école doctorale **sciences pour l'ingénieur et microtechniques** SPIM

Novel spin-orbital optical state in plasmonic nanostructures

Host research team:

FEMTO-ST Institute / Optics Department / Nano-optics team

Thesis supervisor:

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Fundings:

MESRI (French Ministry of research)

Start of the contract:

Around 1st October 2023

Application deadline:

7th June 2023

Scientific context and objective:

In addition to their energy and linear momentum, optical waves possess spin and orbital angular momentum (SAM and OAM), which are polarization and spatial degrees of freedom of light, respectively [1]. These components quantify the idea of rotation or helicity of light: the continuous polarization rotation of light carries the SAM, while the helical phase structure or field pattern rotation of light produces OAM [2]. Whereas these two components are independent in paraxial beams, they become intrinsically coupled in light fields with high nonparaxiality and/or inhomogeneity [2,3]. This phenomenon, called optical spin-orbit interaction (SOI) has recently attracted much attention from fundamental and application point-of-views [4-6]. The SOI phenomena play crucial roles in modern optics dealing with sub-wavelength scale systems, including nano-photonics and plasmonics [6-9].

Analogies between electronic and optical spin effects have recently been demonstrated. Numerous manifestations of electron spin-orbit coupling exist in magnetic materials, including nanoscale electron spin vortices called skyrmions [10]. Benefiting from a "topological protection", these modes are extremely robust to perturbations of their environment, making them very efficient for information processing, data storage, and many other applications. In 2018, the existence of a plasmonic analog of the magnetic skyrmions, called “optical skyrmions”, was shown for the first time [11]. Like their electronic counterpart, optical skyrmions are "topologically protected" and thus offers new prospects for classical and quantum information processing but also in the fields of metrology, subwavelength imaging, etc.

We propose the transposition to optics of another manifestation of spin-orbit coupling in magnetic materials. The objective is to demonstrate a new photonic state involving optical spin-orbit coupling in plasmonic nanoantennas. This new chiral electromagnetic mode opens new degrees of freedom in the manipulation of light and paves the way towards integrated classical and quantum “spin-optics”.

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[10] U. K. Rossler, A.N. Bogdanov, C. Pfleiderer, Spontaneous skyrmion ground states in magnetic metals. Nature 442, 797-801 (2006).

[11] Du, L., Yang, A., Zayats, A. V., & Yuan, X. (2019). Deep-subwavelength features of photonic skyrmions in a confined electromagnetic field with orbital angular momentum. *Nat. Physics*, *15*, 650.

Workplan:

- Bibliographic research
- Modeling of the plasmonic structures and numerical simulation of their optical properties (FDTD method mainly, commercial software)
- Fabrication of the systems in clean room by combining different technologies.
- Characterization of the intrinsic properties of the optical states. Implementation of "far field" techniques: imaging in the Fourier plane of a microscope objective and polarimetry. The nanostructures will be analyzed with an optical bench integrated to an inverse microscope and controlled with a computer (with Labview). The system is already operational.
- First manipulation of the new optical states, experimental demonstration.

Requested profile:

We are seeking a highly motivated student ready to invest in the field of subwavelength optics:

- Good university degree (Master level) in optics or nanotechnologies
- Advanced knowledge in nanophotonics and/or plasmonics
- Good level in physics
- Good experience or interest in numerical simulations (FDTD method will be used via commercial software) and experimental methods.
- Programming skills, especially with Octave/Matlab
- It is not necessary to have extensive knowledge in the field of magnetism.
- Good written and spoken English skills (French skills welcome)
- Good communication and information behavior, goal-oriented and structured way of working, initiative/commitment, ability to work in a team and willingness to cooperate as well as willingness to learn.

Bibliography of the host team related to the PhD:

Lefier, Y., & Grosjean, T. (2015). Unidirectional sub-diffraction waveguiding based on optical spin–orbit coupling in subwavelength plasmonic waveguides. *Opt. Lett.*, *40*, 2890.

Lefier, Y., Salut, R., Suarez, M. A., & Grosjean, T. (2018). Directing nanoscale optical flows by coupling photon spin to plasmon extrinsic angular momentum. *Nano Lett.*, *18*, 38.

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