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This invited oral presentation Tu-I-SQU-01 was given at ISEC 2017.

NMR Relaxation Times of Animal Brains and Protein Models: Implications for Human Brain ULF-MRI

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Outline

- **Background**
- **ULF T_1 vs. High Field $T_{1\rho}$ of *Ex Vivo* Pig Brains**
- **ULF T_1 vs. High Field $T_{1\rho}$ of Protein Models**
- **Conclusions and Outlook**

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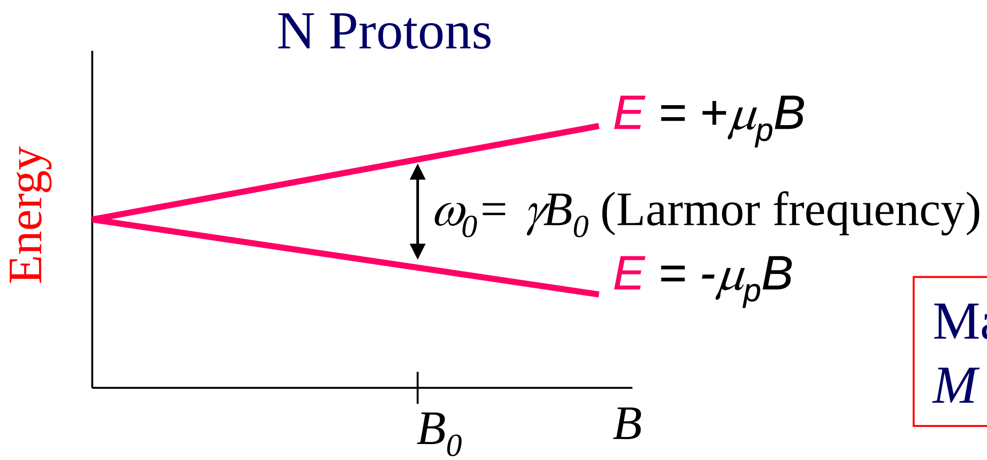
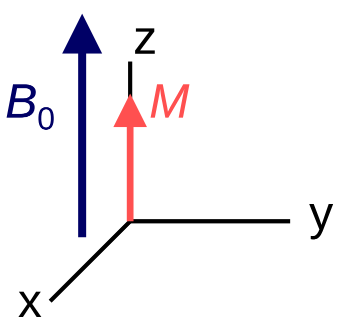
Nuclear Magnetic Resonance (NMR)

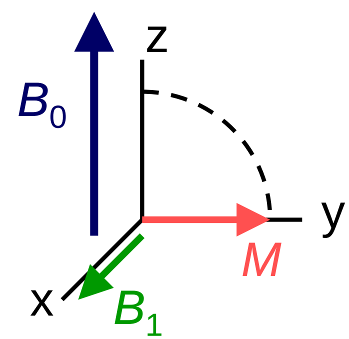


ν_0 = 42.58 MHz/tesla
γ : gyromagnetic ratio

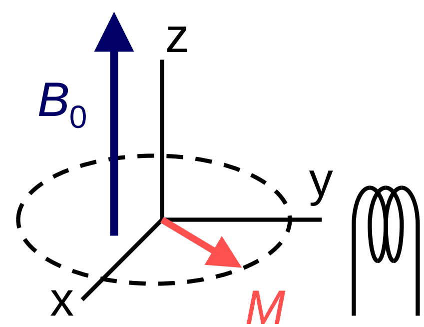
Magnetic moment ($\mu_p B_0 << k_B T$):
$M = N\mu_p^2 B_0 / k_B T$ (Curie Law)



Equilibrium



90° RF pulse



Precession

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Relaxation Processes in NMR

- **Longitudinal (spin-lattice) relaxation time T_1**
  - Time for polarization to return to equilibrium along the magnetic field direction

- **Transverse (spin-spin) relaxation time T_2**
  - Time for precessing spins to dephase

- **T_1 and T_2 depend strongly on magnetic field**
  - NMR Dispersion (NMRD)
    Microscopic interactions, motional processes…
  - The challenge of measuring T_1 and T_2 below 10 kHz

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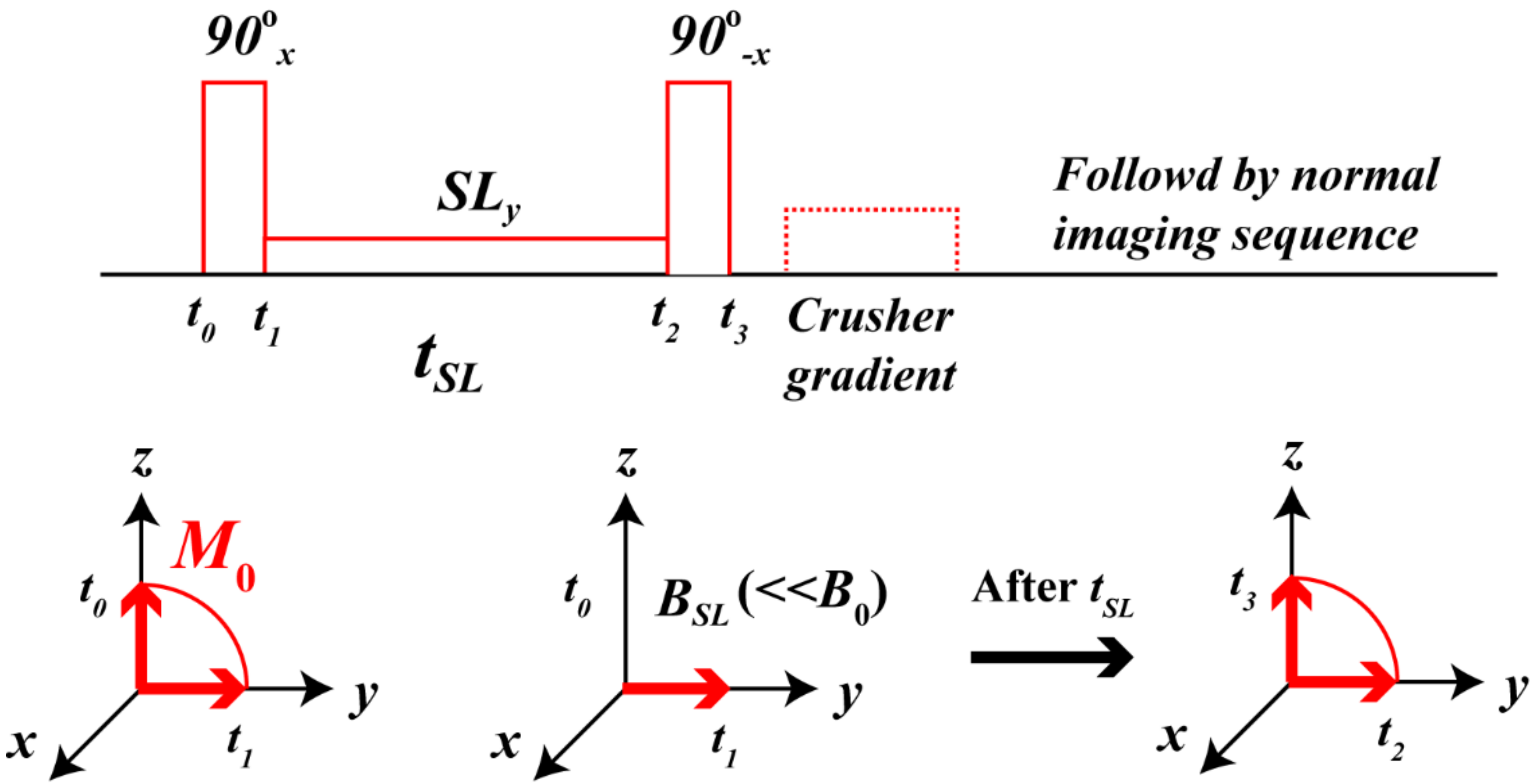
Revised for SNF publication

$T_{1\rho}$ Technique

$T_{1\rho}$ time: spin-lattice relaxation time in the rotating frame



$$\omega_{SL} = \gamma B_{SL}$$

$$M(t_{SL}) = M(0)e^{-t_{SL}/T_{1\rho}}$$

Revised for SNF publication

$T_{1\rho}$ Technique (cont.)

$T_{1\rho}$ enables the measurement of low frequency processes at any currently available clinical B_0 field strengths (SL frequency: 100 Hz to a few kHz)

- Applications:
  - ✓ Estimation of stroke onset time
  - ✓ Progression of Alzheimer's and Parkinson's diseases
  - ✓ Collagen-rich tissues such as cartilage
- Challenge:
  - ✓ Specific Absorption Rate (SAR) limit
    SAR scales as $B_0^2 \cdot B_{SL}^2$: at $B_0 = 3$ T, maximal SL field is ~12 μT.

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NOTE THAT:

The B_0 field in the laboratory frame at ULF is comparable to the B_{SL} field in the rotating frame

Motivation

To compare ULF T_1 and conventional $T_{1\rho}$ and study their relation.

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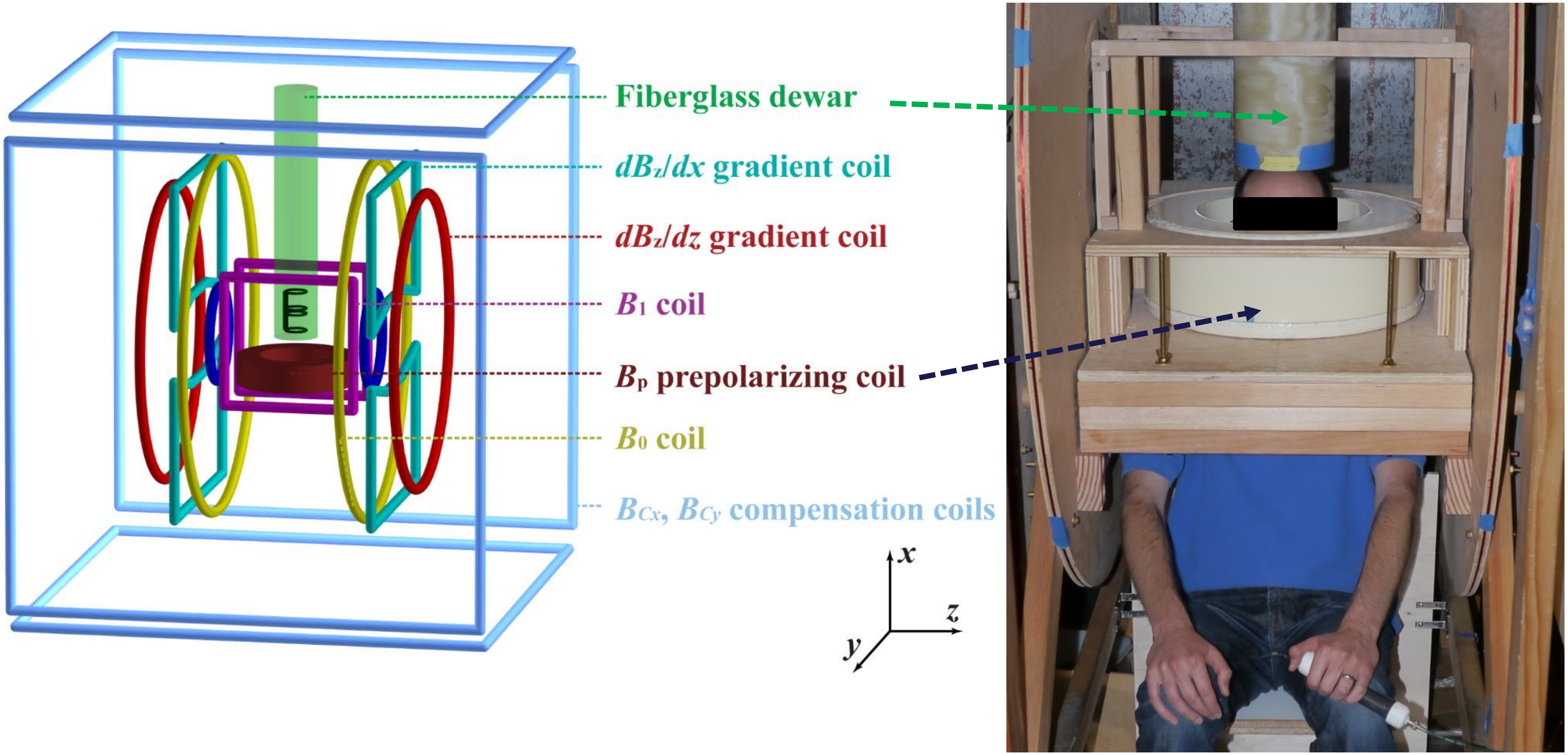
ULF MRI System at Berkeley



- $B_p \approx 80$ mT
- $B_0 \approx 58 \sim 240$ μT $\rightarrow f_{Larmor} \approx 2.5 \sim 10$ kHz
- Low-T_c Superconducting Quantum Interference Device

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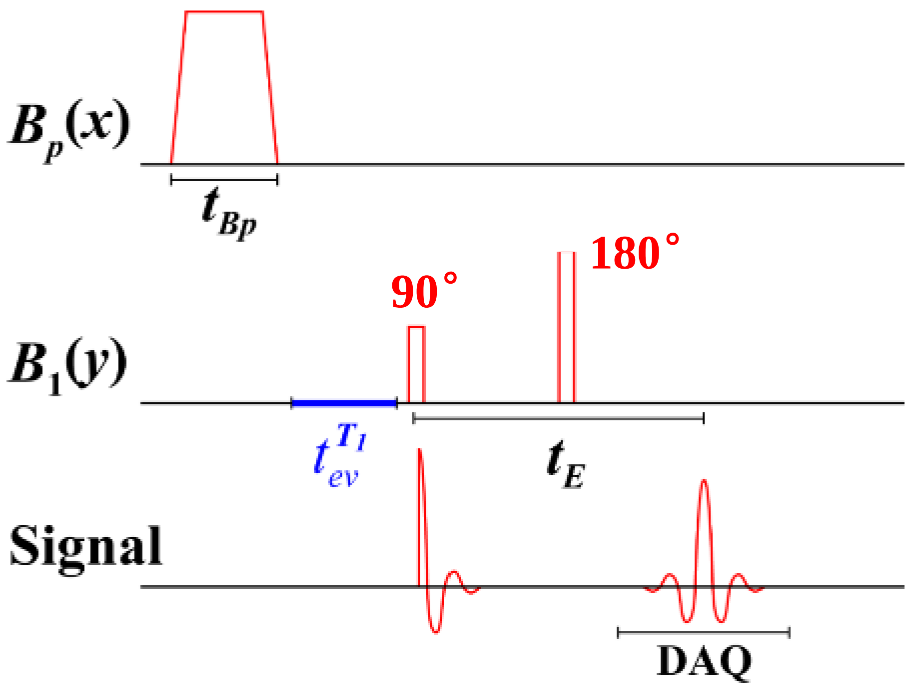
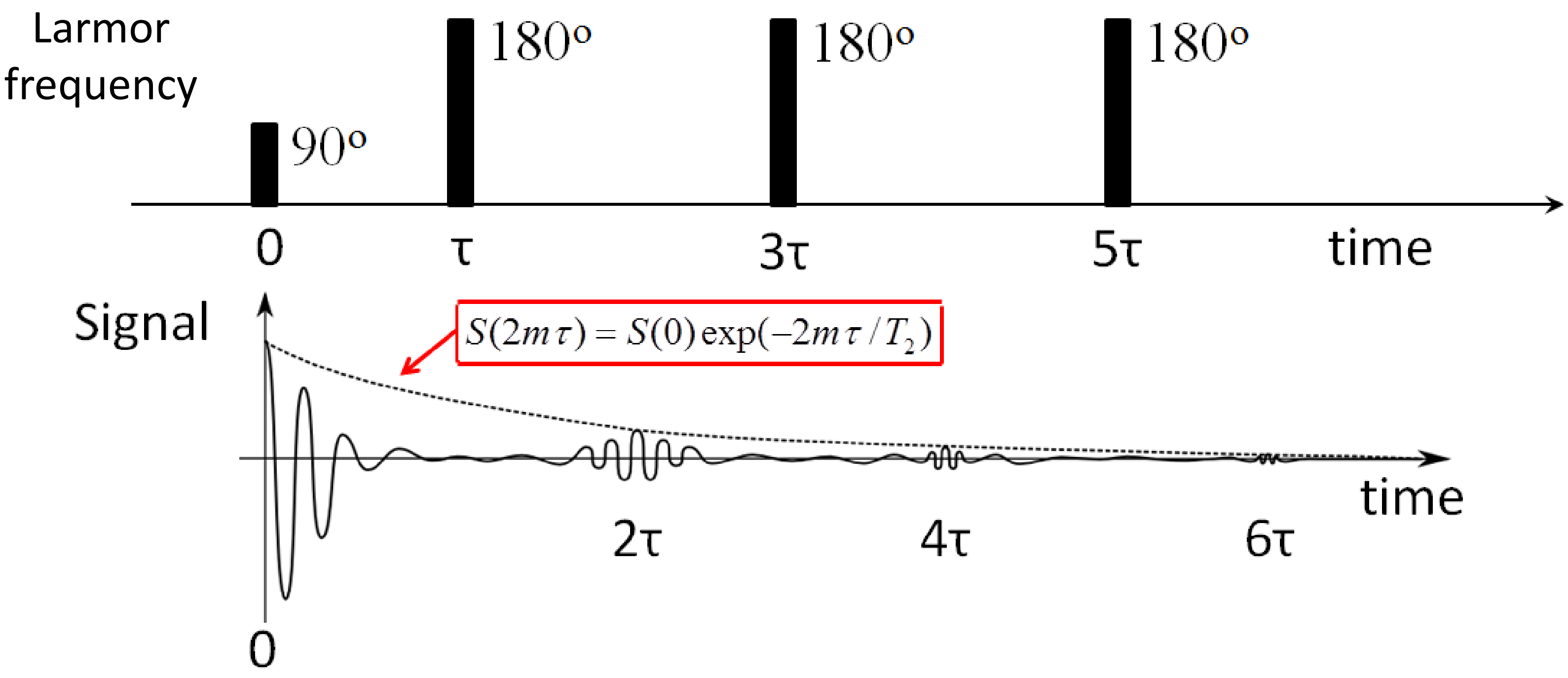
Single Spin Echo (SSE) Sequence for ULF T_1 Measurement



Varying $t_{ev}^{T_1} \longrightarrow T_1$

Carr-Purcell-Meiboom-Gill (CPMG) Pulse Sequence for T_2 Measurement



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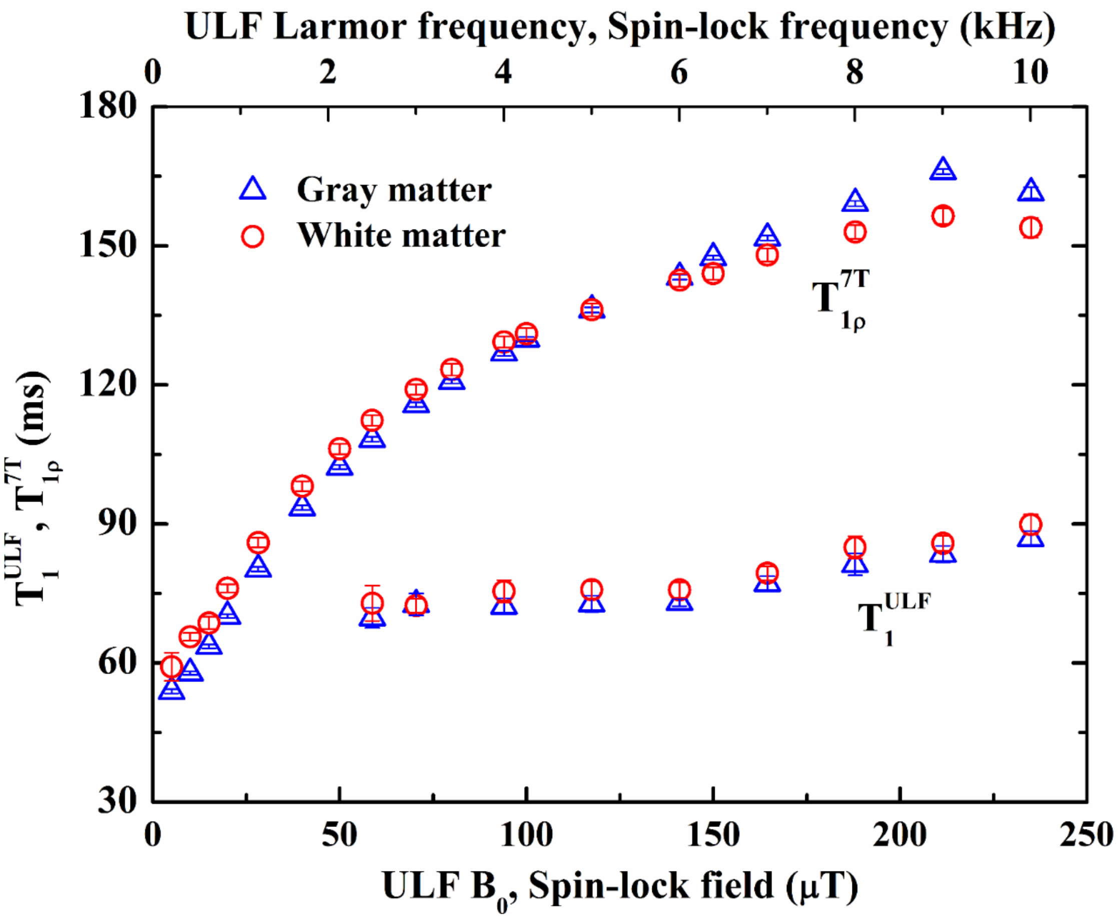
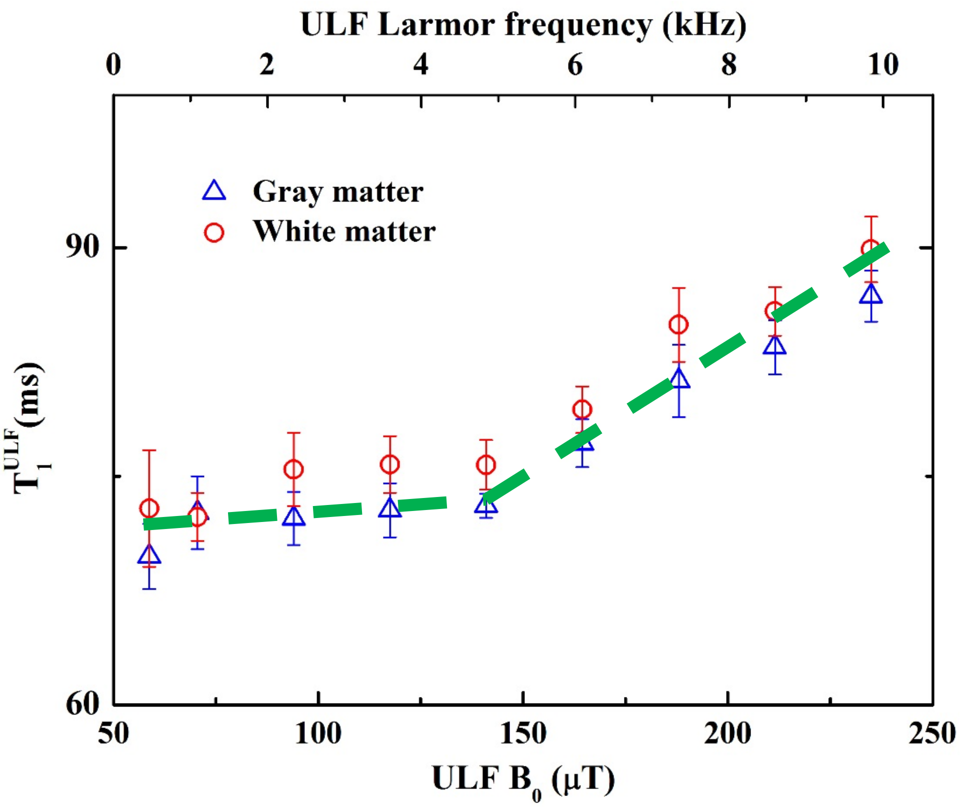
Pig Brain White & Gray Matter: $T_{1\rho}$ @7 T vs. T_1 @ULF



- Field dependence of T_1 and $T_{1\rho}$
- Different dominant relaxation mechanisms

Dong *et al*. *Magn. Reson. Med.* (2017) DOI: 10.1002/mrm.26621

The "Elbow"



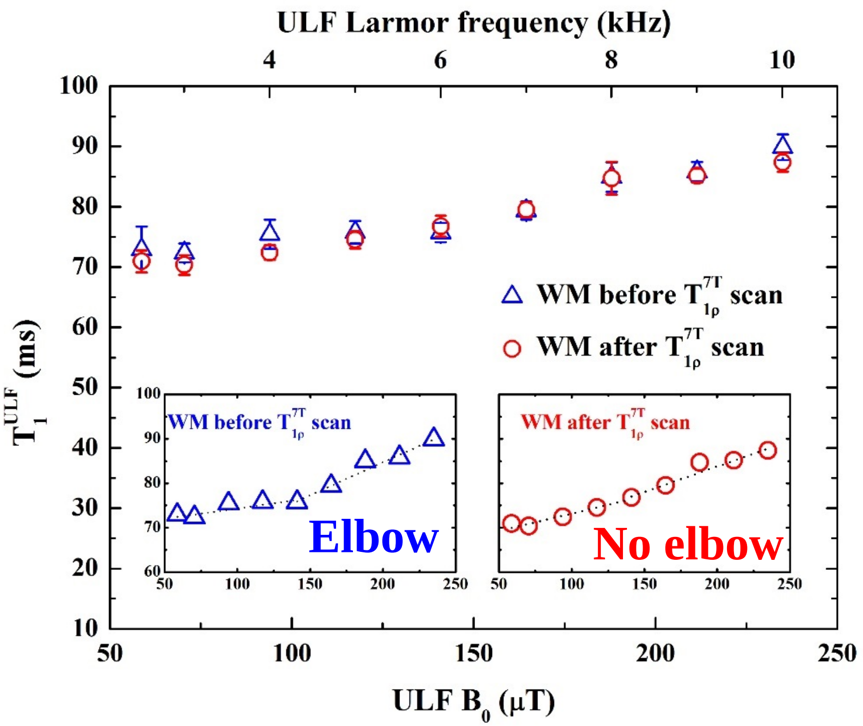
Origin of the "elbow":

When B_0 is reduced below ~ 150 μT, the minimum field is determined by the local dipolar field produced by macromolecules.

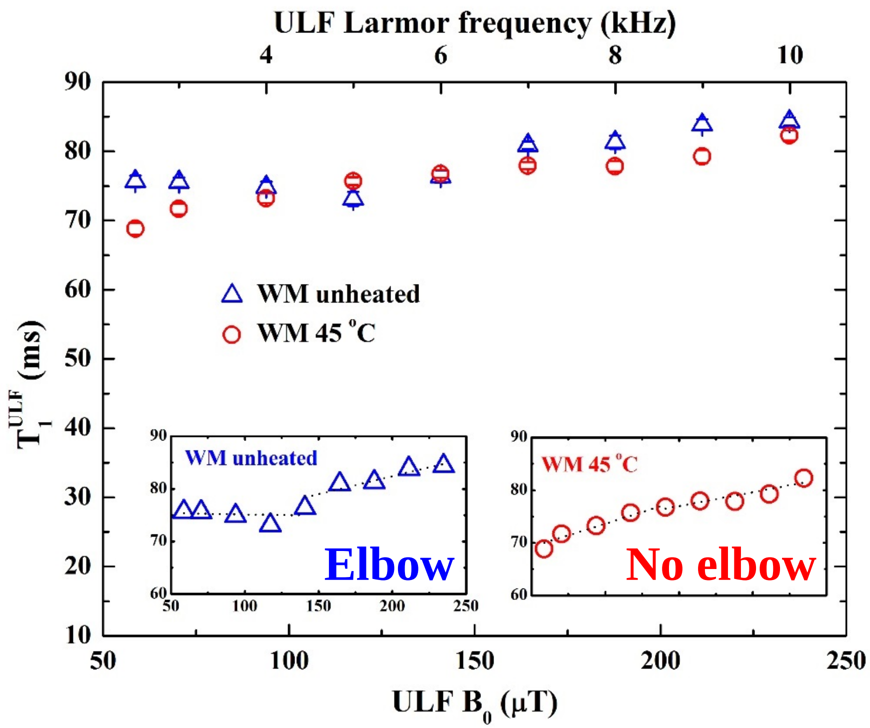
Dong *et al. Magn. Reson. Med.* (2017) DOI: 10.1002/mrm.26621

Heating Effect of $T_{1\rho}$

Spin lock → Temperature increase → Protein conformation change



Before and after $T_{1\rho}$ scan



Unheated and 45 °C heating

The elbow disappears after $T_{1\rho}$ scan because of heating effect!

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Slides 15 ~ 19 were removed for Copyright reason

Conclusions & Outlook

- $T_{1\rho}$ and ULF T_1 have different dominant relaxation mechanisms
- The "elbow" reflects the average local dipolar field

- More efforts required for theoretical explanation
- Stroke and traumatic brain injury (TBI) study

Many thanks for your attention!

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