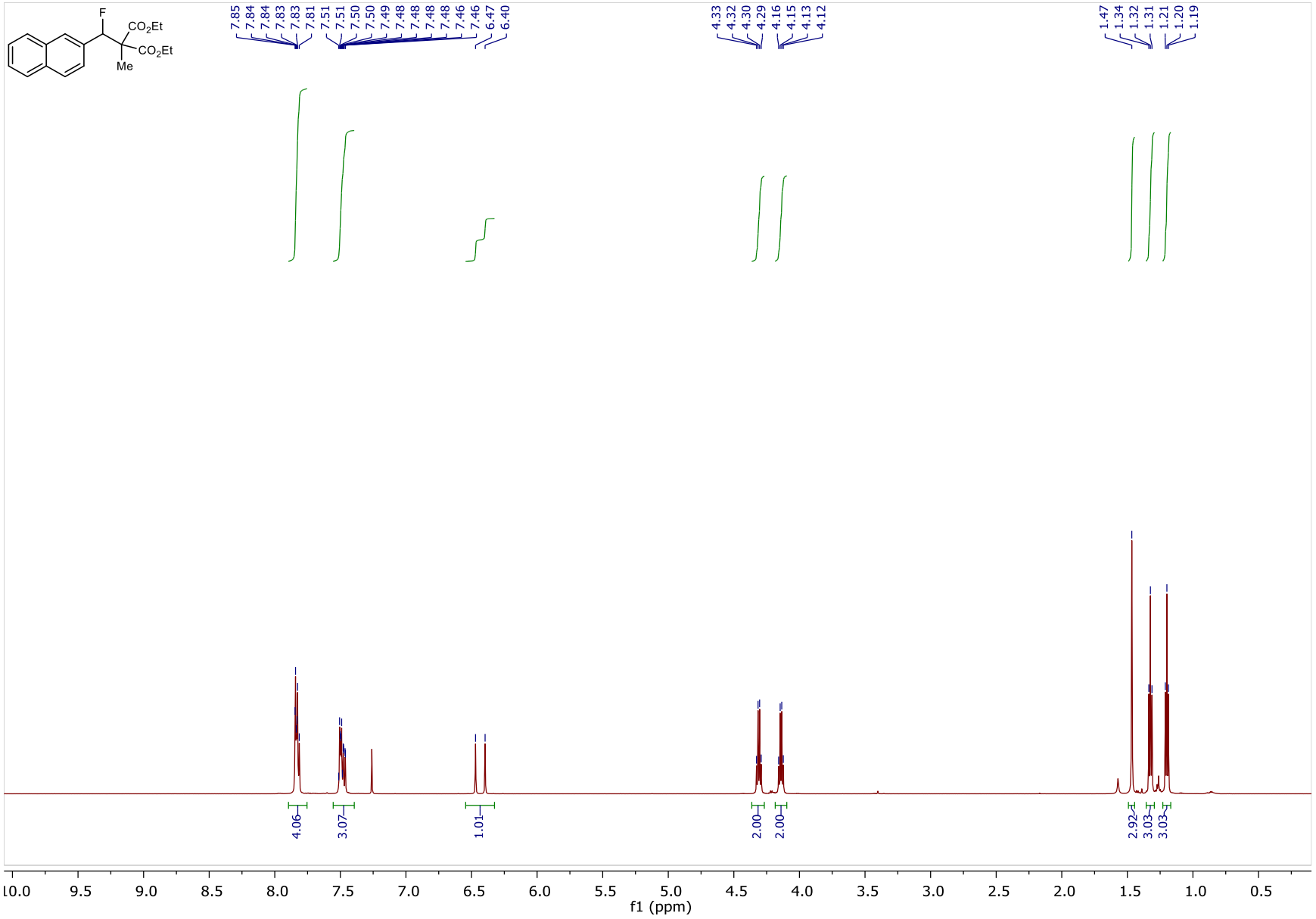

t-Bu
t-Bu
Me
N
H
(R)
150.68
143.19
141.11
140.52
138.15
134.08
131.36
130.33
129.90
129.00
127.38
127.12
127.05
125.92
125.70
125.30
123.46
123.07
122.91
121.00
53.09
50.21
35.04
31.65
23.74
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

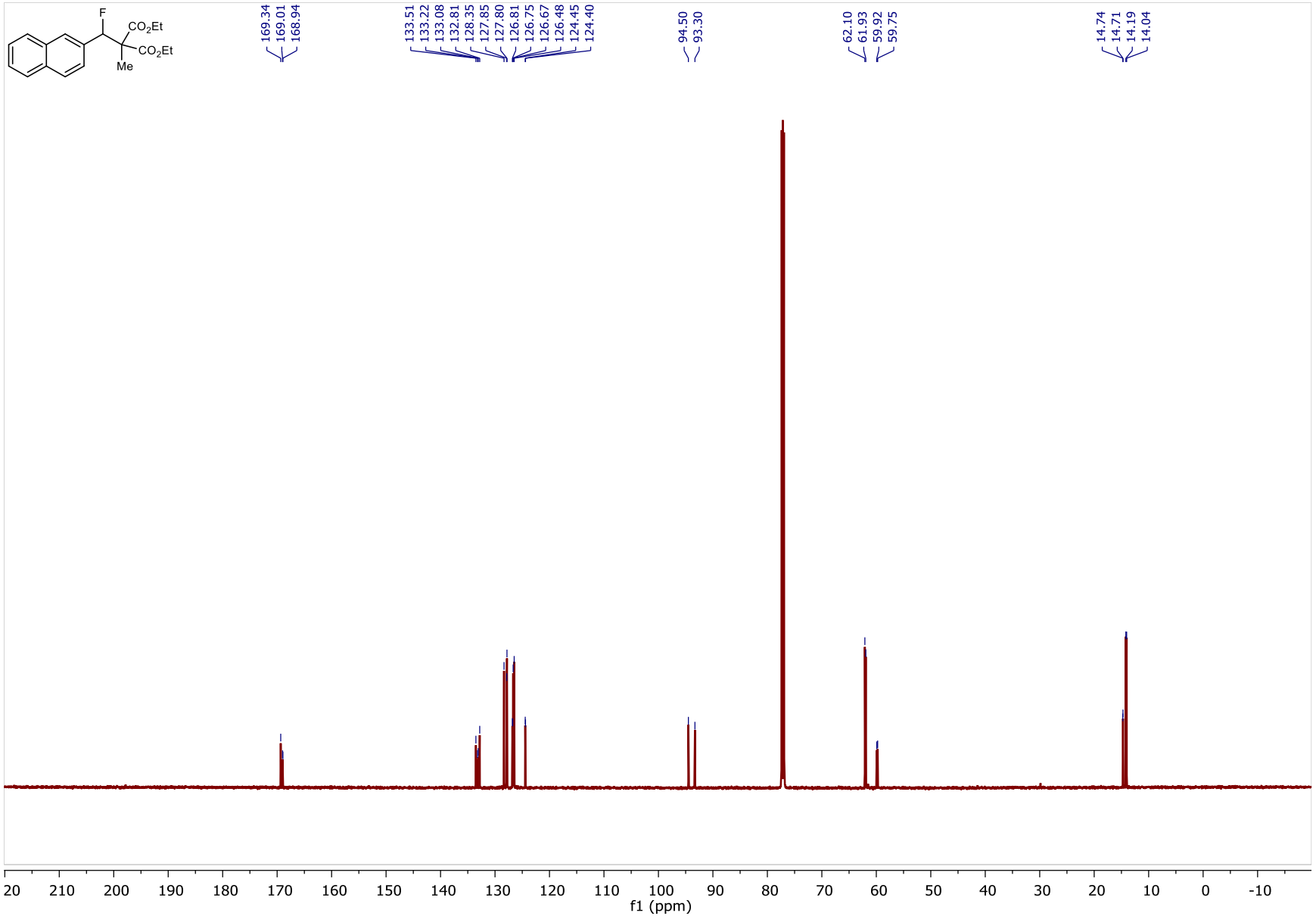

8.04 8.03 8.03 8.02 8.02 7.83 7.82 7.82 7.81 7.80 7.69 7.67 7.54 7.52 7.44 7.44 7.43 7.42 7.42 7.41 7.40 7.40 7.39 7.39 7.37 7.37 7.35 7.32 7.32 7.31 7.30 7.30 7.29 7.28 7.28 7.27 7.27 7.26 7.25 7.25 7.24 7.23 7.23 7.22 7.22 7.21 7.20 7.20 4.49 4.47 4.46 4.44 4.44 3.75 3.71 3.62 3.59
1.49 1.34 1.33
t-Bu
Me
N
H
(R)
1.00 1.04 1.03 1.01 4.15 7.22
1.02
1.01 1.01
1.08 12.22
10.0 9.5 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 0.0
f1 (ppm)

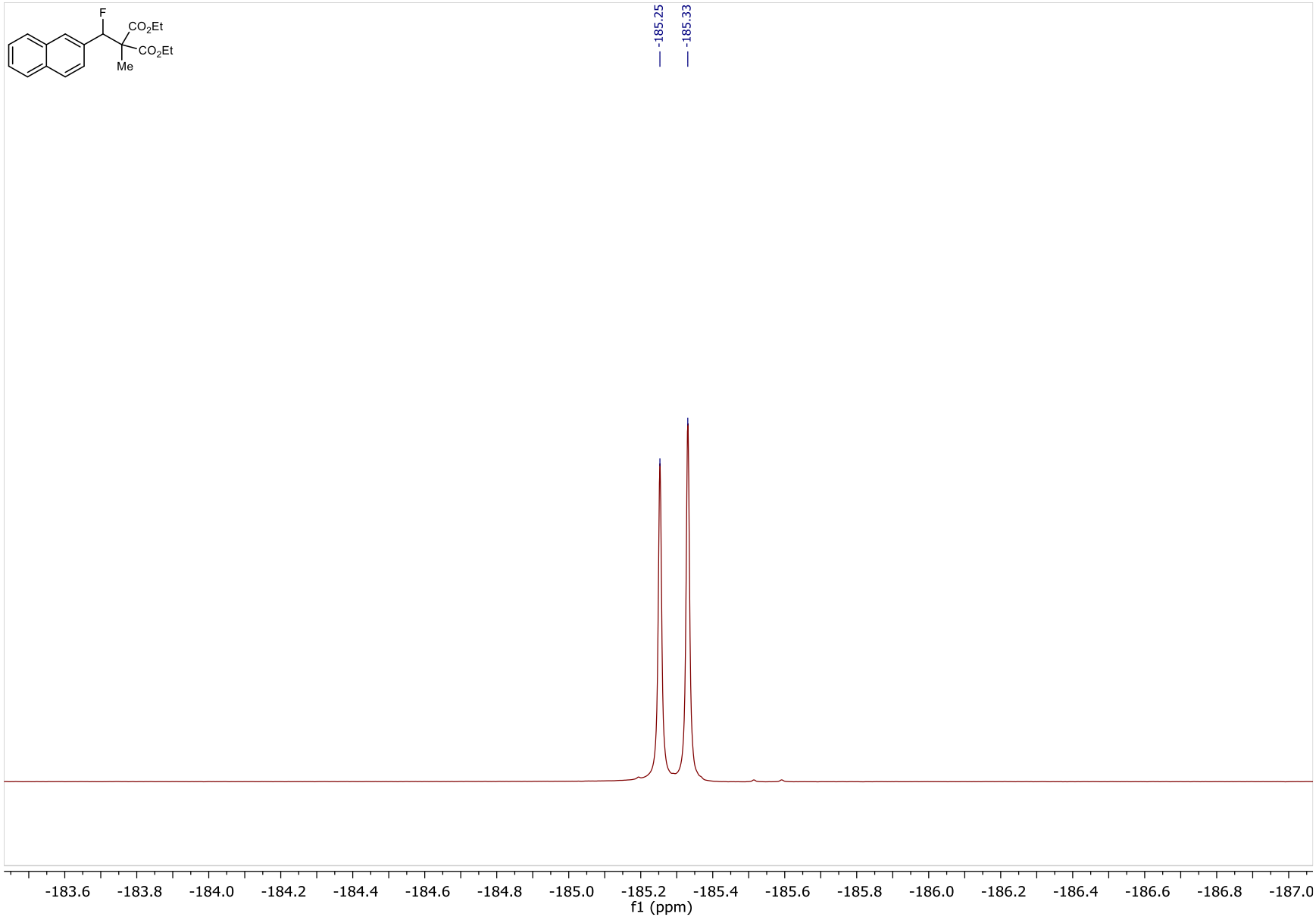

t-Bu
Me
N
H
(R)
149.93
141.98
141.03
138.30
138.19
134.10
131.43
130.34
129.83
129.02
128.86
127.42
127.18
127.04
125.85
125.69
125.31
125.13
123.25
123.11
53.46
49.92
34.68
31.56
23.74
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


Me
Me
Me
N
H
(R)
f1 (ppm)


140.89
140.44
140.38
138.19
136.29
136.09
134.07
131.36
129.61
129.57
129.01
127.54
127.47
127.46
127.38
127.32
127.05
125.97
125.69
125.27
123.09
122.70
53.38
49.89
23.92
20.86
20.66
Me
Me
Me
N
H
(R)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


F
CO2Et
CO2Et
Me
7.85
7.84
7.84
7.83
7.83
7.81
7.51
7.51
7.50
7.50
7.49
7.48
7.48
7.48
7.48
7.46
6.47
6.40
4.33
4.32
4.30
4.29
4.16
4.15
4.13
4.12
1.47
1.34
1.32
1.31
1.21
1.20
1.19
4.06
3.07
1.01
2.00
2.00
2.92
3.03
3.03
10.0
9.5
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
f1 (ppm)


F
CO2Et
CO2Et
Me
169.34
169.01
168.94
133.51
133.22
133.08
132.81
128.35
127.85
127.80
126.81
126.75
126.67
126.48
124.45
124.40
94.50
93.30
62.10
61.93
59.92
59.75
14.74
14.71
14.19
14.04
20 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


F
CO2Et
CO2Et
Me
-185.25
-185.33
-183.6
-183.8
-184.0
-184.2
-184.4
-184.6
-184.8
-185.0
-185.2
-185.4
-185.6
-185.8
-186.0
-186.2
-186.4
-186.6
-186.8
-187.0
f1 (ppm)