5-Bromo-1,2,3-trifluorobenzene

Spinsolve 80

^{1}H Spectra

5-Bromo-1,2,3-trifluorobenzene ($BrC_6H_2F_3$) is a structurally simple molecule commonly used as a building block in a variety of synthetic organic reactions. As this molecule contains ^{1}H, ^{19}F, and ^{13}C (in natural abundance), it is a beautiful example to demonstrate the unique advantage offered by the Spinsolve of accessing all three nuclei simultaneously without requiring retuning or user intervention. Figure 1 shows the ^{1}H NMR spectrum of neat 5-Bromo-1,2,3-trifluorobenzene measured in a single scan taking 10 seconds to acquire (top) and the respective 1D proton ^{19}F decoupled spectrum (bottom). As no retuning of the probe is required to switch from ^{1}H and ^{19}F, the ^{1}H signal can be acquired while the ^{19}F nuclei are being decoupled.

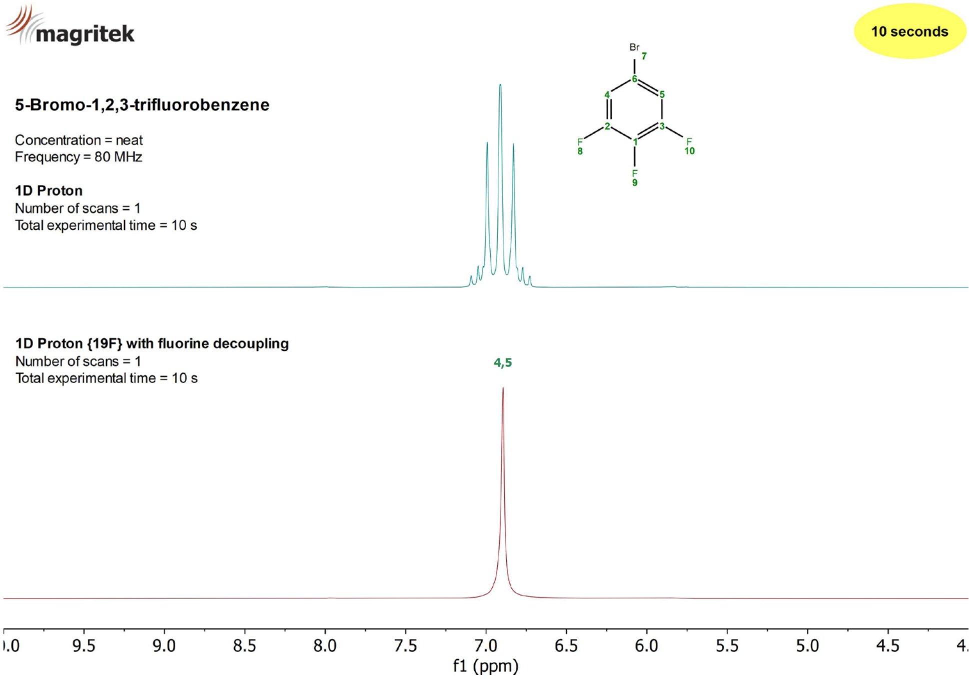


Figure 1: ^{1}H NMR spectrum of neat 5-Bromo-1,2,3-trifluorobenzene measured on a Spinsolve 80 MHz system in a single scan.

^{19}F Spectra

5-Bromo-1,2,3-trifluorobenzene is a good example to highlight the advantage of ^{19}F protocols with ^{1}H decoupling possibilities. The usual ^{19}F NMR spectrum (top spectrum) allows one to identify the two expected ^{19}F resonances for the fluorine atoms at positions 8, 9, and 10. The bottom spectrum shows the ^{1}H decoupled ^{19}F NMR spectrum. The multiplet structure of each peak is defined only by the fluorine couplings, so as expected we can observe a triplet at position 9 and a doublet at positions 8 and 10.

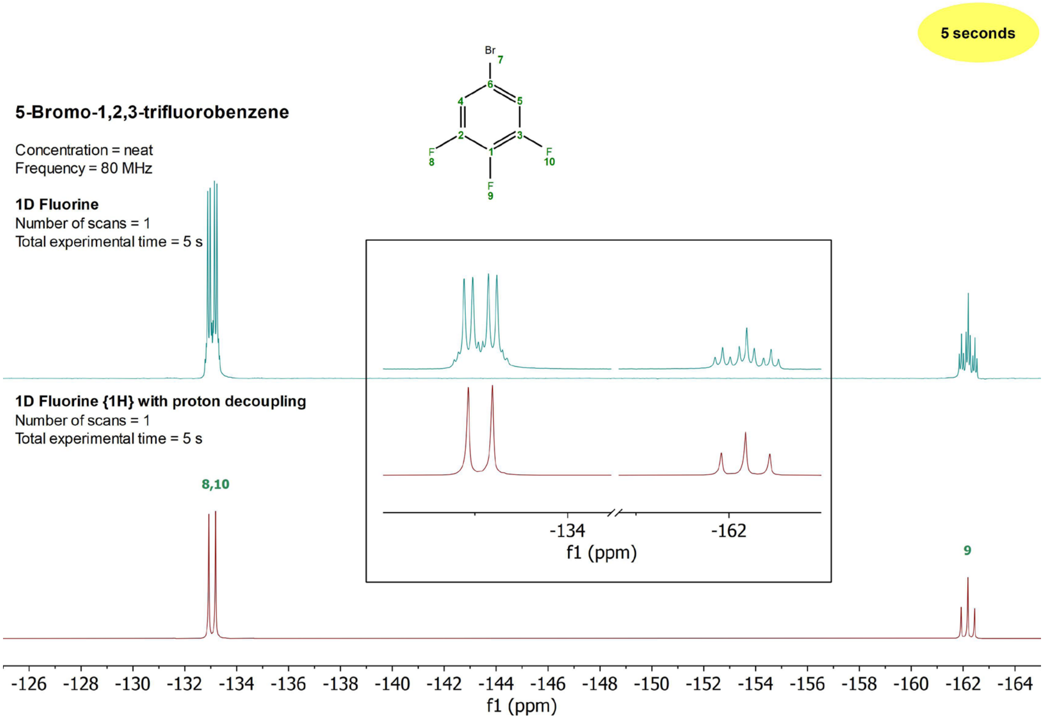


Figure 2: ^{19}F NMR spectrum of neat 5-Bromo-1,2,3-trifluorobenzene measured on a Spinsolve 80 MHz system in a single scan. With (bottom) and without (top) ^{1}H decoupling.

^{13}C Spectra

Figure 3 shows the ^{13}C NMR spectra of neat 5-Bromo-1,2,3-trifluorobenzene acquired using NOE polarization transfer. The top spectrum was measured without any decoupling. It clearly resolves the expected resonances but shows a crowded multiplicity structure for each carbon. The 1D carbon acquired with ^{1}H decoupling (middle spectrum) eliminates some couplings and slightly simplifies some of the peaks, but only the 1D carbon acquired with simultaneous ^{1}H, ^{19}F decoupling (bottom spectrum) shows a singlet for each carbon atom to clearly resolve the four expected resonances.

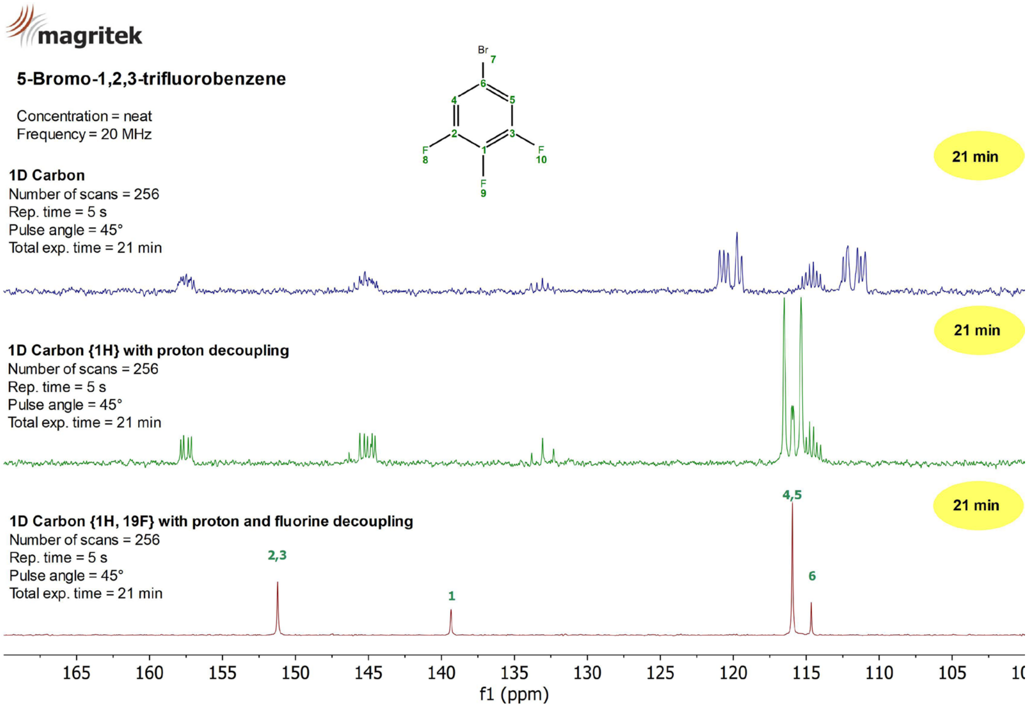


Figure 3: Carbon NMR spectra of neat 5-Bromo-1,2,3-trifluorobenzene measured on a Spinsolve 80 MHz system using NOE (top), ^{1}H decoupling (middle) and ^{1}H,^{19}F decoupling sequences (bottom).

^{13}C DEPT Spectra

Figure 4 shows the ^{13}C NMR spectra of neat 5-Bromo-1,2,3-trifluorobenzene acquired using NOE and DEPT polarization transfer from ^{1}H to ^{13}C and ^{1}H decoupling. The 1D Carbon experiment using NOE (top spectrum) is sensitive to all ^{13}C nuclei in the sample. It clearly resolves the expected resonances. The DEPT experiments show only ^{13}C nuclei directly attached to ^{1}H and can be used for spectral editing. Since the peaks in the range of 160-130 ppm do not appear in the DEPT spectra they must correspond to the quaternary carbons. .

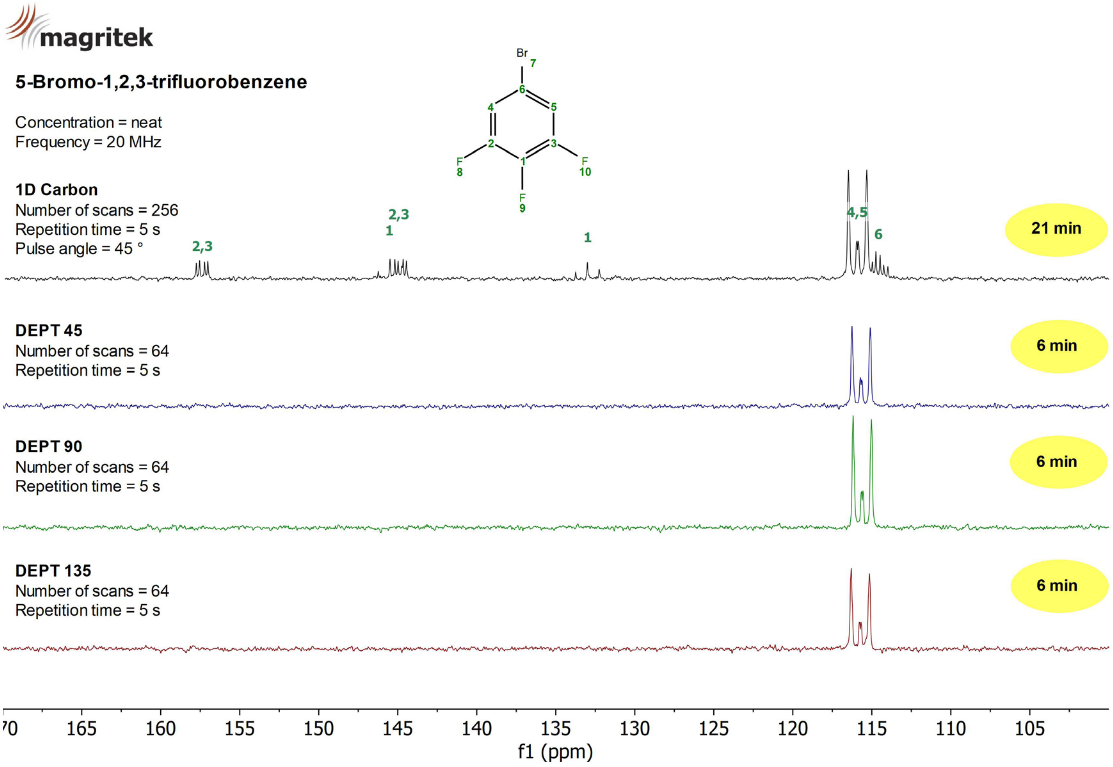


Figure 4: Carbon NMR spectra of neat 5-Bromo-1,2,3-trifluorobenzene measured on a Spinsolve 80 MHz using NOE (top) and DEPT-45, -90 and -135 sequences.

2D ^{1}H-COSY and ^{19}F-COSY

The 2D ^{19}F COSY experiment (right) allows one to identify coupled ^{19}F nuclei as they generate cross peaks out of the diagonal of the 2D data set. The fluorine atom at position 9 couples to the fluorine atoms at positions 8 and 10 (light blue). The respective ^{1}H COSY (left) in the same manner allows one to identify coupled ^{1}H nuclei. In Figure 5 this is not very useful as no coupling between protons is expected for the corresponding molecule.

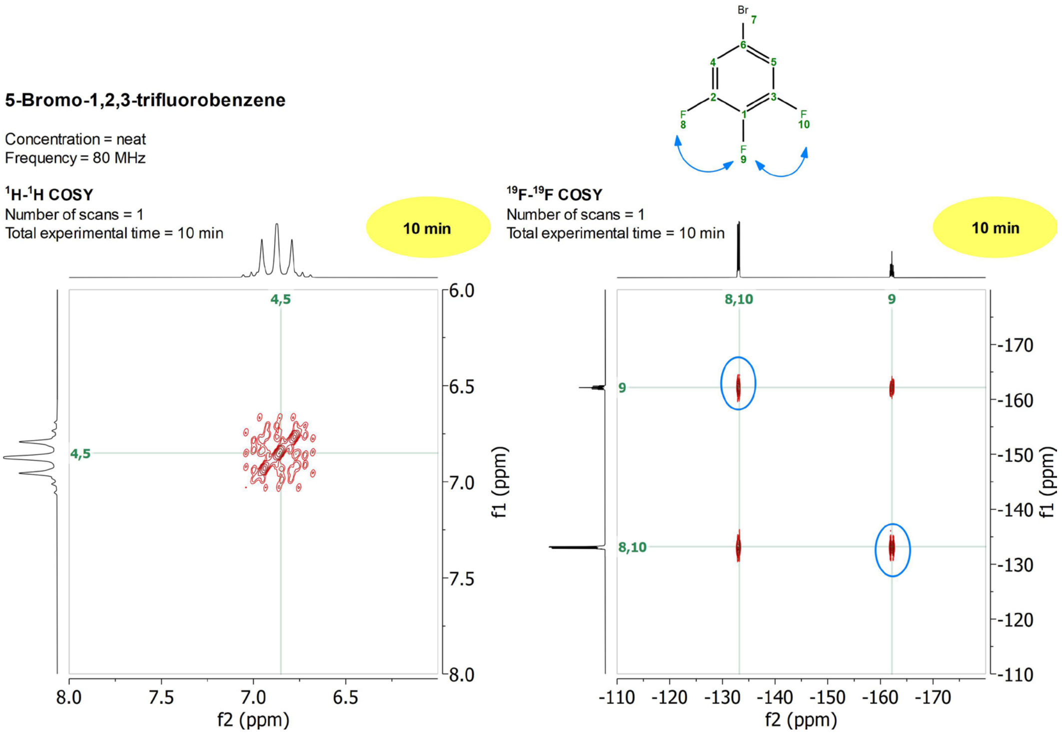


Figure 5: ^{1}H COSY (left) and ^{19}F COSY (right) experiment of a neat 5-Bromo-1,2,3-trifluorobenzene sample acquired in 10 minutes on a Spinsolve 80 MHz system.

2D HF-COSY

The HF COSY experiment allows one to identify ^{1}H and ^{19}F nuclei that couple with each other. Here, the benzene protons at positions 4 and 5 couple to the fluorine atoms at position 8 and 10 (green). On the other hand, the same benzene protons couple to the fluorine atom at position 9 (orange).

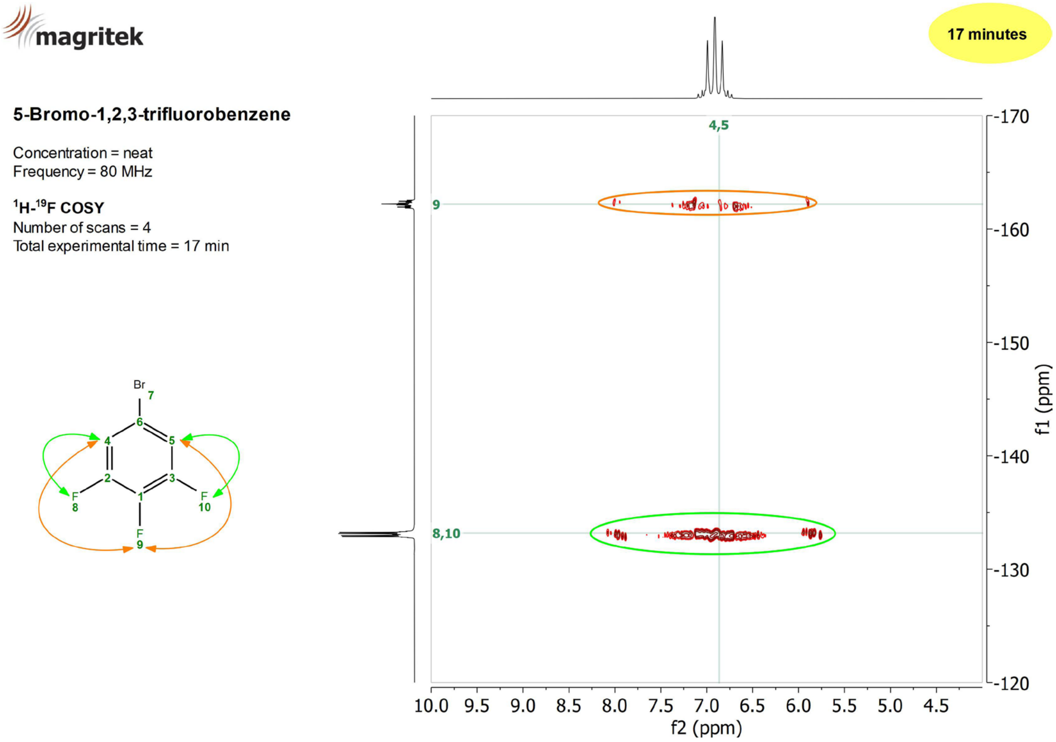
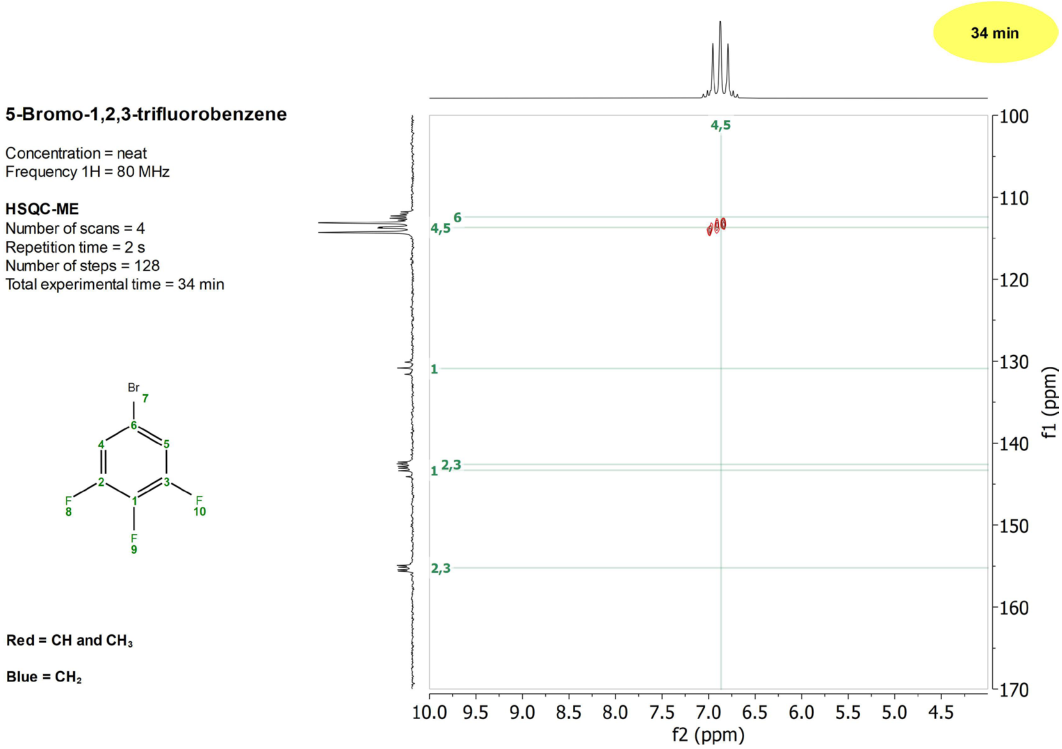


Figure 6: HF-COSY experiment of a neat 5-Bromo-1,2,3-trifluorobenzene sample acquired in 17 minutes on a Spinsolve 80 MHz system.

2D HSQC-ME

The HSQC is a powerful sequence widely used to correlate the ^{1}H with the one-bond coupled ^{13}C nuclei. The Spinsolve is equipped with a multiplicity edited version (HSQC-ME) of this method. It provides the editing power of the DEPT-135 sequence, which is useful to identify the signal of the CH$_2$ groups (blue) from the CH and CH$_3$ (red). Figure 8 shows the HSQC-ME spectrum of neat 5-Bromo-1,2,3-trifluorobenzene acquired in 34 minutes.



5-Bromo-1,2,3-trifluorobenzene

Concentration = neat
Frequency 1H = 80 MHz

HSQC-ME
Number of scans = 4
Repetition time = 2 s
Number of steps = 128
Total experimental time = 34 min

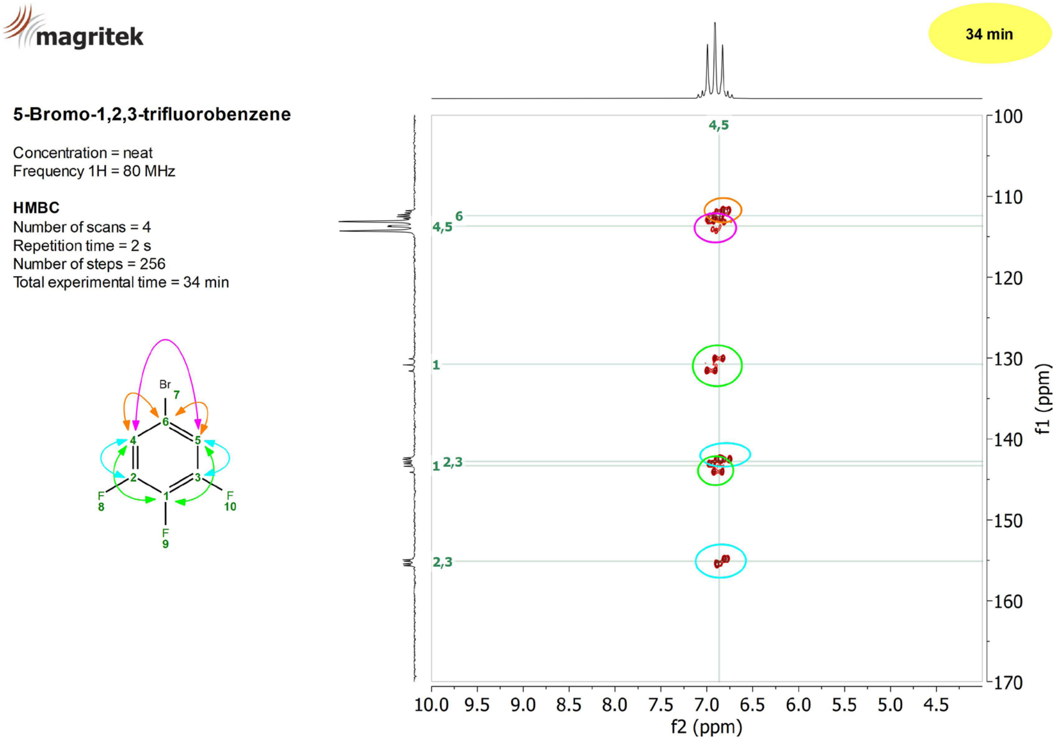
Red = CH and CH$_3$

Blue = CH$_2$

Figure 8: HSQC-ME spectrum of neat 5-Bromo-1,2,3-trifluorobenzene showing the correlation between the ^{1}H (horizontal) and ^{13}C (vertical) signals.

2D HMBC

To obtain long-range ^{1}H-^{13}C correlations through two or three bond couplings, the Heteronuclear Multiple Bond Correlation (HMBC) experiment can be used. Figure 9 shows the long-range correlation of protons 4 and 5 with carbons 6, 1, 2 and 3 (the sequence shows the correlation with quaternary carbons, too).



5-Bromo-1,2,3-trifluorobenzene

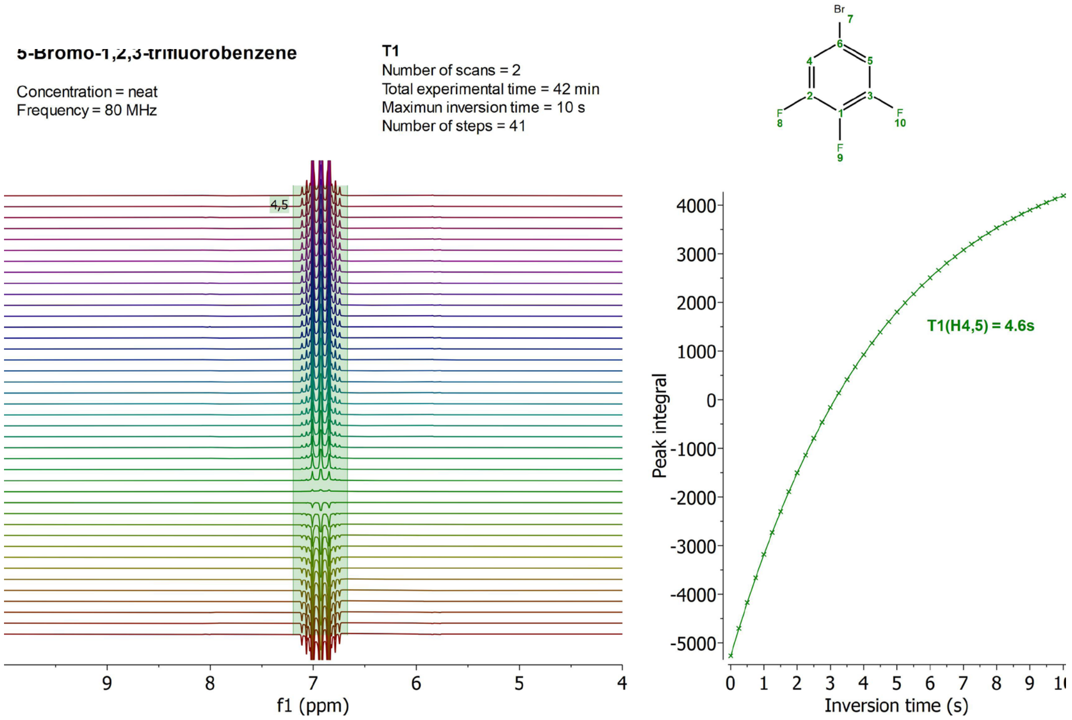
Concentration = neat
Frequency 1H = 80 MHz

HMBC
Number of scans = 4
Repetition time = 2 s
Number of steps = 256
Total experimental time = 34 min

Figure 9: HMBC spectrum of neat 5-Bromo-1,2,3-trifluorobenzene showing the long-range couplings between ^{1}H and ^{13}C nuclei.

T_1 proton relaxation

This experiment is used to measure the T_1 relaxation time of each chemical group. Figure 10 shows the T_1 build up curves for the protons 4 and 5 in 5-Bromo-1,2,3-trifluorobenzene . The T_1 value obtained by fitting the build up curve with a single exponential function is shown next to the build up curve. The remarkable quality of the fits demonstrate the high signal-to-noise ratio and reproducibility of the Spinsolve spectrometer.



5-Bromo-1,2,3-trifluorobenzene

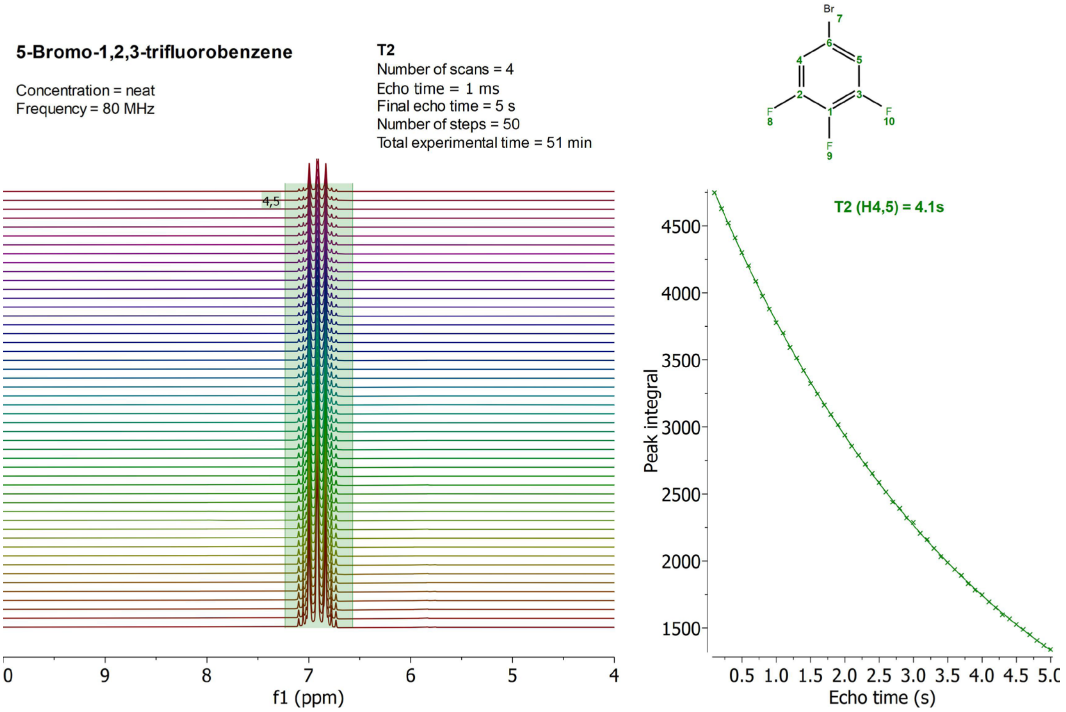
Concentration = neat
Frequency = 80 MHz

T1
Number of scans = 2
Total experimental time = 42 min
Maximun inversion time = 10 s
Number of steps = 41

Figure 10: Proton T_1 relaxation measurement done employing neat 5-Bromo-1,2,3-trifluorobenzene on a Spinsolve 80 MHz system.

T_2 proton relaxation

This experiment uses a CPMG sequence to allow the protons to relax with the transverse relaxation time T_2 and acquires only the signals during the last echo. To acquire the full data set, it is necessary to repeat the experiment incrementing the duration of the CPMG module by increasing the number of echoes generated during this period. The T_2 values are obtained by fitting the peak integrals of each group as a function of the CPMG evolution time. Figure 11 shows the T_2 decay curve for the protons 4 and 5 in 5-Bromo-1,2,3-trifluorobenzene.



5-Bromo-1,2,3-trifluorobenzene

Concentration = neat
Frequency = 80 MHz

T2
Number of scans = 4
Echo time = 1 ms
Final echo time = 5 s
Number of steps = 50
Total experimental time = 51 min

Figure 11: Proton T_2 relaxation curves measured for neat 5-Bromo-1,2,3-trifluorobenzene on a Spinsolve 80 MHz system.