# List of Talks

# Abstracts of Talks

## On type I singularity for the Euler equations

**Dongho Chae**
Chung-Ang University

In this talk we discuss the finite time blow up problem. In particular we consider possibility of type I blow up, which means scaling invariant rate of blow up for the gradient of velocity. It is a generalization of self-similar(discrete, rotational) blow up, and in the energy conserving case we can show that the energy concentration is rather restricted by the type condition. We also consider the case where the singularity is isolated.

## Global existence, asymptotic behavior, and pattern formation driven by the parametrization of a nonlocal Fisher-KPP problem

**Li Chen**
Universität Mannheim

The global boundedness and the hair trigger effect of solutions for a Fisher KPP type nonlinear nonlocal reaction-diffusion equation are investigated. Under appropriate assumptions on the nonlocal kernel, it is proved that for any nonnegative and bounded initial condition, the solution exists globally. Under further assumptions on the initial datum, the solutions are shown to converge to the constant stationary state locally uniformly on any compact subset, which is known as the hair trigger effect. 1D numerical simulations of the above nonlocal reaction-diffusion equation are performed and the effect of several combinations of parameters and convolution kernels on the solution behavior is investigated. This is a joint work with Jing Li and Christina Surulescu.

## Mixed boundary value problem on nonsmooth domains

**Hongjie Dong**
Brown University

I will discuss some recent results about elliptic equations in a nonsmooth domain, with the Dirichlet boundary condition on part of the boundary and the conormal boundary condition in the complement. Both homogeneous and nonhomogeneous boundary conditions are considered. This is based on joint work with Jongkeun Choi (KIAS) and Zongyuan Li (Brown).

## On the topology of integrable Hamiltonian fibrations

**Konstantinos Efstathiou**
Duke Kunshan University

Motivated by the structure of the joint spectrum of integrable quantum systems we consider the topological properties of the integrable Hamiltonian fibration of the corresponding classical systems. We focus on Hamiltonian monodromy, which is related to the non-triviality of certain torus bundles, and on its generalizations. We show how monodromy is reflected on the joint spectrum and how it is related to the topology of a certain circle bundle (for standard monodromy) or a Seifert fibration (for generalized monodromy).

## Isometric embedding in $R^3$ of Alexandrov-Nirenberg surfaces

**Jiaxing Hong**
Fudan University

In this talk the compactness of Alexandrov-Nirenberg surfaces will be given and construction of some Alexandrov-Nirenberg surfaces will be discussed.

## Random Batch Methods for Interacting Particle Systems and Consensus Based Global Optimization in High Dimensional Machine Learning Problems

**Shi Jin**
Shanghai Jiao Tong University

We develop random batch methods for interacting particle systems with large number of particles. These methods use small but random batches for particle interactions, thus the computational cost is reduced from $O(N^2)$ per time step to $O(N)$, for a system with N particles with binary interactions. For one of the methods, we give a particle number independent error estimate under some special interactions. Then, we apply these methods to some representative problems in mathematics, physics, social and data sciences, including the Dyson Brownian motion from random matrix theory, Thomson's problem, distribution of wealth, opinion dynamics and clustering. Numerical results show that the methods can capture both the transient solutions and the global equilibrium in these problems. We also apply this method and improve the consensus-based global optimization algorithm for high dimensional machine learning problems. This method does not require taking gradient in finding global minima for non-convex functions in high dimensions.

## Complete monotonicity-preserving numerical methods for time fractional ODEs

**Lei Li**
Shanghai Jiao Tong University

The time fractional ODEs are equivalent to convolutional Volterra integral equations with completely monotone kernels. We introduce the concept of complete monotonicity-preserving (CM-preserving) numerical methods for fractional ODEs, in which the discrete convolutional kernels inherit the CM property as the continuous equations. We prove that CM-preserving schemes are at least $A(\pi/2)$ stable and can preserve the monotonicity of solutions to scalar nonlinear autonomous fractional ODEs. We also show that the L1 scheme is CM-preserving by a characterization of the convolution inverse of completely monotone sequences. The good signs of the coefficients for such class of schemes ensure the discrete fractional comparison principles, and allow us to establish the convergence in a unified framework when applied to time fractional sub-diffusion equations and fractional ODEs.This is a joint work with Dongling Wang.

## Some Recent Process on scRNA-seq Data Analysis

**Tiejun Li**
Peking University

scRNA-seq data analysis is one of the most exciting topics in computational biology and it is currently in the fast developing stage. In this talk I will introduce some challenging issues in this area and some recent methods developed by our group. The covered topics include the stemness quantification, lineage inference, cell clustering and batch removal.

## Oscillatory Integral Operators and Interpolative Butterfly Factorization

**Yingzhou Li**
Duke University

The far-field interactions of some oscillatory integral operators can be represented by a matrix that satisfy a complementary low-rank property. In this talk, we introduce a interpolative butterfly factorization for such matrices. A preliminary interpolative butterfly factorization is first constructed based on interpolative low-rank approximations. A novel sweeping matrix compression technique further compresses the preliminary interpolative butterfly factorization via a sequence of structure-preserving low-rank approximations. The sweeping procedure propagates the low-rank property among neighboring matrix factors to compress dense submatrices in the preliminary butterfly factorization to obtain an optimal one in the butterfly scheme.For an $N \times N$ matrix, it takes $O(N \log N)$ operations and complexity to construct the factorization as a product of $O(\log N)$ sparse matrices, each with $O(N)$ nonzero entries. Hence, it can be applied rapidly in $O(N \log N)$ operations. Numerical results are provided to demonstrate the effectiveness of this algorithm.

## Passive Scalar Mixing Measures and Optimal Stirring

**Zhi Lin**
Zhejiang University

Recently much research efforts have been dedicated to the study of scalar mixing and transport in fluid flows using a multiscale measure closely connected to Sobolev norms. Based on the advection-diffusion model with sources for scalar fields, we propose to investigate the evolution of the multiscale mixing norms under complex flow/source fields as well as general initial and boundary conditions. We aim to identify the dominant physical mechanisms under different characteristic scales and to derive the corresponding scaling laws for the scalar mixing enhancement due to flow stirring. We see for a theoretical and numerical approach to systematically evaluate, predict and eventually control the fundamental phenomena involving scalar mixing and transport which are ubiquitous in nature and in engineering.

## The sharp interface limits of some phase field models

**Yuning Liu**
New York University Shanghai

The phase field models are widely adopted in the description of the evolution of interfaces in continuum mechanics. They can be constructed to purposely reproduce a given sharp interface model when the thickness of their diffused interface trends to zero. In this talk we shall start by reviewing a few classical methods in the proof of the convergence of the Allen-Cahn equation, a typical phase field model. Then we discuss the possible applications of these methods to other models.

## Derivation of the Vlasov equation

**Peter Pickl**
Duke Kunshan University

The rigorous derivation of the Vlasov equation from Newtonian mechanics of $N$ Coulomb interacting particles is still an open problem. In the talk I will present recent results, where an $N$-dependent cutoff is used to make the derivation possible. The cutoff is removed as the particle number goes to infinity. Our result holds for typical initial conditions, only. This is, however, not a technical assumption: one can in fact prove deviation from the Vlasov equation for special initial conditions for the system we consider.

## The Teichmüller spacea as a reduced symplectic space

**Tudor Stefan Ratiu**
Shanghai Jiao Tong University

It will be shown that the classical Teichmüller space is a symplectic reduced space for a group valued momentum map. The background on this kind of very general momentum map will be also presented.

## Reinforced random walks and statistical physics

**Pierre Michel Tarres**
New York University Shanghai

We will review recent results on two processes, namely the Edge-reinforced random walk (ERRW), introduced by Coppersmith and Diaconis in 1986, and the Vertex-reinforced jump process (VRJP), proposed by Werner and introduced by Davis and Volkov in 2002. We will explain how the ERRW and VRJP are explicitly related to several models in statistical physics, namely the supersymmetric hyperbolic sigma model, the random Schrödinger operator and Dynkin's isomorphism. These correspondences enable us in particular to show recurrence/transience results on the Edge-reinforced random walk, using results of Disertori, Spencer and Zirnbauer (2010) and they also allow us to provide insight into these models. This work is joint with Christophe Sabot, and part of it is also in collaboration with Margherita Disertori, Titus Lupu and Xiaolin Zeng.

## PDE description of Brownian microswimmer interacting with walls

**Jean-Luc Thiffeault**
University of Wisconsin-Madison

We consider a simple model of a two-dimensional microswimmer with fixed swimming speed. The direction of swimming changes according to a Brownian process, and the swimmer is interacting with boundaries. This is a standard model for a simple microswimmer, or a confined wormlike chain polymer. The shape of the swimmer determines the range of allowable values that its degrees of freedom can assume — its configuration space. Using natural assumptions about reflection of the swimmer at boundaries, we compute the swimmer's invariant distribution across a channel consisting of two parallel walls, and the statistics of spreading in the longitudinal direction. This gives us the effective diffusion constant of the swimmer's large scale motion. When the swimmer is longer than the channel width, it cannot reverse, and we then compute the mean drift velocity of the swimmer. This model offers insight into experiments of scattering of swimmers from boundaries, and serves as an exactly-solvable baseline when comparing to more complex models. This is joint work with Hongfei Chen.

## Approximation of the Atomistic Model by Higher Order Continuum Model

**Hao Wang**
Sichuan University

We derive a nonlinear elasticity model for elastostatic problems from the atomistic description of a crystal lattice in one dimension. The elasticity model is of higher order compared with the well-known Cauchy- Born model in the sense that it utilizes higher order derivatives of the deformation gradient and is thus also called the higher order continuum model. We present a sharp convergence analysis for such higher order continuum model and we show that, compared to the second order accuracy of the Cauchy-Born model, the higher order continuum model is of forth oder accuracy with respect to the interatomic spacing in the thermal dynamic limit. The theoretical results are illustrated by our numerical experiments.

## A second order in time energy stable variable step method for the Cahn-Hilliard equation

**Xiaoming Wang**
Southern University of Science and Technology

We propose a novel second-order in time variable step method for the Cahn-Hilliard equation. The scheme is a proper combination of variable BDF2, convex splitting, and viscous regularization at the discrete level. With the aid of a novel discrete Gronwall type inequality, we are able to show that the error is second-order in time and energy stable under a mild restriction on the ratio of the successive step-sizes. Such a result is new even for the linear case.

## An iterative thresholding method for topology optimization

**Xiao-Ping Wang**
Hong Kong University of Science and Technology

Topology optimization (TO) is a promising numerical technique for designing optimal engineering designs in many industrial applications. It is expected that it might become an unavoidable engineering tool for many new rising technologies such as the additive manufacturing or metal 3D printing. We propose an efficient and robust iterative thresholding method for topology optimization with applications to fluids and heat transfer system. For the Stokes fluid flow, the proposed algorithm is based on minimization of an objective energy function that consists of the dissipation power in the fluid and the perimeter approximated by nonlocal energy, subject to a fluid volume constraint and an incompressibility condition. We show that the minimization problem can be solved with an iterative scheme in which the Stokes problem is approximated by a Brinkman equation and solved with the mixed finite-element method. The indicator functions of the fluid-solid regions are then updated according to simple convolutions followed by a thresholding step. We demonstrate mathematically that the iterative algorithm has the total energy decaying property. The proposed algorithm is simple and easy to implement. Extensive numerical experiments in both two and three dimensions show that the proposed iteration scheme is robust, efficient and insensitive to the initial guess and the parameters in the model. Generalization to heat transfer system will also be discussed.

## Effective boundary conditions of diffusion equations on domains containing thin layers

**Xuefeng Wang**
Chinese University of Hong Kong at Shenzhen

This is going to be a survey talk on a class of diffusion equations. Of concern is the following scenario: a domain consists of two parts, with one of them being a thin layer; on the domain we have a diffusion equation, one of whose physical parameters such as diffusion coefficient has different size scales on different subdomains. This kind of problem arises in real applications such as thermal barrier coatings of turbine engine blades, effects of roads on the spreading of populations and epidemics. Numerical computation of such a diffusion equation on such a domain is time-consuming because we would need very fine grids on the thin layer; moreover, we cannot see easily the effects of the thin layer on the dynamics of the diffusion equation. A good way to resolve this problem is to think of the thin layer as a thickless surface/curve, on which we impose an effective boundary condition(EBC); then hopefully with ease we can solve, numerically, the diffusion equation on the remaining subdomain with the EBC; furthermore, we can see the effects of the thin layer via EBC. We will review classic theorems, and introduce results obtained in recent years, as well as results that have not been published, including derivation of the "bulk-surface" model for interaction of inactive proteins in the interior of a cell and active proteins on the surface of the cell. These results not only are of practical significance, but also bring some new challenges to pure PDE-research.

## Back flow of the Prandtl boundary layer

**Ya-Guang Wang**
Shanghai Jiao Tong University

In this talk, we study the back flow point of the Prandtl boundary layer under an adverse pressure gradient. The occurrence of back flow is an important physical event in the evolution of boundary layer, which eventually leads to separation. For the two-dimensional unsteady Prandtl boundary layer equations, we obtain the existence of a back flow point on the boundary when the initial tangential velocity is strictly monotonic with respect to the normal variable, and the pressure gradient of the outer flow is adverse. Both of flows with and without heat conduction will be studied. This is a joint work with Shi-Yong Zhu.

## Stability and partial dissipation

**Jiahong Wu**
Oklahoma State University

In collaboration with Peter Constantin, Charlie Doering and a group of young colleagues, we have been attempting to understand how partial or fractional dissipation affects the stability, regularity and large-time behavior of solutions. This talk presents recent results on the global stability and large-time behavior concerning three partially dissipated PDE systems. They include the 2D Boussinesq equations near the hydrostatic equilibrium, several partially dissipated magneto-hydrodynamic systems near a background magnetic field, and partially dissipated Oldroyd-B models near the trivial solution.

## Energy and Dynamics of Grain Boundaries Based on Underlying Mircrostructure

**Yang Xiang**
Hong Kong University of Science and Technology

Grain boundaries are the interfaces of grains with different orientations in polycrystalline materials. Energetic and dynamic properties of grain boundaries play essential roles in the mechanical and plastic behaviors of the materials. These properties of grain boundaries strongly depend on their microscopic structures. We present continuum models for the energy and dynamics of grain boundaries based on the continuum distribution of the line defects (dislocations or disconnections) on them. The long-range elastic interaction between the line defects is included in the continuum models to maintain stable microstructure on grain boundaries during the evolution. The continuum models is able to describe both normal motion and tangential translation of the grain boundaries due to both coupling and sliding effects that were observed in atomistic simulations and experiments.

## Uniform structural stability of Hagen-Poiseuille flows in a pipe

**Chunjing Xie**
Shanghai Jiao Tong University

We discuss the recent progress on nonlinear structural stability of Hagen-Poiseuille flows, in particular, the uniform stability of these flows with respect to the mass flux. The key ingredient of the analysis is the linear structural stability of Hagen-Poiseuille flows in a pipe. This linear problem closely relates to dynamical stability of Hagen-Poiseuille flows. The stability of other shear flows in a nozzle will also be addressed.

## Subsonic and Sonic Jet Flows

**Zhouping Xin**
Chinese University of Hong Kong

In this talk, I will discuss some results on jet flows for the steady compressible potential flows from a finite converging nozzle. Both subsonic and sonic jets will be considered which correspond to some free boundary problems for uniform elliptic equations and degenerate elliptic equations respectively. Formulation of the problems and the existence (and non-existence) of solutions will be discussed. Both finite jets and infinite jets can be obtained by a PDE approach and regularity and properties of the solutions will be discussed.

## Nonuniform time-stepping approaches for reaction-subdiffusion problems

**Jiwei Zhang**
Wuhan University

Nonuniform time-stepping methods are promising for Caputo reaction-subdiffusion problems because they would be simple and effectiveness in resolving the initial singularity and other nonlinear behaviors occurred away from the initial time. Compared with traditional local methods for the first-order derivative, the numerical analysis for nonlocal time-stepping schemes on nonuniform time meshes are challenging due to the convolution integral (nonlocal) form of fractional derivative. We develop a general framework for the stability and convergence analysis with three tools: a family of complementary discrete convolution kernels, a discrete fractional Grönwall inequality and a global (convolutional) consistency analysis, which is not limited to a special time mesh by building a convolution structure of local truncation error. It seems that the present techniques are extendable to the variable-order, distributed-order diffusion equations and other nonlocal-in-time diffusion problems. This framework works for a family of widely-used scheme such as L1 scheme, Alikhanov's scheme (second-order scheme), and fast-algorithm-based L1 scheme and Alikhanov's scheme, et al.

## Global solutions of 3-D anisotropic Navier-Stokes system with uni-directional derivative small

**Ping Zhang**
Chinese Academy of Sciences

The goal of this paper is to extend this type of result to the 3-D anisotropic Navier-Stokes system $(ANS)$ with only horizontal dissipation. More precisely, given initial data $u_0 = (u_0^h, u_0^3) \in B^{0,\frac{1}{2}}$, $(ANS)$ has a unique global solution provided that $|D_h|^{-1}\partial_3 u_0$ is sufficiently small in the scaling invariant space $B^{0,\frac{1}{2}}$.

## Finite topologies and $p$-group actions

**Ying Zhang**
Soochow University

Let $T(n)$ (resp., $T_0(n)$) denote the number of distinct topologies (resp., $T_0$-topologies) which can be defined on a finite set of cardinality $n$. We obtain arithmetic properties of $T(n)$ and $T_0(n)$ by constructing certain $p$-group actions on suitable subsets of topologies. First, we obtain a formula which expresses $T(n+p^k)$ modulo $p^m$ in terms of the numbers of certain finite topologies, and thus establish the periodicity of $T(n)$ modulo $p^m$; precisely, we have, for $p \geq 3$, $T(n+p^{p+m-1}) \equiv T(n+p^{m-1}) \bmod p^m$, and for $p=2$ similar but slightly sharper formulas. By the same methods we prove that, for any prime power $p^k$, $T_0(n+p^k) \equiv T_0(n+p^{k-1}) \bmod p^k$, answering an unsolved problem in the work of Z. I. Borevich in around 1980. In another aspect, we obtain remarkable recursive relations for $T_0(n)$ and $T(n)$ modulo $p^m$. Finally, as byproducts of the methods thus developed, we also obtain similar formulas for the Bell numbers as well as the Stirling numbers of the second kind. This is joint work with Xiangfei Li.

## On the Vlasov-Maxwell-Boltzmann system near Maxwellians

**Huijiang Zhao**
Wuhan University

This talk is concerned with some results on the construction of global solutions to the Cauchy problem of the Vlasov-Maxwell-Boltzmann system near Maxwellians and its global-in-time Vlasov-Poisson-Boltzmann limit as the light velocity tends to infinity.

# Mathematical Aspects of Topologically Protected Wave Propagation

**Yi Zhu**
Tsinghua University

Mathematical analysis on wave dynamics in topological material is a current research focus. In this talk, we will first show the subtle and novel wave patterns which are immune to defects and disorders. Then, we will present a rigorous justification of the 2-D Dirac system derived from the Maxwell's equation with a slowly modified honeycomb material weight. This 2-D Dirac system is regarded as the simplest continuous model to describe the wave dynamics in topological materials. With some analysis and numerical simulations on this equation, we will explain why chiral wave propagation is admissible in topological materials. Nonlinear modes will also be discussed if the nonlinear effects are included.

# List of Speakers

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