Multiscale magnetization dynamics

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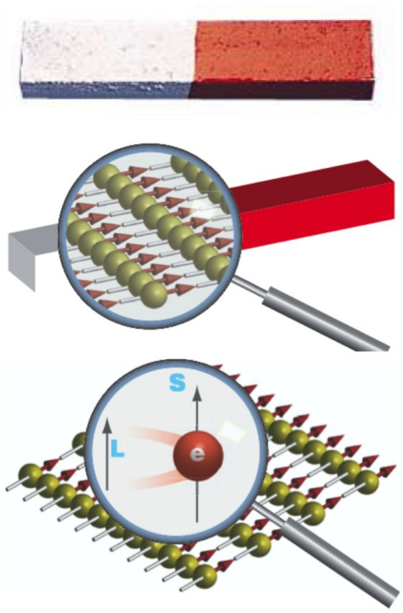
Magnetism is present in a wide range of materials, due to the long ranged ordering of atomic spins. Understanding and controlling the dynamics of magnets is of central importance, not only from a basic scientific point of view, where questions regarding the ultimate speed of a magnetic medium enter, but also for optimizing technological devices that store information in a magnetic medium (currently some 70 % of the world's accumulated information is stored magnetically). For this reason, both theoretical and experimental activities are focused on magnetization dynamics (for a review of this see Ref1). Often the investigations involve manipulation of magnetism that is done via spin-polarised electrical currents, a field that in general is referred to as spintronics. Spin currents used in spintronics have the advantage to reduce the problem of heat generation associated with moving charges in conventional electronics. Therefore, spintronic devices are much more energy efficient and can be scaled to smaller dimensions without encountering a Joule heat catastrophe.



From top to bottom: continuum, atomistic and quantum scale spin dynamics.

The dynamics of the magnetization of a system can typically be resolved on three different scales as shown the figure above. On the shortest length and time scale – the *quantum* scale – the dynamics explicitly depends on the motion of the individual electrons within the system. Time-dependent density functional theory would be the most appropriate method for describing magnetization dynamics on this scale, but is very costly and at the moment can only be applied to very small systems (less than 10 atoms) during short times (femto-seconds). Over time, the largest fluctuations of the fast motion of the electrons average out, and the magnetization around each atom can be well approximated as a localized atomic spin moment, or more generally magnetic moment, that processes with a characteristic time in the pico- to nanosecond regime – the *atomic scale*. The dynamics of these spins is described by a coupled system of differential equations. The length-scale which is accessible here ranges from Ångström to fractions of micrometers, where the huge number of atoms start to make the simulations unaffordable. Finally, on the largest scale, which is of the order of micrometers and nano- to microseconds, the motions of the individual magnetic spins are averaged to form a continuous magnetization vector field –

the *continuum scale.* The dynamics in the continuum regime is typically determined by a combination of exchange interactions and classic magnetostatic dipole-dipole interactions. The dynamics of this vector field is modeled by a system of nonlinear partial differential equations. However, many phenomena in magnetization dynamics cannot be fully described within only one of these scales. For instance, in the case of a spintronic device, length and time scales belong to the continuum scale, but many of its features stem from the atomistic scale, e.g. interfaces of different materials, temperature induced atomistic fluctuations, defects etc.. Hence, the overall magnetization dynamics has a multiscale character, and one has to find methods that bridge over the three length scales outlined in the figure at the beginning of this proposal.

There is an ongoing effort for developing computational tools based on the multiscale description of magnetization, and it is especially needed to attack this scientific question in a cross-disciplinary approach. Involved in this proposoal are the materials theory division at physics, headed by prof Olle Eriksson, and Gunilla Kreiss, and her co-workers at the division of Scientific computing. The postdoc would be part of this interdisciplinary research environment. The aim of this project is to develop the multiscale computational methodology for specific multiscale phenomena. In the research there will be elements of developing models and understanding physics, mathematical and numerical analysis, and high performance computing.

Research questions:
To treat long-range dipolar interactions and couple Maxwell's equation to the atomistic spin dynamics equation and to couple spin currents that enter the equation of motion via spin-transfer torques, to a multiscale method that couples the continuum description and the atomistic description. Finally, successful implementations of the developed methodologies will be applied to analyze the dynamics of topological magnetic solitons, such as skyrmions.

The candidate needs a PhD in either physics or in scientific computing/computational mathematics, but with experience from 'the other' field.