CEMPI CONFERENCE
STATISTICAL MECHANICS AND NONLINEAR PHYSICS
VILLENEUVE D'ASCQ , November, 12th-15th (2013)

SHORT COURSES

Fluid models as scaling limits of systems of particles

Laure Saint Raymond (Ecole Normale Supérieure-Département de Mahématiques et Applications)

The goal of this course is to present a derivation of some fluid equations starting from the microscopic dynamics of hard spheres as the number of particles N goes to infinity and their diameter ε simultaneously goes to 0, in the fast relaxation limit $N \varepsilon^{d-1} \to \infty$. As suggested by Hilbert in his sixth problem, we use the Boltzmann equation as an intermediate level of description.

Wave turbulence

Sergey Nazarenko (Mathematics Institute-University of Warwick)

I will give an introduction to Wave Turbulence aimed at nonspecialists. The emphasis will be on the main underlying assumptions of the theory, quick ways to obtain important scalings without complicated derivations, extentions of the theory beyond the weak nonlinearity restriction. I will discuss the theory of systems with dual cascades, nonlocal interactions and some other recent developments.

Nonequilibrium statistical mechanics

Kirone Mallick (Institut de Physique Théorique-CEA Saclay)

In these lectures, we shall present some remarkable results that have been obtained for systems far from equilibrium during the last two decades. We shall put a special emphasis on the concept of large deviation functions that provide us with a unified description of many physical situations. These functions are expected to play, for systems far from of equilibrium, a role akin to that of the thermodynamic potentials.
We shall review the Jarzynski and Crooks Work Identities, the Gallavotti-Cohen Fluctuation Theorem and the Macroscopic Fluctuation Theory.
These concepts will be illustrated on simple systems such as the Brownian ratchet model for molecular motors and the asymmetric exclusion process.

INVITED TALKS

Parametric subharmonic instability for internal waves

T. Dauxois (CNRS & ENS Lyon)

Internal waves are believed to be of primary importance as they affect ocean mixing and energy transport. Several processes can lead to the breaking of internal waves and they usually involve non linear interactions between waves.

In this work, we study experimentally the parametric subharmonic instability (PSI), which provides an efficient mechanism to transfer energy from large to smaller scales. It corresponds to the destabilization of a primary plane wave and the spontaneous emission of two secondary waves, of lower frequencies and different wave vectors. Using a time-frequency analysis, we observe the time evolution of the secondary waves, thus measuring the growth rate of the instability. In addition, a Hilbert transform method allows the measurement of the different wave vectors. We compare these measurements with theoretical predictions, and study the dependence of the instability with primary wave frequency and amplitude. Experiments with vertical modes [1], plane waves [2] and inertial waves [3] will be presented.

A related laboratory study on the instability of internal wave attractors (limit cycles for these waves) in a trapezoidal fluid domain will be also discussed. Above a threshold of the injected energy, attractors are found to be destroyed by PSI via a triadic resonance which is shown to provide a very efficient energy pathway from long to short length scales. This study provides an explanation why attractors may be difficult or impossible to observe in natural systems subject to large amplitude forcing.

[1] S. Joubaud, J. Munroe, P. Odier, T. Dauxois, Experimental parametric subharmonic instability in stratified fluids, Physics of Fluids 24, 041703 (2012).

[2] B. Bourget, T. Dauxois, S. Joubaud, P. Odier, Experimental study of parametric subharmonic instability for internal waves, Journal of Fluid Mechanics 723 (2013) 1-20.

[3] G. Bordes, F. Moisy, T. Dauxois, P-P. Cortet, Experimental evidence of a triadic resonance of plane inertial waves in a rotating fluid, Physics of Fluids 24, 014105 (2012).

[4] H. Scolan, E. Ermanyuk,T. Dauxois, Nonlinear fate of internal waves attractors, Physical Review Letters 110, 234501 (2013).

A zero-mode mechanism for spontaneous symmetry breaking in turbulent von Karman flow

B. Dubrulle (Laboratoire SPHYNX, Gif sur Yvette)

Spontaneous symmetry breaking is a classical phenomenon in statistical or particle physics, where specific tools have been designed to characterize and study it. Spontaneous symmetry breaking is also present in out-of-equilibrium systems, but there is at the present time no general theory to describe it in theses systems. To help developing such a theory, it is therefore interesting to study well-controlled laboratory model of out-of-equilibrium spontaneous symmetry breaking. In that respect, the turbulent von Karman (VK) flow is an interesting example. In this system, the flow is forced by two counter-rotating impellers, providing the necessary energy injection to set the system out-of-equilibrium. This energy is naturally dissipated through molecular viscosity, so that, for well controlled forcing protocols, statistically states can be established, that may be seen as the out-of-equilibrium counterpart of the equilibria of classical ideal systems [1,2]. Changing the forcing protocol for the VK flow leads to various transitions with associated symmetry breaking. In the sequel, we focus on the special case of *O(2)* symmetry breaking, that has been reported in [3]. For exact counter-rotation (zero relative motion) of the impeller, the VK set up is exactly isomorphic to *O(2)* – which is the symmetry group of XY-models [4]-. Increasing the relative rotation between the two impellers, one induces an *O(2)* symmetry breaking, in analogy with an applied external magnetic field. Studying the flow response to this continuous symmetry breaking for a Reynolds number ranging from $Re=10^2$ (laminar regime) to $Re=10^6$ (highly turbulent regime), Cortet *et al*. observe a divergence of the flow susceptibility around a critical Reynolds number Re_c=40 000. This divergence coincides with intense fluctuations of the order parameter near Re_c corresponding to time-wandering of the flow between states which spontaneously and dynamically break the forcing symmetry. In this talk, we investigate a possible mechanism of emergence of such spontaneous symmetry breaking in a toy model of an out-equilibrium system, derived from its equilibrium counterpart by adding forcing and dissipation. We show that the stationary states of this toy model are subject to a spontaneous symmetry breaking through a zero-mode mechanism. We discuss how this toy model can be tuned to get a qualitative agreement with the phase transition observed in the von Karman experiment. We then show that the observed intense fluctuations of the order parameter near Re_c in the VK flow can be described through a continuous one parameter family transformation (amounting to a phase shift) of steady states and could be the analog of the Goldstone modes of the *O(2)* symmetry breaking.

[1] Monchaux R., Ravelet F., Dubrulle B. Chiffaudel A. and Daviaud F., Phys. Rev. Lett. **96**, 124502 (2006)
[2] Monchaux R., Cortet P.-P., Chavanis P.-H., Chiffaudel A., Daviaud F., Diribarne P. and Dubrulle B., Phys. Rev. Lett. **101**, 174502 (2008)
[3] Cortet P.-P., Chiffaudel A.,Daviaud F.,and Dubrulle B., Phys. Rev. Lett. **105**, 214501 (2010)
[4] Nore C., Tuckerman L. S., Daube O. and Xin S. J., J. Fluid Mech. **477**, 1 (2003)

Dynamical aspects of information: From chaos in dissipative dynamical systems to information processing at the molecular scale

P. Gaspard (Université Libre de Bruxelles)

Abstract: A review is presented of information-theoretic concepts to characterize randomness and disorder not only in equilibrium systems, but also in dynamical systems and nonequilibrium processes. The aim of the talk is to show that fruitful connections can be established between abstract concepts and physically relevant quantities. In dissipative dynamical systems, temporal randomness characterized by the Kolmogorov-Sinai entropy is related to dynamical instability characterized by the Lyapunov exponents. Beyond, such considerations extend to transport processes, nonequilibrium thermodynamics, and symmetry breaking phenomena in the context of statistical mechanics. Along the same way, fundamental relationships can be obtained at the molecular scale between the thermodynamic entropy produced during copolymerization processes and the information stored in the growing copolymers.

References:

- P. Gaspard and X.-J. Wang, Noise, chaos, and (epsilon,tau)-entropy per unit time, Phys. Rep. 235 (1993) 291.
- P. Gaspard, Chaos, Scattering and Statistical Mechanics (Cambridge University Press, Cambridge UK, 1998).
- P. Gaspard, Time-Reversed Dynamical Entropy and Irreversibility in Markovian Random Processes, J. Stat. Phys. 117 (2004) 599.
- D. Andrieux and P. Gaspard, Nonequilibrium generation of information in copolymerization processes, PNAS 105 (2008) 9516.
- P. Gaspard, Fluctuation relations for equilibrium states with broken discrete symmetries, J. Stat. Mech.: Th. & Exp. (2012) P08021.

The statistical mechanics of negative response

C. Maes (Institut de Physique Théorique, Louvain)

The Green-Kubo formula for linear response coefficients gets modified when dealing with nonequilibrium dynamics. In particular negative differential conductivities are allowed to exist away from equilibrium. We give a unifying framework for such negative differential response in terms of the frenetic contribution in the nonequilibrium formula. It corresponds to a negative dependence of the escape rates and reactivities on the driving forces. Partial caging in state space and reduction of dynamical activity with increased driving cause the current to drop. These are time-symmetric kinetic effects that are believed to play a major role in the study of nonequilibria. We give various simple examples treating particle and energy transport, which all follow the same pattern in the dependence of the dynamical activity on the nonequilibrium driving, made visible from recently derived nonequilibrium response theory.

Joint work with Pieter Baerts, Urna Basu, Soghra Safaverdi, arXiv:1308.5613v2 [cond-mat.stat-mech].

Optimal non-equilibrium fast random processes

C. Mejia-Monasterio (Laboratory of Physical Properties, Technical University of Madrid)

This talk is about stochastic thermodynamics and stochastic control which concerns findings the optimal non equilibrium driving that minimizes the entropy production in a finite time transition, and it is important when one needs to set up a thermodynamical framework adapted to small (stochastic) systems.

Triadic interaction of inertial waves and energy cascade in rotating turbulence

Frédéric Moisy (Université de Paris Sud)

Turbulence in a rotating frame is present in a number of geophysical and astrophysical contexts, including ocean, atmosphere, and the liquid core of rotating stars and planets. In the limit of fast rotation rate (low Rossby number), rotating turbulence may be described as a sea of weakly interacting inertial waves. Inertial waves are dispersive, anisotropic, circularly-polarized transverse waves, which result from the restoring nature of the Coriolis force. Triadic interaction between inertial waves lead to an angular transfer of energy towards slow, quasi two-dimensional motions. We present here experiments giving direct evidence of such triadic interactions from a single plane wave. In the case of decaying rotating turbulence ("strong" wave turbulence, i.e. low but not too low Rossby number), we describe the energy transfers in the physical space in terms of anisotropic third order structure functions. Interestingly, anisotropy is more pronounced at small scales, and propagates towards larger scales as time proceeds, a result which could be explained from a dual energy and helicity cascade.

Wave turbulence served up on a plate

N. Mordant (Université Joseph Fourier- Grenoble)

We studied wave turbulence of flexion waves in a thin elastic (metallic) plate. Such plates have been used for ages to mimic the thunder noise in theaters. The noise generated when shaking gently a large steel plate is actually the noise of the Kolmogorov spectrum. Turbulence of flexion waves turbulence develops on the plate and generates a wide spectrum of the deformation (that ultimately radiates a wide acoustic spectrum). We studied this turbulence experimentally on 2mx1m steel plates by using 2D, time resolved profilometry so that to finely probe the structure of the wave field. The observed spectrum is actually not quite the Kolmogorov spectrum. A numerical investigation allowed us to show that this disagreement with the theory is due to dissipation. When tuning the dissipation in the numerics we are able to gradually change the experimental spectrum into the Kolmogorov-Zakharov one. Further investigation of the strongly forced regime showed a transition from weak turbulence to dynamical crumpling due to the appearance of singularities and consequently of intermittency. The ability to perform space-time resolved measurements coupled with numerical simulations make elastic wave turbulence a privileged system for wave turbulence.

Toward a 'long-range' optical wave turbulence?

Antonio Picozzi (Institut Carnot de Bourgogne-Dijon)

We consider the dynamics of turbulent optical waves in the presence of a highly nonlocal nonlinearity -- either in the spatial or temporal domain. Recent works show that this long-range turbulent system self-organizes into nonequilibrium and nonstationary states, which exhibit properties analogous to the weak Langmuir turbulence and the Vlasov turbulence in plasma.

Experimental Realization of One-dimensional Optical Wave Turbulence

Stefania Residori (Institut Non linéaire de Nice)

I will present a review of the latest developments in one-dimensional optical wave turbulence, which is based on an original experimental setup where a laminar shaped laser beam propagate inside a liquid crystal cell. In this system, an inverse cascade occurs through the spontaneous evolution of the nonlinear field up to the point when modulational instability leads to soliton formation. Further interaction of the solitons among themselves and with incoherent waves leads to a final condensate state dominated by a single strong soliton. The theoretical description shows that the inverse cascade develops through six-wave interaction and that different statistical regimes result from the long-wave, respectively, short-wave limit. A comparison with the experimental results is carried out in the long-wave limit. The coexistence and mutual interaction between solitons and the weakly nonlinear random wave background is explained in the form of a wave turbulence life cycle.