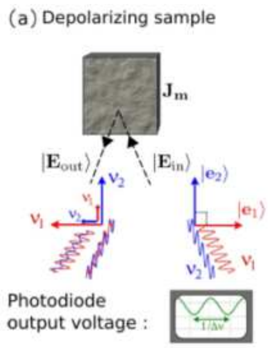
Advanced imaging

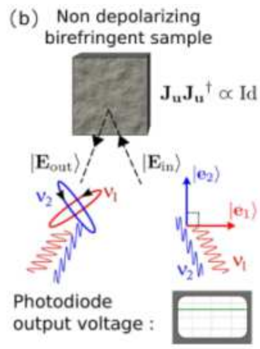
Within this research activity, the development and optimization of non-conventionnal techniques for **polarimetric imaging** (spectro-polarimetric imaging, microwave-photonics imaging …) and **ballistic photon imaging through diffusive media** provide tools to better understand light-matter interaction. These research activities are also studied in terms of biomedical applications in collaboration with biologists, in particular for **unconventional biological microscopy**. This research field falls within the dynamics of the "Images & Réseaux " (Images & Networks) international competitiveness cluster.

Non conventional polarimetric imaging techniques

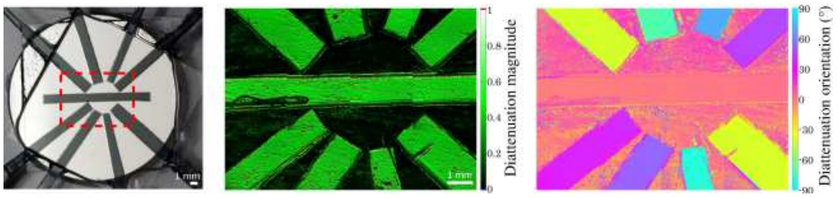
Polarimetric imaging aims at mapping informations on the polarization state of the light emitted by a scene, and it enables to obtain interesting physical contrasts which are able to complement those provided by conventional imaging. For that reason, this type of imaging has numerous applications in biomedical imaging, industry, teledetection, or also materials characterization. It is a central research topic amon the Advanced imaging activities.

- **Depolarisation/dichroism sensing by orthogonality breaking :** This new sensing modality proposed in 2011 in the FOTON-DOP team is inspired from microwave-photonics techniques, and enables a direct, rapid and highly sensitive measure of the depolarizing strength, and/or diattenuation coefficient of a sample. It relies on the preparation and use of a specific illumination beam, so as to shine the sampe to characterize with two optical waves of slightly different frequencies ν_1 and ν_2, and whose respective polarization states are arbitrary (not necessarily linear), but orthogonal to each other in a mathematical sense. When this beam interacts with a dichroic or purely depolarizing sample, the interference of the two fields at frequencies ν_1 and ν_2 yields a periodic modulation of the intensity measured on a photodetector at the frequency difference $\Delta\nu = |\nu_1 - \nu_2|$ between the two waves. The amplitude of this modulation informs on the depolarization strength, or on the diattenuation of the sample. Contrarily, interaction with a birefringent sample will not induce any « orthogonality breaking » : as a result, the technique is insensitive to birefringences and rotations of the polarization, and is thus highly adapted to remote measurement through fibers, paving the way for applications in polarimetric endoscopy. The first experimental validations of the technique, termed DSOB (Depolarization/Dichroism Sensing by Orthogonality Breaking) were carried out in the infrared [Fad12a] at 1.55 µm using a dual-frequency Er:Yb laser developed in the laboratory, and which intrinsically provides the illumination state required for the DSOB technique. In parallel, we have implemented this technique on a custom confocal microscopy setup with a visible dual-frequency source based on acousto-optic frequency shifting. The light-matter interaction on a biological sample revealed new structures through the measurement of the amplitude and the phase of the scattered signal (See Fig. ? below). In addition, circular states of polarization have shown to be perfectly suited to characterize completely and instantaneously dichroic sample properties [Ort15] (Fig. 1.c). More recently, we have developed an infrared active polarimetric imaging demonstrator based on the orthogonality breaking technique to investigate its benefits for target detection and identification at long range [Par17] (Fig. 2).Towards endoscopy applications, we explore the capabilities of the orthogonality breaking technique to be remotely performed through multimode fibers [Par16].



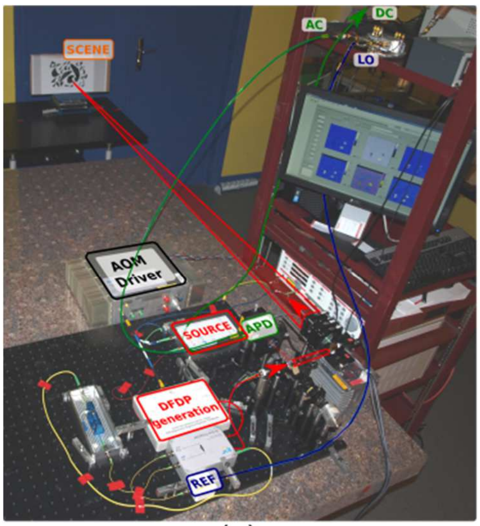


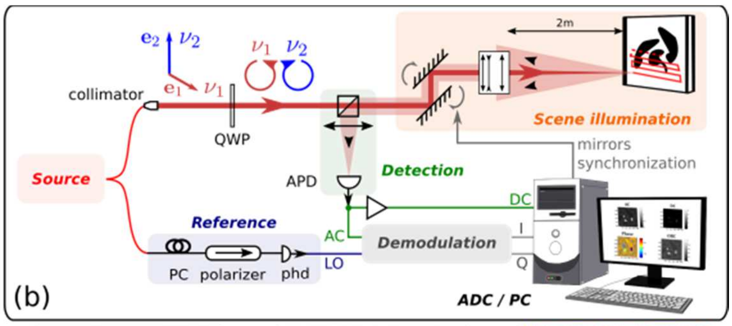
(a) (b)



(c)

Fig. 1 : Principle of depolarization sensing by orthogonality breaking. Case of (a) a depolarizing material ; (b) a non-depolarizing/dichroic material. The beatnote component at frequency Δν appearing on the intensity detected reveals the dichroic/depolarizing nature of the sample ; (c) Left : standard intensity image of a dichroic test sample made of pieces of polarizing sheets, center : DSOB contrast map providing the diattenuation of the sample, right : DSOB phase signal image providing the orientation of the absorption anisotropy of the sample.





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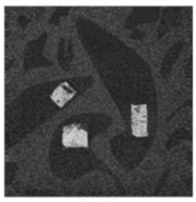
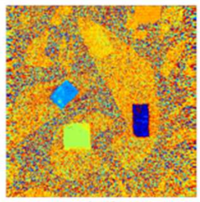
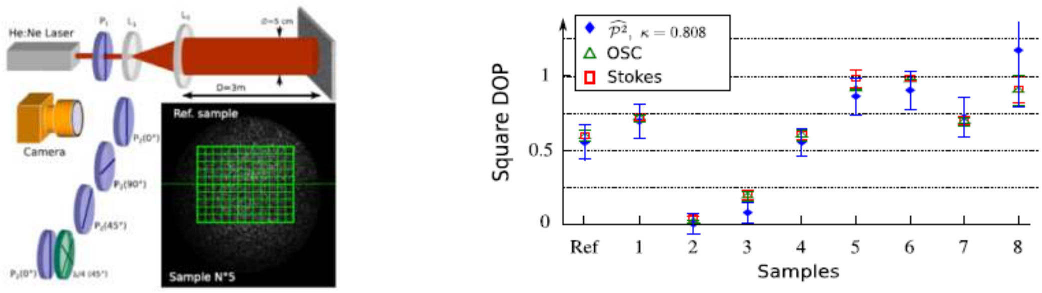




(a) (c) (d) (e)

Fig. 2: (a) Photograph and (b) sketch of the active infrared imaging demonstrator based on the orthogonality breaking Technique.(g) Intensity, (h) contrast and (i) phase images obtained with the setup in a single acquisition on a scene made of three infrared polarizers conceiled on dark patterns printed on a white sheet.

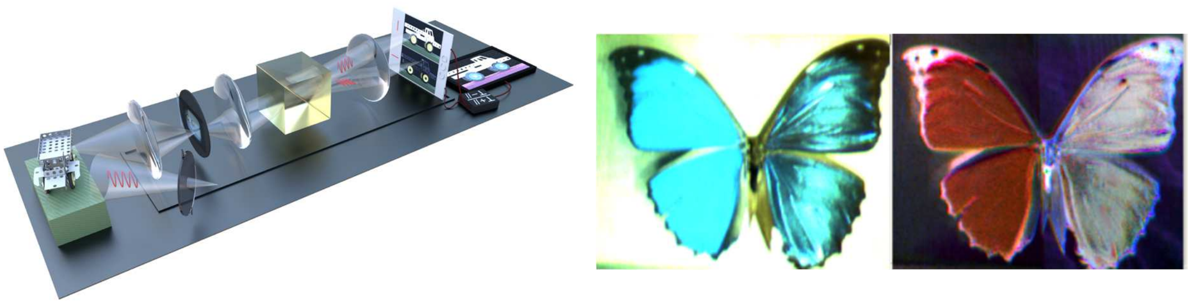
- **<u>Computational degree of polarization imaging :</u>** One of the non-conventional techniques studied in the FOTON-DOP team allows one to obtain a map of the depolarization strength of the imaged samples (through the degree of polarization of the light) from a single measurement. This computational imaging technique is based on a statistical analysis of local intensity fluctuations of the speckle pattern in the image acquired under coherent illumination (laser), without requiring any polarimetric analysis component [Fad12b]. This experimental work is conducted in close collaboration with the Institut Fresnel (Marseille, France) and has permitted to check theoretical predictions on the performances of estimators and to confirm, at various wavelenghts, the validity of the technique in the presence of birefringent samples. Current works aim at theoretically characterizing the performance of this snapshot measurement technique for detection/discrimination tasks [Fad15].



(a) (b)

Fig. 2: Analyzing the speckle contrast of a single intensity image obtained by illuminating an object with a coherent beam (a) allows to obtain a local estimation of the depolarizing strength of the object in agreement with conventional techniques (b).

- **<u>Spectro-polarimetric imaging :</u>** A snapshot spectro-polarimetric imager has been designed to provide polarimetric contrast images on several spectral channels. This imager opens various scientific perspectives (light-matter interaction study, signal/image processing) as well as numerous potential applications (materials discrimination, décamouflage, etc.) [Alo09]. Indeed, *combining spectral and polarimetric informations makes it possible to reveal contrasts hidden in a standard color intensity image.* These studies are conducted in collaboration with Thales Research and Technology.



(a) (b)

Fig. 3: (a) Schematic of the RGB spectro-polarimetric imaging demonstrator developed in the FOTON-DOP team. (b) Example of specific spectro-polarimetric contrast (pigment/interferential coloration discrimination).

Selected publications:

[Fad12a] J. Fade, and M. Alouini, "Depolarization remote sensing by orthogonality breaking," Phys. Rev. Letters 109 (4), 043901 (2012).

[Ort15] N. Ortega-Quijano, J. Fade, E. Schaub , F. Parnet and M. Alouini, "Full characterization of dichroic samples from a single measurement by circular polarization orthogonality breaking," Optics Letters , 40 (7), 1270-1273 (2015).

[Par17] F. Parnet, J. Fade, N. Ortega-Quijano, L. Goulc'hen, L. Frein and M. Alouini, "Free-space active polarimetric imager operating at 1.55 µm by orthogonality breaking sensing," Optics Letters , 42 (4), 723-726 (2017).

[Par16] F. Parnet, J. Fade and M. Alouini, "Orthogonality breaking through few-mode optical fiber," JOSAA, 55 (10), 2508-2520 (2016).

[Fad12b] J. Fade, M. Roche and M. Alouini, "Computational polarization imaging from a single speckle image," *Optics Letters* 37 (3), 386-388 (2012).

[Fad15] J. Fade, M. Roche, M. Alouini, "Polarizer-free degree of polarization computational imaging from a single speckle image," SPIE Optical Engineering + Applications, Polarization Science and Remote Sensing VII, San Diego, United States (2015).

[Alo09] M. Alouini, *et al.*, "Near-infrared active polarimetric and multispectral laboratory demonstrator for target detection," *Applied Optics* 48, 1610-1618 (2009).

Polarimetric imaging at the speckle grain scale

Real-time ballistic photons imaging

Biophotonic imaging

PhD theses (*past* / ongoing):

Swapnesh Panigrahi, « Real-time imaging through fog over long distances », 2016

François Parnet, *« Imagerie spectro-polarimétrique temps réel à longue distance par approche optique-hyper-fréquence et traitement avancé d'images spectro-polarimétriques »*

Collaboration:

Raman Research Institute (Bangalore, India)

Laboratoire Aimé Cotton (Palaiseau)

Thales Research and Technology (Palaiseau)

Institut Fresnel (Marseille)

IRFU, Service d'Astrophysique, CEA (Gif-sur-Yvette)

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