Master in Photonics – "PHOTONICS BCN"
Master ERASMUS Mundus "EuroPhotonics"

MASTER THESIS PROPOSAL

Starting full time from April 2025
Presentation at the end of July or beginning of September 2025

Laboratory: DONLL group , Nonlinear Dynamics, Nonlinear Optics and Lasers
Institution: Universitat Politècnica de Catalunya
City, Country: Terrassa, Catalunya

Title of the master thesis: Control of optical turbulence and spatiotemporal solutions by spacetime modulations

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Keywords:. Optical turbulence, Non-Hermitian structured materials, localized structures, solitons, spatiotemporal solutions.

Summary of the subject (maximum 1 page):

Spontaneous pattern formation and arousal of turbulence in spatially extended nonlinear systems generally occurs through Turing or Modulation Instability (MI). The control of the MI is paramount for the management of the system stability and spatial patterns formation. At UPC, we uncovered the possible modification or elimination of MI by a spatiotemporal periodic modulation [1,2]. In optics for instance, turbulence represents one of the main drawbacks for laser sources.

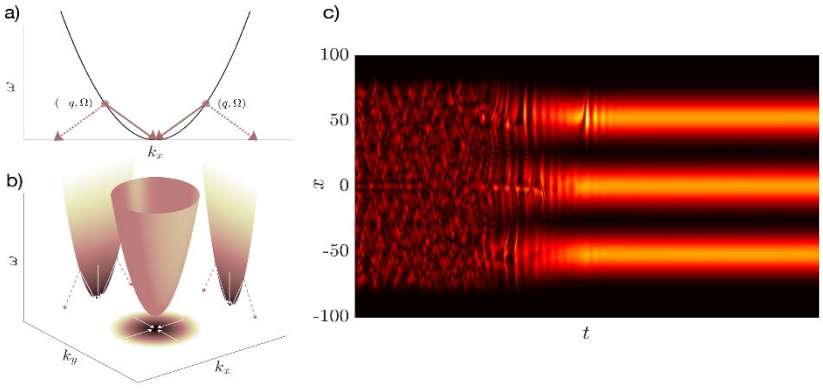

Figure. *Proposed mechanism on a parabolic dispersion for: a) 1D and b) 2D parabolic dispersion curve. Arrows indicate asymmetric mode couplings for a harmonic non-Hermitian modulation. c) Evolution of the field intensity of a VCSEL when the non-Hermitian potential is switched on*

A current research line of the UPC group is precisely devoted to the control of turbulence by the introduction of spatial non-Hermitian modulations and already obtained relevant results including systems with fractional potentials and in applications like Class-B lasers, see the Figure [3,4,5]. Three objectives can be explored in this master thesis involving different physical systems or particular applications:

Spatiotemporal modulation of the Fractional Ginzburg Landau Equation (FCGLE). Semi-analytically solutions will be calculated and the stability of the solutions will be analyzed by Floquet multipliers. The results would be implemented in Ginzburg-like models describing physical systems, such as VCSELs.

Coupled equations FCGLE and lasers

This model accounts for the amplitude of two coupled fields. It is the case of the forward and backward propagating fields in lasers. We plan to exploit the asymmetric properties of non-Hermitian systems to stabilize and increase the lasing power.

Extension to systems with external pump

We extend the proposal to systems with external pump, for instance modeled by the Generalised Lugiato-Lefever Equation (LLE) covering systems such as Kerr Microresonators or injected ring quantum cascade lasers. Preliminary results on the LLE have shown that we may be able not only to enlarge the stability of existing structures like frequency combs but, more interestingly, to stabilize new arising solutions.

[1] Ahmed, W. W., Kumar, S., Herrero, R., Botey, M., Radziunas, M., & Staliunas, K. Stabilization of flat-mirror vertical-external-cavity surface-emitting lasers by spatiotemporal modulation of the pump profile. *Phys. Rev. A* 92, 043829, 2015

[2] Kumar, S., Herrero, R., Botey, M., Staliunas, K. Taming of modulation instability by spatio-temporal modulation of the potential. *Scientific Reports* 5, 1-7, 2015

[3] Ivars, S. B., Botey, M., Herrero, R., Staliunas, K. Optical turbulence control by non-Hermitian potentials. *Phys. Rev. A*, 105, 033510, 2022

[4] Ivars, S. B., Botey, M., Herrero, R., Staliunas, K. Non-Hermitian control of optical turbulence in systems with fractional dispersion. *Chaos, Solitons & Fractals*,165, 112774, 2022

[5] Ivars, S. B., Botey, M., Herrero, R., & Staliunas, K. Stabilisation of spatially periodic states by non-Hermitian potentials. *Chaos, Solitons & Fractals* 165, 112774, 2022.

Additional information (if needed):

* Recommended skills: Programming (C++, MatLab,..)

* Miscellaneous: This study is in the framework of a Project “Exploring complex spacetime systems for light control“ (PID2022-138321NB-C21) inside the coordinated project “Exploring complex spacetime systems for unconventional light and sound wave control“. Possibility of joining the DONLL group for a PhD.