Scaling and dynamics in quantum spin chains with bond randomness

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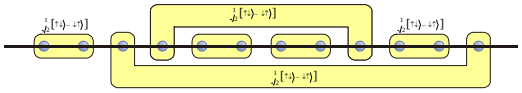
Random Singlet model and universality

$$\hat{H} = \sum_j J_i \vec{S}_j \vec{S}_{j+1} \qquad |J_i| > 0, \langle J_i \rangle = J$$

- The **S=1/2** spin chain is **critical** in the absence of disorder.
- Disorder is **relevant** in low-dimensional systems.
- Regardless of the details or strength of disorder, the low-energy properties of random-bond spin chains are as those in the **infinitely** disordered Random Singlet state:



- Abundant weakly coupled large-scale singlets
- Divergent density of states at **ω→0**: **n(ω)~1/ωln³ω**
- Universal scaling laws:

$$\chi(T) = \frac{1}{T \ln^2(\Omega_0 / T)}$$

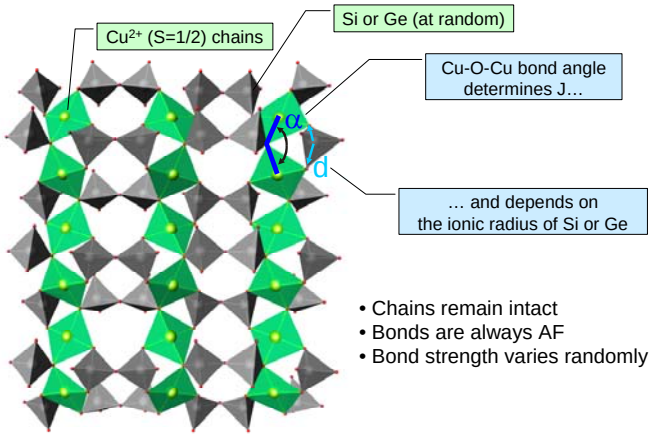
Doty, Fischer *et al.*, 1992-1995

$$S(q,\omega) = \frac{1}{\omega \ln^3(\Omega_0 / \omega)} F\left(|q - q_0| d \frac{\delta J}{J} \ln^2(\Omega_0 / \omega)\right)$$

K. Damle, O. Motrunich and D. Huse, PRL 84, 3434 (2000)

A family of model compounds

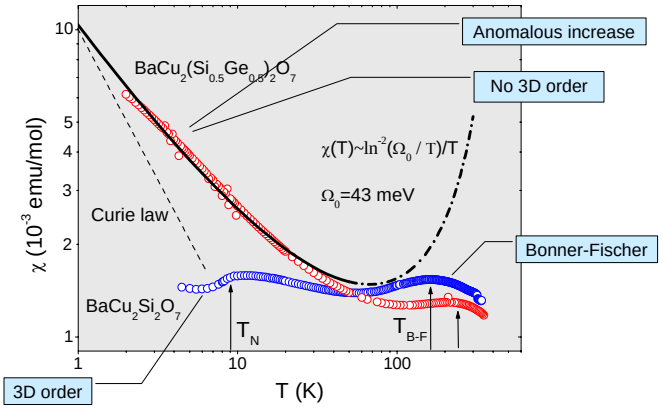
$BaCu_2(Si_xGe_{(1-x)})_2O_7$



- Chains remain intact
- Bonds are always AF
- Bond strength varies randomly

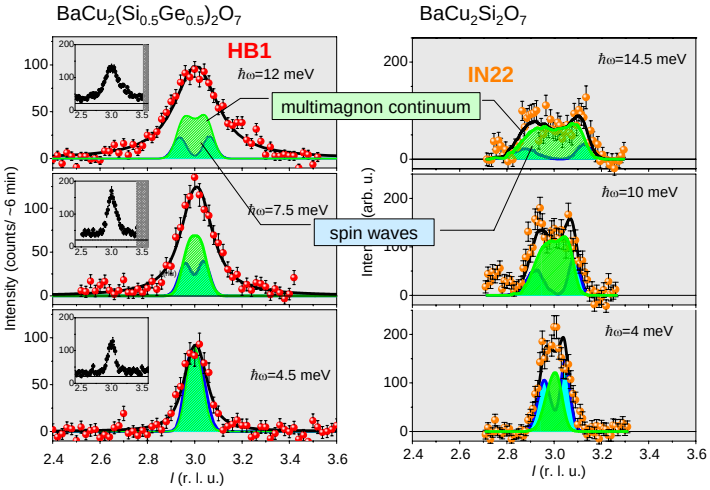
- **x=1** $BaCu_2Si_2O_7$: **J=24 meV** T_N**=9.2 K**
- **x=0** $BaCu_2Ge_2O_7$: **J=50 meV** T_N**=8.5 K**

X=0.5: bulk properties



- **χ(T)** increase observed in all **0<x<1** compounds.
- Can be explained by divergent **n(ω)** in random chains.

Nature of spin excitations

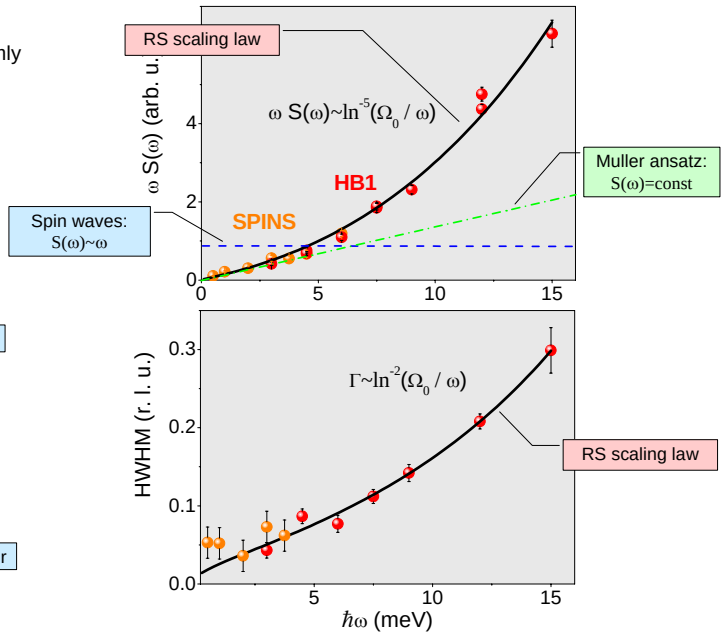


- Broad Lorentzian shape
- Spread over entire zone
- **Diffusive** propagation of **local excitations**
- Width determined by size of excitations

- Typical "top hat" shape
- Confined to the **ħω>|q|v** cone
- **Coherent** propagation of **quasiparticles**
- Width determined by dispersion relation

Scaling of the dynamic structure factor

- q-integrated intensity **increases** with energy!



- Scaling of HWHM allows to estimate **δJ~1 meV**

Conclusion

quenched disorder + quantum critical spin state

=

universal scaling of spin dynamics

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