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M. Fanciulli,[1, 2] M. Pancaldi,[3] E. Pedersoli,[3] M. Vimal,[1] D. Bresteau,[1] M. Luttmann,[1] D. De Angelis,[3] P. R. Ribic,[3] B. Rösner,[4] C. David,[4] C. Spezzani,[3] M. Manfredda,[3] R. Sousa,[5] I.-L. Prejbeanu,[5] L. Vila,[5] B. Dieny,[5] G. De Ninno,[3,6] F. Capotondi,[3] M. Sacchi,[7,8,*] and T. Ruchon[1]

[1] *LIDYL, Université Paris-Saclay, CEA, CNRS, 91191 Gif-sur-Yvette, France*
[2] *Laboratoire de Physique des Matériaux et Surfaces, CY Cergy Paris Université, 95031 Cergy-Pontoise, France*
[3] *Elettra-Sincrotrone Trieste S.C.p.A., 34149 Basovizza, Trieste, Italy*
[4] *Paul Scherrer Institut, 5232 Villigen, Switzerland*
[5] *IRIG-SPINTEC, Université Grenoble Alpes, CNRS, CEA, Grenoble INP, 38000 Grenoble, France*
[6] *Laboratory of Quantum Optics, University of Nova Gorica, 5001 Nova Gorica, Slovenia*
[7] *Institut des NanoSciences de Paris, CNRS, Sorbonne Université, 75005 Paris, France*
[8] *Synchrotron SOLEIL, L'Orme des Merisiers, Saint-Aubin, B.P.48, 91192 Gif-sur-Yvette, France*
[*] *maurizio.sacchi@synchrotron-soleil.fr*

Abstract: We report magnetic helicoidal dichroism (MHD) in the interaction between XUV beams carrying orbital angular momentum and magnetic vortices. The results match theoretical predictions and confirm the potential of MHD for studying laser-triggered ultrafast dynamics in complex magnetic materials. © 2022 The Authors.

The interaction of polarized light beams, ranging from infra-red to hard-x-rays, with magnetic materials defines the rich set of analytical tools used in magneto-optics and it is also widely employed for studying magnetization dynamics in time-resolved experiments. Light polarization is associated with a spin angular momentum (SAM) that, in $\hbar$ units, takes values S=0 for linear polarization and S=±1 for circular polarization, the latter imparting a well-defined handedness to the photon beam. It is less common to exploit the orbital angular momentum (OAM) of value L$\hbar$ carried by light beams characterized by a spiraling wavefront, also called light springs. The phase singularity at the center of the photon beam imposes a vanishing intensity on the axis, producing a characteristic donut shape. The quantified projection of the OAM along the propagation axis (L) can take any positive or negative integer value of $\hbar$, with a sign determined by the spiraling sense of the phase. This represents an important difference with respect to SAM, since OAM beams can carry and transfer a larger topological charge $|L|>1$, with additional potential for new kinds of light-matter interaction.

After finding many applications in the visible range [1,2], OAM beams with ultra-short pulse duration and XUV wavelengths became available recently at high-harmonic generation (HHG) and free-electron laser (FEL) sources [3,4], widening considerably the range of experiments that can be envisaged, notably in the field of spectroscopic applications.

We analyzed theoretically the interaction of OAM beams with magnetic structures featuring non-uniform magnetization, in particular of XUV beams with magnetic vortices consisting of a curling in-plane magnetization. We predicted that the far field intensity profile encodes the vortex symmetry in a way that depends on the sign and value of L, an effect deriving from the inhomogeneous modification of the regular reflectivity coefficients by the local magnetization. We named this effect Magnetic Helicoidal Dichroism (MHD) [5]. As for magnetic circular dichroism, MHD can be observed by inverting the sign of either the orbital momentum or of the magnetization, i.e. by switching the handedness of either the light spring or the magnetic vortex.

Understanding the interaction of OAM-light with a magnetic vortex has many potential interests. At the fundamental level, it allows to observe a new kind of dichroism, to study the role of photon spin-orbit coupling, as well as to explore new possibilities of angular momentum transfer between light and matter. In terms of applications, MHD in reflection can be exploited as a new spectroscopic tool joining the family of magnetic dichroism techniques. For their symmetry and size, magnetic vortices can be considered as an ideal benchmark sample to explore the interaction with OAM beams; moreover, given their rich dynamical response in the ultrafast domain, they are promising structure for light manipulation of the magnetization topology.

In this contribution we report on the first experimental evidence of MHD (see, e.g., Fig. 1) obtained at the DiProI station of the FERMI free-electron laser source by measuring the scattered intensity from an Fe-Ni-alloy dot forming a magnetic vortex. The photon energy of the ~100 fs long pulses was set to 52.8 eV (~23 nm wavelength) in order to match the Fe 3p→3d core resonance, enhancing magneto-optical effects at XUV wavelengths and providing element selectivity. The scattered intensity data collected as a function of L and of the magnetic vortex clockwise or anti-clockwise winding sense are compared to previous theoretical model predictions [5].

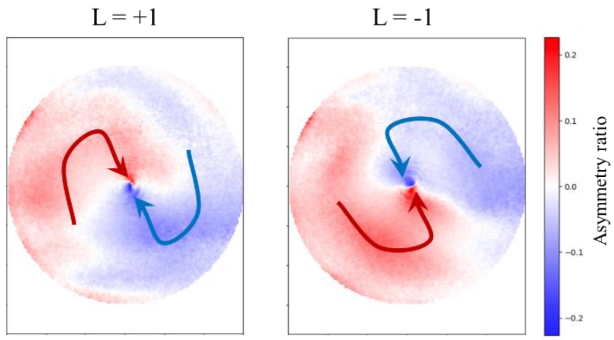

Figure 1. Example of magnetic helicoidal dichroism. For a given value L of the orbital angular momentum, the scattered intensity in the far field is collected for the two opposite winding senses of the vortex magnetization. Each panel represents, for a given L, the difference of the two intensity maps divided by their sum.

We show also how the short pulses of the free-electron laser OAM beam make it possible to follow the evolution of the magnetization topology at the sub-ps timescale after an optical excitation.

The obtained experimental results [6] match very well our theoretical predictions [5], confirming the potential of the new toolset provided by MHD for studying complex magnetic structures and, in particular, for addressing their laser-triggered ultrafast dynamics.

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