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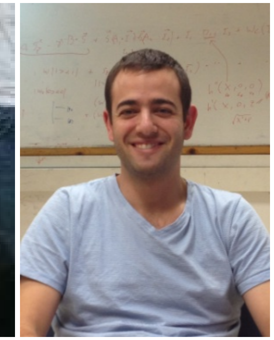


Yahel Guberman

EQuaM Proposal

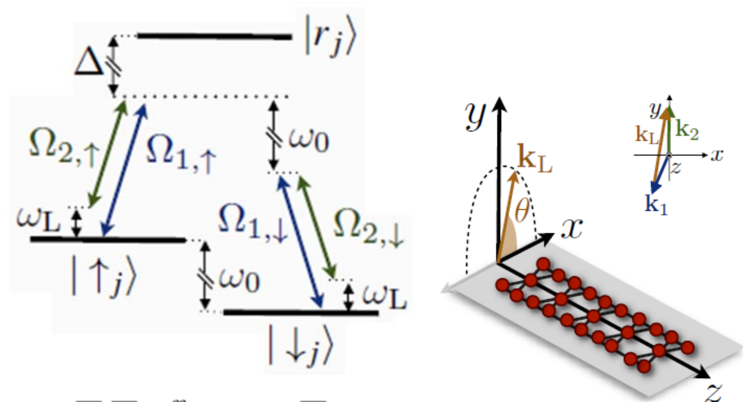
The Hebrew University of Jerusalem

Expertise: Theory of trapped Ions and NV centers

Vienna 4.11.2013

1. Quantum Ising Model in Trapped Ions
Bermudez *et al.*

D2.2, D2.3 the effective Hamiltonian



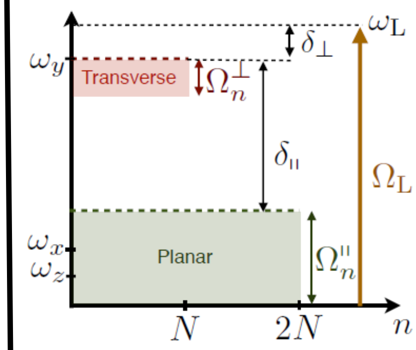
$$H_{\rm eff} = \sum_i \sum_{j\neq i} J_{ij}^{\rm eff} \sigma_i^z \sigma_j^z - h \sum_i \sigma_i^x$$

J1-J2 model

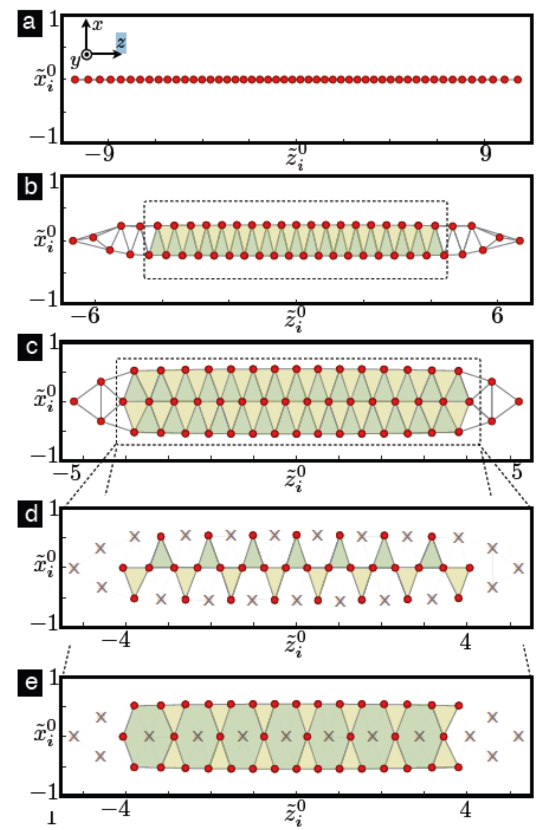
$$J_{ij}^{\rm eff} = -\sum_n \frac{\Omega_L^2 k_L^2 \sin^2\theta}{8m\Omega_n^{\perp}\delta_{n\perp}} \mathscr{M}_{in}^{\perp}\mathscr{M}_{jn}^{\perp}\cos(\mathbf{k}_L\cdot\mathbf{r}_{ij}^0) \propto \frac{\cos\phi_{ij}}{|\tilde{\mathbf{r}}_i^0 - \tilde{\mathbf{r}}_j^0|^3}$$

Ion lattice formation

$$H = \sum_{i=1}^{N} \sum_{\alpha=x,y,z} \left(\frac{1}{2m} p_{i\alpha}^2 + \frac{1}{2} m\omega_\alpha^2 r_{i\alpha}^2 \right) + \frac{e^2}{2} \sum_i \sum_{j\neq i} \frac{1}{|\mathbf{r}_i - \mathbf{r}_j|}$$



$$\omega_y \gg \omega_x, \omega_z$$

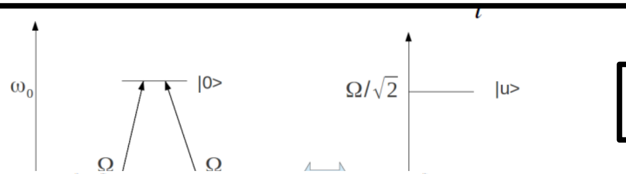


D1.1 - Noise sources:

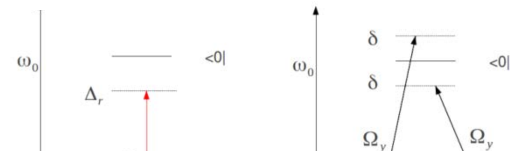
1. Dephasing due to magnetic field and Rabi Frequencies fluctuations. Dynamical decoupling techniques and decoherence-free subspace.
2. Ion's micro motion
3. Thermal motion
4. Spontaneous photon scattering
5. Inhomogenities due to spatial dependence of the laser-beam.

2. One-spin XXZ antiferromagnets in trapped ions

$$H=\sum_i S_x^i S_x^{i+1}+S_y^i S_y^{i+1}+\lambda S_z^i S_z^{i+1}+D\left(S_z^i\right)^2$$



D2.2,D2.3



D2.2) Small-scale emulation of competing interactions on different lengths scales: theory and experiment:

D2.3) Tuning of dipolar interactions and their characterization: theory and experiment: UNIULM (6 man months): Tuning of dipole-dipole interactions between electronic and nuclear spins. Magnitude and sign control in the parameters of the long-range quantum XXZ Hamiltonian. JGUM (4 man months), HUJI (4 man months), UNIULM (4 man months): Design, development and demonstration of a improved planar traps with integrated wire patterns and emulation of the Ising model in transverse field with long-range interactions. [month 30]

H_{XY}

24 months

$$J_{ij}^{eff}=\left(\frac{\Omega}{2}\right)^2\sum n_{i\alpha}^{\alpha}n_{j\alpha}^{\alpha}\frac{2\nu_n^{\alpha}}{\ldots}\propto\left|\vec{r}_i^{\,0}-\vec{r}_j^{\,0}\right|^{-\alpha}$$

$\sin^2\theta\Big)\left(S_z^i\right)^2$

D1.1) Theoretical assessment of realistic conditions for the emulation of spin models: Description: HUJI (12 man months): schemes to reduce the fluctuations using dynamical decoupling. Schemes for disorder and imperfections suppression.

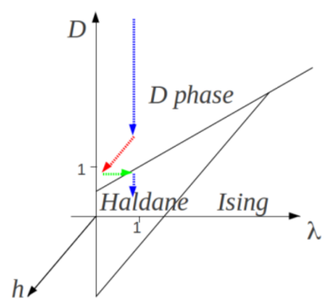
D2.6) Analysis of entanglement entropies and entanglement spectra in frustrated systems with long-range interactions. Comparison with expriments: UNIULM (12 man months), JGUM (8 man months), HUJI (8 man months), ICFO (8 man months), UNISA (8 man months): Experimental realization of quantum registers of N centres coupled to a few nuclear spins, six-ion quantum register in corner- and bond-sharing triangular lattices. Reconstruction of local density matrices. Scaling of the entanglement entropies from data sets. [month 36]

6months

$S\rangle=0$

Reaching the Haldane ground state adiabatically

$$H_{pert}=-h\sum_i(-1)^i S_z^i$$



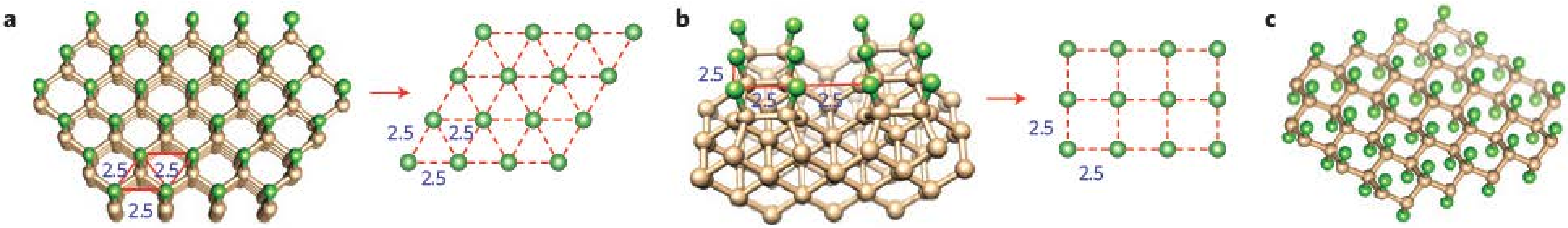
D2.6 the Haldane GS signatures

1. Exponentially decaying Correlation functions
2. non-local String order
3. Double-degenerate entanglement spectrum

D>1 area-law

Collaboration HUJI and ULM

3. Half-spin XXZ antiferromagnets in nuclear spins on a fluorine-terminated diamond surface, using NV centers for manipulation

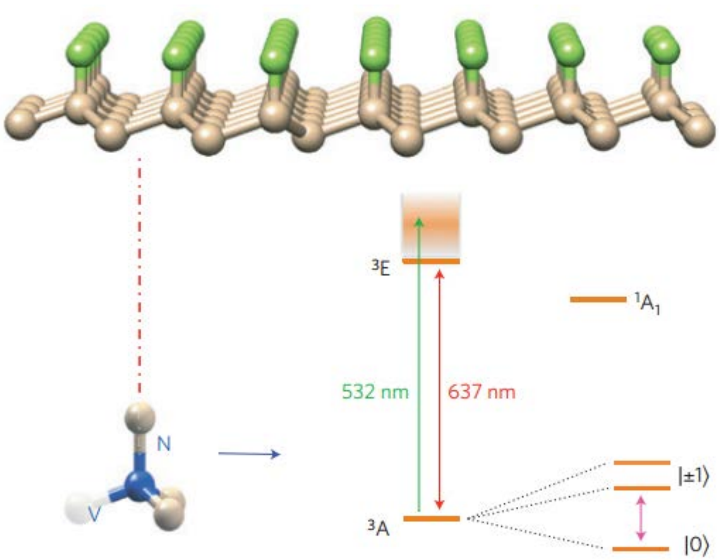


$$H = H_{\rm nv}^{\rm gs} + H_{\rm F} + H_{\rm NV-F}$$

$$H_{\rm nv}^{\rm gs} = \frac{\omega_{\rm nv}}{2}\sigma_z \Rightarrow H_{\rm nv}^{\rm eff} = \frac{\Omega_{\rm nv}}{2}\sigma_x$$

$$H_{\rm F} = \sum_i \gamma_N {\rm B} s_i^z + \frac{\mu_0}{4\pi}\sum_{i,j}\frac{\gamma_N^2}{r_{ij}^3}\left[{\rm s}_i\cdot{\rm s}_j - 3\left({\rm s}\cdot\hat{\rm r}_{ij}\right)\left({\rm s}_j\cdot\hat{\rm r}_{ij}\right)\right]$$

$$H_{\rm NV-F} = \frac{\mu_0}{4\pi}\sum_i \frac{\gamma_e\gamma_N}{r_i^3}\left[{\bf S}\cdot{\rm s}_i - 3\left({\bf S}\cdot\hat{r}\right)\left({\rm s}_i\cdot\hat{r}\right)\right]$$



Collaboration HUJI and ULM

3. Half-spin XXZ antiferromagnets in nuclear spins on a fluorine-terminated diamond surface, using NV centers for manipulation

QSim Hamiltonian

$$2\Omega_F \cos\left[(\gamma_N \mathrm{B} - \omega_F)t\right] \sum_i \mathrm{s}_i^x$$

Magnetic dipole-dipole interaction

$$V_{ij} = g(\mathbf{r}_{ij})\left[\mathbf{s}_i^z \mathbf{s}_j^z - \Delta\left(\mathbf{s}_i^x \mathbf{s}_j^x + \mathbf{s}_i^y \mathbf{s}_j^y\right)\right]$$

$$g(\mathbf{r}_{ij}) = g(r_{ij})(1 - 3\cos^2\theta_{ij})$$

Measuring and Cooling

$$\Omega_{\mathrm{p}}\{\sum_i \cos(\omega_{\mathrm{rf}}t)\mathrm{s}_i^x + \sin(\omega_{\mathrm{rf}}t)\mathrm{s}_i^y\} \quad \omega_{\mathrm{rf}} = \gamma_N \mathrm{B} - \Delta_{\mathrm{p}}$$

Non-interacting Hamiltonian

Hartmann-Hahn spin locking technique

$$H_{\mathrm{p}}^{(2)} = \frac{\omega_{\mathrm{nv}}}{2}\sigma_x + \omega_{\mathrm{f}}\sum_i \tilde{\mathrm{s}}_i^z + \sum_i g_i^{\|}\tilde{\mathrm{s}}_i^z + \sum_i g_i^{\perp}\left(\sigma_{(x)}^+ \tilde{\mathrm{s}}_i^- + h.c\right)$$

J_1-J_2 model

^{13}C impurities noise – D1.1

continuous wave decoupling techniques

Other noise sources in the system – D3.1

D1.1) Theoretical assessment of realistic conditions for the emulation of spin models: Description: HUJI (12 man months): schemes to reduce the fluctuations using dynamical decoupling. Schemes for disorder and imperfections suppression.

D3.1) Optimized schemes for noise and decoherence control (all partners): UNIHAMBURG (16 man months), CNR-INO (16 man months), UNIWIEN (8 man months), JGUM (8 man months), HUJI (12 man months), UNIULM (12 man months), UNISA (8 man months): Development of methods for the understanding and the control of the different sources of noise in all the experimental platforms within the consortium. [month 18]

Summary

D1.1,D3.1 – noise treatment

<u>accomplished:</u>

1. Decoupling from the main noise sources in the Haldane model - the fluctuations in the magnetic field and Rabi frequencies .

2. Decoupling from the noise from the impurities in the nuclear spin model.

<u>yet to be done:</u>

1. Solutions for the other noise sources in both models,
especially, for the main noise sources in the nuclear spin model.

MS15	Transfer of ideas of decoherence free subspaces and dynamical decoupling between different quantum s

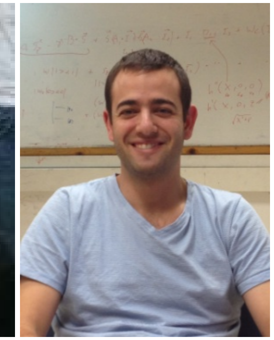
D2.2 – Designing long range interactions.

D2.3 – Tunable power law parameter. It could be done in the trapped ions model.

D2.6 - Analysis of entanglement entropies and entanglement spectra.

We showed several signatures of the Haldane phase, and of the spin liquid phase (d>1).
Based on experimental data, we will have more entanglement signatures,
so we could think about other ways to improve the tomography.

MS17	Theoretical support for analysis of local density matrices and entanglement properties in experiment



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Thanks!

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