Thierry Dauxois (2014-2018)

Research Activities

Internal Gravity Waves

The study of internal waves (IW) is of great interest owing to the evolving appreciation of their role in many geophysical systems. In addition to their particularly intriguing properties from a fundamental point of view, these waves play an important role in dissipating barotropic tidal energy in the ocean, are an important means of momentum transport in the atmosphere, while IW activity also impacts modern-day technology. However, many unanswered questions remain, particularly regarding the fate of internal waves and how much mixing do they generate in the ocean and via what processes ?

Until recently, most studies were focused on plane wave solutions. However, these solutions are not a satisfactory description of most geophysical manifestations of internal gravity waves, and it is now recognized that internal wave beams with a confined profile are ubiquitous in the geophysical context. We studied [A.100] the reason for the ubiquity of wave beams in stratified fluids, which is related to the fact that they are solutions of the nonlinear governing equations. More specifically, we focused on the two main mechanisms of instability for those beams : (a) the triadic resonant instability generating two secondary wave beams and (b) the streaming instability corresponding to the spontaneous generation of a mean flow.

One of our study that has attracted a lot of the attention was related to parametric subharmonic instability (PSI). We were indeed able to provide [A87] the first experimental verifications of this nonlinear resonant interaction through which a primary wave excites pairs of waves whose frequencies and wave numbers add up to the frequency and wavenumber, respectively, of the primary wave. Interestingly, we discovered that the disconnect between theory, which assumes the waves are periodic in space and time, and reality in which waves are transient and more importantly spatially localized, modifies drastically the result. We have thus shown theoretically, numerically and experimentally that the width of the internal wave beam is a key element, a feature totally overlooked previously, despite numerous numerical simulations. In particular, we have reported dramatic consequences on the triad selection mechanism. The subharmonic plane waves that are theoretically unstable can only extract energy from the primary wave if they do not leave the primary beam too quickly. This finite-width mechanism has two opposite consequences on the wave energy dissipation : it can hinder the PSI onset (reducing transfer and therefore dissipation), but when PSI is present it enhances the transfer towards small wavelengths [A.94,A.99], more affected by dissipation.

In parallel, we proposed a unique self-consistent experimental (and also numerical) set-up that models a cascade of triadic interactions transferring energy from large-scale monochromatic input to multi-scale internal wave motion [A.92,A.95]. We provided explicit evidences of a wave turbulence framework for internal waves [A.91], with a clear transition to a cascade of small-scale overturning events. We showed how beyond the wave turbulence, this original set-up can induce mixing that can be inferred from the calculation of the potential energy or directly by measuring the stratification. Finally, as a necessary preliminary step toward geophysically significant extrapolations, we also studied [A.98] the scale effects in internal wave attractors in the linear and nonlinear regimes.

The **main projets** for the future are three folds : i) Confirm the first experimental study of internal waves turbulence and provide a careful analysis of the mechanisms at play and the frequency and wavevector spectra. ii) Study internal waves attractors to reveal the convergence toward 2D attractors. iii) Thorough study of the mixing due to the different mechanisms encountered by internal waves (breaking, instability, collision, ...). Three PhD thesis on these three different lines of research are ongoing.

Long-Range Interacting Systems

We wrote a comprehensive book [B.10], on the recent advances on the statistical mechanics and out-of-equilibrium dynamics of solvable systems with long-range interactions. The abstract of the book is the following : "Physics of Long-range Interacting Systems" deals with an important class of many-body systems : those where the interaction potential decays slowly for large inter-particle distance. In particular, systems where the decay is slower than the inverse inter-particle distance raised to the dimension of the embedding space. Gravitational and Coulomb interactions are the most prominent examples. However, it has become clear that long-range interactions are more common than previously thought. This has stimulated a growing interest in the study of long-range interacting systems, which has led to a much better understanding of the many peculiarities in their behaviour. The seed of all particular features of these systems, both at equilibrium and out-of-equilibrium, is the lack of additivity. It is now well understood that this does not prevent a statistical mechanics treatment. However, it does require a more in-depth study of the thermodynamic limit and of all related theoretical concepts. A satisfactory understanding of properties generally considered as oddities only a couple of decades ago has now been reached : ensemble inequivalence, negative specific heat, negative susceptibility, ergodicity breaking, out-of-equilibrium quasi-stationary-states, anomalous diffusion, etc. The book, intended for Master and PhD students, tries to gradually acquaint the reader with the subject. The first two parts describe the theoretical and computational instruments needed for addressing the study of both equilibrium and dynamical properties of systems subject to long-range forces. The third part of the book is devoted to discuss the applications of such techniques to the most relevant examples of long-range systems. The only prerequisite is a basic course in statistical mechanics.

We have also pursued the research on these systems with long-range interactions. The main directions were there folds : i) analyzing systems beyond the mean-field approximation [A.86], ii) considering physical systems (not only toy models) such as a system of hard spheres with gravitational interactions [A.86] or two-dimensional flows with varying interaction range [A.89] and iii) studying the effect of noise [A.93].

Miscellaneous Works with Solitons

• Using a dynamical system insight, I was directly involved in the explanation of emergent spatial structures in flocking models for active matter : We showed [A.84] that hydrodynamic theories of polar active matter generically possess inhomogeneous traveling solutions. We introduced a unifying dynamical-system framework to establish the shape of these intrinsically nonlinear patterns, and showed that they correspond to those hitherto observed in experiments and numerical simulation : periodic density waves, and solitonic bands, or polar-liquid droplets both cruising in isotropic phases. We elucidated their respective multiplicity and mutual relations, as well as their existence domain.The article was selected as a Focus by Physical Review Letters.

• We studied [A.88] instabilities and relaxation to equilibrium in a long-range extension of the

Fermi-Pasta-Ulam-Tsingou (FPU) oscillator chain. We showed that localization in mode space is stronger for the long-range FPU model, allowing us to uncover the sporadic nature of instabilities. These findings also clarify the long-standing problem of the relaxation to equilibrium in the short-range FPU model. We also obtained [A.96] an analytic perturbative expression of traveling envelope solitons by introducing a nonlinear Schrödinger equation for the slowly varying amplitude of short wavelength modes. Due to the non analytic properties of the dispersion relation, it is crucial to develop the theory using discrete difference operators. Those properties are also the ultimate reason why kink-solitons may exist but are unstable, at variance with the short-range FPU model. More recently, we studied [A101] the dynamics of FPU chains with both harmonic and anharmonic power-law long-range interactions. We show that the dynamics is described in the continuum limit by a Generalized Fractional Boussinesq differential Equation.

Scientific Production

1 Book

[B.10] A. Campa, T. Dauxois, D. Fanelli, S. Ruffo, Oxford University Press (2014).
Physics of Long-Range Interacting Systems.

18 Articles (available at http ://perso.ens-lyon.fr/thierry.dauxois/listepubli.html)

[A101] G. N. Chendjou Beukam, J. P. Nguenang, A. Trombettoni, T. Dauxois, R. Khomeriki, S. Ruffo, CNSNS 60, 115-127 (2018) - Fermi-Pasta-Ulam chains with harmonic and anharmonic long-range interactions.

[A100] T. Dauxois, S. Joubaud, P. Odier, A. Venaille, Annual Review of Fluid Mechanics 50, 131-156 (2018) Instabilities of internal wave beams.

[A99] Y. Dossmann, F. Pollet, P. Odier, T. Dauxois, Journal of Geophysical Research - Oceans 122 (2017) Mixing and formation of layers by internal wave forcing.

[A98] C. Brouzet, I.N. Sibgatullin, E.V. Ermanyuk, S. Joubaud, T. Dauxois, Physical Review Fluids 2, 114803 (2017) Scale effects in internal wave attractors.

[A97] C. Brouzet, E.V. Ermanyuk, M. Moulin, G. Pillet, T. Dauxois, Journal of Fluid Mechanics 831, 101-127 (2017) Added mass : a complex face of tidal conversion.

[A.96] G. Miloshevich, JP Nguenang, T. Dauxois, R. Khomeriki, S. Ruffo, Journal of Physics A 50, 12LT02 (2017) - Traveling Solitons in Long-Range Oscillator Chains.

[A.95] C. Brouzet, E.V. Ermanyuk, S. Joubaud, G. Pillet, T. Dauxois, Journal of Fluid Mechanics 811, 544-568 (2017) Internal wave attractors : different scenarios of instability.

[A.94] Y. Dossmann, B. Bourget, C. Brouzet, T. Dauxois, S. Joubaud, P. Odier, Experiments in Fluids 57, 132 (2016) Mixing by internal waves quantified using combined PIV/PLIF technique.

[A.93] S. Gupta, T. Dauxois, S. Ruffo, Europhysics Letters 113, 60008 (2016) - Out-of-equilibrium fluctuations in stochastic long-range interacting systems.

[A.92] C. Brouzet, I. Sibgatullin, H. Scolan, E.V. Ermanyuk, T. Dauxois, Journal of Fluid Mechanics 793, 109 (2016). Internal wave attractors examined using laboratory experiments and 3D numerical simulations.

[A.91] C. Brouzet, E.V. Ermanyuk, S. Joubaud, I. Sibgatullin, T. Dauxois, Europhysics Letters 113, 44001 (2016) - Energy cascade in internal wave attractors.

[A.90] S. J. Ghaemsaidi, S. Joubaud, T. Dauxois, P. Odier, T. Peacock, Physics of Fluid (2015).
Nonlinear internal wave penetration via parametric subharmonic instability.

[A.89] A. Venaille, T. Dauxois, S. Ruffo, Physical Review E 92, 011001(R) (2015).
Violent relaxation in two-dimensional flows with varying interaction range.

[A.88] G. Miloshevich, J.-P. Nguenang, T. Dauxois, R. Khomeriki, S. Ruffo, Physical Review E 91, 032927 (2015).
Instabilities and relaxation to equilibrium in long-range oscillator chains.

[A.87] B. Bourget, H. Scolan, T. Dauxois, M. Le Bars, P. Odier, S. Joubaud, Journal of Fluid Mechanics 759, 739 (2014). *Finite-size effects in parametric subharmonic instability.*

[A.86] M. Champion, A. Alastuey, T. Dauxois, S. Ruffo, Journal of Physics A 47, 225001 (2014). *Validity conditions of the hydrostatic approach for self-gravitating systems : microcanonical analysis.*

[A.85] M. Peyrard, T. Dauxois, Physics of Life Reviews 11, 173 (2014). *Can we model DNA at the mesoscale ?*

[A.84] J-B Caussin, A. Solon, A. Peshkov, H. Chaté, T. Dauxois, J. Tailleur, V. Vitelli, D. Bartolo, Physical Review Letters, Physical Review Letters 112, 148102 (2014). *Emergent spatial structures in flocking models : a dynamical system insight.*

4 Conference Proceedings

[C6] T. Dauxois, E. Ermanyuk, C. Brouzet, S. Joubaud, I. Sibgatullin, *Abyssal mixing in the laboratory*, in "The Ocean in Motion : Circulation, Waves, Polar Oceanography", Eds. M. G. Velarde, R.Y. Tarakanov, A. V. Marchenko, Springer-Verlag, Oceanography Series (2017).

[D22]. T. Dauxois, C. Brouzet, E. Ermanyuk, S. Joubaud, H. Scolan, I. Sibgatullin. 8th Stratified Flow Conference in San Diego (2016). Energy cascade in internal wave attractors.

[D21]. P. Odier, Y. Dossmann, B. Bourget, C. Brouzet, S. Joubaud, T. Dauxois. 8th Stratified Flow Conference in San Diego (2016). Tracking mixing by overturning internal waves.

[D20]. T. Dauxois, C. Brouzet, E. Ermanyuk, S. Joubaud, D. Le Tourneau, I. Sibgatullin, Procedia IUTAM 20, 120-127 (2017). Energy cascade in internal wave attractors.

17 Invited Conferences

61) Dynamics Days, Loughborough (UK), September 2018.
60) International Conference on Nonlinear Localization in Lattices, Spetses (Grèce), June 2018.
59) Les Journées de Physique Statistique, Paris, January 2018.
58) Ivannikov ISPRAS Open Conference, Moscou (Russie), December 2017.
57) Irreversibility and Turbulence, Les Treilles, September 2017.
56) Fundamental aspects of turbulent flows in climate dynamics, Les Houches, August 2017.
55) Rencontres du Nonlinéaire, Paris, March 2015.
54) International Symposium, Taschkent (Ouzbekistan), November 2016.
53) The Dynamics of Complex Systems, Warwick (UK), May 2016.
52) Innovation Workshop on Tsunami, Snow Avalanche, Flash Flood, Lyon, January 2016.
51) New Wave : New challenges in internal wave dynamics, Lyon, October 2015.
50) Bifurcations and Instabilities in Fluid Dynamics (BIFD), Paris, July 2015.
49) Rencontres du Nonlinéaire, Paris, March 2015.
48) Free surface and geophysical flows, Rennes, January 2015.
47) Congrès des Professeurs de Physique (Udppc), Lyon, October 2014.
46) Advances in Non Equilibrium Statistical Mechanics, Florence (Italie), May 2014.
45) Sillages et Ondes de Surface, Paris, April 2014.

12 Seminars

- Laboratoire Charles Coulomb, Université de Montpellier, February 2014
- Lycée du Parc, Lyon, March 2015.
- Unité de Mathématiques Pures et Appliquées, ENS de Lyon, November 2016
- Department of Physics, University of Oxford (UK), February 2017
- School of Mathematical Sciences, Queen Mary, University of London (UK), February 2017
- British Petroleum Institute, University of Cambridge (UK), February 2017
- Department of Physics, University of Tbilissi (Georgia), May 2017
- Institut Camille Jordan, University Lyon 1, June 2017
- Shirshov Institute of Oceanology, Moscow (Russia), November 2017
- Faculy of Mechanics and Mathematics of Moscow State University (Russia), November 2017
- Lycée Diderot, Langres, December 2017
- Laboratoire de Physique Théorique de la Matière Condensée, June 2018

2 Organisation of Conferences

• *Nonlinear Effects In Internal Waves Conference*, Cornell University, June 2014.
Co-organizers : P. Diamessis (Cornell), S. Wunsch (Baltimore). 66 participants.
• *STATPHYS26*, Lyon, July 2016. Chairman in collaboration with A. Alastuey, F. Bouchneb, P. Holdsworth, M. Peyrard, N. Taberlet. 1250 participants.

Research Contracts

• ANR DisET 2018-2021 : "Disentangling eddy turbulence and wave turbulence : the challenge of rotating and stratified fluids" with FAST (Cortet, Moisy), NÉEL (Gibert, Chabaud), LMFA (Godeferd, Delache, Naso). 600 k€.
• PICS CNRS 2016-2018 : "Dynamics and Thermodynamics in Magnetic Nanoparticle Systems" with R. Khomeriki from Tbilisi State University (Georgia). 12 k€.
• Labex iMUST WDT 2016-2019 : "Wave dynamics in turbulence" with LMFA (Godeferd, Delache). 120 k€.
• ANR ONLITUR 2011-2014 : "Ondes non-linéaires et turbulence en écoulements tournants et stratifiés" with FAST (Moisy, Cortet, Rabaud). 300 k€.

Jurys in 2014-2018

• **17 PhD Committees** (6 as referee and 5 as president) : B. Bourget (ENSL), M. Labousse (ESPCI), T. Beitzel (LOCEAN), M. Benzaquen (ESPCI), T. Le Goff (ILM), T. Jamin (MSC), C. Brouzet (ENSL), JB. Fouvry (IAP), S. Merminod (MSC), T. Dessup (MSC), N. Shmakova (LEGI), G. Lérisson (Ladhyx), G. Michel (LPS-ENS), G. Facchini (IRPHE), K. Raja (LEGI), F. Damiens (LMD, Paris), G. Pillet (ENSL).
• **3 HDR Committees** as referee : F. Nadal (CRPP), R. Monchaux (ENSTA), H. Yoshikawa (Dieudonné).
• **2 reports on tenure** for Cornell University and Singapore University.

5 Directions of PhD Thesis

• **Baptiste Bourget** (2011-2014) has defended his PhD *Ondes Internes : de l'instabilité au mélange. Approche expérimentale*, performed under my supervision and the one of P. Odier. Baptiste is Professeur en classes préparatoire.
• **Christophe Brouzet** (2013-2016) has defended his PhD *Internal wave attractors : from geometrical focusing to nonlinear energy cascade*, performed under my supervision and the one of S. Joubaud. He is Post-doc in Stockholm.
• **Grimaud Pillet** (2015-2018) will defend his PhD in July 2018, performed under my supervision, on the study of 3D attractors, revealing the mechanism of convergence toward 2D attractors.
• **Géraldine Davis** (2016-2019) is doing her PhD under my supervision and the one of S. Joubaud on internal waves turbulence.
• **Pauline Husseini** (2016-2019) is doing her PhD under my supervision and the one of P. Odier on the mixing in stratified fluids.

3 Post-doc

• **Hélène Scolan**, Agrégé Préparateur ENS de Lyon (2011-2014) : *Instabilities of internal wave attractors.* Hélène is post doc at Oxford University.
• **Yvan Dossmann**, Agrégé Préparateur ENS de Lyon (2014-2016) : *PIV-LIF et Mesure du mélange.* Yvan is now Maître de Conférence in Nancy.
• **Samuel Paillat**, ATER (2016-2017) : *Internal wave turbulence.* Samuel is now Professeur en classe préparatoire at Istanbul University (Turquie).

Responsabilities in the Administration of Research

• Director of the Laboratoire de Physique (2012-2018), Deputy-Director in 2011.
• President of 4 HCERES Committees : CPT-Marseille (2017), LPS-ENS Paris (2017), Département de Physique de l'ENS Paris (2018), MSC Paris (2018).
• Member of the Committee for the evaluation of the National Institute for Theoretical Physics in Johannesburg, Durban and Stellenbosch (South Africa) in March 2017.
• Member of the C3 commission of IUPAP (The International Union of Pure and Applied Physics) dedicated to Statistical Physics (2018-2020).
• Member of 4 Comités de sélection : Prof. at l'Université de Toulouse (2016), Prof. de Physique at l'Université de Lyon (2016), Prof. de Mathématiques at ENS de Lyon (2016), Prof. de Physique at l'Université de Nice (2017).
• Member of the editorial committee of the Journal of Physics A (Editor of section "Chaotic and Complex Systems").
• Member of the Conseil d'Administration de l'école des Houches (2010-2019).
• Expert for ANR, NSF (USA), CNR and ISMER (Canada) NSF (Poland), FONDECYT (Chile), ERC (Europe).

Teaching Activities

2017-2020 : Lecture *Systèmes Dynamiques et Chaos* en M1 à l'ENS de Lyon (24h).
2013-2018 : Lecture *Physique Non Linéaire* à la préparation à l'Agrégation de l'ENS de Lyon (6h).
2015-2018 : Lecture *Physics of Long-range Interacting Systems* en M2 à l'ENS de Lyon (18h).