New Challenges in Turbulence Research V

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Book of abstracts

Invited lectures

Laurent Chevillard, Laboratoire de Physique, ENS de Lyon, UCB Lyon 1 & CNRS

A (modern) view of energy transfers in homogeneous and isotropic turbulence (lecture, 2 x 1h30)

These two lectures are intended to recall basic phenomena that are taking place in fully developed three-dimensional turbulence, governed by the forced Navier-Stokes equations of incompressible fluids. All along the presentation, as a guide, we will repeatedly refer to measurements of the streamwise component of the velocity field as it is observed in wind tunnels and jets.

In the first lecture, we begin with the precise derivation of the kinetic energy budget in a local fashion using a conservation equation formulation. This will lead us to state the peculiar asymptotic behaviors of viscous dissipation and energy injection as the Reynolds number goes to infinity, as they are extrapolated from experimental observations and as assumed in the axiomatic approach of Kolmogorov. To illustrate these non-intuitive irregular behaviors, we will then present the predictions (and failures) of the stochastic heat equation, and build up a Gaussian representation of the expected singular behaviors of velocity gradients using fractional random fields.

In the second lecture, we go beyond kinetic energy budget, and derive a local version of the two-points velocity product budget. Doing so, we exhibit a novel term, that originates from the nonlinearity of the underlying equations, that governs the energy transfer across scales, also known as the cascade mechanism. We interpret this term in light of recent approaches related to weak formulations of the Euler equations, and relate its averaged behavior to the third moment of longitudinal velocity increments (i.e. the 4/5th-law). In the latter, we, furthermore, assume statistical stationarity and isotropy.

If time remains, we will mention some facts about additional intermittent (i.e. multifractal) corrections to this picture, their stochastic modeling using non-Gaussian random fields, and explore the predictions of some closures of the velocity gradient dynamics.

Jacques Vanneste, School of Mathematics, University of Edinburgh

Wave-flow interactions in geophysical fluids (lecture, 2 x 1h30)

The dynamics of the atmosphere and ocean combine two types of motion with well separated time scales: slow balanced motion on the one hand, and fast inertia-gravity waves (IGWs) on the other. Because of the time-scale separation, the two types of motion are often regarded as independent but they interact and this interaction is central to several important phenomena.

In the first lecture, I will discuss how the presence of a turbulent balanced flow affects the propagation of IGWs. Under a realistic assumption of a weak flow represented as a random field, it is possible to derive a kinetic equation that captures the scattering of the IGWs resulting from their advection and refraction by the flow. Because this scattering is restricted to IGWs of identical frequency, this equation describes energy transfers on the constant-frequency surface in wavenumber space, namely a cone. The equation predicts the horizontal isotropisation of the IGW field and cascade to small scales and makes it possible to estimate time scales for these processes. For short-wavelenth IGWs, the kinetic equation reduces to a diffusion equation with a wavenumber dependent diffusivity. This predicts, among other things, that a stationary forcing of IGWs leads to a stationary spectrum scaling like k^{-2}. The relevance of this prediction to oceanic and atmospheric observations will be discussed.

In the second lecture, I will consider the feedback that waves exert on the balanced flow, focusing on the case of near-inertial waves (NIWs). Averaged equations governing the coupled dynamics of the balanced flow and the NIWs can be obtained using multiscale methods. These equations can be interpreted as an instance of generalised-Lagragian-mean equations, in which the wave feedback appears as a modification of the relation between velocity and potential vorticity that characterises the balanced flow. I will discuss the phenomenology of the NIW-balanced flow interactions as described by the average equations and relate it to open questions in physical oceanography.

Colm-cille P. Caulfield, BP Institute & DAMTP, University of Cambridge

Turbulence in Stratified Fluids (lecture, 1h30)

Understanding how turbulence leads to the enhanced irreversible transport of heat and other scalars (such as salt and pollutants) in density-stratified fluids is a fundamental and central problem in environmental fluid dynamics, with a wide range of highly important applications. Density stratification further complicates the profoundly challenging problem of understanding turbulence, not least because stratified fluids can support internal waves, and fluid motions generically can lead to variations, both reversible and irreversible, in the system's potential energy. Recently, due not least to the proliferation of data obtained through direct observation, numerical simulation and laboratory experimentation, there has been an explosion in research activity directed at improving the community's understanding, modelling and parameterization of the subtle interplay between energy conversion pathways, waves, turbulence, and irreversible mixing in a wide range of environmentally relevant flow geometries. However, as I will discuss in this talk, there are still leading order open questions and areas of profound uncertainty concerning turbulence in stratified fluids. Therefore, I will present a personal perspective on some future priorities for research into this hugely complex, interconnected and important fluid dynamical challenge.

Basile Gallet, SPEC, CNRS & CEA Saclay

Dynamo magnetic fields in high-Reynolds-number flows (lecture, 1h30)

The dynamo instability is the process by which a flow of electrically conducting fluid spontaneously generates a magnetic field. This process is believed to be at play in stellar and planetary cores: turbulent flows driven by convective and/or mechanical forcing amplify infinitesimal magnetic perturbations to generate large-scale magnetic fields.

After providing a simple example of solid-state dynamo, I will derive the equations of magnetohydrodynamics and introduce two central questions in dynamo theory:

1) Which flows generate magnetic field?

2) What is the magnitude of the resulting dynamo field?

The key challenge is that, for most astrophysical objects and all laboratory experiments, the dynamo instability arises over a high-Reynolds-number background flow. The latter can be fully turbulent, which complicates the use of standard analytical tools, such as linear stability analysis and weakly nonlinear expansion. Nonetheless, we can address question 1) by identifying simple and fundamental magnetic-field generating mechanisms. I will illustrate them in the context of the few laboratory realizations of the dynamo effect.

We will then move on to question 2) above. We will see that the numerical determination of the dynamo intensity remains challenging, even with modern-day supercomputers. At the theoretical level, it has been studied mostly through dimensional analysis and scaling-laws. I will discuss recent analytical efforts to provide examples of flows that realize the resulting high-Reynolds-number scaling-laws.

Alex Liberzon, School of Mechanical Engineering, Tel Aviv University

Lagrangian study of a wind tunnel model of urban canopy flow using real-time, open-source 3D-Particle Tracking Velocimetry (lecture + practical, 2h40)

Three dimensional Particle Tracking Velocimetry is a well-known experimental method for the Lagrangian measurements of fluid flows. It has been developed independently in many groups, mainly because of its intuitiveness and conceptual simplicity. The tracer particles need to be detected in the multi-view videos and through the three-dimensional calibration and matching between different views to be registered in the 3D space and time. The next obvious step is the so-called tracking, that links 3D clouds of particles between the frames in time, solving an assignment problem. Despite the simplicity of the concept, the technical details are important and need to be translated into a working computer software solution. We will present one of the existing solutions, abbreviated OpenPTV which is an open source software (http://www.openptv.net). We will work through the details of the 3D-PTV, focusing on turbulence and Lagrangian turbulence statistics. We will also demonstrate and make a hands-on tutorial of the test case, providing the pre- and post-processing toolset to get to the Lagrangian turbulence statistics such as a second order Lagrangian structure function or pair dispersion analysis.

Carlo Barenghi, School of Mathematics, Statistics and Physics, Newcastle University

Cold, quantum, and turbulent: Low temperature physics and atomic physics meet fluid dynamics (lecture, 1h30)

In the last few years, new experimental techniques have revealed new faces of the turbulence problem in quantum fluids such as superfluid helium and atomic Bose-Einstein condensates. Quantum fluids exist at temperatures near absolute zero, where the reduced thermal disorder allows quantum mechanics to rule the behaviour of macroscopic amounts of matter. Turbulence in quantum fluids, or "quantum turbulence", has two remarkable properties: the lack of viscosity and the quantisation of the circulation. At first, quantum turbulence seems intriguingly simple, taking the form of an apparently disordered tangle of quantised vortex lines which move in a perfect background. Yet, despite this simplicity, in some regimes quantum turbulence displays the same properties which we observe in ordinary turbulent flows, such as the distribution of kinetic energy over the length scales represented by the Kolmogorov energy spectrum. In other regimes, for reasons which we do not fully understand, quantum turbulence shows different properties, involving forms of energy dissipation unlike ordinary fluids, or displaying turbulent two-fluid behaviour of great complexity. The aim of this lecture is to introduce the problem and the new experimental and theoretical challenges which it presents.

Reference: C.F. Barenghi, L. Skrbek, and K.R. Sreenivasan, Introduction to quantum turbulence, Proc. Nat. Acad. Sciences USA, vol. 111, suppl. 1, 4647-4652 (2014).

Léonie Canet, LPMMC, Université Grenoble Alpes & CNRS

Time-dependence of correlation functions in isotropic and homogeneous turbulence and Non-Perturbative Renormalisation Group approaches (lecture, 1h30)

This lecture is devoted to showing how useful theoretical results on the statistical properties of a homogeneous and isotropic turbulent flow can be obtained from a non-perturbative renormalisation group approach. For this, I will first briefly review how one can derive a field theory from Navier-Stokes equation for incompressible flows, and I will stress the symmetries of this field theory, more precisely its extended symmetries, and what can be deduced from them. I will then explain the principles of the renormalisation group. I will show in particular how symmetries can be deeply exploited within the framework of the non-perturbative renormalisation group, to obtain a closed flow equation for any correlation functions, which is exact in the limit of large wave-numbers. We will solve this equation at the fixed point, to obtain analytical results on the time dependence of generic n-point correlation functions in the stationary turbulent state. These predictions will be compared with available results from both numerical simulations and experiments.

Alexandros Alexakis, LPS, ENS & CNRS

Critical Transitions in Turbulent flows (lecture, 1h30)

Turbulent flows are characterized by the non-linear cascade of energy and other inviscid invariants across scales, from where they are injected to where they are dissipated. Recent experimental, numerical and theoretical works have revealed that many turbulent configurations deviate from the ideal cases of strictly forward cascade of three dimensional turbulence or the strictly inverse cascade of two dimensional turbulence. In the presence of confinement, rotation, stratification or magnetic fields (to mention a few examples) the direction of cascade can change direction and possibly display a split cascade where energy cascades to both small and large scales. In this lecture, I will present a short summary of these recent results from a unified point of view and attempt a classification of all different cascading states and all possible transitions from one scenario to another as the control parameters are varied. The presentation will be based on a set of paradigmatic examples. I will conclude with a series of open problems and challenges that future theoretical and experimental work needs to address in this new direction of turbulence research.

Benjamin Favier, IRPHÉ, Aix-Marseille Université, CNRS & École Centrale Marseille

Rotational dynamics of planetary cores: from geostrophic to inertial wave turbulence (lecture, 1h30)

In this lecture, we discuss the properties of confined rotating turbulence at low Rossby number combining experimental and numerical approaches.

We are in particular interested in the dynamics of small liquid planetary cores, which might not be convectively unstable, but are nevertheless mechanically forced due to gravitational interactions with orbiting companions.

Experimentally, we are interested in the flow inside an ellipsoidal container mechanically forced by a harmonic perturbation of its rotation rate (libration forcing). We discuss various aspects of this system, from the elliptic instability mechanism involving resonances of inertial modes to the turbulent saturation involving both waves and vortices. In a second part, an idealized local Cartesian model is introduced in order to further explore the small-scale homogeneous dynamics. This tool allows us to reach unexplored regimes in terms of Rossby and Ekman numbers, and highlights/confirms the existence of an inertial wave turbulence regime. We conclude with a brief discussion involving applications to planetary cores, dynamo action and links with more classical homogeneous rotating turbulence.

Julien Salort, Laboratoire de Physique, ENS de Lyon, UCB Lyon 1 & CNRS

Local measurements in turbulent flows: sensor design and signal analysis (lecture, 1h30)

Although flow visualization methods such as PIV or PTV are getting more and more popular with the progress of image acquisition systems and image processing tools, there are still use cases for the local Eulerian approach. Indeed, the information of interest may lie at very small and fast scales, still inaccessible to visualization. And some experiments may have no optical access at all. Cryogenic turbulence experiments are examples of such setups: the GReC experiment in CERN, the SHREK experiment in CEA Grenoble, or Rayleigh-Bénard convection cells, all have no optical access.

In this lecture, I will give an overview of the developments of fast and small local velocity and temperature sensors, with a focus on their limits, such as invasiveness or flow induced by the sensor itself. I will discuss several methods to go beyond the Taylor frozen turbulence hypothesis, such as the Pinton & Labbé method, or the He & Zhang Elliptical Approximation. Examples of application and limits of these methods will be shown.

Finally, a recent example of local velocity fluctuations measurements, obtained using a dedicated cantilever sensor in superfluid helium will be shown. The analysis of velocity structure function using the Extended Self-Similarity method, has granted access to the intermittency exponents over a wide range of temperatures, spanning relative densities of superfluid component from 96 % down to 0 %.

Marco La Mantia, Faculty of Mathematics and Physics, Charles University
Turbulent flows of superfluid helium-4: an experimentalist view (lecture, 1h30)

Superfluid helium-4 (He II) is a quantum liquid, characterized by unique properties, such as an extremely small kinematic viscosity. Turbulent flows of He II are specifically defined by the presence of tangles of quantized vortices, which are line singularities within the superfluid and can be viewed as the carriers of the flow vorticity. Relevant experimental techniques are introduced and their features outlined. Special emphasis is given to the second sound attenuation method and to the techniques enabling the visualization of turbulent flows of superfluid helium-4, which have been giving in recent years significant contributions to our understanding of the underlying physics. Selected experimental findings are reviewed, in order to highlight close similarities, as well as striking differences, with classical turbulent flows of viscous fluids. Indeed, it has been shown that quantum features are apparent at scales smaller than the mean distance between quantized vortices, while, at larger scales, a classicallike picture is observed in most cases.

Participants talks

Wouter Bos (LMFA) with Rémi Zamansky

Power fluctuations in turbulence

To generate or maintain a turbulent flow, one needs to introduce kinetic energy. This energy injection necessarily fluctuates and these power fluctuations act on all turbulent excited lengthscales. If the power is injected using forces proportional to the velocity, such as common in shear flows, or with a force acting at the largest scales only, the spectrum of these fluctuations is shown to have a universal inertial range.

Jan-Bert Flor (LEGI) with Natalia D. Shmakova and Evgueni Ermanyuk

Focusing of waves in stratified and/or rotating fluids

We investigate waves emitted by the oscillation of a horizontal torus in a stably stratified or rotating fluid by means of laboratory experiments. These waves are emitted in the form of a cone below and above the torus, with a focal point in the apex where the waves reach a maximum amplitude. For the waves in a linearly stratified fluid and a horizontally oscillating torus, we show the flow characteristics for different amplitudes of oscillation, and discuss the properties of the wave field for small and large amplitude oscillations. A new nondimensional number that is based on heuristic arguments allows us to characterize the wave field and in the focal region. Above a certain threshold of this focusing number, wave breaking appears for a Richardson number equal to 0.25, and coincides with resonant wave triads appearing near the focal region.

Next we consider the flow induced by the oscillation of a vertically oscillating torus in a rotating fluid, and the formation of an isolated blob of turbulence in the focal point. Whereas the turbulent blob in the rotating fluid leads to the formation of an organized columnar vortex, the overturning waves in a stratified fluid hardly organize into a large scale motion. We discuss the differences in dynamics when stratification and/or rotation are present.

Jérémy Vessaire (ENS Lyon) with Romain Volk, Mickaël Bourgoin

Turbulence modulation by inertial particles in a swirling flow

Many of industrial and natural flows are multiphase and turbulent. Here we investigate experimentally the turbulence modulation in a highly seeded laden flow where the particles and the fluid dynamics are strongly coupled. In such conditions, there is no general consensus regarding the impact of the particles on the energy modulation of the flow. Our experiment runs in a one disk vertical von Kármán flow. We use a «multi-scale» approach to characterize the energy modulation from (i) a global measure of the injected mechanical power by the impeller and (ii) a measure of pressure fluctuations to explore how and at which scales the flow is impacted by the particles. The results highlight: (i) at large scale, an effect of the effective density of the mixture (fluid+particle) and (ii) at small scale, an attenuation of the fluctuations as the particle volume fraction increases.

Raúl Bayoán Cal (Portland State University) with Elizabeth Camp

Influencing side-by-side cylinders wakes via turbulence intensity

Despite a large body of work utilizing inflows with low levels of freestream turbulence, many applications exhibit significant amounts of incoming turbulence although the influence of freestream turbulence has received less attention. Here, wind tunnel experiments are performed for a variety of cases of cylinder-to-cylinder distance over diameter ratios as well as varied level of turbulence. The facility has geometry of 1.2m by 0.8m by 5m and cylinders are placed approximately 3m downstream from the inlet. Cases considered are transverse spacing to diameter ratios (T/D) of T/D=1.5, 2.1 and 2.7; while the turbulence intensities are comprised of: 0.5%, 2.4%, 11% and 14%. Three-dimensional particle image velocimetry is used to acquire the data in the wake of the cylinders at a downstream distance of 11D.

Ron Shnapp (Tel Aviv University) with Yardena Bohbot-Raviv, Eyal Fattal, Alex Liberzon

Direct Measurements of Lagrangian Statistics in Canopy Flow Turbulence

It is important to understand turbulent dispersion and mixing in the canopy-flows, for example, for modeling of air pollution, or for momentum and admixtures fluxes estimations. In our research, we implement the 3D-PTV method in a wind-tunnel to provide Lagrangian statistics in canopy flows, vital for atmospheric Lagrangian stochastic models. We specifically investigate the acceleration and the pair-dispersion of the Lagrangian particles. We recognize a direct effect of the mean shear at the canopy top on the standard deviation of accelerations. Furthermore, we find that the particles' diffusivity is dependent on the standard deviation of velocities and a length scale that is constant with height. These results will be used to improve Lagrangian stochastic models in canopy flows.

Emeric Durozoy (Institut Néel) with Mathieu Gibert

Exploring Superfluid Helium Turbulence

Liquid helium is of particular interest when it comes to study high Reynolds turbulence due to its low viscosity. Furthermore, when it cools down below 2.17K, a quantum phase called superfluid appears together with peculiar properties. In superfluid helium, quantum turbulence can be observed: this is a tangle of vortices of angstrom sized core that interact with each other. In 2006, Bewley has shown that frozen dihydrogen particles could be used to illuminate these vortices, allowing their study by Lagrangian Particle Tracking. Building on these progresses, we have developed a cryostat with 8 optical accesses allowing performing all possible visualization techniques (from 2D-PIV to 3D-LPT). Its temperature can be adjusted between 4.2 and 1.12K, and its uniqueness relies on the fact that it can spin up to 2Hz. We will present this unique infrastructure and report on our recent experiments and results.

Santiago Benavides (Massachusetts Institute of Technology) with Glenn R. Flierl

2D partially-ionized turbulence in the interior of gas giant planet atmospheres

Ionization occurs in the upper atmospheres of Hot Jupiters and in the interiors of Gas Giant Planets, leading to Magnetohydrodynamic (MHD) effects which couple the momentum and the magnetic field, thereby significantly altering the dynamics. In regions of moderate temperatures the gas is only partially ionized, which also leads to interaction with neutral molecules. To explore the dynamics of these regions we utilize Partially-Ionized MHD (PIMHD), a two-fluid model -- one neutral and one ionized -- coupled by a collision term proportional to the difference in velocities. We examine the parameter space of 2D PIMHD turbulence and pay particular attention to the collisional heating term and its role in dissipation and energy exchange between the two species. This knowledge will serve as the basis to further studies in more realistic planetary settings.

Bernard Rousset (CEA Grenoble) and the SHREK collaboration

SHREK: a facility to reach ultra-high Reynolds numbers

Most of the turbulence theories rely on the limit of infinite Re. On the other hand, numerical computations can only solve problems involving weak turbulence intensity due to the drastic increase in mesh size with Re. Last but not least, turbulence experiments able to reproduce classical atmospheric event on scale down mock up are difficult as representative values of non-dimensional numbers as Re cannot be reached using standard fluid in reduced apparatus.

A way to reach high Re at the laboratory scale is to use a fluid with low viscosity. The best candidate is liquid helium, with its lowest kinematic viscosity (roughly two decades lower than classical fluid).

Concerning “steady” turbulence in closed flow, von Kármán flow allows probably the highest Re numbers. Combining these two aspects we built a giant von Karman experiment able to work with liquid helium and were able to obtain R_λ up to 10000 for hours. Results in different configurations (co-flow, counter-flow, with smooth disks or including blades or various aspect) are presented.

Alexander Blass (University of Twente) with Xiaojue Zhu, Roberto Verzicco, Detlef Lohse and Richard Stevens

Plume sweeping and meandering structures in turbulent sheared thermal convection

A series of direct numerical simulations of Rayleigh-Bénard convection with added wall shearing have been performed using a second-order finite difference code, optimized for a GPU cluster (AFiD GPU). The code shows excellent agreement with literature results for RB convection and plane Couette flow. Defining h as the channel height, shear Reynolds numbers up to Re_τ = 370 have been achieved. For low Ra the flow is dominated by shear effects, whereas a higher shear is necessary to overcome the buoyancy forces at higher Ra. For higher Ra the heat transfer first decreases with increasing shear before it increases strongly for higher mechanical driving. This unexpected non-monotonic change of Nu as a function of the wall shearing is due to a breakup of the large-scale convection rolls formed by the buoyancy forces when moderate shear is applied.

Andrea Maffioli (LMFA) with Alexandre Delache & Fabien Godeferd

Signatures and energetics of internal gravity waves in stratified turbulence

In stratified turbulence, internal gravity waves coexist with eddies, or vortices. At high Reynolds numbers, in the strongly stratified turbulence regime, motions occur in flat horizontal layers so it is not clear if waves are important or even energetically significant, since they typically involve vertical motions. In this work, we have carried out a spatio-temporal analysis on forced DNS of stratified turbulence approaching this regime. We use a time Fourier transform of DNS data to obtain velocity components, binned over the same equatorial angle, as a function of frequency. This allows us to verify directly if there are motions in agreement with the dispersion relation of internal gravity waves, which relates the angle to a specific frequency, and to quantify the wave energy. Waves of all admissible frequencies were found in the DNS and their energy was found to be smaller than the energy of the vortices but remaining of the same order of magnitude. Our results also show that the widespread wave-vortex decomposition overpredicts the energy in the waves, which may be due to KH-type instabilities visible in the DNS that are erroneously considered as being part of the wave component in this linear decomposition.

Robin Vallée (Laboratoire Lagrange) with Jérémie Bec

Turbophoresis of small heavy particles in homogeneous turbulence

Small heavy particles transported by a turbulent flow detach from the flow and form uneven distribution leading to clustering or preferential concentration. That fundamental phenomenon, called turbophoresis, is mainly observed in inhomogeneous turbulent flow where particles concentrate in low energy regions. We show here that this phenomenon can also be observed in homogeneous turbulent flows and we illustrate and quantify the importance of instantaneous inhomogeneities by performing direct numerical simulations.

Gautier Verhille (IRPHE) with Sihem Bounoua, Gilles Bouchet, Ankur Bordoloi

Rotation of fibers in turbulence

The transport of anisotropic particles in turbulent flows is ubiquitous in natural and industrial flows, going from the advection of plankton in the ocean to the transport of fibers in the textile industry. Since 2010 more and more fundamental studies are devoted to this topic. It has been shown theoretically and numerically that fibers smaller than the Kolmogorov scale tend to be parallel to the local vorticity. There are less studies for fibers whose sizes are in the inertial range. Two previous experimental studies show apparent incompatible results. Whereas the first one finds an evolution of the tumbling rate with the fiber length in agreement with the slender body theory, the second one suggests that the fiber diameter influences also the rotation rate of the particle. We show here that this apparent discrepancy can be explained by taking into account the fiber inertia and we study the influence of this inertia on the correlation time, the variance and the distribution of the tumbling rate.

Vincent Bouillaut (CEA Saclay) with Simon Lepot, Sébastien Aumaître, Basile Gallet

Transition to the ultimate regime in a radiatively driven convection experiment

I will present results from a radiatively driven convection experiment, where a fluid gets heated up within a tunable heating length ℓ in the vicinity of the bottom of the tank. We observe two regimes of heat transport depending on the Rayleigh number Ra and the heating length ℓ. The first regime corresponds to the one observed in standard Rayleigh-Bénard experiments, where the Nusselt number Nu scales as the cubic root of Ra. In the second regime, achieved for higher Ra and/or higher values of ℓ, Nu increases as the square-root of Ra, which corresponds to the « ultimate » or mixing-length regime of thermal convection. I will present a simple model that captures the transition between these two regimes in parameter space.

Paul Debue (CEA Saclay) with Valentina Valori, Yasar Ostovan, Christophe Cuvier, Jean-Philippe Laval, Jean-Marc Foucaut, Bérengère Dubrulle, Cécile Wiertel-Gasquet, Vincent Padilla and François Daviaud

Topology of quasi-singularities in an experimental turbulent swirling flow

The existence of singularities in the solution of the 3D Euler and Navier-Stokes equations remains an open mathematical problem. We tried to provide insight on what such singularities may resemble and how they may form by studying the distribution and topology of extreme events of energy transfer in a real turbulent flow. Indeed, a singularity is characterized by a refinement of scales and may result in a non-zero or diverging inter-scale transfer with decreasing scale, as suggested by Duchon and Robert. Local inter-scale energy transfer terms are computed from 3D-3C velocity fields, experimentally obtained by tomographic particle image velocimetry (TPIV) implemented in a compact set-up involving 5 cameras. Compared to previous works of the group, we are now able to measure the gradients in the three directions. This allows to compute the full transfer terms and velocity gradient, and then to find the topology of the flow at extreme events.