FOURTH ‘RIO DE LA PLATA’ WORKSHOP ON LASER DYNAMICS AND NONLINEAR PHOTONICS

Organizers:

Cristina Masoller (Universitat Politecnica de Catalunya, Spain)
Igal Brener (Sandia National Laboratories, USA)

Acknowledgements:

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Held at Argentino Hotel, Piriapolis, Maldonado, Uruguay
December 8 - December 11, 2009

PROGRAM

DAY 1	Tuesday – 8 December
8:30am – 8:55am	**Registration**
Chair person	*Cristina Masoller*
9:00am – 9:40am	**Cornelia Denz** (Münster, Germany *Nonlinear wave propagation in optically-induced complex photonic lattices*
9:40am– 10:20am	**Alejandro Yacomotti** (Marcoussis, France) *Nonlinear and ultrafast 2D Photonic Crystals*
10:20am – 10:50am	Coffee Break
Chair person	*Igal Brener*
10:50am – 11:30am	**Tom Gavrielides** (London, UK) *Delay dynamics of two diode lasers coupled by orthogonal modes: metastable square waves*
11:30am – 12:10 am	**Kathy Lüdge** (Berlin, Germany) *Nonlinear dynamics of semiconductor quantum-dot lasers with delayed optical feedback*
12:10pm – 12:50 pm	**Bryan Kelleher** (Cork, Irlanda) *'Experimental phasor plots for optically injected lasers*
12:50 pm – 2:30 pm	**Lunch**
Chair person	*Cornelia Denz*
3:10pm – 3:50pm	**Laurent Larger** (Besançon, France) *Electro-optic phase chaos: principle, modeling, and application to chaos communication up to 10Gb/s over 120km*
3:50pm – 4:30pm	**Maxime Jacquot** (Besançon, France) *Feedback filter effects in the dynamics of a tunable DBR laser with nonlinear delay optoelectronic loop*
4:30pm – 5:00pm	Coffee Break
Chair person	*Laurent Larger*
5:00pm – 5:40pm	**Stefano Beri** (Brussels, Belgium) *The stochastic and nonlinear dynamics of semiconductor ring lasers*
5:40pm – 6:20pm	**Cristina Masoller** (Terrassa, Spain) *Multi-stability and chaotic transient LFF dynamics in semiconductor lasers with time-delayed optical feedback*

DAY 2	Wednesday – 9 December
8:30am – 8:55am	**Registration**
Chair person	*Roberta Zambrini*
9:00am – 9:40am	**Martine Chevrollier** (João Pessoa, Brazil) *Levy flights of photons scattered in resonant atomic vapors*
9:40am– 10:20am	**Alejandro Hnilo** (Villa Martelli, Argentina) *Quantum paradoxes and time series analysis*
10:20am – 10:50am	Coffee Break
Chair person	*Martine Chevrollier*
10:50am – 11:30am	**Roberta Zambrini** (Palma de Mallorca, Spain) *Nonlocality and off-axis feedback in tranversally multimode optical devices*
11:30am – 12:10 am	**Jason Gallas** (Porto Alegre, Brazil) *On the coexistence of pulsating and steady states in injection-locked semiconductor lasers*
12:10pm – 12:50 pm	**Jorge Tredicce** (Nice, France) *Cavity soliton laser*
12:50 pm – 2:30 pm	**Lunch**
Chair person	*Miguel Hoyuelos*
2:30pm – 3:10pm	**J. R. Rios Leite** (Recife, Brazil) *Advances and retards in the synchronism of chaotic lasers with feedback*
3:10pm – 3:50pm	**Marcos Oria** (João Pessoa, Brazil) *Frequency dynamics of semiconductor lasers*
3:50pm – 4:30pm	**Uwe Bandelow** (Berlin, Germany) *Nonlinear and nonlocal models for ultrashort optical pulses*
4:30pm – 5:00pm	Coffee Break
Chair person	*Marcos Oria*
5:00pm – 5:40pm	**Riccardo Meucci** (Firenze, Italy) *Chaotic dynamics in class B-lasers: Experiments, models and applications*
5:40pm – 6:20pm	**Ernst Wintner** (Wien, Austria) *Development of a monolithic diode-pumped passively Q-switched Nd:YAG laser*

DAY 3	Thursday – 10 December
Chair person	*Ricardo Depine*
9:00am – 9:40am	**Diego Dalvit** (Los Alamos, USA) *Towards Casimir force repulsion using metamaterials*
9:40am– 10:20am	**John O'Hara** (Los Alamos, USA) *Terahertz technology progress with dynamic metamaterials*
10:20am – 10:50am	Coffee Break
Chair person	*Rafael Piestun*
10:50am – 11:30am	**Cid de Araújo** (Recife, Brasil) *Surface - plasmons enhanced nonlinear spectroscopy of random media*
11:30am – 12:10 am	**Roberto Merlin** (Ann Arbor, USA) *Metamaterials, optical magnetism and the Landau-Lifshitz permeability argument*
12:10pm – 12:50 pm	**Igal Brener** *2D and 3D metamaterials for the thermal infrared*
12:50 pm – 2:30 pm	**Lunch**
Chair person	*Riccardo Meucci*
2:30pm – 3:10pm	**Jean-Jacques Greffet** (Paris, France) *Contribution of surface phonon polaritons to radiative heat transfer at the nanoscale*
3:10pm – 3:50pm	**Ricardo Depine** (Buenos Aires, Argentina) *Surface polaritons at the boundary of a corrugated metamaterial*
3:50pm – 4:30pm	**Alexander Popov** (Wisconsin, USA) *Nonlinear optics of backward waves in negative-index plasmonic metamaterials*
4:30pm – 5:00pm	Coffee Break
Chair person	*Jason Gallas*
5:00pm – 5:40pm	**Rafael Piestun** (Boulder. USA) *Diffraction unlimited 3D imaging - Foundations of a revolution in far-field optical nanoscopy*
5:40pm – 6:20pm	**Miguel Hoyuelos** (Mar del Plata, Argentina) *Cavity equations for a positive or negative refraction index material with electric and magnetic non-linearities*
8:30 pm – 10:30 pm	**Conference Dinner (asado)**

DAY 4	**Friday – 11 December**
Chair person	*Cid de Araujo*
9:00am – 9:40am	**Arturo Lezama** (Montevideo, Uruguay) *Light squeezing by single passage in an atomic vapor*
9:40am– 10:20am	**Paulo Nussenzveig** (Sao Paulo, Brazil) *Three-color entanglement*
10:20am – 11:00am	**Alfredo Dubra** (Rochester, USA) *Latest advances in retinal imaging*

TALKS

Uwe Bandelow (bandelow@wias-berlin.de)
Weierstrass Institute for Applied Analysis & Stochastics, Berlin, Germany

Nonlinear and nonlocal models for ultrashort optical pulses

Ultrashort pulses contain only a few optical cycles, and corresponding mathematical models are rare. The well-established theory of envelope equations is no longer appropriate as the frequency spectrum is widened too much.
In the frame of short pulse equations we have found a family of ultrashort traveling-pulse solutions of Maxwell equations in a Kerr medium within the anomalous dispersion regime. We directly observed a continuous transition between envelope and non-envelope solitons and obtained the shortest possible pulse shape and duration in a given medium.
Further, we have empirically found that the complex refraction index of a bulk medium is excellently reproduced by its Pade approximant.
On this basis we constructed a very general pseudo-differential equation for pulse propagation, which contains all previous models as special cases. In contrast to common envelope equations, this new class of nonlocal models easily accounts for basic physical restrictions, as the correct asymptotics of refractive index for large frequencies and the causality principle.
In contrast to Taylor approximants the Pade approximants avoid the artificial numerical stiffness and provide much better overall approximation even in the case that complex resonances with related dissipation are important.

Stefano Beri (Stefano.Beri@vub.ac.be)
Department of Applied Physics and Photonics, Vrije Universiteit Brussel, Brussels, Belgium

The stochastic and nonlinear dynamics of semiconductor ring lasers

Semiconductor Ring Lasers (SRLs) are a modern class of lasers whose active cavity is characterized by a circular geometry. SRLs have attracted attention due to their potential in applications such as all-optical memories and data treatment.
This talk will address the stochastic and nonlinear dynamics of SRL, putting emphasis on the experimentally observable effects that are a consequence of the ring symmetry and that can be theoretically addressed in a device-independent way by investigating the invariant manifolds of the system.
We will show how to experimentally control the internal parameter of the SRL such as the mode-coupling and how to break the ring symmetry in a controllable and reversible way. In particular, we will discuss non-Arrhenius features appearing in the residence time distribution in the symmetric SRL as well as the anatomy of a mode-hopping event. Multi-stability between three coexisting operating states will be disclosed.
Finally, when the symmetry of the system is broken in a controlled way, excitability will be revealed, suggesting that SRL are possible candidates for scalable optical excitable units which could be in principle integrated on chip with densities exceeding 100000/cm2.

Martine Chevrollier[1] (martine@otica.ufpb.br), N. Mercadier[2], W. Guérin[2] and R. Kaiser[2]
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Levy flights of photons scattered in resonant atomic vapors

Random walk processes are often interpreted through the use of Gaussian statistics, which essentially characterizes them by a mean value and a finite variance of the steps distribution

P(x). However, an increasing number of physical systems are found to elude this interpretation and to show unusual transport properties: in these systems, rare events dominate the overall dynamics, and the variance of the steps distribution is infinite. These so-called Lévy flights are characterized by heavy-tail steps distributions, with asymptotic decays $P(x) \sim 1/x^{\alpha}$ with $\alpha<3$ [1]. Levy flights of photons are known to occur in resonant vapors and have been numerically studied [2], but their experimental observation is elusive because in most systems where they occur, their signature can only be inferred from an averaging over many random steps, in a regime of multiple scattering. We present experimental measurements of the elementary step process for photons in a hot vapor and evidence their propagation mode in the vapor as Lévy flights [3].

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[2] E. Pereira *et al*., Phys. Rev. Lett. **93**, 120201 (2004).
[3] N. Mercadier *et al*., Nature Physics **5** (8), 602-605 (2009).

Diego Dalvit (dalvit@lanl.gov)
Theoretical Division, Los Alamos National Laboratory, USA

Towards Casimir force repulsion using metamaterials

In this talk I will give a brief review of quantum vacuum dispersive forces, generally known as Casimir forces. Such forces offer challenges and opportunities to nanotechnology, such as "stiction" in nanomachines and contactless force transmission. The holy grail in the field is to achieve Casimir repulsion (also known as "quantum levitation") between air-separated surfaces. I will discuss recent proposals of using different types of metamaterials, including magnetic, polaritonic, plasmonic, and chiral metamaterials, to achieve Casimir repulsion.

Cid B. de Araújo (cid@df.ufpe.br)
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Surface - plasmons enhanced nonlinear spectroscopy of random media *

Nonlinear optical spectroscopy of composites containing metallic nanoparticles will be presented. Enhanced nonlinear susceptibilities and increased luminescence efficiencies due to the influence of surface Plasmons will be reported for photonic glasses and colloids. Phenomena related to frequency generation, stimulated emission and energy transfer processes will be discussed. The optical response of the materials is controlled changing the volume fraction occupied by the nanoparticles and their physical characteristics. The selection of the materials is based on their potential for uses in photonic devices such as colored displays, random lasers, temperature sensors, optical limiters and all-optical switches.

Cornelia Denz (denz@uni-muenster.de)
Institut für Angewandte Physik und Center for Nonlinear Science, Universität Münster, Germany

Nonlinear wave propagation in optically-induced complex photonic lattices

Wave propagation in periodic nonlinear structures is associated with many exciting possibilities to control, mold and route light for future applications in all-optical information processing. In contrast to light propagation in prefabricated permanent structures, an increased flexibility can be achieved when light itself induces its own periodic structure through the nonlinear response of the material. Due to the ability of the photorefractive effect to create refractive index changes at very low laser powers and to realize adaptive and reconfigurable structures, the formation of multidimensional, nonlinear, optically induced lattices can be easily achieved. The interplay between periodicity and nonlinearity has been shown to cause a variety of fascinating nonlinear effects, among them discrete solitons, Zener Tunneling and Bloch oscillations.

In this presentation, we present an overview of several approaches to realize on the one hand complex one-, two- and even three-dimensional photonic lattices. Especially, we focus on more complex lattice geometries as superlattices or three-dimensional crystallographic and quasi-crystallographic lattices. On the other hand, we will demonstrate nonlinear wave propagation leading to slow light in one-dimensional, phase-engineered lattices, and discrete spatial solitons or clusters of vortices in two-dimensional lattices.

Ricardo A. Depine (rdep@df.uba.ar)
Grupo de Electromagnetismo Aplicado, Departamento de Física, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires (Argentina)

Surface polaritons at the boundary of a corrugated metamaterial

It is known that, under certain particular conditions, the interface between two different isotropic dielectric materials can support the propagation of surface polaritons (SPs), which is electromagnetic waves that propagate along the interface with their fields strongly localized near the interface. Hence, the interface forms a peculiar resonator with eigenmodes that are localized along the normal to the interface and can propagate freely along the interface. Since SPs propagate with a wave vector greater than that corresponding to a free space photon of the same frequency, resonances cannot be excited by a propagating incident electromagnetic wave on a flat surface.
Most of the literature in this field has been devoted to p- (or TM-) polarized SPs, which occur at interfaces between isotropic materials with opposite signs of the real part of their dielectric permittivities, i.e., between insulators (positive permittivity) and metals or plasmas below a critical frequency (generally complex permittivity with a negative real part). Apart from the well-known p-polarized SP supported by insulator-metal interfaces, s- (or TE-) polarized SPs can be excited if the materials separated by the interface have a real part of their magnetic permeabilities with opposite signs. This condition cannot be easily attained with conventional (generally nonmagnetic) materials, which is why the vast majority of research in the last century was focused on p-polarized SPs involving nonmagnetic media. Possibilities have been widened with the recent advent of metamaterials (MMs), artificially constructed composites exhibiting electromagnetic properties that are difficult or impossible to achieve with conventional naturally occurring materials. Key representatives of this class of materials are MMs with negative index of refraction, a property that arises in nonabsorbing media with a negative electric permittivity together with a negative magnetic permeability in the same frequency range.
In this contribution we discuss the propagation and excitation of SPs along the boundary of a corrugated MM, providing numerical examples that illustrate how the corrugation affects the propagation characteristics of the SPs and the resonant optical response of the boundary. Contrary to what has been known so far for the SP-photon coupling mechanism in metallic boundaries, with SPs always radiating into the "air side", we find that the corrugated boundary between a conventional dielectric and a negative refractive index MM can exhibit novel SP-photon coupling regimes, with SPs radiating either into the conventional dielectric but not into the MM medium, or into the MM medium but not into the conventional dielectric, or into both the conventional dielectric and the MM medium.

Alfredo Dubra (adubra@cvs.rochester.edu)
University of Rochester Eye Institute, Rochester, USA

Latest advances in retinal imaging

In vivo retinal imaging is a critical part of the clinical diagnosis of eye disease, and a powerful tool for basic eye researchers. Recent technical advances and cost reduction in detectors, digital electronics, adaptive optics and light sources have led to a revolution in ophthalmic instrumentation. Two prime examples of such devices are the confocal scanning laser ophthalmoscope and the optical coherence tomograph (OCT). The former, developed by combining robust low-cost, high quantum efficiency detectors and compact lasers, is used in various modalities to produce reflectance, fluorescence and polarization images. The axial sectioning resulting from the use of a confocal aperture increases contrast and also allows one to generate 3-dimensional maps of structures, such as the optic nerve cup. Broadband sources, such as super-luminescent diodes and short pulsed lasers, together with optical fibers, are the key components for OCT systems. This phase imaging modality provides unprecedented axial sectioning, which is limited only by the source bandwidth and is currently about an order of magnitude below the diffraction limit. The incorporation of adaptive optics to these imaging modalities is dramatically changing the way we look at the retina, shifting the emphasis from the macroscopic to the microscopic scale. The resulting images, that show cellular resolution, require a radically different interpretation. Being able to resolve cell mosaics in vivo has the potential to increase both the sensitivity and specificity of clinical diagnosis, while also being able to aid basic researchers studying eye disease pathways and evaluating new treatments. With the increase in lateral and axial resolution provided by adaptive optics, a new generation of imaging modalities is in development and is heavily relying on the development of new light sources. Examples of these light sources are super-continuum CW sources, in the visible range for spectroscopic and fluorescence imaging, and CW entangled photon sources, for multi-photon imaging, that could provide increased axial sectioning and reduce photochemical damage.

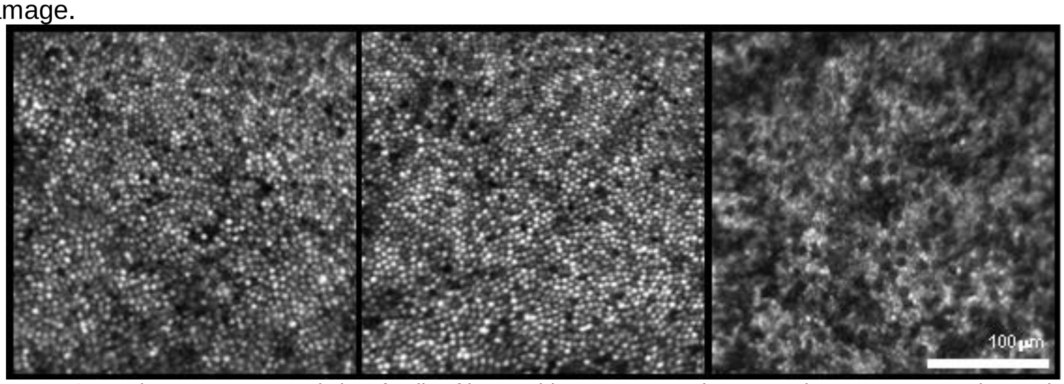

Figure 1 - Cone photoreceptor mosaic in a family of human blue cone monochromats. The two cone mosaics on the left correspond to the family females (genetic carriers) look complete, while the mosaic of the male (rightmost panel) is drastically different. The black holes in the mosaic of the male correspond to cone photoreceptors that are normal in size for the retinal eccentricity, but appear not to be functional (i.e. not wave-guiding). The surrounding rod photoreceptors are swollen to the extent that they can be resolved. In healthy retinas, rods are below the resolution limit.

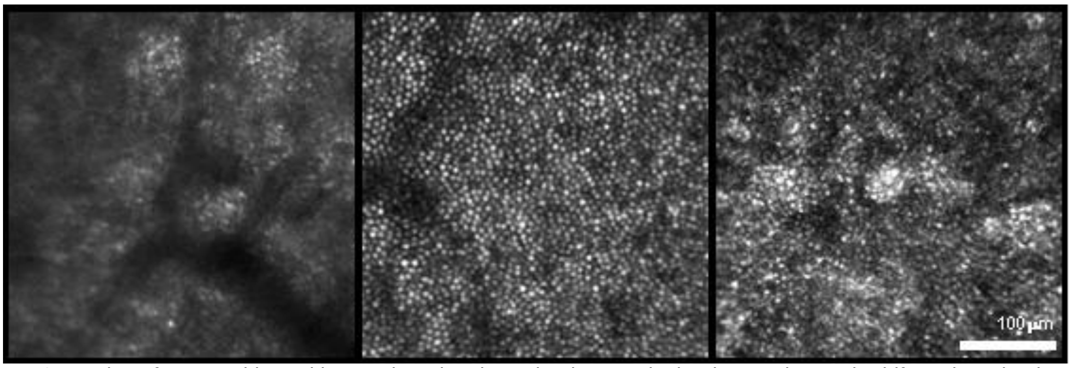

Figure 2 - Retinas from a subject with macular telangiectasia, that results in abnormal vascular bifurcations (T-shaped), and two subjects with the genetic condition known as cone-rod dystrophy, which has not yet manifested in the son (middle panel) and it is quite advanced in the mother (right panel) who is already legally blind.

Jason A. C. Gallas (jason.gallas@gmail.com)
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On the coexistence of pulsating and steady states in injection-locked semiconductor lasers

Analytical investigations of injection-locked semiconductor lasers have shown the coexistence of steady and pulsating solutions. In particular, it was shown that for moderate and large negative detunings the coexistence of steady and pulsating intensities is quite unusual because they correspond to separate branches not connected by Hopf bifurcation points. In addition to the coexisting steady state and pulsating solutions for large negative detunings, two distinct pulsating regimes where reported in the literature to coexist for moderately large negative detunings. Although a number of pulsating regimes have been described in the literature, their relative abundance has not been discussed. In the present communication we close this gap. We report detailed computations of Lyapunov phase diagrams characterizing the parameters where pulsating solutions are predicted as well as the relative amplitude of regions of coexistence.

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Delay dynamics of two diode lasers coupled by orthogonal modes: metastable square waves

We present a detailed analysis for the emission dynamics of two semiconductor lasers coupled through the non-lasing delayed orthogonal polarization mode. The presentation includes experiments, numerical modeling and bifurcation analysis. The computations reveals that the experimentally observe asymmetric wave square and other waveforms similar waves are metastable. We present an analytical coupled two neuron model that captures the essential features of the metastable waveforms and show analytically that they approach and vanish exponentially to the steady states for long delays. We review the steady states stable and unstable and show that the metastable states are indeed supported by the spontaneous noise present in diode laser. We also present numerical results that provide a support for the experimentally observed waveforms.

E. Rousseau[1], A. Siria[2], G. Jourdan[2], S. Volz[3], F. Comin[2], J. Chevrier[2] and **J. J. Greffet**[1]
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Contribution of surface phonon polaritons to radiative heat transfer at the nanoscale

It is usually taken for granted that the radiative flux has an upper bound given by the blackbody radiation. Yet, the radiative heat transfer between two parallel surfaces can be enhanced by several orders of magnitude at the nanoscale. The enhancement is particularly important when surface phonon polaritons can be excited. In this paper, we report the first quantitative comparison between data and theory [1].
Heat can be exchanged between two surfaces through emission and absorption of thermal radiation. This is described using Planck's law. In the late sixties, an anomalous radiative heat transfer between at metallic surfaces was reported by Domoto at cryogenic temperatures [2] and by Hargreaves [3] at room temperature. In both cases, an increase of the flux was measured for separation gaps in the micrometer range. A theoretical explanation was given by Polder and Van Hove [4] in the framework of stochastic electrodynamics introduced by Rytov a few years before.
The increase of the flux can be viewed as energy tunneling through the gap between the surfaces. The first attempt to detect quantitatively the heat transfer for submicron gaps was reported by Xu et al.[5] but was inconclusive. More recently, the Oldenburg group has demonstrated [6] unambiguously a heat transfer that increases as the distance decreases in the submicron range. They studied the heat transfer between a gold coated scanning tunneling microscope (STM) and a plate of gold or GaN. Unfortunately, the geometry of the experiment was too complex to allow a quantitative comparison with theory. It was predicted that heat transfer between polar dielectric surfaces is more efficient because of surface-phonon polariton contribution [7]. The first measurements between two dielectric materials have been reported by the MIT group[8]. They measured the heat transfer between a sphere and a plate both made of

silica. While these effects have already been observed, a detailed quantitative comparison between theory and experiments in the nanometer regime is still lacking. Here, we describe an experimental set-up that allows measuring the conductance for gaps varying between 30 nm and 2:5 μm. Our measurements pave the way to the design of submicron nanoscale heaters that could be used for heat-assisted magnetic recording or heat-assisted lithography.

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Quantum paradoxes and time series analysis

The Einstein-Podolsky-Rosen (EPR) paradox is the most enduring and challenging problem in the history of Physics. It refers to a contradiction between Quantum Mechanics (QM) and a set of intuitive, hard to leave notions on the separability of natural phenomena and even on the existence of a real world outside our own mind. After being discussed by four generations of physicists (amounting a number of brilliant individuals much larger than the sum of all the previous generations) and still remain unsolved, it seems clear that it will hardly be elucidated by mere thinking, and that new experimental data may be the key. Many experiments have measured stationary probabilities confirming the QM predictions, but "the vital time factor", as John S. Bell named it, has been left almost unexplored. The so-called "non ergodic theories", on the other hand, reconcile QM with intuition by hypothesizing that the apparent randomness at the quantum level is the consequence of some complex, perhaps chaotic, nonlinear dynamics underlying. These dynamics are not detectable by measuring averaged rates, but they may be revealed through the analysis of the series formed by recording the time of observation of each single event (the detection of a photon, in our case). Even though the hope of success is small, the consequences of actually finding them are so important that the search is anyway justified. In this talk, results of the search of dynamics in the data of time resolved EPR-Bohm type optical setups are reviewed or presented, and also a description of the characteristics the ideal experiment to test the non-ergodic hypothesis should have.

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Departamento de Física, Universidad Nacional de Mar del Plata, Argentina.

Cavity equations for a positive or negative refraction index material with electric and magnetic non-linearities

We study evolution equations for electric and magnetic field amplitudes in a ring cavity with plane mirrors. The cavity is filled with a positive or negative refraction index material with third order electric and magnetic non-linearities. Two coupled non-linear equations for the electric and magnetic amplitudes are obtained. We prove that the description can be reduced to one

Lugiato Lefever equation with generalized coefficients. A stability analysis of the homogeneous solution, complemented with numerical integration, shows that any combination of the parameters should correspond to one of three characteristic behaviours.

Maxime Jacquot (maxime.jacquot@univ-fcomte.fr), Romain Martinenghi, and Laurent Larger.
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Feedback filter effects in the dynamics of a tunable DBR laser with nonlinear delay optoelectronic loop

An optoelectronic wavelength nonlinear delay dynamics is investigated experimentally. The particular influence of the filtering feedback determining the differential process of the dynamics is reported. Multiple time scales phenomena ranging over several orders of magnitude are observed, under various parameter and filtering feedback conditions. Time-frequency approach with wavelet transform is proposed in order to analyze multi scale behavior of the recorded time series. The influence of the characteristic delay frequency, and its location in the Fourier spectrum with respect to the filtering feedback cut-off is also reported. The observed behavior is connected to various applications in random number generation, chaos communications, and high spectral purity microwave generation.

Laurent Larger (laurent.larger@univ-fcomte.fr), R. Lavrov, M. Jacquot, M. Peil
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Electro-optic phase chaos: principle, modeling, and application to chaos communication up to 10Gb/s over 120km

A novel electro-optic nonlinear delay architecture is presented, which is combining optical phase modulation, differential phase shift keying demodulators of standard DPSK optical communication techniques, and the dynamical principles of the Ikeda ring cavity. Fast, reliable, highly complex, and controlable chaos can be generated. Especially designed for high speed chaos communications, the set-up demonstrated for the first time the capability of 10Gb/s transmission, over an installed metropolitan network of more than 100km. The flexibility of the setup will be also emphasized in order to improve the security of this physical layer encryption.

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Instituto de Física, Facultad de Ingeniería, Universidad de la República, Montevideo, Uruguay

Light squeezing by single passage in an atomic vapor

The properties of light fluctuations resulting from resonant interaction with an atomic system are revisited. I comment on recent experiments showing significant light squeezing after single passage of light through an atomic vapor. A simple theoretical picture providing new insight into the relevant mechanisms is presented.

Kathy Lüdge, C. Otto, and E. Schöll (luedge@physik.tu-berlin.de)
Institut für Theoretische Physik, Technische Universität Berlin, Germany

Nonlinear dynamics of semiconductor quantum-dot lasers with delayed optical feedback

In this work we investigate the complex dynamics of semiconductor quantum dot (QD) lasers subjected to optical feedback from an external cavity generating a time-delayed feedback signal. The system is modeled by a modified Lang-Kobayashi equation for the electric field combined with microscopically based rate equations for the carriers in the quantum dots and surrounding wetting layer. By varying the feedback strength we obtain complex bifurcation scenarios. For large linewidth enhancement factor we find a bifurcation cascade leading to chaotic regions alternating with short regions of periodic intensity pulsations and stable steady state (cw) operation. This resembles the behavior found in quantum well lasers. However, for low linewidth enhancement factor, typical for QD devices, the laser exhibits reduced feedback sensitivity and performs stable cw operation over a wide range of increasing feedback strength. The microscopic scattering rates that determine the damping rate and relaxation oscillation frequency of the solitary laser do not influence the general bifurcation scenarios discussed here but they determine their quantitative position, i.e. the critical feedback strength.

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Multi-stability and chaotic transient LFF dynamics in semiconductor lasers with time-delayed optical feedback

Multi-stability of coexisting attractors often results in long chaotic transients, in particular, in networks of coupled systems and in time-delayed systems. In the case of systems with delayed feedback loops, the delay in the feedback can induce a set of coexisting attractors which do not exist in the un-delayed case. Coexistence of attractors can lead to long transients before a system reaches a stationary state, and noise can turn the transient dynamics into noise-sustained dynamics.

I will illustrate these ideas about the interplay of multi-stability, noise, and transient dynamics using as an example a semiconductor laser with optical feedback from an external mirror. The feedback has a time delay because of the finite round-trip time of the light in the external cavity. The delayed optical feedback induces a set of coexisting fixed points which are called external cavity modes (ECMs). The regime of low-frequency fluctuations (LFF) is a feedback-induced regime where the laser output intensity randomly and abruptly drops to zero and recovers gradually. Based on the standard model for semiconductor lasers with optical feedback (the Lang- Kobayashi model), LFFs have been understood as due to chaotic itinerancy among destabilized ECMs. However, in the deterministic Lang- Kobayashi model and for a large range of realistic parameters, the LFFs are a transient dynamics towards a stable ECM. This transient can become, in the presence of noise, a noise-sustained chaotic behavior. I will present a statistical analysis of the lifetime of the LFF regime and discuss the possibility of controlling the LFF lifetime via fine tuning the laser parameters that control the position of the coexisting ECM fixed points in the phase space.

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Metamaterials, optical magnetism and the Landau-Lifshitz permeability argument

Homogeneous composites, or metamaterials, made of dielectric or metallic particles are known to show magnetic properties that contradict arguments by Landau and Lifshitz [*Electrodynamics of Continuous Media* (Pergamon Press, Oxford, 1960), p. 251] indicating that the magnetization and, thus, the permeability loses its meaning at relatively low frequencies. Here we show that these arguments do not apply to composites made of substances with $\kappa_S = \mathrm{Im}\sqrt{\varepsilon_S} >> \lambda / \ell$ or $n_S = \mathrm{Re}\sqrt{\varepsilon_S} \sim \lambda / \ell$ (ε_S and ℓ are the complex permittivity and the characteristic length of the particles, κ_S and n_S are, respectively, the extinction coefficient and the refractive index, and $\lambda >> \ell$ is the vacuum wavelength). Our general analysis is supported by studies of split-rings, one of the most common constituents of electromagnetic metamaterials, and spherical inclusions. An analytical solution is given to the problem of scattering by a small and thin split ring of arbitrary permittivity. Results reveal a close relationship between ε_S and the dynamic magnetic properties of metamaterials. For $\left|\sqrt{\varepsilon_S}\right| << \lambda / a$ (*a* is the ring cross-sectional radius), the composites exhibit very weak magnetic activity, consistent with the Landau-Lifshitz argument and similar to that of molecular crystals. In contrast, large values of the permittivity lead to strong diamagnetic or paramagnetic behavior characterized by susceptibilities whose magnitude is significantly larger than that of natural substances.

The double constraint $\kappa_S >> \lambda / \ell >> 1$ (or, $n_S \sim \lambda / \ell >> 1$ if $\kappa_S << n_S$) poses severe limitations for attaining magnetism at arbitrarily high frequencies. Because they have a large extinction coefficient, metals are to be favored at optical frequencies. Since $\varepsilon_S \approx -\omega_P^2 / \omega^2$ for $\omega\tau >> 1$, the constraint becomes $\lambda >> \ell >> \lambda_P$. The measured values of the permittivity for noble metals indicate that magnetism can coexist with the effective-medium condition for frequencies up to $\sim 1.5\times 10^{14}$Hz ($\lambda \sim 2.5$ μm).

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Chaotic dynamics in class B-lasers: Experiments, models and applications

Chaos in a single mode laser was numerically observed in 1963 [1] as early as the Lorenz model [2]. In fact the two dynamics are ruled by the same equations for three coupled variables [3]. However, in practical laser systems, the time scales associated with different variables are usually widely different, thus the relevant dynamics takes place with only one or two dominant variables. We have called class A and B, respectively, these dynamical situations [4]. Adding a third dynamical variable to a class B laser, single mode chaos has been demonstrated. The experimental implementation was realized with by modulation [5] or by feedback [6].

We present methods to control chaotic dynamics as well as to suppress bursting phenomena emerging in a chaotic laser as a consequence of an internal crisis. We also discuss the problem of attractor selection in a bistable regime with jumps between independent attractors and give evidence of Coherence and Stochastic Resonance. The CO_2 and semiconductor laser with optoelectronic feedback will be considered. Furthermore, we report on different forms of synchronization of coupled lasers. Identical, phase and generalized synchronization will be discussed in autonomous and non autonomous systems dealing with class B lasers [7-9].

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Three-color entanglement

Continuous-variable systems have been increasingly investigated for applications in Quantum Information Science. Most of these rely on the creation of multipartite entanglement, for the implementation of sophisticated information tasks. Since many different physical systems are under consideration as the building blocks of these new technologies, hybrid architectures are a likely strategy for initial implementations. Exchanging information between different physical systems is thus important and will require entangled light beams capable of interacting with each of these systems. We have recently been able to directly generate entanglement between

more than two continuous-variable systems, a strategy that has enabled entanglement of three bright light beams all of different wavelengths. We further observed the phenomenon of so-called entanglement sudden death, for the first time in a continuous-variable system.
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Terahertz technology progress with dynamic metamaterials

The terahertz frequency regime (0.1-10 THz) represents a relatively undeveloped portion of the electromagnetic spectrum. Where natural materials have proven insufficient for developing THz technology, metamaterials are beginning to prove highly useful. Our work shows that THz devices that are typically difficult to create can often be easily fabricated and understood, all while providing unsurpassed performance. These devices include amplitude and phase modulators, frequency-agile filters, reflection-less optics, spatial light modulators, and polarization control devices. We present our experimental results as well as some modeling results that reveal some of the operational principles at work.

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Recent progress in the study of the spectral behavior of semiconductor lasers will be discussed. Particularly, we will focus on the technique of orthogonal feedback and its use to generate bi- and multistability in semiconductor laser frequency. We will present an application of this technique where an all-optical configuration is used to produce a frequency switch, controlled by a second laser that modifies the transmission of the nonlinear filter placed in the feedback loop. Another optical configuration allowing exploring frequency dynamics is a laser diode with an external cavity containing a strongly saturated resonant vapor. We review the observed dynamics and present a recently developed model whose numerical simulations account for the observed behavior of the laser frequency.

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Diffraction unlimited 3D imaging - Foundations of a revolution in far-field optical nanoscopy

Superresolution microscopy methods are now making it possible to resolve objects that are smaller than the optical diffraction limit, which has historically restricted spatial resolution to about ~200nm in the transverse dimension. Remarkable among these methods are simulated emission and depletion (STED) microscopy, structured illumination microscopy (SIM), photoactivated localization microscopy (PALM), and stochastic optical reconstruction microscopy (STORM).
Photoactivation-localization methods work by photoactivating a sparse subset of fluorescent molecules at a given time, and localizing each molecule with great precision. Superresolution images are obtained by sequentially photoactivating and localizing different sparse molecule subsets and by combining the position information. New principles extend superresolution to the third dimension by means of point spread function engineering and matched computational reconstruction algorithms.

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Nonlinear optics of backward waves in negative-index plasmonic metamaterials

Extraordinary properties and specific features of coherent nonlinear-optical coupling of electromagnetic waves in negative-index plasmonic metamaterials are studied and reviewed. They stem from the backwardness of electromagnetic waves inherent to this revolutionary class of artificial electromagnetic materials. Negative group velocity for light waves promise numerous breakthrough in nanophotonics. However, strong absorption of light intrinsic to metals imposes severe limitation on the majority of such applications. Herein we show the feasibility and numerically demonstrate different nonlinear-optical techniques of compensating such losses, producing transparency, amplification and even generation of counter-propagating entangled ordinary and left-handed photons in the originally strongly absorbing microscopic samples of plasmonic nanostructured metal-dielectric composites.

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Advances and retards in the synchronism of chaotic lasers with feedback

Time leadership competition was studied in the synchronized excitable behavior of two coupled chaotic diode lasers. Experiments show synchronized excitable Low Frequency Fluctuation spikes with isochronous, time leading or time lagging behavior whose stability is shown to depend on a simple relation between the feedback and the coupling times. Numerical calculations with rate equations for monomode optically coupled laser verify the predicted stability conditions for synchronization. Synchronism with intermittent time leadership exchange was also observed and characterized.

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Cavity soliton laser

We describe the experimental observation of self localized laser sources, or a cavity soliton laser. We use a compound laser system consisting of two mutually coupled broad area VCSELS, one of which is used as a saturable absorber. We demonstrate that under suitable parameter conditions, independent and bistable localized structures can be generated by means of an external optical perturbation.
Localized Structures (LS) form in large aspect-ratio media where two or several solutions coexist in the parameter space. Cavity Solitons (CS) are LS generated in a cavity filled with a non linear medium driven by a coherent injected field (holding beam, HB) and they appear as bright intensity -single peaks- coexisting with a homogeneous background. The existence and the independence of these structures in semiconductors have been experimentally demonstrated in a Vertical Cavity Surface Emitting Laser (VCSEL) operated as amplifier [1]. This injection configuration has been used to demonstrate the fundamental properties of CS. Nevertheless, in order to implement competitively CS to all-optical devices, a radical simplification of the experimental setup is required.
Such improvement could be achieved implementing the concept of Cavity Soliton Lasers, i.e. a device capable of generating CS without an external injection beam. A laser with saturable absorber (SA) has been theoretically shown to possess the necessary ingredient for CS generation[2, 3].

In this contribution, we show the experimental realization of a CSL based on two mutually coupled micro resonators where one plays the role of an active laser and the second of a saturable absorber. It is important to point out that the proposed scheme can be easily implemented in a very compact device by growing monolithically the two coupled micro-resonators.

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Development of a monolithic diode-pumped passively Q-switched Nd:YAG laser

A ns/>10mJ monolithic Nd-laser was developed by simulation and experimental testing. The rate equations for the laser medium as well as for the passive Cr4+ Q-switch were solved numerically by appropriate approximations. In this way, for instance, the temporal development of saturated transmission and the occupation of the levels in the absorber were analyzed as well as population inversion and photon density versus time in the laser medium. Furthermore, the dependence of the pulse duration on resonator length as well as the pulse energy in dependence of the absorber's initial transmission T0 and the mirror's reflectivity R were calculated to be compared with the later experiments. For diode pumping of the various experimental setups, quasi-cw fiber-coupled diode arrays of up to 600 W peak power were employed. This resulted in pulse energies of up to 20 mJ for durations of 1.5 ns. Variable incoupling geometries and the influence of temperature of the laser medium were carefully investigated.
These results represent best values, to our knowledge, and may be very useful for practical implementation like the initiation of certain kinds of chemical reaction.

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Nonlinear and ultrafast 2D Photonic Crystals

Photonic crystals (PhCs) allow strong light confinement due to high-Q resonances, which can be realized either by point defects in a periodic array of holes or using low group velocity modes of the dispersion relation (photonic band diagram). In semiconductor materials, electronic confinement can also be achieved through the inclusion of nanostructures (quantum wells, quantum dots…). Both electronic and optical confinement leads to the enhancement of light-matter interaction, making the PhC a good platform for non-linear studies. In the context of applications for optical telecommunications, several active functions for all-optical treatment of signals such as ultrafast switching and bistability have recently been demonstrated by our group.
Besides the inherent capability of a PhC to reduce power thresholds, PhC structures allow novel regimes for dynamical non-linear phenomena in which the optical and material time scales are modified with respect to standard semiconductor devices. This talk will focus on two experimental demonstrations concerning time resolved nonlinear optics in 2D PhCs. They point to nonlinear regimes directly associated either to the increase of the photon lifetimes or to the decrease of the thermal evacuation time in such systems.
In the first experiment [1] it is shown that, due to the high Q factor, the photon lifetime within the resonator becomes non-negligeable with respect to the carrier recombination lifetime. Under these conditions the carrier dynamics affects the field evolution within the resonator when the two relax freely, which we have shown by means of femtosecond pump and probe techniques.
In the second experiment [2] a fast thermo-optical excitability is demonstrated on the basis of a microsecond time scale dynamics for thermal dissipation [3]. An excitable system is known to exhibit all-or-none pulse responses to an external perturbation, depending on whether this

perturbation is above or below a threshold. For perturbation energies close to the excitable threshold, a critical slowing down delays the output pulse for an amount comparable to the pulse duration (up to 5 ns) which can be a mean for generating all-optical delays.
The end of the talk will be devoted to a more general discussion of new trends on temporal behavior in 2D PC nonlinear resonators and coupled cavities.

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Nonlocality and off-axis feedback in tranversally multimode optical devices

External feedback loops in nonlinear optical devices have been largely studied in relation to temporal delay. In some recent works we studied a different effect induced by a feedback when it is placed off-axis or misaligned. In this case a peculiar spatial nonlocaliy occurs that couples pairs of shifted points and that leads to important and surprising consequences: Two-point nonlocality moves the lasing threshold and opens large windows of control parameters where weak light spots can be strongly amplified. Furthermore, transverse phase and group velocities are tunable to have the same or opposite sign, and we predict that for an out-of-phase feedback the laser operates as a signal splitter. Our predictions encompass a large class of systems, as a broad class of nonlinear models are considered also taking into account either positive or negative refractive index, diffusion and noise.