Master 2 “Photonics, Complex and Quantum Systems (PhoCQS)”: Research Training 2023-2024

Supervisor: Pierre Suret

Topic: Nonlinear Dynamics of complex Systems

Optical turbulence: ultrafast measurement of wave thermalization and of energy cascade

From the conceptual point of view, the subject enters within the framework of wave turbulence, a field of interdisciplinary research in optics, hydrodynamics and mathematical physics. Great scientists such as V. Zakharov have developed the theory of wave turbulence, at the interface between nonlinear dynamics and statistical physics, in the 70s. This theory predicts fundamental Physical phenomena such as the Kolmogorov- Zakharov energy cascade (large scales give energy to small scales) or the wave thermalization (equipartition of energy) [1]. The last twenty years, some experiments have been performed in mechanics or hydrodynamics to test the validity of this theory. In optics, a several research groups have attempted to observe wave thermalization or energy cascade, but, up to now, the results are very limited for several reasons. In many optical experiments, losses break the thermalization process. In single optical fiber, light can propagate over extremely long distance with very small losses, but unfortunately, in this system, the third order nonlinearity and the dispersion relation k(w) allows the emergence of solitons. This leads to the emergence of soliton gas or integrable turbulence in which equipartition of energy or energy cascade cannot occur.

The goal of the internship is to build an original setup to study optical wave turbulence. Experiments may use a recent ultrafast measurement device called “time microscope”. This setup designed in our group is unique in the world and allows the recording of fluctuations of light having timescales of the order of 10^{-13} seconds [2]. The study proposed in this internship will be both experimental and theoretical including numerical simulations. The key concepts under study are statistical Physics and nonlinear dynamics. The balance between theory and experiments together with the exact project of research will be discussed with the student.

[1] A Picozzi, J Garnier, T Hansson, P Suret, S Randoux, G Millot, Demetrios N Christodoulides , *Optical wave turbulence: Towards a unified nonequilibrium thermodynamic formulation of statistical nonlinear optics*, Physics Reports **542**, 1, 1-132 (2014)

[2] Tikan Alexey, Bielawski Serge, Szwaj Christophe, Randoux Stéphane and Suret Pierre. *Single-shot measurement of phase and amplitude by using a heterodyne time-lens system and ultrafast digital time-holography*, Nature Photonics, **12**, 4, 228-234, (2018)

Key words: Statistical Physics, Optical turbulence, optical fibers, ultrafast measurement, nonlinear dynamics