Quantum and Cosmological Turbulence

ESF-Warwick workshop, Warwick, December 17-22 2005

Abstract

A 5-day workshop is proposed to bring together in Warwick scientists working on turbulence in many different contexts, in the expectation of fruitful interactions that will help to advance this highly interdisciplinary topic. The workshop is supported in part by Warwick University as part of its year-long Warwick Turbulence Symposium.

Scientific Summary

The main goal of the workshop is to improve communication, and establish collaboration, between different communities working on inter-disciplinary problems in the nonlinear dynamics of macroscopic systems far from equilibrium. For our workshop on quantum and cosmic turbulence, we wish to bring together both experimentalists and theorists, including specialists in stochastic nonlinear dynamics, classical turbulence and quantum turbulence.

Recent progress in the theory of stochastic systems has revealed that many non-equilibrium statistical systems are better described by their phase-space energy fluxes than by their thermodynamic temperature and chemical potential. Consequently, there has been a surge of interest in stochastic dynamics on the part of specialists in turbulence – which provides the most classical example of a non-equilibrium state determined by a flux: the Kolmogorov energy cascade through length-scales. There exist turbulent systems of special interest which allow complete theoretical treatment. One of them, a passive scalar advected by a stochastic velocity field, was recently solved and in our conference we are going to have a review talk on this subject. This will help in the application of methods developed in the present context to other important systems of stochastic dynamics and turbulence, e.g. zero modes, instanton formalism. Another example of turbulent stochastic dynamics which allows theoretical treatment is a system of weakly nonlinear random dispersive waves, e.g. waves on sea after a fresh storm, Alfven waves in the interstellar medium or even cosmological waves during the era of inflation reheating. We are going to have a section devoted to these systems and review various aspects of this rapidly developing area.

Quantum turbulence provides another new direction – turbulence in complex quantum systems such as superfluids and Bose and Fermi condensates of ultracold atoms. Quantum turbulence bears the essential features of classical turbulence, since it also represents the chaotic dynamics of vortex lines. The advantage of quantum systems is that their vortices are usually well isolated from each other, which helps to simplify analytic and numerical investigations. That is why its study can help to shed light on the long-standing puzzles of the phenomenon of turbulence in general.

An essential part of the workshop concentrates on the novel features of quantum turbulence, as compared to the classical phenomenon. The onset of turbulence, the Kolmogorov cascade in developed turbulence, and the decay of turbulence, are all modified in the quantum regime, especially at low temperature where dissipation practically vanishes. Such a regime can never occur in a conventional classical liquid. Some of the most surprising new features are: observation of a sharp phase transition between the laminar and turbulent states, governed by the velocity-independent internal parameter of a quantum liquid; the non-Kolmogorov energy cascade in developed quantum turbulence; weak turbulence on a vortex filaments (Kelvin wave turbulence) which is an extension of the weak turbulence of the capillary waves to the one-dimensional case. And yet, remarkably, there is recent evidence suggesting that in certain regimes quantum turbulence has unexpectedly classical features.

The instabilities in quantum systems leading to the formation of quantized vortices, thus to quantum turbulence, share many common features with the instabilities discussed in connection with the vacua of relativistic quantum fields. In particular, the instability of the surface of the rotating Bose condensate, or of the interface between two sliding superfluid liquids, has the same origin as the instability of the quantum vacuum behind the black-hole event horizon. The reason is that the ground state of the quantum system serves as an analogue of the vacuum in the relativistic system. This opens the possibility of simulating experimentally in superfluids and in cold gases the properties of the quantum vacuum in the presence of black-hole and white-hole horizons, even including the physical singularity inside the black hole. This is one of many points for collaboration of the condensed-matter community with the cosmological and high energy communities.

Amongst other features in common, there are the properties shared by quantized vortices and cosmic strings. For example, the reconnection of vortices and formation of a kink (cusp) play an important role in the development of quantum turbulence at low temperature. These cusp-like singularities give rise to the burst of Kelvin waves and/or fermionic quasiparticles in Fermi superfluids and condensates. These singularities are similar to those on cosmic strings, where they give rise to burst of gravitational waves and other radiation. There are other aspects common to condensed-matter and cosmology in relation to turbulence – e.g. the "chaotic turbulence" of space near a big crunch singularity.

All these phenomena are driven by stochastic forces in highly nonlinear systems. They have many features in common with those of classical hydrodynamics, which is why the collaboration between the stochastic dynamics, turbulence, and cosmological communities is much to be encouraged and likely to be highly fruitful. The expertise obtained by study of turbulence in classical liquids is very important for quantum turbulence. Turbulence in classical liquids is thought to be characterized by the dynamics of the vortex tubes, whose radii are of order of the dissipative Kolmogorov scale. In some regimes, superfluid turbulence is similar to that in classical liquids with modified dissipation. Thus the quantum liquid serves as a physically motivated example of a liquid with non-canonical dissipation, requiring a general analysis of different models of dissipation and forcing. It also allows one to study the general problem of intermittency and large fluctuations (large deviations) – the emergence of rare but large events (large vortex loops in the case of quantum turbulence). All this can give a new impulse for our understanding of the main concepts of the phenomena of turbulence in general.

The proposed conference forms a natural part of the Warwick Turbulence Symposium which is year-long series of activities in 2005-2006 to be held at the University of Warwick Mathematics Research Centre. The backbone of the symposium will consist of a series of thematically interconnected workshops. The workshops will be complemented by a year-long active seminar series and visitor programme including a small number of long-term collaboration visits, and by instructional courses to maximize the benefit to junior researchers and postgraduate students.

Preliminary Meeting Programme

1. QUANTUM TURBULENCE IN SUPERFLUIDS AND BOSE CONDENSATES

Lev Pitaevski: review of BEC

Alexander Fetter, Stanford: review on vortices in BEC

Joe Vinen, Birmingham : theory of quantum turbulence

Ladislav Skrbek, Prague : experimental phase diagram of quantum turbulence

Demos Kivotides: topological scaling of quantum turbulence

Peter McClintock, Lancaster: Grid turbulence in quantum liquids

2. ONSET OF CLASSICAL AND QUANTUM TURBULENCE

Tom Mullin, Manchester: Transition to turbulence in a pipe

Matti Krusius, Helsinki : Intrinsic criterion for generation of quantum turbulence from a single vortex

K. W. Madison, F. Chevy, V. Bretin, and/or **J. Dalibard**, ENS: Stationary states of a rotating Bose-Einstein condensate: Routes to vortex nucleation

Castin, ENS: Dynamic instability of a rotating Bose-Einstein condensate

Grigory Volovik, Helsinki and Landau: Dynamic instability of interfaces between moving superfluids

Marc Rabaud, Université Paris-Sud: Subcritical Kelvin-Helmholtz instability in Hele-Shaw cell

Peter Talkner, Augsburg: Breakdown coefficients in turbulence

3. PROPAGATION AND DECAY OF QUANTUM TURBULENCE

Natalia Berloff, DAMTP Cambridge: Interactions of vortices with rarefaction solitary waves in a Bose-Einstein condensate and their role in the decay of superfluid turbulence

Carlo Barenghi, Newcastle: Decay of quantum turbulence at T=0: Kelvin wave radiation and vortex reconnection

Vladimir Eltsov, Helsinki: Experiments on propagation of vorticity front in superfluids

George Pickett and his group, Lancaster: Experiments on propagation of quantum turbulence in superfluid ^{3}He-B at ultra-low T

Andrei Golov, Henry Hall, Manchester: Ion trapping and decay of quantum turbulence in superfluid ^{4}He

4. TURBULENCE IN PLASMA AND COSMOLOGY

Thibault Damour, IHES: Interconnection of cosmic strings and gamma ray bursts

Renato Gatto, Rome: Turbulence in magnetized plasmas

Etienne Rolley (Ecole Normale Superieur): hydraulic jump as experimental white hole

Igor Tkachev, CERN: turbulence in cosmology

5. WAVE TURBULENCE IN QUANTUM, CLASSICAL AND ASTROPHYSICAL CONTEXTS

Alan Newell, Per Jakobsen, University of Arizona: Wave turbulence and the entropy production

Vladimir Zakharov, Landau Institute and University of Arizona : Wave turbulence in Bose-Einstein condensates and the nonlinear optics

Sergey Nazarenko, Warwick and Landau, Wave Turbulence predictions beyond spectra.

German Kolmakov, Chernogolovka : experiments on 2D wave turbulence in quantum liquid

Evgeny Kozik, Boris Svistunov, Kurchatov Institute, Turbulence on vortex filaments (Kelvin wave turbulence)

Yves Pomeau, Christophe Josserand, ENS Paris : Wave turbulence and Bose-Einstein condensates; Vortices in condensate mixtures

Sebastien Galtier, IAS, Paris-Sud, MHD wave turbulence in interstellar medium

Stefania Residori, Nice: turbulence in optical systems

6. CLASSICAL TURBULENCE

Igor Kolokolov, Vladimir Lebedev, Landau: review talk on intermittency and review talk on passive scalar turbulence

Wim van Saarloos, Leiden : Polymer flow instabilities: Turbulence without intertia

Siegfried Grossmann, Marburg : Hydrodynamic shear flow turbulence

Victor Lvov, Weizmann: Near-wall turbulence

Francesco Sagues, Barcelona: Turbulence and pattern formation

Aneta Stefanovska, Ljubljana: Turbulence in blood flow

Outline Curriculum Vitæ of Scientific Organisers

PETER V. E. McCLINTOCK

Career outline

1940	Born in Omagh, N. Ireland
1963-1966	Junior Demonstrator, Clarendon Laboratory, Oxford
1966-1968	Research Associate, Duke University, N. Carolina
1969-1991	Research Associate, Lecturer, S. Lecturer, Reader, Lancaster University
1990-1995	SERC/EPSRC Senior Fellow, Lancaster University
1991-	Professor, Lancaster University
1997-2003	Head of Department of Physics, Lancaster University

Academic qualifications

1962	BSc, Queen's University, Belfast
1966	DPhil, Oxford
1983	FInstP, Institute of Physics
1983	DSc, Queen's University, Belfast

Scientific publications

More that 400 publications in total, including a co-authored book, 2 edited books and over 200 scientific papers in refereed journals.

List of 5 most relevant publications during the last 5 years

1. S I Davis, P C Hendry, P V E McClintock and H Nichol, "Experiments on quantized turbulence at mK temperatures", in *Quantized Vortex Dynamics and Superfluid Turbulence*, ed. C F Barenghi, W F Vinen and R J Donnelly, Springer, Berlin, 2001, pp 73–79.

2. P S Landa and P V E McClintock, "Development of turbulence in subsonic submerged jets", *Phys. Reports* **397**, 1–62 (2004).

3. H A Nichol, L Skrbek, P C Hendry and P V E McClintock, "Flow of He II due to an oscillating grid in the low temperature limit", *Phys. Rev. Lett.* **92**, 244501/1–4 (2004).

4. H A Nichol, L Skrbek, P C Hendry and P V E McClintock, "Experimental investigation of the macroscopic flow of He II due to an oscil-

lating grid in the zero temperature limit", *Phys. Rev. E* **70**, 056307 (2004).

5. G V Kolmakov, A A Levchenko, M Yu Brazhnikov, L P Mezhov-Deglin, A N Silchenko and P V E McClintock, "Quasi-adiabatic decay of capillary turbulence on the charged surface of liquid hydrogen", *Phys. Rev. Lett.* **93**, 074501 (2004).

GRIGORY E. VOLOVIK

Career outline

Born, September 7, 1946 in Moscow
1973: PhD in Landau Institute for Theoretical Physics in Moscow;
1973 – present time: staff member of Landau Institute;
1993 – present time: sharing the position in Landau Institute and the position of visiting professor in the Low Temperature Laboratory of Helsinki University of Technology (collaboration with Laboratory started in 1981).
2001 – : Foreign member of the Finnish Academy of Science and Letters;
2001–2005: Co-Chair of the European Science Foundation Programme "Cosmology in the Laboratory";
1991–present: Associate Editor of Russian physical journal *JETP Letters*.

Prizes

1992: Landau Prize of Russian Academy of Sciences;
2004: Simon Prize

Books, as author

Exotic Properties of Superfluid ^3He, World Scientific, Singapore, 1992.
The Universe in a Helium Droplet, Clarendon Press, Oxford, 2003.

Books, as editor

Vortices in Unconventional Superconductors and Superfluids, Springer, 2002.
Artificial Black Holes, World Scientific, 2002.

Scientific papers

About 300 published papers.

List of 5 most relevant publications during the last 5 years

1. R. Blaauwgeers, V. B. Eltsov, G. Eska, A.P. Finne, R.P. Haley, M. Krusius, J.J. Ruohio, L. Skrbek, and G.E. Volovik, Shear flow and

Kelvin-Helmholtz instability in superfluids, *Phys. Rev. Lett.* **89**, 155301 (2002).

2. G.E. Volovik, Black-hole horizon and metric singularity at the brane separating two sliding superfluids, *JETP Letters* **76**, 240-244 (2002).

3. G.E. Volovik, *The Universe in a Helium Droplet*, Clarendon Press, Oxford (2003).

4. A.P. Finne, T. Araki, R. Blaauwgeers, V.B. Eltsov, N.B. Kopnin, M. Krusius, L. Skrbek, M. Tsubota, and G.E. Volovik, An intrinsic velocity-independent criterion for superfluid turbulence, *Nature* **424**, 1022–1025 (2003).

5. V.S. L'vov, S.V. Nazarenko, G.E. Volovik, Energy spectra of developed superfluid turbulence, *JETP Letters* **80**, 479–483 (2004).

SERGEY NAZARENKO

Career outline

1964	Born, Frunze, USSR
1986 – 1990	Junior Scientist, Moscow Radio-Technological Institute
1990 – 1995	Member of Landau Institute for Theoretical Physics, Moscow
1992 – 1993	Postdoc, Department of Mechanical and Aerospace Engineering, Rutgers University, Piscataway, New Jersey
1993 – 1994	Postdoc, Department of Mathematics, University of Arizona, Tucson
1994 – 1996	Visiting Assistant Professor, Department of Mathematics, University of Arizona
1995 –	Associate Member, Landau Institute for Theoretical Physics, Moscow
1996 – 2002	Warwick Research Fellow, Mathematics Institute, Warwick University
1997 – 2001	Deputy Director, Fluid Dynamics Research Centre at Warwick
2001 –	Reader in Mathematics, Mathematics Institute, University of Warwick.

Academic qualifications

1986	MSc in Physics, Moscow Institute of Physics and Technology
1990	PhD in Theoretical and Mathematical Physics, Landau Institute for Theoretical Physics

Conference organisation

- 0rganiser, one-day conference *2D Turbulence*, devoted to theory and experiments on two-dimensional incompressible fluids, November 1997.
- Organiser, one-day conference *Water Wave Day*, devoted to the nonlinear dynamics of ocean waves, June 1997, including co-organisation of EUROMECH Colloquium *The Dynamics of Slicks over Water Waves*.
- Organizing committee for *Solitons, Weak Turbulence and Integrability*, Tucson, Arizona, October 1999.
- Organiser, *Near-wall Turbulence Day*, November 1999.
- Organizer (with Robert MacKay, Richard Pelz and Xinyu He), international workshop *Singularities in Classical and Quantum fluids*, University of Warwick, October 2000 .
- Organiser, *Statistical Mechanics of Waves*, Paris, February 2003.
- Organiser the *Wave Turbulence Day*, Warwick, April 2004.
- Organizer, international symposium *Turbulence*, Warwick 2005-2006.

List of 5 most relevant publications during the last 5 years

1. Yu. Lvov, S.V. Nazarenko and R.J. West, "Wave turbulence in Bose-Einstein condensates", *Physica D* **184** 1-4 , 333–351 (2003).
2. Y. Lvov and S.V. Nazarenko, "Noisy spectra, long correlations and intermittency in wave turbulence", *Phys. Rev. E* **69**, 066608 (2004).
3. Y.Choi, Y.Lvov and S.V. Nazarenko, "Probability densities and preservation of randomness in wave turbulence", *Phys. Lett. A* **332**, 230–238 (2004).
4. with V.S.Lvov and G.Volovik, "Energy spectra of developed superfluid turbulence", *JETP Lett.* **80**, 535–539 (2004).
5. C. Connaughton and S.V. Nazarenko, "Warm cascades and anomalous scaling in a diffusion model of turbulence", *Phys. Rev. Lett.* **92**, 044501 (2004).