1. Homogeneous turbulence and flow structure

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1.1 ______________________________

Session 1 Poster-Talk
Homogeneous Turbulence and Flow Structure

Multi-mode stretched spiral vortex and non-equilibrium energy spectrum in homogeneous isotropic and shear flow turbulence

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The stretched spiral vortex (Lundgren 1982, LSV) is identified in turbulence in homogeneous isotropic (Horiuti & Fujisawa 2008) and shear flow (Horiuti & Ozawa 2011), and the spectral properties of these flows are studied using DNS and experimental measurement data. With regard to the vorticity alignment along two spiral sheets and the vortex tube in the core region, two symmetric modes and a third asymmetric mode of configurations are extracted. The genesis, growth and annihilation processes of LSV are elucidated, and the role of LSV in generation of turbulence is shown. The power law in the inertial subrange energy spectrum is studied. The base steady spectrum fits the equilibrium Kolmogorov -5/3 spectrum, to which a non-equilibrium component induced by the fluctuation of the dissipation rate is added. This component is extracted using the conditional sampling on dissipation rate, and it is shown that it fits the -7/3 power in accordance with the statistical theory. The correlation between these spectra and the appearance and diminution of the three modes of LSV is discussed. The temporal variations of the spectrum are divided into two regimes, Phases 1 and 2. Large energy contained in the low-wavenumber range in Phase 1 is cascaded to the small scales in Phase 2. This energy transfer is accomplished by the reversal in the sign of -7/3 power component.

1.2 ______________________________

Session 1 Poster-Talk
Homogeneous Turbulence and Flow Structure

Similarity scaling and small-scale structure in DNS at high resolution

P.K. Yeung (Georgia Tech),
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and K.P. Iyer (Georgia Tech)
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Advances in massively parallel computing are providing an opportunity to study small-scale turbulence structure in great detail, at Reynolds numbers near or beyond those in typical laboratory experiments. We are particularly interested in the behavior of fluctuations of dissipation and enstrophy, both pointwise and averaged locally over a region of linear size. Data at Taylor-scale Reynolds number 1000 show conclusively that intense dissipation and enstrophy tend to scale together in the limit of high Reynolds number. However scaling exponents can be inferred reliably only if the small scales are better resolved than usually done in the turbulence literature. In the case of compressible turbulence the statistics of the compressible part of the dissipation rate depends strongly on the turbulent Mach number. In addition to the science results we also give an overview of the status of parallelized computational algorithms, including the nature of challenges in algorithmic development that must be addressed in order to reach the next frontier.

1.3________________________________

Session 1 Poster-Talk
Homogeneous turbulence and flow structure

Wavelet versus Fourier analysis of the conditional vorticity budget in fully developed turbulence

Michael Wilczek (Münster Universität), Benjamin Kadoch (M2P2, Marseille), Kai Schneider (M2P2, Marseille), Rudolf Friedrich (Münster Universität) and Marie Farge (LMD, Paris)
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We study the conditional balance of vortex stretching and vorticity diffusion of fully developed three-dimensional homogeneous isotropic turbulence with respect to coherent and incoherent flow contributions. This decomposition is achieved by the Coherent Vorticity Extraction (CVE) based on orthogonal wavelets applied to DNS data, which yields insights into the influence of the different contributions as well as their interaction. It is shown that CVE yields an excellent representation of the total flow using a reduced number of degrees of freedom, which is particularly interesting as the conditional budget of vortex stretching and vorticity diffusion represents a dynamical rather than a purely kinematic relation. The results are compared to a decomposition with a standard Fourier filter.

1.4________________________________

Session 1 Poster-Talk
Homogeneous turbulence and flow structure

Phase transition and multistability of a highly turbulent closed flow

Francois Daviaud
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We experimentally study the response of a closed turbulent von K\'{a}rm\'{a}n swirling flow to a continuous breaking of its forcing symmetry from $Re =150$ to $Re = 10^{6}$. We report a divergence of the susceptibility to symmetry breaking at a critical Reynolds number $Re_c \simeq 40\,000$ revealing a phase transition. This transition is furthermore associated with a change in the statistical properties and a peak in the amplitude of fluctuations of the instantaneous flow symmetry corresponding to intermittencies between spontaneously symmetry breaking metastable states.

1.5________________________________

Session 1 Poster-Talk
Homogeneous Turbulence and Flow Structure

Statistical mechanics of axisymmetric turbulence: theory and experiments

Berengere Dubrulle
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A turbulent flow is characterized by a very large number of degrees of freedom which sets a number of practical challenges for simulations and models. A long standing dream in

turbulence theory is to devise a "statistical mechanics" of turbulence, enabling the identification of a few macroscopic global quantities (analog of temperature, pressure in kinetic theory) describing the flow, thereby describing the effective complexity of turbulence. In my talk, I present such a theory, based on recent theoretical breakthrough by Robert and Sommeria. Specifically, I derive the conservation laws of an axisymmetric turbulent flow and a mixing entropy characterizing the probability distribution of the turbulent velocity. Then, using standard tools of statistical mechanics, I derive the corresponding Gibbs distributions, the equilibrium states and fluctuations around them. I show that the equilibrium states are multi-stable and discuss the possible transitions between them. The theoretical predictions are compared with experimental fields, and a good agreement is found. I discuss the perspectives in terms of turbulence models and effective numerical simulations.

1.6________________________________

Session 1 Talk
Homogeneous Turbulence and Flow Structure

Dynamics of cubic velocity correlations from isotropic to strongly anisotropic homogeneous turbulence

Claude Cambon (ECL, Lyon)
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Revisiting generalised `4/5 Kolmogorov's' laws and related cascade processes. Why spectral modelling/theory ranging from `Rapid Distortion Theory' to triadic closures (Kraichnan's and Orszag's legacy + Craya) are more and more neglected in `modern' (fashionable ?) fundamental turbulence studies ?

1.7________________________________

Session 1 Talk
Homogeneous Turbulence and Flow Structure

Lagrangian stochastic modeling of velocity gradients in homogeneous turbulence

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The velocity gradient tensor encodes many fundamental and intrinsic geometric and statistical properties of small-scale motions in homogeneous turbulence. Examples include alignment of vorticity with respect to the strain-rate eigenvectors, rate of deformation and shapes of fluid material volumes, non-Gaussian statistics, and intermittency. In the inertial range of turbulence, similar properties can be described using the coarse-grained or filtered velocity gradient tensor. In this short presentation, we review a model for pressure Hessian and viscous forces based on the "Recent Fluid Deformation Approximation", and summarize successes in predicting alignments and time-correlations. Challenges to describe high-Reynolds number statistics are summarized.

1.8______________________________

Session 1 Poster-Talk
Homogeneous Turbulence and Flow Structure

Comparison between kinetic energy and passive scalar energy transfer in locally Homogeneous Isotropic Turbulence

Luminita Danaila, Robert Antonia
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The general focus of this talk is on the mixing of a passive scalar for Sc=1 (Sc is the Schmidt number), in decaying homogeneous isotropic turbulence and mixing with the same initial conditions (decaying HITSIC). The *philosophy is to understand and predict the scalar behaviour, when the velocity field is determined*, either completely (all the statistics are known) or through a minimal number of ingredients (e.g. the spectral slope in the restricted scaling range or RSR and the integral scale associated with the kinetic energy).

The approach, carried out in spectral space (*Danaila and Antonia, 2009*), showed that m_{θ}, the spectral slope of θ is closer (at any given R_{λ}) to 5/3 than m_{u}, the spectral slope of u (or q). In real space, we have shown (*Danaila et al., 2011*) firstly that the scaling exponent of the scalar second-order structure function is closer to the asymptotic value of 2/3 than that of the velocity field. The departure of the scaling exponent for the scalar from the asymptotic value of '2/3' can be quantified. We have established that this departure is smaller by a factor of two than that of the velocity field, a result consistent with that in spectral space, also for decaying HIT. The crux of the latter approaches, for either real or spectral spaces, is the closure of the third-order (nonlinear) term in the scalar transport equation. In our model, this term is interpreted as the scalar energy at a given scale/wavenumber transferred during a characteristic time identical (for $Sc = 1$) to that of the velocity field. This time is the analogue in real space to that already defined by *Batchelor, 1959* and *Kraichnan, 1971* the spectral domain, and takes into account the strain exerted by scales larger than or equal to the considered scale. These considerations lead, in turn, to explaining why the energy transfer rate (third-order terms) is also larger for the passive scalar than for the transporting velocity field.

The 'key' element of the explanation is the recognition of the role played by the velocity field itself via the characteristic time which takes into account the strain imposed by all scales larger than the one under consideration.

1.9______________________________

Session 1 Talk
Homogeneous Turbulence and Flow Structure

Statistical theories and statistical mechanics of fluid turbulence

Tomomasa Tatsumi

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In this talk, the relative merit of the statistical approach to turbulence against the dynamical one is explained in relation with the closure problem of turbulence. As an example, the theory of turbulence based on the cross-independence closure (Tatsumi (2011)) and its future perspectives are overviewed.

T. Tatsumi, J. Fluid Mech. 670, 365-403 (2011).

1.10________________________________

Session 1 Poster-Talk
Homogeneous Turbulence and Flow Structure

Initial Conditions for Isotropic Decaying Turbulence in many Dimensions

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In grid turbulence, turbulent kinetic energy is build up in the initial region immediately behind the grid through the interaction between jets and wakes generated by the grid. At this stage the turbulent velocity field must be inhomogeneous and non-isotropic. However, the turbulence decays downstream and the field relaxes to a quasi-homogeneous and isotropic state, which is believed to be self-similiar and characterized by a power law decay of the turbulent kinetic energy with a decay exponent n. The turbulence characteristics however do not relax to a single, universal state, but rather remain dependent on the initial conditions at the turbulence production which then determine the value of the decay exponent n. For homogeneous isotropic decaying turbulence the evolution of the two-point velocity correlation is described by the von Kármán-Howarth equation, which in its non-dimensionalized form contains the term $1/n\ (1 - n/2)\ \partial r/\partial f$. This term vanishes for $n = 2$ which is shown to correspond to the limit of infinite dimensions $d \to \infty$, so that the dependence on the initial conditions vanishes and the turbulence relaxes to a unique state. For this state we derive leading order solutions and obtain an algebraic balance between the two-point correlation f and the third order structure function d_{LLL}. For $d = 3$, however all leading order solutions are shown to be subject to a band of uncertainty which is argued to absorb the effect of the unknown initial conditions.

1.11________________________________

Session 1 Poster-Talk
Homogeneous Turbulence and Flow Structure

Quantifying the locality/nonlocality of nonlinear interactions in homogeneous, isotropic turbulence

J.A. Domaradzki, University of Southern California

D. Carati, Université Libre Bruxelles

Using results of direct numerical simulations of isotropic turbulence we compute detailed energy exchanges among different scales of motion, defined by a decomposition of velocity fields into wavenumber bands. The elementary energy exchange event involves two scales interacting nonlinearly and producing an effect in the third scale. The analysis of such detailed interactions reveals that individual nonlocal contributions are large, in agreement with known results of previous investigations. However, for the inertial range the global energy quantities such as the energy transfer, the spectral energy flux, and the subgrid-scale dissipation are asymptotically dominated by the local interactions because of significant cancelations among individual nonlocal triads. The locality functions introduced by Kraichnan are used to quantify these conclusions. The locality functions give the fraction of the energy flux across a given cutoff wavenumber kc that is due to nonlinear interactions with wavenumbers k smaller than the cutoff (the infrared locality function) or greater than the cutoff (the ultraviolet locality function). Our analysis of the locality functions for the infinite inertial range confirms the theoretical scaling exponent of n=4/3 in the wavenumber ratio k/kc.

1.12______________________________

Session 1 Poster-Talk
Homogeneous Turbulence and Flow Structure

Vortex reconnection in superfluids

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Superfluids flow without friction and possess other extraordinary properties. One of them is the formation of line vortices with diameters of the order of atomic dimensions. Their circulation is quantized. The vortices can intersect, reconnect and change their topology. The situation is identical, in a suitable outer limit, to that in classical fluids. Reconnection is the basic mechanism for quantized vortices to form a random tangle of vortex elements. This is called superfluid or quantum turbulence. It has some aspects of resemblance to classical turbulence and some that are different. The understanding of these issues can be quite important to our understanding of turbulence.

2. Shear and wake flow turbulence

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2.1________________________________

Session 2 Poster-Talk
Shear and wake flow turbulence

Stability of coherent vortex structures in shear and wake flows

Paolo Luzzatto-Fegiz (Woods Hole Oceanographic Institution)
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The dynamics of elementary vortices play an essential role in the evolution of turbulent shear and wake flows. Surprisingly, even for remarkably simple vortex flows, stability properties have often been the subject of debate. In this work, we develop a stability approach that links the number of unstable modes, for a family of steady vortices, to a simple bifurcation diagram. To this end, we build on ideas from bifurcation theory, and link turning points in a velocity-impulse plot to gains or losses of stability. We further introduce concepts from imperfection theory into these problems, enabling us to reveal hidden solution branches. As an illustration of our stability approach, we examine several fundamental flows, including infinite single and double-rows of vortices, as well as Kirchhoff elliptical vortices and vortex pairs. For all of these flows, the “imperfect-velocity-impulse” (IVI) diagram methodology yields stability boundaries in agreement with linear analysis, while simultaneously revealing lower-symmetry solutions.

2.2________________________________

Session 2 Talk
Shear and Wake Flow Turbulence

Dissipation of turbulent kinetic energy

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The relation e = Ce K 3/2 /L (where e is the local dissipation rate of the local turbulent kinetic energy K and L is a local integral length-scale, all three quantities evaluated at the same location in the flow) is a cornerstone assumption in turbulence theory and modelling. This relation is customarily used for a wide raft of flows, including wakes, jets, shear layers, decaying homogeneous turbulence, etc when the Reynolds number is large enough. The independence of Ce on Reynolds number is the basis of the Richardson-Kolmogorov cascade. That Ce depends on the boundary/initial conditions of the turbulent flow was suspected by G.I. Taylor since he introduced it in 1935 and has been found to be so in various studies over the past one or two decades, most notably by Antonia and his collaborators. Ce is also believed to be independent of Reλ when the turbulence is fully developed. (Re_λ is the local Reynolds number based on the Taylor microscale λ.) We have found a turbulent flow which has wide near −5/3 power-law energy spectra but where Ce depends diffon Reλ according to how Reλ is varied over the same range of Reλ values. It remains constant if Reλ is varied by varying the inlet Reynolds number, but it is a decreasing function of Reλ if the Reynolds number is varied by changing the measuring position. This turbulent flow was generated by a particular type of fractal/multiscale grid in the wind tunnel. An alternative way to appreciate this phenomenon is in terms of the length-scale ratio L/λ which must be proportional to Reλ if Ce is Reynolds number-independent. This proportionality simply states that the range of excited length-scales widens as the Reynolds number increases, in accordance with Richardson-Kolmogorov phenomenology. However, the turbulent flows reported here are such that, as the turbulence and $Re\lambda$ decay in the downstream direction, L/λ remains constant thus violating the proportionality $L/\lambda \sim Re\lambda$. Even so, L/λ increases at all downstream positions together as the inlet Reynolds number increases.

Mazellier, N. & Vassilicos, J.C. Turbulence without Richardson-Kolmogorov cascade. 2010 Phys. Fluids 22, 075101.
Valente, P. & Vassilicos, J.C. 2010 The decay of turbulence generated by a class of multi-scale grids. J. Fluid Mech. (submitted 17 December 2010; revised 16 July 2011).

2.3________________________________

Session 2 Poster-Talk
Shear and wake flow turbulence

Scale-by-scale energy budgets which account for the coherent motion

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Scale-by-scale energy budget equations are written for flows where coherent structures may be prominent. Both general and locally isotropic formulations are provided. In particular, the contribution to the production, diffusion and energy transfer terms associated with the coherent motion is highlighted. Preliminary results are presented in the intermediate wake of a circular cylinder for phase-averaged second-and third-order structure functions. The experimental data provide adequate support for the scale-by-scale budgets.

2.4________________________________

Session 2 Poster-Talk
Shear and wake flow turbulence

Yaglom-like equation in axisymmetric anisotropic turbulence

L. Danaila, J.F. Krawczynski, F. Thiesset and B. Renou
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Scalar and dynamic fields are studied by using scale-by-scale energy budget equations under the axisymmetry hypothesis. A scale-by-scale kinetic energy budget equation is developed for inhomogeneous and anisotropic turbulence. This equation involves second-and third-order structure functions which depend on two variables: the scale r (the modulus of the vectorial increment **r**) and the cosinus of the angle between **r** and the axisymmetry direction. We show that the equation reduces to Yaglom's 4/3 law, under more strict assumptions. Experimental data obtained in the impact region of two opposed jets, in a multiple-opposed-jets flow, are used to partially validate the analytical development and to better characterize this complex flow. It is shown that the energy transfer is mainly performed in planes perpendicular to the axisymmetry axis, whereas it is strongly inhibited over the axisymmetry direction, thus emphasizing the cascade directionality (*Danaila et al., 2011*).

L. Danaila, J.F. Krawczynski, F. Thiesset and B. Renou, 'Yaglom-like equation in axisymmetric anisotropic turbulence', Physica D, accepted, 2011.

3. Pipe and channel flow turbulence

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3.1______________________________

Session 3 Poster-Talk
Pipe and Channel Flow Turbulence

Compression of vortices in supersonic boundary layer interacting with a shock, and of wavepackets by helical pairings during a noisy event in a subsonic jet

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The effect of an oblique shock on the statistics and the turbulent structure of a supersonic boundary layer is looked at in Direct Numerical Simulation, both with adiabatic and isothermal (cooled) wall conditions. Some concepts introduced in the First Colloquium 'Mécanique de la turbulence' 1961, such as the Strong Reynolds Analogy (Morkovin) and its subsequent evolutions (anticipated in the presentation by Waltz and the remark of Michel during the discussion) are checked, while quadrant analysis and anisotropy invariant maps (Lumley & Newman) complement vizualizations of the vortical structures.
As noted in the First Colloquium, the acoustic mode (in Kovasznay's terms) carries less energy than the vortical and entropy modes, and can be considered as a by-product of turbulence. Its investigation in supersonic boundary layers (Laufer) has remained extremely difficult, partly because of the wall echoing effect, the thin region underneath the sonic line, and the non-compactness of the sources, with respect to subsonic jet flows, for example, for which the sources are more compact. The distinction of noisy and relatively quiet vortical events in turbulent subsonic jet flow invites looking at the way helical pairings contribute to the radiated noise, found to be dominated by the axisymetric contribution at low propagation angles. Could vortex reconnection during these pairings be identified as a direct contributor ? In a particularly noisy event, extracted from a Large-Eddy Simulation database by means of wavelet analysis, the radiated pressure level has been retrieved within 1.5dB by means of wavepacket model within Lighthill's framework, with an analytical wavepacket, compressed and truncated during a helical pairing episode.

3.2______________________________

Session 3 Poster-Talk
Pipe and Channel Flow Turbulence

Coherent structures and secondary flow in square-duct turbulence

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Mean secondary flow in square-duct turbulence at low Reynolds numbers is characterized in terms of coherent structures, i.e., instantaneous quasi-streamwise vortices. It is observed in direct numerical simulation that streamwise vortices appear in their preferential spanwise locations under the constraint of side walls to induce mean secondary motion as their statistical footprint. This observation is theoretically interpreted based on nonlinear steady traveling-wave solutions to the Navier-Stokes equation which reproduce not only the coherent structures but also the mean secondary flow.

3.3______________________________

Session 3 Poster-Talk
Pipe and Channel Flow Turbulence

Imperfect synchronization of wall turbulence with implications to control

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Instantaneous amplitude and phase concept emerging from analytical signal formulation is applied to the wavelet coefficients of streamwise velocity fluctuations in the buffer layer of a near wall turbulent flow. Experiments and direct numerical simulations show both the existence of long periods of inert zones wherein the local phase is constant. These regions are separated by random phase jumps. The local amplitude is globally highly intermittent, but not in the phase locked regions wherein it varies smoothly. These behaviors are reminiscent of phase synchronization phenomena observed in stochastic chaotic systems. The lengths of the constant phase inert laminar zones reveal a type I intermittency behavior, in concordance with saddle-node bifurcation, and the periodic orbits of saddle nature recently identified in Couette turbulence. The imperfect synchronization is related to the footprint of coherent Reynolds shear stress producing eddies convecting in the low buffer layer.

3.4______________________________

Session 3 Poster-Talk
Pipe and channel flows

Dissipation by two-dimensional channel "Flows at vanishing viscosity"

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The two-dimensional plane Couette flow configuration is taken as a toy model to study possible dissipation mechanisms in incompressible flows of fluids in the limit of vanishing viscosity. The volume penalized Navier-Stokes equations are discretized using a pseudo-spectral scheme, and the Reynolds number is varied up to the discretization limit of about 10000. At these Reynolds numbers, the flow first passes through a long lived transient

turbulent state involving production of vorticity at the channel boundaries, while the long time asymptotics resembles the Kelvin Cat's eyes solution of the 2D Euler equations. The role played by two possible dissipative mechanisms previously outlined in simpler 2D flows are studied by applying scale-wise coherent vorticity extraction to the turbulent channel flow.

3.5______________________________

Session 3 Poster-Talk
Pipe and channel flows

Lie-group prediction of kinetic energy profile in a turbulent pipe

Xi Chen, Fazle Hussain, Zhen-Su She,
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A theory for turbulent kinetic-energy profile (TKP) in a pipe is developed using a multi-layer Lie-group analysis of a kinetic energy length. Solution parameters are determined by a systematic procedure from empirical data, and the resulting TKP is shown to be in good agreement with observations. The conjectured meso-layer is interpreted as a new emergent order from correlated streamwise-normal velocity fluctuations, at high Reynolds numbers (Re). A new energy constant f defining is introduced and determined as, which predicts a Kolmogorov constant of, in good agreement with measurements.

3.6______________________________

Session 3 Poster-Talk
Pipe and channel flows

A mean-field theory for fluid turbulence: prediction of channel and pipe flows

Zhen-Su She, Xi Chen, You Wu, Fazle Hussain,
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Prandtl's boundary layer concept, which, although has had strong impact on twentieth century applied mathematics and mechanics, has not led to an analytic solution to the mean velocity profile (MVP) of the even the simplest turbulent flow - channel/pipe flow - now for over one hundred years. Here a Lie-group analysis for turbulence governing equation is renovated by studying group-invariance property of order functions – an extension of statistical mean-field concept of 'order parameter' - the latter is central to the description of the macroscopic order arising from microscopic fluctuations. Furthermore, a multi-layer postulate is formulated to describe the role of the fluctuations in the mean flow and the nature of the symmetry in each layer; and hence it specifies the form of restored statistical symmetry in turbulent wall-bounded flow. This framework then achieves an analytic form of the entire profile, as well as a procedure for objective and accurate determination, from empirical data, of key parameters involved in the solution. A remarkable outcome is that both simulation and experimental data support a universal Karman constant, having the value of 0.45. The most important result is that, based on the measured parameter, the predicted MVPs agree with experimental/simulation data within 1% *at all points* for a wide range of the Reynolds number (*Re*)covering nearly three decades. Moreover, the theory derives and improves several formulas for quantities of engineering interest. All findings attest to the promising use of the Lie-group symmetry in the analysis of empirical data for resolution of the long-standing mean-flow problem of turbulence for a wide class of flows.

3.7______________________________

Session 3 Poster-Talk

Pipe and channel flows

The geometry of stress and dissipation in wall-bounded flows.

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Examples will be shown of the multi-scale three-dimensional geometry of the Reynolds stress and of the vorticity in channels and boundary layers at relatively high Reynolds numbers (Re_tau=2000), including the turbulent/non-turbulent interface in boundary layers, and the organization of the viscous, logarithmic and outer layers in turbulent channels. If the logistics can be arranged (red-blue glasses), some displays of particularly complex objects will be in three dimensions.

3.8______________________________

Session 3 Poster-Talk

Pipe and channel flows

A novel Lie-group analysis for wall-bounded turbulent flows

Xi Chen, Zhen-Su She, Fazle Hussain
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Symmetry analysis based on the Lie-group method is highly effective for solving nonlinear problems. Here, we present a novel Lie-group analysis for wall-bounded turbulent flow: First, the governing equations for symmetry analysis are inner and outer mean momentum equations, instead of the Navier-Stokes equation. Second, the dilation and Galilean transformations are applied to space variable, mean velocity, and in particular to the mixing length and its spatial gradient. Finally, a transition ansatz is formulated, as a special choice of the similarity solution, which accomplishes a composite solution across adjacent layers. We thus achieve a rare occasion that symmetry is used to construct the complete solution: an analytic expression for the entire mixing length profile and hence the mean velocity profile. Thus, a classical turbulence closure problem is analytically solved by combining multi-layer perturbation with Lie-group analysis.

4. Boundary layer turbulence

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4.1________________________________
Session 4 Poster-Talk
Boundary layer turbulence

Turbulent scaling laws, invariant solutions of the multi-point correlation equations

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In the past decades turbulent scaling laws to a large extend relied on proposed equations not linked to the fundamental equations of fluid dynamics, or, if statistical equations were employed, only a finite number of unclosed equations have been employed for the analysis the latter often based on ad hoc assumptions. A rigorous way to find turbulent scaling behavior is to analyze the infinite set of multi-point equations with respect to its symmetry properties and, in a second step, generate invariant solutions thereoff which guarantees completeness. In the course of this program it only recently turned out that one of the key ingredients of turbulent scaling are new statistical symmetries not observed in the Euler or Navier-Stokes equations though being the necessary basis for most of the laws including the classical log-law and further allowing to construct solutions for higher order moments.

4.2________________________________

Session 4 Poster-Talk
Boundary layer turbulence

Near-wall streak modification by spanwise oscillatory wall motion

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The near-wall structure in a turbulent boundary layer experiences profound changes when periodic spanwise wall motion is introduced to the streamwise flow. For judiciously chosen conditions, the resulting unsteady Stokes strain virtually destroys the quasi-organised streaky structure and wall-normal fluctuations within the viscosity-affected layer, thus resulting in a drastic reduction in near-wall turbulence and in the streamwise wall friction. The mechanisms responsible for the above interactions are analysed, based on DNS and LES data, for friction Reynolds numbers of up to 1000, in channel flow and a spatially evolving boundary layer. A range of statistical data (e.g. budgets, joint PDFs, enstrophy, two-point correlations, spectra fields, etc.) are analysed in relation to structural information (*e.g.*, phase- and conditionally-averaged fields around streaks, unsteady streak orientation, filtered large-scale/small-scale streak fields, etc.) in an effort to identify the mechanisms at play. Linear analysis is found to replicate some major streak-related properties brought out by the simulations, and both suggest that the streak behaviour is governed, primarily, by the time-variation of the shear-strain vector and the relationship between the time scale of this vector and the streak decay/amplification time scale. Outer “super-streaks”, present in the turbulent layer and having a streak distance of the order of the boundary-layer thickness (or half-channel height), are shown to make significant contributions to the drag, to modulate the near-wall streaks and to influence the decay/amplification characteristics of these streaks by altering the unsteady strain field in the viscosity-affected layer.

4.3________________________________

Session 4 Poster-Talk
Boundary layer turbulence

A critical layer framework for wall turbulence

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The critical layer framework for turbulent pipe flow proposed by McKeon & Sharma (J. Fluid Mech, 2010) provides a simple model by which to understand qualitative and quantitative aspects of the structure of wall turbulence. This framework utilizes an input-output formulation of the Navier-Stokes equations to analyze the transfer function and identify the dominant forcing and response mode shapes at each combination of frequency, streamwise and spanwise wavenumbers relevant to experimental observations. This poster will describe and expand the framework, demonstrating that our model gives important predictive information about both the statistical and structural make-up of wall turbulence. Implications for both the classical picture of wall turbulence and control of turbulent flows will be discussed.

4.4______________________________

Session 4 Poster-Talk
Boundary layer turbulence

Multi-layer structure of a supersonic/hypersonic turbulent boundary layer.

You-Sheng Zhang, Xi Chen, Wei-Tao Bi, Fazle Hussain, and Zhen-Su She
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A mean-field theory is applied to analyze compressible turbulent boundary layers (TBL) obtained from direct numerical simulations (DNS). A new characteristic boundary thickness is identified, which defines a new Reynolds number that the normalized mean shear, the Reynolds stress, and hence the mixing length function, show Ma invariance at the same.
Further, using a novel Lie-group method, a five layer model for the mixing length is obtained, with a bulk layer structure 1-z5, and an intermittency layer, in analogy to the core layer in the channel and pipe flows, separating the bulk from the free stream. In addition, a two layer model for the defect of the total stress is obtained for the incompressible TBL, thus giving an accurate prediction of the entire mean velocity profile (MVP). Finally, under the above Ma-similarity, we propose an improved Van Driest transformation, and achieve a unified mean field theory of MVPs for both incompressible and compressible boundary layers.

4.5______________________________

Session 4 Poster-Talk
Boundary layer turbulence

Statistics, structure and theory of shear turbulence.

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The first hundred years of the study of turbulence can be described as dedicated to the relation of theoretical descriptions with statistical measures. The last fifty have seen a phenomenal increase in our knowledge of the structures of shear flows. We have also learned a lot about the relation of structure with statics, ranging from the intermittent nature of the turbulent/non-turbulent interface to the near-wall organization of wall-bounded turbulence. It is probably now time to pay attention to closing the circle and focus of the relation of structures, as revealed, for example, by simulations and visualizations, and classical theory. For example, what is the relation of coherent structures with the Kolmogorov energy cascade? How can linear stability theory, a phase-neutral process, give rise to coherent structures? How do the vortex structures found by many in wall-bounded flows give rise to the self-similar logarithmic layer?

4.6________________________________
Session 4 Poster-Talk
Boundary layer turbulence

Remarks on boundary layers and energy dissipation in high Reynolds number 2D flows

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In the attached boundary layer regime, incompressible flows around solid obstacles can be described using the Euler equations of perfect fluids far from the obstacle, and the Prandtl equations within a thin boundary layer close to it. These equations follow form a matched asymptotic analysis of the Navier-Stokes equations assuming the so-called parabolic scaling of the boundary layer thickness, which is well understood. The description of the flow after boundary layer detachment (whether downstream in space or later in time) has eluded description for more than a century. By closely analyzing a numerical solution of the volume-penalized Navier-Stokes equations featuring a dipole-wall collision, we attempt to get a grasp on the mechanical process underlying a specific unstationnary boundary layer detachment event, and on the associated Reynolds number scalings, which we hope could provide some hints to mathematicians looking for a solid asymptotic.

5. Turbulent stirring and mixing

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5.1______________________________

Session 5 Poster-Talk
Turbulent Stirring and Mixing

The pirouette effect in turbulent flows

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We report on the Lagrangian evolution of inertial scale tetrads, *i.e.*, four fluid elements carried by the flow that are initially arranged in a regular tetrahedron [1]. We define a "perceived" velocity gradient in the moving frame from the velocity of the four tracers and decompose it into rotation and stretching. We show that in the Lagrangian evolution the axis of rotation of the tetrahedron aligns with the initially strongest stretching direction, and that for times given by the Batchelor time, as defined by the initial size of the tetrad and energy dissipation, the angular momentum is conserved. We conjecture that this 'pirouette effect' represents the nonlinear interaction between strain and rotation that is known to be necessary for the generation of smaller scales from larger ones.

[1] H. Xu, A. Pumir, and E. Bodenschatz, Nature Physics (2011) doi:10.1038/nphys2010

5.2______________________________

Session 5 Poster-Talk
Turbulent Stirring and Mixing

Lagrangian statistics of turbulent dispersion in high-Reynolds-number DNS

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Subject to several requirements for accuracy, direct numerical simulations at high grid resolution provide a very appealing approach for studying turbulent dispersion at high Reynolds number. Despite limitations in the range of time scales present, a combination of DNS data (up to Taylor-scale Reynolds number 1000 on a \$4096^3\$ grid) and stochastic modeling arguments provide a rational means for inferring Kolmogorov scaling behavior based on the acceleration frequency spectrum. In the case of multi-particle clusters universality is also better observed in the statistics of shape than in the statistics of size. Conditional sampling based on time histories of dissipation, enstrophy and pseudo-dissipation along fluid particle trajectories is effective in providing a linkage between Lagrangian dispersion and Eulerian intermittency. We also study Lagrangian intermittency via the moments of dissipation rates averaged over a range of time intervals.

5.3______________________________

Session 5 Poster-Talk
Turbulent Stirring and Mixing

Antoine Venaille and Joel Sommeria
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Mixing through turbulent cascade: self-convolution models

We propose a simple model for the temporal evolution of a tracer advected by a turbulent flow at moderate Reynolds number. The model mimics the effects of the turbulent cascade processes that stretch tracer filaments and fold them randomly. We discuss generalizations of this approach i) in presence of a mean tracer gradient, and ii) when fluctuations of the stretching rates are taken into account.

5.4______________________________

Session 5 Poster-Talk
Turbulent Stirring and Mixing

S. S. Ray, D. Mitra, R. Pandit, and P. Perlekar
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The persistence problem in two-dimensional fluid turbulence

We present a natural framework for studying the persistence problem in two-dimensional fluid turbulence by using the Okubo-Weiss parameter Λ to distinguish between vortical and extensional regions. We then use a direct numerical simulation (DNS) of the two-dimensional, incompressible Navier--Stokes equation with Ekman friction to study probability distribution functions (PDFs) of the persistence times of vortical and extensional regions by employing both Eulerian and Lagrangian measurements. We find that, in the Eulerian case, the persistence-time PDFs have exponential tails; by contrast, this PDF for Lagrangian particles, in vortical regions, has a power-law tail.

5.5______________________________

Session 5 Poster-Talk
Turbulent Stirring and Mixing

Turbulent mixing in isotropic and anisotropic (axisymmetric) flows

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A remarkable property of turbulence is its ability to enhance the mixing of scalar contaminants, either passive or active. Consequently, the accurate prediction and/or control of these phenomena requires a thorough understanding of scalar mixing in turbulent flows and its dependence on (or, interconnection with) the dynamic field which transports it. This talk is focused on turbulent, passive and active scalar mixing, characterized by using analytical and experimental tools. Two issues will be addressed:

1) One-point characterisation of gaseous (Schmidt number, Sc=1) mixing, via e.g. the scalar probability density function (Pdf). We improve a phenomenological Pdf model based on the self-convolution hypothesis, by taking into account local characteristic times, via strain-rate fluctuations. The model is validated in turbulent mixing in a multiple jets reactor, by using simultaneous measurements of both scalar and velocity fields.

One and two-point characterisation of gaseous, variable viscosity mixing. A turbulent propane jet issues in still air (air is 5 times more viscous than propane). In comparison with a constant-viscosity flow, mixing is strongly enhanced, self-similarity and local isotropy are very rapidly achieved, the local Sc progressively increases (from 1 to 7) for increasing downstream positions. The scalar spectra exhibit an increasingly prominent Batchelor regime with a '-1' scaling law.

1) One-point characterisation of gazeous (Sc=1) mixing. In this part, we improve a phenomenological Pdfs model based on the self-convolution hypothesis, by taking into account local characteristic times, via strain-rate fluctuations. The exact shape of the Pdf provides a clear information about the state of the mixing (mixed, or incompletely mixed). In a opposed-jets mixing reactor Fig.2 (*Krawczynski et al., Phys. Fluids 2010*), in which scalar is injected via several pairs of jets, velocity and scalar fields have been measured with PIV and PLIF on acetone respectively (Figs. 3 and 4). Several phenomenological mixing models based upon self-convolution hypothesis (e.g., *Venaille et Sommeria 2007 and references therein*) are tested. We find that the mixing model of Venaille and Sommeria (VS), which does not require long time/space mixing, reasonably describes mixing in the central zone of our reactor (Fig. 5), but over very short distances (*G. Boutin, PhD thesis, Univ. Rouen, 2010*). The main shortcome of VS model is that it considers frozen strain rates, hypothesis which holds well in liquid (high Sc) mixing, but which is not adequate in gaseous, large Reynolds numbers mixing. We generalize this model, mainly by accounting for strain-rate fluctuations and intermittency, as well as large turbulent Reynolds numbers, and good agreement with our data is achieved.

2) Active scalar mixing in variable-viscosity flows.
Velocity and concentration measurements were performed in a turbulent propane jet discharging into an air–neon co-flow, for which the density ratio is 1.52 and the viscosity ratio is 5.5. The Reynolds number (based on injection diameter and velocity) is 15400. These measurements are first validated: the axial decay of the mean velocity and concentration, as well as the lateral mean and RMS profiles of velocity and concentration, is in full agreement with the existing literature. The variable-viscosity flow along the axis of the round jet is then characterized and compared with a turbulent air jet discharging into still air, for which the Reynolds number (based on injection diameter and velocity) is 5400. Both flows have the same initial jet momentum. As mixing with the viscous co-flow is enhanced with increasing downstream position, the viscosity of the fluid increases rapidly for the case of the propane jet. In comparison with the air jet, the propane jet exhibits: (1) a lower local Reynolds number based on the Taylor microscale (by a factor of four); (2) a reduced range of scales present in the flow; (3) the isotropic form of the mean energy dissipation rate is first more enhanced and then drastically diminishes and (4) a progressively increasing local Schmidt number (from 1.36 to 7.5) for increasing downstream positions. Therefore, the scalar spectra exhibit an increasingly prominent Batchelor regime with a '-1' scaling law.

Acknowledgements: Financial support from ANR (under the activities 'Micromélange' and 'ANISO') is gratefully acknowledged.

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5.6______________________________

Session 5 Poster-Talk
Turbulent Stirring and Mixing

Universality of passive scalar fluctuations at small scales in homogeneous turbulence

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Statistical properties of passive scalar fluctuations at small scales in homogeneous isotropic steady turbulence are studied by using very high resolution direct numerical simulation. The probability density functions and structure functions of the scalar increment with separation distance r are computed for the purely isotropic scalar injection and for the injection due to the mean uniform gradient. It is found that the anisotropy of the structure functions for the latter is weak and the isotropic part is easily obtained by the three direction average. Obukhov Corrsin constants for the spectrum of the scalar variance in the inertial convective range are computed and found to be consistent with the experimental values. However, unlike the idea of Kolmogorov, Obukhov, and Corrsin, the local scaling exponents for the above two cases differ at high order. This implies that the statistics of the passive scalar at small scales are dependent of large scale conditions and universality of the scaling exponents of the scalar structure functions needs to be carefully examined. A new type of scaling of the scalar increment in the inertial-convective is proposed.

5.7______________________________

Session 5 Poster-Talk
Turbulent Stirring and Mixing

Depletion of advection in turbulent mixing

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Closures of the DIA family predict a reduction in the variance of the coupling term in passive scalar advection that is analogous to the ‘depression of nolinearity’ in hydrodynamic turbulence. We show that the predicted reduction is largely consistent with direct numerical simulation data. The phenomenon is demonstrated for a range of Schmidt numbers, and is shown to be determined by the small scales of the scalar field. The variance is significantly reduced at the small scales, subbesting a suppression of scalar mixing at small scales. A link to observations of front-like structures in scalar turbulence is suggested to explain this reduction in terms of physical space structures in the scalar field.

5.8______________________________

Session 5 Poster-Talk
Turbulent Stirring and Mixing

Multiscale mixing efficiencies for steady sources

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Mixing efficiencies for passive scalar advection may be defined in terms of the suppression of variance weighted at various length scales. We consider scalars maintained by temporally steady but spatially inhomogeneous sources, stirred by statistically homogeneous and isotropic incompressible flows including fully developed turbulence. The mixing efficiencies are rigorously bounded in terms of the P\'eclet number and specific quantitative features of the source. Scaling exponents for the bounds at high P\'eclet number depend on the spectrum of length scales in the source, indicating that molecular diffusion plays a more important quantitative role than that implied by classical eddy diffusion theories.

6. Geophysical turbulence

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6.1______________________________

Session 6 Poster-Talk
Geophysical Turbulence

Statistical mechanics of simple ocean models

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Oceanic flows are kown to self-organize at large scale despite their complicated, turbulent dynamics. It gives a strong incentive for a statistical mechanics approach, which allows to predict some properties of the large scale organization without describing the small scale dynamics. We apply such a theory in very idealized contexts, by discussing i) the spontaneous formation of oceanic rings and mid-basin eastward jets ii) barotropization processes, *i.e.*, the tendency to homogenize the energy in the vertical direction.

6.2______________________________

Session 6 Poster-Talk
Geophysical turbulence

The baroclinic instability as a physical forcing of homogeneous anisotropic turbulence.

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The `shearing sheet approximation' (eg. Goldreich & Lynden-Bell 1965) is used by astrophysicists and geophysicists as a modern avatar of both `Rapid Distortion Theory', for the linear response of turbulence, and of nonlinear pseudo-spectral DNS in a frame comoving with the mean shear (*e.g.*, Rogallo 1981, Lesur 1987). In this context, we have shown that a combination of shear, with uniform rate S, vertical system vorticity W and vertical density stratification with uniform frequency N, reproduces the conditions of geostrophic front ajustment in tilting the horizontal mean isopycnes: This triggers a baroclinic instability relevant in many geophysical flows. Quasi-analytical linear analysis is performed for identifying exponential and algebraic instability in sweeping a large range of Richardson numbers, $Ri = N^2/S^2$, and baroclinicity parameters SW/N, before applying DNS to the most relevant cases. The most promising result is an approach to dramatic transient growth of turbulence, in the `exponentially stable' case at Ri > 1, using a generalized `vortex-wave' decomposition.

6.3______________________________

Session 6 Poster-Talk
Geophysical turbulence

From the origins of stars ... to the shocking origins of turbulence

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Observations of velocity and density fluctuations in the interstellar medium (ISM) and molecular clouds suggest these astrophysical flows are strongly turbulent. In this poster we examine the density and velocity structure of interstellar gas traversed by multiple shock waves in the kinematic limit. We show that just a few passages of intersecting or focused shock waves generically produces a power-law energy spectrum (with Kolmogorov-like scaling) and a log-normal density PDF. Subsequent interaction with a spherical blast wave adds a power-law tail to the density PDF, qualitatively similar to the Salpeter power-law for the initial mass function (IMF). These results suggest that fully-developed turbulence may not be required to explain the observed energy spectrum and density PDF in the ISM.

6.4______________________________

Session 6 Poster-Talk
Geophysical turbulence

Modelling bistability of middle latitude atmospheric jets

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Bistability is a stricking property of some climate features. Bistability can be obtained in purely hydrodynamic systems in turbulent regimes and explained in terms of statistical mechanics. After a review of previous results, we report laboratory experiments reproducing middle-atmosphere jets in an annular tank, similar to the set-up of Swinney and Ghil (1997). The jet is influenced by a non-axisymmetric bottom topography interfering with the natural wavy pattern of the jet, related to barotropic instability. Two states can emerge from this interaction, a wave 'blocked' with respect to the topography and a freely propagating wave. These two states can be obtained with the same control parameter, depending on the previous history of the system. No transition is observed, in spite of the strong turbulent fluctuations. Differences with respect to the previous results of Swinney and Ghil (1997) will be discussed, as well as comparisons with the theoretical and numerical approaches of Bouchet et al. . Finally possible applications to the oceanic currents and decenal climatic fluctuations will be discussed.

6.5______________________________

Session 6 Poster-Talk
Geophysical turbulence

Ultimate State of Two-Dimensional Rayleigh-Bénard Convection between Free-Slip Fixed-Temperature Boundaries

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Rigorous upper limits on the vertical heat transport in two-dimensional Rayleigh-Bénard convection between stress-free isothermal boundaries are derived from the Boussinesq

approximation of the Navier-Stokes equations. The Nusselt number Nu is bounded in terms of the Rayleigh number Ra according to Nu < 0.2891 Ra^{5/12} uniformly in the Prandtl number Pr. This scaling challenges some theoretical arguments regarding asymptotic high Rayleigh number heat transport by turbulent convection.

6.6______________________________

Session 6 Poster-Talk
Geophysical turbulence

Lagrangian statistics and flow topology in two-dimensional turbulence,

B. Kadoch, D. del-Castillo-Negrete, W.J.T. Bos and K. Schneider
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A study of the relationship between Lagrangian statistics and flow topology in fluid turbulence is presented. The topology is characterized using the Weiss criterion, which provides a conceptually simple tool to partition the flow into topologically different regions: elliptic (vortex dominated), hyperbolic (deformation dominated), and intermediate (turbulent background). The flow corresponds to forced two-dimensional Navier-Stokes turbulence in doubly periodic and circular bounded domains, the latter with no-slip boundary conditions. The pdfs of residence time in the topologically different regions are computed introducing the Lagrangian Weiss field, i.e., the Weiss field computed along the particles' trajectories.

Ref: B. Kadoch, D. del-Castillo-Negrete, W. Bos and K. Schneider, *Phys. Rev E*, 83; 036314 (2011)

6.7______________________________

Session 6 Poster-Talk
Geophysical turbulence

High Rayleigh number convection

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The content would be two-fold:

(a) to discuss briefly some of the recent experimental results on turbulent convection and
(b) to point out that the domain about which we know the least is the

case of large Rayleigh numbers (Ra) and low Prandtl numbers (Pr).
Here, we will discuss the findings from the recent helio-seismological study of the convection in the Sun, which corresponds, indeed, to large Ra and low Pr. The major conclusion is that the convection velocities are far smaller than that predicted by the mixing length or the ASH simulations.

6.8______________________________

Session 6 Talk
Geophysical turbulence

From statistical averages to statistical distributions of turbulence

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It was a long-time question for the author why the theoreticians on turbulence have been so indifferent to statistical distributions of turbulence that devoted in the nonlinear closure problem of turbulence. The views and opinions of the mathematicians are highly appreciated.

7. Magnetohydrodynamic turbulence

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7.1________________________________

Session 7 Poster-Talk
MHD turbulence

Anisotropy in rotating MHD turbulence

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Homogeneous axisymmetric turbulence in an electrically-conducting fluid is subjected to both a uniform magnetic field and to system rotation, with angular velocity aligned with it. This configuration is relevant in the core of the earth and in astrophysics. Properties of magneto-inertial waves are studied analytically, and numerically using pseudo-spectral DNS, when nonlinearity is weak. For significant nonlinearity, the nonlinear transfers for both magnetic and kinetic energy are quantified. A large range of Elsasser numbers is investigated, varying the relative strength of the Coriolis force versus the Lorentz one. Anisotropy naturally develops without artificial forcing, and yields a depletion of magnetic energy at decreasing Elsasser number. This analysis is complemented by angle-dependent spectra and pdf of angles between velocity fluctuations and magnetic ones.

7.2________________________________

Session 7 Poster-Talk
MHD turbulence

Intermittency of quasi-static magnetohydrodynamic turbulence: A wavelet viewpoint

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Intermittency of quasi-static magnetohydrodynamic (MHD) turbulence in an imposed magnetic field is examined, using three-dimensional orthonormal wavelets. This analysis is applied to two turbulent MHD flows computed by direct numerical simulation with 512^3 grid points and with different intensities of the imposed magnetic field. It is found that the imposed magnetic field leads to a substantial amplification of intermittency of the flow, especially in the direction of the imposed magnetic field.

7.3________________________________

Session 7 Poster-Talk
MHD turbulence

VKS experiment: a chaotic turbulent dynamo?

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The VKS experiment studies dynamo action in the flow generated inside a cylinder filled with liquid sodium by the rotation of coaxial impellers. We first report observations related to the self-generation of a stationary dynamo when the flow forcing is Rp symmetric, i.e., when the impellers rotate in opposite directions at equal angular velocities. The bifurcation is found to be supercritical with a neutral mode whose geometry is predominantly axisymmetric. We discuss the role of turbulence in the dynamo mechanism. We then report the different dynamical dynamo regimes observed when the flow forcing is not symmetric: stationary dynamos, transitions to relaxation cycles or to intermittent bursts, and random field reversals. We show that these dynamics result from the interactions of a few modes and display characteristic features of low dimensional dynamical systems despite the high degree of turbulence in the flow. (VKS collaboration: CEA - CNRS - ENS Paris - ENS Lyon).

7.4______________________________

Session 7 Poster-Talk
MHD turbulence

Vortex Tubes, Magnetic Flux Tubes and the Magnetic Prandtl Number

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The sun has magnetic flux tubes that make sunspots. Jupiter has vortices that make the great red spot and other such blemishes. Why are there no vortices on the sun? How is the difference in the two kinds of system controlled by the magnetic Prandtl number*? How can we characterize these qualitative differences in the topologies of the relevant fields? What happens at the crossover between the two behaviors, which ought to take place in some intermediate bodies such as Brown Dwarfs? We raise these issues in the form of a few illustrations of the different flows simulated for different Prandtl numbers but have yet to find a suitable quantification of the different regimes.

* The ratio of the kinematic viscosity to the product magnetic permeability times electric conductivity.

7.5______________________________

Session 7 Poster-Talk
MHD turbulence

Systematics of the magnetic-Prandtl-number dependence of homogeneous, isotropic magnetohydrodynamic turbulence

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We present an overview of the results of our detailed pseudospectral direct numerical simulation (DNS) studies [1], with up to 1024^3 collocation points, of incompressible, magnetohydrodynamic (MHD) turbulence in three dimensions, without a mean magnetic field. Our study concentrates on the dependence of various statistical properties of both decaying and statistically steady MHD turbulence on the magnetic Prandtl number Pr_M over a large range, namely $0.01 \leq Pr_M \leq 10$. We obtain data for a wide variety of statistical measures, such as probability distribution functions (PDFs) of the moduli of the vorticity and current density, the energy dissipation rates, and velocity and magnetic-field increments, energy and other spectra, velocity and magnetic-field structure functions, which we use to characterize intermittency, isosurfaces of quantities, such as the moduli of the vorticity and current density, and joint PDFs, such as those of fluid and magnetic dissipation rates. Our systematic study yields a a crossover from a larger intermittency in the magnetic field than in the velocity field, at large Pr_M, to a smaller intermittency in the magnetic field than in the velocity field, at low Pr_M. Furthermore, a comparison of our results for decaying MHD turbulence and its forced, statistically steady analogue suggests that we have strong universality in the sense that, for a fixed value of Pr_M, multiscaling exponent ratios agree, at least within our error bars, for both decaying and statistically steady homogeneous, isotropic MHD turbulence.

[1] Systematics of the magnetic-Prandtl-number dependence of homogeneous, isotropic magnetohydrodynamic turbulence - G. Sahoo, P. Perlekar and R. Pandit, New J. Phys., 13,0130363 (2011); doi:10.1088/1367-2630/13/1/013036.

7.6______________________________

Session 7 Poster-Talk
MHD turbulence

Modeling flow--turbulence interaction in magnetohydrodynamics: Cross-helicity effects

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Roles of turbulence in the context of magnetic-field destruction and generation are investigated with special emphasis on the mutual interaction between global inhomogeneous structures ("flow") and statistical properties of fluctuation ("turbulence"). Turbulence modeling provides a useful tool for investigating such interaction. A self-consistent magnetohydrodynamic turbulence model based on a closure theory of magnetohydrodynamic turbulence is presented. In order to evaluate effective transports due to turbulence, it is indispensable to take account of the {\it structure} information represented by pseudoscalar turbulent statistical quantities or helicities as well as the {\it intensity} information of turbulence represented by the turbulent energy. In the self-consistent model, evolution equations for the statistical quantities relevant to turbulent transports should be incorporated. As one of such pseudoscalar turbulent quantities, the turbulent cross helicity (velocity--magnetic-field correlation in turbulence) is considered and its effects are examined. On the basis of evolution equation, mechanisms that provide turbulence with cross helicity are shown. FIrst, cross-helicity effect in the magnetic induction equation, which is related to the magnetic-flux freezing, magnetic reconnection, and dynamo in highly turbulent media, is considered with special emphasis on the spatial distribution of the turbulent cross helicity. Second, cross-helicity effect in the momentum equation is also investigated. In the context of magnetic reconnection, it is shown that the large-scale flow and magnetic-field configurations favorable for the cross-helicity generation are compatible with the fast reconnection. Through these illustrative examples, importance of the self-consistent modeling in magnetohydrodynamic turbulent flow is stressed.

7.7_______________________________

Session 7 Poster-Talk
MHD turbulence

A Remaining Puzzle in Direct-Interaction Approximation

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The direct-interaction approximation (DIA) initiated by Kraichnan is the first and only, to my knowledge, statistical theory of turbulence deduced, without introducing any adhoc free parameters, from the first principle, i.e. the Navier-Stokes equation. However, it is a pity that this theory is not well appreciated by turbulence community despite that it predicts successfully the universal-range spectrum of energy including the Kolmogorov -5/3 and the Iroshnikov-Kraichnan -3/2 power laws for hydrodynamic and magneto-hydrodynamic turbulence, respectively. It seems to me that the primary cause of unpopularity of DIA may be attributed to the formal derivation scheme described, e.g. in Leslie's book. Since it is the Reynolds number expansion in nature, the application to the high-Reynolds number phenomena, such as turbulence, is questionable in principle. Here we must realize that the Kraichnan's original idea was completely different from the above easy formal derivation scheme. The same DIA equations (both Eulerian and Lagrangian versions) can be derived by the following two assumptions:
(i) If we remove a single triad interaction among arbitrarily chosen three modes of wavenumbers from the Navier-Stokes equation, then these modes are statistically independent of each other.
(ii) The effects of removal of this single interaction on the full system are small. The validity of these assumptions was verified numerically for a dynamical model having quadratic nonlinear terms of the same structure as those of the Navier-Stokes equations. A mathematical proof of justification of these assumptions remains as a puzzle to me before applying DIA to other canonical turbulence.

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7.8________________________________

Session 7 Poster-Talk
MHD turbulence

Quantifying the locality/nonlocality of nonlinear interactions in MHD turbulence

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D. Carati, Université Libre Bruxelles

The locality functions introduced by Kraichnan give the fraction of the energy flux across a given cutoff wavenumber kc that is due to nonlinear interactions with wavenumbers k smaller than the cutoff (the infrared locality function) or greater than the cutoff (the ultraviolet locality function). Previous analysis of DNS data for the infinite inertial range of hydrodynamic turbulence (HD) confirmed the theoretical scaling exponent of n=4/3 in the wavenumber ratio k/kc. We have extended the analysis to DNS data to MHD turbulence. The analysis is performed in spectral space, which is decomposed into a series of shells following a power law for the boundaries. The triadic transfers occurring among these shells are computed and the fluxes and locality functions are recovered by partial summation over the relevant shells. Values of 1/3 and 2/3 for the scaling exponents of the four MHD energy fluxes are found. These values are smaller than the value of 4/3 found for HD turbulence, indicating significantly more nonlocal character of nonlinear interactions in MHD than in HD turbulence.