

# Supplementary Materials

## Mechanochemical Dimerization of Aldoximes to Furoxans

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## 1. Calculation of green chemistry metrics for the synthesis of 2a.

Environmental factor (*E* factor) is a metric for quantifying the actual amount of waste produced in the process. The waste was originally defined as “everything but the desired product” [1–3]. According to the recently proposed new *E* factor derivatives, we calculated two *E* factors: the complete *E* factor (cEF); the simple *E* factor (sEF) [4]. The cEF metric accounts for all process materials, including raw materials, reagents, solvents water and product. The sEF metric discounts water and solvents.

$$cEF = \frac{\sum m(\text{raw materials}) + \sum m(\text{reagents}) + \sum m(\text{solvents}) + \sum m(\text{water}) - m(\text{product})}{m(\text{product})}$$

$$sEF = \frac{\sum m(\text{raw materials}) + \sum m(\text{reagents}) - m(\text{product})}{m(\text{product})}$$

Higher cEF and sEF mean more waste. The ideal value of cEF and sEF is zero.

Atom economy (AE) is defined as “how much of the reactants end up in the product” [5]. It can be calculated as the molecular weight of the desired product divided by the total molecular weights of all reactants produced in the stoichiometric equation.

$$AE = \frac{MW(\text{product})}{\sum MW(\text{raw materials})} \times 100\%$$

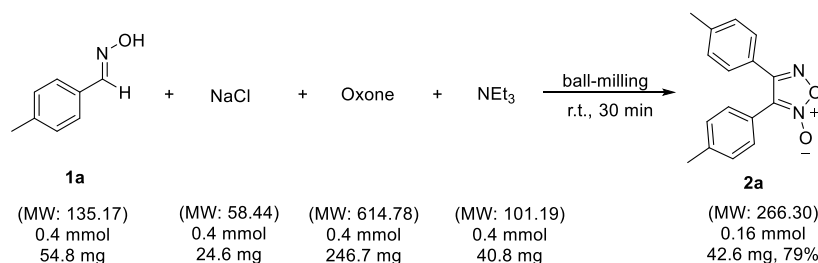
The ideal value of AE is 100%.

Reaction mass efficiency (RME) takes into account yields, the actual molar quantities of reactants, and the concepts of atom efficiency. RME is defined as the percentage of the mass of the isolated product divided by the total mass of the reactants used in the reaction [6].

$$RME = \frac{m(\text{product})}{\sum m(\text{raw materials})} \times 100\%$$

The ideal value of RME is 100%.

## Calculation of green chemistry metrics for the mechanochemical synthesis of 2a



dichloromethane: density 1.33 g/mL at 25 °C  
 water: density 1.00 g/mL at 25 °C  
 ethyl acetate: density 0.90 g/mL at 25 °C  
 petroleum ether: density 0.64 g/mL at 25 °C  
**workup:** dichloromethane, 46 mL, 61.2 g; water, 6 mL, 6.0 g  
**purification:** ethyl acetate, 8 mL, 7.2 g; petroleum ether, 440 mL, 281.6 g

$$cEF = \frac{54.8 + (24.6 + 246.7 + 40.8) + (61200 + 7200 + 281600) + 6000 - 42.6}{42.6}$$

= 8364.4 kg waste/1 kg product

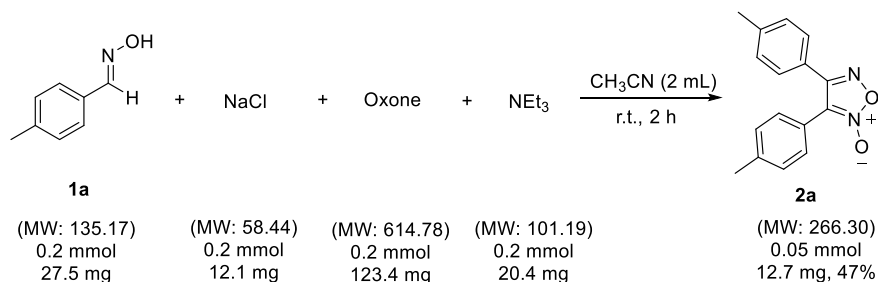
$$sEF = \frac{54.8 + (24.6 + 246.7 + 40.8) - 42.6}{42.6}$$

= 7.6 kg waste/1 kg product

$$AE = \frac{266.30}{135.17 \times 2} \times 100\% = 99\%$$

$$RME = \frac{42.6}{54.8} \times 100\% = 78\%$$

### Calculation of green chemistry metrics for solution-based synthesis of 2a



acetonitrile: density 0.79 g/mL at 25 °C  
ethyl acetate: density 0.90 g/mL at 25 °C  
petroleum ether: density 0.64 g/mL at 25 °C  
**workup:** acetonitrile, 2 mL, 1.6 g; ethyl acetate, 15 mL, 13.5 g  
**purification:** ethyl acetate, 6 mL, 5.4 g; petroleum ether, 270 mL, 172.8 g

$$cEF = \frac{27.5 + (12.1 + 123.4 + 20.4) + (1600 + 13500 + 5400 + 172800) - 12.7}{12.7}$$

= 15233.9 kg waste/1 kg product

$$sEF = \frac{27.5 + (12.1 + 123.4 + 20.4) - 12.7}{12.7}$$

= 13.4 kg waste/1 kg product

$$AE = \frac{266.30}{135.17 \times 2} \times 100\% = 99\%$$

$$RME = \frac{12.7}{27.5} \times 100\% = 46\%$$

## 2. NMR spectra of compounds 1a & 1a', 2a-r, 3s, 3t and 5a.

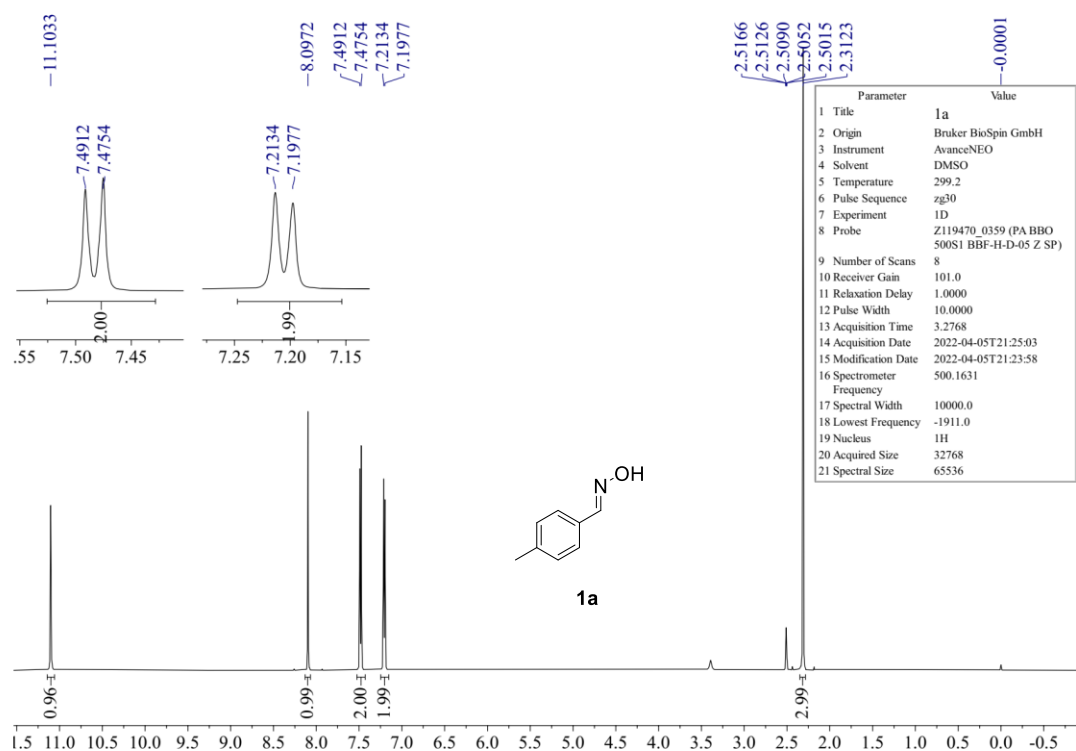


Figure S1. <sup>1</sup>H NMR (500 MHz, DMSO-*d*<sub>6</sub>) of compound **1a**.

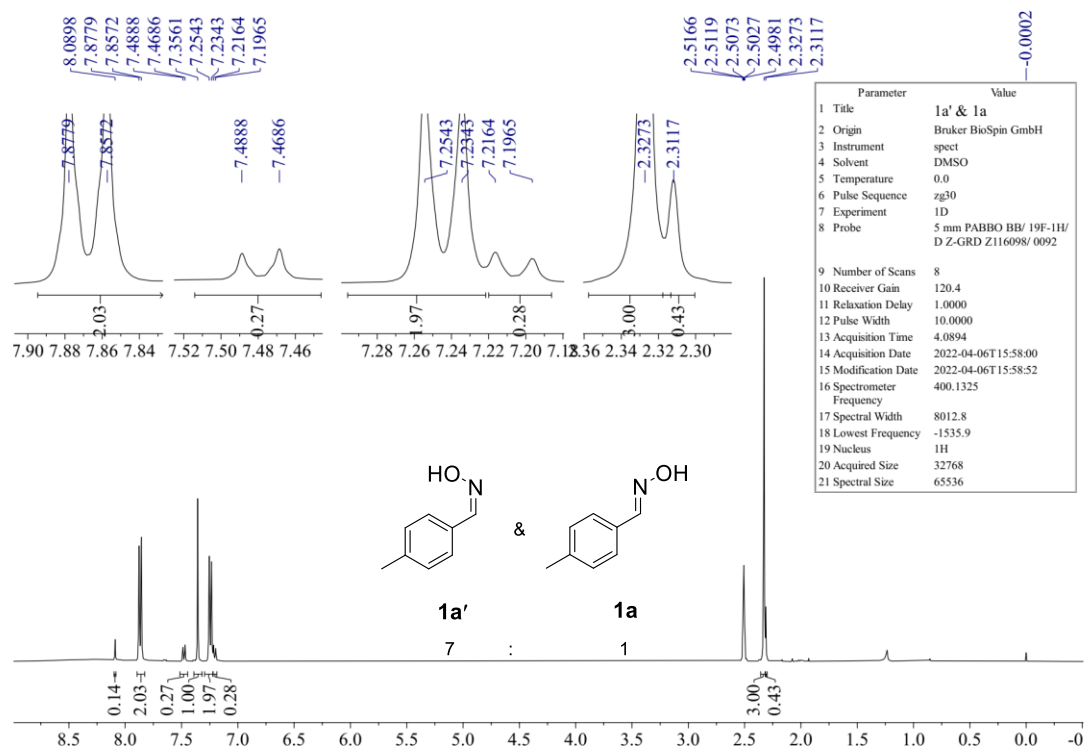
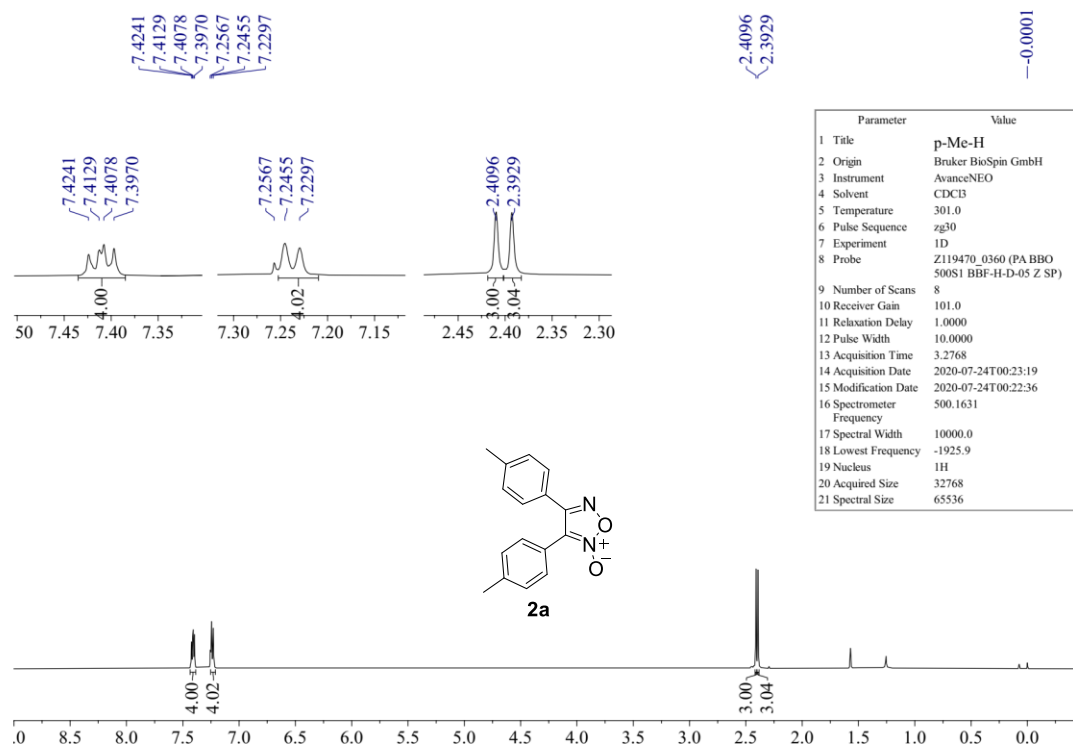
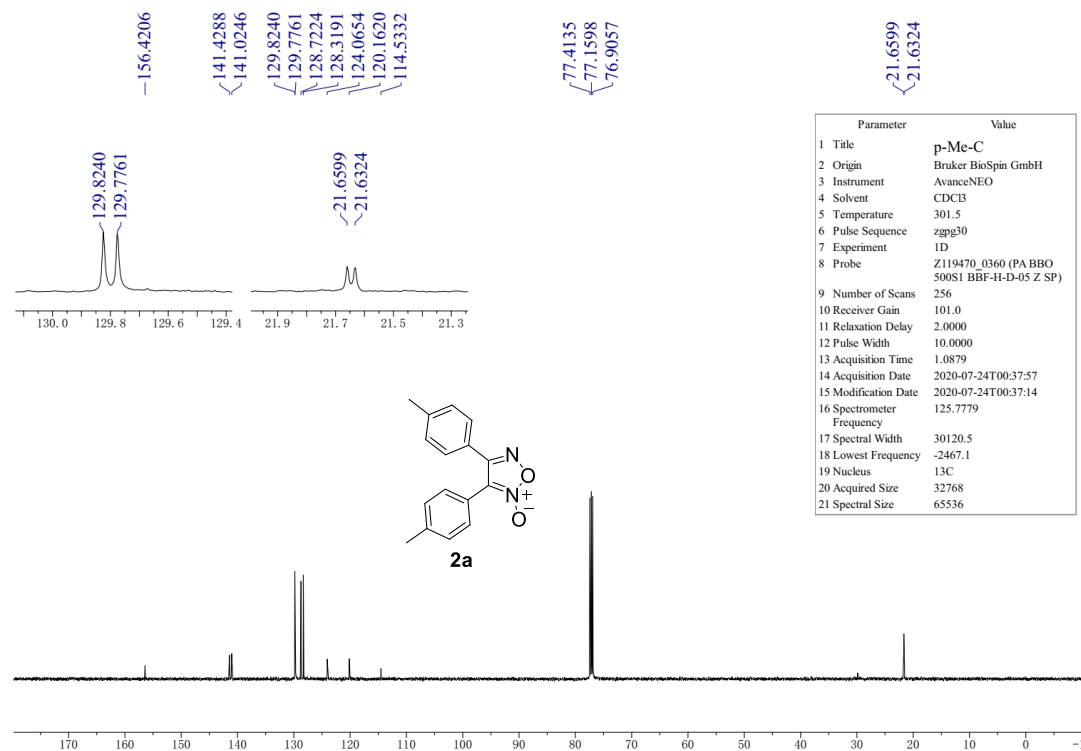


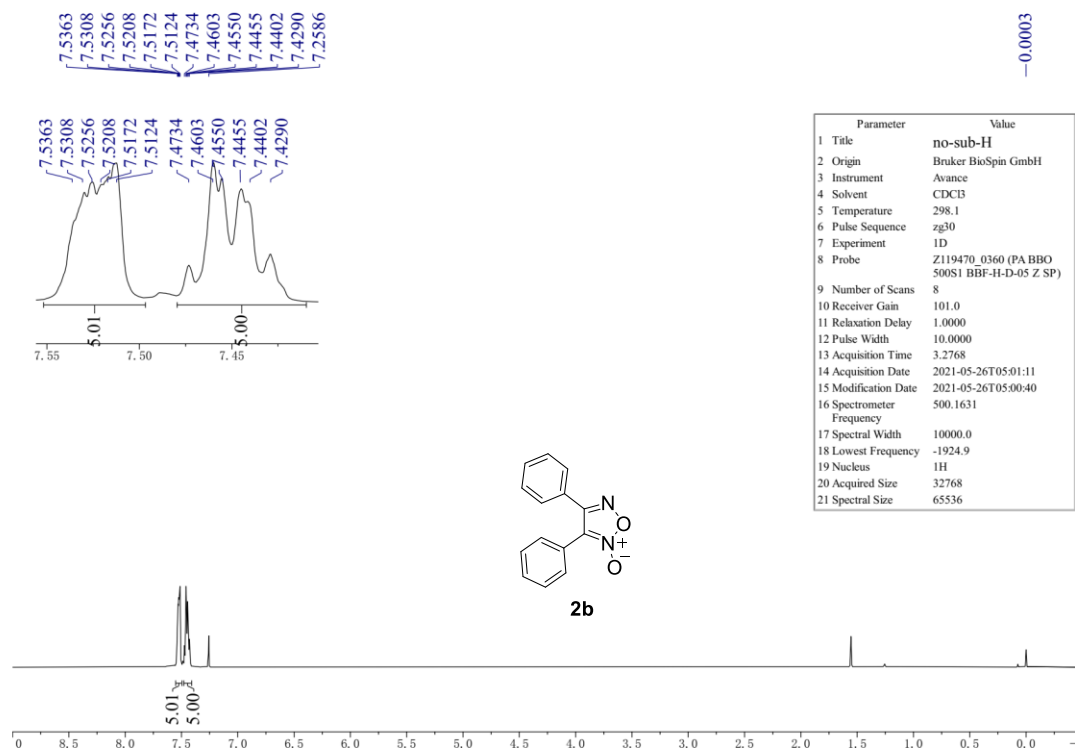
Figure S2. <sup>1</sup>H NMR (400 MHz, DMSO-*d*<sub>6</sub>) of compound **1a** and **1a'**.



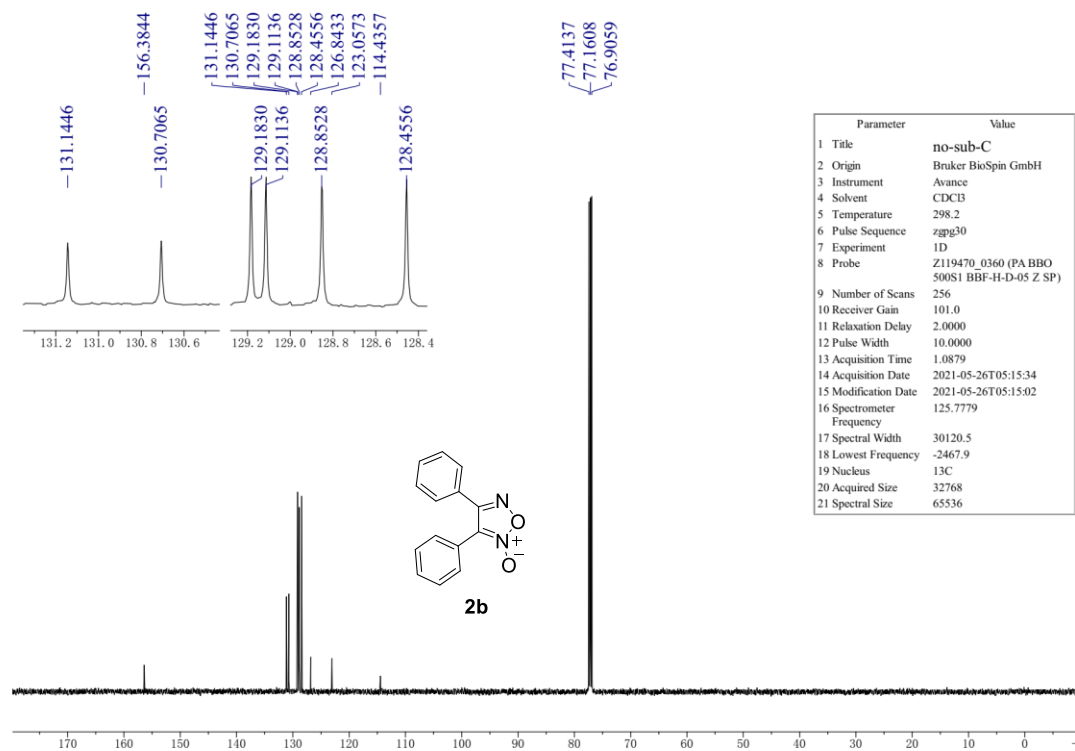
**Figure S3.** <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) of compound **2a**.



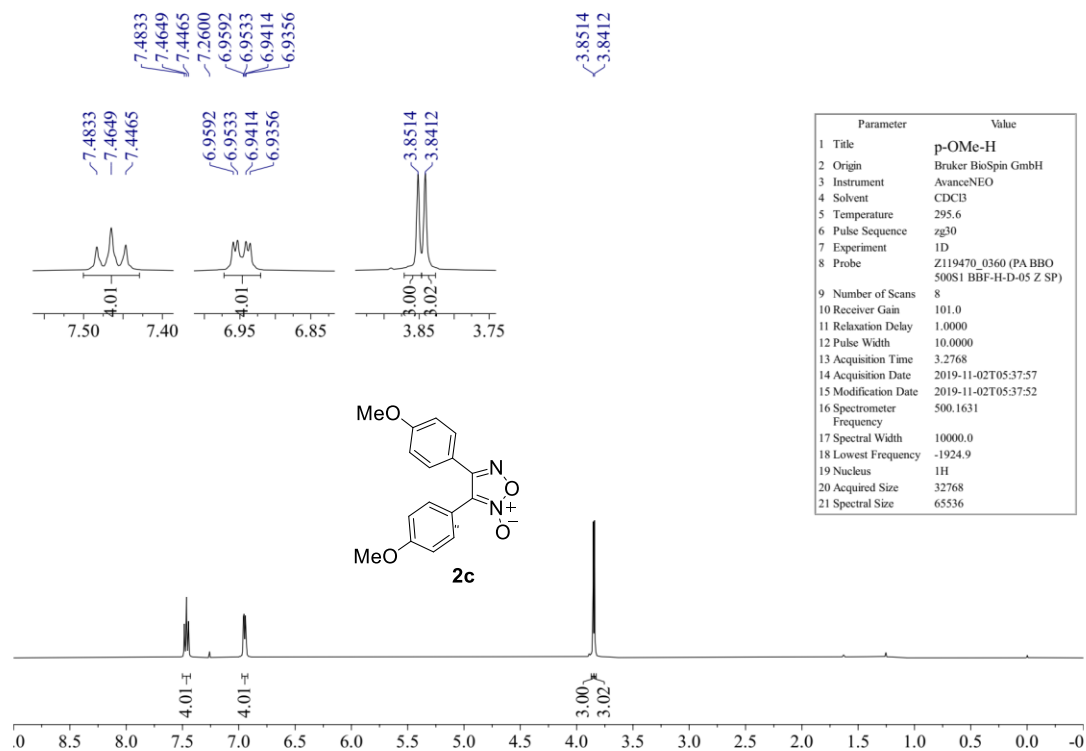
**Figure S4.** <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) of compound **2a**.



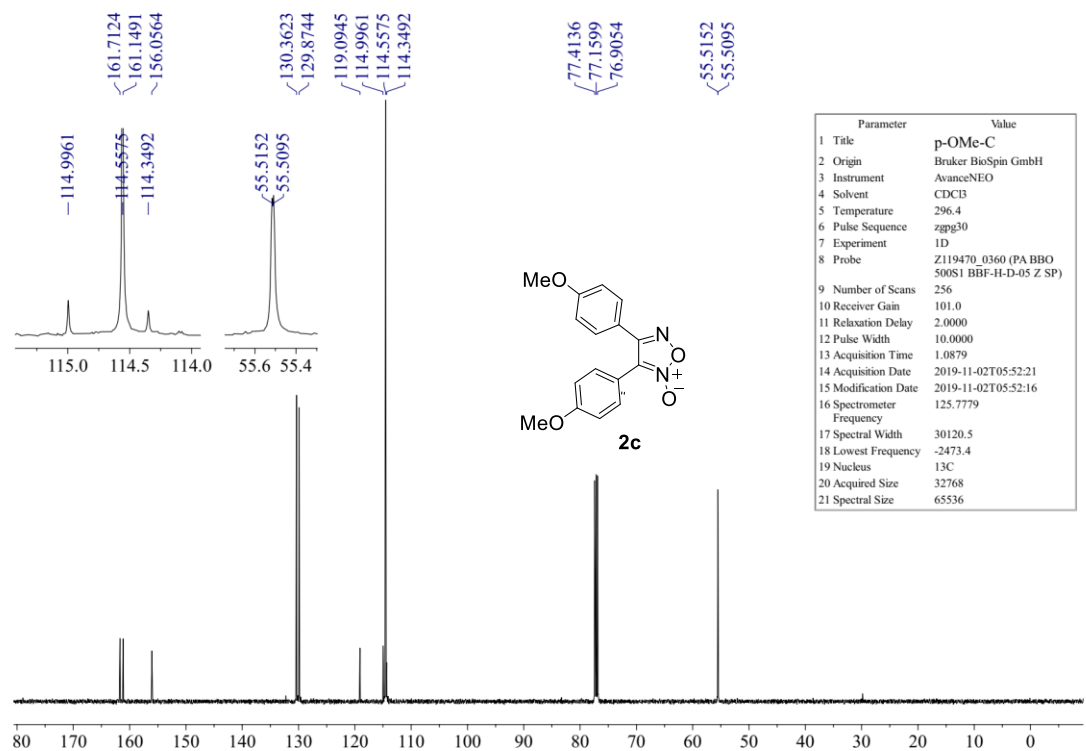
**Figure S5.** <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) of compound **2b**.



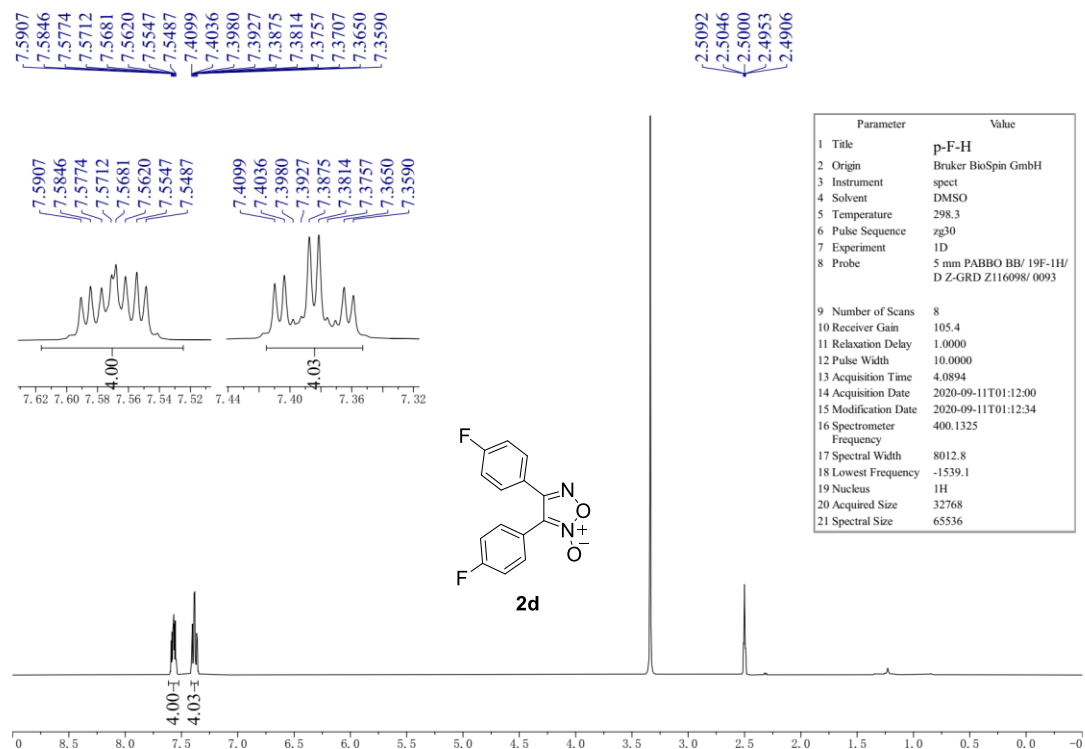
**Figure S6.** <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) of compound **2b**.



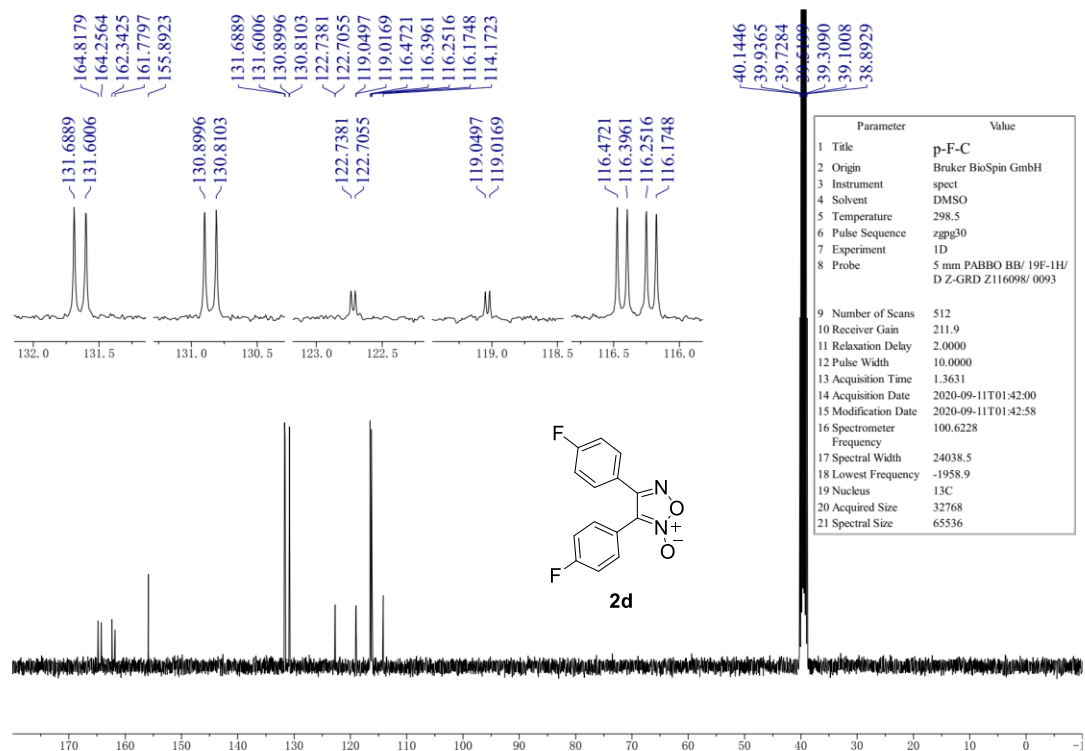
**Figure S7.** <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) of compound **2c**.



**Figure S8.** <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) of compound **2c**.

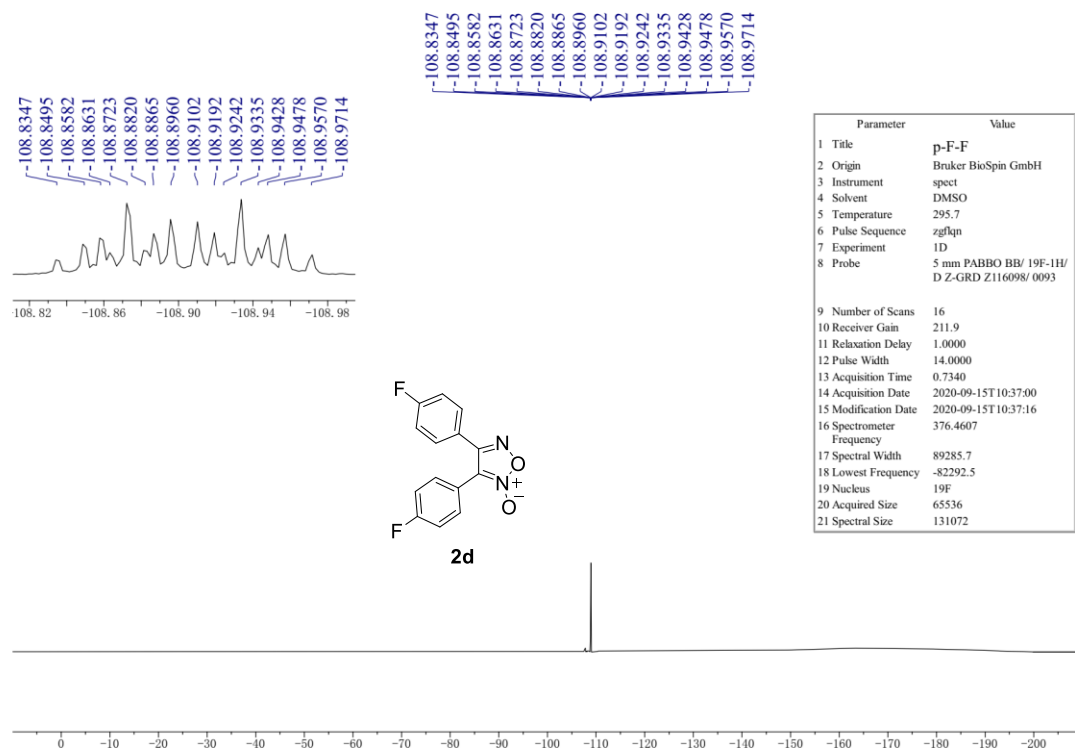


**Figure S9.** <sup>1</sup>H NMR (400 MHz, DMSO-*d*<sub>6</sub>) of compound **2d**.

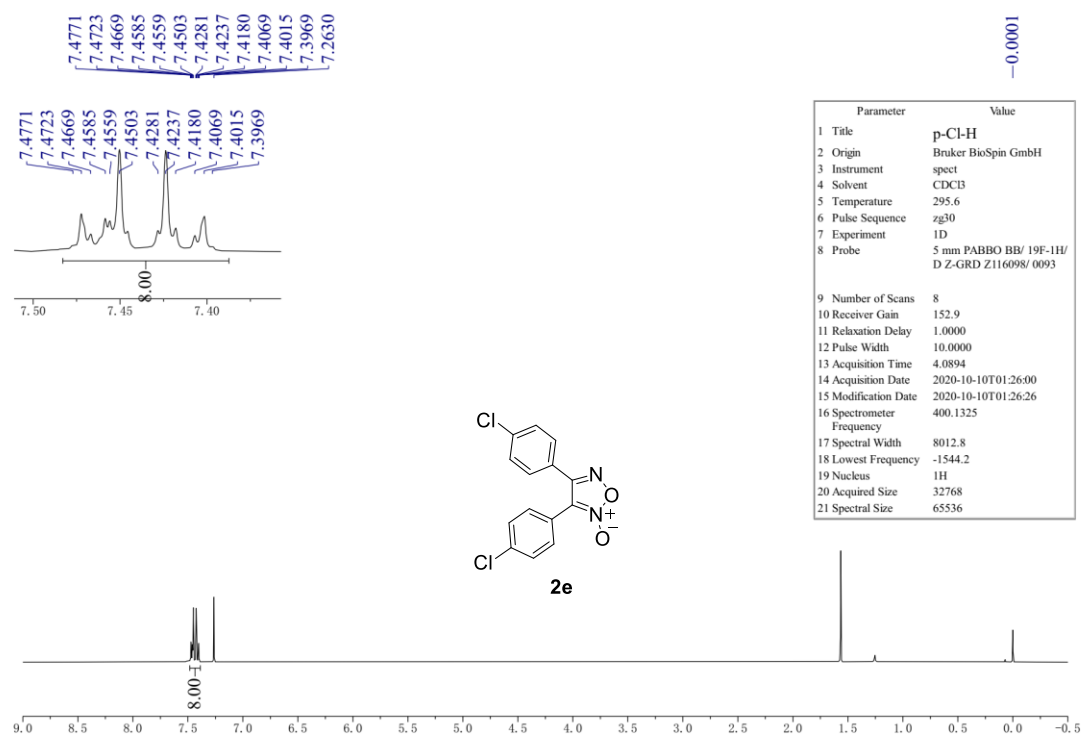


**Figure S10.** <sup>13</sup>C NMR (101 MHz, DMSO-*d*<sub>6</sub>) of compound **2d**.

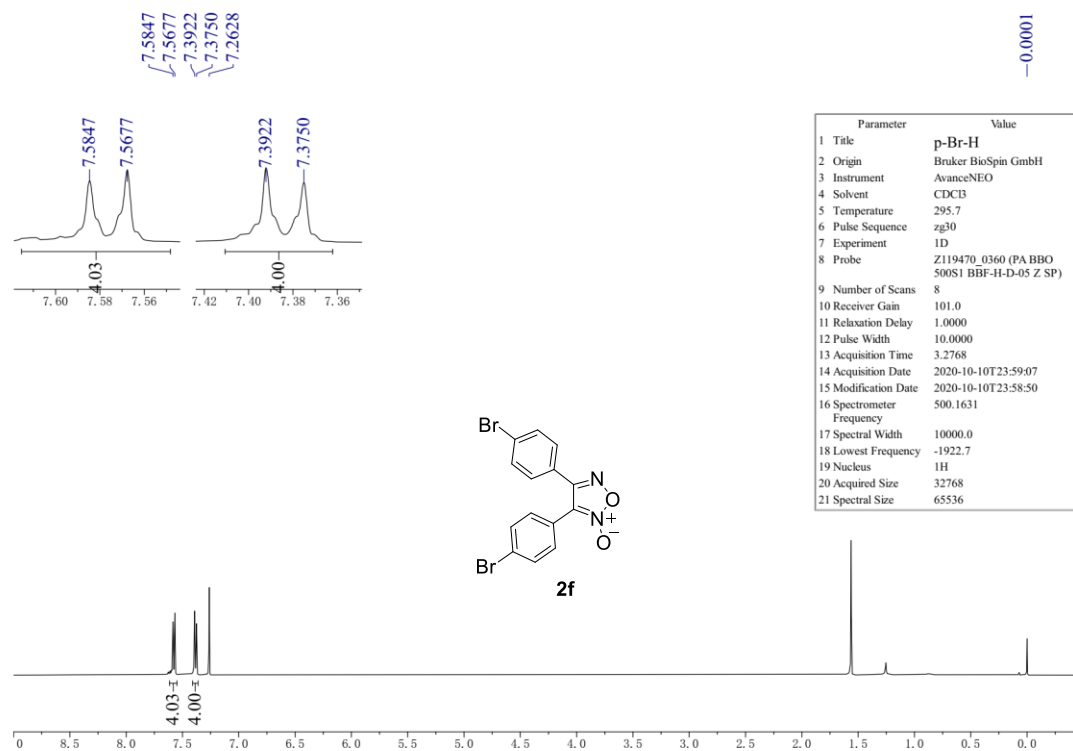
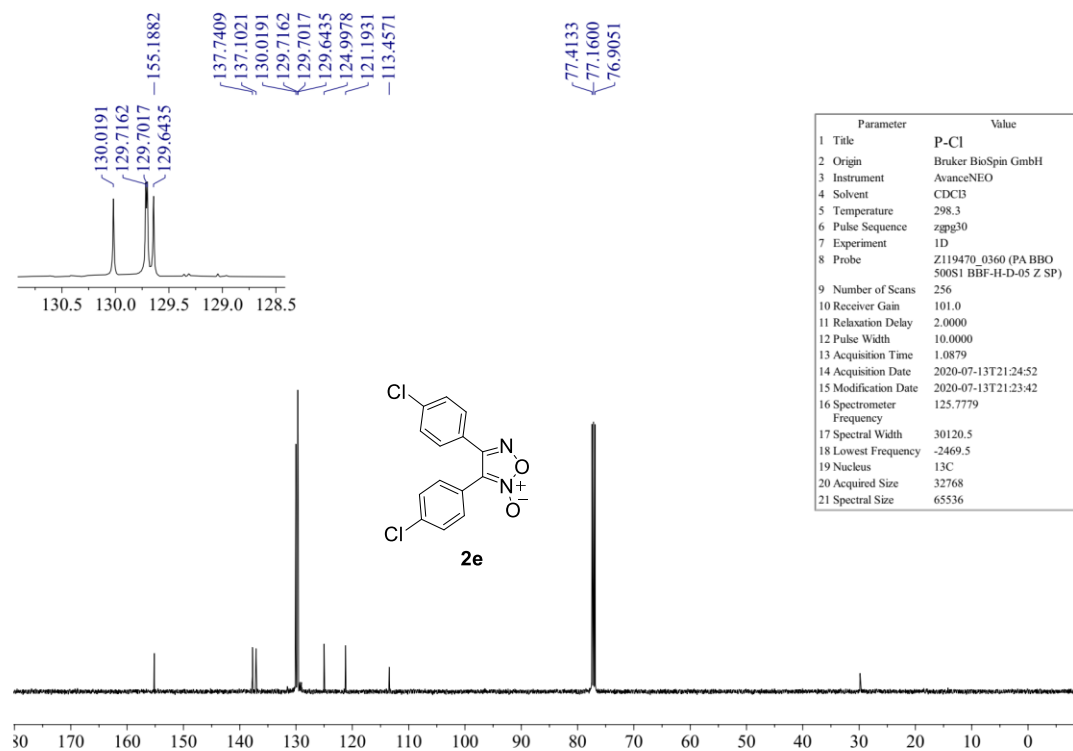


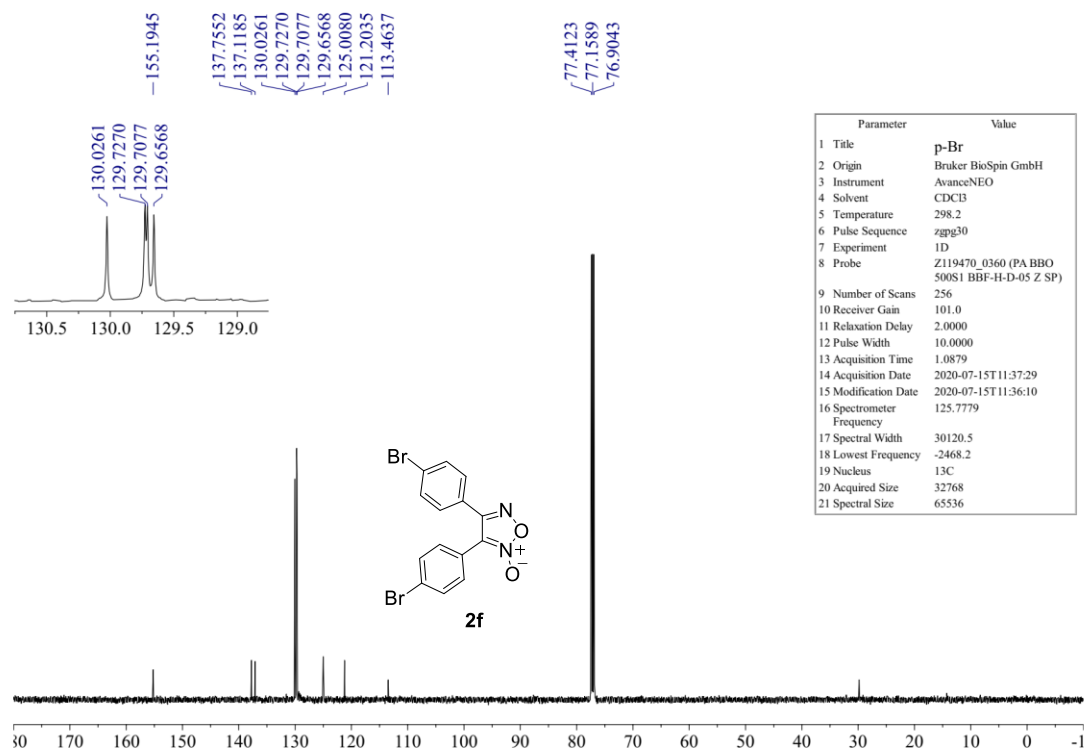


**Figure S11.**  $^{19}\text{F}$  NMR (376 MHz,  $\text{DMSO}-d_6$ ) of compound **2d**.

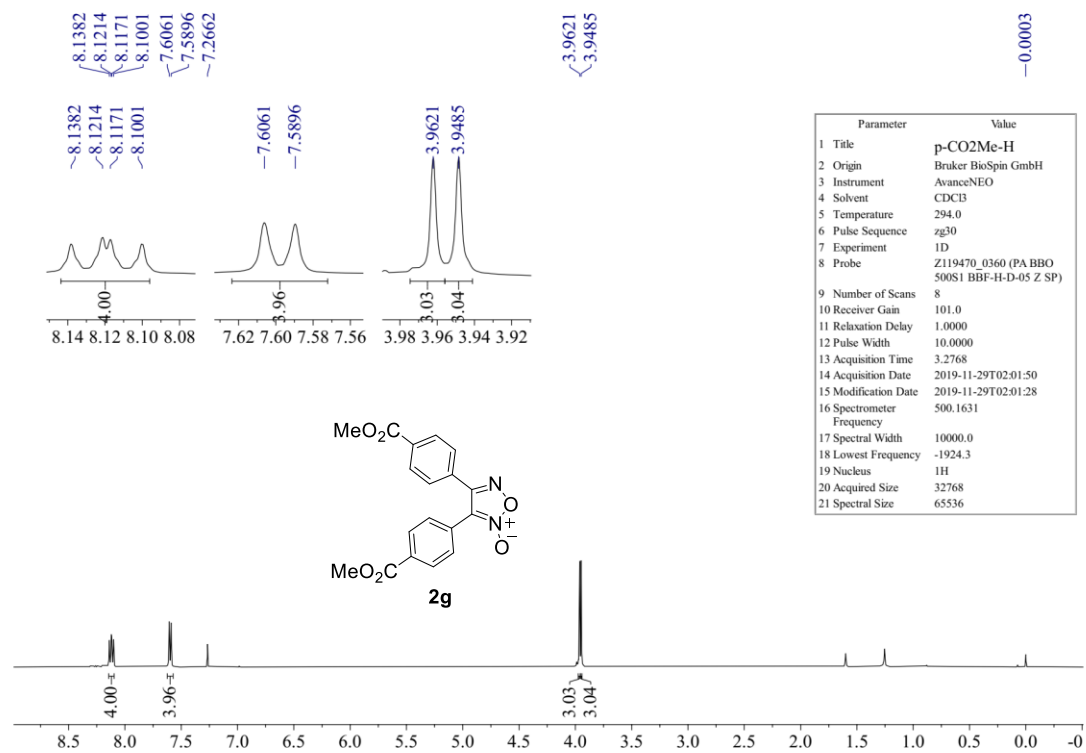


**Figure S12.**  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ) of compound **2e**.

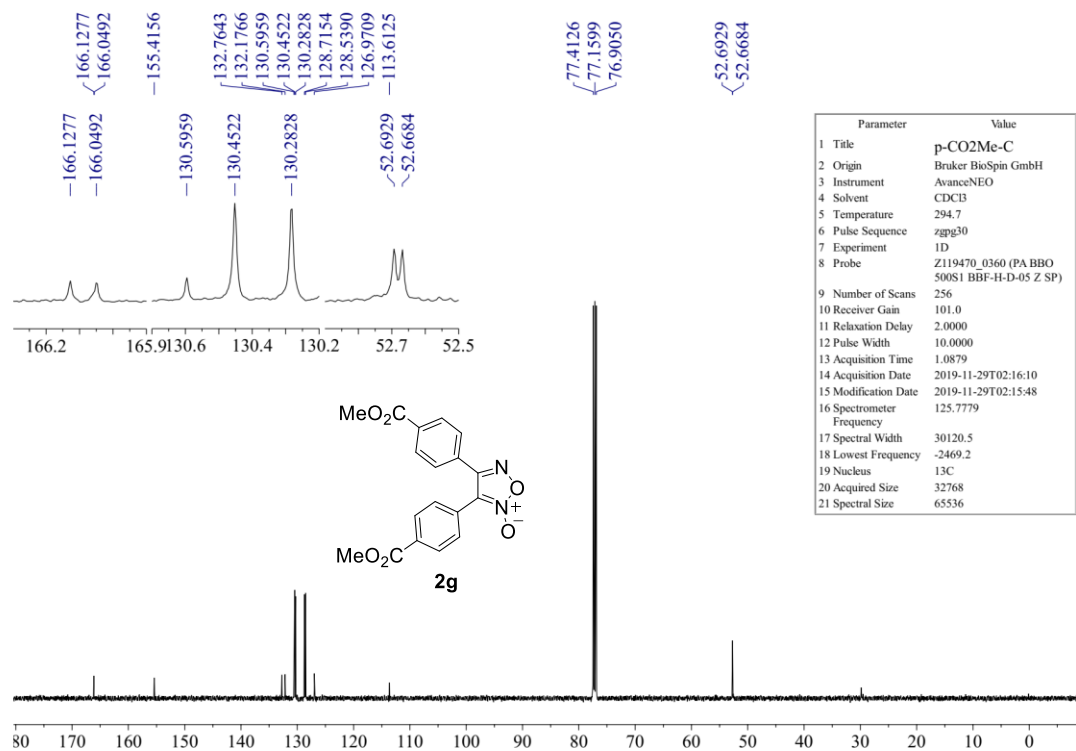




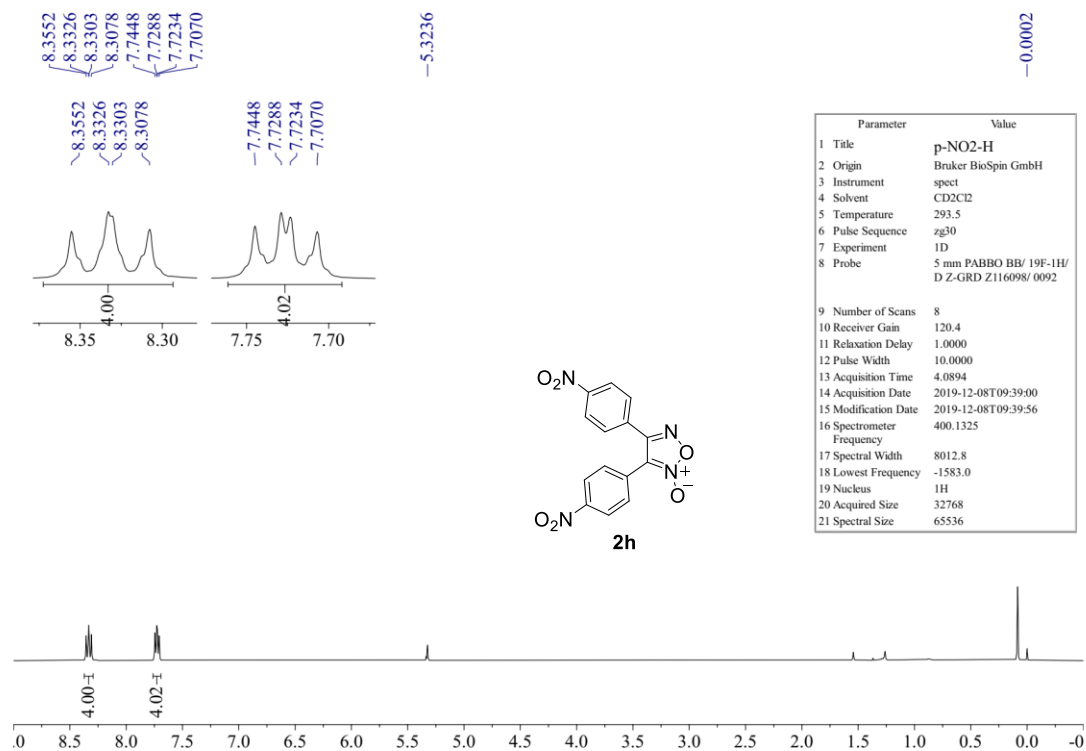
**Figure S15.** <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) of compound **2f**.



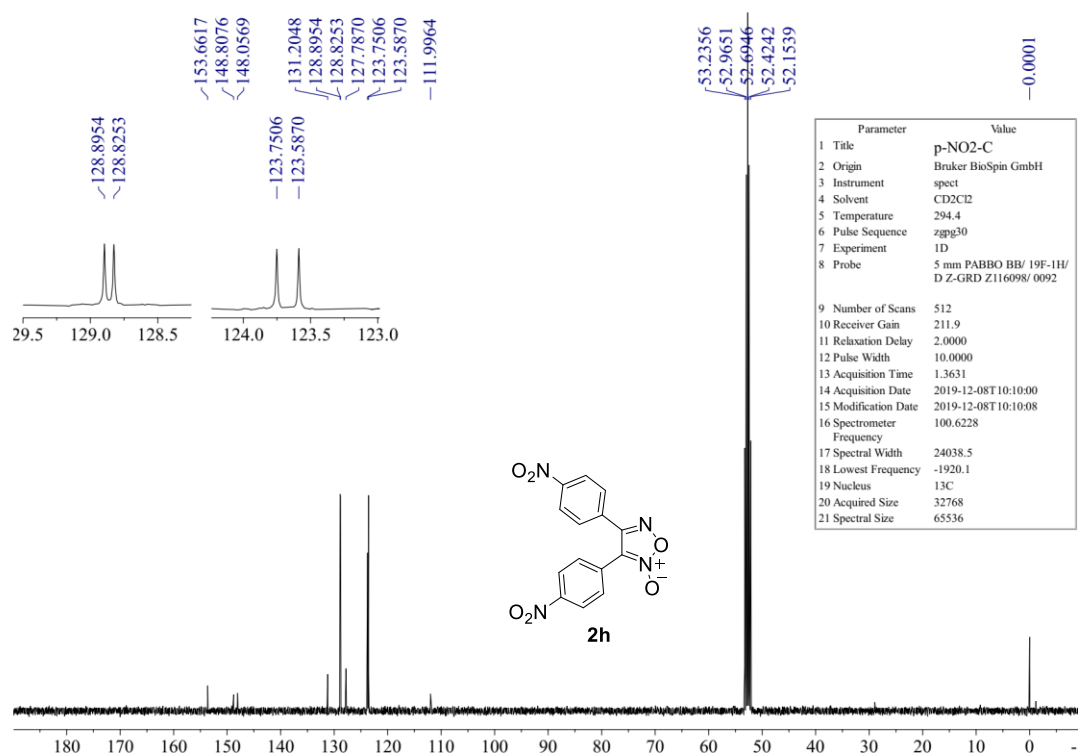
**Figure S16.** <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) of compound **2g**.



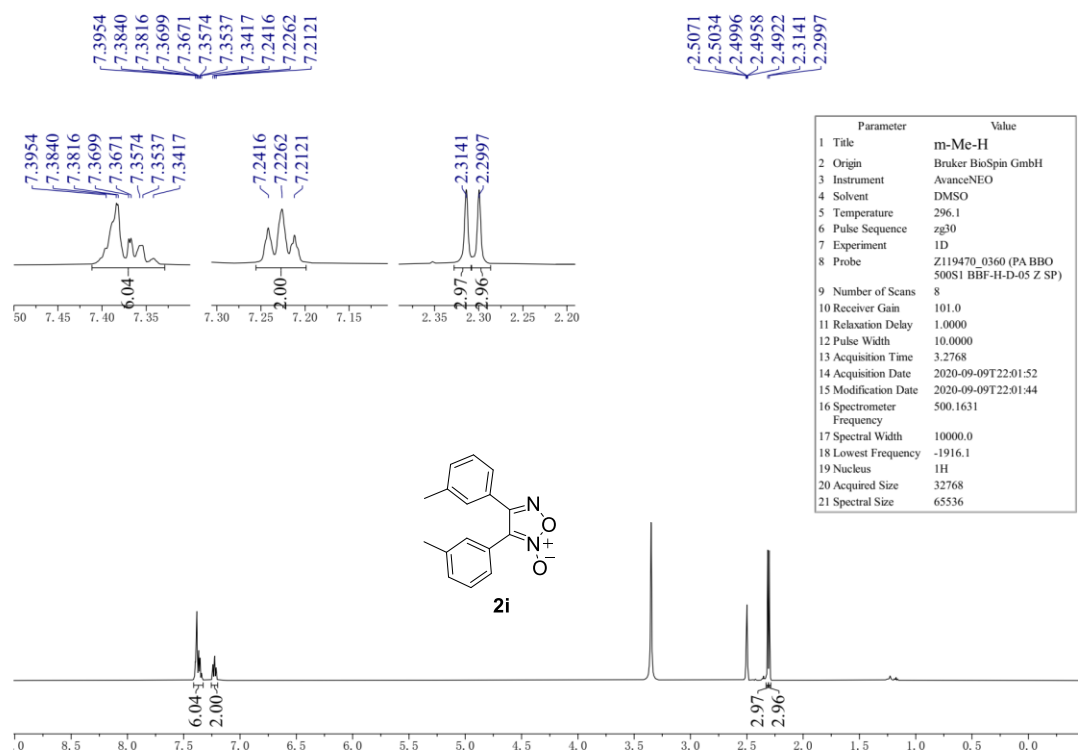
**Figure S17.** <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) of compound **2g**.



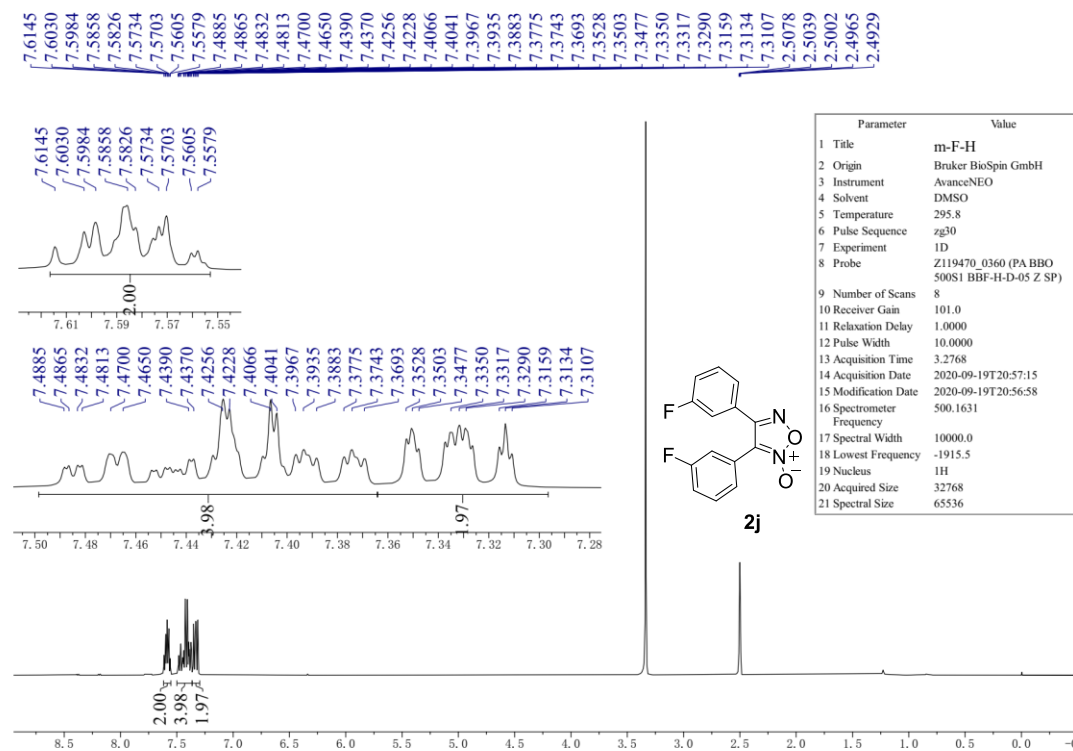
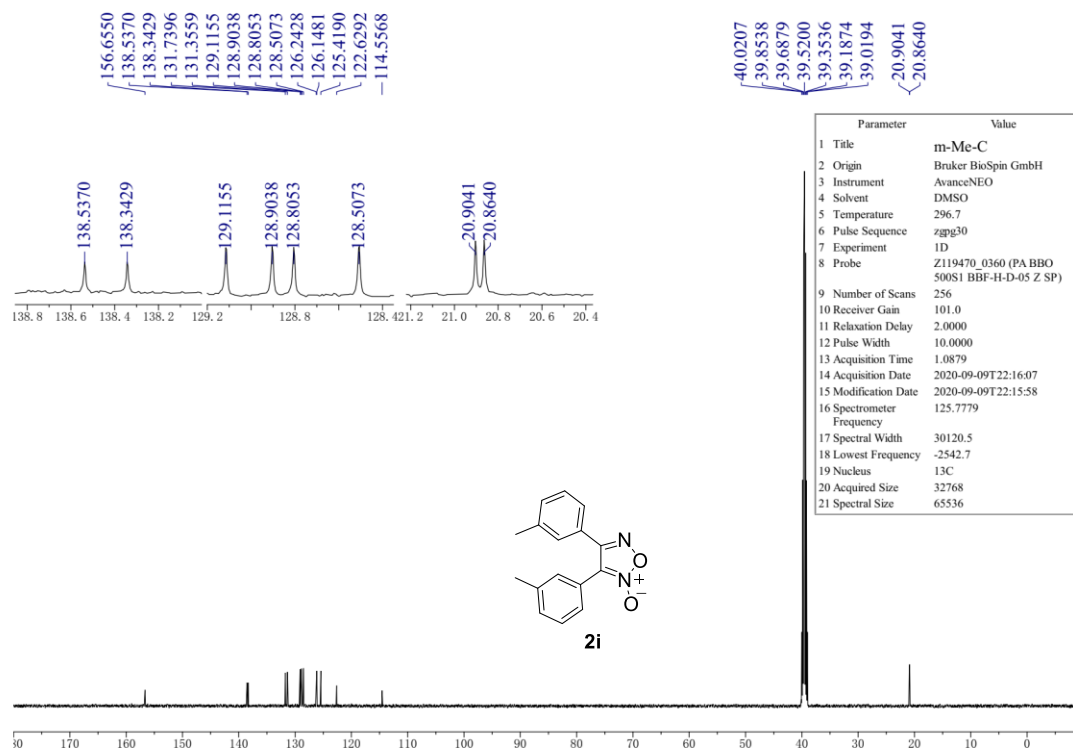
**Figure S18.** <sup>1</sup>H NMR (400 MHz, CD<sub>2</sub>Cl<sub>2</sub>) of compound **2h**.

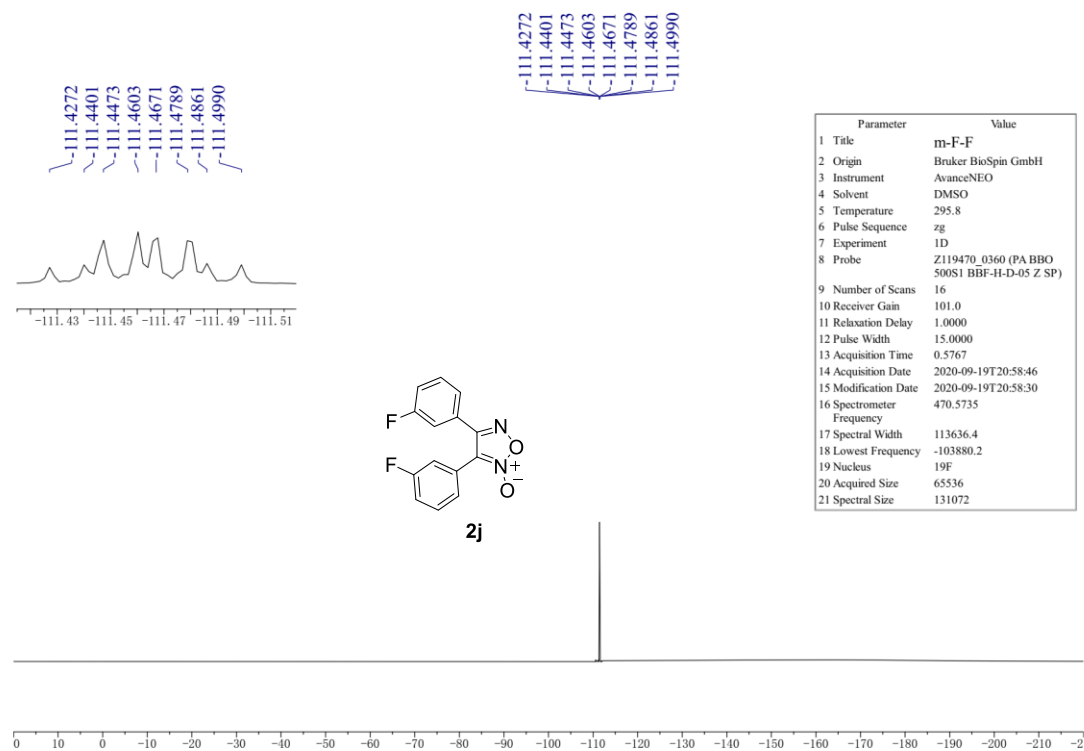
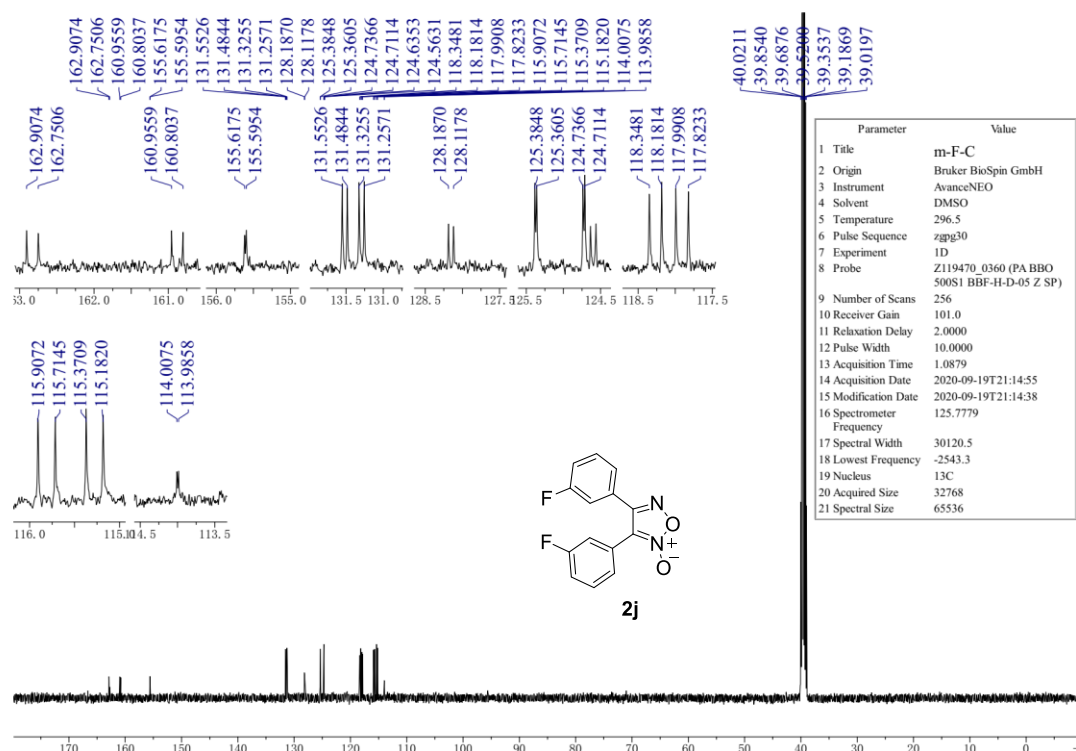


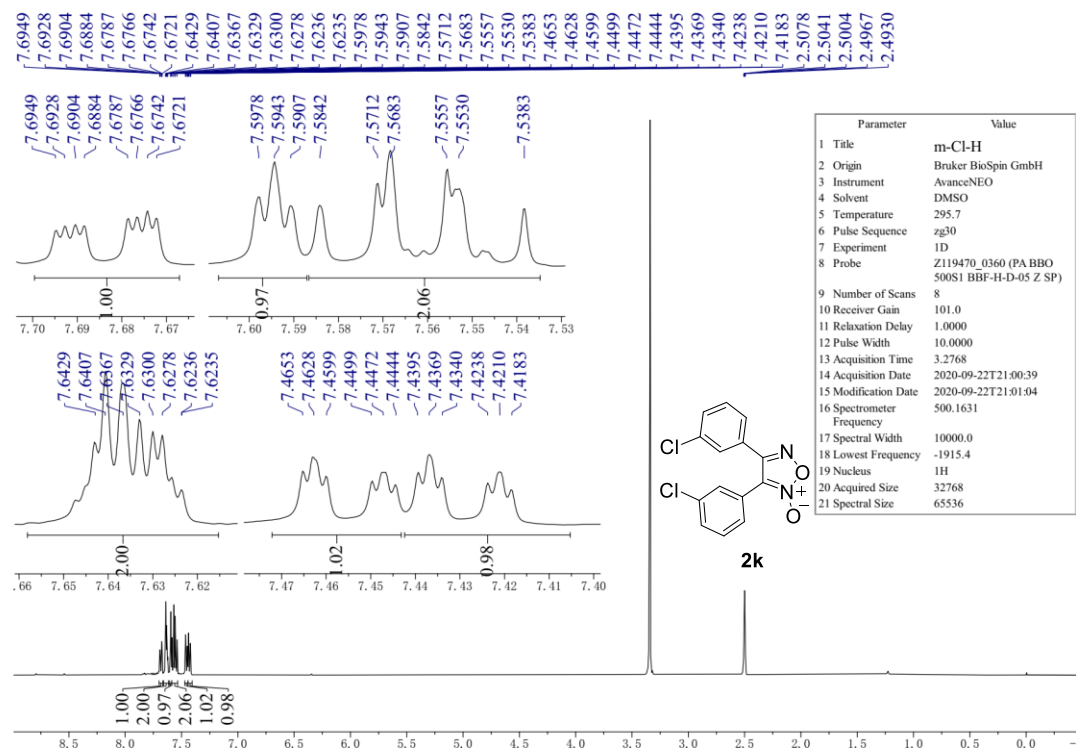
**Figure S19.** <sup>13</sup>C NMR (101 MHz, CD<sub>2</sub>Cl<sub>2</sub>) of compound **2h**.



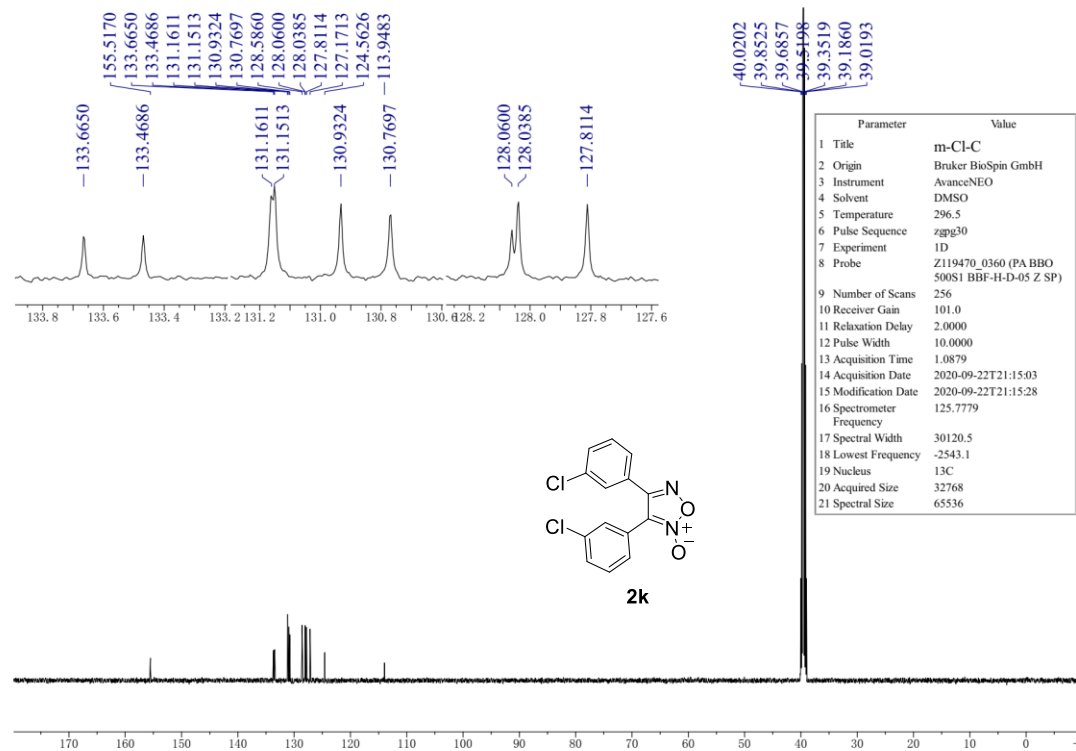
**Figure S20.** <sup>1</sup>H NMR (500 MHz, DMSO-*d*<sub>6</sub>) of compound **2i**.







**Figure S25.**  $^1\text{H}$  NMR (500 MHz,  $\text{DMSO}-d_6$ ) of compound **2k**.



**Figure S26.**  $^{13}\text{C}$  NMR (126 MHz,  $\text{DMSO}-d_6$ ) of compound **2k**.



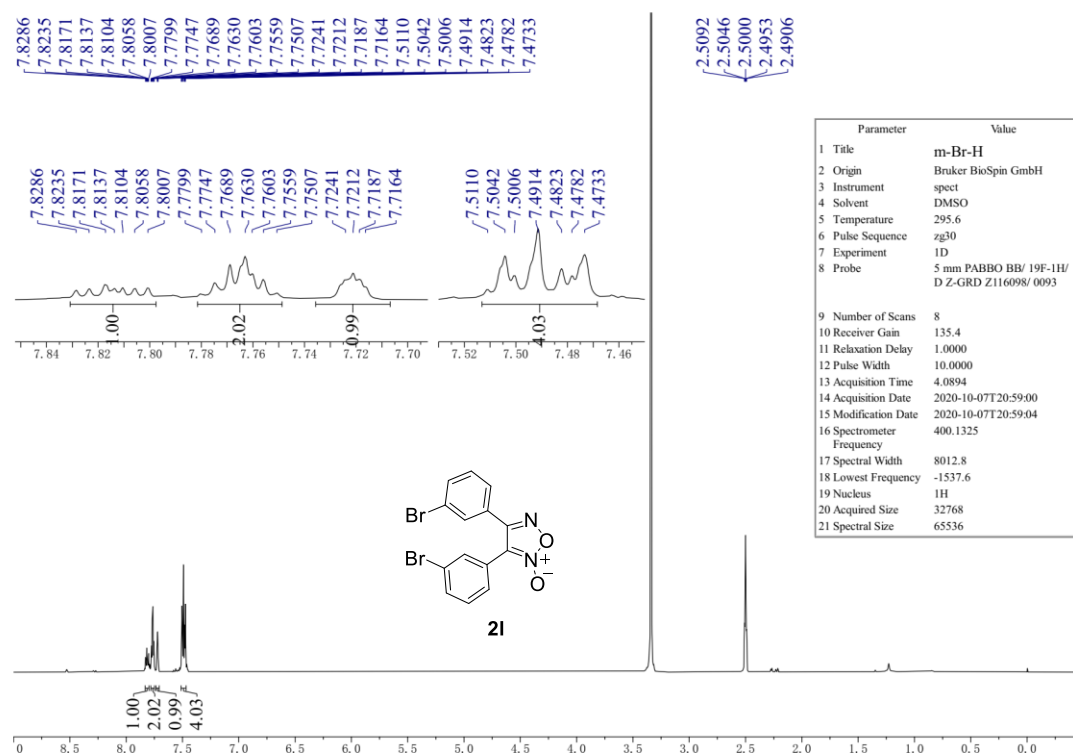


Figure S27.  $^1\text{H}$  NMR (400 MHz,  $\text{DMSO}-d_6$ ) of compound 2I.

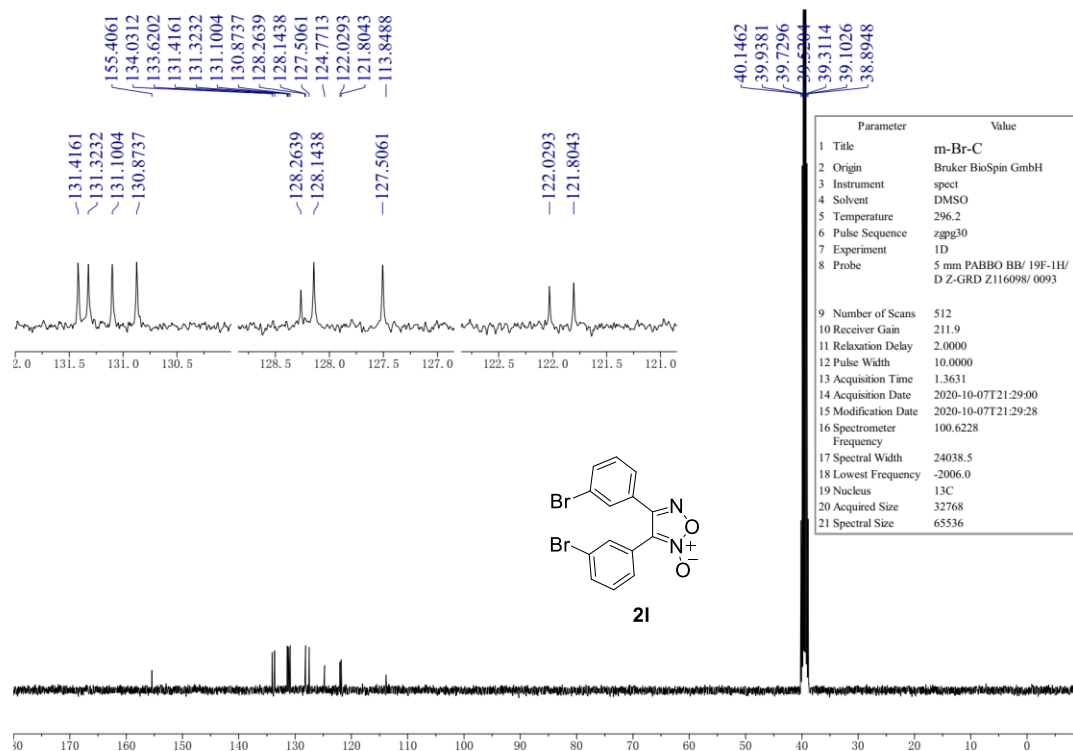


Figure S28.  $^{13}\text{C}$  NMR (101 MHz,  $\text{DMSO}-d_6$ ) of compound 2I.

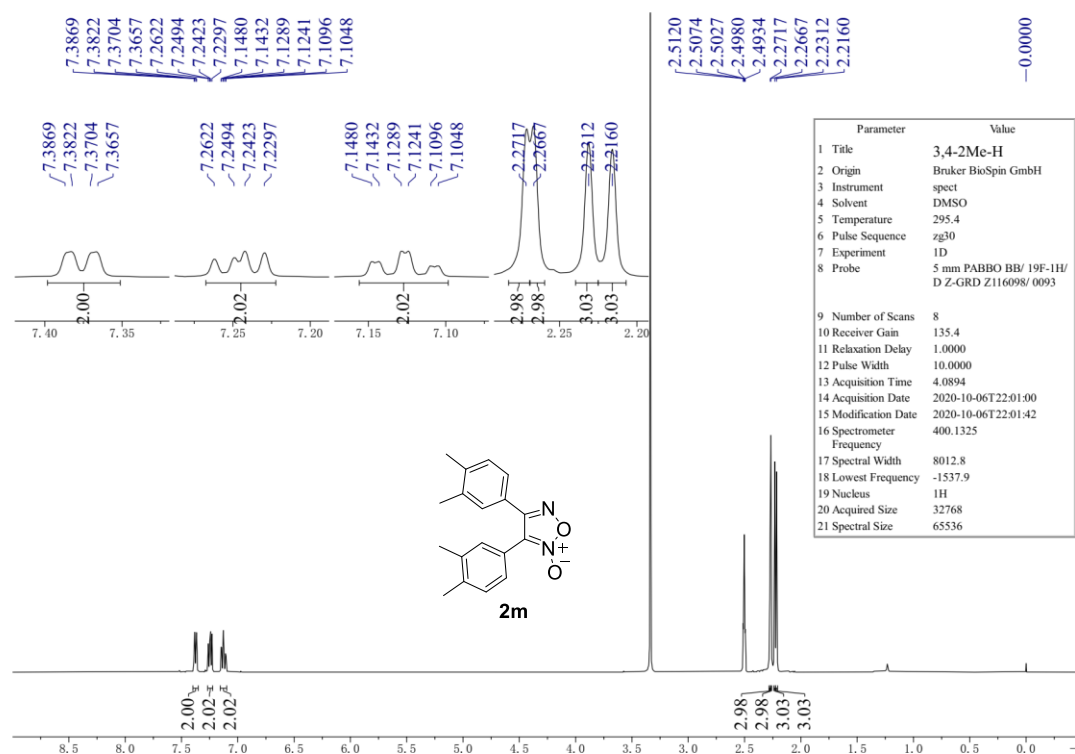


Figure S29.  $^1\text{H}$  NMR (400 MHz,  $\text{DMSO}-d_6$ ) of compound **2m**.

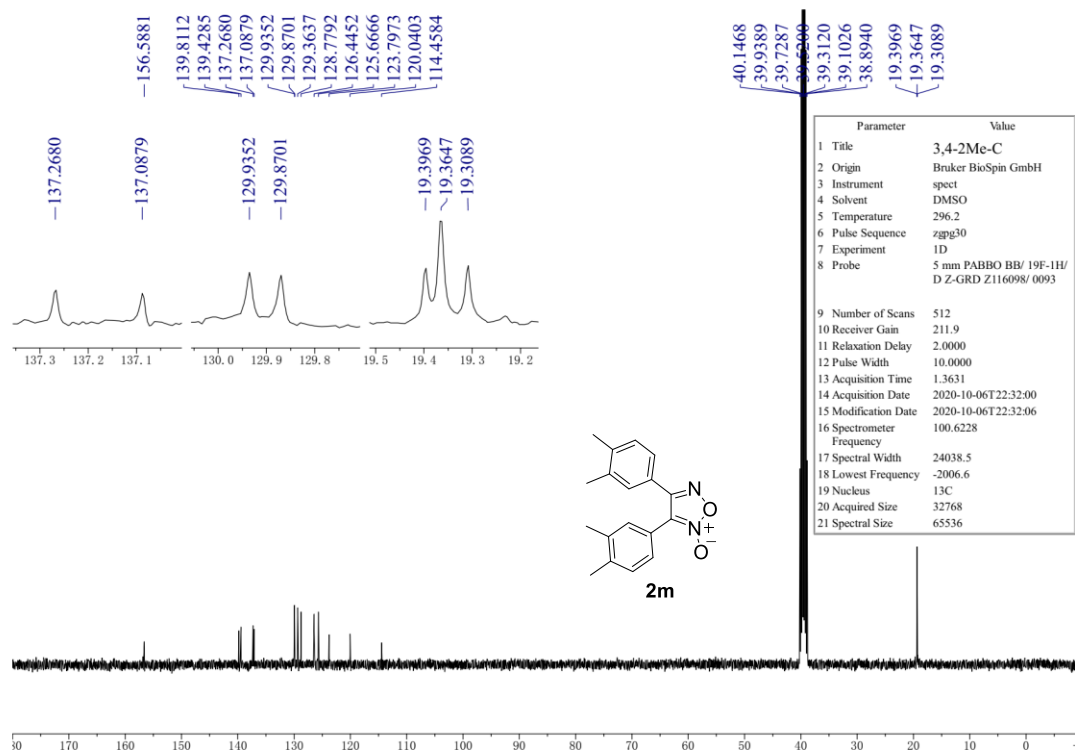
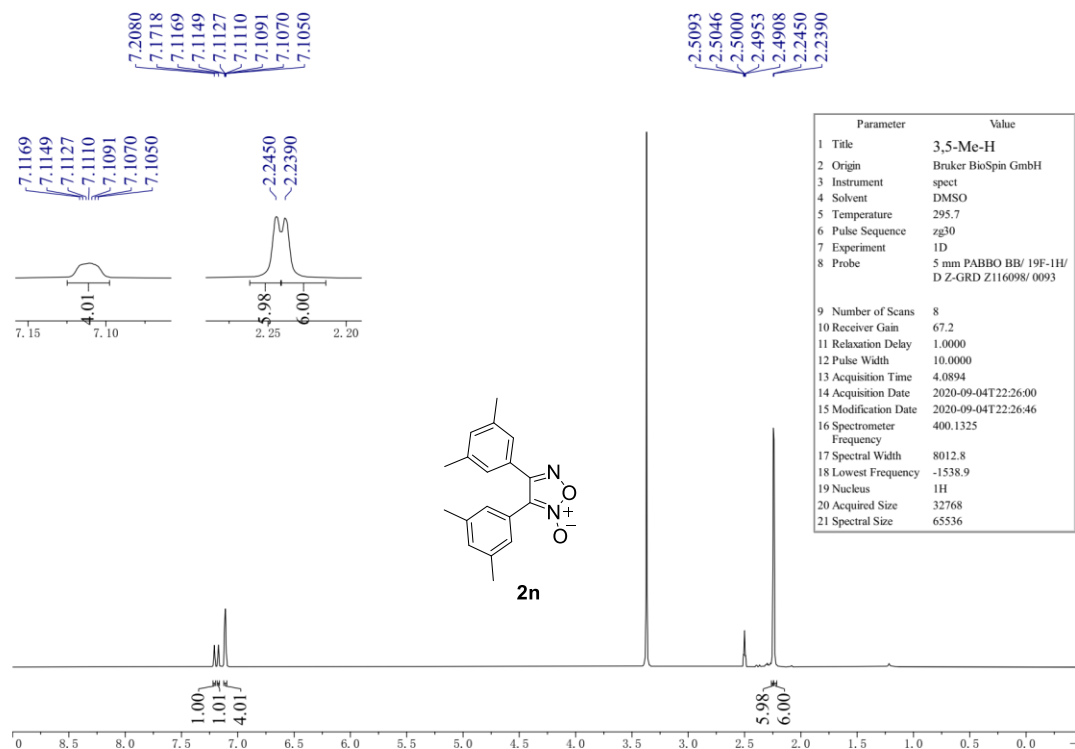
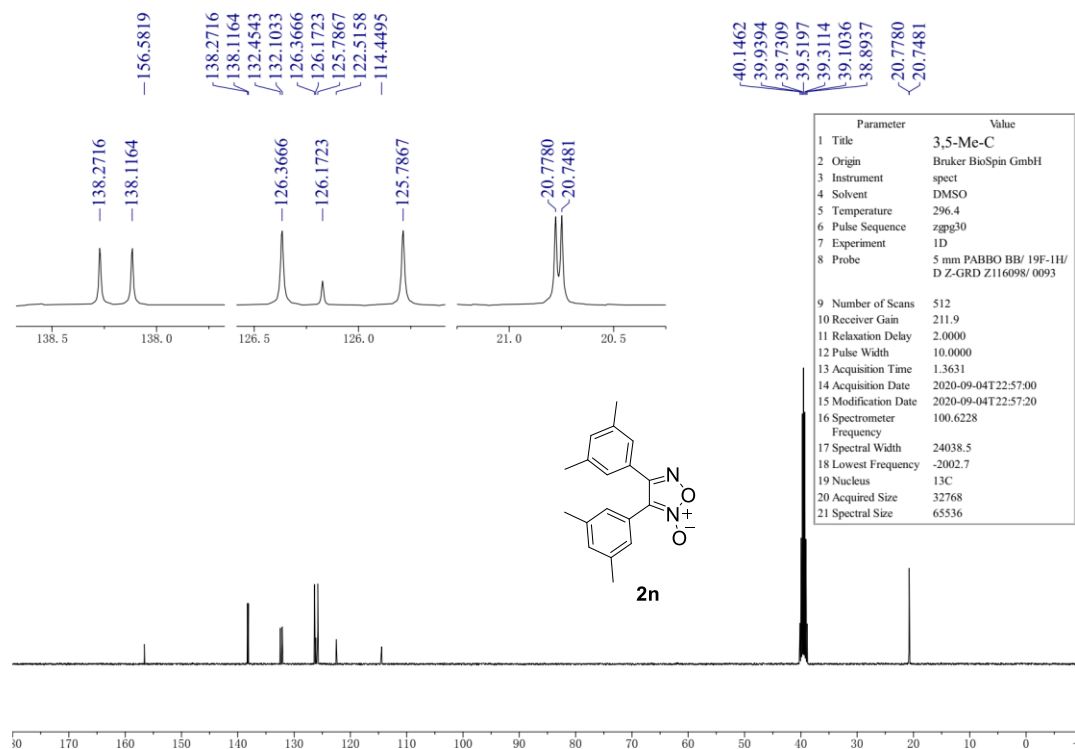


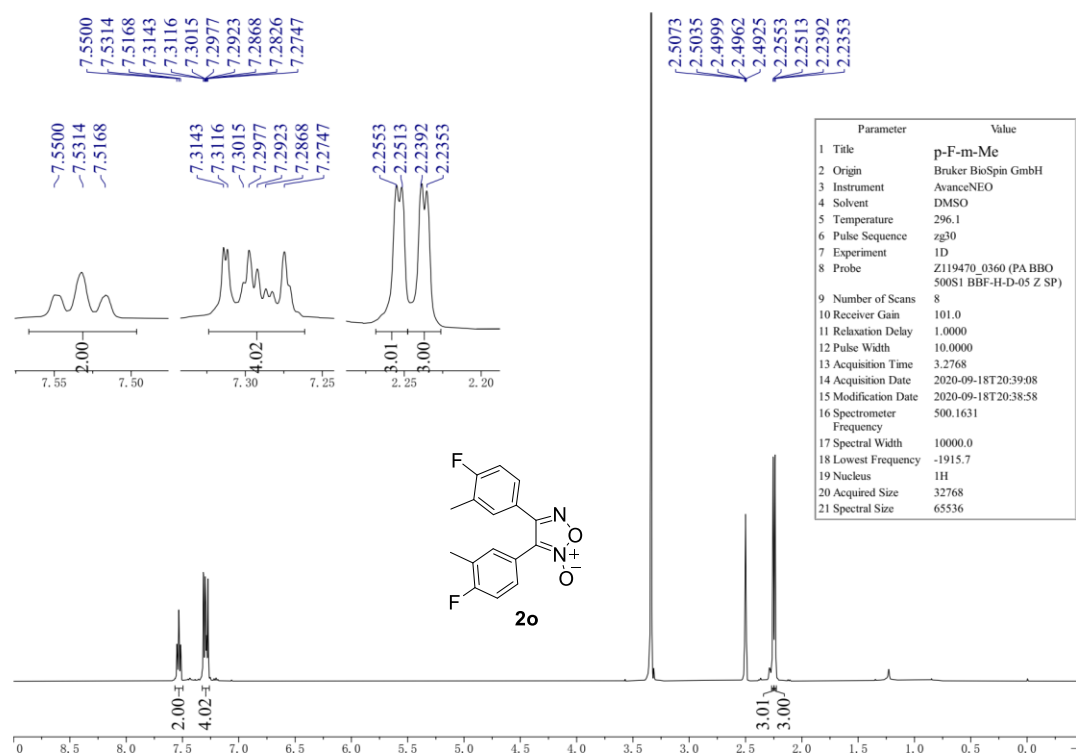
Figure S30.  $^{13}\text{C}$  NMR (101 MHz,  $\text{DMSO}-d_6$ ) of compound **2m**.



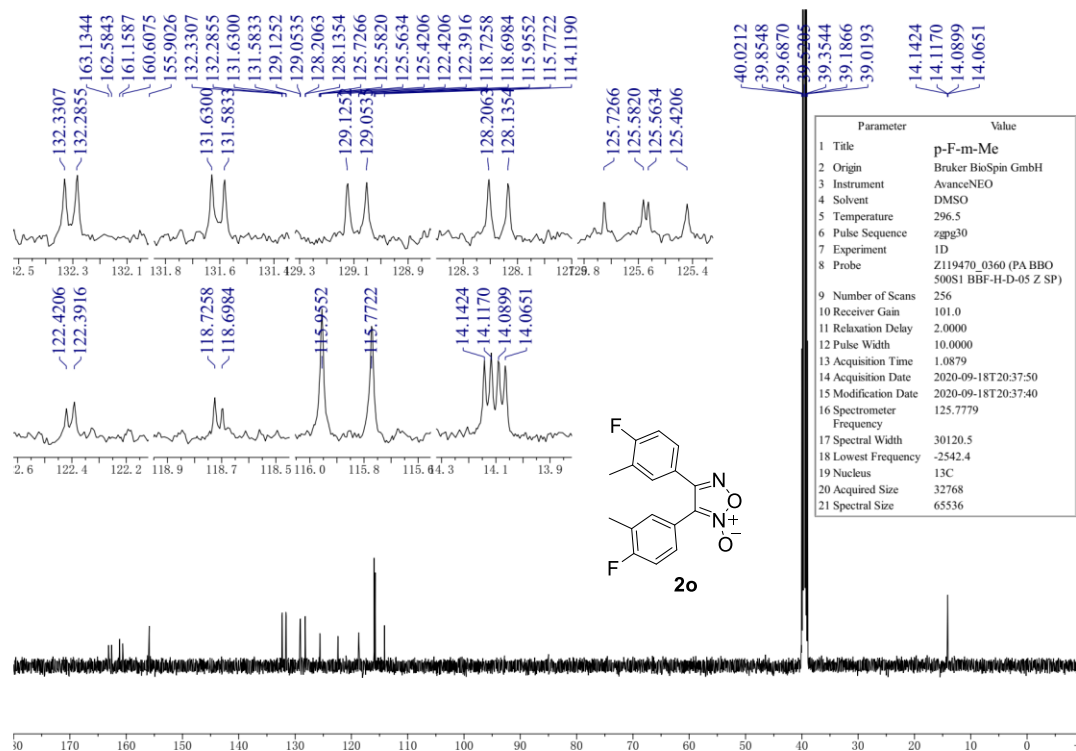
**Figure S31.** <sup>1</sup>H NMR (400 MHz, DMSO-*d*<sub>6</sub>) of compound **2n**.



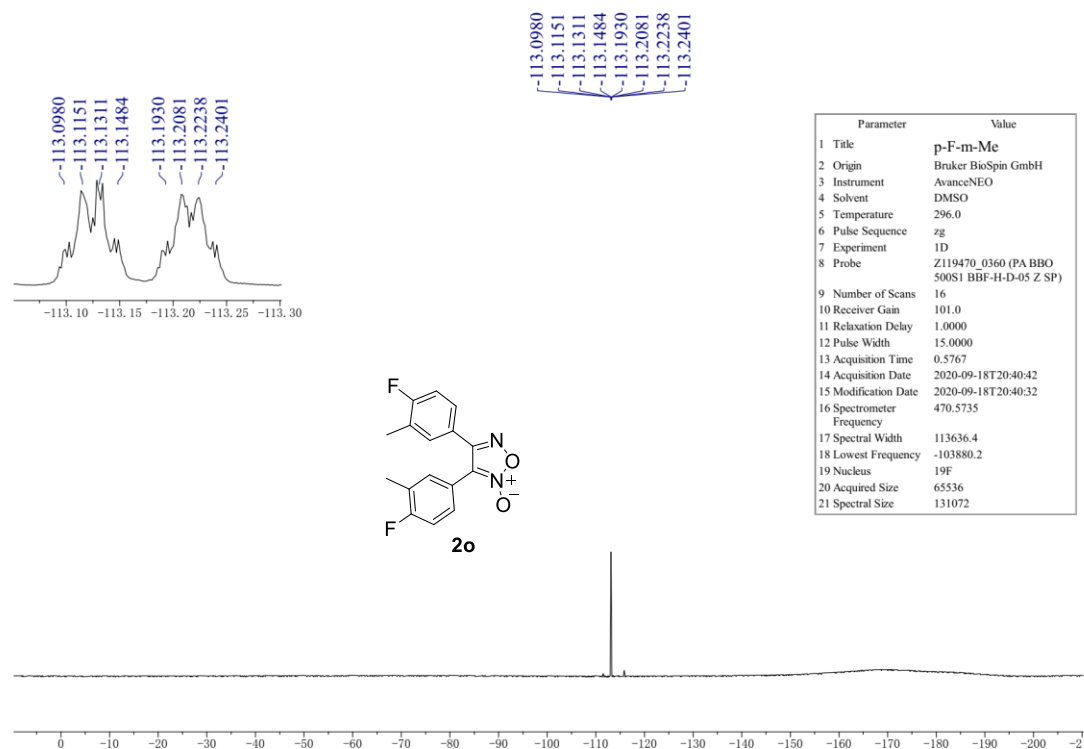
**Figure S32.** <sup>13</sup>C NMR (101 MHz, DMSO-*d*<sub>6</sub>) of compound **2n**.



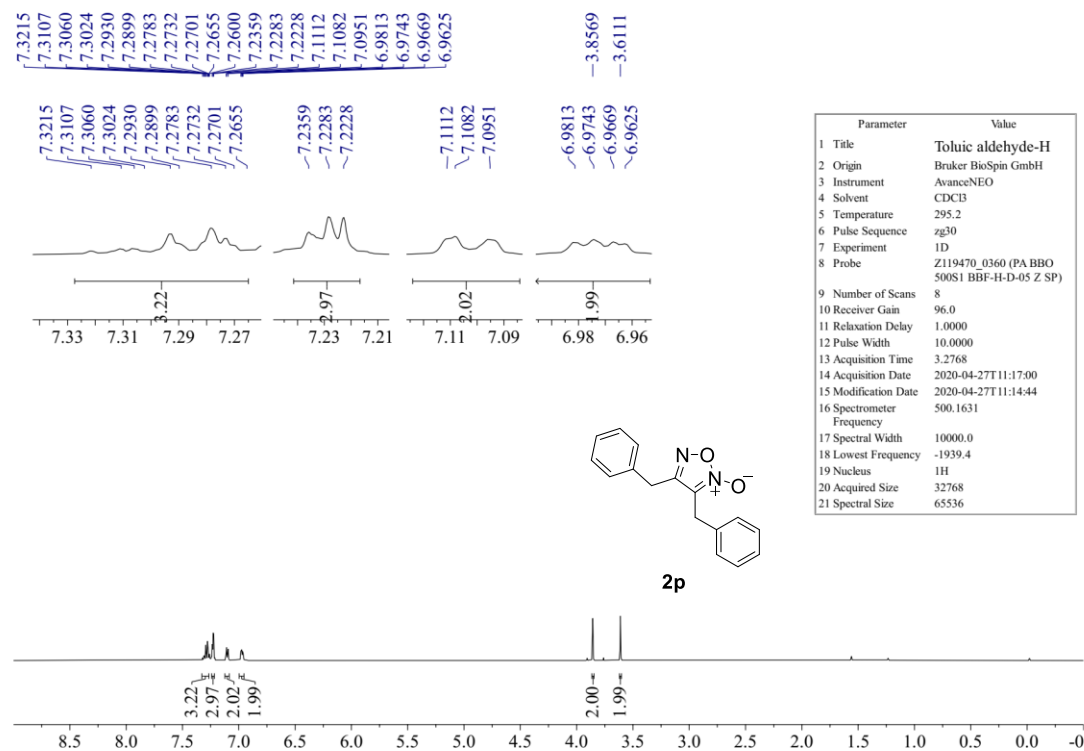
**Figure S33.** <sup>1</sup>H NMR (500 MHz, DMSO-*d*<sub>6</sub>) of compound **2o**.



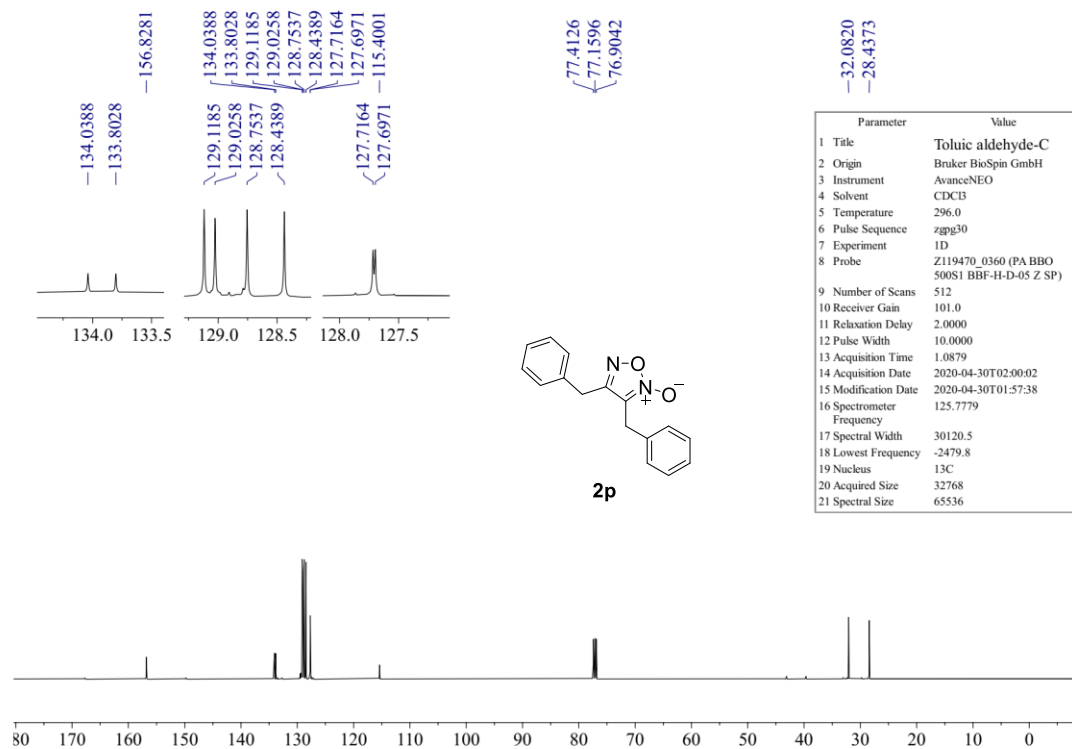
**Figure S34.** <sup>13</sup>C NMR (126 MHz, DMSO-*d*<sub>6</sub>) of compound **2o**.



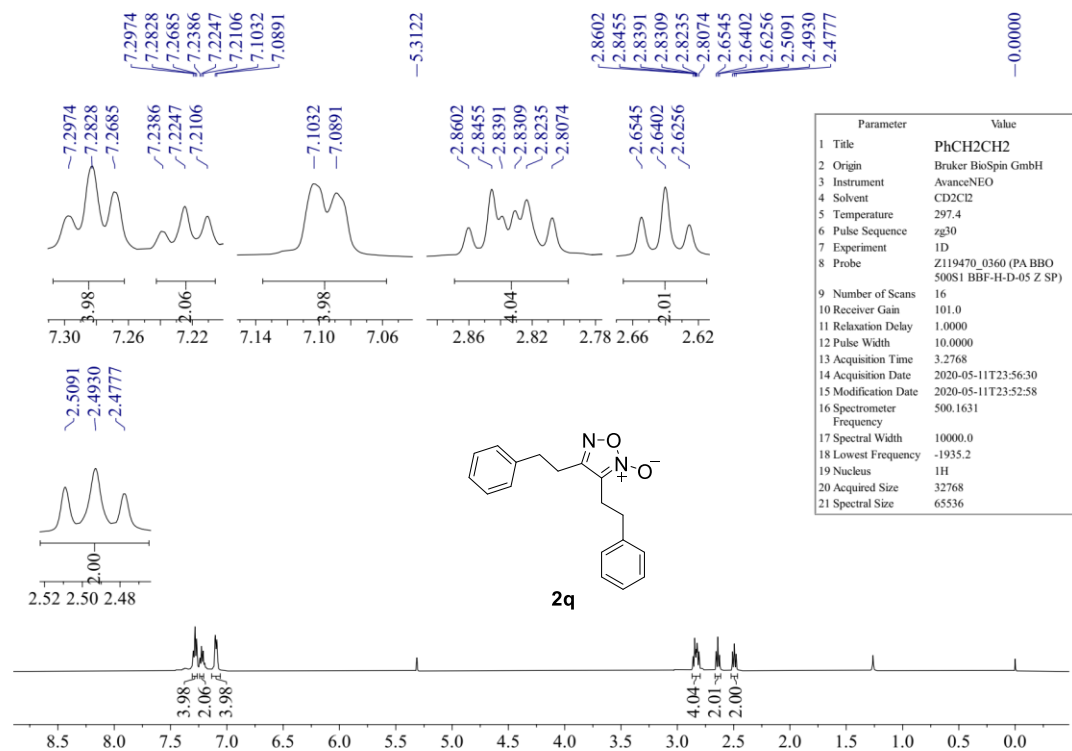
**Figure S35.**  $^{19}\text{F}$  NMR (471 MHz,  $\text{DMSO-}d_6$ ) spectrum of compound **2o**.



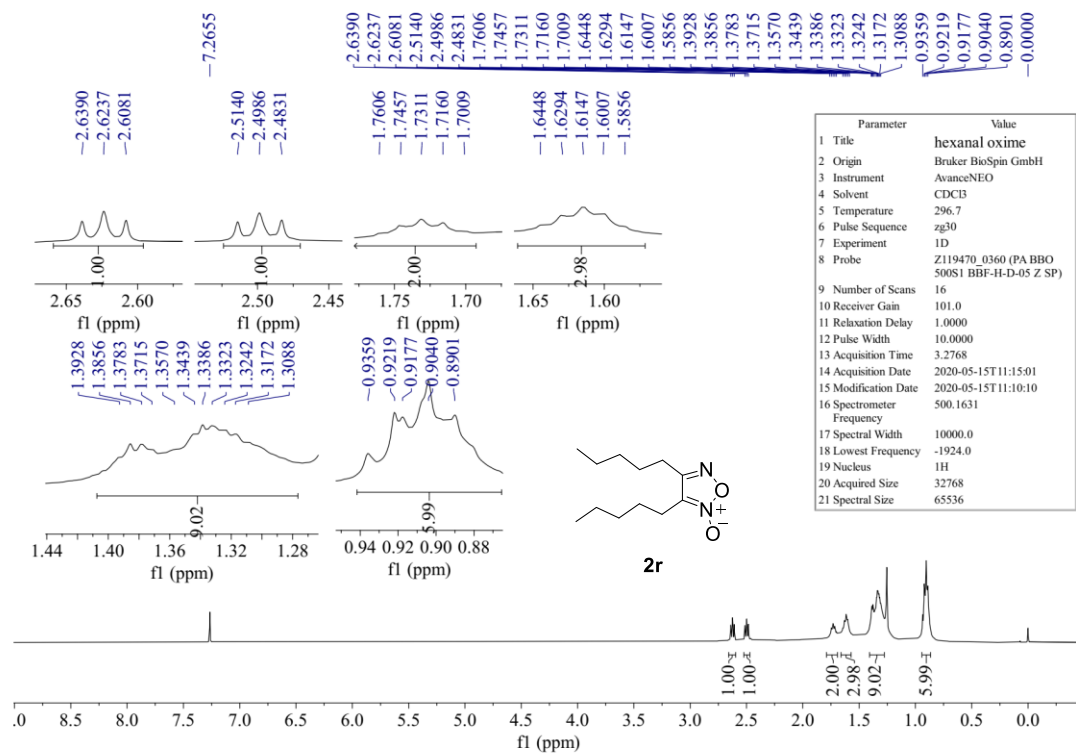
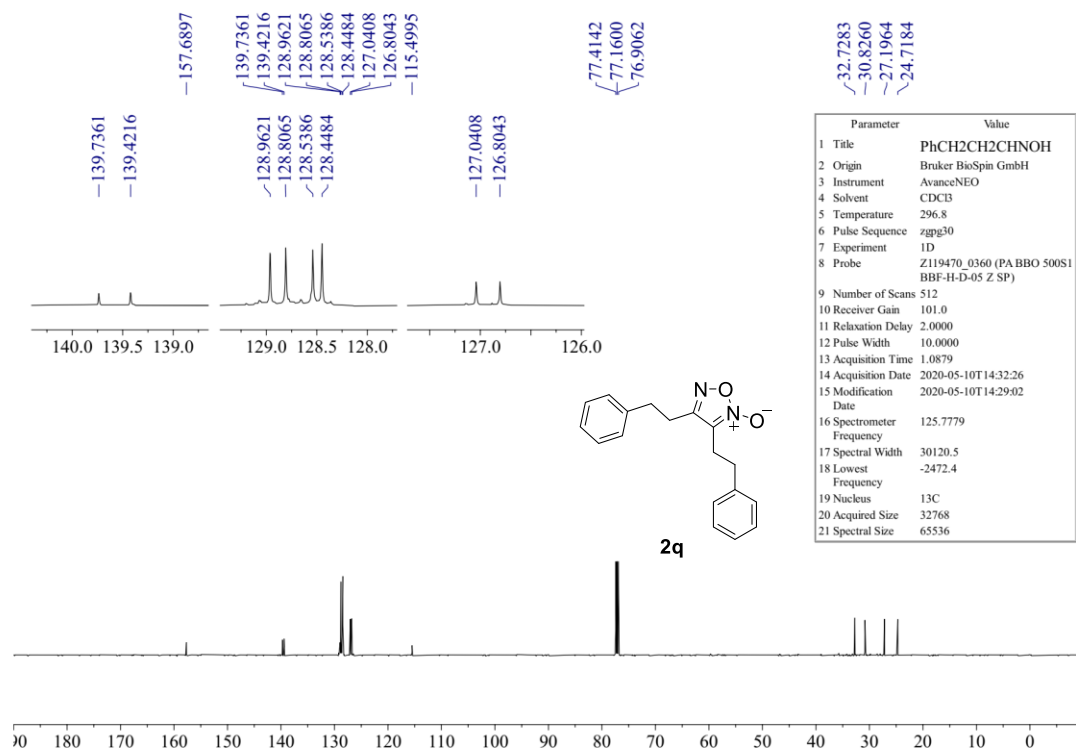
**Figure S36.**  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ ) of compound **2p**.

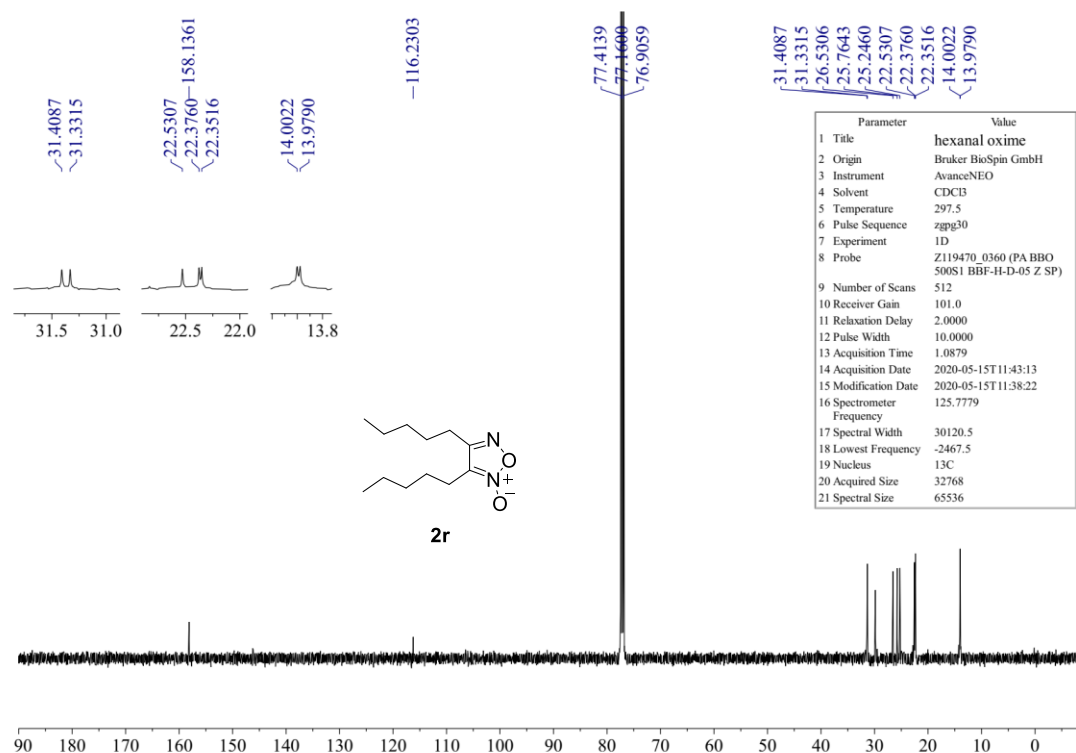


**Figure S37. <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) of compound 2p.**

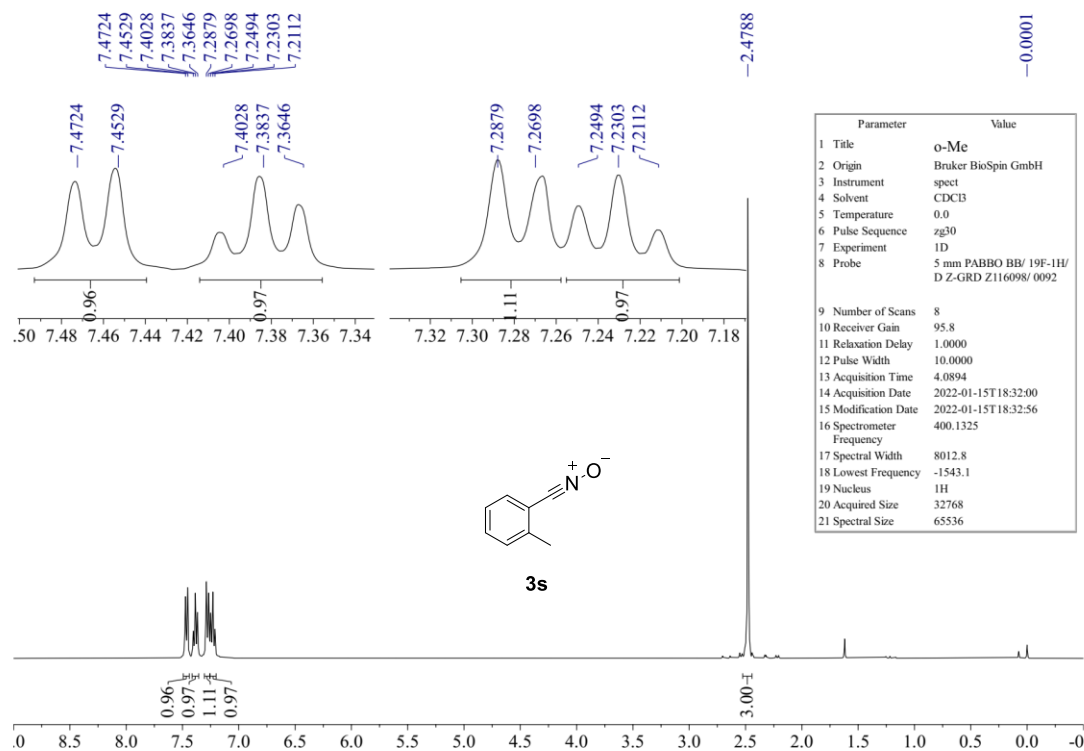


**Figure S38. <sup>1</sup>H NMR (500 MHz, CD<sub>2</sub>Cl<sub>2</sub>) of compound 2q.**



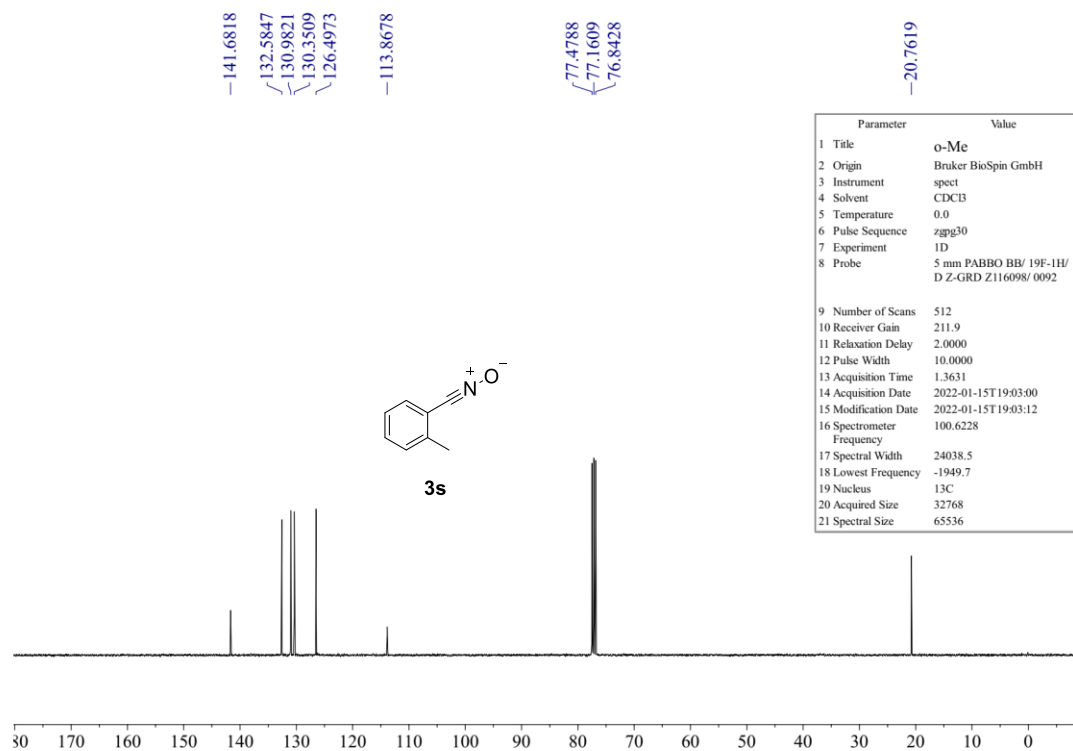


**Figure S41.** <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) of compound **2r**.

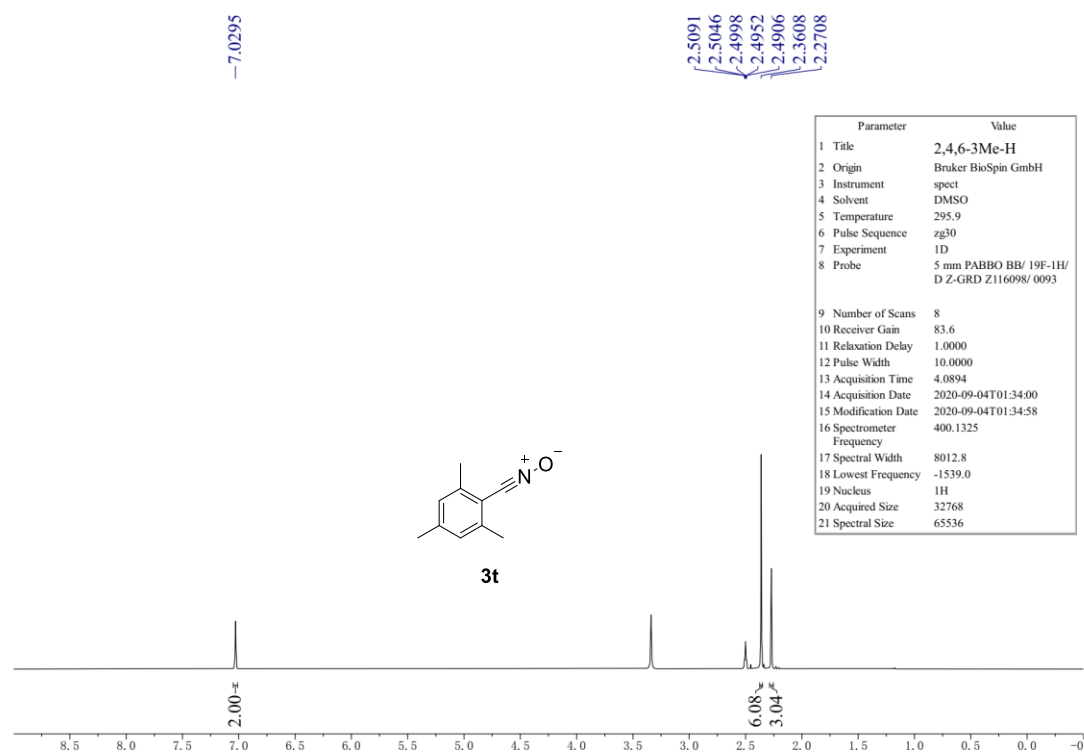


**Figure S42.** <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) of compound **3s**.

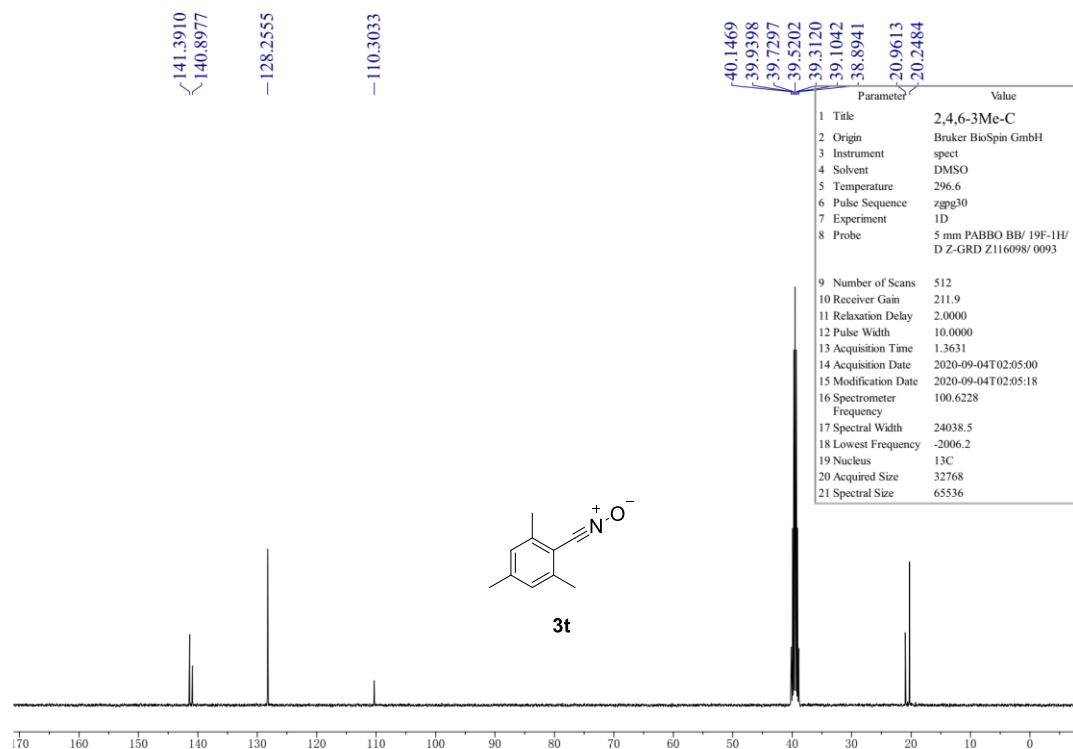




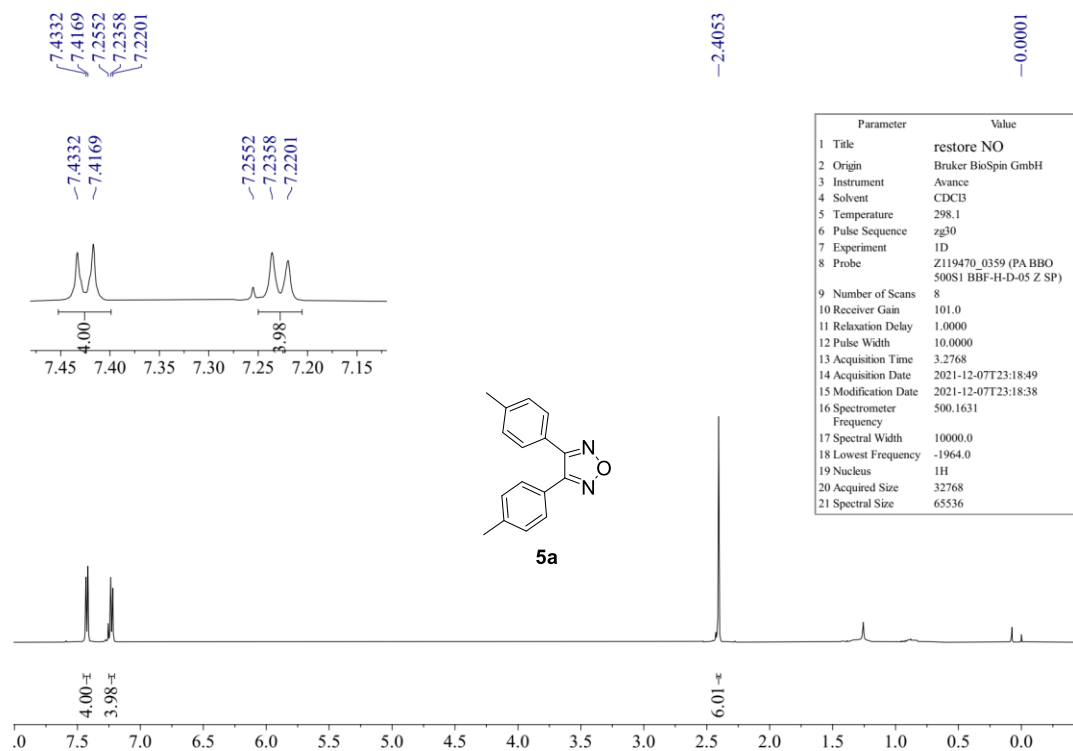
**Figure S43.**  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ ) of compound **3s**.



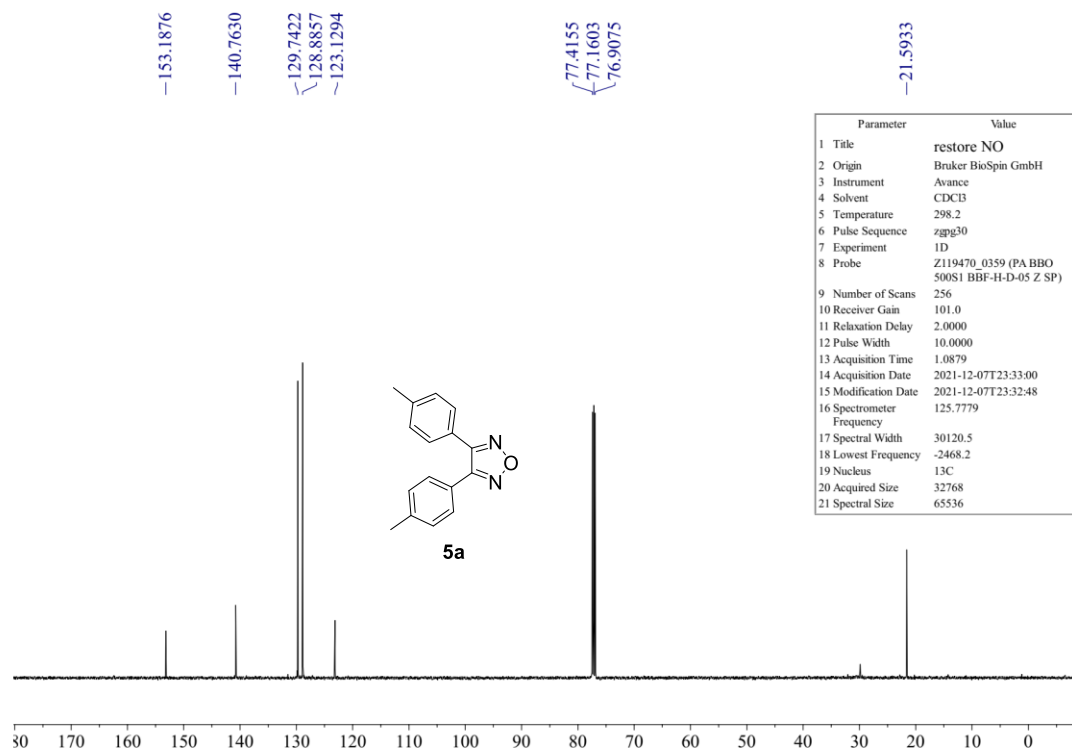
**Figure S44.**  $^1\text{H}$  NMR (400 MHz,  $\text{DMSO}-d_6$ ) of compound **3t**.



**Figure S45.**  $^{13}\text{C}$  NMR (101 MHz,  $\text{DMSO}-d_6$ ) of compound **3t**.



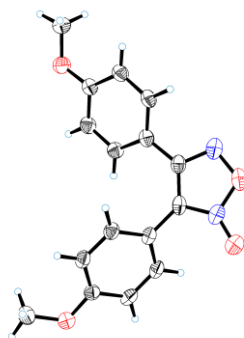
**Figure S46.**  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ ) of compound **5a**.



**Figure S47.**  $^{13}\text{C}$  NMR (126 MHz,  $\text{CDCl}_3$ ) of compound **5a**.

### 3. X-Ray single-crystal data of compound **2c**.

Single crystals of **2c** were obtained by slow evaporation from a mixture of dichloromethane/*n*-hexane at 4 °C. Single-crystal X-ray diffraction data were collected on a diffractometer (Gemini S Ultra, Agilent Technologies) equipped with a CCD area detector using graphite-monochromated  $\text{CuK}\alpha$  radiation ( $\lambda = 1.54184 \text{ \AA}$ ) in the scan range  $9.438^\circ < 2\theta < 133.12^\circ$ . The structure was solved with direct methods using SHELXT and refined with full-matrix least-squares refinement using the SHELXL program within OLEX2. Crystallographic data have been deposited in the Cambridge Crystallographic Data Centre as deposition number CCDC 2157590.



**Figure S48.** ORTEP diagram of **2c** with 30% thermal ellipsoids

**Table S1.** Crystal data for **2c**.

Identification code	2157590
Empirical formula	C <sub>16</sub> H <sub>14</sub> N <sub>2</sub> O <sub>4</sub>
Formula weight	298.29
Temperature/K	293(2)
Crystal system	orthorhombic
Space group	Pbca
<i>a</i> /Å	12.2790(4)
<i>b</i> /Å	8.1025(2)
<i>c</i> /Å	29.0019(8)
$\alpha$ /°	90
$\beta$ /°	90
$\gamma$ /°	90
Volume/Å <sup>3</sup>	2885.42(14)
<i>Z</i>	8
$\rho_{\text{calc}}$ /cm <sup>3</sup>	1.373
$\mu$ /mm <sup>-1</sup>	0.834
F(000)	1248.0
Crystal size/mm <sup>3</sup>	0.22 × 0.15 × 0.08
Radiation	CuK $\alpha$ ( $\lambda$ = 1.54184)
2 $\theta$ range for data collection/°	9.438 to 133.12
Index ranges	-14 ≤ <i>h</i> ≤ 14, -9 ≤ <i>k</i> ≤ 7, -22 ≤ <i>l</i> ≤ 34
Reflections collected	6400
Independent reflections	2545 [R <sub>int</sub> = 0.0211, R <sub>sigma</sub> = 0.0153]
Data/restraints/parameters	2545/1/202
Goodness-of-fit on F <sup>2</sup>	1.060
Final R indexes [ <i>I</i> ≥ 2 $\sigma$ ( <i>I</i> )]	R <sub>1</sub> = 0.0721, wR <sub>2</sub> = 0.2063
Final R indexes [all data]	R <sub>1</sub> = 0.0796, wR <sub>2</sub> = 0.2151
Largest diff. peak/hole/e Å <sup>-3</sup>	0.80/-0.41

#### 4. References

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