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# Crossover from transient spin structures to the field-induced Griffiths phase of FeBr<sub>2</sub>

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## Abstract

In the presence of an applied axial magnetic field  $H_a$  the uniaxial antiferromagnets FeCl<sub>2</sub> and FeBr<sub>2</sub> show fluctuating domain-like antiferromagnetic correlations above the phase boundary  $T_c(H_a)$ . They are detected by SQUID measurements of the low frequency out-of-phase susceptibility  $\chi''$  and indicate a field-induced Griffiths phase at temperatures  $T_c(H_a) < T < T_N$ . In contrast to FeCl<sub>2</sub>, important additional frustration-induced intraplanar non-critical contributions to  $\chi''$  vs.  $T$  are found in FeBr<sub>2</sub>. For external fields above the  $T_c(H_a)$  line,  $H_a > 2.6$  MA/m, they are shown to superimpose linearly on the Griffiths contributions. These dominate at  $H_a = 2.67$  MA/m and are unequivocally modeled within the Landau theory of fluctuations near phase transitions by introducing a Lorentzian  $T_c$  distribution.

The Griffiths phase conjecture was theoretically introduced for diluted Ising-ferromagnets [1]. It is based on the idea of ‘local phase transitions’ in a diluted system due to the finite probability of arbitrarily large pure and differently diluted clusters. However, despite a possible dynamical signature of the Griffiths phase in inelastic neutron scattering data of  $KMn_{0.3}Ni_{0.7}F_3$  [2] and recent Monte Carlo simulations [3], its clear experimental verification is still lacking. A more favorable situation is encountered in an analogous experimental realisation of a Griffiths phase-like phenomenon. It was recently detected on the uniaxial antiferromagnet FeCl<sub>2</sub> in an applied axial magnetic field [4]. Domain-like antiferromagnetic correlations are created by fluctuating demagnetizing fields and, hence, transition temperatures due to the unambiguous relationship  $T_c = T_c(H_a)$ . Within the temperature regime  $T_c(H_a) < T < T_c(H_a = 0) \equiv T_N$  the quasicritical order parameter fluctuations give rise to anomalous contributions to the magnetic loss function  $\chi''$  at low frequencies  $0.1 < f < 10$  Hz. Regions with local antiferromagnetic correlations are analogous to the non-diluted clusters, which are responsible for the Griffiths phase in diluted ferromagnets. As shown in Ref. [4], these antiferromagnetic fluctuations are suitably described within the framework of the Landau theory of fluctuations near second-order phase transitions [5]. In addition, the concept of local transition temperatures, which

is accounted for by a Lorentzian  $T_c$  distribution function, allows one to model the temperature dependence of the out-of phase susceptibility  $\chi''$  within and above the Griffiths regime  $T_c(H_a) < T < T_N$ . An approximate analytic expression is given by [6]

$$\chi'' \propto \frac{\epsilon}{\pi V D q^2 (\epsilon^2 + t_c^2)} \times \begin{cases} T_N - T_c + \frac{t_c(t_c^2 - t_N^2)}{\epsilon^2 + t_c^2} \\ - \frac{A_0}{D q^2 T} \left( \frac{1}{2} t_c^2 + t_N^2 \right) & \text{if } T \leq T_N, \\ T_N - T_c + \left( \frac{t_c}{\epsilon^2 + t_c^2} - \frac{A_0}{2 D q^2 T} \right) \\ \times (t_c^2 - t_N^2) & \text{if } T > T_N, \end{cases}$$

with  $t_c = T - T_c$ ,  $t_N = T - T_N$ ,  $A_0$  and  $D$  the Landau expansion coefficients of the quadratic and gradient term of the Gibbs free energy density,  $\epsilon = b/T$  the temperature-dependent width of the  $T_c$  distribution,  $V$  the sample volume and  $q$  the wave-vector of the order parameter fluctuations. While the field-induced Griffiths phase is driven by inhomogeneous demagnetizing fields, FeBr<sub>2</sub> shows an important additional intrinsic loss mechanism. As outlined in Ref. [7], non-critical fluctuations are attributed to intraplanar frustration. It gives rise to transient non-uniform spin structures, which carry excess magnetisation. Their location in the  $H_a$ - $T$  phase diagram is shown in Fig. 1. Below the  $T_c(H_a)$  line they appear only on the

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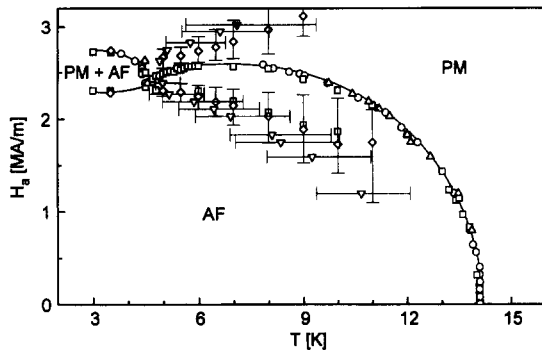


Fig. 1.  $H_a$ - $T$  phase diagram (data points with eye-guiding lines) and regimes of strong non-critical fluctuations (data points with bars indicating full widths at 0.6 maximum) obtained from  $M$  vs.  $T$  ( $\circ$ ) and  $H_a$  ( $\square$ ),  $\chi'$  vs.  $T$  ( $\Delta$ ),  $\chi''$  vs.  $T$  ( $\nabla$ ) and  $H_a$  ( $\diamond$ ) [7].

sublattice with magnetisation antiparallel to  $H_a$ , whereas above  $T_c(H_a)$  they are assumed to spread over all  $\text{Fe}^{2+}$  layers by symmetry.

Fig. 2a (circles) shows  $\chi''$  vs.  $T$  measured by SQUID magnetometry at  $H_a = 3.02$  MA/m and constant frequency  $f = 5$  Hz obtained for a [0001] oriented Bridgman-grown single crystal with  $\sim 0.2$  mm thickness. The non-critical fluctuations above the phase transition are responsible for the maximum of  $\chi''$  vs.  $T$  at  $T = 7.1$  K (solid symbol in Fig. 1). With increasing temperature,  $\chi''$  decreases due to the thermal decay of spin clusters. However, contributions from the field-induced Griffiths phase cause a delay of the thermal decay in the vicinity of the 'Griffiths-temperature'  $T_N = 14.1$  K. With decreasing external

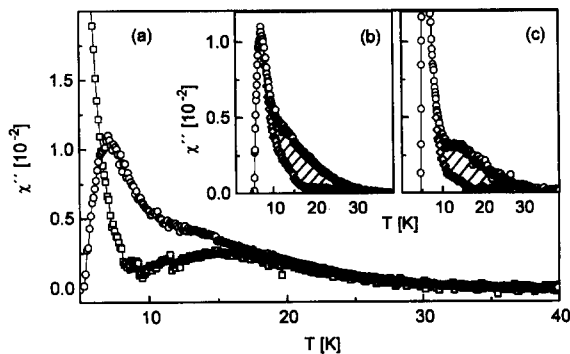


Fig. 2. (a)  $\chi''$  vs.  $T$  measured at  $f = 5$  Hz and  $H_a = 2.67$  ( $\square$ ) and  $H_a = 3.02$  MA/m ( $\circ$ ). The solid line is a least-squares fit to the theory (see text). The insets show  $\chi''$  vs.  $T$  for  $H_a = 3.02$  (b) and  $H_a = 2.86$  MA/m (c) before ( $\circ$ ) and after ( $\diamond$ ) subtracting the Griffiths-type contribution, see text. The hatched areas indicate the excess in  $\chi''$  due to the Griffiths contributions.

field, the frustration-induced fluctuations shift to lower temperatures and thus gradually separate from the Griffiths-like contributions appearing at higher  $T$ . At  $H_a = 2.67$  MA/m this is indicated by a clear minimum close to zero at  $T = 8.5$  K (Fig. 2a, squares).

The solid line in Fig. 2a shows the least-squares fit of the above function to these data.  $T_N$ ,  $T_c$ ,  $A_0/Dq^2$ ,  $b$  and an additional proportionality constant are involved as fit parameters. The result from the fitting procedure,  $T_N = 13.97$  K, comes close to the experimental value,  $T_N = 14.1$  K, which was obtained by the temperature dependence of the low-field magnetization. This demonstrates that the concept of the field-induced Griffiths phase can be extended from the prototype  $\text{FeCl}_2$  [4] to the frustrated Ising system  $\text{FeBr}_2$ . Under the assumption that the field-dependent change of  $\chi''$  vs.  $T$  is mainly caused by the frustration-induced fluctuations, we are able to separate these and the virtually constant Griffiths contributions from each other. As a result, Figs. 2b and c show  $\chi''$  vs.  $T$  for  $H_a = 3.02$  and 2.86 MA/m, respectively, before and after subtracting the Griffiths-type contribution. This is taken from the fit of the data at  $H_a = 2.67$  MA/m (Fig. 2a) and represented by the hatched areas in Figs. 2b and c. As expected, the frustration-induced fluctuations increase with increasing field from  $H_a = 2.86$  to 3.02 MA/m. This is consistent with the phase diagram as discussed in Ref. [7]. It shows that in contrast to the Griffiths contributions, the frustration-induced fluctuations develop their main intensity far from the phase transition line. This is observed above and also below [7] the  $T_c(H_a)$  line. This remarkable property and the interplay of the frustration-induced and three-dimensional critical fluctuations are still under investigation.

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## References

- [1] R.B. Griffiths, Phys. Rev. Lett. 23 (1969) 17.
- [2] R.G. Lloyd and P.W. Mitchell, J. Phys. C 1 (1989) 5013.
- [3] V.B. Andreichenko, W. Selke and A.L. Talapov, J. Phys. A 25 (1992) L283.
- [4] Ch. Binek and W. Kleemann, Phys. Rev. Lett. 72 (1994) 1287.
- [5] A.Z. Patashinskii and V.L. Pokrovskii, Fluctuation Theory of Phase Transition (Pergamon, Oxford, 1979).
- [6] Ch. Binek and W. Kleemann, Proc. 19th Meeting Middle Europ. Coop. Statis. Physics, Smolenice, 1994, Acta Phys. Slovaca 44 (1994) 435.
- [7] M.M.P. de Azevedo, Ch. Binek, J. Kushauer, W. Kleemann and D. Bertrand, J. Magn. Mater. 140–144 (1995) 1557 (these Proceedings).