Th.C-P04 Low-temperature spin-glass behaviour in a diluted dipolar Ising system.

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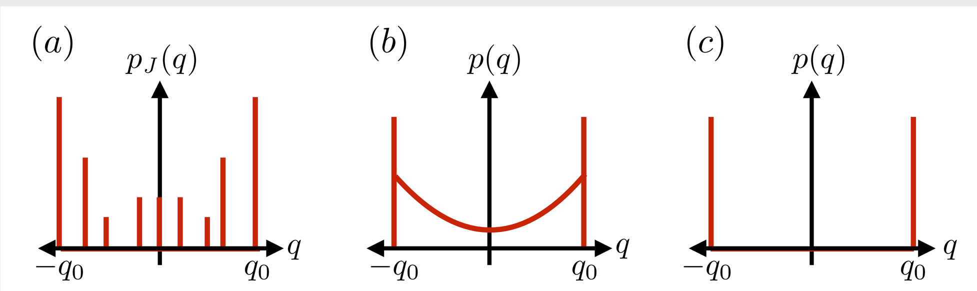
Introduction

In complex systems, different random distributions of their microscopic constituent parts give rise to *diverse* values of some macroscopic properties.

A paradigmatic example is the Sherrington- Kirkpatrick (SK) model, where the couplings between any pair of spins are randomly fixed to be FM or AF. SK has both *quenched disorder* and *frustration*, the two essential ingredients of spin glasses (SG).

SK exhibits RSB: identical replicas of a given *sample J* (with a given distribution of couplings) may stay trapped in several *pure states* that are *sample-dependent*. The distribution of the overlap q between states of a given sample, $p_{\mathcal{J}}(q)$ is like depicted in Fig.(a). In the macroscopic limit, after averaging over *J's*, the *averaged distribution p(q)* is like in Fig.(b). It is said to be *non-trivial*.



Whether the RSB picture describes correctly the behaviour of *realistic SGs* still an open question. In the *droplet picture*, the SG phase is described in terms of a unique state with excitations that are compact droplets. According to this scenario, $p(q)$ distributions do not exhibit diversity, as shown in Fig.(c).

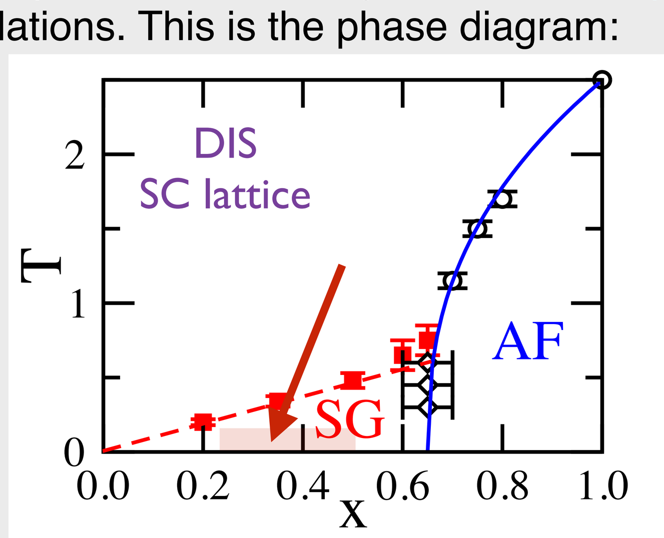
Systems of dipoles in crystals have *frustration*. Put together with *spatial-disorder* may result in SG behaviour, as observed in some ferroelectrics and in diluted dipolar Ising systems (DIS) as the *$LiHo_xY_{1-x}F_4$*.

Model

We consider site-diluted systems of classical Ising spins on SC lattices. All spins point up or down along the *z* axis of a *L^3* lattice. At each site a spin is placed with probability *x* . These spins are coupled by *dipolar interactions*.

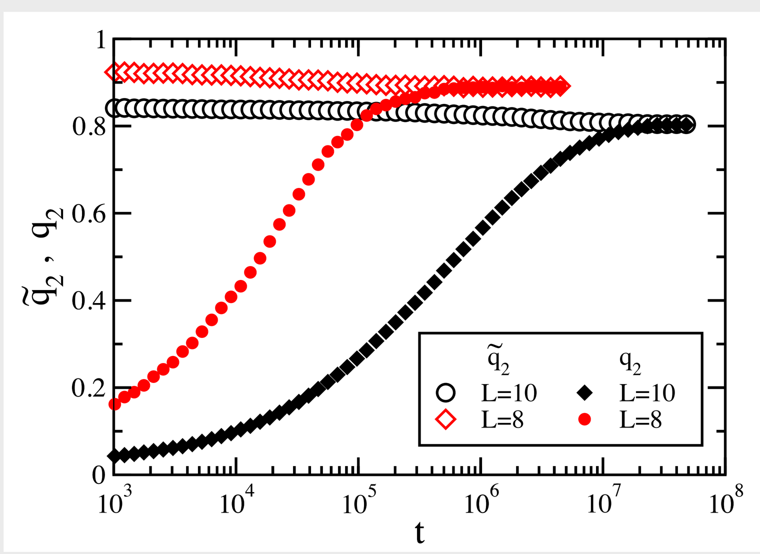
$$\mathcal{H} = \sum_{<i,j>} \varepsilon_a (a/r_{ij})^3 (1 - 3z_{ij}^2/r_{ij}^2)\sigma_i\sigma_j,$$

We obtain equilibrium results by means of Tempered Monte Carlo simulations. This is the phase diagram:



Here we focus on the character of the SG at very low temperature, well deep in the SG phase.

Equilibration times



We were able to equilibrate systems of several hundreds of dipoles. For strong dilution we observe extremely large relaxation times (we need *10^8 MCS* for *x=0.35* and *L=10*).

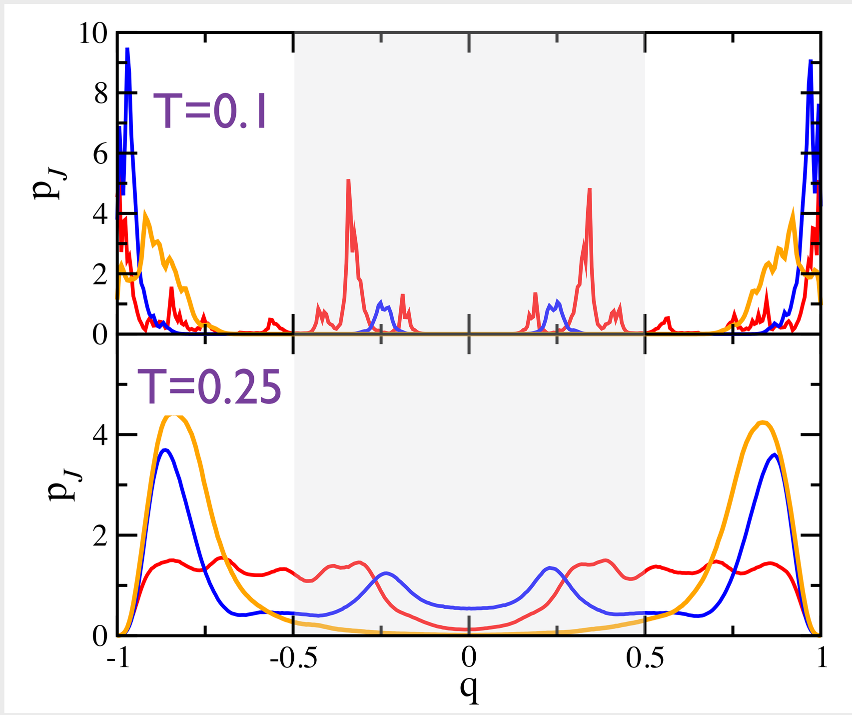
Diversity in SGs?

We measure the Edwards-Anderson overlap parameter

$$q = N^{-1} \sum_j \sigma_j^{(1)} \sigma_j^{(2)},$$

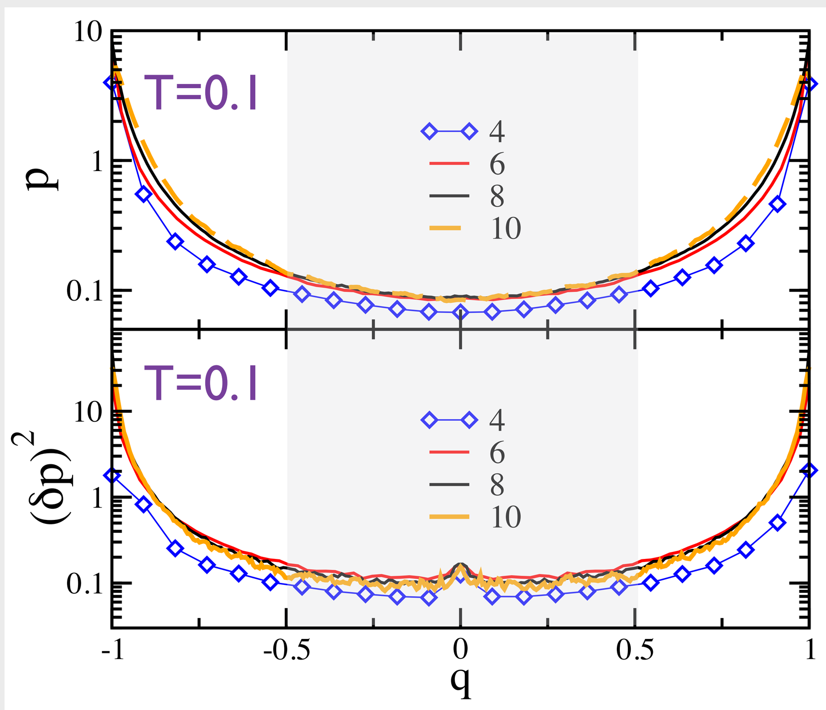
where $\sigma_j^{(1)}$ and $\sigma_j^{(2)}$ are the spins on site *j* of identical replicas *(1)* and *(2)* of a given sample $\mathcal{J}$.

For each sample $\mathcal{J}$ we compute the overlap probability distribution $p_{\mathcal{J}}(q)$:



We find spiky distributions that are strongly sample-dependent. We study sample-to-sample fluctuations. In particular, the deviations of $p_{\mathcal{J}}(q)$ from the average $p(q)$,

$$\delta p(q)^2 = [\ \{p_{\mathcal{J}}(q) - p(q)\}^2\ ]_{\mathcal{J}}$$



We find $p(q) \neq 0$ for $q \in (-Q, Q)$ with $Q \sim 1/2$. (This central region stands for overlaps between states of different basins of attraction). This result is in contradiction with *Dp*.

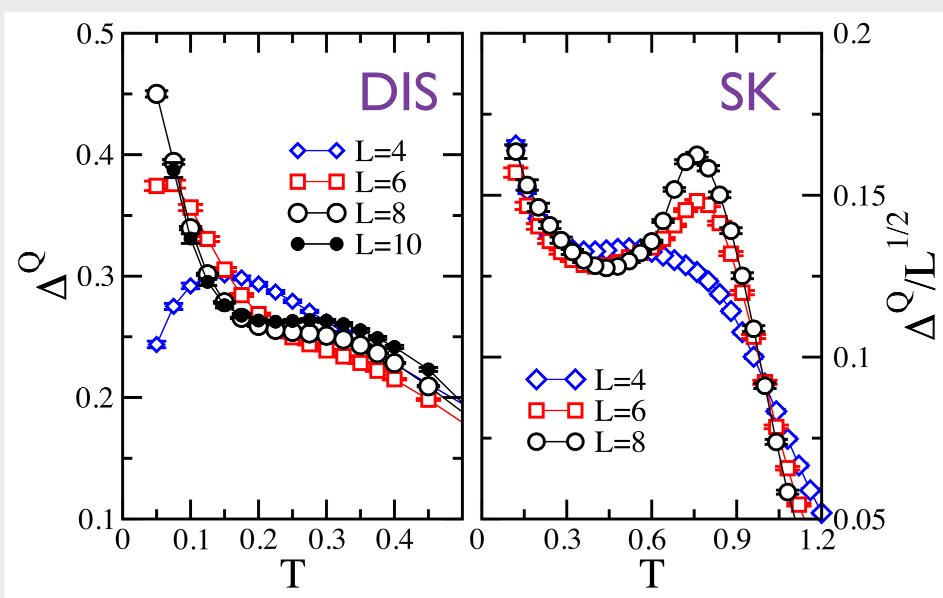
Strikingly, $\delta p(q)^2$ do not grow with *L*, in contradiction with *RSBp*. For SK one expects many sharp spikes that become δ-like functions as L increases: a diverging diversity.

Cross-overlap spikes

We focus on spikes situated on $q \in (-Q, Q)$. We compute

$$X_{\mathcal{J}}^Q = \int_{-Q}^{Q} p_{\mathcal{J}}(q)dq,\ \ \Delta_{\mathcal{J}}^Q = \Big(\int_{-Q}^{Q} \{p_{\mathcal{J}}(q) - p(q)\}^2 dq \Big)^{1/2}$$

We find that *X^Q* does not change with *L* at low temperatures, in agreement with *RSBp*.



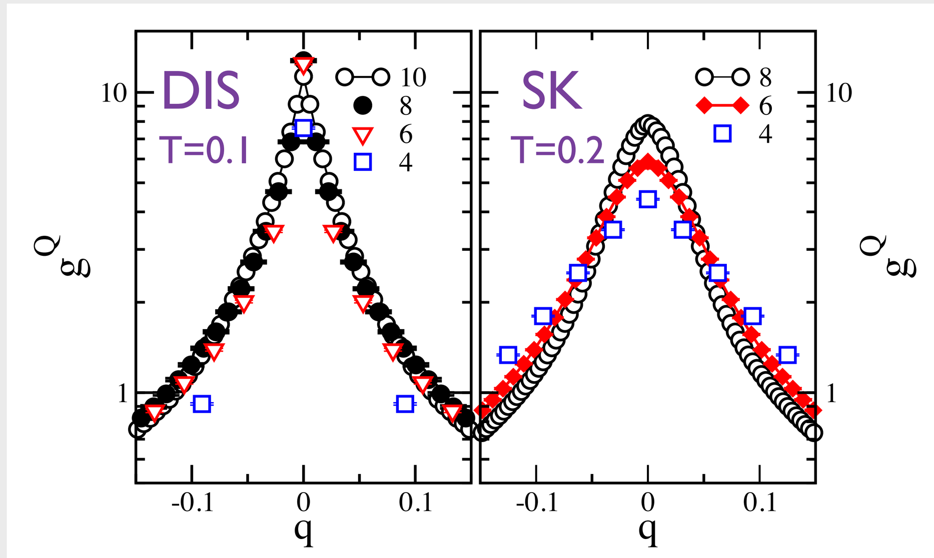
On the contrary, we find that *Δ^Q* does not diverge as L increases. This is at odds with *RSBp* and in sharp contrast with results for the SK model, for which *Δ^Q* diverges as $L^{1/2}$.

Pair correlation function

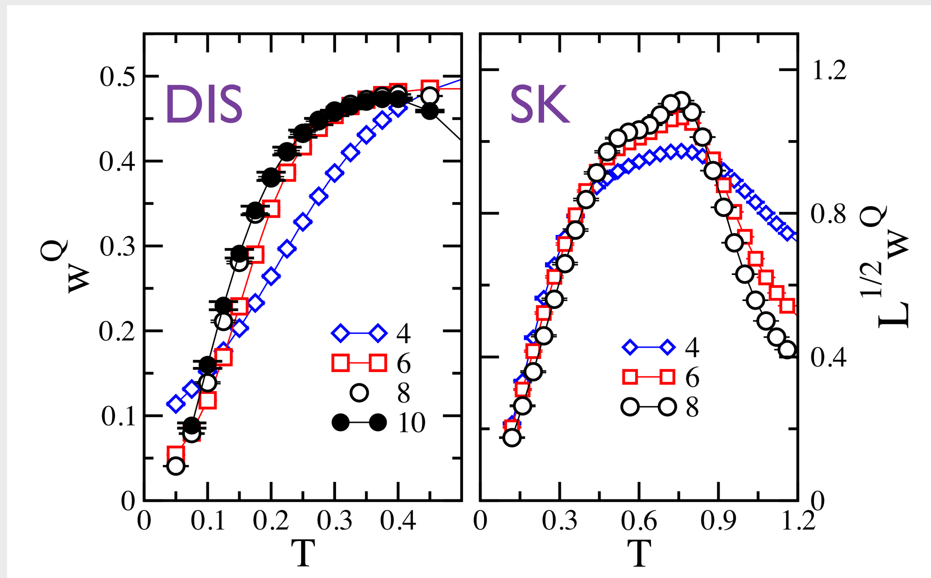
From a pair correlation function g^Q, we study the shape and average width of CO spikes:

$$g_{\mathcal{J}}^Q(q) = \int_0^Q \int_0^Q dq_1 dq_2\ \delta(q_2 - q_1 - q) f_{\mathcal{J}}(q_1, q_2),$$

where $f_{\mathcal{J}}(q_1, q_2) \equiv p_{\mathcal{J}}(q_1) p_{\mathcal{J}}(q_2)$.
$g^Q(q)$ is a conditional probability that *$q=q_2-q_1$*, given that *$q_1,q_2 \in (0,Q)$*. *It is also* a sort of average over all CO spikes.



A suitable width *w^Q* of *$g^Q(q)$ is* $w^Q = 1/g^Q(0)$, *which is a measure of pattern thermal fluctuations.*

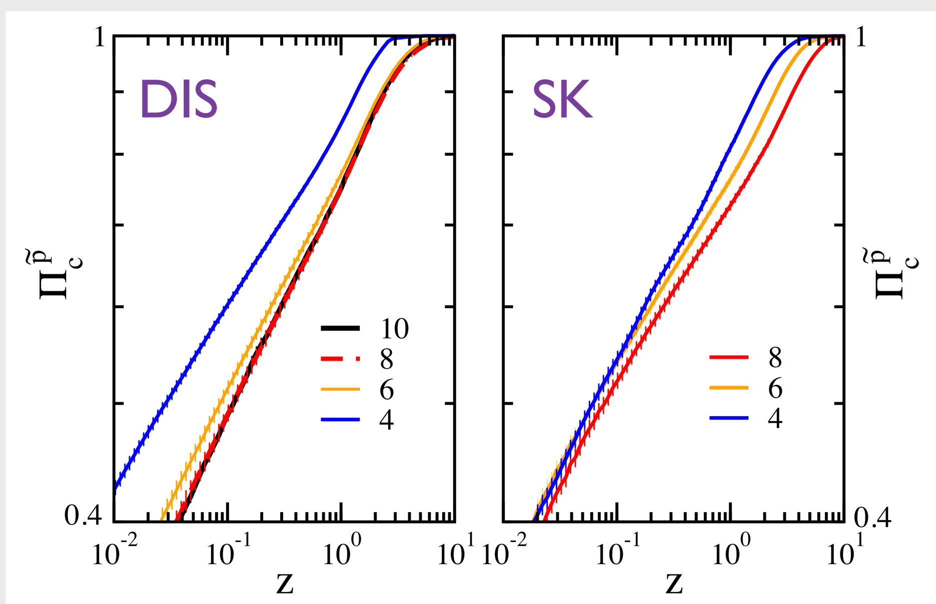


We find *$g^Q(q)$* curves rather pointed with widths smaller than *Q*. For DIS, there is no significant size dependence: *w^Q* appear to be size independent. In contrast, *w^Q* values for SK appear to vanish as $L^{-1/2}$ as L increases.

Cumulative distributions

We also study the height of CO spikes. For each sample we calculate $M_{\mathcal{J}}$, the maximum value of $p_{\mathcal{J}}(q)$ in *(-Q,Q).*

We compute $\Pi_c^{\tilde{p}}(z)$, the fraction of samples having $M_{\mathcal{J}} < z$. We find that, at least for $z > 0.5$, *high spikes* do proliferate *only* for the SK model, but not for DIS.



Conclusions

Using Monte Carlo simulations, we study the character of the spin-glass (SG) state of a site-diluted dipolar Ising model. At high dilution, well deep in the SG phase, we find spiky distributions that are strongly sample-dependent.

For the system sizes studied, the average width of spikes, and the fraction of samples with spikes higher than a certain threshold does not vary appreciably with system size. These results are at odds with crucial predictions of the droplet and RSB scenarios. Our findings are similar to the ones found for the short-ranged Edwards-Anderson model.

References: PRB **86**, 140402(R) (2012); PRB **87**, 134205 (2013); PRB **91**, 09446 (2015).

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