

Nonlinear dynamics in complex fiber networks

Keywords: fiber laser, nonlinear dynamics and chaos, frequency combs, wave-dynamical chaos

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Start of thesis: end of 2026 or beginning of 2027 (total duration 3 years)

Description of the research project

Fiber lasers, particularly erbium-doped ones emitting in the telecommunications band around 1550 nm, have been studied in great detail. The most common configuration is a single-mode fiber (SMF) ring cavity containing an erbium-doped section as the gain medium. It is well known that even these simple ring lasers can exhibit unstable and chaotic dynamics with unpredictable power fluctuations with bandwidths greater than 10 GHz [1]. These ultrafast instabilities are attributed to the Kerr effect and dispersion in optical fibers [2]. Chaotic fiber lasers have been proposed for cryptography applications based on chaos synchronization [3].

The objective of this PhD project is to investigate the static and dynamic properties of fiber lasers that use a complex network as a resonator, that is, several coupled fiber loops providing a large number of possible propagation paths, instead of just a single ring cavity. Such network lasers have received very little attention to date [4], and in particular, the impact of their geometry and polarization-related effects remains poorly understood. The PhD project will be carried out in three phases. In the first phase, the properties of passive fiber networks (without gain medium) will be studied in detail. The large number of possible paths in such a network creates complex interference. In addition, the polarization state of a signal propagating through a SMF is not preserved. The objective of this first phase is to understand the influence of network topology and polarization effects by comparing experimental measurements of the spectrum and polarization state with theoretical models developed during the thesis. The theoretical modeling will build upon studies of wave graphs [5], which are investigated in the context of wave-dynamical chaos [6], but generally without accounting for polarization effects, dispersion, or nonlinearities.

During the second phase, an erbium-doped fiber will be incorporated to create network lasers, and their spectral and dynamical properties will be investigated using high-resolution spectrometers and high-bandwidth temporal measurements (> 20 GHz). The experiments will be complemented by developing a theoretical model based on the results of the first phase and on classical models of fiber lasers [2]. Beyond gaining a deeper understanding of the relationship between network topology and laser dynamics, we will also search for ultra-wideband chaotic dynamics for chaos-based applications such as cryptography [7].

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Third, solitons [8] and frequency combs [9] have been demonstrated in conventional fiber lasers, but never in a network laser. Frequency combs consist of a series of equally spaced, phase-locked modes and have become very important tools in metrology and spectroscopy [10]. Of particular interest are dual frequency combs, which consist of two frequency combs with slightly different frequency spacing and have applications in spectroscopy [11]. Our ultimate goal is to demonstrate the generation of solitons and dual-frequency combs in a network laser.

This PhD project is part of an ANR-funded collaborative project involving the C2N at Paris-Saclay University and the Max Planck Institute for the Physics of Complex Systems (MPI-PKS) in Dresden, Germany. The experiments will be conducted at LMOPS in Metz, and experience with optical experiments is a prerequisite. The theoretical modeling will be developed in collaboration with Barbara Dietz at MPI-PKS.

Profile of the candidate

The candidate should be interested and skilled in optical experiments, in particular with fiber systems, and must show independence and scientific curiosity. A solid background in laser physics, nonlinear optics, and optical fibers is required. Given the international nature of the collaborations, and good English skills are essential. Experience with numerical simulations and programming languages (Matlab, Python, C++, etc.) would be useful.

Contact

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