XX International Workshop

BOOK OF ABSTRACTS

UNIVERSITÉ CÔTE D'AZUR · DOEBLIN · cnrs · fcfm Ingeniería UNIVERSIDAD DE CHILE

CONFERENCE PROGRAM

Monday 7 October		Tuesday 8 October		Wednesday 9 October	
9 :00-10 :00	Opening remarks (UniCA, Idex, P. Coullet, G. Huyet, M. Giudici)		Chaired by : G.L. Lippi		Chaired by : M. Tlidi
		9:00-9:25	MUSSOT	9:00-9:25	9:00-9:25 ARGENTINA
	Chaired by M. Giudici	9:25-10:00	LAROZE	9:25-10:00	9:25-10:00 RICA
10:00-10:25	TURITSYN	10:00-10:25	LEO	10:00-10:25	FRISCH
10:25-10:50	SCALLY	10:25-10:50	STALIUNAS	10:25-10:50	MICHEL
10:50-11:15	COFFEE BREAK	10:50-11:15	COFFEE BREAK	10:50-11:15	COFFEE BREAK
11:15-11:50	VALDIVIA	11:15-11:50	CLERC	11:15-11:50	POMEAU
11:50-12:15	COULIBALY	11:50-12:15	BARBAY	11:50-12:15	NAZARENKO
12:15-12:40	GENTY	12:15-12:40	SKRYABIN	12:15-12:40	KRSTULOVICS
12:40-14:00	LUNCH	12:40-14:00	LUNCH	12:40-14:00	LUNCH
	Chaired by S. Turitsyn		Chaired by G. Huyet		Chaired by F. Raineri
14:00-14:35	CHEMBO	14:00-14:35	DURING	14:00-14:25	LIPPI
14:35-15:00	GIACOMOTTI	14:35-15:00	BARLAND	14:25-14:50	MARCONI
15:00-15:25	BRES	15:00-15:25	VLADIMIROV	14:50-15:15	GARNACHE
15:25-15:50	RAINERI	15:25-15:50	SONNINO	15:15-15:35	RAUFASTE
15:50-16:15	COFFEE BREAK	15:50-16:15	COFFEE BREAK	15:35-15:55	BEC
	Chaired by G. Genty		Chaired by M. Clerc		Concluding Remarks
16:15-16:40	JACQUOT	16:15-16:40	AMIRANASHVILI		
16:40-17:05	TREDICCE	16:40-17:05	TLIDI		
17:05-17:30	ROJAS	17:05-17:35	COULLET / IOOSS		
17:30-17:50	KOSTET	17:35-17:55	SOUPART		

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Sergei Turitsyn, Aston University, United Kingdom

Asymmetric optical nonlinear pulses

Formation and propagation of high-power optical pulses both is important for various practical applications, and is an interesting fundamental nonlinear science problem. Stability and ability of such pulses to accumulate large nonlinear phase without wave-breaking is the key to creating various high-power coherent structures. I will discuss a generic novel model governing optical pulse propagation in a nonlinear dispersive amplifying medium with asymmetric gain. In a quasi-classical limit some solutions of the introduced model can be described by the simplified system of equations that is a modification of the well-known one-dimensional shallow water equations. We examine the properties of asymmetric optical pulses formed in such gain-skewed media, both theoretically and numerically. We derive a dissipative optical modification of the classical shallow water equations that highlights an analogy between this phenomenon and hydrodynamic wave-breaking. We observe the development of spectral optical shock waves, and discuss the conditions and origins of this spectral wave-breaking in media with asymmetric gain. These findings provide insight into the nature of asymmetric optical pulses capable of accumulating large nonlinear phase without wave-breaking, a crucial aspect in the design of nonlinear fiber amplifiers.

Anas Skalli, FEMTO-ST, Université Bourgogne Franche-Comté, France

A fully optical neural network based on a multimode semiconductor laser.

Artificial Neural Networks (ANNs) have become a pervasive technology, excelling in a variety of applications, from medical diagnosis to language modeling, due to their adaptability. Unlike traditional algorithms, these networks process information in parallel, and as such, differ from classical von- Neumann architectures. Recently, there have been significant efforts to implement ANNs on a plethora of unconventional hardware substrates. Photonics, in particular, offers significant potential as a platform for implementing ANNs, with advantages in scalability, speed, energy efficiency, and parallel information processing.

In this study, we experimentally demonstrate a high-performance, robust, autonomous, fully tunable, and scalable neural network composed of over 400 discrete nodes, utilizing a vertical cavity surface-emitting laser (VCSEL). Although fully autonomous photonic neural networks (PNNs) have been realized before, they are still relatively rare. Our approach stands out by fully implementing all components of the neural network, including input and output weights as well as nonlinearities, directly in hardware using exclusively off-the-shelf components. Our optical neural network achieves impressive performance, with a high classification bandwidth of 15 kHz on the MNIST dataset, and it shows potential scalability towards the MHz range and beyond. Additionally, all learning is conducted online, employing various hardware-compatible learning strategies. We benchmarked these strategies including reinforcement learning, evolutionary strategies, and gradient estimation methods against each other in terms of performance and energy efficiency.

Our approach is highly relevant, fully parallel and scalable both in terms network size and depth as we have a clear avenue for using VCSELs in a deep PNN configuration. Lastly the inference bandwidth is also highly scalable due to a fast VCSEL response time (GHz range) without any significant increase in power consumption.

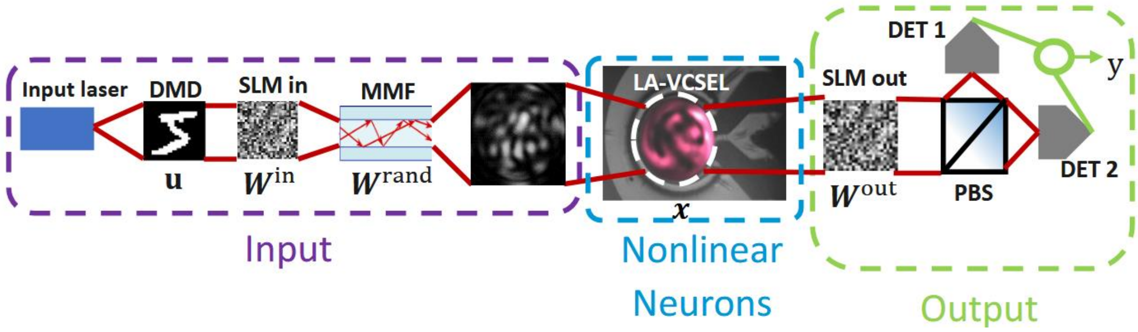

Figure 1 Working principle of our experimental VCSEL-based optical neural network

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Alejandro Valdivia, University of Chile, Chile

Complexity in city traffic

Vehicle traffic dynamics in cities is becoming a relevant area of research because of its social, economical, and environmental implications. We will show our latest results of micro-physical simulations and data analysis of vehicles and buses propagating in a network of roads, for real and synthetic cities, and the consequences they suggest for urban design. In the simulations of cars moving through the cities it is possible to test different transport modes, such as single trips, deliveries with multiple stops, or the usage of path and time optimizations software. In the case of bus simulations, it is possible to study the interaction of passenger loading with bus and traffic light parameters. In terms of data analysis, we consider the cities using a complex network and the consequences it has for city traffic and flow.

Saliya Coulibaly, University of Lille, France

Spatiotemporal Chaos in Kerr Resonators: An Anatomy

Recent advancements in data-driven machine learning have shown great potential for forecasting complex systems. Kerr resonators, widely recognized for their role in generating optical frequency combs, also exhibit intricate and chaotic dynamics. However, the effectiveness of data-driven approaches can be hindered without a deeper understanding of the underlying complexity. In this work, we present a comprehensive analysis of the spatiotemporal chaos exhibited by Kerr resonators, shedding light on the chaotic pulses that sustain these irregular dynamics. Our findings offer new insights into the nature of this complexity, potentially enhancing the performance of predictive models for such nonlinear systems.

Goëry Genty, Tampere University of Technology, Finlands

Real-time spatial field measurement in multimode fibers

Yanne K. Chembo, University of Maryland, USA

Advances on pattern formation in nonlinear microresonators

Kerr optical frequency combs (or microcombs) are expected to play a major role in photonic technology, with applications related to spectroscopy, sensing, aerospace, and communication engineering. For this reason, it is of high importance to understand pattern formation in these optical cavities, as well as the influence of random noise on these patterns. Here, we present some of the latest advances in this field to investigate the nonlinear, stochastic and quantum dynamics of these systems.

Alejandro Giacomotti, Institut d'Optique Bordeaux, France

Non-Hermitian zero modes in a nanophotonic trimer

Topological lasers based on optical cavity arrays –such as the Su-Schrierfer-Heeger (SSH) array– in active media have been recently realized in various platforms. In all these studies the coupling coefficient between any adjacent sites of the lattice was positive. Consequently, the lasing zero mode featured an out of phase oscillation which is typically impractical for any application because it weakens the far field intensity. This problem can be mitigated by altering the coupling signs along the array. However, implementing negative evanescent coupling in microrings, microdisks or micropillars is not possible using standard designs and fabrication processes. In this talk, I'll present a design, the realization and the experimental implementation a photonic crystal cavity array that consists of three sites where the sign of one coupling parameter is inverted, which enables the observation of an in-phase topological zero mode. The photonic crystal array presented here utilizes the recently proposed "image barrier" technique, where the photonic barriers are copied at opposite sides of the array, which mitigates chain-termination effects, and at the same time enables sign flip from one barrier to the adjacent one, resulting in "twisted coupling". Consequently the overall symmetry of the zero mode is inverted and becomes even, which is experimentally demonstrated. Our work opens the door for implementing a new generation of phase-locked topological laser arrays that oscillates in the same phase with enhanced far field optical intensities.

Camille Brés, Swiss Federal Institute of Technology in Lausanne, Switzerland

Optical poling in waveguides and resonators: dynamics of self-organized nonlinear grating inscription.

Abstract: In this talk, I will describe how amorphous materials such as silicon nitride can be endowed with an effective second-order nonlinearity and photoinduced quasi-phase matching (QPM) via the coherent photogalvanic effect (CPE). The CPE, studied in fibers decades ago, also enables all-optical poling (AOP) in both integrated waveguides and resonators. I will show how our generalized model for waveguides predicts the existence of multiple simultaneous grating, both for degenerated and non-degenerate nonlinear effects, and sheds light on the dynamics of AOP. Finally, while the spatial properties of photoinduced QPM have been extensively investigated, the dynamics of the resonant process had been left unexplored. I will show that such photoinduced QPM is actually spatio-temporal: the dynamics of resonant AOP yields a temporal modulation of the photoinduced nonlinearity, associated with the spatial one, which altogether can be regarded as a traveling $\chi(2)$ grating that moves indefinitely alongside the microring circumference.

InP on Silicon spiking nanolasers

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[2] THALES Research and Technologies, Palaiseau, France
[3] NcodiN, Ivry-sur-Seine, France
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Integrated optics constitutes a highly promising platform for achieving portable machine learning (ML) chips with unprecedented power-efficiency and bandwidth [1]. Despite recent observations of ML key functionalities using integrated Silicon photonics, such as reconfigurable matrix multiplication [2] and nonlinear activation functions [3], excitability observation, the spiking mechanism of our biological neurons, remains incomplete in all-integrated systems; up to now they are based on opto-thermal (slow) effects [4] that drastically limits its applicability in ML systems with high bandwidth requirements. Here, we use InP-based photonic crystal nanocavities heterogeneously integrated on top of a Silicon on Insulator (SOI) waveguide to demonstrate the first all-integrated fast excitable nanolaser.

The nanolaser relies on an InP-based nanobeam cavity coupled to a SOI waveguide which embeds 2 spatially separated regions, one for the gain and one for saturable absorption. The gain region of the nanolaser is optically pumped by the surface whereas the saturable absorber region remains unpumped. The emission at 1.55µm is collected using a single mode fiber (SMF) approached to grating couplers made at the extremities of the Si waveguide and is further analyzed using high bandwidth (≥10 GHz) detection devices.

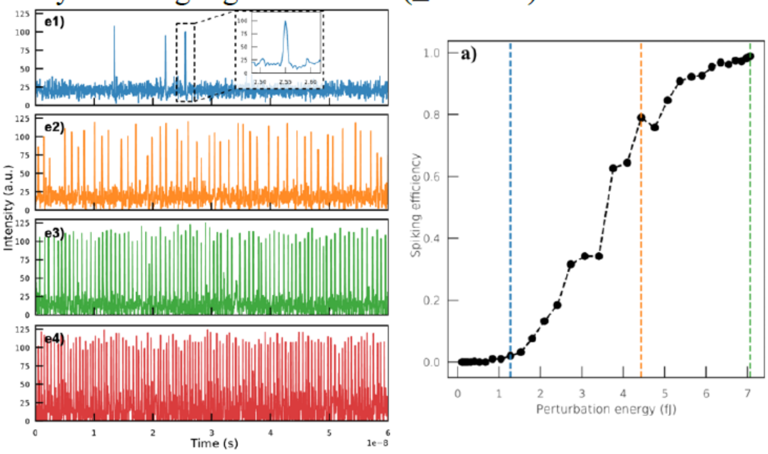

Fig: Left: output power for increasing pump power. Right: Probability of observing spikes versus perturbation energy.

Depending on the pumping conditions, different dynamical regimes such as self-pulsing and noise induced spiking may be observed (see Fig. Left). Excitable behavior is demonstrated by injecting short optical pulses (≈4 ps), with energy E_{pert}, at wavelength of the laser. It shows when the system emits a short pulse (typ. 100ps) which is independent from the perturbation itself. Fig. right shows the perturbation efficiency, defined as the number of excitable responses observed over the number of perturbations applied, with the perturbation amplitude; it is 0 (≈1) for low (large) perturbation amplitudes. We thus demonstrate here the possibility to trigger on-demand pulses with femtojoule perturbation levels.

References

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Maxime Jacquot, FEMTO-ST, Université Bourgogne Franche-Comté, France

Computer micro-vision and deep holographic Microscopy

In many advanced areas such as computer vision, robotics and microscopy, accurate 3D positioning and trajectory determination are crucial for a variety of applications, including industrial and clinical. Deep Neural networks plays now a significant role in visual data processing. We will present the developing of advanced and hybrid imaging techniques for 3D motion measurement at small-scale mechatronics and automated microscopy. This work explores extended computer micro-vision capabilities offered by combining digital holographic microscopy and different architecture of deep learning algorithms such as convolutional neural networks, Vision Transformer networks and GedankenNet model. In high-tech areas such as micro-robotics, micro-electronics and photonics, design and measurement requirements are increasing in terms of high resolution and their controls are based on multi-scale and complex parameters. Deep neural networks based on physics-driven learning make also it possible to train neural networks with a reduced data set and also have the potential to transfer part of the numerical computations to optical processing. Preliminary works will be presented on the first deep holographic microscope device incorporating a hybrid neural network based on the angular spectrum of plane waves method for autofocusing of dynamic images used in microscopy applications.

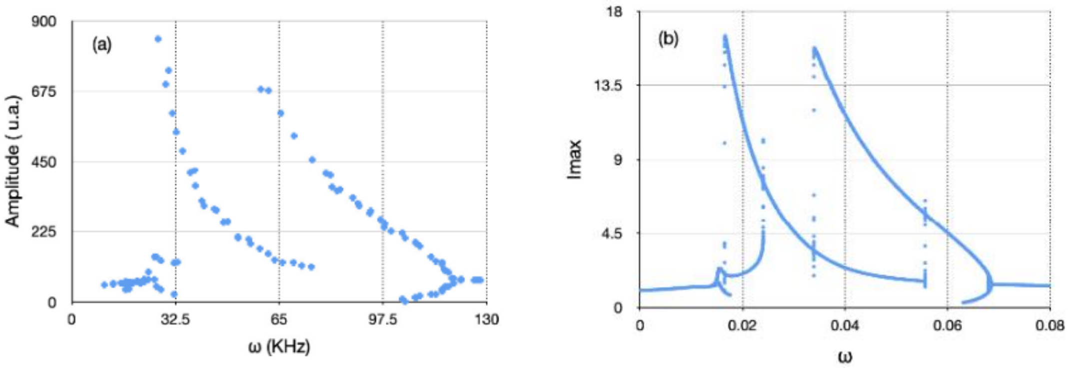
Jorge Tredicce, Universidad Rey Juan Carlos, Spain

Garden of Bifurcating Paths in a Solid State Laser

Lucas Sarrazin[1], Mathias Marconi[1], Massimo Giudici[1] , Monica Agüero[2], Myriam Nonaka[2], Marcelo Kovalsky[2] , Karin Alfaro Bittner[3] and Jorge Tredicce[3]

1 Université Côte d'Azur, Institut de Physique de Nice, France
2 Laboratorio de Láseres Solidos, CEILAP, CITEDEF-CONICET, Buenos Aires, Argentina
3 Universidad Rey Juan Carlos, Matemat Aplicada Ciencia and Ing. Mat. and Tecnol, Madrid, Spain

We study both theoretically and experimentally the dynamical behaviour of a solid state laser with modulated losses. We focus our attention on the bifurcation diagrams as we sweep the modulation frequency. The nonlinearity of the system is at the origin of different branches of periodic solutions at harmonics and subharmonics of the modulation frequency. Each coexisting solution is originated at a different resonance of the system. We analyse the coexistence of such periodic solutions and with chaotic solutions. There is no coexistence among different chaotic solutions. The experimental results with solid state lasers show a reasonable quantitative agreement with numerical results from the simplest laser model. the different branches of solutions can show the three types of crisis: internal, external and boundary. Boundary crisis is at the origin of the disappearance of stable solutions, while external crisis generates large increase in the size of chaotic attractors.



Bifurcation diagrams. Intensity maxima as a function of the modulation frequency obtained by sweeping slowly forward and backward the modulation frequency. (a) experimental result (b) numerical results.

Nicolas Rojas, Université Côte d´Azur, Institut de Physique de Nice, France

Cell migration in killifish epiboly and single-cell growth in C. Albicans

Biophysics is a research field that permanently employs borrowed tools from different areas such as nonlinear physics, fluid dynamics and statistical mechanics. These tools are used in a combination of experimental and theoretical techniques, for instance, in active processes such as chemotaxis and active de/wetting, which have opened new routes of research and new concepts that have revolutionized other fields such as medical physics and medicine, finding practical solutions to numerous diseases. In this talk I will present current results on cell migration in annual killifish and on single-cell growth such as the yeast C. Albicans. In the former, the killifish egg is engulfed by three (extra-embryonic and embryonic) layers as epiboly advances. A viscoelastic theory is developed to model the progression of the deep cell layer (DCL) and the enveloping cell layer (ECL) where the geometry of the egg plays an important role. In the second part of the talk I will present latest findings on fungi growth, here the development of C. Albicans is modelled as an active interfacial instability obtained from a Helfrich free energy functional and an active motile force that depends on interface curvature which yields finger-like patterning.

Bilal Kostet, Université Libre de Bruxelles, Belgium

Vectorial dark dissipative solitons in Kerr resonators

We investigate the formation of vector solitons in weakly birefringent high-Q resonators. The presence of nonlinear polarization mode coupling in optical resonators subject to a coherent optical injection allows stabilizing up to two families of bright or dark vector dissipative solitons, depending on dispersion properties of the system. We use coupled Lugiato–Lefever equations to investigate the dynamical properties of interacting laser fields confined in Kerr optical resonators. The normal dispersion regime is considered, and it is shown that in both cases two branches of dissipative solitons coexist and exhibit different peak powers and polarization properties. In these regimes, the input-output characteristics possesses either a bistable or a tristable homogeneous response. The coexistence of two vectorial branches of localized states is not possible without taking into account the polarization degrees of freedom. The stabilization mechanism of these localized states is attributed to a front locking mechanism in the normal dispersion regime, contrary to the case of anomalous dispersion where the underlying cause is modulational instability. Their bifurcation diagrams exhibit a heteroclinic snaking type of instability.

Arnaud Mussot, University of Lille, France

Frequency combs in fiber Fabry Perot resonators

Davide Laroze, Instituto de Alta Investigación, Universidad de Tarapaca, Arica, Chile

Characterization of Faraday patterns, spatiotemporal chaos and Chimera states in parametrically driven dissipative systems

We study numerically the dynamics of the parametrically driven damped nonlinear Schrödinger equation (PDDNLS) [1]. The PDDNLS is a universal model to describe parametrically driven systems. In particular, we have characterized stationary Faraday patterns, periodic, quasi-periodic, and spatiotemporal chaos as a function of the amplitude and the frequency of the parametric driving force. We have computed the Lyapunov spectra, the Fourier spectra, the amplitude norm, and the Kaplan–Yorke dimensions as valuable indicators for the identification of several dynamical regimes [2]. We show that in the Faraday regime, close to the bifurcation of the trivial state, the pattern amplitude scales with power one-fourth (1/4) of the bifurcation parameter. Furthermore, we have found that the pattern wavelength decreases when the detuning parameter increases. In the case of the high dimensional spatiotemporal chaotic states, we have found that the Kaplan– Yorke dimension increases linearly with the length of the system, showing its extensive character in this dynamical regime. We have also found a transition from low to high dimensional chaos when the forcing amplitude is increased. Finally, in the discrete limit of the PDDNLS equation, we characterize the region of existence of chimera states [3].

References

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François Leo, ULB Bruxelles, Belgium

Temporal cavity solitons in lasers and optical parametric oscillators

Driven solitons are short optical pulses that propagate indefinitely in optical resonators. They are currently attracting a lot of attention both for their fundamental interest and potential applications in metrology and spectroscopy. The term “driven” comes from the coherent continuous wave injected source which provides energy to the soliton via phase-sensitive processes. This makes them significantly different from laser solitons (sustained through incoherent gain) and strongly connects them to other fields of science such as hydrodynamics and plasma physics.

Until recently, most results have focused on passive cavities with a driving laser at the soliton carrier frequency. However, it is now well known that this configuration is strongly limited in terms of energy conversion (pump to output soliton), and several proposals have been made to increase the output power. In this talk, I will discuss our recent results on novel types of driven solitons, such as solitons in laser cavities pumped below the lasing threshold and solitons in degenerate optical parametric oscillators.

Kestutis Staliunas, Universitat Politècnica de Catalunya, Spain

Light Trapping in Non-Hermitian Thin Films

One of the exceptional features of non-Hermitian systems is the unidirectional wave interactions. Simultaneous modulation of the real and the imaginary part of the potentials (of the refractive index and the gain/loss in the case of optical systems) can result in unequal coupling coefficients between the fields of different parts of the system. The unidirectional coupling can also be arranged not only between the internal fields of the system but also between internal fields and external radiation. At a particular (exceptional) point, the situation can be achieved, that the external radiation is efficiently coupled into the system, but the internal radiation cannot escape backwards. In this way, the incident radiation can be trapped inside the non-Hermitian system and, eventually, can be efficiently absorbed there.
We realize this idea in non-Hermitically modulated thin films. The modulation consists of a Hermitian part – the periodic corrugation of the surfaces of a thin film, and a non-Hermitian part – the losses modulated along the film. We prove numerically and demonstrate experimentally that the incident radiation, coupled with such a non-Hermitian thin film, is unidirectionally trapped into a planar mode of the film, does not escape from the film (or escape weakly due to experimental imperfections), and is efficiently absorbed there.

Marcel Clerc, University of Chile, Chile

Localized dissipative vortices in chiral nematic liquid crystal cells

Solitary waves and solitons have been fundamental in understanding nonlinear phenomena and emergent particle-type behaviors in out-of-equilibrium systems. This dynamic phenomenon has been essential to comprehending the behavior of fundamental particles and establishing the possibilities of novel technologies based on optical elements. Dissipative vortices are topological particle-type solutions in vectorial field out-of-equilibrium systems. Under homeotropic anchoring, chiral nematic liquid crystal cells are a natural habitat for localized vortices or spherulites. However, chiral bubble creation and destruction mechanisms and their respective bifurcation diagrams are unknown. In this talk, we propose a minimal two-dimensional model based on experimental observations of a temperature-triggered first-order winding/unwinding transition of a cholesteric liquid crystal cell and investigate this system experimentally. This model reveals the main ingredients for the emergence of chiral bubbles and their instabilities. Experimental observations have quite fair agreement with the theoretical results. Our findings are a starting point for understanding dissipative particles' existence, stability, and dynamical behaviors with topological properties.

Sylvain Barbay, Université Paris-Saclay, France

Nonlinear amplification and chaos synchronization in driven nano-mechanical resonators

Nano-mechanical resonators show good promises for applications in nonlinear and quantum regimes. Being intrinsically nonlinear, driven nano-mechanical resonators are naturally good candidates for nonlinear physics and dynamics studies. Using a photonic-crystal membrane electrically actuated by integrated electrodes and probed by a laser beam, we report the possibility to amplify a small signal by the phenomenon of vibrational resonance. In this regime, a resonant and a high-frequency, non-resonant signal are used in conjunction to drive the resonator. Small signal amplification results from the manipulation of non-linear resonances thanks to the non-resonant drive. In addition, driven coupled nano-mechanical resonators can sustain chaos dynamics. We study how two coupled resonators can synchronize in the chaotic regime, with applications to chaos communication and random number generation. We finally discuss some prospects of these studies.

Dmitry Skryabin, University of Bath, UK

Multimode and multi-octave chi-2 photonics

I will briefly review some recent results on modelocking, frequency comb and dissipative soliton generation triggered and sustained by chi-2 nonlinearity and three-wave mixing in optical microresonators. I will highlight how differences between parametric oscillations and second harmonic generation impact multimode generation and soliton properties and present and interpret recent experimental and theoretical data sets.

Gustavo During, Pontificia Universidad Catolica de Chile, Chile

From active actuation to collective motion: the many faces of an active solid model.

Active solids, such as cell collectives, colloidal clusters, and active metamaterials, exhibit a wide range of collective phenomena, including rigid body motion, shape-changing mechanisms, and active actuation. However, the nonlinear dynamics of these materials remain poorly understood, particularly in relation to how the interplay between activity, elasticity, and noise gives rise to novel and remarkable behaviors. In this talk, I will first demonstrate that stress propagation in a model of active solids induces the spontaneous actuation of multiple zero-energy deformation modes, even in the absence of vibrational excitations. By introducing an adiabatic approximation, we map the dynamics onto an effective Landau free energy, which predicts mode selection and the onset of collective dynamics. In the second part of my talk, I will show that, in systems without floppy modes, collective actuation can emerge from the interaction between activity and elasticity when the coupling is sufficiently strong. Interestingly, only a few elastic modes are actuated, and these are not necessarily the lowest-energy ones. These findings in active solids open new avenues for studying and designing living and robotic materials with multiple modes of locomotion and shape change.

Stéphane Barland, Université Côte d´Azur, Institut de Physique de Nice, France

Can some semiconductor lasers operate as Bose Einstein condensates?

Bose Einstein condensates consist of a large number of bosons in a single quantum state. This is strongly reminiscent of laser light, where many photons occupy a single coherent state. Thus, the question about the relation between BEC and laser light is less about the state itself than about the process that leads to said state. In BECs, bosons at equilibrium thermalize and, if their density is large enough for their wavefunctions to significantly overlap, eventually condense to a single state.

On the other hand, Vertical-Cavity Surface-Emitting Lasers (VCSELs) are a mature semiconductor technology, where coherent optical conversion is efficiently obtained from a heterostructure. They are routinely used in applications including telecommunications, sensing or illumination. They are usually described as light emitters where the coherent emission threshold is reached when optical gain compensates losses. Thus, this lasing transition is typically an out of equilibrium process, in contrast to BEC.

In this context, we revisit the near-threshold region in a Vertical Cavity Surface Emitting laser and discuss, on the basis of experimental observations, the question of Bose Einstein condensation of photons.

Andrei Vladimirov Weierstrass Institute for Applied Analysis and Stochastics, Germany

Modeling dispersive nonlinear optical cavities using delay differential equations

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We develop an approach to describe dispersive nonlinear optical cavities based on delay differential equations (DDE). This approach is similar to the mean-field models in that it models dispersion by time derivatives. We consider a Kerr cavity with coherent injection used for optical frequency comb generation and derive a neutral DDE model that can be considered a generalization of the Ikeda map. This model becomes conservative with zero losses and injection. Being free from some of the limitations of the Luiato-Lefever equation (LLE) it can be reduced to this equation in the mean-field limit. It is demonstrated that temporal cavity solitons exist in the neutral DDE model not only in the vicinity of the LLE limit, but also beyond it. In the latter case, the solitons are significantly influenced by Cherenkov radiation, which ultimately leads to their destruction. We discuss the analytical conditions that ensure the absence of spurious instabilities in the model equations. We present a methodology for extending the neutral DDE model to include higher-order derivative terms, which are responsible for high-order dispersion. Furthermore, we demonstrate that by incorporating spectral filtering into the model, it can be transformed into a regular DDE. Finally, we discuss the application of the neutral DDE model to study the dynamics of a Kerr cavity with pulsed injection and the effect of dispersion on the pulse characteristics of a passively mode-locked laser.

Giorgio Sonnino, Université Libre de Bruxelles, Belgium

The Golden Ratio: Deciphering the Symmetry of Extreme Black Holes

Giorgio SONNINO and Pasquale NARDONE

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We describe two relevant extreme black holes where their fundamental quantities, i.e., energy, charge, and angular momentum are proportional to the irreducible mass through an irrational number. In particular, i) In the first extreme black hole its fundamental physical quantities are proportional via an irrational number to the irreducible mass. Furthermore, at the poles of its event surface, the Gaussian curvature is zero. Physically, this affects the stability of the black hole, its interaction with external matter, and impacts observational signatures such as gravitational waves and thermodynamic properties. ii) In the second extreme black hole all the physical quantities, including the irreducible mass and the Gaussian Curvature at the Umbilics, align with the golden ratio. The golden ratio appearing in all these fundamental quantities suggests a deep symmetry and self-similarity in the structure of the black hole. An extreme black hole is already at the maximal charge or spin threshold for a given mass. The appearance of the golden ratio might indicate an ultimate state of stability and extremality. Such a configuration could represent a limit where any small perturbation would lead to a more stable configuration or the black hole losing its extreme status (e.g., emitting charge or angular momentum). The above results allow calculating Einstein's cosmological constant" in the (asymptotically) Kerr-Newman-de-Sitter metric. Finally, we estimate the extractible energy of all extreme Kerr-Newmann black holes by reversible and irreversible transformations by distinguishing the families of black holes fully embedded in the Euclidean space (E3) from the ones embedded in the pseudo-Euclidean space.

Shalva Amiranashvili, Weierstrass Institute, Germany

Role of modulation instability in numerical analysis

Modulation instability (MI) is one of the most common and important instabilities in nature. A natural way to describe it is to use a simplified propagation equation for the wave envelope. The equation is solved either analytically (nonlinear Schrödinger equation, NLSE) or numerically (NLSE generalizations), very often using a simple and fast split-step method. However, the numerical solution can be gradually distorted by the appearance of numerical instabilities that look like normal four-wave mixing processes. To avoid them, we developed MI theory directly for the discrete generalized NLSE, solved by an arbitrary splitting method. The comparison between continuous and discrete MI theories provides explicit information about the validity of the split-step methods [1,2].

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Mustapha Tlidi, Free University of Brussels, Belgium

Light bullets and extreme waves in Kerr resonators

We confirm the existence of stable, dissipative light bullets in diffractive and dispersive Kerr cavities. These three-dimensional localized structures are either isolated, bounded, or clustered, and they form well-defined 3D patterns. They are stationary states in the reference frame, moving with the group velocity of light inside the cavity. The number of light bullets and their 3D distribution are determined by the initial conditions. Their maximum power remains constant for a fixed value of the system parameters. The bifurcation diagram clearly shows that this phenomenon is a manifestation of the homoclinic snaking for dissipative light bullets. However, as the injected beam intensity increases, the light bullets lose their stability, and the cavity field exhibits giant 3D pulses of short duration. The statistical characterization of the pulse amplitude reveals a long-tailed probability distribution, indicating the occurrence of extreme events.

Pierre Coullet

Inflection lines of wavefronts and generalized rainbow

Gerard IOOSS

Heteroclinic and orthogonal walls

Youri Soupart, Free University of Brussels, Belgium

Optical pattern turbulence in the liquid crystal light-valve with feedback

The liquid crystal light-valve experiment is a flexible setup suitable for the study of optical dissipative structures, such as stationary patterns, fronts, and localized structures. In two spatial dimensions we observed the formation of a fingerprint type of pattern with permanent reorganization dynamics. By means of statistical and dynamical tools we characterized these dynamics that is chaotic and of intermittent nature. We also show that power-law spectra are associated with the intensity as well as with pseudo-phase and pseudo-amplitude variables with well-defined decay exponents in each case. Finally, a phenomenological non-variational Swift--Hohenberg model allows for reproducing qualitatively the experimental observations.

Medric Argentina, Université Côte d’Azur, INPHYNI, France

Optimum control strategies for maximum thrust production in underwater undulatory swimming

Fishes, cetaceans, and many other aquatic vertebrates undulate their bodies to propel themselves through water. Swimming requires an intricate interplay between sensing the environment, making decisions, controlling internal dynamics, and moving the body in interaction with the external medium. Within this sequence of actions initiating locomotion, biological and physical laws manifest complex and nonlinear effects, which does not prevent natural swimmers to demonstrate efficient movement. This raises two complementary questions: how to model this intricacy and how to abstract it for practical swimming. In the context of robotics, the second question is of paramount importance to build efficient artificial swimmers driven by digital signals and mechanics.

In this study, we tackle these two questions by leveraging a biomimetic robotic swimmer as a platform for investigating optimal control strategies for thrust generation. Through a combination of machine learning techniques and intuitive models, we identify a control signal that maximizes thrust production. Optimum tail-beat frequency and amplitude result from the subtle interplay between the swimmer's internal dynamics and its interaction with the surrounding fluid. We then propose a practical implementation for autonomous robotic swimmers that requires no prior knowledge of systems or equations. Direct fluid-structure simulations confirms the effectiveness and reliability of the proposed approach. Hence, our findings bridge fluid dynamics, robotics, and biology, providing valuable insights into the physics of aquatic locomotion.

Sergio Rica, Pontificia Universidad Catolica de Chile, Chile

Some thoughts on finite-time singularity solutions of the Euler equations: a simpler nonlocal approximation

Thomas Frisch, Université Côte d'Azur, CNRS, Institut de Physique de Nice, France

Vortex nucleation in a superfluid in a sinuous channel

In collaboration with

Sergio Rica (*Instituto de Física, Pontificia Universidad Católica de Chile, Avenida Vicuña Mackenna 4860, Santiago, Chile)*

Sergey Nazarenko (*Université Côte d'Azur, CNRS, Institut de Physique de Nice), 06100 Nice, France)*

The transition from a free vortex superflow to a dissipative vortex flow in a superfluid remains an open problem since in experiments microscopic asperities on the walls are present. In my talk, I will present results obtained by the numerical simulations of the Gross-Pitaevskii equation (Nonlinear Schrödinger equation) in two spatial dimensions along a corrugated wall made of a sinusoidal perturbation. We will show that there exists a critical velocity beyond which vortex nucleation occurs and that this phenomenon may lead to a complex spatio-temporal dynamic. A phase diagram (velocity, amplitude and wavelength) will also be presented. In particular, we will show by means of numerical simulations that the critical velocity depends in a non-monotonous way on the perturbation wavelength.

Reference: T Frisch, S Nazarenko, S Rica, Superflow passing over a rough surface: Vortex nucleation, Physical Review Fluids 9 (2), 024701, (2004)

Claire MICHEL - Université Côte d'Azur, CNRS, INPHYNI, France
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Fluids of light in disordered environment

Merging nonlinear optics and quantum hydrodynamics has given rise to quantum fluids of light, which have gained a great interest in the past few years. Indeed, in properly engineered experimental photonic systems, photons can acquire an effective mass and be in a fully controlled effective (repulsive) interaction. They thus behave collectively as a quantum fluid, and share remarkable common features with other platforms – helium 4 [1,2], atomic Bose-Einstein condensates [3] – such as superfluidity and quantum turbulence.
Fluids of light have been investigated, in one and two-dimensions, in various photonic platforms. The major ones are semi-conductor microcavities [4] and propagating geometries [5] where the propagation axis plays the role of time as sketched in Fig.1. Examples are liquid crystals [6,7], thermal liquids [8], atomic vapours [9,10] and photorefractive (PR) crystals [11-13]. Such experimental optical systems allow a full control and flexibility in the generation, manipulation and observation of photonic fluids. In addition, the nonlinear interactions and the environment can be precisely customed. Consequently, they form ideal systems to investigate light hydrodynamics in more complex environments.
At the Institut de Physique de Nice, we developed a state-of-the-art experimental set-up based on a versatile photonic platform [14] and recently reported a direct experimental detection of the transition to superfluidity in the flow of a fluid of light past an obstacle in a bulk nonlinear [12]. In particular, we currently investigate the evolution of the superfluid of light in disordered environments, and we will present preliminary results.

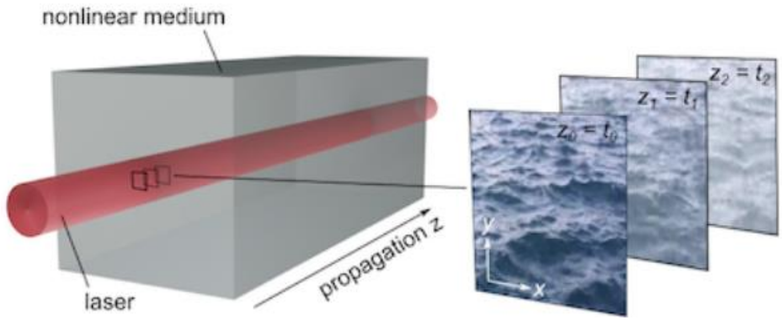

Figure 1 — Fluid of light: propagation of a laser beam in a nonlinear crystal and analogy with the time evolution of a 2D quantum fluid.

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Yves Pomeau,

A case of instability and non equilibrium in everyday world

Rain is a way to transform water in clouds from swarms of tiny airborne droplets into much larger drops falling under their weight and reaching the surface of earth. A statistical theory, inspired by Boltzmann kinetic theory of gases, can explain the growth in size of drops from cloud to rain drops. This is an example of Smoluchowski kinetic equation. The basic process are the two-body collisions: there droplets merge to make a bigger one, something at the root of a growth process generally absent in gases where collisions are elastic. The resulting kinetic equation for droplets is quadratic with respect to the probability distribution of the size of drops and has a solution with a finite time singularity where droplets reach an infinite size. Such a divergence (called gelation in the literature on Smoluchowski equation) exists for an infinite system but does not happen in reality and is replaced by a divergence stopped when growing droplets fall and cross the lower boundary of the cloud.

Sergey Nazarenko, Université Côte d´Azur, Institut de Physique de Nice

Universal scalings in evolving and stationary wave turbulence.

in collaboration with G. Krstulovic, B. Semisalov and Y. Zhu.

Using the Nonlinear-Schrodinger (NLS) equation as a master model, I will present analytical and numerical results concerning several types of universal scaling regimes in wave turbulence. In stationary turbulence, these will be concerned with a revised theory of the famous Kolmogorov-Zakharov (KZ) spectra, both the direct and the inverse cascades. In evolving wave turbulence, the universal scalings manifest themselves in self-similar asymptotics (referred to as "non-thermal fixed points" in some recent papers). The latter behaviour comes in three flavours: self-similarity of the first, second and third kinds respectively. The self-similarity of the first kind appears as a large time asymptotic of the spectrum propagating toward high frequencies. Its scaling is fully determined by energy conservation. The self-similarity of the second kind appears as a finite time blow-up of the wave-kinetic equation (WKE) at the zero frequency: it is related to a physical phenomenon of the Bose-Einstein condensation. The scaling of this self-similarity is non-trivial: it cannot be found from conservation laws, and it is determined by solving a "nonlinear eigenvalue problem". The self-similarity of the third kind appears in the forced-dissipated settings as a final stage of transition to the KZ spectrum and it takes the form of a frequency-space wave reflected from the low-frequency dissipative range. Its scaling is inherited from the previous (blowup) self-similar stage. I will present numerical results testing the analytical predictions arising from simulations of both the WKE and the 3D NLS equation.

Giorgio Krstulovic, Université Côte d´Azur, Institut de Physique de Nice, France

2D classical and quantum turbulence and the fluctuations of velocity circulation

In this talk, I will present new results on 2D classical and quantum turbulence using simulations of the incompressible Navier-Stokes and the Gross-Piteavskii model. We first show the existence of an enstrophy cascade in the Gross-Pitaevskii model. Then, we use the velocity circulation over loops of a given size to proxy turbulent fluctuations at that scale. This quantity is a real number in classical fluids, whereas it takes discrete values in quantum flows. We observe thatlow-Mach 2D quantum turbulence shares the same statistics as classical turbulence in both the inverse energy and the direct enstrophy cascades, including intermittency corrections. When compressible effects are non-negligible, deviations from classical incompressible turbulence are observed only for high-order statistics.

Gian Luca Lippi, Université Côte d´Azur, Institut de Physique de Nice, France

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System size and dynamics: a laser-based illustration

A multitude of observations and models have demonstrated a correlation between spatial extent and spatio-temporal dynamics across a range of systems. Nevertheless, it is less straightforward to anticipate a correlation between reservoir size and temporal dynamics in a spatially homogeneous system. A class of systems that is particularly well-suited for these investigations has emerged in the past decades with the development of micro- and nanolasers. These devices are so small that no intrinsic spatial dynamics can take place. Driven by technological interest and the potential for advanced applications, their characterisation has revealed the emergence of a surprising scale dependence stemming from the size of their energy reservoir. This dependence is evidenced by experimental and numerical evidence for the modification that is induced by the system size, examples of new dynamics and the emergence of a regime where determinism and stochasticity coexist to give rise to complex phenomena.

Mathias Marconi, INPHYNI, Université Côte d'Azur

Generation, manipulation and spectral analysis of laser temporal localized structures

Temporal Localized Structures are optical pulses that can be addressed independently in an optical resonator. In this presentation, I will show how such state of light can be generated in a passively mode-locked Vertical External-Cavity Surface-Emitting Laser closed by a saturable absorber mirror. I will also describe the mechanisms that can be implemented in order to manipulate these structures via a pump perturbation or optical feedback. Lastly, a recent experimental spectral analysis of the optical frequency combs resulting from the pulsed dynamics of the laser shows that, for a given number of pulses in the cavity, multiple combs can coexist and exchange their stability without affecting the intensity dynamics of the pulses.

Arnaud Garnache, IES, CNRS Université de Montpellier, France

Non-linear dynamics of multimode semiconductor laser: phase instability and route to single state regime

Spectro-temporal emission dynamics of a multimode broadband interband semiconductor laser have been investigated experimentally and theoretically. Non-linear dynamics of a III–V semiconductor quantum well surface-emitting laser reveal the existence of a modulational instability, observed in the anomalous dispersion regime. An additional unstable region arises in the normal dispersion regime, owing to carrier dynamics and beating, and has no analogy in systems with fast gain recovery. The interplay between cavity dispersion and phase sensitive non-linearities is shown to affect the character of laser emission with phase turbulence, leading to regular selfexcited oscillations of mode intensity, self-mode locking, and single-frequency emission stabilized by spectral symmetry breaking. Such physical behavior is a general phenomenon for any laser with a slow gain medium relative to the round trip time, in the absence of spatial inhomogeneities.

Christophe Raufaste, Université Côte d´Azur, Institut de Physique de Nice

Shape and dynamics of menisci at the contact with soap films

Soap films and bubbles are micron-thick liquid membranes that both delight children and serve as the basis for numerous applications, particularly through their role in liquid foams. Their stability and shape are intrinsically linked to the menisci at their contact, resulting in specific flow patterns and nonlinear effects. In this presentation, I will provide examples of the typical dynamics associated with deformable interfaces and their impact on the stability of soap films, bubbles, and bubble assemblies.

Jeremy Bec, Université Côte d´Azur, Institut de Physique de Nice

Harnessing swarms to optimize the displacement of interacting micro-swimmers

We explore the potential of leveraging self-organization in swarms of interacting self-propelled particles to optimize their displacement in confined geometries. Using a discrete model with Vicsek-like interactions, we examine how channel geometry and external fluid flow influence spontaneous pattern formation and transport properties. Without flow, wall-induced particle accumulation leads to clogs and band formations that obstruct movement. In the presence of flow, fluid-induced vorticity disrupts orientational order, causing particles to align against the flow. This detailed analysis of collective behaviors enables us to develop global strategies for controlling particle alignment and optimizing displacement. We apply reinforcement learning techniques to devise policies that enhance transport efficiency. This work offers new insights for applications involving swimming micro-robots, such as targeted drug delivery and environmental monitoring.