SCIENCES & BIOENGINEERING SCIENCES

The Research Group

Applied Physics

has the honour to invite you to the public defence of the Joint PhD thesis of

Pedro PARRA RIVAS

to obtain the degree of Doctor of Sciences

Title of the PhD thesis:

Dynamics of dissipative localized structures in driven nonlinear optical cavities

Joint PhD with Universitat de les Illes Balears

Promotor:

Prof. Jan Danckaert
Prof. Lendert Gelens
Prof. Damià Gomila

The defence will take place on

Friday 3 March 2017

At the Universitat de les Illes Balears

Members of the jury:

Prof. Alexander Sevrin (chairman)
Prof. Guy Van der Sande (secretary)
Prof. Pere Colet (Univ. de les Illes Balears)
Prof. Alan Champneys (Univ. of Bristol)
Prof. Giovanna Tissoni (Inst. Non linéaire de Nice)
Prof. Marc Haelterman (ULB)
Prof Edgar Knobloch (UC Berkeley)
Dr. François Leo (ULB)

Curriculum vitae

- 2004-2010: Licentiate in Physics
Universidad de Granada (Spain)

- 2010-2011: Master in Mathematics
Universidad de Salamanca (Spain)

- 2012-2017: Joint PhD in Physics
Universidad de les Illes Balears (UIB, Spain) and Vrije Universiteit Brussel (VUB, Belgium)

- Oct – Dec 2015: Research stay
UC Berkeley (USA)

- 9 first author journal papers (among which in Physical Review Letters and Optics Letters) and 1 book chapter

Abstract of the PhD research

In this thesis, we study emergent structures in spatially extended systems. We restrict our attention to systems that are internally dissipative and externally driven, also referred to as systems out of thermodynamical equilibrium. We investigate a particular type of emergent structures, called localized structures (LSs). As their name indicates, LSs are confined in time and/or space. LSs can develop instabilities that make them move, deform or oscillate. Oscillations can also lie at the origin of a dynamical, neuron-like phenomenon called "excitability".

Although LSs, and their various instabilities, can be observed in a wide range of physical systems, we focus on the field of optics, where LSs can be observed in nonlinear optical cavities. In this context, LSs are also called cavity solitons. To study this type of cavities we use the Lugiato-Lefever (LL) model, a partial differential equation first proposed in 1987 to describe transversal electric field in a passive optical cavity filled with a nonlinear medium. In the last decade, this model has sparked new interest as it was found to also describe the formation and dynamics of Kerr frequency combs in microresonators. A frequency comb consists in a broad optical spectrum of sharp comb lines with an equidistant frequency spacing that can be used to perform ultra-precise measurements of optical frequencies, and has numerous other applications in spectroscopy, optical clocks and waveform synthesis. The interesting and essential point here is that such coherent frequency combs correspond to the frequency spectrum of cavity solitons and patterns circulating inside the cavity. Therefore, by studying LSs in the LL model we obtain crucial information about the dynamics and stability of Kerr frequency combs.

In the first chapters of the thesis we provide a detailed study of LSs in the LL model in its two main regimes of operation, namely the region with anomalous group velocity dispersion (GVD) and the one with normal GVD. For anomalous GVD, we focus on patterned solutions and bright solitons and characterize their bifurcation structure and instabilities leading to oscillations in time and/or space. In contrast, in the normal GVD regime, we show that the main LSs are dark solitons, which have a very different origin and bifurcation structure, but undergo similar instabilities. Next, we focus on how higher order dispersion effects modify the soliton dynamics in both regimes, showing that a various LSs can be stabilized by the higher order dispersion. Another question that we address is how bound states of solitons can form, where interaction between solitons is largely determined by the oscillatory tails in the soliton's profile. Finally, we focus on how defects and advection can modify the dynamics of LSs, showing the combination of defects and advection can induce excitability.