COSLAB-QUDEDIS-STOCHDYN workshop

Universal features in turbulence: From quantum to cosmological scales

Warwick, December 5-10, 2005

http://www.maths.warwick.ac.uk/

Summary

The main goal of the workshop is to establish collaboration between different communities working on inter-disciplinary problems of nonlinear dynamics of macroscopic systems far from equilibrium. That is why the workshop was organized by three ESF Programmes – COSLAB, QUDEDIS and STOCHDYN – in collaboration with the University of Warwick Mathematics Research Centre. The topic of the workshop is turbulence in different systems. There is a new direction in the study of the phenomenon of turbulence – the quantum turbulence, i.e. turbulence in such complex quantum systems as superfluids and Bose and Fermi condensates of ultracold atoms. The quantum turbulence bears the essential features of classical turbulence, since it represents the chaotic dynamics of vortex lines. The advantage of the quantum system is that vortices there are well isolated from each other and this is more simple for 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. Also the macroscopic quantum systems have many common properties with quantum vacuum of our Universe. All this allows us to simulate in laboratory different astrophysical and cosmological phenomena.

Essential part of the workshop was concentrated on new features of quantum turbulence compared to the classical one. Also the influence of the superfluid turbulence to its classical counterpart was demonstrated. For example, the spectrum of turbulence in superfluid liquid is modified compared to that in classical liquids, and this modification appeared to be useful for the description of the spectrum of the planetary atmospheric turbulence. This parallel which follows from the common properties of the atmospheric and superfluid turbulence has been presented at workshop.

The first realization of the analog of the event horizon has been reported

at the workshop. The hydraulic jump recently observed in superfluids simulates the white-hole event horizon, while the observed instability inside the analog of the horizon, provides the new mechanism of the relaxation of the astronomical black hole candidates.

Scientific content

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The spectrum of turbulence in superfluid liquid which consists of two interpenetrating components, superfluid and normal, is reacher than in conventional liquids. Compared to the spectrum of turbulence in classical liquid, the spectrum is modified by the nonlinear energy dissipation caused by the mutual friction between quantized vortices and the normal component of the liquid. The turbulent states are characterized by two Reynolds parameters: velocity-independent and velocity-dependent. In the second Reynolds parameter the circulation quantum enters, and this parameter is responsible for the separataion of the classical and quantum regimes of the superfluid turbulence. In some region of the two Reynolds parameters the new state of the fully developed turbulence was found. This state displays both the Kolmogorov-Obukhov 5/3-scaling law $E_k \propto k^{-5/3}$ and the new "3-scaling law" $E_k \propto k^{-3}$, each in a well separated range of k. The modified Kolmogorov cascade in the developed superfluid turbulence was discussed by Joe Vinen (Birmingham), who gave the general overview of superfluid turbulence, and by Ladislav Skrbek (Prague), who presented different regimes of the turbulence in superfluids.

This new development of the theory of turbulence in superfluids gave a new impulse for our understanding of the main concepts of turbulence in general. It was demonstrated by Eleftherios Gkioulekas (Seattle) that the same behavior of the spectrum occurs in planetary atmospheric turbulence. The reason for the common behavior of the two systems could be the mutual friction force proportional to the velocity difference which takes place in both systems. The title of the talk "The Nastrom-Gage Energy Spectrum of the Atmosphere, Proposed Theoretical Explanations, and Comparison with the Predicted Energy Spectrum of Superfluid Turbulence" explicitly contains connection to quantum liquids.

Instabilities leading to the transition to turbulence were discussed by Tom Mullin (Manchetser) on the example of the flow of classical liquids in a pipe. The quantum counterpart of the transition to turbulence via formation of quantized vortices in rotating superfluids was discussed by Matti Krusius (Helsinki). The common features of these two experiments have been established: in both cases a small perturbation was introduced into a rapidly moving liquid, and the criterion for the development of different types of turbulent flow were investigated in terms if the magnitude of the initial perturbation and Reynolds number. The new feature compared to the classical case is that in superfluids the relevant Reynolds number does not depend on velocity, and this leads to further generalization of the phenomenon of turbulence.

On the other hand, the instabilities in quantum systems which lead to formation of quantized vortices and then to quantum turbulence, share many common features with the instabilities which may occur in quantum vacuum of relativistic quantum fields, for example during the evolution of the Universe or inside the black holes. In particular, the hydraulic jump in superfluids is similar to the white-hole event horizon, as was demonstrated in the talk by Grigory Volovik (Helsinki). The instability of the vacuum inside the hydraulic jump has been recently observed in superfluid ^{4}He. If the astronomical black holes have the same type of instability, their lifetime must be shorter than it follows from the Hawking radiation mechanism of the black hole decay.

In the talk by Vladimir Eltsov (Helsinki) the experimental discovery of the formation and propagation of vorticity front in superfluids was reported, which has no counterpart in classical liquid. However, after Wim van Saarloos (Leiden) presented the general review on the phenomenon of the front propagation, the further discussion allowed to formulate the phenomenon observed in superfluids using the general theory of front propagation. As a result the place of the new phenomenon in physics has been indicated. The collaboration between two groups which started during the workshop will be continued.

Talk by George Pickett (Lancaster) “Turbulence: From Quantum to Cosmological Scales”, presented the experimental results on turbulence in superfluids in the limit of very low temperatures, when the quantum liquids does really imitate the quantum vacuum. The numerical simulations of vortex turbulence under these conditions were presented by Makoto Tsubota (Osaka). At low temperature, the reconnection of vortices and formation of a kink (cusp) play an important role in the dissipation of quantum turbulence. 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 that on cosmic strings, where they give rise to the burst of gravitational waves and other radiation from cosmic strings.

Among the other condensed matter systems, the cold gases experiencing the Bose-Einstein condensation (BEC), or Cooper pairing (BCS), are becoming extremely useful tools both for study the quantum turbulence and for simulation of quantum vacuum. Review on quantized vortices in rapidly rotating Bose-Einstein condensates were presented by Alexander Fetter (Stanford); Natalia Berloff (Cambridge) talked on turbulence and different coherent structures in BEC. It was found that BEC experiences both the wave turbulence and the vortex turbulence. Formation of the BEC starts with the wave turbulence which results in the formation of the condensate together with vortices. This represents the condensed matter realization of the cosmological process of formation of cosmic strings by Kibble-Zurek mechanism. Numerical simulations of turbulence in BEC using Gross–Pitaevsky equation were presented in many talks and posters, for example in the talk by Kyo Yoshida (Tsukuba).

Roland Combescot (Paris) attracted attention to the novel features, which emerge in the ultra-cold Fermi gases near the Feshbach resonance where there is a crossover between BEC-like and BCS-like behavior. The unusual behavior of vortices in the crossover region is expected.

Experiments on wave turbulence in the three dimensional quantum systems (quantum liquids and superfluids) and for the two dimensional capillary waves on the surface of quantum liquids were presented by German Kolmakov (Lancaster and Chernogolovka). Quantized vortices in superfluids and BEC provide a perfect one-dimensional system where the new type of weak turbulence can be studied – for the Kelvin waves propagating along the vortex filament. This topic has been intensively discussed at the workshop. As a result of discussions, one paper has been submitted for publication (by Sergey Nazarenko) and another one, by Vladimir Lebedev is under preparation. The extension of the weal turbulence theory to the zero-dimensional systems with discrete spectrum was discussed by Elena Kartashova (Linz) and Vladimir Zakharov (Arizona).

Astrophysical aspects of turbulence were presented by Sebastien Galtier (Paris) in his talk on solar wind turbulence. Among the other connection let us mention the talk by Aneta Stefanovska (Ljubljana) on turbulence, and oscillatory processes in blood flow, and by Stefania Residori (CNRS) on turbulent-like behaviour in non-linear optical systems.

Assessment of the results and impact on the future direction

New features found in superfluid turbulence and presented at the workshop extended our understanding of the phenomenon of turbulence in general. They had aleardy indluenced the physics of classical turbulence. In particular, they have an impact on the planetary atmospheric turbulence. This is probably the most spectacular demonstration of the unity of physics. This allows us to apply the methods developed in one area to the other areas of physics. There were numerous examples of such interaction between communities at the workshop, which included front propagation, wave turbulence, etc

Another important example of the unity of physics, which demonstrates that the collaboration between different communities is extremely useful for the development of physics, is the first experimental realization of the analog of the event horizon reported at the workshop. The hydraulic jump recently observed in superfluids simulates the white-hole event horizon, while the observed instability inside the analog of the horizon, demonstrates the possible mechanism of the relaxation of the astronomical black hole candidates. If the astronomical black holes experience this type of instability, their lifetime must be shorter than it follows from the Hawking radiation mechanism of the black hole decay. This is one of many points for collaboration of condensed-matter community with cosmological and high energy communities.

The workshop also demonstrated the ultra-cold gases experiencing superfluidity either via the Bose-Einstein condensation, or through the Cooper pairing (BCS), are becoming extremely useful tools both for study of the quantum turbulence and for simulation of quantum vacuum of relativistic fields.

In conclusion, the more tense collaboration between representatives of different areas of physics has been established, it has already led to new achievements, and new results of the collaboration are expected in a recent future.

The final programme of the meeting

Monday 5 December

10.00 11.15 Registration, coffee

11.15 11.30 Welcome address from Prof. Stuart Palmer, Deputy Vice Chancellor of the University of Warwick

11.30 12.30 Joe Vinen (School of Physics and Astronomy, University of Birmingham)

An Introduction to Quantum Turbulence

Bose Einstein Condensates and Non-Linear Optical Turbulence

1.30 2.10 Kyo Yoshida (University of Tsukuba)

Direct Numerical Simulation of Gross-Pitaevskii Turbulence

2.10 2.50 Natalia Berloff (DAMTP, University of Cambridge)

Turbulence and coherent structures in Bose gases

2.50 3.30 Roland Combescot (ENS, Paris)

Ultra-cold Fermi gases: the BEC-BCS crossover

4.00 4.40 Alexander Fetter (Dept of Physics, Stanford University)

Rapidly Rotating Bose-Einstein Condensates

4.40 5.20 Brian Jackson (Newcastle University)

Persistent Currents and Hysteresis in Bose-Einstein Condensates

5.20 6.00 Stefania Residori (Institut Non-Linaire de Nice, CNRS)

Turbulent-like Behaviour in Non-Linear Optical Systems

Tuesday 6 December

Quantum Turbulence

9.00 9.40 Vladimir Lebedev (Landau Institute for Theoretical Physics) Passive Scalar Evolution in Peripheral Region

9.40 10.20 Yves Pomeau (ENS Paris)

Dynamical BE-condensation and creation of long-range order
10.50 11.30 Vladimir Eltsov (Helsinki University of Technology)
Propagation of Vortex Front in Rotating Superfluid
11.30 12.10 Wim van Saarloos (Instituut-Lorentz, Leiden University)
Front Propagation into Unstable States
1.30 2.10 Peter McClintock (Lancaster University)
Quantum Turbulence, Oscillating Grids, and Where We Go Next
2.10 2.50 Demosthenes Kivotides (University of Newcastle)
Turbulence in Thermal Superfluids.
2.50 3.30 Makoto Tsubota (Osaka City University)
Numerical Study of Quantum Turbulence
4.10 4.50 Carlo Barenghi (University of Newcastle)
Flow Visualisation and the Motion of Small Particles in Liquid Helium
4.50 5.30 Gary Ihas (University of Lancaster)
How to Make and Detect Turbulence in a Quantum Fluid
5.30 Discussion

Wednesday 7 December

Classical, Geophysical and Astrophysical Turbulence

9.00 9.40 Victor Lvov (Weizmann Institute of Science)
Asymptotical universality of drag reduction in Wall Bounded Turbulence
9.40 10.20 Konstantin Turitsin (Landau Institute)
Polymer Dynamics in Chaotic Flows
11.00 11.40 Polina Landa (Moscow State University, Dept of Physics)
What is Turbulence from Oscillatory Point of View?
11.40 12.20 Gregory Falkovich (Weizmann Institute of Science)
Conformal Invariance in Turbulence
1.30 2.10 Eleftherios Gkioulekas (University of Washington)
The Nastrom-Gage Energy Spectrum of the Atmosphere, Proposed Theoretical Explanations, and Comparison with the Predicted Energy Spectrum of Superfluid Turbulence
2.10 2.50 Tom Mullin (University of Manchester)
Transition to Turbulence in Pipe Flow

2.50 3.30 Aneta Stefanovska (Faculty of Electrical Engineering, University of Ljubljana)

Hydrodynamics, Turbulence, and Oscillatory Processes in Blood Flow

4.15 5.00 Sebastien Galtier (Institut dAstrophysique Spatiale)

Solar Wind Turbulence

5.00 6.00 Discussions, posters

6.00 Buffet dinner

Thursday 8 December

Wave Turbulence

9.00 9.40 Elena Kartashova (RISC, J.Kepler University Linz)

Wave Turbulence Theory of Discrete Systems

9.40 10.20 Sergey Lukashuk (Hull University)

Clustering and Mixing of Floaters by the Surface Waves

11.00 11.40 German Kolmakov (Lancaster University)

Wave Turbulence at the Surface and in the Bulk of Quantum Fluids

11.40 12.20 Sergey Nazarenko (University of Warwick)

Wave Turbulence beyond Spectra

1.30 2.10 Sergio Rica (LPS CNRS, France)

Weak Turbulence for an Elastic Plate

2.10 2.50 Vladimir Zakharov (University of Arizona)

Wave Turbulence in Finite Systems

3.30 4.10 Oleg Zaboronski (University of Warwick)

Constant flux relation in non-equilibrium statistical physics.

4.10 4.40 Stephan Fauve (LPS ENS, France)

Fluctuations of energy flux in wave turbulence 4.40 Discussion

Friday 9 December

Cosmological Turbulence and Laboratory Modelling of Cosmological Processes

9.30 10.15 Grigory Volovik (Helsinki University of Technology)

Black-Hole and White-Hole Horizons for Capillary-Gravity Waves in Superfluids

Quantum Turbulence (Continued)

11.00 11.45 Andrei Golov (University of Manchester)

Quantised Vortices in Cold Superfluid 4He

11.45 12.30 Ladislav Skrbek (Joint Low Temperature Laboratory Institute of Physics ASCR and Charles University)

Quantum Turbulence in Helium Superfluids

1.30 2.15 Matti Krusius (Low Temperature Laboratory, Helsinki University of Technology)

Vortex Formation, Propagation, and Turbulence in Superfluid 3He-B

2.15 3.00 George Pickett (Lancaster University)

Turbulence: From Quantum to Cosmological Scales

3.30 4.15 Victor Efimov (Lancaster University)

Experimental Study of Non-Linear Second Sound Waves in He-II

4.15 Final Discussions