

The magnetic side of light: a new degree of freedom in light-matter interactions

Light-matter interactions are often viewed as driven primarily by the electric field, with the magnetic component frequently overlooked. Yet the magnetic field is critical in many optical processes, including rare-earth ion energy schemes, highly nonlinear photon avalanching, chiral light-matter interactions, and quantum control of NV centers in sensing. **This seminar explores the magnetic component of light as a new degree of freedom in light-matter interactions.**

By engineering the spatial distributions of electric and magnetic fields in the intermediate field through **standing waves**¹ and in the near field through **localized plasmons**², we demonstrate selective control over the coupling of matter to either the electric or magnetic component of light, in both excitation and emission. Building on this, we study Tm³⁺-doped **avalanching nanoparticles**, which respond nonlinearly to both electric and magnetic components of the excitation³ and, like self-organized critical phenomena such as earthquakes or social revolutions, display avalanche-like behavior⁴. I will show the magnetic field's key role in the reversible optical control of criticality in a highly nonlinear system⁵, and in the counterintuitive luminescence behavior observed when the local density of optical states (LDOS) is modified⁶.

I will then show how the magnetic field is crucial for enhancing intrinsically weak **chiral light-matter interactions**, presenting high-refractive-index (Si) antennas and self-assembled DNA-based antennas⁷ that enable new detection schemes, pushing chiral sensing down to the single-molecule level. Finally, I will present a theoretical study of a new photonic antenna behaving like **a magnetic monopole**, operating from the visible down to GHz frequencies⁸, and discuss why controlling electric and magnetic fields at GHz matters for **NV-center quantum schemes**. Together, these results underscore the importance of controlling light's magnetic component across spatial and frequency scales for a wide range of applications.



Figure 1: (left) Standing wave generation with a SNOM set-up, allowing the controlled electric or magnetic excitation and emission. (center) Coupling between the matter and the magnetic part of the localized plasmon. (right) A newly designed antenna which behaves like a magnetic monopole. Credits: M. Mivelle.

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5. Reynier, B. et al. Optical Magnetic-Field-Gated Criticality in Photon Avalanching Quantum Processes. (in preparation).
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