QSS23 - Martin Plenio - Questions & Answers

Martin Plenio

Is Sotheby's really a good place to buy a diamond for these applications? Or more technically, could you do these things with natural diamonds, or is it really important to work with factory-produced diamonds with a small number of highly-controlled defects ?

MARTIN: No, Sotheby's is NOT a good place to buy diamonds for quantum technology applications. In principle a natural diamond might be used in some applications, e.g. nanodiamonds, but for high end quantum technology applications it is best to use specially grown diamonds as this allows to include desirable specifications such as changes in the 13C isotope content etc.

In terms of controlling spin dynamics, how important is it to be able to engineer a regular arrangement of either nuclear spins or electron spins? On the many-body side, are we restricted to dynamics of disordered systems (and if so, is this perhaps anyway a feature?)

MARTIN: It all depends on the applications. If you wish to create a quantum gate between the electron spin of an NV center and a nuclear spin in a spin register you would have to ensure that their distance is not too large while there should not be too many nuclear spins near the target nucleus in order to make selective addressing easier. Typically, also the coherence times of the NV center are better when there are not too many impurities around, either in the diamond or on the diamond surface, as these create magnetic noise. On the many body side in principle a nuclear spin lattice on a diamond surface can be very regular as each carbon atom on the surface can bind to exactly one fluorine atom. A challenge is to ensure that there are not too many missing atoms in the lattice but the achievable percentage of coverage should be sufficient to observe phase transitions.

What are in your opinion the perspectives for getting NV center experiments out of the lab and into practical applications, given that the environment does need to be rather well controlled? In particular, how does an NV center compare to a hot vapor cell of (say) Rb atoms?

MARTIN: There are very good perspectives for moving NV diamond into real world applications. In fact, a variety of companies are pursuing such goals, both established global players and smaller start-ups. These applications are most likely in the field of sensing and medical imaging. Hot vapour cells are amazing magnetic field sensors. There are a variety of differences though. Vapour cells typically require magnetic shielding and it seems difficult to miniaturise them to a degree that is possible with colour centers in diamond. As usual with these things each technology will be best suited for specific application areas.

How are you planning to interrogate the surface spin lattice using an NV center and you compared this to NMR machines. How does the NV center compare to magnetic resonance force microscopy (MRFM) where a little magnet stuck to an AFM tip is brought close.

MARTIN: The surface spin lattice would be interrogated via an NV center that is situated close to the diamond surface, less than 10nm below. Magnetic resonance force microscopy might be feasible in principle but it seems technically harder to control than an NV just below the surface. I also suspect that the sensitivity of the NV center will be better in this case.

Tatiane Pereira dos Santos: What are the current difficulties for the realization of single spin control? Could you talk a bit more about it?

MARTIN: One challenge is the deterministic generation of single NV spins in a diamond which is, in essence, a material science problem. For NV centers close to the diamond surface, noise that originates from impurities on the diamond surface is not well understood and represents a challenge for dynamical decoupling schemes. In a variety of low temperature applications as well as biological sensing applications spin control has to be achieved under energy constraints as cooling power is limited or we simply want to avoid to much heating due to absorption.

Sashank Kaushik: Is there a way to change the lattice configuration here to accomodate different topologies of the spin connectivity?

MARTIN: Here we are a bit limited as the topologies are mainly given by the diamond surface, so we can envisage triangular lattices, square lattices and perhaps hexagonal lattice structures. But going beyond that becomes tricky.

Antonio Negretti: With regard to the second part on quantum simulation: Apart from the room-temperature feature, compared to Rydberg or dipolar simulators, what is the real advantage to use NV-centers simulators compared to those systems?

MARTIN: No trapping potentials are needed, the simulator is quite stable physically, no ultralow temperatures or vacuum is needed.

Xueyue Sherry Zhang: Thanks for the wonderful talk. I'm wondering what would be the limit for the system size of 2d spin simulation and also whether the the disorder would influence the physics.

MARTIN: The disorder would certainly affect the physics but this may be interesting in itself. In principle one could envisage 2d lattices with millions of nuclei. But we should not forget that we also need to control these spins, i.e. we need to cool them to a low entropy state and read them out. An NV center at a depth of, say, 5nm would see a lattice of size of order 5x5nm ie about 400 nuclei. Much bigger than that may require new ideas for control.

Iñigo Arrazolacan: You aim to initialize in a product state that does not correspond to all spins pointing "down"?

MARTIN: This would be quite hard to do. The spins in the simulator are very close together, having a distance of about 0.25nm. I order to make them distinguishable we would need either very sophisticated pulse sequences or strong magnetic field gradients. Hence, we tend to envisage more global control.

Neda Bathaee: Can one use this NV-center configuration for holonomic universal quantum gate?

MARTIN: I think that this may indeed be possible. Certainly people are exploring geometric phases in NV centers and I believe that that there are proposals for holonomic universal quantum gates in spin systems that are equivalent to NV center electron spin.