Magnetic Fluctuations in $ZnGeP_2$:Mn

P.W. Mengyan *[a], R.L. Lichti [a], Y.G. Celebi [b], B.B. Baker [a], E. Catak [b], B.R. Carroll [c], K.T. Zawilski [d], P.G. Schunemann [d]

[a] Texas Tech University, Lubbock, TX 79409-1051, USA
[b] Istanbul University, Beyazit, 34459 Istanbul, Turkey
[c] Arkansas State University, Jonesboro, AR 72467, USA
[d] BAE Systems, Advanced Systems and Technology, Nashua, NH 03061-0868, USA

Project Focus

•Dilute Magnetic Semiconducting (DMS) systems gaining importance as prospects in spin-based electronics

•Mechanism responsible for connecting local magnetic features to bulk magnetic properties – not yet understood in DMS systems

MuSR & μ^+ as Local Probe [1]

•Muon Spin Relaxation utilizes unique sensitivity of 100% spin polarized and positively charged muons to probe local magnetic and electronic environment

•Local B-field environment for μ:

$$B_{loc} = \langle B_{loc} \rangle + \delta B_{loc} = B_{ext} + B_{dip} + B_{hyp} + B_{fermi} + \delta B_{loc}$$

B_{ext} =Applied external field

B_{dip} = dipolar field
→ Sum of localized moments over entire crystal
→ Including site to site differences

B_{hyp}= Field from HF interaction
→ Short range magnetic interaction between μ^+ and local electronic moments (cf: wavefunction overlap)

B_{fermi} =Fermi contact interaction
→ Mag. interaction of μ^+&e^- spins for *s*&*p* e^- metals
→ RKKY – indirect exchange between μ^+ and unpaired e^- via conduction e^- [*d*&*f* materials]
→ Transferred hyperfine field [μ^+ & e^- wavefunction overlap in insulators]

δB_{loc}= Contribution from fluctuation in neighboring magnetic moments → ν

Material Properties: $ZnGeP_2$:Mn

• $E_g \approx$ 1.83eV to 2.0eV (decreases as Mn conc. increases) [2]
• FM order above RT ($T_c \approx$ 310K to 350K) [2]
• AFM below 47K for Mn > 5% [2]
• PM/AFM below 47K mixed state for Mn < 5% [2]
• Prime candidate for spin-based electronics
  (1) Semiconducting properties
  (2) FM and AFM characteristics
• Mn^{2+} substitution:
  (1) Group II: Isovalent (high concentration of Mn^{2+})
  (2) Group IV: Double Acceptor (light concentration of Mn^{2+})
  (3) Result of (1) and (2) [ie hole abundance] is strong FM coupling instead of the AFM order produced by group II substitution only
• Powder XRD results [3]
  support 2nd ordering transition but lacks evidence to conclusively demonstrate if small inclusions of MnP dominate magnetic features
• NMR [4]
  Suggests 90+% Mn atoms in MnP impurity phase with nm sized clusters for 8% to 15% Mn; no additional information for samples with Mn concentration < 8%

The Experiment

• LF muon spin relaxation measurements:
  - EMU & HiFi spectrometers on surface muon channel at ISIS in Didcot, UK
  - Helios spectrometer on M20 surface muon channel at TRIUMF in Vancouver, Canada
• 4 different $ZnGeP_2$:Mn samples, varying Mn concentration
• Temperature scans: ~2 K to 700 K at B_{LF} = {0.1, 0.375, 0.7, 1.5} T
• B-field scans at various temperatures
• Time dependent muon spin polarization, P(t), fit with up to 3 Lorentzian relaxing and 1 non-relaxing component

Samples

• BAE Systems provided 6 high quality, p-type $ZnGeP_2$:Mn
•All samples cut from the same single crystal boule from starting melt of 1.6% Mn grown by horizontal gradient freeze technique
• Each with different Mn content (9 x ~13 x 1.1 mm^3)

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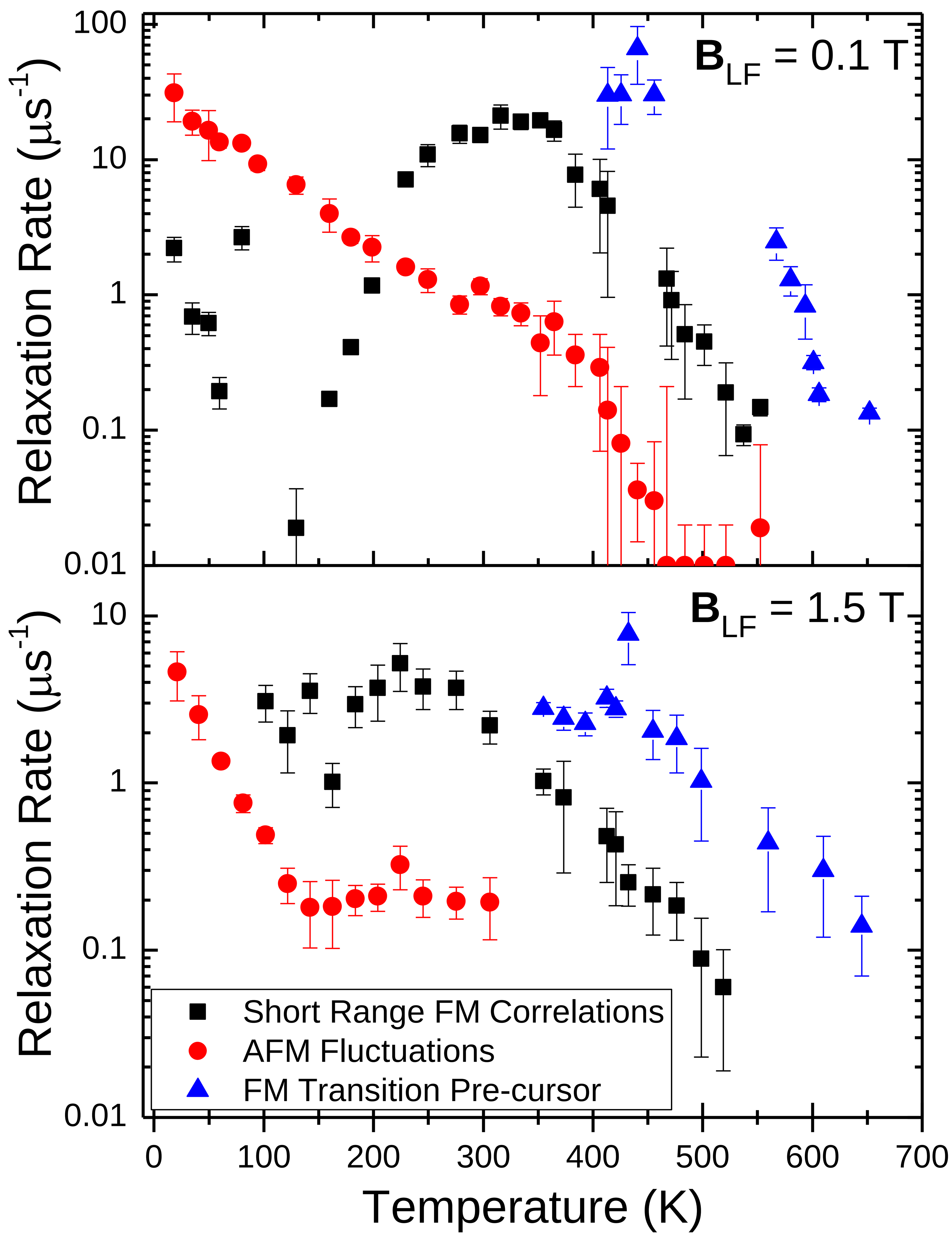

Observed Features Consistent Across all Samples

AFM Fluctuations (●)[5]:

• $\frac{1}{T_1} \sim \frac{2\Delta_i^2}{\nu}$ | T^{-1}_1= μ^+ Rlx rate; ν=Spin fluctuation rate
$\Delta_i = \gamma_\mu \delta \mathbf{B}_i$=($\mu$ gyromagnetic ratio)(RMS value of fluctuating field)

Short Range FM Correlations (■):

• Further analysis and modeling required to positively identify and further characterize short range correlations

FM Transition Precursors (▲):

• Further analysis and modeling required to positively identify and further characterize fluctuations above 350 K
• Preliminary analysis of spin precession data hint at SP at T > 300 K
• SQUID Measurements at 350 K show field induced FM that collapses to 0 at zero applied field

Future Work and Open Questions

• Overall: Improve understanding of magnetism within DMS systems
• Additional data analysis: improve separation of relaxation rates in regions containing more than 2 components; ie. 300K to 500K
• Modeling of fluctuations in DMS systems for AFM, FM, SP
• Link between dilute local moments and bulk magnetism?
• How is magnetism distributed throughout sample?, ie:
  (1) MnP impurity phase with clustering throughout?
  (2) Distributed relatively uniformly throughout?

References
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* rick.mengyan@ttu.edu