Workshop on the Intersection of Dynamics and PDE
Abstracts

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Research Talks

Quasiperiodic Operators: Global Theory, Aubry Duality and Partial Hyperbolicity

Lingrui Ge

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We will briefly introduce the partially hyperbolic structure of quasiperiodic operators, its link to Avila's global and its important role in the study of spectral theory.

Multiple Boundary Peak Solution for Strongly Indefinite Elliptic System with Neumann Boundary

Yuxia Guo

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We consider the following elliptic system with Neumann boundary:

$$\begin{cases} -\Delta u + \mu u = v^p, & \text{in } \Omega, \\ -\Delta v + \mu v = u^q, & \text{in } \Omega, \\ \frac{\partial u}{\partial n} = \frac{\partial v}{\partial n} = 0, & \text{on } \partial\Omega, \\ u > 0, \ v > 0, & \text{in } \Omega, \end{cases}$$

where $\Omega \subset \mathbb{R}^N$ is a smooth bounded domain, μ is a positive constant and (p, q) lies in the critical hyperbola:

By using the Lyapunov-Schmidt reduction technique, we establish the existence of infinitely many solutions to above system. These solutions have multiple peaks that are located on the boundary $\partial\Omega$. Our results show that the geometry of the boundary $\partial\Omega$, especially its mean curvature, plays a crucial role on the existence and the behavior of the solutions to the problem.

Non-minimizing and Min-max Solutions to Bernoulli Problems

Dennis Kriventsov

Rutgers, The State University of New Jersey, USA

Bernoulli type free boundary problems have a well-developed existence and regularity theory. Much of this, however, is restricted to the case of minimizers of the natural energy (the Alt-Caffarelli functional). I will describe a compactness and regularity theorem that applies to any critical point instead, based on a nonlinear frequency formula and Naber-Valtorta estimates. Then I will explain, via an example involving gravity water waves, how to use this theorem to find min-max type (mountain pass) solutions. This is based on joint work with Georg Weiss.

Classification of Atmospheric Traveling Waves at Cloud Level

Zhiwu Lin

Fudan University, China

We classify within the quasi-geostrophic framework all types of traveling waves in zonal bands of the planetary atmosphere at cloud level according to their wave speeds. This classification pertains to waves of all amplitudes, going beyond the small-amplitude perturbative regime. It provides a structurally robust criterion for determining which traveling-wave profiles are dynamically possible and we show that each wave classification type was observed on Jupiter or Saturn. Building on this classification, we also investigate the related rigidity issue for large-amplitude traveling waves and waves propagating near shear flows. Our study offers a unified quantitative characterization of the intrinsic constraints for traveling waves in the quasi-geostrophic regime of planetary atmospheric flow. This is a joint work with Adrian Constantin and Hao Zhu.

Quasiperiodic Solutions for the Generalized SQG Equations

Jaemin Park

Yonsei University, S. Korea

In this talk, I will discuss an application of KAM theory to an active scalar equation arising in fluid mechanics. More precisely, we construct a family of quasiperiodic solutions to the generalized SQG equations (gSQG). Since global well-posedness remains an open question, our result reveals a richer structure of global-in-time solutions to the equation. Our construction is carried out in a patch setting, where a disk-shaped patch is perturbed, and we show that the boundary of the patch evolves quasiperiodically in time. I will also discuss recent results in this direction. This is joint work with Javier Gómez-Serrano (Brown University) and Alexander Ionescu (Princeton University).

Towards Large Scientific Learning Models with In-Context Operator Networks (ICON)

Liu Yang

National University of Singapore, Singapore

Can we build a single large model for a wide range of scientific problems? We proposed a new framework for scientific machine learning, namely "In-Context Operator Learning" and the corresponding model "In-Context Operator Networks" (ICON). A distinguishing feature of ICON is its ability to learn operators from numerical prompts during the inference phase, without weight adjustments. A single ICON model can tackle a wide range of tasks involving different operators, since it is trained as a generalist operator learner, rather than being tuned to approximate a specific operator. This is similar to how a single Large Language Model can solve a variety of natural language processing tasks specified by the language prompt. We will show how a single ICON model (without fine-tuning) manages multiple distinct problem types, encompassing forward and inverse ODE, PDE, and mean-field control problems. Through a case study on 1D conservation laws, we will show ICON's strong generalization capability to new PDEs, as well as its advantage compared with classic operator learning methods, e.g., Fourier neural operator (FNO). We will also show the application of ICON in 2D fluid problems, where a single model can make predictions for incompressible or compressible fluids, with different viscosity.

Characteristic Initial Value Problem for the 3D Compressible Euler Equations

Sifan Yu

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We present the results on the characteristic initial value problem of the compressible Euler equations in three space dimensions without any symmetry assumption. We allow presence of vorticity and consider any equation of state. Compared to the standard Cauchy problem, where initial data can be freely prescribed on a constant-time hypersurface, we formulate the problem by distinguishing between the "free-component" and the "constrained-component" of the initial data. The latter is to be solved by the "free-component" utilizing the properties of the compressible Euler equations on the initial null hypersurfaces. Then, we establish a priori estimates, followed by a local well-posedness in a neighborhood of initial hypersurfaces. Moreover, we prove a regularity theory in Sobolev norms. Our analysis critically relies on the vectorfield method. This talk is based on the joint works with Jared Speck, Yuxuan Wang and Pin Yu.

Mini Talks

The Past Stability of Kasner Singularities for the $3+1$-Dimensional Einstein Vacuum Spacetime under Polarized $U(1)$-Symmetry

Kai Dong

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In this talk, we will provide a new proof to a past stability result established in Fournodavlos-Rodnianski-Speck [FRS23], for Kasner solutions of the $(3+1)$-dimensional Einstein vacuum equations under polarized $U(1)$-symmetry. Our method, inspired by Beyer-Oliynyk-Olvera-Santamaría-Zheng [BOOS21], [BOZ25], relies on a newly developed $(2+1)$ orthonormal-frame decomposition and a careful symmetrization argument, after which the Fuchsian techniques can be applied.

We show that the perturbed solutions are asymptotically pointwise Kasner, geodesically incomplete and crushing at the Big Bang singularity. They are achieved by reducing the $(3+1)$ Einstein vacuum equations to a Fuchsian system coupled with several constraint equations, with the symmetry assumption playing an important role in the reduction. Using Fuchsian theory together with finite speed of constraint propagation, we obtain global existence and precise asymptotics of the solutions up to the singularities.

Smoothness for the Free Boundary of One-phase Fractional Laplacian Problem and Graphical Solutions

Runcao Lyu

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The regularity of the one-phase problem involving the fractional Laplacian was proven to be $C^{1,\alpha}$ by D. De Silva, O. Savin, and Y. Sire. Specifically, De Silva and Savin proved the smoothness of the boundary for $(-\Delta)^{1/2}$. We extend this result to $(-\Delta)^s$ for $0 < s < 1$. Building on this, we prove that graphical solutions of the fractional one-phase problem are minimizers and establish the rigidity of these minimizers.

Finite Time Blowup for Keller-Segel Equation with Logistic Damping in Three Dimensions

Tao Zhou

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The Keller-Segel equation, a classical chemotaxis model, and many of its variants have been extensively studied for decades. In this work, we focus on 3D Keller-Segel equation with a quadratic logistic damping term $-\mu\rho^2$ (modeling density-dependent mortality rate) and show the existence of finite-time blowup solutions with nonnegative density and finite mass for any $\mu \in \left[0, \frac{1}{3}\right)$. This range of μ is sharp; for $\mu \geq \frac{1}{3}$, the logistic damping effect suppresses the blowup as shown in [Kang-Stevens, 2016] and [Tello-Winkler, 2007]. A key ingredient is to construct a self-similar blowup solution to a related aggregation equation as an approximate solution, with subcritical scaling relative to the original model. Based on this construction, we employ a robust weighted L^2 method to prove the stability of this approximate solution, where modulation ODEs are introduced to enforce local vanishing conditions for the perturbation lying in a singular-weighted L^2 space. As a byproduct, we exhibit a new family of type I blowup mechanisms for the classical 3D Keller-Segel equation. This talk is based on the joint work with Jiaqi Liu (USC) and Yixuan Wang (Caltech).