Ultrafast coherent laser-spin interactions in nanoscale objects

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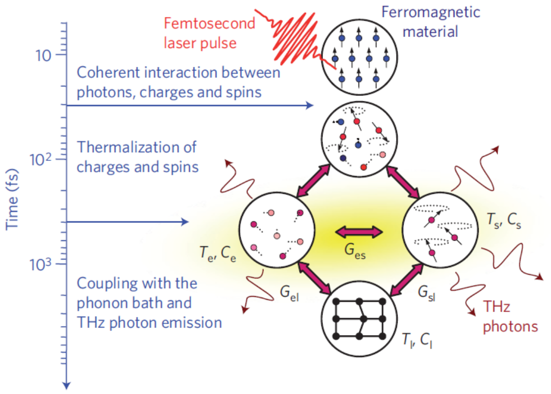
The proposed PhD project has the ambition of exploring theoretically the coherent dynamics of spins excited by intense and ultrashort laser pulses. It is at the interface of two major areas of physics, namely the magnetism of condensed-matter systems and relativistic quantum electrodynamics. This *a priori* unexpected link is particularly original and may lead to fundamental findings in the area of ultrafast phenomena.

The interaction of a femtosecond electromagnetic pulse with the electron spin in a ferromagnetic metal has been the object of intense investigations, both theoretical [1] and experimental [2], during the past fifteen years. The main effect that has been observed – though not yet fully elucidated – is the quick loss of magnetization following the excitation by a femtosecond laser pulse [3]. New experiments – carried out at the IPCMS in the team led by Dr. Jean-Yves Bigot – have given a new twist to this problem, with promising future developments, both theoretical and experimental.

These experiments have shown the existence of a coherent coupling between a femtosecond laser pulse and the magnetization of a ferromagnetic thin film [4]. The underlying interaction may involve a spin-orbit coupling (SOC) that goes beyond the usual one due to the ions electric field. In order to properly describe this additional SOC, one must take into account the material polarization induced by the laser pulse, which interacts coherently with the spins. This coherent mechanism is clearly distinguished from the incoherent ultrafast demagnetization associated with the thermalization of the spins [3].



Sequence of mechanisms in ultrafast magnetization dynamics, from Ref. [4].

In order to tackle this complex problem, we propose to develop a quantum-relativistic self-consistent model based on the Wigner phase-space distribution function. Compared to existing models incorporating spin effects [5], our approach will include relativistic corrections to higher order in 1/c [6], such as the standard spin-orbit interaction and higher-order coherent laser-spin coupling. This approach will provide a many-body model where both quantum-mechanical and relativistic effects coexist and should appear in a transparent fashion.

In addition, we will construct a hydrodynamic model based on the velocity moments of the Wigner equation. The hydrodynamic approach should lead to considerable gains in computing time in comparison with simulations based on conventional methods, such as DFT or Hartree-Fock.

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