Ultrafast phenomena in correlated quantum matter

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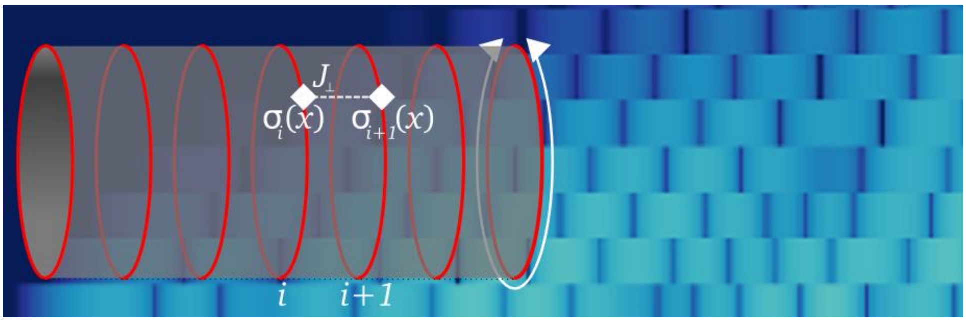

Project highlights:

1. Simulate cutting-edge experiments on quantum materials by developing new theoretical physics tools.
2. Investigate the properties of new quantum states of matter that don't occur in equilibrium, and compare results with experiment and other theory methods.
3. Use and develop skills in theoretical physics, numerical methods and programming that are applicable in academia and the tech industry.
4. Collaborate with theoretical and experimental physicists at a US national laboratory.

Project description:
The latest experimental synchrotron facilities with 'free electron lasers' allow for time resolved studies of non-equilibrium quantum matter. In ultrafast pump-probe experiments an intense but ultra-short femtosecond laser pulse is used to 'pump' a quantum material, exciting it and shifting it far from its ordinary equilibrium state. This is followed by 'probing' the system using x-rays to study its behaviour and how it relaxes to a new equilibrium state.

Such experiments have already been used to engineer and control non-equilibrium states that have desirable properties like superconductivity. They also act as a microscope for studying the fundamental dynamics of many-body quantum systems. This is particularly interesting for correlated quantum systems, where the interactions between degrees of freedom (particles or quantum spins) are non-negligible, and behaviour can be strange and unexpected, even in equilibrium.

However, theoretical physics tools to study these complicated time dependent phenomena in correlated quantum matter are still lacking, making the interpretation of experimental results difficult.

This project aims to address this absence of understanding, by developing a set of numerical tools, based on matrix product state and tensor network methods, that can accurately and efficiently simulate ultrafast pump-probe experiments on correlated quantum magnets. A key aim is to understand the large system 'thermodynamic' limit (representative of the samples studied) and two-dimensional materials.

As well as developing these tools, it will be important to benchmark them on small systems using exact methods, and to develop approximate theoretical models that describe the key physics. The models will then provide insight into the mechanisms behind the non-equilibrium physics and should in turn inform improvements in the efficiency and accuracy of the numerical methods.

A strong aptitude for theoretical physics, mathematics and programming are vital for this project. Experience with c++, python, and linux/unix are highly desirable.

References:

1. Laser-induced transient magnons in Sr3Ir2O7 throughout the Brillouin zone DG Mazzone, et al. Proceedings of the National Academy of Sciences 118 (22)
2. Quantum quenches in two spatial dimensions using chain array matrix product states AJA James, RM Konik Physical Review B 92 (16), 161111(R)
3. Nonthermal states arising from confinement in one and two dimensions AJA James, RM Konik, NJ Robinson Physical Review Letters 122 (13), 130603

Further reading:

4. M Mitrano, Y Wang, Probing light-driven quantum materials with ultrafast resonant inelastic X-ray scattering. Commun Phys 3, 184 (2020). https://doi.org/10.1038/s42005-020-00447-6
5. U. Schollwoeck, The density-matrix renormalization group in the age of matrix product states, https://arxiv.org/abs/1008.3477