QSS15 - Ana Maria Rey - Questions & Answers

Ana Maria Rey

Bill Phillips: There is another kind of boson-mediated interaction, when, for example, a gas of fermions is embedded in a gas of bosons. Could you comment?

ANA MARIA: Yes, that is correct. In this case I believe however the range of the interactions can not be all to all and instead set by the dispersion relation of the particles that are mediating the interactions. An example of that type are RKKY interactions: spin spin interactions between localized magnetic moments mediated by conducting electrons. They decay as $1/r^3$.

Bill Phillips: In the Toronto expt. you characterized the weak interaction as being long range because the spatial wavefunction is delocalized, but it is still a contact interaction. Could you say more about this?

ANA MARIA: Yes, that is correct. I am using just using a delocalized basis to write the interactions. Think about momentum eigenstates. Even with contact interactions a particle in a momentum eigenstate |k> can interact with a particle with any other momentum eigenstate |q>.

If we have long-range interactions because we have a weak contact interaction and the atoms are delocalised, what does that mean for the timescales in the system? How hard is it to avoid decoherence on the relevant timescales, and what is the maximum "size" of the system that you can reach this way?

ANA MARIA: The key assumption is that particles do not change their quantum state during a collision. For example if a particle in momentum k, collides with a particle with momentum q, the basic idea is that the particles can exchange their momenta o remain in the same states (at a rate $\gamma_{ex}=\hbar$ n a/m, here is the n density, a scattering length, m: mass) but do not scatter to new momentum states |k+k'> and |q-k'> which happens at a rate $\gamma_t \sim n\, a^2\, v$ (n density, a scattering length , v : thermal velocity). At times $1/\gamma_t$ the model breaks down. But this time scale can be much longer than $1/\text{gamma}_{ex}$. Working at a very low scattering length always helps. Also quantum statistics helps since it can block mode changing processes.

Yu-Ting Chen: I'm curious about the connection between this kind of long range Hamiltonian to biological systems. There is a model called the Hopfield model that describes memory formation with a long-range Ising model. I'm curious if this research can help address those problems?

ANA MARIA: Unfortunately I do not know the answer to this question. What I can point out is Ref. https://journals.aps.org/pra/abstract/10.1103/PhysRevA.87.042101 where we find analytic solutions to the dynamics of long range Ising models.

Yu-Ting Chen: It is interesting that when putting all kinds of dynamics together, there is a new viewpoint to see it as a dynamical phase transition and connected to the Lipkin-Meshkov-Glick model. So far, it seems like each type of the dynamics itself has been studied before in similar cavity QED. I'm curious if there are other new kinds of dynamics that can be seen in this setup?

ANA MARIA: That is great question. The answer is yes. For example in the cavity system if instead of working with two level atoms you work with multilevel atoms (e.g 87 Sr) and also use both polarization of the cavity, the models that result are much more complicated and to our knowledge have not been studied before. We are trying to look into this direction.

W. Vincent Liu: For the spin model, it seems the spin exchange is over all sites? Is the theoretical calculation obtained for 1D?

ANA MARIA: Yes, the Hamiltonian is $\sum_{i,j} J_{i,j} \vec{s}_i \cdot \vec{s}_j$. The theory calculations were done in 3D. I showed the 1D Lax analysis just because this is the limit where we can get an analytic solution. But for comparisons with experiment we had to go to 3D.

Gal Ness: I have a question regarding the Thywissen experiment. The introduction of the intermediate "pi pulse" by virtue of flipping the scattering length offers a "first-order" correction to the dephasing. What could we learn from higher-order techniques of dynamical-decoupling, like those used in NMR experiments?

ANA MARIA: Yes, correct. I am sure dynamical-decoupling will be useful to remove dephasing if that were the goal.

Bill Phillips: Thinking about the Toronto experiment and the phase transition between retaining magnetization and having it decay, the picture was of an effective field about which dephasing spins would precess, retaining their magnetization. Is there a way to understand that this (or other interactions) lead to a phase transition as opposed to a crossover?

ANA MARIA: Actually this is not a trivial question. We know there is a phase transition because the model is integrable, we can compute the dynamics and prove there is indeed non-analytic behavior of the order parameter at the critical point. If you change us the underlying model I will not be able to guarantee there is a phase transition instead of a cross over.

Also, in a Harmonic trap, the interaction strength should decrease (slowly) with the difference in harmonic oscillator quantum number n. If you use this way to create very long-range interactions, to what extent it is important in the resulting dynamics that this is not an exactly all-to-all interaction?

ANA MARIA: We can solve the dynamics with the actual inhomogeneous couplings numerically and what we see is that the inhomogeneity shifts the actual value of the critical point and introduces a bit of broadening. In other words the transition is not as sharp as the homogeneous case.

Could you say more about which of the systems are most promising for robust generation of entangled states? For a lattice clock, how would you set this up? In individual 3D lattice, or with harmonic traps with multiple atoms as you discussed before? And are there opportunities to have long-lived states on a scale of the normal interaction time for lattice clocks

ANA MARIA: Yes, we are thinking about the Hubbard model in a 3D lattice. Jun Ye's current 3D optical lattice clock provides the perfect system. We want to operate in the weak lattice limit where particles can tunnel. This is also important to avoid light scattering from the lattice beams. Yes, even though you might think that tunneling will generate Doppler shifts the gap protection generated by interactions can prevent the associated dephasing. We believe this set up could be used to generate spin squeezing and even cat states in the clock. Please look at https://journals.aps.org/prresearch/abstract/10.1103/PhysRevResearch.1.033075