

Synthesis of a Bis(thiophenolate)pyridine Ligand and its Titanium, Zirconium, and Tantalum Complexes

Taylor N. Lenton, David G. VanderVelde, and John E. Bercaw

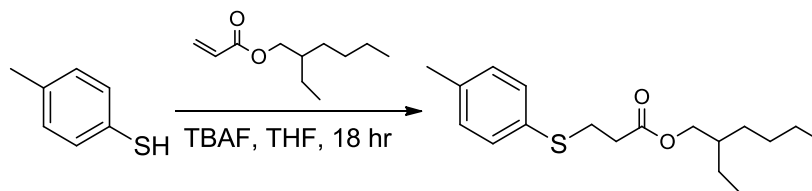
Arnold and Mabel Beckman Laboratories of Chemical Synthesis, California Institute of
Technology, Pasadena, California 91125

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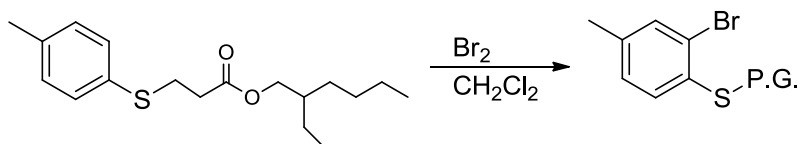
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Figure 1. Synthesis of 3-(4-methylphenylsulfanyl)propionic Acid 2-Ethylhexyl Ester



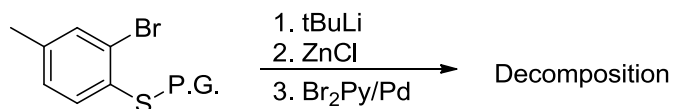
In a (100 mL) round-bottom flask *p*-thiocresol (1.00 g, 8.05 mmol) and isooctylacrylate (1.48 g, 8.05 mmol) were dissolved in THF (30 mL) and stirred at room temperature for 18 hours. Ethyl acetate was added to the solution and the organic layer was separated. The aqueous layer was washed once with ethyl acetate. Organic layers were combined, dried over MgSO_4 and volatiles were removed under reduced pressure. The product was purified by flash column chromatography (99:1 hexanes-ethyl acetate) to afford the protected thiol as a clear oil (1.43 g, 5.00 mmol, 62.1%). ^1H NMR (300 MHz, C_6D_6) δ : 7.03 (dd, $J = 125.7, 8.0$ Hz, 4H), 4.00 (dd, $J = 5.7, 2.3$ Hz, 1H), 3.00 (t, $J = 7.2$ Hz, 1H), 2.43 (t, $J = 7.2$ Hz, 1H), 2.01 (s, 3H), 1.49 – 1.09 (m, 3H), 0.99 – 0.73 (m, 4H).

Figure 2. Synthesis of 3-(2-bromo-4-methylphenylsulfanyl)propionic Acid 2-Ethylhexyl Ester



The protected thiol (1.43 g, 5.00 mmol) was added to a 100 mL round-bottom flask and dissolved in CH_2Cl_2 (50 mL). Bromine (1.60 g, 10.0 mmol) was syringed into the flask and the reaction was stirred at room temperature for 5 days. The solvent and excess bromine were removed under reduced pressure to afford the desired product (1.94 g, 5.00 mmol, 100%). ^1H NMR (300 MHz, CD_2Cl_2) δ 7.43 (dd, $J = 1.8, 0.7$ Hz, 1H), 7.25 (d, $J = 8.0$ Hz, 1H), 7.12 (ddd, $J = 8.0, 1.9, 0.7$ Hz, 1H), 4.00 (dd, $J = 5.8, 0.8$ Hz, 1H), 3.17 (t, $J = 7.4$ Hz, 1H), 2.63 (t, $J = 7.4$ Hz, 1H), 2.30 (s, 3H), 1.43 – 1.21 (m, 3H), 0.94 – 0.79 (m, 4H).

Figure 3. Attempts to couple protected thiol with 2,6-dibromopyridine



A mixture of the protected thiol (1.94 g, 5.00 mmol) and THF (30 mL) in a Schlenk tube fitted with a screw-in Teflon stopper was cooled in a cold well, in an inert atmosphere glove box. A tBuLi solution (1.7 M in pentanes, 6.2 mL, 10.5 mmol, 2.1 equiv) was added via syringe. The mixture was stirred for 1 h, in the cold well. ZnCl₂ (0.48 g, 3.5 mmol, 0.7 equiv) was added with the aid of 25 mL THF. The reaction turned dark brown. After stirring the reaction mixture for 30 minutes, 2,6-dibromopyridine (0.54 g, 2.25 mmol, 0.45 equiv) and Pd(PPh₃)₄ (0.05 g, 0.05 mmol, 0.01 equiv) were added with the aid of some THF (~2 mL). No products could be isolated from the mixture.

Figure 4. ^1H – ^1H NOESY of **5** in C_6D_6 at 25 °C.
Through-space interactions between protons of **5**.

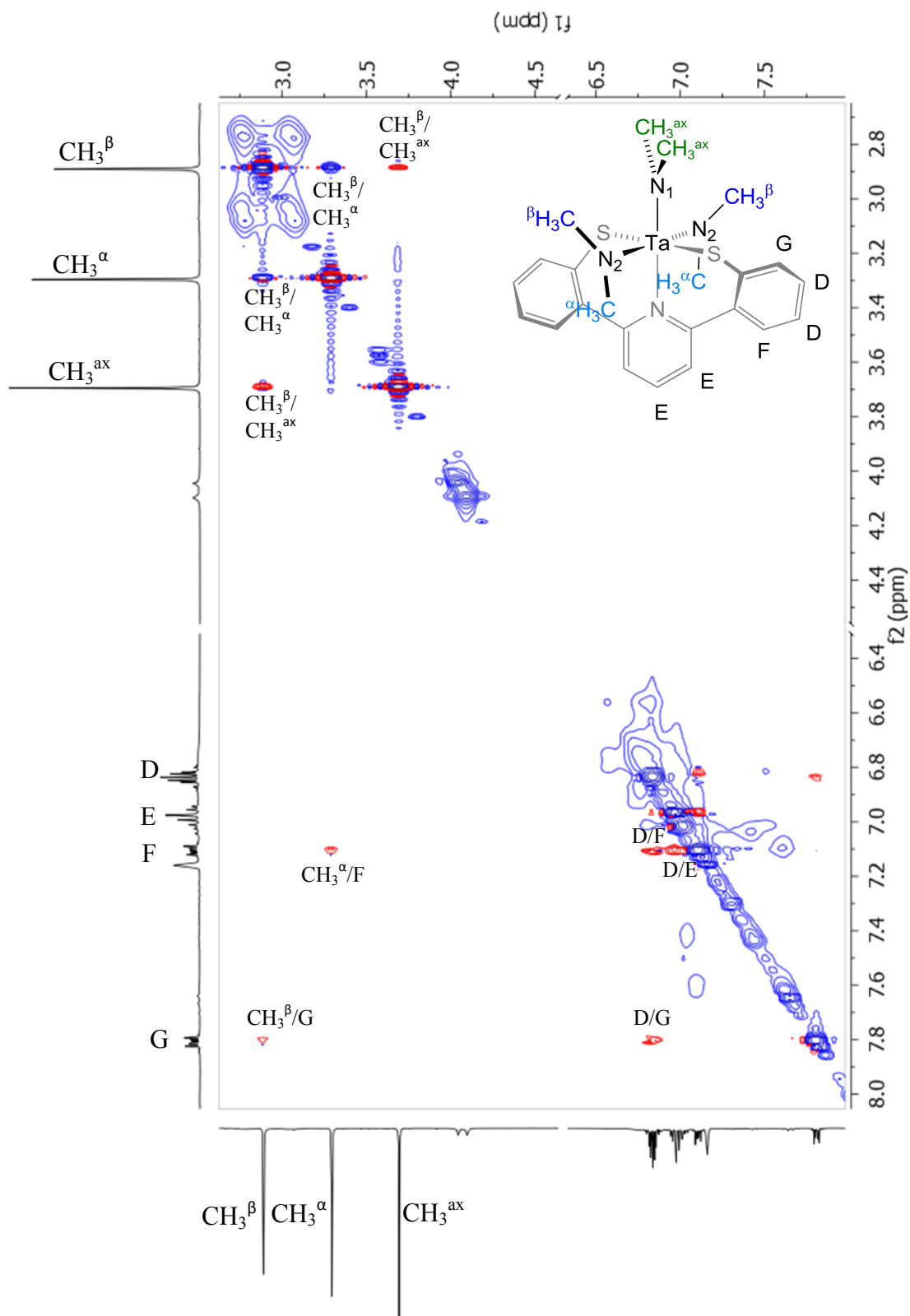
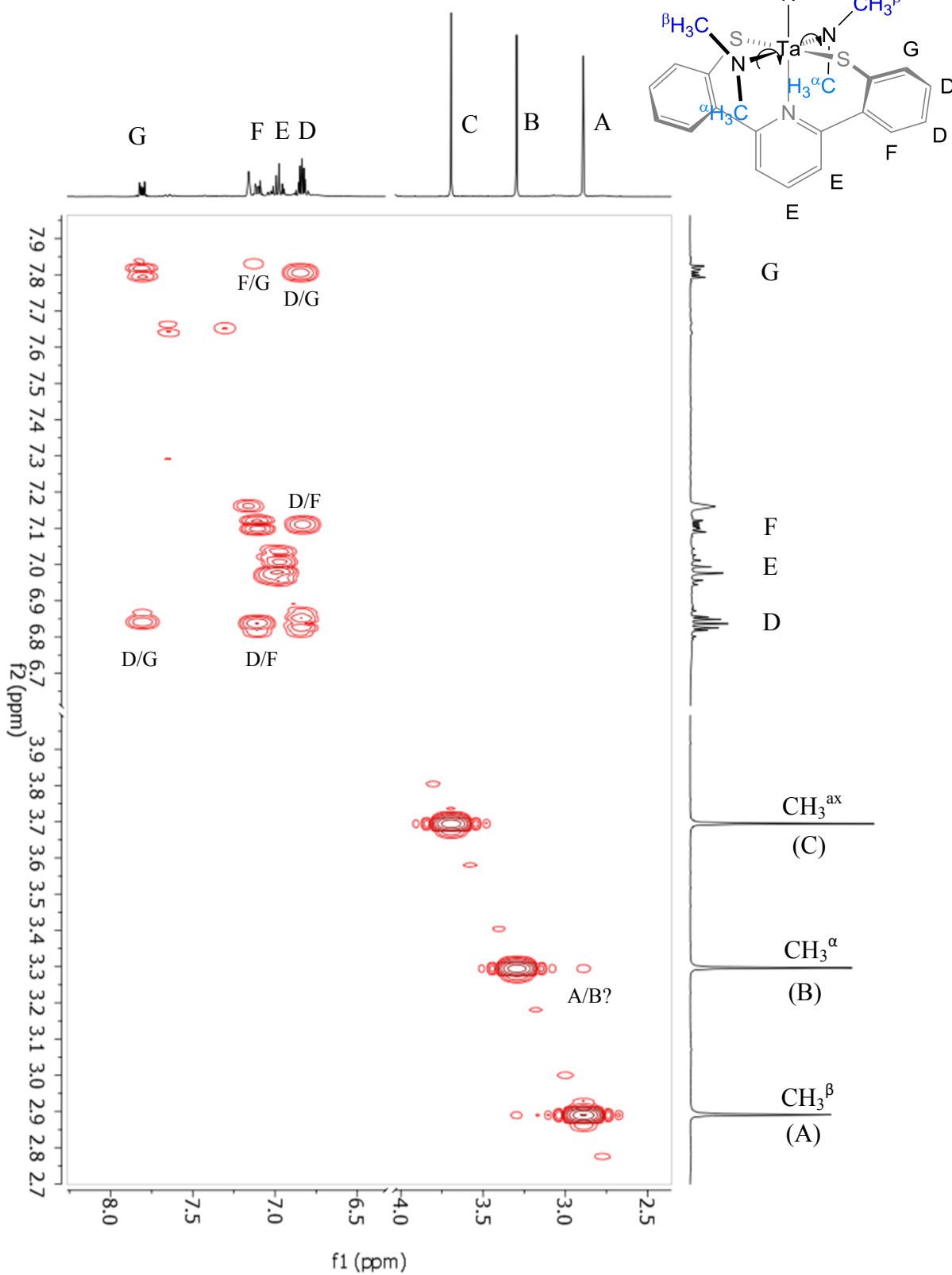


Figure 5. ^1H – ^1H COSY of **5**

Through-bond interactions between proton resonances of **5**.



Technique provides correlation between ^{13}C resonances and directly bound ^1H nuclei. Note: ^{13}C resonance E is partially obstructed by the solvent peak. Unlabeled carbon resonances are from the carbon atoms connecting aryl rings.

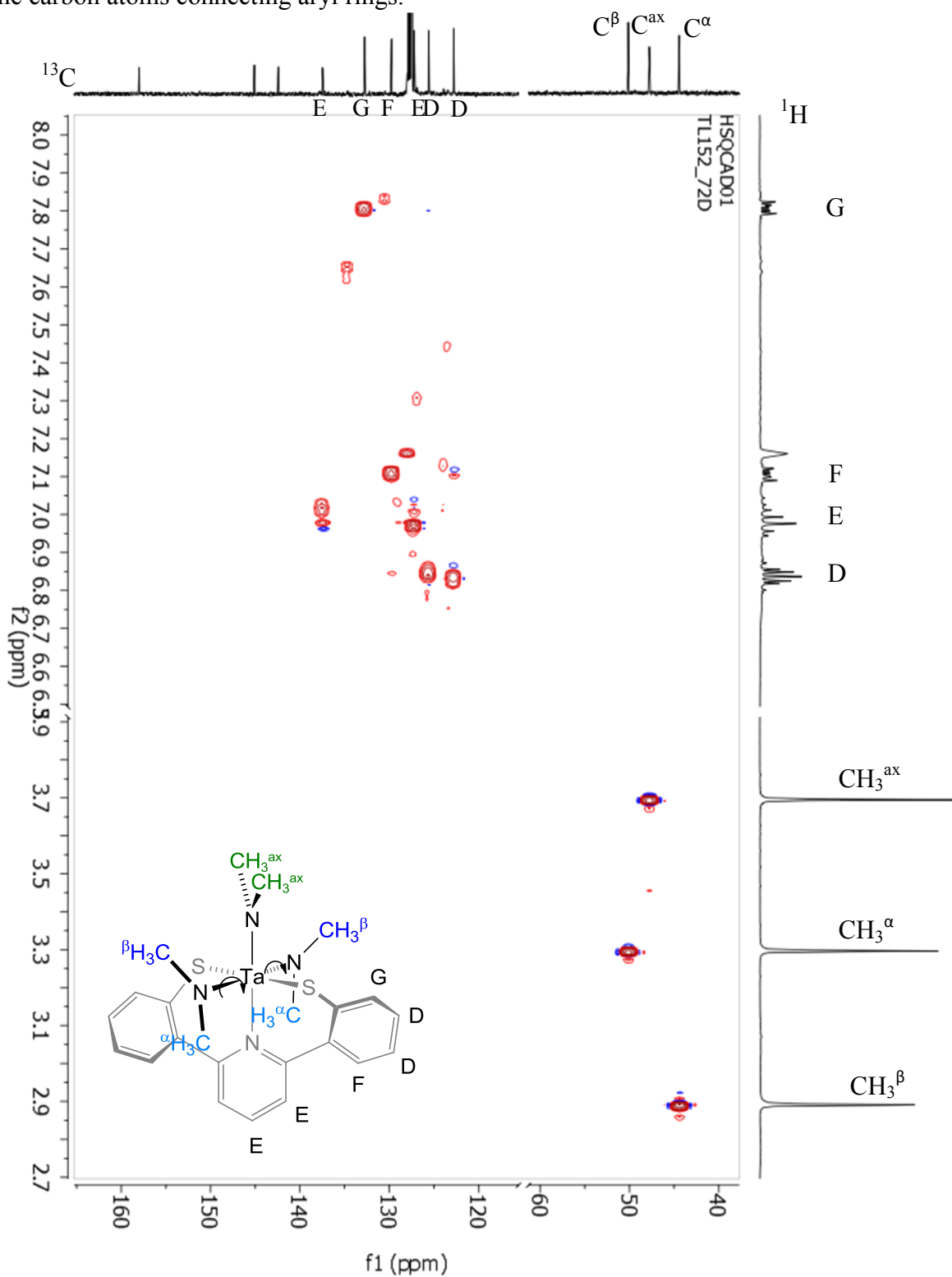


Figure 7. ^1H - ^{13}C HMBC of **5**

Spectrum correlates chemical shifts of protons with carbons separated by multiple bonds and was used to assign quaternary carbon centers. Note: ^{13}C resonance **E** is partially obstructed by the solvent peak.

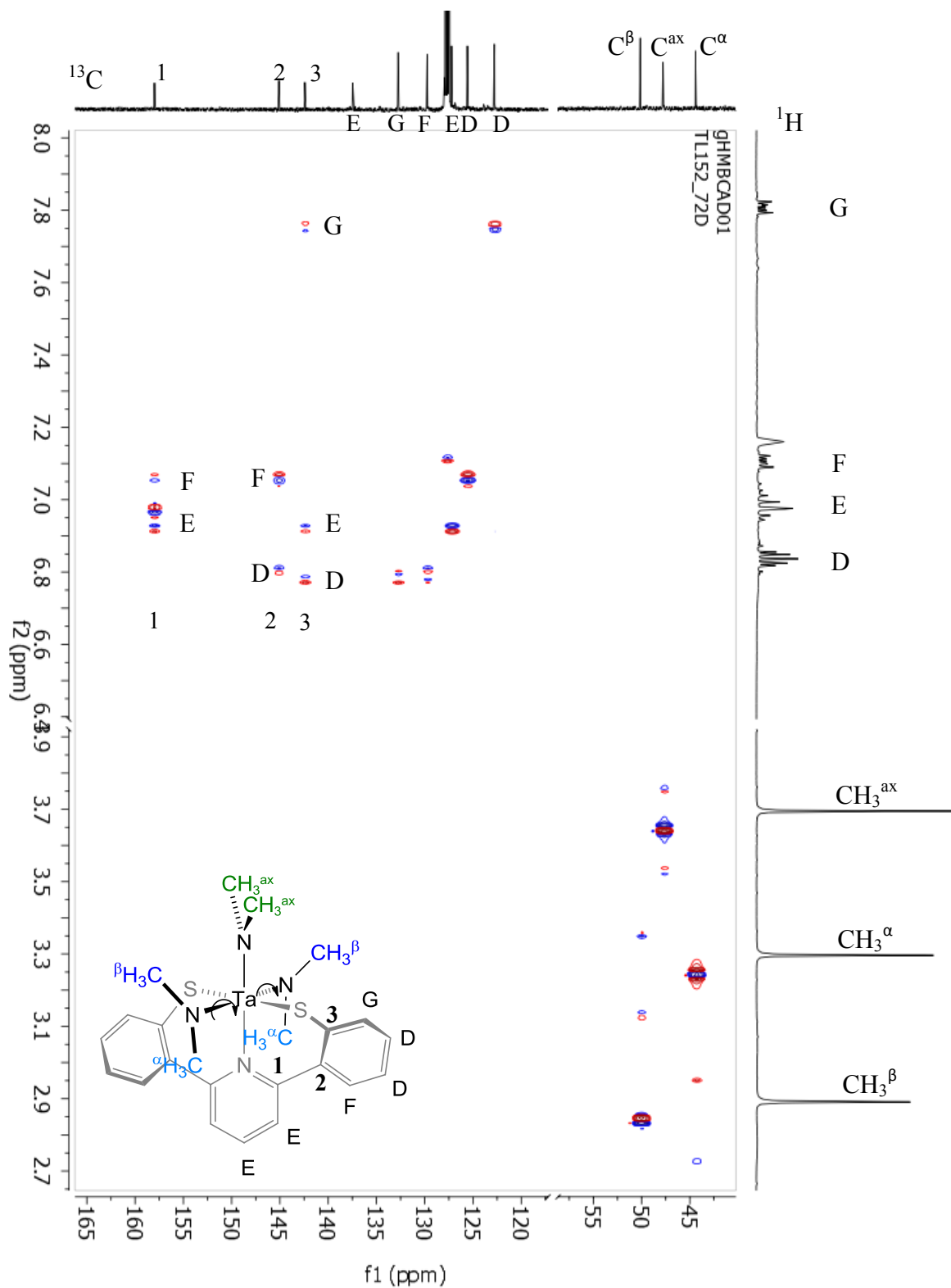


Figure 8. ^1H - ^{15}N HMBC of **5** in C_6D_6 at 25 °C.

Natural abundance ^{15}N - ^1H HMBC, using an internal projection of nitrogen resonance, detects proton resonances within two bonds. This establishes that the protons of A and B are both associated with the same nitrogen resonance and rules out an asymmetric solution state structure of **5**.

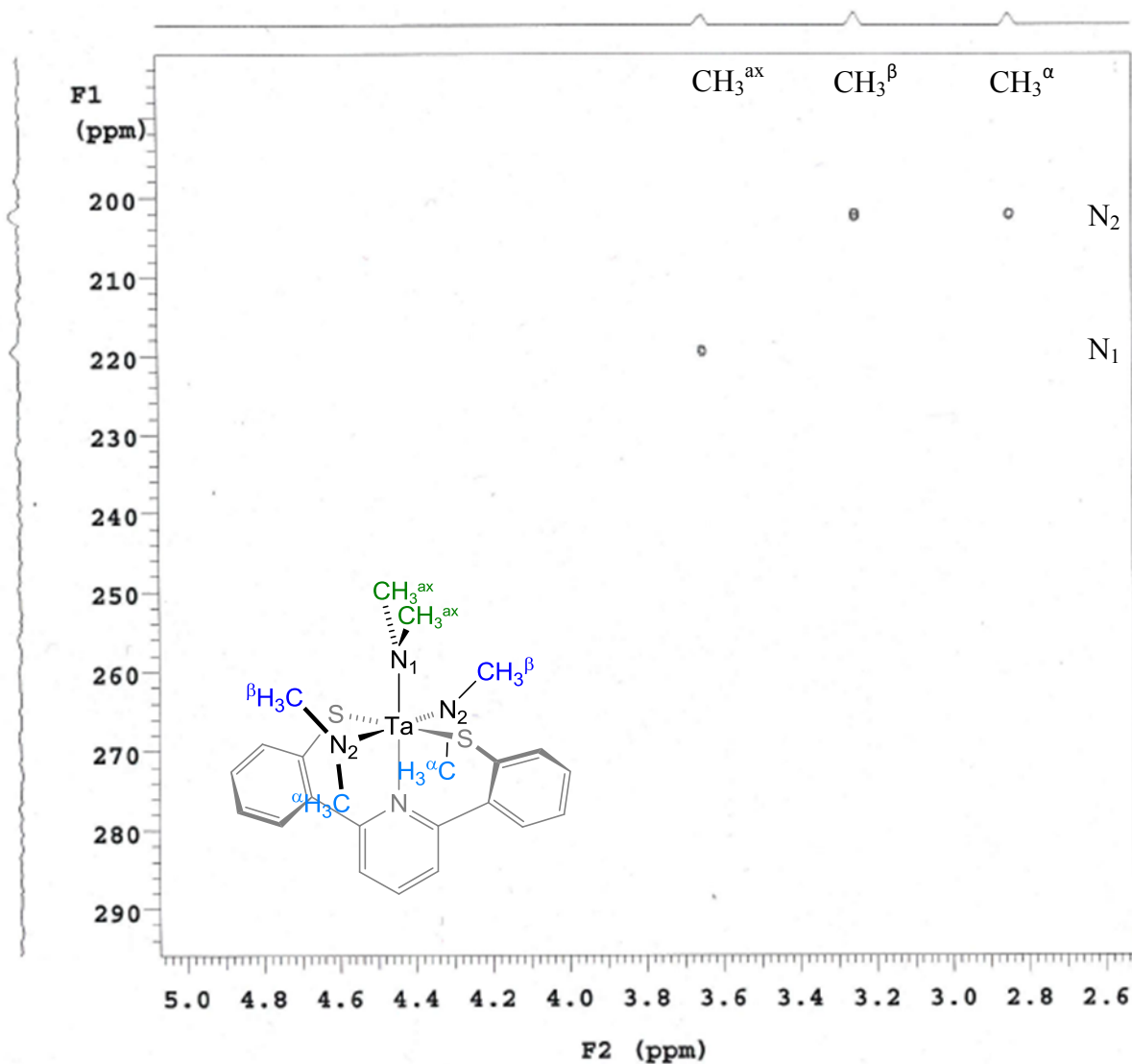


Figure 9. 1D ^1H -NOE of **5 in C_6D_6 at 25 $^\circ\text{C}$**

Selective band center $\delta 3.22$ (CH_3^α). Magnetic resonance transfer to position CH_3^β (likely from slow rotation of the equatorial Ta–N) results in a negative peak at $\delta 2.83$ (CH_3^β).

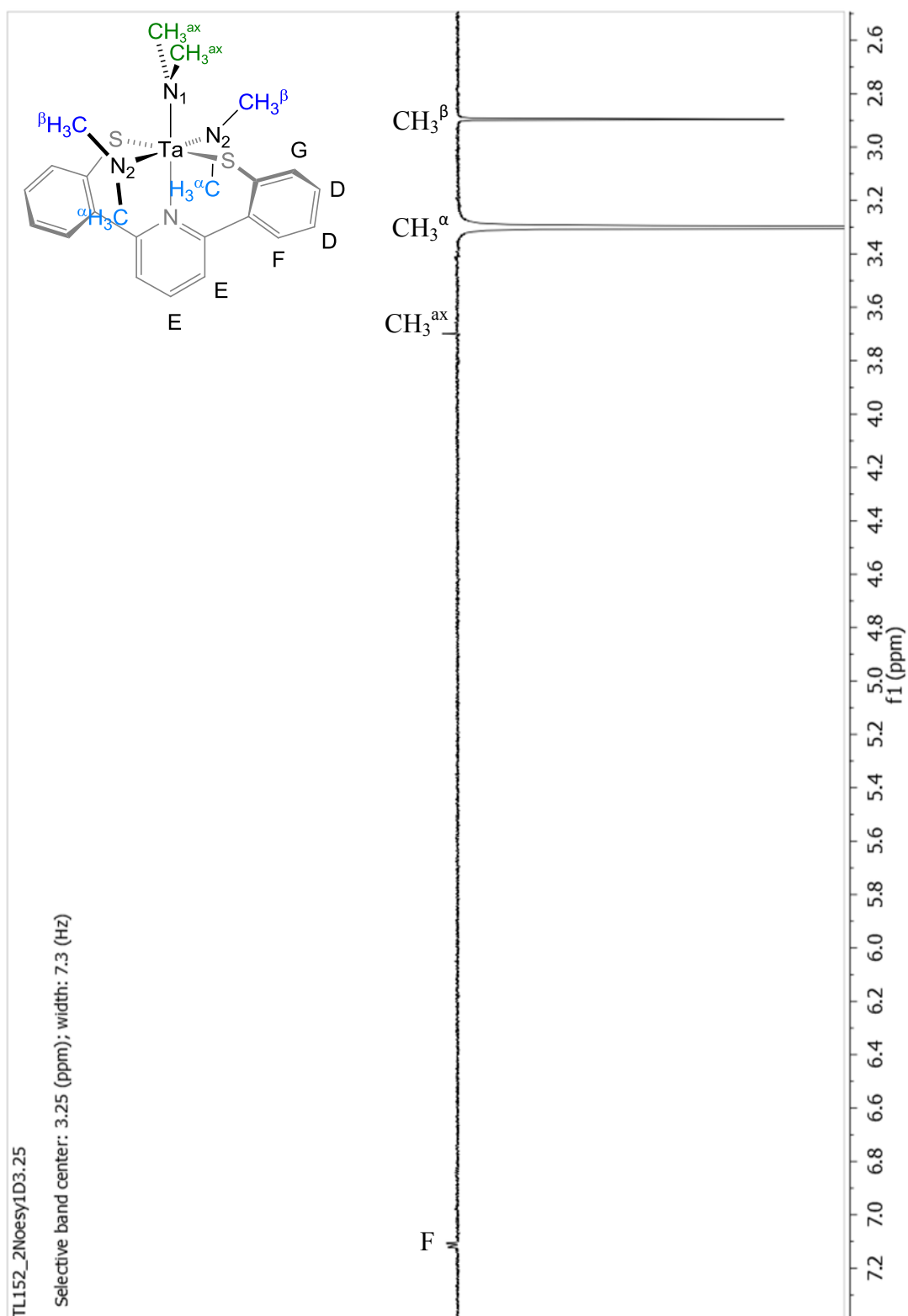


Figure 10. 1D ^1H -NOE of 5 in d_8 -toluene at 25 $^\circ\text{C}$.

Selective band center $\delta 2.83$ (CH_3^β). Magnetic resonance transfer to position CH_3^α (likely from slow rotation of the equatorial Ta–N) results in a negative peak at $\delta 3.22$ (CH_3^α).

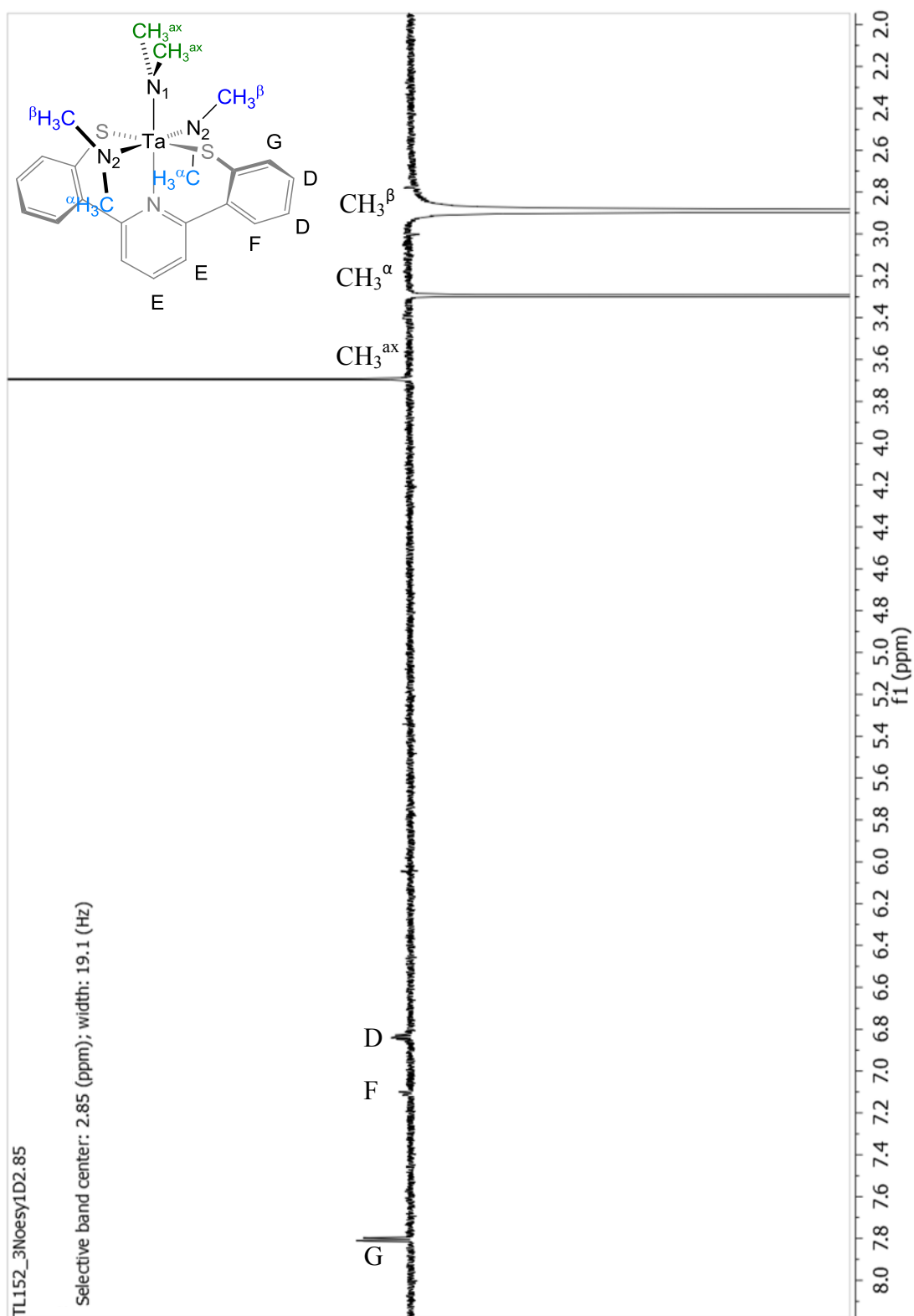


Figure 11. 1D ^1H -NOE of **5 in d_8 -toluene at $-10\text{ }^\circ\text{C}$**

Selective band center $\delta 2.85$ (CH_3^β) shows through space interactions with protons at positions CH_3^α and CH_3^{ax} , implicating it as the 'upper' methyl of **5**. The solution has been cooled to stop rotation between CH_3^β and CH_3^α on the NMR time scale.

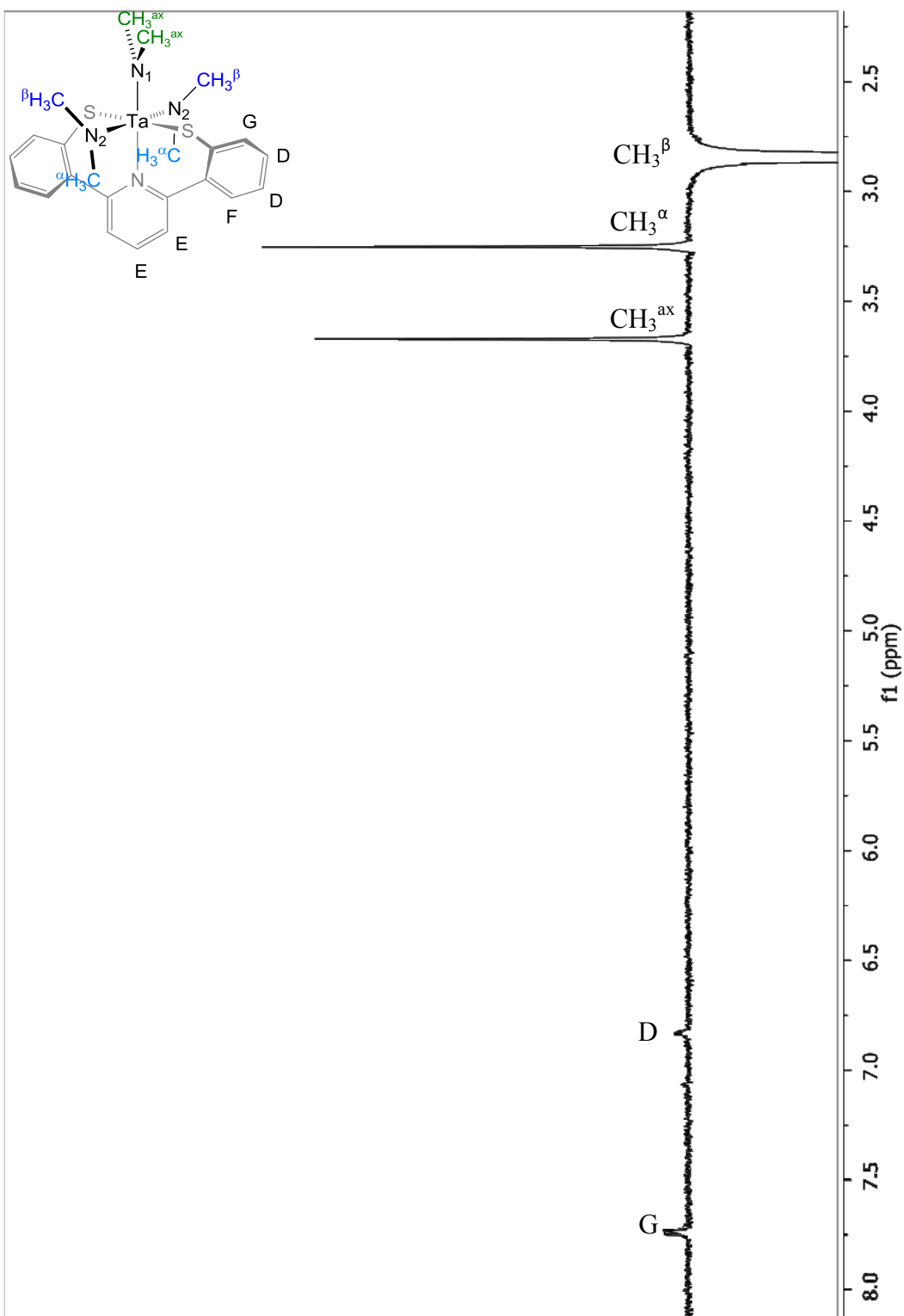


Figure 12. 1D ^1H -NOE of **5** in d_8 -toluene at -10°C .

Selective band center at $\delta 3.25$ (CH_3^α) shows through space interactions with positions CH_3^β and CH_3^{ax} .

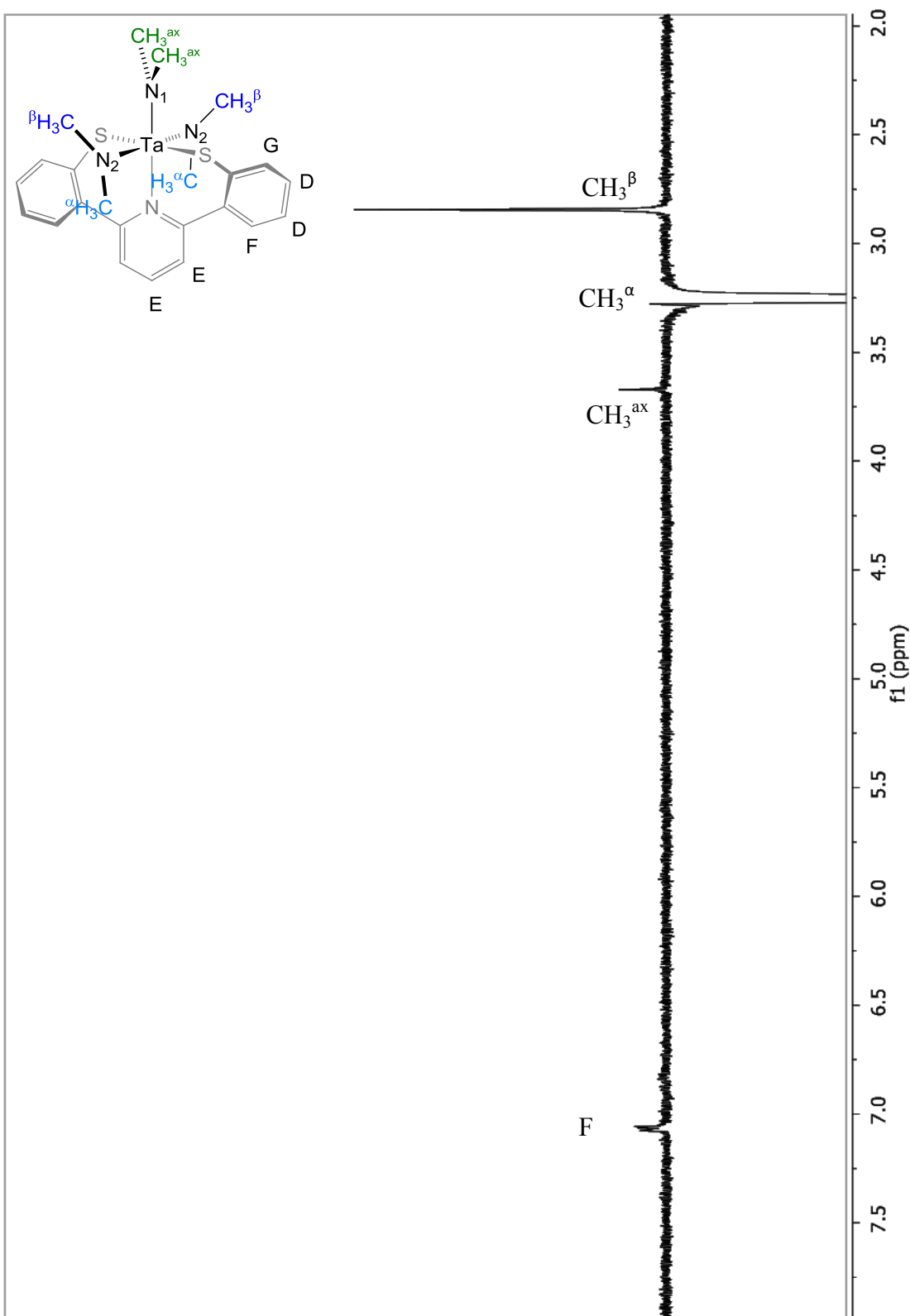


Figure 13. a.) Front and Side Views of **5** with protons omitted for clarity. b.) ^1H NMR of **5** in C_6D_6 at room temperature c.) 1D-NOE ^1H NMR of **5** at $-10\text{ }^\circ\text{C}$ in d_8 -toluene. Note: aromatic region has been enlarged for easier viewing and is not on the same scale as the aliphatic region.

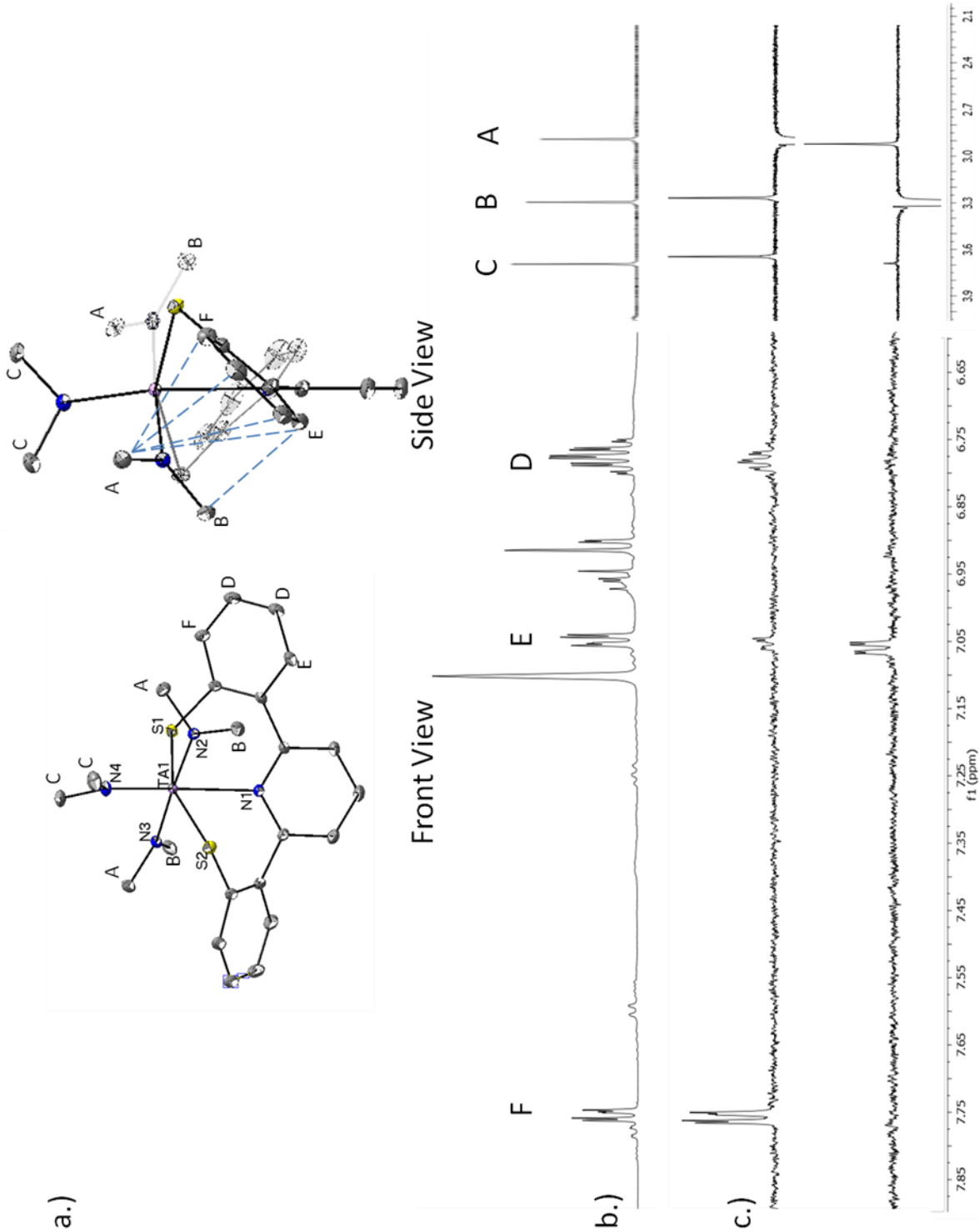
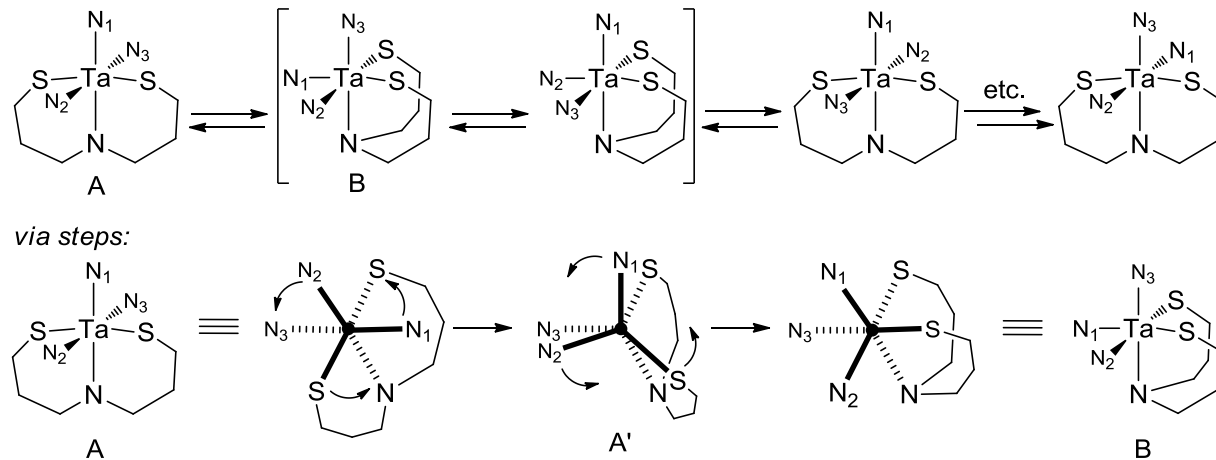


Figure 14. Possible Mechanism to Exchange Amides A, B, and C of complex 5.



Measuring through bond interactions of 6 established which protons were bound to each ethyl group.

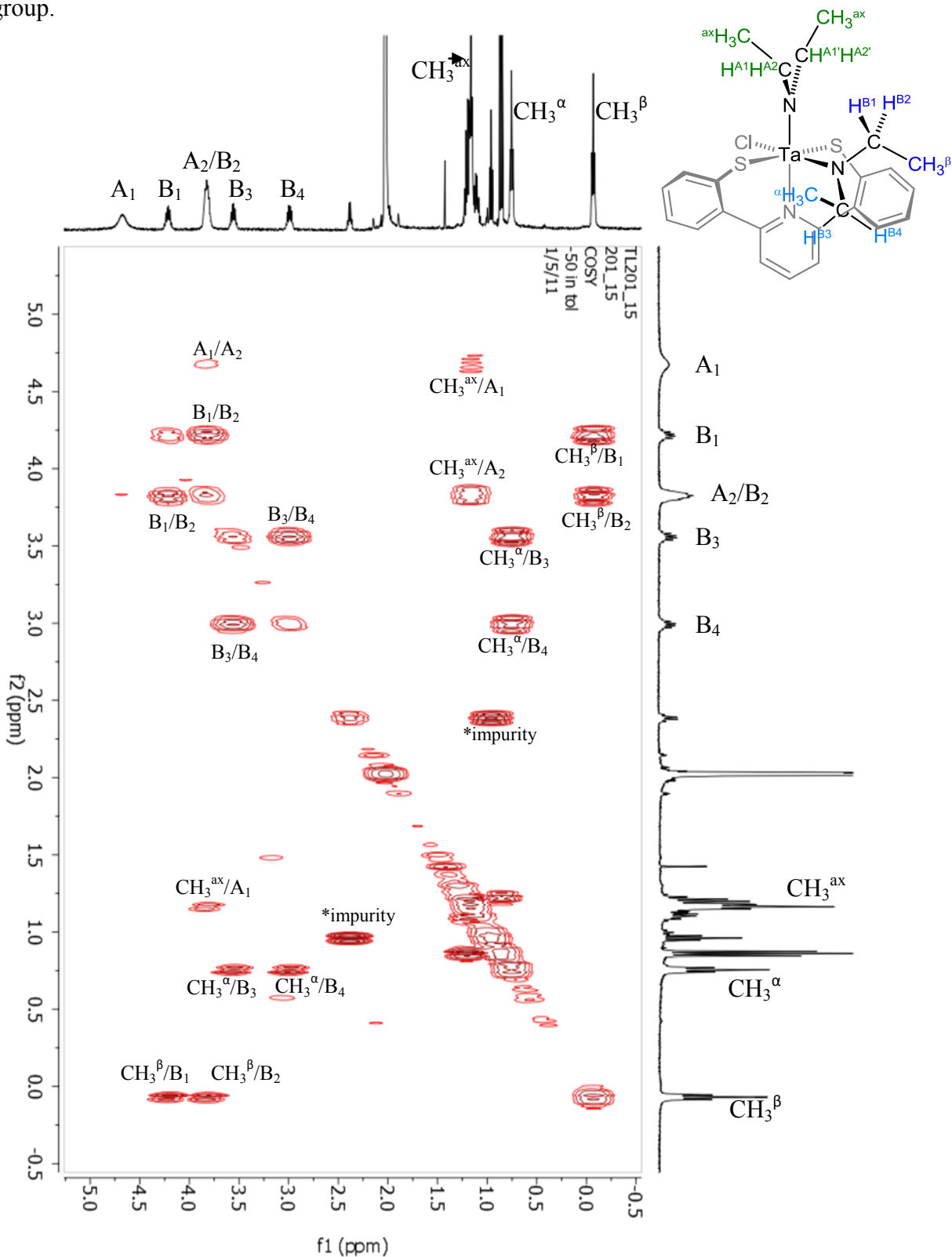


Figure 16. ^1H - ^1H ROESY of **6** at $-50\text{ }^\circ\text{C}$.

Red peaks denote through-space (NOE) interaction while blue peaks are a result of exchange.

