Society for Industrial and Applied Mathematics

Conference Program

7th SIAM Annual Meeting of Central States Section

Oklahoma State University
October 1-2, 2022

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1 SIAM Central States Section

Welcome to the 7th annual meeting of the SIAM Central States Section at Oklahoma State University.

The SIAM-CSS was formed in 2014 to serve SIAM members in Arkansas, Colorado, Iowa, Kansas, Mississippi, Missouri, Nebraska, and Oklahoma. The purpose of this section is to enhance the communication among the section members, promote the collaboration for both basic research and applications of mathematics to industry and science, represent applied and computational mathematics in the entire proposed central region, and support the SIAM mission in the central region of the USA.

The SIAM-CSS Annual Meeting is one of the most important activities of the section. The SIAM-CSS Annual Meeting has been held annually since 2015, except for 2020 canceled due to the COVID-19 pandemic. The 7th SIAM-CSS annual meeting will be held at Oklahoma State University on October 1-2, 2022.

Local Organizing Committee

- **Xu Zhang (co-chair)**, Oklahoma State University
- **Xukai Yan (co-chair)**, Oklahoma State University
- **Jiahong Wu**, Oklahoma State University
- **Ning Ju**, Oklahoma State University
- **Lucas Stolerman**, Oklahoma State University

SIAM CSS Leadership (2022-2023)

- **President:** Weizhang Huang, University of Kansas
- **Vice President:** Nathan Albin, Kansas State University
- **Secretary:** Xukai Yan, Oklahoma State University
- **Tresure:** Paul Sacks, Iowa State University

SIAM CSS Advisory Committee

- **Xiaoming He**, Missouri University of S&T, President of SIAM-CSS (2015-2016)
- **Jiangguo Liu**, Colorado State University, President of SIAM-CSS (2017-2018)
- **Ying Wang**, University of Oklahoma, President of SIAM-CSS (2019-2021)

We are grateful that the conference has received generous supports from the following organizations

- **National Science Foundation (NSF)**
- **Society of Industrial and Applied Mathematics (SIAM)**
- **Department of Mathematics**, Oklahoma State University
- **College of Arts and Sciences**, Oklahoma State University

2 Schedule at a glance

Friday, September 30

6:00pm-7:30pm	Welcome Reception (not a dinner)	Math Science Building 423
6:00pm-7:30pm	Registration Table Opens	Math Science Building 423

Saturday, October 1

8:00am-8:45am	Registration Table Opens	Alumni Center
8:45am-9:00am	Opening Remarks	Alumni Center, Click Hall
9:00am-10:00am	Plenary Lecture #1 – Long Chen	Alumni Center, Click Hall
10:00am-10:10am	Group Photo	in front of Edmon Low Library
10:10am-10:40am	Coffee Break	Alumni Center
10:40am-12:00pm	Mini-Symposium Session I	Classroom Building
12:00pm-2:00pm	Lunch Break	
2:00pm-3:00pm	Plenary Lecture #2 - Anna Mazzucato	Alumni Center, Click Hall
3:00pm-3:10pm	Transition to parallel sessions	
3:10pm-4:30pm	Mini-Symposium Session II	Classroom Building
4:30pm-5:00pm	Coffee Break	Alumni Center
5:00pm-6:20pm	Mini-Symposium Session III	Classroom Building
6:45pm-9:00pm	Banquet Dinner	Alumni Center, Click Hall

Sunday, October 2

8:30am	Registration Table Opens	Alumni Center
9:00am-10:00am	Plenary Lecture #3 – Daniela Calvetti	Alumni Center, Click Hall
10:00am-10:30am	Coffee Break	Alumni Center
10:30am-11:50am	Mini-Symposium Session IV	Classroom Building

3 Campus Map


A
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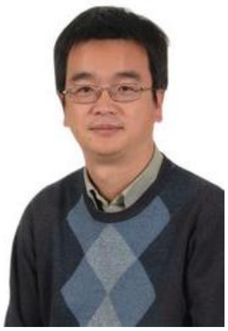
NUCLEAR MAGNETIC RESONANCE LABORATORY
NOBLE RESEARCH CENTER
PHYSICAL SCIENCE BUILDING
ENGINEERING NORTH
HENRY BELLMON RESEARCH CENTER
ADVANCED TECHNOLOGY RESEARCH CENTER
ENDEAVOR
DONALD W. REYNOLDS SCHOOL OF ARCHITECTURE
LIFE SCIENCES EAST
ENGINEERING SOUTH
LIFE SCIENCES WEST
EDMON LOW LIBRARY
THATCHER
BUSINESS
BARTLETT CENTER FOR THE VISUAL ARTS
MATH SCIENCES
WHITEHURST
CLASSROOM
GENERAL ACADEMIC
MORRILL
GUNDERSEN
WILLARD
STUDENT UNION
SERETEAN CENTER FOR THE PERFORMING ARTS
CONOCOPHILLIPS OSU ALUMNI CENTER
OLD CENTRAL
PAUL MILLER JOURNALISM AND BROADCASTING
STUDENT UNION PARKING GARAGE
BENNETT MEMORIAL CHAPEL
CAMPUS FIRE STATION
SIAM-CSS-OSU-Map
1 I5 15
2 I7 17
3 J9 19
4 I6 16
5 C8 36
6 B7 35
Parking is free after 5pm Friday and over the weekend.
You can park at any of the six parking lots on the map.

4 Plenary Lectures



Long Chen is currently a Professor of Mathematics at University of California at Irvine (UCI). He graduated from Nanjing University in 1997, obtained a master's degree from Peking University in 2000, and finished Ph.D from Pennsylvania State University in 2005. His doctoral supervisor is Professor Jinchao Xu. From 2005 to 2007, he worked as a postdoctoral fellow at the University of California, San Diego and the University of Maryland, College Park. Since 2007, he has been working at UCI, and was tenured in 2011, and promoted to full professor in 2015. Professor Chen's research field is the numerical solution of partial differential equations, especially the design and analysis of finite element methods. In addition, Professor Chen developed the iFEM finite element software package, which provided great convenience for the teaching and research of finite element methods. Professor Chen has published more than 60 academic papers in internationally renowned journals, and serves on the editorial board of several SCI journals. Since his work till now, Professor Chen has been constantly supported by the National Science Foundation.

Title: Finite Element Complexes

Saturday, October 1st, 9:00am-10:00am, Click Hall, Alumni Center

Abstract: A Hilbert complex is a sequence of Hilbert spaces connected by a sequence of closed densely defined linear operators satisfying the property: the composition of two consecutive maps is zero. The most well-known example is the de Rham complex involving grad, curl, and div operators. A finite element complex is a discretization of a Hilbert complex by replacing infinite dimensional Hilbert spaces by finite dimensional subspaces based on a mesh of the domain. Usually inside each element of the mesh, polynomial spaces are used and suitable degree of freedoms are proposed to glue them to form a conforming subspace. The finite element de Rham complexes are well understood and can be derived from the framework Finite Element Exterior Calculus (FEEC). In this talk, we will survey the construction of finite element complexes. We present finite element de Rham complex by a geometric decomposition approach. We then generalize the construction to smooth FE de Rham complexes and derive more complexes including the Hessian complex, the elasticity complex, and the divdiv complex by the Bernstein-Gelfand-Gelfand (BGG) construction. The constructed finite element complexes will have application in the numerical simulation of the biharmonic equation, the linear elasticity, the general relativity, and in general PDEs in Riemannian geometry etc. This is a joint work with Xuehai Huang from Shanghai University of Finance and Economics.

Anna Mazzucato is Professor of Mathematics at Penn State University. She is an applied analyst working on PDE problems in continuum mechanics. Prior to joining Penn State in 2003, she was a Gibbs Instructor at Yale University and a Postdoctoral Fellow at the IMA and MSRI. She obtained her PhD from the University of North Carolina-Chapel Hill in 2000 under the direction of Michael Taylor. In 2011 she received the Ruth I. Michel Memorial Prize from the AWM and Cornell University and was elected SIAM Fellow in 2021. She is on the editorial boards of several journals, including the SIAM Journal on Mathematical Analysis.

Title: Boundary layers and the vanishing viscosity limit for incompressible flows

Saturday, October 1st, 2:00pm-3:00pm, Click Hall, Alumni Center

Abstract: I will discuss recent results on the analysis of the vanishing viscosity limit, that is, whether solutions of the Navier-Stokes equations converge to solutions of the Euler equations, for incompressible fluids when walls are present. At small viscosity, a viscous boundary layer arise near the walls where large gradients of velocity and vorticity may form and propagate in the bulk (if the boundary layer separates). I will present cases of flows where Prandtl approximation and the vanishing viscosity limit can be rigorous justified, in particular a result on concentration of vorticity at the boundary for symmetric flows and convergence for an Oseen-type equation in smooth domain, showing the effect of curvature on the pressure corrector.

Daniela Calvetti the James Wood Williamson professor, is an applied mathematician whose work on inverse problems connects mathematical models, scientific computing, Bayesian inference and uncertainty quantification. After receiving her Laurea in Mathematics from the University of Bologna, Italy in 1980, she moved to the University of North Carolina at Chapel Hill, where she completed her PhD in 1989. After holding faculty positions at North Carolina State University, Colorado State University-Pueblo and the Stevens Institute of Technology, she moved to Case Western Reserve University in 1997, where she chaired the department from 2007 to 2013. She has co authored three monographs, Introduction to Bayesian Scientific Computing, Computational Mathematical Modeling and Mathematics of Data Science, with two more coming soon, and approximately 150 peer reviewed papers. Her research has been supported by NSF, NIH and the Simons Foundation. She has graduated 20 PhD students and she has been in the editorial board of several scientific journals, including SIAM Journal on Matrix Analysis and its Applications, Mathematics of Computation, Inverse Problems and SIAM Review. She is currently the Program Director of the SIAM activity group on Uncertainty Quantification .

Title: The partnership of Bayesian inference and numerical analysis for the solution of inverse problems

Sunday, October 2nd, 9:00am-10:00am, Click Hall, Alumni Center

Abstract: The numerical solution of inverse problems where the number of unknowns exceeds the available data is a notoriously difficult problem. Regularization methods designed to overcome the paucity of data penalize candidate solutions for unlikely or undesirable features. Discretization level of the underlying continuous problem can also be used to improve the accuracy of the computed solution. In this talk we show how recasting the inverse problems within the Bayesian framework makes it possible to express via a probability density function features believed to characterize the solution in a way that interfaces naturally with state of the art computational schemes. In that context, we will present an efficient computational scheme for the recovery of sparse solutions, where the sparsity is encoded in terms of hierarchical models whose parameters can be set to account for the sensitivity of the data to the solution. The computations can be organized as an inner-outer iteration scheme, where a weighted linear least squares problem is solved in the inner iteration and the outer iteration updates the scaling weights. When the least squares problems are solved approximately by the Conjugate Gradient method for least squares (CGLS) equipped with a suitable stopping rule, typically the number of CGLS iterations quickly converges to the cardinality of the support, thus providing an automatic model reduction. Computed examples will illustrate the performance of the approach in a number of applications.

5 Mini-Symposium and Contributed Talk Sessions

MS01. Recent developments in computational inverse problems in imaging

Organizers: *Dinh-Liem Nguyen*, Kansas State University; *Thi-Phong Nguyen*, New Jersey Institute of Technology

Session A: Saturday, October 1, 10:40am-12:00pm, CLB102

- **MS01-A-1** (10:40am) Orthogonality sampling method for inverse elastic scattering from anisotropic media. *Thu Le*, Kansas State University
- **MS01-A-2** (11:00am) An inverse scattering obstacle problem with partial thin coatings. *Heejin Lee*, Purdue University
- **MS01-A-3** (11:20am) Asymptotic analysis applied to small volume inverse shape problems. *Govanni Granados*, Purdue University
- **MS01-A-4** (11:40am) A comparative study of time- vs. frequency- domain inverse elastic scattering using laboratory test data. *Fatemeh Pourahmadian*, University of Colorado Boulder

Session B: Saturday, October 1, 3:10pm-4:30pm, CLB102

- **MS01-B-1** (3:10pm) A sampling-type method combined with deep learning for inverse scattering with one incident wave.*Trung Truong*, Kansas State University
- **MS01-B-2** (3:30pm) Machine learning techniques for inverse problems in sonar imaging. *Christina Frederick*, New Jersey Institute of Technology
- **MS01-B-3** (3:50pm) Lippmann-Schwinger-Lanczos algorithm for imaging problems. *Mikhail Zaslavsky*, Southern Methodist University
- **MS01-B-4** (4:10pm) A direct approach for inverse source problems in photoacoustic tomography. *Thi-Phong Nguyen*, New Jersey Institute of Technology

MS02. Recent advances in application-oriented numerical computation and optimization

Organizers: *Xiang-Sheng Wang*, University of Louisiana at Lafayette; *Qin Sheng*, Baylor University; *Bruce Wade*, University of Louisiana at Lafayette

Session A: Saturday, October 1, 10:40am-12:00pm, CLB108

- **MS02-A-1** (10:40am) Splitting with and Exponential Time Differencing Scheme for Advection-Diffusion-Reaction Systems *Bruce Wade*, University of Louisiana at Lafayette
- **MS02-A-2** (11:00am) Exponential time differencing with real distinct poles for simulating chemotaxis problems. *Emmanuel Asante-Asamani*, Clarkson University
- **MS02-A-3** (11:20am) Subgradient extragradient method with double inertial and self-adaptive step size: applications in Dynamical systems. *Olaniyi Samuel Iyiola*, Clarkson University
- **MS02-A-4** (11:40am) Scattered results on the recovery of 3D volumetric density information from a single projection view. *Sean R. Breckling*, Department of Energy

Session B: Saturday, October 1, 3:10pm-4:30pm, CLB108

- **MS02-B-1** (3:10pm) Notes on global error analysis for splitting methods. *Qin Sheng*, Baylor University
- **MS02-B-2** (3:30pm) A study of the numerical stability of a Crank-Nicolson method for solving singular Kawarada equations. *Eduardo Servin Torres*, Baylor University
- **MS02-B-3** (3:50pm) Biquintic B-Spline solutions of smart material structures and applications to control theory. *Lisa Kuhn*, Southeastern Louisiana University
- **MS02-B-4** (4:10pm) Solving a friction stir welding problem with reduced order models and neural networks. *Zilong Song*, Utah State University

Session C: Saturday, October 1, 5:00pm-6:20pm, CLB108

- **MS02-C-1** (5:00pm) Stable generalized finite element method for Richards equation in heterogenous soil in 1D. *Tilsa Aryeni*, University of Wyoming
- **MS02-C-2** (5:20pm) Convergence of adaptive least-squares finite element methods. *Jaeun Ku*, Oklahoma State University
- **MS02-C-3** (5:40pm) Block preconditioners for the MAC discretization of the Stokes-Darcy equations. *Yunhui He*, The University of British Columbia
- **MS02-C-4** (6:00pm) Bivariate Lagrange interpolation at the checkerboard nodes *Srijana Ghimire*, Tulsa Community College

Session D: Sunday, October 2, 10:30am-11:50am, CLB108

- **MS02-D-1** (10:30am) Dimension reduction for data assimilation: Particle filters with reduced order models and data. *Erik Van Vleck*, University of Kansas
- **MS02-D-2** (10:50am) Modeling a cylindrical end irradiated cavity with EMPIRE: investigating the effects of approximating geometric features. *Sidney Shields*, Sandia National Laboratories
- **MS02-D-3** (11:10am) The condition number of a Vandemonde-like matrix arising from a direct parallel-in-time algorithm. *Xiang-Sheng Wang*, University of Louisiana at Lafayette

MS03. Recent advances in scientific computation for general mathematical models

Organizers: *Huijing Du*, University of Nebraska-Lincoln; *Yuan Liu*, Wichita State University

Session A: Saturday, October 1, 5:00pm-6:20pm, CLB102

- **MS03-A-1** (5:00pm) Neural finite element method. *Shuhao Cao*, University of Missouri-Kansas City.
- **MS03-A-2** (5:20pm) A chemical-mechanical coupled model for simulating cell morphogenesis and tissue development. *Weitao Chen*, University of California, Riverside
- **MS03-A-3** (5:40pm) Structure-preserving machine learning moment closures for the radiative transfer equation. *Juntao Huang*, Texas Tech University
- **MS03-A-4** (6:00pm) Modeling and simulation of turbulent mixing due to hydrodynamic instabilities. *Tulin Kaman*, University of Arkansas

Session B: Sunday, October 2, 10:30am-11:50am, CLB102

- **MS03-B-1** (10:30am) An approximate Bayesian computation approach for biological model selection and validation. *Tracy Stepien*, University of Florida
- **MS03-B-2** (10:50am) Comparing R_0 for a class of PDE epidemic models with ODE models. *Chayu Yang*, University of Nebraska-Lincoln
- **MS03-B-3** (11:10am) Numerical methods for heterogeneous problems with variable-order fractional Laplacian. *Yanzhi Zhang*, Missouri University of Science and Technology
- **MS03-B-4** (11:30am) Solving and learning phase field models using the modified physics informed neural networks. *Jia Zhao*, Utah State University

MS04. Analysis and applications of PDEs modeling fluids

Organizers: *Jiahong Wu*, Oklahoma State University; *Xukai Yan*, Oklahoma State University

Session A: Saturday, October 1, 10:40am-12:00pm, CLB114

- **MS04-A-1** (10:40am) Stability of homogeneous solutions of stationary incompressible Navier-Stokes equations.. *Xukai Yan*, Oklahoma State University
- **MS04-A-2** (11:00am) The 2D quasi-geostrophic equation in holder and uniformly local Sobolev spaces. *Elaine Cozzi*, Oregon State University
- **MS04-A-3** (11:20am) On Euler equations with in-flow and out-flow boundary conditions. *Anna Mazzucato*, The Pennsylvania State University
- **MS04-A-4** (11:40am) Existence and Stability of Traveling Waves of Boussinesq-Burgers Equations. *Kun Zhao*, Tulane University

Session B: Saturday, October 1, 3:10pm-4:30pm, CLB114

- **MS04-B-1** (3:10pm) Regular solutions of the stationary incompressible Navier-Stokes equations. *Zhuolun Yang*, Brown University
- **MS04-B-2** (3:30pm) Decay of multi-point correlation functions in $\mathbb{Z}^d$. *Rui Han*, Louisiana State University
- **MS04-B-3** (3:50pm) Liouville-type theorems for steady solutions to the Navier-Stokes system in a slab. *Jeaheang Bang*, University of Texas at San Antonio
- **MS04-B-4** (4:10pm) Data assimilation in turbulent fluids: Movement paradigms for improved convergence rates. *Collin Victor*, University of Nebraska-Lincoln

Session C: Saturday, October 1, 5:00pm-6:20pm, CLB114

- **MS04-C-1** (5:00pm) Poiseuille flow of nematic liquid crystals via Ericksen-Leslie model. *Geng Chen*, University of Kansas
- **MS04-C-2** (5:20pm) A remark on the two dimensional water wave equation with surface tension. *Shuanglin Shao*, University of Kansas
- **MS04-C-3** (5:40pm) Reductions of the 2D Kuramoto-Sivashinky equations. *Adam Larios*, University of Nebraska Lincoln
- **MS04-C-4** (6:00pm) Nonlinear calming for the 2D Kuramoto-Sivashinsky equations. *Matthew Enlow*, University of Nebraska Lincoln

Session D: Sunday, October 2, 10:30am-11:50am, CLB114

- **MS04-D-1** (10:30am) Non-uniqueness results of stochastic PDEs via probabilistic convex integration. *Kazuo Yamazaki*, Texas Tech University
- **MS04-D-2** (10:50am) Bounds on the separation rate of non-unique 3D Navier-Stokes flows. *Zachary Bradshaw*, University of Arkansas
- **MS04-D-3** (11:10am) Stabilizing phenomenon for electrically conducting fluids. *Jiahong Wu*, Oklahoma State University

MS05. Interactions among analysis, optimization and network science

Organizers: *Pietro Poggi-Corradini*, Kansas State University; *Nathan Albin*, Kansas State University; *Dominique Zosso*, Montana State University; *Lukas Geyer*, Montana State University

Session A: Saturday, October 1, 10:40am-12:00pm, CLB103

- **MS05-A-1** (10:40am) Random matrix theory for homogenization of composites. *Tom Alberts*, University of Utah
- **MS05-A-2** (11:00am) The resampling property of multiple radial SLE. *Vivian Healey*, Texas State University
- **MS05-A-3** (11:20am) The scaling limit of fair Peano paths. *Joan Lind*, University of Tennessee Knoxville
- **MS05-A-4** (6:00pm) Riesz capacities and density conditions in metric space. *Lizaveta Ihnatsyeva*, Kansas State University

Session B: Saturday, October 1, 3:10pm-4:30pm, CLB103

- **MS05-B-1** (3:10pm) From Convex Geometry to Convex Optimization. *Dominique Zosso*, Montana State University
- **MS05-B-2** (3:30pm) An approximation of the modulus of the family of edge covers. *Adriana Ortiz-Aquino*, Kansas State University
- **MS05-B-3** (3:50pm) Estimation of causal effects under K-nearest neighbors interference. *Mike Higgins*, Kansas State University
- **MS05-B-4** (4:10pm) Identifying graph-derived features of trained neuronal networks via machine learning. *Nethali Fernando*, University of Texas Arlington

Session C: Saturday, October 1, 5:00pm-6:20pm, CLB103

- **MS05-C-1** (5:00pm) Extremal graph realizations and graph Laplacian eigenvalues. *Braxton Osting*, University of Utah
- **MS05-C-2** (5:20pm) The phase transition of discrepancy in random hypergraphs. *Xavier Perez Gimenez*, University of Nebraska Lincoln
- **MS05-C-3** (5:40pm) p-Modulus on orthodiagonal maps. *Pietro Poggi-Corradini*, Kansas State University

Session D: Sunday, October 2, 10:30am-11:50am, CLB103

- **MS05-D-1** (10:30am) Ehrhart polynomials of pseudo-reflexive polygons. *Tyrrell McAllister,* University of Wyoming
- **MS05-D-2** (10:50am) Fulkerson duality for spanning trees and partitions. *Huy Truong,* Kansas State University
- **MS05-D-3** (11:10am) A Non-Markovian networked spreading model to assess the effectiveness of contact tracing. *Aram Vajdi,* Kansas State University

MS06: Data-driven fluid dynamics

Organizer: *Omer San,* Oklahoma State University

Session A: Sunday, October 2, 10:30am-11:50am, CLB106

- **MS06-A-1** (10:30am) Nonintrusive reduced order modeling of convective Boussinesq flows. *Pedram Hashem Dabaghian,* Oklahoma State University
- **MS06-A-2** (10:50am) Nonlinear proper orthogonal decomposition for Rayleigh Bénard convection. *Saeed Akbari,* Oklahoma State University
- **MS06-A-3** (11:10am) Automatic Mixed-Precision (AMP) Computational Fluid Dynamics (CFD). *Mehrdad Zomorodiyan,* Oklahoma State University
- **MS06-A-4** (11:30am) Fluid flow modeling in elastic networking tubes. *Shafi Romeo,* Oklahoma State University

MS07. New trends on discontinuous Galerkin methods for partial differential equations

Organizers: *Yang Yang,* Michigan Technological University; *Yangwen Zhang,* Carnegie Mellon University

Session A: Saturday, October 1, 10:40am-12:00pm, CLB106

- **MS07-A-1** (10:40am) A reinterpreted discrete fracture model for fracture and barrier networks. *Yang Yang,* Michigan Technological University
- **MS07-A-2** (11:00am) Bound-preserving discontinuous Galerkin methods with second-order implicit pressure explicit concentration time marching for compressible miscible displacements in porous media. *Yue Kang,* Michigan Technological University
- **MS07-A-3** (11:20am) Bound-preserving discontinuous Galerkin Methods with Patankar time discretization for chemical reacting flows. *Fangyao Zhu,* Michigan Technological University
- **MS07-A-4** (11:40am) Discontinuous Galerkin methods for network patterning phase-field models. *Yuan Liu,* Wichita State University

Session B: Saturday, October 1, 3:10pm-4:30pm, CLB106

- **MS07-B-1** (3:10pm) Dual-wind discontinuous Galerkin methods for fully nonlinear second order PDEs. *Thomas Lewis,* The University of North Carolina at Greensboro
- **MS07-B-2** (3:30pm) Dual-wind discontinuous Galerkin methods for time-dependent Hamilton Jacobi equation. *Aaron Rapp,* University of the Virgin Islands
- **MS07-B-3** (3:50pm) Superconvergent interpolatory HDG methods for nonlinear reaction diffusion equations II: HHO-inspired methods. *Yangwen Zhang,* Carnegie Mellon University

- **MS07-B-4** (4:10pm) A generalized framework for direct discontinuous Galerkin methods. *Mustafa Danis* , Iowa State University

Session C: Saturday, October 1, 5:00pm-6:20pm, CLB106

- **MS07-C-1** (5:00pm) A Local Macroscopic Conservative (LoMaC) low rank tensor method with the discontinuous Galerkin method for the Vlasov dynamics. *Wei Guo*, Texas Tech University
- **MS07-C-2** (5:20pm) Locally-implicit discontinuous Galerkin schemes for the kinetic Boltzmann-BGK system that are arbitrarily high-order and asymptotic-preserving. *James Rossmanith*, Iowa State University
- **MS07-C-3** (5:40pm) Hybridizable discontinuous Galerkin methods for coupled Stokes-Biot problems. *Jeonghun Lee*, Baylor University
- **MS07-C-4** (6:00pm) A conservative and positivity-preserving implicit-explicit approach for compressible fluid flow simulation. *Chen Liu*, Purdue University

MS08. PDEs and dynamical systems

Organizer: *Ning Ju*, Oklahoma State university

Session A: Saturday, October 1, 10:40am-12:00pm, CLB101

- **MS08-A-1** (10:40am) A free boundary inviscid model of flow-structure interaction. *Igor Kukavica*, University of Southern California
- **MS08-A-2** (11:00am) Inertial manifolds for regularized Navier-Stokes equations. *Yanqiu Guo*, Florida International University
- **MS08-A-3** (11:20am) Relaxation-based parameter recovery from partial observations for hydrodynamic systems. *Vincent R Martinez*, CUNY Hunter College and CUNY Graduate Center
- **MS08-A-4** (11:40am) Error estimates for the physical informed neural networks (PINN) approximating the primitive equations. *Quyuan Lin*, University of California, Santa Barbra

Session B: Saturday, October 1, 3:10pm-4:30pm, CLB101

- **MS08-B-1** (3:10pm) Intermittency in turbulence and the 3D NSE regularity problem. *Aseel Farhat*, Florida State University
- **MS08-B-2** (3:30pm) On stochastic partial differential equations with a Ladyzenskaya-Smagorinsky type nonlinearity. *Krutika Tawri*, University of California, Berkeley
- **MS08-B-3** (3:50pm) Particle trajectories of large scale oceanic flow. *Ning Ju*, Oklahoma State university
- **MS08-B-4** (4:10pm) Ice sheets melting as an obstacle problem. *Paolo Piersanti*, Indiana University

MS09. Recent development on mathematical and numerical analysis of PDEs and their applications

Organizers: *Songting Luo*, Iowa State University; *Hailiang Liu*, Iowa State University

Session A: Saturday, October 1, 3:10pm-4:30pm, CLB 219

- **MS09-A-1** (3:10pm) A moving mesh finite element method for Bernoulli free boundary problems. *Weizhang Huang*, University of Kansas
- **MS09-A-2** (3:30pm) Fast and efficient numerical methods for a class of PDEs with free boundaries. *Xinfeng Liu*, University of South Carolina
- **MS09-A-3** (3:50pm) Analysis of weak Galerkin Finite Element with Supercloseness. *Saqib Hussain*, Texas A&M International University
- **MS09-A-4** (4:10pm) An asymptotic Green's function method for vector wave equations. *Jay Mayfield*, University of Arizona

Session B: Saturday, October 1, 5:00pm-6:20pm, CLB 219

- **MS09-B-1 (cancelled)** (5:00pm) Phase field modeling and computation of vesicle growth and shrinkage. *Shuwang Li*, Illinois Institute of Technology
- **MS09-B-2** (5:20pm) A stable sampling method for imaging of photonic crystals. *Dinh-Liem Nguyen*, Kansas State University
- **MS09-B-3** (5:40pm) Pressure robust scheme for incompressible flow. *Lin Mu*, University of Georgia
- **MS09-B-4** (6:00pm) Dynamic behavior for a gradient algorithm with energy and momentum. *Xuping Tian*, Iowa State University

MS10. Recent advanced in numerical PDE for multi-physics problems

Organizers: *Cuiyu He*, Oklahoma State University; *Jiangguo Liu*, Colorado State University

Session A: Saturday, October 1, 10:40am-12:00pm, CLB121

- **MS10-A-1** (10:40am) Adaptive multiresolution sparse grid DG: algorithms and its open source C++ package. *Juntao Huang*, Texas Tech University
- **MS10-A-2** (11:00am) Image reconstruction using an adaptive and accelerated iterative gradient type method for Electrical Impedance Tomography problems. *Sanwar U. Ahmad*, Virginia State University
- **MS10-A-3** (11:20am) Unconditionally stable numerical methods for Cahn-Hilliard-Navier-Stokes-Darcy system with different densities and viscosities. *Xiaoming He*, Missouri University of Science and Technology
- **MS10-A-4** (11:40am) Fast numerical solvers for subdiffusion problems with spatial interfaces. *Jiangguo Liu*, Colorado State University

Session B: Saturday, October 1, 3:10pm-4:30pm, CLB121

- **MS10-B-1** (3:10pm) A spatially variant fractional Laplacian model: theory and applications. *Carlos Nicolas Rautenberg*, George Mason University
- **MS10-B-2 (cancelled)** (3:30pm) A new CDG method for the Stokes equations with order two superconvergence. *Xiu Ye*, University of Arkansas at Little Rock
- **MS10-B-3** (3:50pm) High-order IPDG method for anisotropic diffusion equations. *Lin Mu*, University of Georgia
- **MS10-B-4** (4:10pm) A stable enriched Galerkin method for Brinkman problem. *Seulip Lee*, University of Georgia

Session C: Saturday, October 1, 5:00pm-6:20pm, CLB121

- **MS10-C-1 (cancelled)** (5:00pm) A finite element modeling of two-phase variable density surface fluids. *Maxim Olshanskii*, University of Houston
- **MS10-C-2** (5:20pm) A stable immersed discontinuous Galerkin method for wave propagation in heterogeneous acoustic elastic media. *Slimane Adjerid*, Virginia Tech
- **MS10-C-3** (5:40pm) A Cartesian FMM-accelerated Galerkin boundary integral Poisson-Boltzmann solver. *Weihua Geng*, Southern Methodist University
- **MS10-C-4** (6:00pm) A fast method for evaluating volume potentials in the Galerkin boundary element method. *Johannes Tausch*, Southern Methodist University

MS11. Mathematical methods in population biology and neuroscience

Organizers: *Lucas Martins Stolerman*, Oklahoma State University; *Pedro Maia*, University of Texas at Arlington

Session A: Sunday, October 2, 10:30am-11:50am, CLB121

- **MS11-A-1** (10:30am) Network modeling and simulation of infectious diseases: new epidemic thresholds for the SIR-network model. *Haridas K. Das*, Oklahoma State University
- **MS11-A-2** (10:50am) Complex dynamics of predator-prey systems with generalized Holling type IV functional response and Allee effects in prey. *Chanaka Kottegoda*, Oklahoma State University
- **MS11-A-3** (11:10am) Data-driven techniques for dynamical systems with applications to neuroscience. *Khitam Zuhair Bader Aqel*, University of Texas at Arlington
- **MS11-A-4** (11:30am) Analysis of goal, feedback and rewards on sustained attention via machine learning. *Nethali Fernando*, University of Texas at Arlington

MS12. Recent advances in numerical algorithms for partial differential equations and applications

Organizers: *Qiao Zhuang*, Worcester Polytechnic Institute; *Ruchi Guo*, University of California, Irvine; *Xu Zhang*, Oklahoma State University

Session A: Saturday, October 1, 10:40am-12:00pm, CLB112

- **MS12-A-1** (10:40am) Convergent finite difference methods with higher order local truncation errors for stationary Hamilton-Jacobi equations. *Thomas Lewis*, University of North Carolina at Greensboro
- **MS12-A-2** (11:00am) Continuous data assimilation and long-time accuracy in a C0-IP Method for the Cahn-Hilliard Equation. *Amanda Diegel*, Mississippi State University
- **MS12-A-3** (11:20am) SAV Ensemble Algorithms for the magnetohydrodynamics equations. *John Carter*, Missouri University of Science and Technology.
- **MS12-A-4** (11:40am) Runge-Kutta discontinuous Galerkin methods with compact stencils for hyperbolic conservation laws. *Qifan Chen*, The Ohio State University

Session B: Saturday, October 1, 3:10pm-4:30pm, CLB112

- **MS12-B-1** (3:10pm) A nonconforming primal hybrid finite element method for the two-dimensional vector Laplacian. *Ari Stern*, Washington University in St. Louis
- **MS12-B-2** (3:30pm) Spurious solutions for high-order curl problems. *Qian Zhang*, Michigan Technological University
- **MS12-B-3** (3:50pm) An immersed Crouzeix-Raviart finite element method for Navier-Stokes equations with moving interfaces. *Qiao Zhuang*, Worcester Polytechnic Institute
- **MS12-B-4** (4:10pm) A high-order immersed C0 interior penalty method for biharmonic interface problems. *Yuan Chen*, The Ohio State University

Session C: Saturday, October 1, 5:00pm-6:20pm, CLB112

- **MS12-C-1** (5:00pm) Solving interface problems by immersed spline functions. *Tao Lin*, Virginia Tech
- **MS12-C-2** (5:20pm) On a numerical artifact of solving shallow water equations with a discontinuous bottom. *Zheng Sun*, University of Alabama
- **MS12-C-3** (5:40pm) Modeling Calcium Dynamics in Neurons with Endoplasmic Reticulum: Well-Posedness and Numerical Methods. *Qingguang Guan*, University of Southern Mississippi
- **MS12-C-4** (6:00pm) Enriched Galerkin methods for the Stokes equations with modified weak Galerkin bilinear forms. *Seulip Lee*, University of Georgia

Session D: Sunday, October 2, 10:30am-11:50am, CLB112

- **MS12-D-1** (10:30am) Dual-wind discontinuous Galerkin methods for an elliptic optimal control problem. *Yi Zhang*, University of North Carolina at Greensboro
- **MS12-D-2** (10:50am) Reduced Deep Networks (RDNs) for model reduction of nonlinear waves. *Donsub Rim*, Washington University in St. Louis
- **MS12-D-3** (11:10am) A numerical scheme for a two-field model for binary systems containing surfactants. *Natasha Sharma*, University of Texas at El Paso
- **MS12-D-4** (11:30am) A new reduced order model of linear parabolic PDEs. *Yangwen Zhang*, Carnegie Mellon University

MS13. SIAM CSS student chapter presentations

Organizers: *Tulin Kaman*, University of Arkansas; *James Rossmanith*, Iowa State University

Session A: Saturday, October 1, 10:40am-12:00pm, CLB118

- **MS13-A-1** (10:40am) Efficient Regionally-Implicit Discontinuous Galerkin Methods: A Dimensional Splitting Strategy for Linear Hyperbolic Systems. *Yifan Hu*, Iowa State University
- **MS13-A-2** (11:00am) A Positivity-Preserving Limiting Strategy for Locally-Implicit Lax-Wendroff Discontinuous Galerkin Methods. *Ian Pelakh*, Iowa State University
- **MS13-A-3** (11:20am) Optimization of the Glimm's scheme random choice method for mutliphasic flow simulations. *James Burton*, University of Arkansas
- **MS13-A-4** (11:40am) Simulation of turbulent mixing due to Richtmyer-Meshkov instability using high order weighted essentially non-oscillatory schemes. *Ryan Holley*, University of Arkansas

Session B: Saturday, October 1, 3:10pm-4:30pm, CLB118

- **MS13-B-1** (3:10pm) Asymptotic-preserving schemes for the kinetic Boltzmann-BGK equation. *Preeti Sar*, Iowa State University
- **MS13-B-2** (3:30pm) Model order reduction for elliptic partial differential equations. *Xuan Gu*, University of Arkansas
- **MS13-B-3** (3:50pm) Cell-Average Based Neural Network Solvers For Partial Differential Equation. *Tyler Kroells*, Iowa State University

MS14. Theoretical and computational aspects of nonlocal operators

Organizers: *Animesh Biswas*, University of Nebraska-Lincoln; *Debdeep Bhattacharya*, Louisiana State University; *Patrick Diehl*, Louisiana State University

Session A: Saturday, October 1, 10:40am-12:00pm, CLB 208

- **MS14-A-1 (cancelled)** (10:40am) Hele-Shaw flow and parabolic integro-differential equations. *Farhan Abedin*, Lafayette College
- **MS14-A-2** (11:00am) Asymptotic mean value formulas for nonlinear equations. *Fernando Charro*, Wayne State University
- **MS14-A-3 (cancelled)** (11:20am) New regularity estimates for a class of nonlocal operators. *Thialita Nascimento*, University of Central Florida
- **MS14-A-4** (11:40am) Accurate and efficient spectral method for fractional wave equations. *Shiping Zhou*, Missouri University of Science and Technology

Session B: Saturday, October 1, 3:10pm-4:30pm, CLB 208

- **MS14-B-1** (3:10pm) Load-controlled evolution of quasistatic nonlinear peridynamics. *Debdeep Bhattacharya*, Louisiana State University
- **MS14-B-2** (3:30pm) Convergence of Solutions for Linear Peridynamic Models. *Mikil Foss*, University of Nebraska-Lincoln
- **MS14-B-3** (3:50pm) A Monotone meshfree finite difference method for linear elliptic PDEs via nonlocal relaxation. *Qihao Ye*, University of California San Diego

Session C: Saturday, October 1, 5:00pm-6:20pm, CLB 208

- **MS14-C-1** (5:00pm) Convergence of nonlocal nonlinear conservation laws with respect to horizon. *Anh Vo*, University of Nebraska-Lincoln
- **MS14-C-2** (5:20pm) Nonlocal Equations on the Boundary. *Mitch Haeuser*, Iowa State University
- **MS14-C-3** (5:40pm) On a semilinear nonlocal elliptic equation in the context of plasma physics. *Daniel E Restrepo Montoya*, University of Texas Austin
- **MS14-C-4** (6:00pm) Extension equation for fractional power of operator defined on Banach spaces. *Animesh Biswas*, University of Nebraska-Lincoln

MS15. Advances in modeling complex systems with applications to space engineering

Organizer: *Daoru Han*, Missouri University of Science and Technology

Session A: Saturday, October 1, 5:00pm-6:20pm, CLB 118

- **MS15-A-1** (5:00pm) Understanding reinforcement learning-based agents in self-organizing systems. *Bingling Huang*, University of Southern California
- **MS15-A-2** (5:20pm) Development of grid-based Vlasov method for kinetic studies of plasma flows in space engineering. *Chen Cui*, University of Southern California
- **MS15-A-3** (5:40pm) Kinetic simulations of charging of irregularly-shaped dust grains in space plasmas. *David Lund*, Missouri University of Science and Technology
- **MS15-A-4** (6:00pm) Kinetic modeling of electrostatic transport of lunar regolith particles with applications to In-Situ resource utilization. *Easton Ingram*, Missouri University of Science and Technology

CT1. Topics in numerical mathematics

Session A: Saturday, October 1, 10:40am-12:00pm, CLB 122

Session-Chair: *Shadi Heenatigala*, Texas Tech University

- **CT1-A-1** (10:40am) An age-and Phase-Structured Model of Malaria Parasite Replication in Erythrocytes and Anti-malarial Therapies *Md Afsar Ali*, Kansas Wesleyan University
- **CT1-A-2** (11:00am) A Local Macroscopic Conservative (LoMaC) low-rank tensor method for the Vlasov Maxwell system. *Shadi Heenatigala*, Texas Tech University
- **CT1-A-3** (11:20am) Coupling deep learning with full waveform inversion. *Lu Zhang*, Columbia University
- **CT1-A-4** (11:40am) A new artificial viscosity approach for adaptive multiresolution discontinuous Galerkin method for hyperbolic conservation laws. *Jannatul Ferdous Ema*, Texas Tech University

Session B: Saturday, October 1, 3:10pm-4:30pm, CLB 122

Session-Chair: *Tianshi Lu*, Wichita State University

- **CT1-B-1** (3:10pm) Convergence Analysis For A Semi-discrete Energy Stable Scheme For Hydrodynamic Q-tensor Model. *Yukun Yue*, Carnegie Mellon University
- **CT1-B-2** (3:30pm) Higher temporal accuracy for LES-C turbulent models. *Yasasya Batugedara Mohottalalage*, Michigan Technological University
- **CT1-B-3** (3:50pm) Melt pool formation by a moving heat source. *Tianshi Lu*, Wichita State University
- **CT1-B-4** (4:10pm) Optimal Ordering Policy For Forest Residues and Willow Biomass For Continuous Industrial Supply. *Md Abu Helal*, Colorado State University

CT2. Topics in PDE Analysis

Session A: Saturday, October 1, 5:00pm-6:20pm, CLB 122

Session-Chair: *Taige Wang*, University of Cincinnati

- **CT2-A-1** (5:00pm) Higher order Liouville weighted composition operators over the Fock space. *Himanshu Singh*, University of South Florida
- **CT2-A-2** (5:20pm) Preliminary report on symmetric and asymmetric cell division and modeling of interacting cell populations in the colonic crypt. *Khoi Vo*, University of California, Riverside

- **CT2-A-3** (5:40pm) Quasi-interpolation for the Helmholtz–Hodge decomposition. *Nicholas Fisher*, Minnesota State University, Mankato
- **CT2-A-4** (6:00pm) Forced oscillations of incompressible Navier-Stokes equation in a 2D bounded domain. *Taige Wang*, University of Cincinnati

Session B: Sunday, October 2, 10:30am-11:50am, CLB 122

Session-Chair: *Wojciech Ożański*, Florida State University

- **CT2-B-1** (10:30am) Global well-posedness and exponential decay of a model of fluid-structure interaction. *Wojciech Ożański*, Florida State University
- **CT2-B-2** (11:10am) Densely defined multiplication operators in a NARMAX-type identification scheme. *John Kyei*, University of South Florida
- **CT2-B-3** (11:30am) Mathematical modeling of the process of movement of arterial blood in the arteries for angioplasty and stenting of the coronary arteries. *Bakhyt Alipova*, University of Kentucky, International IT University

6 Abstracts of Mini-Symposium and Contributed Talks

MS01-A-1: Orthogonality sampling method for inverse elastic scattering from anisotropic media.

Thu Le, Kansas State University

Abstract: In this talk, we investigate the inverse scattering problem of time-harmonic elastic waves for anisotropic inclusions in an isotropic homogeneous background. The elasticity tensor and mass density are allowed to be heterogeneous inside the inclusion and may be discontinuous across the background-inclusion interface. We derive the far-field pattern of the scattered wave using the Lippmann-Schwinger integral equation of the scattering problem. Using the far-field pattern as the data for the inverse problem we construct indicator functions of orthogonality sampling types for the scattering objects. These functions are very robust to noise, computationally cheap, and do not involve any regularization process. We provide some theoretical analysis as well as numerical simulations for the proposed indicator functions. This is joint work with Dinh-Liem Nguyen and Trung Truong.

MS01-A-2: An inverse scattering obstacle problem with partial thin coatings.

Heejin Lee, Purdue University

Abstract: We consider the inverse problem of recovering the shape and boundary coefficients of an obstacle from far-field measurements of the scattered field. More specifically the scatterer is impenetrable with Dirichlet boundary condition on a part of its boundary and anisotropic generalized impedance boundary condition on the complementary boundary. The latter is an approximate model for complicated thin anisotropic, absorbing layer and is given as second-order surface differential operator. A deep analysis of the far-field operator (otherwise known as the relative scattering operator) for this scattering problem leads to unique determination results and reconstruction methods for the shape of the scatterer as well as the boundary coefficients. Our reconstruction method is non-iterative and uses no a priori information on the topology and physics of the unknown object. This inversion approach is mathematically rigorous, it resolves nonlinear information from the range properties of the linear far-field operator, and it is easy to implement.

MS01-A-3: Asymptotic analysis applied to small volume inverse shape problems.

Govanni Granados, Purdue University

Abstract: We consider two inverse shape problems coming from diffuse optical tomography and inverse scattering. For both problems, we assume that there are small volume subregions that we wish to recover using the measured Cauchy data. We will derive an asymptotic expansion involving their respective fields. Using the asymptotic expansion, we derive a MUSIC-type algorithm for the Reciprocity Gap Functional, which we prove can recover the subregion(s) with a finite amount of Cauchy data. Numerical examples will be presented for both problems in two dimensions in the unit circle.

MS01-A-4: A comparative study of time- vs. frequency- domain inverse elastic scattering using laboratory test data.

Fatemeh Pourahmadian, University of Colorado Boulder

Abstract: In this talk, we first review the time-domain linear sampling method for elastic-wave imaging of fractures as a complement to the existing LSM framework in the frequency domain. This opens the door for a comparative performance analysis between time- and frequency- domain waveform inversions using the laboratory test data in [1,2]. The experiments reported by [1] (resp. [2]) capture interaction of ultrasonic waves with a stationary (resp. evolving) fracture in a plate whose footprint is

measured on the boundary. The resulting ultrasonic measurements are then used to computed TLSM maps which successfully reconstruct the evolution of damage in time and space. It is further shown that the time-domain inversion with sparse or reduced-aperture data remain robust at moderate noise levels. Further, a comparative analysis is conducted between the TLSM reconstructions and the corresponding multifrequency LSM maps of [1] using same data. A remarkable contrast in image quality is observed between the time- and frequency- domain inversions.

[1] F. Pourahmadian and H. Yue. Laboratory application of sampling approaches to inverse scattering. Inverse Problems, 37(5):055012, 2021.

[2] F. Pourahmadian. Experimental validation of differential evolution indicators for ultrasonic imaging in unknown backgrounds. Mechanical Systems and Signal Processing, 161:108029, 2021.

MS01-B-1: A sampling-type method combined with deep learning for inverse scattering with one incident wave.

Trung Truong, Kansas State University

Abstract: We are interested in the inverse scattering problem that aims to reconstruct the geometry of a bounded object from measured data of the scattered wave. When the scattered wave data was obtained for only one incident wave, existing reconstruction methods cannot provide satisfactory results for relatively complex geometries. This lack of data is common in practice due to technical difficulties. Therefore, we study a sampling-type method that is fast, simple, regularization-free, stable against high levels of noise, and combine it with a deep neural network to solve the inverse scattering problem in which the scattering data is only provided for one incident wave. This combined method can be understood as a network using the image computed by the sampling method for the first layer and followed by the U-net architecture for the remaining layers. The network is trained on simulated data sets of simple scattering objects and is validated by objects with more complex geometries and real data without any additional transfer training. This is joint work with Thu Le, Dinh-Liem Nguyen, and Vu Nguyen.

MS01-B-2: Machine learning techniques for inverse problems in sonar imaging.

Christina Frederick, New Jersey Institute of Technology

Abstract: In this talk we discuss machine learning for inverse problems in high frequency underwater acoustics, where the goal is to recover detailed characteristics of the seafloor from measured backscatter data generated from SONAR systems. The key to successful inversion is the use of accurate forward modeling that captures of the dependence of the backscatter on seafloor properties, such as sediment type, roughness, and thickness of layers. To enable a rapid, remote, and accurate recovery of the seafloor, we propose an approach that combines high fidelity forward modeling and simulation of the entire physical wave propagation and scattering process and machine learning strategies. The idea is to partition large underwater acoustic environments, on the order of kilometers in spatial width, into much smaller "template" domains, a few meters in spatial width, in which the sediment layer can be described using a limited number of parameters. Hybrid prediction models can be created by embedding localized simulations of Helmholtz equations on each template domain in a large-scale geometric optics model for larger domains. To solve the inverse problem, machine learning strategies applied to a reference library of acoustic templates can be used to estimate the seafloor parameters that describe the full domain.

MS01-B-3: Lippmann-Schwinger-Lanczos algorithm for imaging problems.

Mikhail Zaslavsky, Southern Methodist University

Abstract: Data-driven reduced order mod-

els (ROMs) are combined with the Lippmann-Schwinger integral equation to produce a direct nonlinear inversion method. The ROM is viewed as a Galerkin projection and is sparse due to Lanczos orthogonalization. Embedding into the continuous problem, a data-driven internal solution is produced. This internal solution is then used in the Lippmann-Schwinger equation, thus making further iterative updates unnecessary. We show numerical experiments for spectral domain data for which our inversion is far superior to the Born inversion and works as well as when the true internal solution is known.

MS01-B-4: A direct approach for inverse source problems in photoacoustic tomography.
Thi-Phong Nguyen, New Jersey Institute of Technology
Abstract: This talk will discuss a direct approach to solve numerically the inverse source problem of recovering the initial condition of a wave equation in time using the boundary measurements. This problem is generally encountered for example in photoacoustic tomography, where the initial condition is generated by the expansion of the part which has been heated by photons. By applying an orthonormal basis in time, we discretize the original equation into a coupled system of elliptical equations. The source is now represented as a Fourier series where the Fourier coefficients are obtained by solving the coupled system above. The representation of the source allows one to recover the source directly instead of applying inverse methods, so the results are robust with respect to noise. This is a joint work with Loc H. Nguyen, Thuy T. Le, and William Powell at the UNC at Charlotte.

MS02-A-1: Splitting with and Exponential Time Differencing Scheme for Advection-Diffusion-Reaction Systems.
Bruce Wade, University of Louisiana at Lafayette
Abstract: We describe a second order Exponential Time Differencing (ETD) scheme for advection-diffusion-reaction systems and analyze their convergence properties under different operator splitting scenarios when applied to systems with nonsmooth or mismatched data.

MS02-A-2: Exponential time differencing with real distinct poles for simulating chemotaxis problems.
Emmanuel Asante-Asamani, Clarkson University
Abstract: Collective migration of cells in response to a chemical gradient (chemotaxis) is important for many biological processes such as tumor angiogenesis and aggregation of unicellular organisms. Mathematical models of these processes fall under the class of advection-diffusion-reaction (ADR) equations posed in 2D or 3D, having positive solutions, variable speed advection, stiff linear diffusion and possibly stiff nonlinear reaction kinetics. In this work, we apply a second order exponential time differencing scheme (ETD-RDP) to solve chemotaxis problems. I will discuss the positivity and stability of ETD-RDP for ADR equations and illustrate its advantage over IMEX methods when applied to chemotaxis problems.

MS02-A-3: Subgradient extragradient method with double inertial and self-adaptive step size: applications in Dynamical systems.
Olaniyi Samuel Iyiola, Clarkson University
Abstract: Dynamical systems are fundamental tools in modeling physical phenomena with applications in several fields of study. In recent decades, constructing fixed-point iterative schemes for solving variational inequality problems (VIP) has found applications in developing robust numerical schemes for dynamical systems and has become active research area for many applied Mathematicians. This talk will focus on the overview of the relationship that exists between dynamical system and several fixed point iterative schemes. In addition, I will discuss our recent results on the subgradient extragradient method with double inertial extrapola-

tion terms and self-adaptive step sizes for solving VIP. Rate of convergence is enhanced in this version which is more relaxed with easy to implement conditions on the inertial-factor and relaxation parameter. Numerical examples are provided to demonstrate the accelerating behaviors of our method over other related methods in the literature.

MS02-A-4: Scattered results on the recovery of 3D volumetric density information from a single projection view.
Sean R. Breckling, Department of Energy.
Abstract: High-speed, high-energy flash X-ray radiography is a cornerstone diagnostic measurement for physics experiments studying hypersonic hydrodynamics. Given that precise timing and coordination of the X-ray light exposure is required for multi-projection view tomography, many premier experimental testbeds operate utilizing as few as one to two projection images. Experimentalists have coped with these limitations by designing studies in settings where recovery of 3D volumetric information remains mathematically possible. A common modality is one that exploits spherical or cylindrical symmetry. In idealized settings, performing tomographic reconstruction is equivalent to solving Abel's integral equation. While this formulation is a fully-determined problem, the Abel transform is unbounded. Discretizations of the reconstruction procedure are frequently beleaguered with noise amplification and instability near the singularity at the axis of rotational symmetry. To address this, several regularization techniques (e.g. TVmin, L_p, $L_1 - L_2$, L_1/L_2, etc) have been tested; many of which have shown promise. Additionally, quite recently, reframing the data discretization paradigm from the classic "rectangle of pixelated data" setting to a regression problem using high-order Radial Basis Functions (RBFs) or the Finite Element Method (FEM) have been considered.

MS02-B-1: Notes on Global Error Analysis for Splitting Methods.
Qin Sheng, Baylor University
Abstract: Splitting methods have been used for solving a broad spectrum of problems in scientific applications. They are designed for the numerical solutions to not only differential equations, but also optimization and machine learning procedures. A splitting method decomposes an original problem to several subproblems, computes separately the solution of each of them, and then combines all sub-solutions to form an approximation of the solution to the original problem. Motivations of different splitting methods are inspired by problems with multiple operators in natural ways. In all cases, the computational advantage is that it is faster to compute the solution of the split components separately, than to compute the solution directly when they are treated together. However, this comes at the cost of an error introduced by the splitting, so strategies must be devised for controlling the error. This talk studies splitting mechanisms via operator formulations. A survey will be conducted in global error estimates of popular exponential splitting strategies. Adaptive splitting, a highly effective decomposition collaborating with mesh adaptations, will also be briefly elaborated.

MS02-B-2: A study of the numerical stability of a Crank-Nicolson method for solving singular Kawarada equations.
Eduardo Servin Torres, Baylor University
Abstract: This presentation focuses on the proof of the numerical stability and convergence of a second-order semi-adaptive method for the numerical solution of nonlinear Kawarada equations. The nonlinear source terms will not be frozen. The convergence and the preservation features of the numerical method will be investigated. Order of convergence will be validated through improved Milne devices. Simulation experiments will be carried out to illustrate our theoretical results. The partial differential equations model a broad spectrum of important phenomena that occur in numerous industrial ap-

plications, including the combustion in thermal engines.

MS02-B-3: Biquintic B-Spline Solutions of Smart Material Structures and Applications to Control Theory.
Lisa Kuhn, Southeastern Louisiana University
Abstract: In distributed parameter control theory researchers employ Galerkin's method in order to guarantee convergent solutions to the corresponding optimal control problem. Recent advances in smart material structures, such as weak internal damping and material continuities, have substantially increased the complexity of models and the computation time required for simulation. In this talk numerical computations are presented for clamped beam and plate smart material structures using quintic and biquintic B-spline basis functions. Convergence and computation time are compared with other known methods.

MS02-B-4: Solving A Friction Stir Welding Problem with Reduced Order Models and Neural Networks.
Zilong Song, Utah State University
Abstract: The friction stir welding process can be modelled using a system of heat transfer and Navier-Stokes equations with a shear-dependent viscosity. Finding numerical solutions to this system of nonlinear partial differential equations over a set of parameter space, however, is extremely time-consuming. Therefore, it is desirable to find a computationally efficient method that can be used to obtain an approximation of the solution with acceptable accuracy. In this talk, we present a reduced basis method for solving the parametrized coupled system of heat and Navier-Stokes equations using a proper orthogonal decomposition (POD). In addition, we apply a machine learning algorithm based on an artificial neural network (ANN) to learn (approximately) the relationship between relevant parameters and the POD coefficients. Our computational experiments demonstrate that substantial speed-up can be achieved while maintaining reasonable accuracy.

MS02-C-1: Stable Generalized Finite Element Method for Richards Equation in Heterogenous Soil in 1D.
Tilsa Aryeni, University of Wyoming
Abstract: This study concentrates on the numerical approximation of the one-dimensional Richards equation for unsaturated flow in heterogeneous soil layers. The nature of each different soil layer enforces the elliptic coefficient to be discontinuous with respect to the spatial variable. It is known that the standard finite element technique fails to maintain the convergence optimality for this type of problem. In particular, it happens when a node of spatial mesh configuration does not match the interface location. The Generalized FEMs (GFEMs) have been utilized to recover this issue. It is based on augmenting the standard finite element basis with some enrichment that can capture the behavior of the solution near the interfaces. Stable GFEM is one version of GFEMs that not only maintains the optimal rate of convergence but also possess the same order of the scaled condition number of the associated stiffness matrix as the standard FEM. The numerical examples are presented and tested with the available analytical solutions to illustrate the performance of the method.

MS02-C-2: Convergence of adaptive least-squares finite element methods. *Jaeun Ku, Oklahoma State University*
Abstract: In this talk, we consider adaptive procedures for least-squares finite element methods. We establish that the sequence of the approximation solutions generated by adaptive procedures is a Cauchy sequence in a Banach space. This leads to the conclusion that the sequence converges. In order to force the sequence converging to the true solutions, we propose a refinement strategy using a weighted least-squares functional as an a posteriori error indicator to identify the local regions to refine

the current underlying mesh.

MS02-C-3: Block preconditioners for the MAC discretization of the Stokes-Darcy equations.
Yunhui He, The University of British Columbia
Abstract: In this talk, we discuss preconditioning methods for solving the Stokes-Darcy equations, discretized by the Marker and Cell (MAC) finite difference method. A central challenge in the solution of the Stokes-Darcy equations is that the equations governing each domain are fundamentally different. This difficulty is particularly highlighted when the parameters involved, specifically the viscosity coefficient and permeability constant, differ from each other by a few orders of magnitude. We propose three block preconditioners and analyze the eigenvalue distribution of the preconditioned operators. Our proposed preconditioned operators have strongly clustered eigenvalues that are independent of physical parameters, and consequently, a minimum residual iterative method such as GMRES rapidly converges. Numerical results validate our theoretical observations.

MS02-C-4: Bivariate Lagrange interpolation at the checkerboard nodes.
Srijana Ghimire, Tulsa Community College
Abstract: An explicit formula for the bivariate Lagrange basis polynomials of a general set of checkerboard nodes is derived. This formula generalizes existing results of bivariate Lagrange basis polynomials at the Padua nodes, Chebyshev nodes, Morrow-Patterson nodes, and Geronimus nodes. In addition, a subspace that is spanned by linearly independent bivariate vanishing polynomials that vanish at the checkerboard nodes is also constructed. As a result, the uniqueness of the set of bivariate Lagrange basis polynomials is proved in the quotient space defined as the space of bivariate polynomials with a certain degree over the subspace of bivariate vanishing polynomials.

MS02-D-1: Dimension reduction for data assimilation: Particle filters with reduced order models and data.
Erik Van Vleck, University of Kansas
Abstract: Particle filters are a class of data assimilation techniques that can estimate the state and uncertainty of dynamical models by combining nonlinear evolution models with non-Gaussian uncertainty distributions. However, estimating high dimensional states, such as those associated with spatially-discretized PDE models, requires an exponentially-large number of ensemble members or particles in order to avoid the so-called filter collapse. This dramatically decreases the accuracy and efficiency in obtaining the estimation. By combining particle filters with projection-based data-driven model reduction techniques, such as Proper Orthogonal Decomposition and Dynamic Mode Decomposition, we demonstrate that it is possible to reduce the effective dimension of the models and reduce the occurrences of filter collapse for a class of dynamical models relevant to forecasting of geophysical fluid flows. This technique can be adapted to account for models with transient change in parameters, by developing time dependent projection matrices using window snapshots. We demonstrate several variants of the technique on Lorenz'96-type models and on a simulation of shallow-water equations.

MS02-D-2: Modeling a cylindrical end irradiated cavity with EMPIRE: investigating the effects of approximating geometric features.
Sidney Shields, Sandia National Laboratories
Abstract: When comparing experimental data with simulation results, great care must be taken in choosing which physics and geometric features to model. The task of simplifying a model for the sake of simulation with minimal loss of fidelity can be quite challenging for even the simplest of problems. This talk will focus on using Sandia's plasma code EMPIRE to model a cylindrical end irradiated cavity fielded at experimental facilities, such as Z and NIF. Photoelectric diodes generate an intense beam of electrons by the interaction of soft X-rays

with an emitter surface driving an electromagnetic mode in the cavity. These electromagnetic modes can be quite sensitive to various geometric features one might want to approximate away in the model. Using various configurations of this cavity, we can quantify some of the sensitivities in the electromagnetic modes due to the geometric description of the problem. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

MS02-D-3: The condition number of a Vandemonde-like matrix arising from a direct parallel-in-time algorithm.

Xiang-Sheng Wang, University of Louisiana at Lafayette

Abstract: We study a direct parallel-in-time (PinT) algorithm for first- and second-order time-dependent differential equations. We use a second-order boundary value method as the time integrator. Instead of solving the corresponding all-at-once system iteratively, we diagonalize the time discretization matrix B, which yields a direct parallel implementation across all time steps. A crucial issue of this methodology is how the condition number (denoted by Cond(V)) of the eigenvector matrix V of B behaves as n grows, where n is the number of time steps. A large condition number leads to a large roundoff error in the diagonalization procedure, which could seriously pollute the numerical accuracy. Based on a novel connection between the characteristic equation and the Chebyshev polynomials, we present an explicit formula for V as a Vandemonde-like matrix and prove that Cond(V) = O(n^2). This implies that the diagonalization process is well-conditioned and the roundoff error only increases moderately as n grows, and thus, compared to other direct PinT algorithms, a much larger n can be used to yield satisfactory parallelism.

MS03-A-1: Neural finite element method.

Shuhao Cao, University of Missouri-Kansas City

Abstract: Finite Element Methods (FEM) are arguably one of the most widely used numerical methods to approve PDEs in science and engineering disciplines. One of the key elements involves using discrete basis functions on a mesh. Recently, Neural Networks are used to approximate the solutions in a mesh free way. This method's popularity is largely facilitated by user-friendly interfaces of the auto-differentiation in various deep learning packages such as PyTorch and JAX. However, using NN changes a well-conditioned problem into a nonconvex ill-conditioned problem. The worse part is that, to achieve the same accuracy, NN and optimization-based PDE solver costs hundreds of thousand more Floating Point Operations (FLOPs) than the old faithful FEM. In this talk, inspired by the popular Transformer that powered multiple scientific breakthrough such as AlphaFold 2 and all new Natural Language models such as GPT-3, we shall introduce a new Finite Element Method algorithm natively implemented in PyTorch to accelerate the solution procedure in nonlinear PDEs.

MS03-A-2: A chemical-mechanical coupled model for simulating cell morphogenesis and tissue development.

Weitao Chen, University of California, Riverside

Abstract: Chemical signals and mechanical properties, as well as the interplay between them, play a critical role in regulating cell growth and tissue development. Most existing mathematical models to study tissue growth focus on either chemical signals or mechanical forces only. In this study, we have developed a multiscale chemical-mechanical coupled model by integrating chemical signaling pathways, cell mechanical properties and cell-cell interaction. The model includes a discrete particle based mechanical submodel and a continuum PDE chemical submodel, integrated by an adaptive mesh generator. It has been applied to simulate the development of Drosophila

wing disc tissue to investigate the general principles involved in growth regulation. Our results show that the spatial distribution of the morphogen is critical in determining tissue size and shape. A larger tissue size with a faster growth rate and more symmetric shape can be achieved if the gradient spreads in a larger domain. Together with the absorbing boundary conditions, the feedback regulation that downregulates receptors on the cell membrane allows the further spread of the morphogen away from its source region, resulting in prolonged tissue growth at a more spatially homogeneous growth rate.

MS03-A-3: Structure-preserving machine learning moment closures for the radiative transfer equation.

Juntao Huang, Texas Tech University

Abstract: In this talk, we present our work on structure-preserving machine learning (ML) moment closure models for the radiative transfer equation. Most of the existing ML closure models are not able to guarantee the stability, which directly causes blow up in the long-time simulations. In our work, with carefully designed neural network architectures, the ML closure model can guarantee the stability (or hyperbolicity). Moreover, other mathematical properties, such as physical characteristic speeds, are also discussed. Extensive benchmark tests show the good accuracy, long-time stability, and good generalizability of our ML closure model.

MS03-A-4: Modeling and simulation of turbulent mixing due to hydrodynamic instabilities.

Tulin Kaman, University of Arkansas

Abstract: Turbulence modeling is one of the most challenging scientific problem because it requires capturing the chaotic and capricious eddies of flows. Turbulence models are classified according to the governing equations and numerical methods. In this talk, we present a brief summary of numerical approaches that are widely used for simulating compressible turbulence mixing such as (i) Direct Numerical Simulation (DNS), the full Navier-Stokes Equations are resolved without any models for turbulence, (ii) Large Eddy Simulation (LES), the flow field is resolved down to a certain length scale and scales smaller than that are modeled rather than resolved, and (iii) Reynolds-Averaged Navier-Stokes (RANS), the time-averaged equations are solved for mean values of all quantities. We present an increasingly accurate and robust algorithm based on dynamic subgrid scale models and front tracking for the simulation of turbulent mixing.

MS03-B-1: An approximate Bayesian computation approach for biological model selection and validation.

Tracy Stepien, University of Florida

Abstract: Mathematical models of cell migration in the context of wound healing, embryonic development, and cancer growth have been developed using a wide variety of frameworks, including reaction-diffusion equations, continuum mechanics, and agent-based models. However, studying model uncertainty or model selection in these settings is less common. We develop a method for studying the appropriateness of model equation components that combines approximate Bayesian computation (ABC) and sensitivity analysis (SA). We provide two case studies in cell migration where we apply this method to sparse experimental data sets of retina development in the eye and tumor-immune dynamics in the brain. We identify model components that can be removed via model reduction using ABC+SA and potential cancer treatment pathways.

MS03-B-2: Comparing R_0 for a class of PDE epidemic models with ODE models.

Chayu Yang, University of Nebraska-Lincoln

Abstract: We present a general numerical framework to compute the basic reproduction number R0 for a reaction-diffusion epidemic model and compare the value with the associated autonomous ODE model.

MS03-B-3: Numerical methods for heteroge-

neous problems with variable-order fractional Laplacian.

Yanzhi Zhang, Missouri University of Science and Technology

Abstract: In this talk, I will introduce the recently developed meshfree methods based on the radial basis function to solve problems with the variable-order fractional Laplacian. The proposed methods take advantage of the analytical Laplacian of the radial basis functions so as to accommodate the discretization of the classical and variable-order fractional Laplacian in a single framework and avoid the large computational cost for numerical evaluation of the fractional derivatives. Moreover, our methods are simple and easy to handle complex geometry and local refinements, and their computer program implementation remains the same for any dimension d. The effects of variable-order fractional Laplacian will also be discussed.

MS03-B-4: Solving and learning phase field models using the modified physics informed neural networks.

Jia Zhao, Utah State University

Abstract: In this talk, we introduce some recent results on solving and learning phase field models using deep neural networks. In the first part, we focus on using the deep neural network to design an automatic numerical solver for the Allen-Cahn and Cahn-Hilliard equations by proposing an adaptive physics informed neural network (PINN). In particular, we propose to embrace the adaptive idea in both space and time and introduce various sampling strategies, such that we are able to improve the efficiency and accuracy of the PINN on solving phase field equations. In the second part, we introduce a new deep learning framework for discovering the phase field models from existing image data. The new framework embraces the approximation power of physics informed neural networks (PINN), and the computational efficiency of the pseudo-spectral methods, which we named pseudo-spectral PINN or SPINN. We will illustrate its approximation power by some interesting examples.

MS04-A-1: Stability of homogeneous solutions of stationary incompressible Navier-Stokes equations.

Xukai Yan, Oklahoma State University

Abstract: In 1944, Landau discovered a three parameter family of explicit (-1)-homogeneous solutions of 3D stationary incompressible NSE with precisely one singularity at the origin, which are axisymmetric with no swirl. These solutions are now called Landau solutions. Sverak proved that all (-1)-homogeneous solutions that are smooth on the unit sphere must be Landau solutions. Karch and Pilarczyk showed that small Landau solutions are asymptotically stable under any L2-perturbation. In recent joint works with Li Li and Yanyan Li, we studied (-1)-homogeneous solutions of 3D incompressible stationary NSE with finitely many singular rays. In this talk, I will first talk about the existence and asymptotic behavior of such solutions that are axisymmetric with two singular rays passing through the north and south poles. I will then discuss the asymptotic stability of Landau solutions and some of the solutions with singular rays we have obtained.

MS04-A-2: The 2D Quasi-Geostrophic Equation in Holder and Uniformly Local Sobolev Spaces.

Elaine Cozzi, Oregon State University

Abstract: We show existence of solutions to the 2D quasi-geostrophic equation (SQG) in Holder spaces without placing an integrability assumption on the solution, generalizing a result of Wu. The main challenge in this setting is lack of validity of the SQG constitutive law. To overcome this difficulty, we introduce a modified relationship between the velocity and the temperature. Time permitting, we also discuss an application of our result to existence of solutions to SQG in uniformly local Sobolev spaces. This is joint work with David M. Ambrose, Daniel Erickson, and James P. Kelliher.

MS04-A-3: On Euler equations with in-flow

and out-flow boundary conditions.
Anna L. Mazzucato, The Pennsylvania State University
Abstract: I will discuss recent results concerning the well-posedness and regularity for the incompressible Euler equations when in-flow and out-flow boundary conditions are imposed on parts of the boundary. This is joint work with Gung-Min Gie (U. Louisville, USA) and James Kelliher (UC Riverside, USA).

MS04-A-4: Existence and Stability of Traveling Waves of Boussinesq-Burgers Equations
Kun Zhao, Tulane University
Abstract: We introduce rigorous mathematical results concerning existence and stability of traveling wave solutions to Cauchy problem of the one-dimensional Boussinesq-Burgers equations modeling propagation of weak tidal bores. Existence of traveling waves is obtained by means of phase plane analysis and geometric singular perturbation. Local stability of traveling waves with arbitrary strength is proven by spatially weighted energy methods. This talk is based on recent joint work with Anita Yang (Chinese University of Hong Kong) and Zhian Wang (Hong Kong Polytechnic University).

MS04-B-1: Regular solutions of the stationary incompressible Navier-Stokes equations.
Zhuolun Yang, Brown University
Abstract: In this talk, we will discuss regular solutions of stationary incompressible Navier-Stokes equations. When the base domain is Euclidean space, the existence of such solutions was known for dimensions less than or equal to 5. In a joint work with Yanyan Li, we extended it to dimensions less than or equal to 15.

MS04-B-2: Decay of multi-point correlation functions in $\mathbb{Z}^d$.
Rui Han, Louisiana State University
Abstract: We prove multi-point correlation bounds in $\mathbb{Z}^d$ for arbitrary $d \geq 1$ with symmetrized distances, answering open questions proposed by Sims-Warzel and Aza-Bru-Siqueira Pedra. As applications, we prove multi-point correlation bounds for the Ising model on $\mathbb{Z}^d$, and multi-point dynamical localization in expectation for uniformly localized disordered systems, which provides the first examples of this conjectured phenomenon by Bravyi-König.

MS04-B-3: Liouville-type Theorems for Steady Solutions to the Navier-Stokes System in a Slab.
Jeaheang Bang, University of Texas at San Antonio
Abstract: I will present on my recent work with Changfeng Gui, Yun Wang, and Chunjing Xie. Liouville type theorems for the three-dimensional Navier-Stokes system in the entire space is a major open problem. In this work, we investigated Liouville-type theorems in a three-dimensional slab with either no-slip boundary conditions or periodic boundary conditions. For the no-slip boundary conditions, we proved that any bounded solution is trivial if it is axisymmetric or ru^r is bounded, and that general three-dimensional solutions must be Poiseuille flows when the velocity is not big in L^∞ space. For the periodic boundary conditions, we proved that the bounded solutions must be constant vectors if either the swirl or radial velocity is independent of the angular variable, or ru^r decays to zero as r tends to infinity. The proofs are based on energy estimates, and the key technique is to establish a Saint-Venant type estimate that characterizes the growth of Dirichlet integral of nontrivial solutions.

MS04-B-4: Data assimilation in turbulent fluids: Movement paradigms for improved convergence rates.
Collin Victor, University of Nebraska-Lincoln
Abstract: In accurately simulating turbulent flows, two major difficulties arise before the simulation begins; namely the problem of determining the initial state of the flow, and the problem of estimating the parameters. Data assimilation helps to resolve the first problem by eliminating the need for complete knowledge of the initial state. It incorporates incoming observa-

tions into the mathematical model to drive the simulation to the correct solution. Recently, a promising new data assimilation algorithm (the AOT algorithm) has been proposed by Azouani, Olson, and Titi, which uses a feedback control term to incorporate observations at the PDE level. In this talk, we examine computationally the effects of observers that move dynamically in time for the 2D incompressible Navier-Stokes equations. We test several movement patterns (which we refer to as "the bleeps, the sweeps, and the creeps") as well as Lagrangian motion and combinations of these patterns, in comparison with static observers. In several cases, order-of-magnitude improvements in terms of the time-to-convergence are observed.

MS04-C-1: Poiseuille flow of nematic liquid crystals via Ericksen-Leslie model.

Geng Chen, University of Kansas

Abstract: In this talk, we will discuss a recent global existence result on the Poiseuille flow of nematic liquid crystals via full Ericksen-Leslie model. The existing results on the Ericksen-Leslie model for the liquid crystals mainly focused on the parabolic and elliptic type models by omitting the kinetic energy term. In this recent progress, we established a new method to study the full model. A singularity formation result will also be discussed, together with the global existence result showing that the solution will in general live in the Holder continuous space. The earlier related result on the stability of variational wave equation using the optimal transport method, and the future work on other wave equations will also be discussed. The talk is on the joint work with Tao Huang, Weishi Liu and Xiang Xu.

MS04-C-2: A remark on the two dimensional water wave equation with surface tension.

Shuanglin Shao, University of Kansas

Abstract: We consider the motion of a two-dimensional interface between air (above) and an irrotational, incompressible, inviscid, infinitely deep water (below), with surface tension present. We propose a new way to reduce the original problem into an equivalent quasilinear system which are related to the interface's tangent angle and a quantity related to the difference of tangential velocities of the interface in the Lagrangian and the arc-length coordinates. The new way is relatively simple because it involves only taking differentiation and the real and the imaginary parts. Then if assuming that waves are periodic, we establish a priori energy inequality.

MS04-C-3: Reductions of the 2D Kuramoto-Sivashinky equations.

Adam Larios, University of Nebraska-Lincoln

Abstract: The flame equation, also known as the Kuramoto-Sivashinsky equation (KSE) is a highly chaotic dynamical system that arises in flame fronts, plasmas, crystal growth, and many other phenomena. Due to its lack of a maximum principle, the KSE is often studied as an analogue to the 3D Navier-Stokes equations (NSE) of fluids. We will discuss some of the relationships between these equations of fire and water. Much progress has been made on the 1D KSE since roughly 1984, but for the 2D KSE, even global well-posedness remains a major open question. In analogy with regularizations of the 3D NSE, we present modifications of the 2D KSE which allow for global well-posedness, while still retaining many important features of the 2D KSE. However, as has been demonstrated recently by Kostianko, Titi, and Zelik, standard regularizations, which work well for Navier-Stokes, destabilize the system when applied to even the 1D KSE. Thus, we present entirely new types of modifications for the 2D KSE. This talk will describe key ideas of the analysis, and also show many colorful movies of solutions.

MS04-C-4: Nonlinear calming for the 2D Kuramoto-Sivashinsky equations.

Matthew Enlow, University of Nebraska-Lincoln

Abstract: The Kuramoto-Sivashinsky (KS) equations model chaotic behavior in reaction-diffusion systems and have found many applications in the sciences. Global well-posedness of the equations have been shown in 1D, but this remains an open problem for higher dimensions. This is due in part to a lack of control over the nonlinear term. In this talk we introduce a modification of the 2D KS equations which allow for a better handle on the nonlinearity. We will perform an analysis of these 'calmed' KS equations and observe some computational demonstrations.

MS04-D-1: Non-uniqueness results of stochastic PDEs via probabilistic convex integration.
Kazuo Yamazaki, Texas Tech University
Abstract: I will discuss recent developments concerning applications of convex integration to stochastic PDEs such as the Navier-Stokes equations, Boussinesq system, magnetohydrodynamics system, transport-diffusion equation, surface quasi-geostrophic equations, all forced by random noise. The types of noise include additive, linear multiplicative, nonlinearly multiplicative, transport, spatially white noise, as well as space-time white noise. We will also discuss some open problems related to stochastic Yang-Mills equation if time permits.

MS04-D-2: Bounds on the separation rate of non-unique 3D Navier-Stokes flows.
Zachary Bradshaw, University of Arkansas
Abstract: There is considerable evidence that non-unique solutions to the 3D Navier-Stokes equations exist within the class of suitable weak solutions. Consequently, it is natural to ask how these hypothetical solutions relate to one another. For example, do these solutions remain relatively close or rapidly separate? In this talk I will present algebraic bounds on the separation rates of suitable weak solutions under appropriate conditions on the initial data. A useful short-time asymptotic expansion will also be discussed, as will related results for non-unique discretely self-similar solutions.

MS04-D-3: Stabilizing phenomenon for electrically conducting fluids.
Jiahong Wu, Oklahoma State University
Abstract: Physical experiments and numerical simulations have observed a remarkable phenomenon that a background magnetic field can actually stabilize electrically conducting fluids. Our goal has been to understand the mechanism and establish this observation as a mathematically rigorous fact on MHD systems. This talk presents a stability result on the 3D incompressible MHD system with anisotropic dissipation. The velocity obeys the 3D incompressible Navier-Stokes equation with dissipation in only one direction, and is thus not known to be stable. However, when this Navier-Stokes is coupled with the magnetic field in the MHD system, the solutions near a background magnetic field are always global and stable. The magnetic field stabilizes the fluid. Mathematically, the system governing the perturbations can be converted to a damped wave equation. I will also briefly mention stability results for compressible MHD systems.

MS05-A-1: Random Matrix Theory for Homogenization of Composites.
Tom Alberts, University of Utah
Abstract: I will discuss the random matrix theory behind two-component random resistor networks on general graphs. This involves random submatrices of the graph's Gamma projection operator, with the particular realization of the submatrix determined by the disorder of the conductances. Certain combinations of graph symmetries together with different models for the random conductances lead to exactly computable spectral statistics. I will discuss recent results for spectral statistics of a percolation model on the diamond hierarchical lattice.

Joint work with Ken Golden, Elena Cherkaev, Ben Murphy, Han Le, Loren Santana.

MS05-A-2: The Resampling Property of Multiple Radial SLE.
Vivian Healey, Texas State University
Abstract: Schramm-Loewner evolution (SLE) is a conformally-invariant process that describes

the scaling limit of many statistical physics models in which an interface (random curve) appears at criticality. The radial version of this process generates a random curve in the disk from the boundary to an interior point. I will discuss the resampling property of the multiple-curve version of this process (as constructed in Healey-Lawler '21). Joint work with Yilin Wang.

MS05-A-3: The scaling limit of fair Peano paths.
Joan Lind, University of Tennessee Knoxville
Abstract: Random spanning trees on planar grids determine random Peano paths. We are interested in studying the limiting behavior of random Peano paths that arise in the context of spanning tree modulus. In contrast to the case for uniform spanning trees, where the scaling limit of the associated Peano paths is SLE(8), we show that the scaling limit of the Peano paths in our context is deterministic. This is joint work with Nathan Albin and Pietro Poggi-Corradini.

MS05-A-4: Riesz capacities and density conditions in metric space. *Lizaveta Ihnatsyeva, Kansas State University*
Abstract: It is well known that the classical Newtonian capacity of a subset of the Euclidean space can be characterized as the minimum of an energy functional in terms of the weak gradient on the Sobolev space. This characterization has led to extensions of the notion of capacity in several directions and, in particular, to the development of a theory of capacities related to Riesz and Bessel potentials. In many cases the different definitions lead to comparable capacities. For instance, the Riesz (b,p)-capacity is comparable to the classical Newtonian capacity when b=1 and p=2.

In out talk we consider Riesz capacities and the capacities defined in terms of Hajlasz gradients in the setting of a metric measure space. Our main goal is to clarify the connections between these two different notions. First, we prove a comparability result for the Riesz (b,p)-capacity and the relative Hajlasz (b,p)-capacity, for 0<b<=1 and p>1, under a suitable kernel estimate related to the Riesz potential. Then we show that in geodesic spaces the corresponding capacity density conditions are equivalent even without assuming the kernel estimate. The talk is based on a joint work with Javier Canto, Juha Lehrbäck and Antti V. Vähäkangas.

MS05-B-1: From Convex Geometry to Convex Optimization.
Dominique Zosso, Montana State University
Abstract: In this talk we present an entirely geometric proof of the well-established Lagrange- and KKT-theorems for first order optimality conditions in the case of convex objectives and constraints. We largely refrain from using calculus and linear algebra concepts, and provide all the geometric definitions and tools in a visually accessible, self-contained form, instead. Our work makes extensive use of convex geometry elements such as tangent cones, normal cones, and hyperplanes of support, to define the objective function's properties such as convexity and sub-gradient. As a result, we provide an illustrative approach to convex optimization, accessible to students before formal calculus, for example. This is joint work with Alexandra Emmons, Henry Fessler, and Ryan Grady.

MS05-B-2: An Approximation of the Modulus of the Family of Edge Covers.
Adriana M. Ortiz Aquino, Kansas State University
Abstract: Modulus on graphs is a very flexible and general tool for measuring the richness of families of objects defined on a graph. It has been shown that the modulus of special families generalizes classical network theoretic quantities such as shortest path, max flow/min cut, and effective resistance. Our focus is on the p-modulus of the families of edge covers, specifically on the family of fractional edge covers on an unweighted, undirected graph. Direct computation of the modulus can be expensive because these families tend to be exponentially large, leading to a large number of constraints

for the modulus problem. Furthermore, computing the modulus of edge covers is difficult (no known efficient algorithm), but if we could compute the modulus of fractional edge covers we obtain an upper bound for the modulus of edge covers. Through the theory of Fulkerson blocking duality, every family of objects has a corresponding dual family, whose modulus is closely related to the modulus of the original family. Our results show that the dual family of fractional edge covers is the family of stars, which greatly reduces the number of constraints for the p-modulus problem. With this we give an approximation for the modulus of edge covers using the modulus of fractional edge covers, and study the complexity of calculating the modulus over the family of stars compared to the family of edge covers.

MS05-B-3: Estimation of causal effects under K-nearest neighbors interference.

Mike Higgins, Kansas State University

Abstract: In causal inference, an experiment exhibits treatment interference when the treatment status of one unit affects the response of other units. While traditional causal inference methods often assume no interference between units, there has been a recent abundance of work on the design and analysis of experiments under treatment interference—for example, those conducted on social networks. We develop properties for the K-nearest neighbors interference model (KNNIM)—a model of treatment interference where the response of a unit depends only on its treatment status and the statuses of units within its K-neighborhood. We define causal estimands for direct and indirect effects under KNNIM and propose Horvitz-Thompson (HT) unbiased estimators for these estimands. We then derive properties and provide conservative variance estimators for the proposed HT estimators. We show the efficacy of our estimators using a simulation study and a study on the efficacy of an anti-conflict program from a randomized experiment among middle school students in New Jersey.

MS05-B-4: Identifying graph-derived features of trained neuronal networks via machine learning.

Nethali Fernando, University of Texas Arlington

Abstract: Neuronal circuits are plastic. Neurons can modulate their connections to form new connections and adjust the strength of current connections to learn new tasks. Among the multiple proposed mechanisms for network training, the full-FORCE model presents a target-based method for modifying the connectivity matrix of a recurrent network to train it to learn temporally complex signals. In this study, we investigate the relationship between the network architecture and the learning that occurs in these neuronal networks. Specifically, we simulate full-FORCE networks learning different types of periodic signals and keep track of the plasticity adjacency matrices of the trained networks. These matrices are pre-processed and then fed into a graph metrics wrapper which provides an ensemble of graph features related to the trained network. We apply an ensemble of machine learning methods to disambiguate the different signals using these graph features. The highest balanced accuracy that we have achieved is 79%. This demonstrates that trained networks have graph features that imprints information of their original signals. Among the commonly selected graph features were, average degree connectivity, edge betweenness centrality, degree centrality and core number of the graphs.

MS05-C-1: Extremal graph realizations and graph Laplacian eigenvalues.

Braxton Osting, University of Utah

Abstract: For a regular polyhedron (or polygon) centered at the origin, the coordinates of the vertices are eigenvectors of the graph Laplacian for the skeleton of that polyhedron (or polygon) associated with the first (non-trivial) eigenvalue. In this talk, I'll discuss a generalization of this relationship. For a given graph, we study the eigenvalue optimization problem of maximizing the first (non-trivial) eigenvalue of the graph

Laplacian over non-negative edge weights. We show that the spectral realization of the graph using the eigenvectors corresponding to the solution of this problem, under certain assumptions, is a centered, unit-distance graph realization that has maximal total variance. This result gives a new method for generating unit-distance graph realizations and is based on convex duality. A drawback of this method is that the dimension of the realization is given by the multiplicity of the extremal eigenvalue, which is typically unknown prior to solving the eigenvalue optimization problem. Our results are illustrated with a number of examples.

MS05-C-2: The Phase Transition of Discrepancy in Random Hypergraphs.
Xavier Perez Gimenez, University of Nebraska Lincoln
Abstract: The discrepancy of a hypergraph is a well-studied parameter which measures how well we can color the vertices with 2 colors so that the edges are as balanced as possible. A famous conjecture of Beck and Fiala states that every hypergraph of maximum degree d has discrepancy $O(d^{1/2})$. In recent years, there has been a significant effort to prove this conjecture (which still remains open) and also characterize the discrepancy of several families of deterministic and random hypergraphs. In this talk, we will describe some of our recent results, which provide nearly tight lower bounds on the discrepancy of two natural models of random hypergraphs. The proofs include both probabilistic and algorithmic ingredients. (This is joint work with Calum MacRury, Tomas Masarik and Leilani Pai.)

MS05-C-3: p-Modulus on orthodiagonal maps.
Pietro Poggi-Corradini, Kansas State University
Abstract: Orthodiagonal maps are a type of quadrangulation of plane domains that arise in numerical analysis in the context of Delaunay triangulations and Voronoi graphs, but also in the theory of circle packings, and have been studied previously in the literature, by Skopenkov, Werness, Gurel-Gurevich, Jerison and Nachmias, et al. We show that, for $p > 1$, discrete p-modulus on orthodiagonal maps converges to the analog p-modulus in the continuum, as the mesh size of the map tends to zero. This is joint work with Nathan Albin, Joan Lind, and Pekka Pankka.

MS05-D-1: Ehrhart polynomials of pseudo-reflexive polygons.
Tyrrell McAllister, University of Wyoming
Abstract: The problem of determining which polynomials are the Ehrhart polynomials of convex rational polytopes is open and unlikely to be resolved soon. Even just in dimension 2, this problem has been solved only for convex *lattice* polygons. However, not all Ehrhart polynomials come from lattice polytopes. More generally, a *pseudo-integral* polytope is a rational polytope P such that, as with lattice polytopes, the Ehrhart counting function $t \mapsto |tP \cap \mathbb{Z}|$ is a polynomial function of $t \in \mathbb{Z}_{\geq 1}$. In particular, P is *pseudo-reflexive* if its polar dual P^* is a lattice polytope. We extend the classification of Ehrhart polynomials to include the Ehrhart polynomials of all pseudo-reflexive triangles. Our approach generalizes techniques developed by Hille & Skarke (2002) to study lattice points in reflexive (lattice) polygons. These techniques exploit a particular presentation of the group $\mathrm{SL}_2(\mathbb{Z})$. In the case of pseudo-reflexive triangles, this approach reduces to studying the positive integer solutions to a certain nonlinear Diophantine equation.

MS05-D-2: Fulkerson duality for spanning trees and partitions.
Huy Truong, Kansas State University
Abstract: We describe Fulkerson duality for spanning trees, the proof uses a result of Nash and Tutte. Then, we study the modulus problem for this dual family. In particular, we introduce the notion of fair feasible partitions. Among those fair feasible partitions, there are two that are very important: they represent the strength and the maximum denseness of arbi-

trary graphs. They also give rise to two reversed deflation processes that identify a hierarchical structure of general graphs.

MS05-D-3 A Non-Markovian networked spreading model to assess the effectiveness of contact tracing.

Aram Vajdi, Kansas State University

Abstract: Compartmental spreading models traditionally assume exponential distributions for the states' sojourn times. This is in contrast to the data regarding the COVID-19 infectious and quarantine periods. To model COVID-19 spreading and assess the effectiveness of contact tracing we have developed a non-Markovian network-based spreading model that allows non-exponential distributions for the states' sojourn times. Using the mean-field approximation we have derived an expression for the epidemic threshold, which guaranties the exponential die-out of the infection in a population. We also applied the model to a real-world COVID-19 spreading and we found that contact tracing can be an effective outbreak mitigation measure by reducing the epidemic size by more than three-fold.

MS06-A-1: Nonintrusive reduced order modeling of convective Boussinesq flows.

Pedram Hashem Dabaghian, Oklahoma State University

Abstract: We formulate three nonintrusive methods and systematically explore their performance in terms of the ability to reconstruct the quantities of interest and their predictive capabilities. The methods include deterministic dynamic mode decomposition (DDMD), randomized dynamic mode decomposition (RDMD) and nonlinear proper orthogonal decomposition (NLPOD). The first two of which are based on the Koopman approximation theory while the third one is a coupled unsupervised and supervised machine learning approach. We apply these methods to a convection dominated fluid flow problem governed by the Boussinesq equations where a fluid with two different temperatures blend together in generating vast variety of vortex patterns evolving in time. We analyze the reconstruction results primarily at two different times. At the earlier time of the flow evolution where there is a relatively fewer fine scale vortical structures, our results indicate that both DMD approaches monotonically decrease errors as we increase the number of retained modes. At a later stage, however, DMD reconstruction error monotonically increases with increasing the number of modes. In contrast, we do not observe such monotonic behavior in the NLPOD approach. These observations can be related to the suboptimal selection of the relevant hyperparameters that intensify overfitting issues. Overall, our results indicate that, with a proper selection of number of retained modes and neural network architectures, all three approaches make predictions that are in a good agreement with the full order model solution.

MS06-A-2: Nonlinear proper orthogonal decomposition approach for modeling Rayleigh Bénard convection.

Saeed Akbari, Oklahoma State University

Abstract: In recent years, many nonintrusive reduced order modeling (NIROM) approaches have been developed in computing science where machine learning algorithms are employed to build inexpensive but accurate surrogate models. In this regard, we present a nonlinear proper orthogonal decomposition (POD) framework, denoted as NLPOD, to build a NIROM for spatio-temporal dynamical systems. POD is a mature NIROM method that projects the high dimensional data into a low-rank but linear manifold, which produces a considerable projection error for highly nonlinear convection-dominated flows. In this study, we aim at using an autoencoder (AE) neural network to break nonlinear correlations and reduce the projection error. We first utilize the POD to forge a linear latent space for modeling Rayleigh Bénard convection, and then, employ the AE to further compress POD temporal coef-

ficients through an unsupervised mapping. The long short-term memory technology is utilized to predict future states in the low-rank manifold.

MS06-A-3: Automatic Mixed-Precision (AMP) Computational Fluid Dynamics (CFD).
Mehrdad Zomorodiyan, Oklahoma State University
Abstract: Nvidia has developed half-precision (FP16) Tensor Cores that operate at 12 times the speed of their double-precision (FP64) cores. In popular deep-learning frameworks, you can already take advantage of Tensor Cores with AMP module and a few adjustments in your code to speed up the training process 2-6 times without losing accuracy for various models. In this work, I solve a simple CFD problem in two modes: single-precision (FP32) as our baseline and mixed-precision (FP16/FP32) as an attempt to leverage Tensor Cores for a faster run. The goal is to use FP16 for everything unless it affects the accuracy; Some operations/tensors must be FP32 as they hold too wide of a range of values to fit in FP16 without clipping. However, other variables can fit in FP16 with proper scaling. Like AMP, I would go over a range of values for a single scaler to fit an operation/tensor into FP16 range. If no such scaler is found that part should run on FP32.

MS06-A-4: Fluid flow modeling in elastic networking tubes. *Shafi Romeo, Oklahoma State University*
Abstract: In diagnosis of heart disease, such as atherosclerosis, arrhythmia or hyper-tension, blood flow rate and pressure are good indicators for the presence of blockage in the arteries. One-dimensional modelling of the human cardiovascular system based on the Pulsed Flow Equations (PFE) can be useful in predicting the dynamics of blood flow propagation through these arterial elastic tubes. Here, the consequent nonlinear coupled system of equations is solved by the finite-differences methods like Lax-Wendroff scheme and is then applied to an open 1D axisymmetric model arterial network of the human vascular system containing the largest 55 arteries. The critical effect of the nonlinear term in bifurcation points in the network have been solved with iterative schemes (e.g., Newton-Raphson method). Moreover, the various lumped parameter outflow boundary conditions for distal terminal points are also analyzed. The results indicate that the proposed numerical model can be used as an effective tool for investigating the dynamics of reduced-order models of flows in physiological systems and would be a good candidate for the macroscopic level of description of geometric multiscale of physiological systems.

MS07-A-1: A reinterpreted discrete fracture model for fracture and barrier networks.
Yang Yang, Michigan Technological University
Abstract: In this talk, we construct the reinterpreted discrete fracture model for flow simulation of fractured porous media containing flow blocking barriers on non-conforming meshes. The methodology of the approach is to modify the traditional Darcy's law into the hybrid-dimensional Darcy's law where fractures and barriers are represented as Dirac-delta functions contained in the permeability tensor and resistance tensor, respectively. This model is able to account for the influence of both highly conductive fractures and blocking barriers accurately on non-conforming meshes. The local discontinuous Galerkin (LDG) method is employed to accommodate the form of the hybrid-dimensional Darcy's law and the nature of the pressure/flux discontinuity. The performance of the model is demonstrated by several numerical tests.

MS07-A-2: Bound-preserving discontinuous Galerkin methods with second-order implicit pressure explicit concentration time marching for compressible miscible displacements in porous media.
Yue Kang, Michigan Technological University
Abstract: In this talk,we will introduce the

construction of the bound-preserving interior penalty discontinuous Galerkin(IPDG) methods with a second-order implicit pressure explicit concentration(SIPEC) time marching for the coupled system of two-component compressible miscible displacements. The SIPEC method is a crucial innovation based on the traditional second-order strong-stability-preserving Runge-Kutta(SSP-RK2) method. The main idea is to treat the pressure equation implicitly and the concentration equation explicitly. However, this treatment would result in a first-order accurate scheme. We can propose a correction stage to compensate for the second-order accuracy in each time step. Numerical experiments will be given to demonstrate that the proposed scheme can reduce the computational cost significantly compared with explicit schemes.

MS07-A-3: Bound-preserving discontinuous Galerkin Methods with Patankar time discretization for chemical reacting flows.

Fangyao Zhu, Michigan Technological University

Abstract: I will talk about bound-preserving DG methods for chemical reactive flows. For this problem we must ensure the density and internal energy are kept positive, and the mass fraction of each species is between 0 and 1. We apply the bound-preserving technique to the DG methods. Though traditional positivity-preserving techniques can successfully yield positive density, internal energy, and mass fractions, it may not enforce the upper bound 1 of the mass fractions. To solve this problem, we need to make sure the numerical fluxes in the equations of the mass fractions are consistent with that in the equation of the density; choose conservative time integrations such that the summation of the mass fractions is preserved. With the above two conditions, the positive mass fractions have summation 1, then they are all between 0 and 1. For time discretization, we apply the modified Runge-Kutta/multi- step Patankar methods. Such methods can handle stiff sources with relatively large time steps, preserve the positivity of the target variables, and keep the summation of the mass fractions to be 1. To evolve in time, suitable slope limiters can be applied to enforce the positivity of the solutions. Numerical examples will be shown.

MS07-A-4: Discontinuous Galerkin methods for network patterning phase-field models.

Yuan Liu, Wichita State University

Abstract: In this talk, we will discuss a class of discontinuous Galerkin methods under the scalar auxiliary variable framework (SAV-DG) to solve a biological patterning model in the form of parabolic-elliptic PDE system. In particular, mixed-type discontinuous Galerkin approximations are used for the spatial discretization, aiming to achieve the balance the high resolution and computational cost. Second and third order backward differentiation formula are considered under SAV framework for energy stability. Numerical experiments are provided to show the effectiveness of the fully discrete schemes and the governing factors of patterning formation.

MS07-B-1: Dual-Wind Discontinuous Galerkin Methods for Fully Nonlinear Second Order PDEs.

Thomas Lewis, The University of North Carolina at Greensboro

Abstract: We will introduce a class of dual-wind discontinuous Galerkin (DG) methods for approximating viscosity solutions of fully nonlinear second order elliptic partial differential equations. The methods will be motivated using the DG interior calculus to define discrete upwind and downwind gradient operators as well as symmetric operators for directly discretizing the Hessian operator in the PDE. Admissibility and stability results will be discussed. By using the dual-wind methodology, the methods are stable without requiring a jump penalization term. The DG methods are a natural extension of narrow-stencil, generalized monotone finite difference methods for approximating viscosity solutions of fully nonlinear PDEs.

MS07-B-2: Dual-Wind Discontinuous Galerkin Methods for Time-Dependent Hamilton Jacobi Equation.
Aaron Rapp, University of the Virgin Islands
Abstract: This talk will discuss a new family of dual-wind discontinuous Galerkin (DG) methods for Hamilton-Jacobi equations (HJEs) and their vanishing viscosity regularizations. The proposed methods, which are non-monotone, utilize a dual-winding methodology and a new skew-symmetric DG derivative operator that, when combined, eliminate the need for choosing indeterminable penalty constants. Admissibility and stability are established for the proposed dual-wind DG methods on stationary HJEs. The stability results for stationary HJEs are shown to hold independent of the scaling of the stabilizer allowing for choices that go beyond the Godunov barrier for monotone schemes, and are believed to still hold for time-dependent HJEs. Many numerical experiments are provided to gauge the performance of the new DWDG methods with time stepping methods on time-dependent HJEs.

MS07-B-3: Superconvergent interpolatory HDG methods for nonlinear reaction diffusion equations II: HHO-inspired methods. *Yangwen Zhang, Carnegie Mellon University*
Abstract: In [J. Sci. Comput., 81:2188-2212, 2019], we considered a superconvergent hybridizable discontinuous Galerkin (HDG) method, defined on simplicial meshes, for scalar reaction-diffusion equations and showed how to define an interpolatory version which maintained its convergence properties. The interpolatory approach uses a locally postprocessed approximate solution to evaluate the nonlinear term, and assembles all HDG matrices once before the time intergration leading to a reduction in computational cost. The resulting method displays a superconvergent rate for the solution for polynomial degree k>=1. In this work, we take advantage of the link found between the HDG and the hybrid high-order (HHO) methods, in [ESAIM Math. Model. Numer. Anal., 50(3):635650, 2016] and extend this idea to the new, HHO-inspired HDG methods, defined on meshes made of general polyhedral elements, uncovered therein. We prove that the resulting interpolatory HDG methods converge at the same rate as for the linear elliptic problems. Hence, we obtain superconvergent methods for k>=0 by some methods. We present numerical results to illustrate the convergence theory.

MS07-B-4: A generalized framework for direct discontinuous Galerkin methods.
Mustafa Danis, Iowa State University
Abstract: In this talk, we present a unified, generalized framework for the direct discontinuous Galerkin (DDG) methods. Unlike the original DDG methods, the antiderivative of the nonlinear diffusion matrix is not needed in the new framework. This leads to a considerable simplification in the numerical flux formulation such that the standard DDG numerical flux for the heat equation can be used for general nonlinear diffusion equations without further modifications. We also present the nonlinear stability analysis of the new DDG methods and their extension to the more general system of conservation laws. We also consider the application of the new DDG methods to various nonlinear diffusion equations, including the compressible Navier-Stokes in subsonic and hypersonic flow settings. In the numerical experiments, we demonstrate that the interface correction and symmetric DDG versions achieve optimal convergence and are superior to the nonsymmetric DDG. Singular or blow-up solutions are also well captured with the new DDG methods.

MS07-C-1: A Local Macroscopic Conservative (LoMaC) low rank tensor method with the discontinuous Galerkin method for the Vlasov dynamics. *Wei Guo, Texas Tech University.*
Abstract: In this talk, we present a novel Local Macroscopic Conservative (LoMaC) low rank tensor method with discontinuous Galerkin (DG) discretization for the physical and phase

spaces for simulating the Vlasov-Poisson (VP) system. The LoMaC property refers to the exact local conservation of macroscopic mass, momentum and energy at the discrete level. The LoMaC low rank tensor algorithm (recently developed in arXiv:2207.00518) simultaneously evolves the macroscopic conservation laws of mass, momentum and energy using the kinetic flux vector splitting; then the LoMaC property is realized by projecting the low rank kinetic solution onto a subspace that shares the same macroscopic observables. This work is a generalization of our previous development, but with DG discretization to take advantage of its compactness and flexibility in handling boundary conditions and its superior accuracy in the long term. The algorithm is developed in a similar fashion as that for a finite difference scheme, by observing that the DG method can be viewed equivalently in a nodal fashion. With the nodal DG method, assuming a tensorized computational grid, one will be able to (1) derive differentiation matrices for different nodal points based on a DG upwind discretization of transport terms, and (2) define a weighted inner product space based on the nodal DG grid points. The algorithm can be extended to the high dimensional problems by hierarchical Tucker decomposition of solution tensors and a corresponding conservative projection algorithm. In a similar spirit, the algorithm can be extended to DG methods on nodal points of an unstructured mesh, or to other types of discretization, e.g. the spectral method in velocity direction. Extensive numerical results are performed to showcase the efficacy of the method.

MS07-C-2: Locally-implicit discontinuous Galerkin schemes for the kinetic Boltzmann-BGK system that are arbitrarily high-order and asymptotic-preserving.

James Rossmanith, Iowa State University

Abstract: The kinetic Boltzmann equation with the Bhatnagar-Gross-Krook (BGK) collision operator allows for the simulation of gas dynamics over a wide range of Knudsen numbers with a simplified collision operator. Efficient numerical methods for Boltzmann-BGK should be asymptotic-preserving, which allows the numerical method to be stable at fixed mesh parameters for any value of the Knudsen number, including in the fluid (very small Knudsen numbers), slip flow (small Knudsen numbers), transition (moderate Knudsen numbers), and free molecular flow (large Knudsen numbers) regimes. In this work we develop a novel approach for solving the Boltzmann-BGK equation for achieving both arbitrary high-order and the asymptotic-preserving property. The proposed method is a locally-implicit discontinuous Galerkin (LIDG) scheme with careful modification in both the prediction and correction steps to achieve the asymptotic-preserving property. Some key advantages of the proposed schemes are: (1) no splitting between macroscale and microscale components of the distribution function is required; (2) only a single unified time-discretization is required; and (3) arbitrary high-order in both space and time can be achieved simply by increasing the spatial polynomial order in each element. Several numerical examples are shown to demonstrate the effectiveness of the proposed numerical scheme.

MS07-C-3: Hybridizable discontinuous Galerkin methods for coupled Stokes-Biot problems.

Jeonghun Lee, Baylor University

Abstract: In this work we develop hybridizable discontinuous Galerkin (HDG) methods for problems such that the Stokes equations and the Biot consolidation equations are coupled with interface. In our HDG methods the compressibilities of fluid and poroelastic matrix, and the fluid mass in poroelastic domain are strongly conservative. We show a priori error estimates of numerical solutions which are robust in the sense that the constants of error bounds are uniformly bounded for nearly incompressible materials and do not grow exponentially in time.

This is a joint work with Aycil Cesmelioglu at Oakland University and Sander Rhebergen at University of Waterloo.

MS07-C-4: A conservative and positivity-preserving implicit-explicit approach for compressible fluid flow simulation.

Chen Liu, Purdue University

Abstract: In many demanding gas dynamics applications such as hypersonic ow simulation, the compressible Navier-Stokes (NS) equations form one of the most popular and important models. In this talk, we proposed an implicit-explicit approach for solving compressible NS system. We utilize operator splitting technique separates the compressible NS equations into a hyperbolic sub-problem and a parabolic sub-problem. The discontinuous Galerkin discretization of hyperbolic sub-problem is invariant domain preserving. The positivity-preserving property for the parabolic sub-problem is constructed via the monotonicity of the system matrix. Our proposed algorithm enjoys the property that the CFL condition is independent of the Reynolds number. Therefore, they are highly preferred and suitable for simulating realistic physical and engineering problems.

MS08-A-1: A free boundary inviscid model of flow-structure interaction.

Igor Kukavica, University of Southern California

Abstract: We address a system describing interaction of an incompressible inviscid fluid, modeled by the Euler equations, and an elastic plate, represented by a fourth-order hyperbolic PDE. We provide a priori estimates for the existence of solutions with a sharp regularity for the Euler initial data and construct solutions with the regularity construct solutions with the fluid initial data in H^r, where $r \geq 3$. The result is joint with Amjad Tuffaha.

MS08-A-2: Inertial manifolds for regularized Navier-Stokes equations.

Yanqiu Guo, Florida International University

Abstract: For a large class of dissipative evolution equations, long-time behavior of solutions possesses a resemblance of the behavior of finite-dimensional systems. In order to capture such phenomena, Foias, Sell, and Temam introduced the concept of inertial manifolds. An inertial manifold of an evolution equation is a finite-dimensional Lipschitz invariant manifold attracting exponentially all the trajectories of the dynamical system. The existence of an inertial manifold for an infinite-dimensional evolution equation represents the best analytical form of reduction of an infinite system to a finite-dimensional one. A number of dissipative PDEs possess inertial manifolds, such as the nonlinear reaction-diffusion equation, the Kuramoto-Sivashinsky equation, and the Cahn-Hilliard equation. But, whether the Navier-Stokes equations possess an inertial manifold is unknown. In this presentation, I will talk about the existence of inertial manifolds for some regularized Navier-Stokes equations, and discuss its connection with large gaps between sums of squares in number theory.

MS08-A-3: Relaxation-based parameter recovery from partial observations for hydrodynamic systems.

Vincent R. Martinez, City University of New York

Abstract: This talk will discuss a dynamical approach for recovering unknown parameters of hydrodynamic equations such as damping coefficients or external forcing from partial observations of the underlying system. The method is based on a feedback-control scheme which incorporates observations as an exogenous term and drives the system to synchronize with the observations. This can be used to devise algorithms that systematically filters the model errors resulting from the unknown parameters. Under suitable assumptions on the observational density and tuning parameters of the algorithm, convergence of the algorithm to the true value of the parameters can be guaranteed.

MS08-A-4: Error estimates for the physical in-

formed neural networks (PINN) approximating the primitive equations. *Quyuan Lin, University of California, Santa Barbra*

Abstract: Large scale dynamics of the oceans and the atmosphere are governed by the primitive equations (PEs). Due to the nonlinearity and nonlocality, the numerical study of the PEs is in general a hard task. Neural network has been shown to be a promising machine learning tool to tackle this challenge. In this talk, I will introduce the physical informed neural networks (PINNs) that approximate the solutions to the PEs with either full viscosity and diffusivity or only the horizontal ones, and establish the error estimates. In particular, I will show the existence of two layer tanh PINNs such that the corresponding training error is arbitrarily small by taking the width of PINNs to be wide enough, and the error between the true solution and the approximation can be made arbitrarily small provided that the training error is small enough and the sample set is large enough. Furthermore, the results are on the higher order (in spatial Sobolev norm) error estimates, which improves some previously known results for PINNs concerning only the L^2 error.

MS08-B-1: Intermittency in turbulence and the 3D NSE regularity problem.

Aseel Farhat, Florida State University

Abstract: We describe several aspects of an analytic/geometric framework for the three-dimensional Navier-Stokes regularity problem, which is directly inspired by the morphology of the regions of intense vorticity/velocity gradients observed in computational simulations of three-dimensional turbulence. Among these, we present a proof that the hyper-dissipative 3D Navier-Stokes are regular within an appropriate functional setting incorporating the intermittency in turbulent regimes, with any power of the Laplacian greater than 1.

MS08-B-2: On stochastic partial differential equations with a Ladyzenskaya-Smagorinsky type nonlinearity.

Krutika Tawri, University of California, Berkeley

Abstract: The theory of monotone operators plays a central role in many areas of nonlinear analysis. Monotone operators often appear in fluid dynamics, for example the p-Laplacian appears in a non-Newtonian variant of the Navier-Stokes equations modeled by Ladyzenskaya or in the Smagorinsky model of turbulence. In this talk, we will discuss global existence results of both martingale and pathwise solutions of stochastic equations with a monotone operator, of the Ladyzenskaya-Smagorinsky type, driven by a general Lévy noise. The classical approach based on using directly the Galerkin approximation is not valid. In this talk we will discuss how one can approximate a monotone operator by a family of monotone operators acting in a Hilbert space, so as to recover certain useful properties of the orthogonal projectors and overcome the challenges faced while applying the Galerkin scheme.

MS08-B-3: Particle trajectories of large scale oceanic flow.

Ning Ju, Oklahoma State university

Abstract: I will present my recent research on global existence and uniqueness of particle trajectories for vector field of viscous Primitive Equations for large scale oceanic flow.

MS08-B-4: Ice sheets melting as an obstacle problem.

Paolo Piersanti, Indiana University

Abstract: In this talk, which is the result of a joint work of the speaker with Roger Temam (IU), we formulate a model describing the evolution of thickness of a grounded shallow ice sheet. The thickness of the ice sheet is constrained to be nonnegative, rendering the problem under consideration an obstacle problem. A rigorous analysis shows that the model is thus governed by a set of variational inequalities that involve nonlinearities in the time derivative and in the elliptic term, and that it admits solutions, whose existence is established by means of a semi-discrete scheme and the penalty method.

MS09-A-1: A moving mesh finite element method for Bernoulli free boundary problems.

Weizhang Huang, University of Kansas

Abstract: A moving mesh finite element method is presented for the numerical solution of Bernoulli free boundary problems. The method first formulates a Bernoulli free boundary problem into a moving boundary problem with explicitly defined velocity for the moving boundary and then solves the latter with a moving mesh PDE method. Examples for both exterior and interior Bernoulli problems will be presented.

MS09-A-2: Fast and efficient numerical methods for a class of PDEs with free boundaries.

Xinfeng Liu, University of South Carolina

Abstract: For reaction-diffusion equations in irregular domain with moving boundaries, the numerical stability constraints from the reaction and diffusion terms often require very restricted time step size, while complex geometries may lead to difficulties in accuracy when discretizing the high-order derivatives on grid points near the boundary. It is very challenging to design numerical methods that can efficiently and accurately handle both difficulties. Applying an implicit scheme may be able to remove the stability constraints on the time step, however, it usually requires solving a large global system of nonlinear equations for each time step, and the computational cost could be significant. Integration factor (IF) or exponential differencing time (ETD) methods are one of the popular methods for temporal partial differential equations (PDEs) among many other methods. In our paper, we couple ETD methods with an embedded boundary method to solve a system of reaction-diffusion equations with complex geometries. In particular, we rewrite all ETD schemes into a linear combination of specific ϕ-functions and apply one start-of-the-art algorithm to compute the matrix-vector multiplications, which offers significant computational advantages with adaptive Krylov subspaces. In addition, we extend this method by incorporating the level set method to solve the free boundary problem. The accuracy, stability, and efficiency of the developed method are demonstrated by numerical examples.

MS09-A-3: Analysis of weak Galerkin Finite Element with Supercloseness.

Saqib Hussain, Texas A&M International University

Abstract: In [1], the computational performance of various weak Galerkin finite element in terms of stability, convergence, and supercloseness in explored and numerical results are listed in 31 tables. Some of the phenomena can be explained by the existing theoretical results and the others are to be explained. The main purpose of this paper is to provide a unified theoretical foundation to a class of WG schemes, where elements are used for solving the second order elliptic equations on a triangle grid in 2D. With this unified treatment, all of the existing results become special cases. The theoretical conclusions are corroborated by a number of numerical examples.

[1]. J. Wang, X. Ye, and S. Zhang, "Numerical investigation on weak Galerkin finite elements," International Journal of Numerical Analysis and Modeling. 17 (4) (2020), 517 – 531.

MS09-A-4: An asymptotic Green's function method for vector wave equations.

Jay Mayfield, University of Arizona

Abstract: We develop an asymptotic Green's function method to numerically solve a vector wave equation. The wavefield is split into its forward and backward propagating parts that can be propagated and presented as an integral with the dyadic Green's function following Huygens' principle. The dyadic Green's function is approximated asymptotically with geometric optics approximations, where its phase and amplitude are determined by an eikonal equation and a recurrent system of transport equations, respectively. The solutions to the

eikonal and transport equations are approximated analytically by short-time Taylor series expansions, which leads to a short-time propagator for the wavefield. In order to efficiently evaluate the short-time propagator, its lowrank structure is explored via a randomized QR factorization such that the approximated integral can be computed by fast Fourier transforms. The perfectly matched layer technique is further incorporated to facilitate the computation on a bounded domain of interest. The method has complexity $O(t_\varepsilon N \log N)$ per time step, with N the number of spatial points in the mesh and ε the low rank for a predetermined accuracy tolerance $\varepsilon > 0$. Numerical experiments are presented to demonstrate the effectiveness of the method.

MS09-B-1: Phase field modeling and computation of vesicle growth and shrinkage.
Shuwang Li, Illinois Institute of Technology
Abstract: We study a phase field model for vesicle growth or shrinkage based on osmotic pressure that arises due to a chemical potential gradient. The model consists of an Allen-Cahn-like equation, which describes the phase field evolution, a Cahn-Hilliard-like equation, which simulates the fluid concentration, and a Stokes-like equation, which models the fluid flow. It is mass conserved and surface area constrained during the membrane deformation. Conditions for vesicle growth or shrinkage are analyzed via the common tangent construction. The numerical computing is in two-dimensional space using a nonlinear multigrid method consisting of a FAS method for the PDE system. Convergence test suggests that the global error is of first order in time and of second order in space. Numerical results are demonstrated under no flux boundary conditions and with boundary-driven shear flow respectively.

MS09-B-2: A stable sampling method for imaging of photonic crystals.
Dinh-Liem Nguyen, Kansas State University
Abstract: We consider the inverse problem of determining the geometry of periodic scattering media from scattered field data. In this talk, we will discuss a sampling type method for solving the inverse problem. This sampling method has a new imaging functional that is simple and easy to implement. The theoretical analysis of the imaging functional is analyzed. Our numerical study shows that this sampling method is more stable than the factorization method and may perform better than the orthogonality sampling method in terms of accuracy. This is joint work with Kale Stahl and Trung Truong.

MS09-B-3: Pressure Robust Scheme for Incompressible Flow.
Lin Mu, University of Georgia
Abstract: In this talk, we shall introduce the recent development regarding the pressure robust finite element method (FEM) for solving incompressible flow. In this talk, we shall discuss the new divergence preserving schemes in designing the robust numerical schemes for incompressible fluid simulation. Due to the viscosity independence in the velocity approximation, our scheme is robust with small viscosity and/or large permeability, which tackles the crucial computational challenges in fluid simulation. We shall discuss the details in the implementation and theoretical analysis. Several numerical experiments will be tested to validate the theoretical conclusion.

MS09-B-4: Dynamic behavior for a gradient algorithm with energy and momentum.
Xuping Tian, Iowa State University
Abstract: We investigate a novel gradient algorithm, using both energy and momentum (called AGEM), for solving general non-convex optimization problems. The solution properties of the AGEM algorithm, including uniformly boundedness and convergence to critical points, are examined. The dynamic behavior is studied through analysis of a high-resolution ODE system. Such ODE system is nonlinear and obtained by taking the limit of the discrete scheme while keeping the momen-

tum effect through a rescale of the momentum parameter. In particular, we show global well-posedness of the ODE system, time-asymptotic convergence of solution trajectories, and further establish a linear convergence rate for objective functions satisfying the Polyak-Lojasiewicz condition.

MS10-A-1: Adaptive multiresolution sparse grid DG: algorithms and its open source C++ package.

Juntao Huang, Texas Tech University

Abstract: In this talk, we present our work on adaptive multiresolution sparse grid DG method and its open source C++ package. This method is constructed based on multiwavelets of various kinds, and are demonstrated to be effective in adaptive calculations, particularly for high dimensional applications. Numerical results for Hamilton-Jacobi equations, nonlinear Schrodinger equations and wave equations will be discussed. We will also illustrate the main structure and feature of the open source C++ package.

MS10-A-2: Image reconstruction using an adaptive and accelerated iterative gradient type method for Electrical Impedance Tomography problems.

Sanwar Uddin Ahmad, Virginia State University

Abstract: Electrical impedance tomography (EIT) is an imaging modality that determines the internal conductivity and permittivity distribution based on the voltage measurements made on an object's surface when currents are applied. Due to its non-invasiveness, non-ionizing characteristics and cost effectiveness, EIT is gaining a lot of attention in recent years. Gradient type methods have been extensively studied and used for solving the EIT problem. However, these methods suffer greatly due to high computational cost at every iteration. In this presentation, we discuss the implementation of an adaptive iterative gradient type method that accelerates the convergence thus reducing the computing cost.

MS10-A-3: Unconditionally stable numerical methods for Cahn-Hilliard-Navier-Stokes-Darcy system with different densities and viscosities.

Xiaoming He, Missouri University of Science and Technology

Abstract: In this presentation, we consider the numerical modeling and simulation via the phase field approach for coupled two-phase free flow and two-phase porous media flow of different densities and viscosities. The model consists of the Cahn-Hilliard-Navier-Stokes equations in the free flow region and the Cahn-Hilliard-Darcy equations in porous media that are coupled by several domain interface conditions. It is showed that the coupled model satisfies an energy law. Then we first propose a coupled unconditionally stable finite element method for solving this model and analyze the energy stability for this method. Furthermore, based on the ideas of pressure stabilization and artificial compressibility, we propose an unconditionally stable time stepping method that decouples the computation of the phase field variable, the velocity and pressure of free flow, the velocity and pressure of porous media, hence significantly reduces the computational cost. The energy stability of this decoupled scheme with the finite element spatial discretization is rigorously established. We verify numerically that our schemes are convergent and energy-law preserving. Numerical experiments are also performed to illustrate the features of two-phase flows in the coupled free flow and porous media setting.

MS10-A-4: Fast Numerical Solvers for Subdiffusion Problems with Spatial Interfaces.

Jiangguo (James) Liu, Colorado State University

Abstract: Subdiffusion may happen in compartments, e.g., different areas in cell cytoplasm. This leads to subdiffusion problems with spatial interfaces. For temporal discretization, we employ L1 approximation and then a fast evaluation algorithm for Caputo derivative. For spatial discretization, we consider finite volume or

similar methods. Based on these, we develop fast numerical solvers for subdiffusion problems with spatial interfaces. Numerical experiments along with brief analysis will be presented to demonstrate the accuracy and efficiency of these new solvers. This is a joint work with Yonghai Li and Boyang Yu at Jilin University (China).

MS10-B-1: A Spatially Variant Fractional Laplacian Model: Theory and Applications.
Carlos N. Rautenberg, George Mason University
Abstract: We establish a variational definition of the spatially variant fractional Laplacian and determine existence and uniqueness of solutions to the associated elliptic equation. The analysis hinges on the use of non-standard Sobolev spaces with non-Muckenhoupt weights. We further prove increased regularity results for the solution to the elliptic problem and present the use of the fractional operator as a regularizer in imaging applications. The latter leads to the optimal selection of the fractional order in image reconstruction. We finalize the talk with test examples and future research directions.

MS10-B-2: A new CDG method for the Stokes equations with order two superconvergence.
Xiu Ye, University of Arkansas at Little Rock
Abstract: A new conforming discontinuous Galerkin (CDG) finite element method is introduced for solving the Stokes equations. The CDG method gets its name by combining good features of both conforming finite element method and discontinuous finite element method. It has the flexibility of using discontinuous approximation and simplicity in formulation of the conforming finite element method. In this method, discontinuous P_k element is used for velocity and continuous P_k+1 element is used for pressure. This new CDG method is not only stabilizer-free but also has the convergence rate two order higher than the optimal order for velocity. Numerical tests are provided. This is a joint work with Shangyou Zhang at University of Delaware.

MS10-B-3: High-order IPDG Method for Anisotropic Diffusion Equations.
Lin Mu, University of Georgia
Abstract: In this talk, we present an interior penalty discontinuous Galerkin finite element scheme for solving diffusion problems with strong anisotropy arising in magnetized plasmas for fusion applications. In such application, the anisotropy is introduced by strong magnetic fields. The heat conduction along the parallel field direction may at the order 10^6 (boundary region) to 10^{12} (core region) larger than that along perpendicular direction. Due to the high anisotropy ratio, the errors in the parallel may significantly affect the error in the perpendicular direction and thus cause numerical pollution. One possible way is to perform the simulation on the aligned mesh. However, for our interested far scrape off layer region, the filed aligned mesh is almost impossible to use. In order to handle the high geometry fidelity and relax the burden in mesh generation, we propose the high order discontinuous Galerkin methods on the non-aligned mesh together with the efficient linear solver of auxiliary space preconditioner. We demonstrate the accuracy produced by the high-order scheme and efficiency in the preconditioning technique, which is robust to the mesh size and anisotropy of the problem. Several numerical tests are provided to validate the proposed algorithm.

MS10-B-4: A stable enriched Galerkin method for Brinkman problem.
Seulip Lee, University of Georgia
Abstract: In this work, we present a stable enriched Galerkin (EG) method for the Brinkman equations with small viscosity. The discrete inf-sup condition for numerical velocity and pressure has been successfully achieved by recent work on new EG methods for the Stokes equations whose numerical velocity is a discontinuous piecewise linear function. We extend the EG methods to the Brinkman equations and apply a velocity reconstruction operator in the discretization to obtain uniform energy errors as

viscosity approaches zero. Numerical analysis shows that our EG method guarantees the optimal convergence rates, and numerical experiments validate the theoretical results.

MS10-C-1: A finite element modeling of two-phase variable density surface fluids.
Maxim Olshanskii, University of Houston
Abstract: This talk reviews a continuum-based model for the process of phase separation in multicomponent lipid membranes exhibiting lateral fluidity. We further introduce a finite element method for solving surface fluid and surface phase-field equations. The models and methods are combined to deliver a finite element method for a thermodynamically consistent phase-field model for surface two-phase fluid with variable density and viscosity. A stable linear splitting approach is introduced and available numerical analysis results are presented. We finally discuss successes and failures of the model to reproduce in vitro experiments with multicomponent vesicles of different lipid compositions.

MS10-C-2: A Stable Immersed Discontinuous Galerkin Method for Wave Propagation in Heterogeneous Acoustic Elastic Media.
Slimane Adjerid, Virginia Tech
Abstract: Immersed finite element methods are applied to solve interface problems on interface-independent meshes that allow interface elements that are cut by the interface. Here we propose an immersed discontinuous Galerkin (DG) method to solve acoustic-elastic interface problems on Cartesian meshes with interface elements that consist of a combination of fluids and solids separated by interfaces. These problems are modeled by different PDE systems that are coupled by jump conditions across the interfaces. We present a stable weak DG formulation combined with a piecewise polynomial immersed finite element (IFE) space. The IFE space is such that on each interface element we use a piecewise polynomial space satisfying the interface jump conditions while on non-interface elements we use standard polynomial spaces. We discuss the stability of the method and a time-marching algorithm. We conclude with several numerical examples showing the performance of our method by solving problems of wave propagation in heterogeneous elastic acoustic media.

MS10-C-3: A Cartesian FMM-accelerated Galerkin boundary integral Poisson-Boltzmann solver.
Weihua Geng, Southern Methodist University
Abstract: The Poisson-Boltzmann model is an effective and popular approach for modeling solvated biomolecules in continuum solvent with dissolved electrolytes. In this paper, we report our recent work in developing a Galerkin boundary integral method for solving the linear Poisson-Boltzmann (PB) equation. The solver has combined advantages in accuracy, efficiency, and memory usageas it applies a well-posed boundary integral formulation to circumvent many numerical difficulties associated with the PB equation and uses an O(N) Cartesian Fast Multipole Method (FMM) to accelerate the GMRES iteration. In addition, special numerical treatments such as adaptive FMM order, block diagonal preconditioners, Galerkin discretization, and Duffy's transformation are combined to improve the performance of the solver, which is validated on benchmark Kirkwood's sphere and a series of testing proteins.

MS10-C-4: A fast method for evaluating volume potentials in the Galerkin boundary element method.
Johannes Tausch, Southern Methodist University
Abstract: We discuss a new algorithm for volume potentials that arise in boundary element methods for elliptic PDEs. The approach is to apply a modified fast multipole method for a boundary concentrated volume mesh. If h is the meshwidth of the boundary, then the volume is discretized using nearly $O(h^{-2})$ degrees of freedom, and the algorithm computes poten-

tials in nearly $O(h^{-2})$ complexity. Here nearly means that logarithmic terms of h may appear. Thus the complexity of volume potentials calculations is of the same asymptotic order as boundary potentials. For sources and potentials with sufficient regularity the parameters of the algorithm can be designed such that the error of the approximated potential converges at any specified rate $O(h^p)$. The accuracy and effectiveness of the proposed algorithms are demonstrated for potentials of the Poisson equation in three dimensions.

MS11-A-1: Network modeling and simulation of infectious diseases: new epidemic thresholds for the SIR-network model. *Haridas K. Das, Oklahoma State University*

Abstract: We study the SIR-network model proposed by Stolerman, Coombs, and Boatto in 2015 that established flux-driven epidemic control by analyzing epidemic thresholds for fully connected networks, where a single node has a different infection rate. Here we extend this result for a larger class of networks, establishing new epidemic thresholds using the basic reproduction number R0 obtained from the classic next-generation matrix. First, we look at star-shaped networks, where all nodes connect to the center with different transmission rates than the others and exhibit the same epidemic thresholds as the fully connected networks. Next, we find the same epidemic thresholds for star-background networks, in which all nodes except the center link with a different flux. Inspired by this preliminary result, we propose a class of networks headed by star-shaped networks that reveal the same epidemic threshold given by explicit formulas as fully connected networks. We also analyze cycle-shaped networks exhibit a different nature from such flux-driven epidemic control. Finally, we present numerical simulations showing a convergence of the epidemic threshold of cycle-shaped networks. We also numerically integrate our system to gain intuition where the theoretical estimates are challenging and explore the temporal epidemic dynamical behavior for the class of networks.

MS11-A-2: Complex dynamics of predator-prey systems with generalized Holling type IV functional response and Allee effects in prey.
Chanaka Kottegoda, Oklahoma State University

Abstract: This talk is devoted to high codimension bifurcations of a predator-prey system with generalized Holling type response function and Allee effects in prey. The system shows rich dynamics such as nilpotent cusp singularity of order 3, degenerate Hopf bifurcation of codimension 3 and Bogdanov-Takens bifurcation of order 3. Moreover, a new unfolding of nilpotent saddle of codimension 3 with a fixed invariant line is discovered and fully developed. Our work extends the existing results of predator-prey systems with Allee effects. The bifurcation analysis and diagram allow us to give biological interpretations.

MS11-A-3: Data-driven techniques for dynamical systems with applications to neuroscience.
Khitam Zuhair Bader Aqel, University of Texas at Arlington.

Abstract: The neuroscience community is keen to understand more about Local Field Potential(LFP) signal alterations in the murine brain's pain circuits in both the absence and presence of anesthesia. The purpose of the study was to compare the LFP signals' complexity in the anesthetized and awake rats using data-driven techniques. We use three data-driven methods: Eigensystem Realization Algorithm(ERA), Sparse Identification of Nonlinear Dynamics(SINDy), and Neural Networks(NNs), to extract coherent structures from the physiological time-series data. Data-driven approaches use the measured LFP signals to generate modal characteristics of the system. We apply these data-driven techniques to reconstruct signals recorded from four brain regions of two groups of rats: (i) freely moving and (ii) anesthetized. We will compare the reconstructions given by each method in different phases of the

experiment and discuss their advantages and pitfalls.

MS11-A-4: Analysis of goal, feedback and rewards on sustained attention via machine learning.

Nethali Fernando, University of Texas at Arlington

Abstract: Sustaining attention is a notoriously difficult task as shown in a recent experiment where reaction times (RTs) and pupillometry data were recorded from 350 subjects in a 30-minute vigilance task. Subjects were also presented with different types of goal, feedback, and reward. In this study, we revisit this experimental data and solve three families of machine learning problems: (i) RT-regression problems, to predict subjects' RTs using all available data, (ii) RT-classification problems, to classify responses more broadly as attentive, semi-attentive, and inattentive, and (iii) to predict the subjects' experimental conditions from physiological data. After establishing that regressing RTs is in general a difficult task, we achieve better results classifying them in broader categories. We also successfully disambiguate subjects who received goals and rewards from those who did not. Finally, we quantify changes in accuracy when coarser features (averaged throughout multiple trials) are used. Interestingly, the machine learning pipeline selects different features depending on their resolution, suggesting that predictive physiological features are also resolution specific.

MS12-A-1: Convergent finite difference methods with higher order local truncation errors for stationary Hamilton-Jacobi equations.

Thomas Lewis, The University of North Carolina at Greensboro

Abstract: A new non-monotone finite difference (FD) method for approximating viscosity solutions of stationary Hamilton-Jacobi problems with Dirichlet boundary conditions will be discussed. The new FD method has local truncation errors that are above the first order Godunov barrier for monotone methods. The method uses a stabilization term called a numerical moment to ensure that the proposed scheme is admissible, stable, and convergent. Numerical tests will be provided that compare the accuracy of the proposed scheme to that of the Lax-Friedrich's method.

MS12-A-2: Continuous data assimilation and long-time accuracy in a C0-IP Method for the Cahn-Hilliard Equation.

Amanda Diegel, Mississippi State University

Abstract: We discuss a numerical approximation method for the Cahn-Hilliard equation that incorporates continuous data assimilation in order to achieve long time accuracy. The method uses a C0 interior penalty spatial discretization of the fourth order Cahn-Hilliard equation, together with a semi-implicit temporal discretization. The method is long time stable and long time accurate, for arbitrarily inaccurate initial conditions, provided enough data measurements are incorporated into the simulation. Numerical experiments illustrate the effectiveness of the method on a benchmark test problem.

MS12-A-3: SAV Ensemble Algorithms for the magnetohydrodynamics equations.

John Carter, Missouri University of Science and Technology

Abstract: We develop two linear, second-order accurate, unconditionally stable ensemble methods with shared coefficient matrix across different realizations and time steps for the magnetohydrodynamics equations. The viscous terms are treated by a standard perturbative discretization. We employ the Generalized Positive Auxiliary Variable method to discretize nonlinear terms, resulting in linearity of the algebra equation for the scalar variable, provable positivity of the scalar variable, and flexibility in handling complex boundary conditions. Artificial viscosity stabilization that modifies the kinetic energy is introduced to improve accuracy of the GPAV ensemble methods.

MS12-A-4: Runge-Kutta discontinuous

Galerkin methods with compact stencils for hyperbolic conservation laws.
Qifan Chen, The Ohio State University
Abstract: In this talk, we develop a new type of Runge-Kutta (RK) discontinuous Galerkin (DG) methods for solving hyperbolic conservation laws. Compared with the standard RKDG methods, the new methods feature improved compactness and allow simple boundary treatment. The convergence to weak solution and the accuracy of the numerical solutions are studied. Their connections with the Lax-Wendroff DG schemes and the ADER DG schemes are also investigated. Numerical examples are given to confirm that the new RKDG schemes are as accurate as standard RKDG methods, while being more compact and cost-effective, for a wide range of problems including two-dimensional Euler systems of compressible gas dynamics.

MS12-B-1: A nonconforming primal hybrid finite element method for the two-dimensional vector Laplacian.
Ari Stern, Washington University in St. Louis
Abstract: We introduce a nonconforming hybrid finite element method for the two-dimensional vector Laplacian, based on a primal variational principle for which conforming methods are known to be inconsistent. Consistency is ensured using penalty terms similar to those used to stabilize hybridizable discontinuous Galerkin (HDG) methods, with a carefully chosen penalty parameter due to Brenner, Li, and Sung [Math. Comp., 76 (2007), pp. 573-595]. Our method accommodates elements of arbitrarily high order and, like HDG methods, it may be implemented efficiently using static condensation. The lowest-order case recovers the P1-nonconforming method of Brenner, Cui, Li, and Sung [Numer. Math., 109 (2008), pp. 509-533], and we show that higher-order convergence is achieved under appropriate regularity assumptions. The analysis makes novel use of a family of weighted Sobolev spaces, due to Kondrat'ev, for domains admitting corner singularities.

Joint work with Mary Barker and Shuhao Cao.

MS12-B-2: Spurious solutions for high-order curl problems.
Qian Zhang, Michigan Technological University
Abstract: In this talk, we investigate numerical solutions of high-order curl problems with various formulations and finite elements. We show that several classical conforming finite elements lead to spurious solutions, while mixed formulations with finite elements in complexes solve the problems correctly. We explain the numerical results by clarifying the cohomological structures in high-order curl problems and relate the partial differential equations to the Hodge–Laplacian boundary problems of the grad curl complexes.

MS12-B-3: An immersed Crouzeix-Raviart finite element method for Navier-Stokes equations with moving interfaces .
Qiao Zhuang, Worcester Polytechnic Institute
Abstract: In this talk, we introduce a Cartesian-mesh finite element method for solving Navier-Stokes interface problems with moving interfaces. The spatial discretization uses the immersed Crouzeix-Raviart nonconforming finite element introduced by Jones and Zhang (JCAM, 2021). A backward Euler full-discrete scheme is developed which embeds Newton's iteration to treat the nonlinear convective term. The proposed IFE method does not require any stabilization terms while maintaining its convergence in optimal order. Numerical experiments with various interface shapes and jump coefficients are provided to demonstrate the accuracy of the proposed method. Numerical results indicate the optimal order of convergence of the IFE method.

MS12-B-4: A high-order Immersed C_0 interior penalty method for biharmonic interface problems.
Yuan Chen, The Ohio State University
Abstract: In this talk, an immersed C0 interior penalty method is proposed to solve biharmonic interface problems on unfitted mesh. The immersed P2 and P3 finite element spaces are con-

structed to match biharmonic interface conditions in a least-squares sense. Basic properties of these new spaces such as unisolvence and partition of unity are analyzed. The new proposed spaces are also used in a symmetric C0 interior penalty scheme to solve the biharmonic interface problems. The well-posedness of discrete solution is also proved. Extensive numerical experiments show optimal convergence of proposed method in L2, H1 and H2 norms. This is a joint work with Dr. Xu Zhang.

MS12-C-1: Solving interface problems by immersed spline functions.

Tao Lin, Virginia Tech

Abstract: We consider a group of interface problems derived from the desire to solve the Stefan problem. We try to solve these interface problems on meshes that are independent of the interface location. The underlying differential equations are discretized by the collocation with spline functions defined on an interface independent mesh. For time-dependent interface problems, the method of line or other popular discretization approaches for the time variable can be adopted. Numerical examples will be presented to demonstrate features of this method.

MS12-C-2: On a numerical artifact of solving shallow water equations with a discontinuous bottom.

Zheng Sun, University of Alabama

Abstract: In this talk, we discuss a numerical artifact of solving the nonlinear shallow water equations with discontinuous bottom topography. For a few first-order schemes, the numerical solution will form a spurious spike in the momentum, which should not exist in the exact solution. The height of the spike cannot be reduced by the mesh refinement. In many problems, this numerical artifact may cause the wrong convergence, which means that the limit of the numerical solution is not a weak solution of the shallow water equations. To explain the formation of the spurious spike, we perform a convergence analysis of the numerical methods. It is shown that the spurious spike is caused by the numerical viscosity at the discontinuous bottom and its height is proportional to the viscosity constant in the numerical flux. Furthermore, by adopting appropriate modifications at the bottom discontinuity, we show that this numerical artifact can be removed in many cases. For various of numerical tests with nontransonic Riemann solutions, the modified scheme is able to retrieve the correct convergence.

MS12-C-3: Modeling Calcium Dynamics in Neurons with Endoplasmic Reticulum: Well-Posedness and Numerical Methods.

Qingguang Guan, University of Southern Mississippi

Abstract: Calcium dynamics in neurons containing an endoplasmic reticulum are governed by diffusion-reaction equations on interface-separated domains. Interface conditions are typically described by systems of ordinary differential equations that provide fluxes across the interfaces. For the model with ODE-flux boundary condition, we prove the existence, uniqueness, and boundedness of the solution. We develop a stable high-order multi-step scheme to overcome the instability and low accuracy of the one-step implicit-explicit method. Parallel algorithms are implemented for coupled PDEs on interface-separated domains. The newly designed scheme is used to solve large-scale 3-D calcium models on neurons.

MS12-C-4: Enriched Galerkin methods for the Stokes equations with modified weak Galerkin bilinear forms.

Seulip Lee, University of Georgia

Abstract: We propose enriched Galerkin (EG) methods for the Stokes equations using modified weak Galerkin (mWG) bilinear forms. The discrete inf-sup stability is a fundamental property of numerical methods for the Stokes equations, and it has been successfully achieved by recent work on new EG methods whose numerical velocity is a discontinuous piecewise

linear function. In the EG methods, interior penalty discontinuous Galerkin (IPDG) approaches have been adopted to weakly impose the continuity of discontinuous numerical velocity, so it is necessary to consider a sufficiently large penalty parameter. For the same numerical velocity, we apply mWG bilinear forms to handle the discontinuity of velocity without such penalty parameter, so our EG method is a parameter-free EG method for the Stokes equations. We prove that our parameter-free EG method guarantees the optimal convergence rates, and pressure-robustness is also achieved by employing a velocity reconstruction operator on the load vector of the right-hand side. Furthermore, the theoretical results are verified by various numerical examples.

MS12-D-1: Dual-wind discontinuous Galerkin methods for an elliptic optimal control problem.

Yi Zhang, University of North Carolina at Greensboro

Abstract: Optimal control problems appear in many applications and have received significant attention in recent years. In this talk we study a symmetric dual-wind discontinuous Galerkin method for solving an elliptic optimal control problem with distributed control constraints. We will discuss the motivation of the proposed method and its convergence analysis. Numerical results will be provided to demonstrate the effectiveness of the proposed method.

MS12-D-2: Reduced Deep Networks (RDNs) for model reduction of nonlinear waves..

Donsub Rim, Washington University in St. Louis

Abstract: Model reduction of partial differential equations rely on low-dimensional representations of solution manifolds. However, linear dimensionality reduction methods such as proper orthogonal decomposition become inefficient for solution manifolds of wave problems. In this talk, we discuss how deep neural networks are suitable for yielding low-dimensional representations of the solution manifold. We will also discuss how these neural network representations satisfy the key requirements in the classical model reduction framework necessary for obtaining online-offline decomposition. Numerical examples involving the 1D Euler's equation will be presented. (This is a joint work with Randall J. LeVeque and Gerrit Welper)

MS12-D-3: A numerical scheme for a two-field model for binary systems containing surfactants.

Natasha Sharma, University of Texas at El Paso

Abstract: We present a numerical approximation for the binary fluid-surfactant two-field model. This model is mathematically represented by two nonlinearly coupled Cahn-Hilliard equations involving two fields namely, the scalar order parameter representing the difference in the local concentration of the binary fluids and the other field representing the local surfactant concentration. This model proposed by Laradji et al. describes not only the microemusification processes but also captures the effects of surfactants on the phase transition dynamics. Hence in this sense presents an advantage over the sixth-order phase field model capturing the microemulsification processes proposed by Gompper and co-authors. Numerical results will be presented to illustrate the performance of our scheme.

The author acknowledges the financial support of NSF DMS-2110774 and the author thanks Texas Advanced Computing Center for providing the high performance computing resources for the numerical simulations.

MS12-D-4: A new reduced order model of linear parabolic PDEs.

Yangwen Zhang, Carnegie Mellon University

Abstract: How to build an accurate reduced order model (ROM) for multidimensional time dependent partial differ- ential equations (PDEs) is quite open. In this paper, we propose a new ROM for linear parabolic PDEs. We prove that our new method can be orders of magnitude faster than standard solvers, and is also much

less memory intensive. Under some assumptions on the problem data, we prove that the convergence rates of the new method is the same with standard solvers. Numerical experiments are presented to confirm our theoretical result.

MS13-A-1: Efficient Regionally-Implicit Discontinuous Galerkin Methods: A Dimensional Splitting Strategy for Linear Hyperbolic Systems.
Yifan Hu, Iowa State University
Abstract: The regionally-implicit discontinuous Galerkin (RIDG) method is an extension of the prediction-correction formulation of the Lax-Wendroff discontinuous Galerkin method, where the prediction step is a regionally-implicit spacetime method that produces reconstructed solutions in spacetime, and the correction step is an explicit update based on those reconstructed solutions. In this work we developed a more efficient version of the RIDG scheme through a dimensional splitting strategy in the prediction step. We show that this new approach inherits the improved stability from the original RIDG method, and reduces the computational cost for multidimensional linear hyperbolic systems such as the advection equation and the wave equation.

MS13-A-2: A Positivity-Preserving Limiting Strategy for Locally-Implicit Lax-Wendroff Discontinuous Galerkin Methods. *Ian Pelakh, Iowa State University*
Abstract: Nonlinear hyperbolic conservation laws admit singular solutions such as shock-waves (discontinuities in conserved variables), rarefaction waves (discontinuities in derivatives), and vacuum states (loss of strong hyperbolicity). When ostensibly high-order numerical methods are applied in such solution regimes, unphysical oscillations present themselves that can lead to large errors and a breakdown of the numerical simulation. In this work we develop a new Lax-Wendroff discontinuous Galerkin (LxW-DG) method with a limiting strategy that keeps the solution non-oscillatory and positivity-preserving for relevant variables, such as height in the shallow water equations and density and pressure in the compressible Euler equations. The proposed LxW-DG scheme updates the solution over each time-step with a locally-implicit predictor followed by an explicit corrector. The locally-implicit prediction phase is formulated in terms of primitive variables, which greatly simplifies the solver. The resulting system of nonlinear algebraic equations are approximately solved via a Picard iteration, where the number of iterations is equal to the order of accuracy of the method. The correction phase is an explicit evaluation formulated in terms of conservative variables in order to guarantee numerical conservation. In order to achieve full positivity-preservation, limiting is required in both the prediction and correction steps. The resulting scheme is applied to several standard test cases for the shallow water and compressible Euler equations. All of the presented examples are written in a freely available open-source Python code.

MS13-A-3: Optimization of the Glimm's scheme random choice method for mutliphasic flow simulations.
James Burton, University of Arkansas
Abstract: Numerical methods for solving systems of hyperbolic conservation laws must contend with shock formation and propagation. In particular, the Euler equations of compressible fluid dynamics require stable, accurate, and robust algorithms for shock computations. The method of choice for our simulation of compressible multiphase flows in 1D is the Glimm's Scheme because of its good algorithmic properties, especially near discontinuities. Glimm's Scheme using the random choice method (RCM) is revisited to investigate convergence properties using low-discrepancy sampling methods. A set of van der Corput sampling sequences is examined to determine the optimal choice in sampling sequence in five test cases. In each test case, simulations on various

mesh sizes for each sequence are performed to determine the optimal sampling choice with a good convergence rate.

MS13-A-4: Simulation of turbulent mixing due to Richtmyer-Meshkov instability using high order weighted essentially non-oscillatory schemes.

Ryan Holley, University of Arkansas.

Abstract: Turbulent mixing due to hydrodynamic instabilities occurs in a broad spectrum of engineering, astrophysical and geophysical applications. Theory, experiment, and numerical simulation help us to understand the dynamics of hydro-dynamically unstable interfaces between fluids. In our present simulations, higher order weighted essentially non-oscillatory (WENO) methods are used. We first introduce the WENO methods in solving hyperbolic partial differential equations. WENO schemes are high order accurate upwind finite difference schemes designed for problems with piecewise smooth solutions containing discontinuities. The convex combinations of candidate stencils are chosen to approximate the flux at cell boundaries to a high order of accuracy and avoid oscillations near shocks. Lastly, the use of higher order WENO methods is investigated in the simulation of turbulent mixing due to Richtmyer-Meshkov Instability.

MS13-B-1: Asymptotic-preserving schemes for the kinetic Boltzmann-BGK equation.

Preeti Sar, Iowa State University

Abstract: In this talk I will review two important asymptotic-preserving (AP) schemes for solving the Boltzmann-BGK equation. The Boltzmann equation describes this motion of a fluid for moderate to large Knudsen numbers. Numerically, the BGK model approximates the Boltzmann equation for moderate Knudsen numbers. The paper "Implicit-Explicit Schemes for BGK Equation" (Pierraccini and Puppo) presents a new class of numerical methods for the BGK model of kinetic equations which is based on an implicit-explicit time discretization. The small scales in kinetic and hyperbolic equations lead to different asymptotic regimes which are expensive to solve numerically. Asymptotic preserving schemes are efficient in these regimes, which preserve at the discrete level, the asymptotic limit which drives the microscopic equation to its macroscopic equation. The paper "Uniformly Stable Numerical Schemes for the Boltzmann Equation preserving the Compressible Navier-Stokes Asymptotics" (Bennoune, Lemou and Mieussens) develops a numerical method to solve Boltzmann like equations of kinetic theory which can capture the compressible Navier-Stokes dynamics at small Knudsen numbers. This method, which is based on the micro/macro decomposition technique, is performed in all the phase space and leads to an equivalent formulation of the Boltzmann equation that couples a kinetic equation with macroscopic ones.

MS13-B-2: Model order reduction for elliptic partial differential equations.

Xuan Gu, University of Arkansas

Abstract: The blooming strategies of finding numerical solutions to partial differential equations (PDE) have been developed in this century, while the computational complexity still poses a major obstacle to large scale PDEs. In this talk, we present multiple reduced order models (ROMs) with the finite element solver on the elliptic second order PDE which is the generalized Laplace equation. The PDEs with specific boundary conditions are firstly discretized and parameterized into full order linear finite element system using NumPy/SciPy packages. The full order model is projected onto the reduced space which is spanned by the reduced basis. We present the construction of reduced basis using strong greedy algorithm, proper orthogonal decomposition, and weak greedy algorithm. A coupled computation framework is utilized with the discretization and the reduced basis construction implemented in the open source pyMOR package, integrated into the finite element solver package deal.II. Finally, we demon-

strate numerical solutions and error analysis on elliptic equations to illustrate the efficiency and accuracy of the ROMs.

MS13-B-3: Cell-Average Based Neural Network Solvers For Partial Differential Equation.

Tyler Kroells, Iowa State University

Abstract: In this talk, we will develop the Cell Average Neural Network (CANN) method to solve time dependent partial differential equations, a method motivated by finite volume schemes. The CANN is based on the weak or integral formula for PDE's. We use a simple feed forward network to learn the difference between cell averages in consecutive time steps. Training data is generated from one solution trajectory, and once the network is trained it operates similar to an explicit one step finite volume method. Unlike a traditional finite volume method, the CANN method can be adapted to larger time step sizes, outside of CFL restrictions. A large time step such as dt=O(dx) can be applied to evolve the solution forward in time. We will focus on numerical examples for the advection equation and heat equation, but the method has also been successfully applied to other, more complex equations.

MS14-A-1: Hele-Shaw flow and parabolic integro-differential equations.

Farhan Abedin, Lafayette College

Abstract: The Hele-Shaw flow is a model for the evolution of an ideal fluid occupying the narrow gap between two parallel plates and subject to an external pressure source. Assuming the fluid interface is given by the graph of a function, it can be shown that this function must solve a parabolic integro-differential equation of 1st order. I will discuss recent joint work with Russell Schwab (Michigan State University) on the regularization properties of such nonlocal parabolic equations. Our results allow us, in certain model scenarios and for short enough times, to conclude improvement-of-regularity for the fluid interface.

MS14-A-2: Asymptotic Mean Value Formulas for Nonlinear Equations.

Fernando Charro, Wayne State University

Abstract: In recent years there has been an increasing interest in whether a mean value property, known to characterize harmonic functions, can be extended in some weak form to solutions of nonlinear equations. This question has been partially motivated by a surprising connection between Random Tug-of-War games and the normalized p-Laplacian discovered some years ago by Peres et al., where a nonlinear asymptotic mean value property for solutions of a PDE is related to a dynamic programming principle for an appropriate game. In this talk we discuss asymptotic mean value formulas for a class of nonlinear second-order equations that includes the classical Monge-Ampère and k-Hessian equations among other examples.

MS14-A-3: New regularity estimates for a class of nonlocal operators.

Thialita Nascimento, University of Central Florida

Abstract: In this talk, we will discuss new universal bounds for the exponent of Hessian integrability of viscosity supersolutions of fully nonlinear and uniformly elliptic equations. Such estimates produce a quantitative improvement in the decay of this exponent with respect to dimension. In particular, we solve, in the negative, the Armstrong-Silvestre-Smart Conjecture about the optimal exponent for the Hessian integrability. This is a joint work with Prof. Eduardo Teixeira (UCF-USA).

MS14-A-4: Accurate and efficient spectral method for fractional wave equations.

Shiping Zhou, Missouri University of Science and Technology

Abstract: In this talk, we will present a Fourier pseudospectral method for solving the variable-order fractional wave equation. In contrast to the constant-order case, the Fourier transform of a variable-order fractional wave equation cannot give a decoupled ODE system anymore. To deal with this, a fast algorithm is pro-

posed by diagonalizing the variable-order fractional Laplacian. We study the accuracy and efficiency of our method, numerical results show that our method can get a spectral order of accuracy in space and a 2nd-order of accuracy in time.

MS14-B-1: Load-controlled evolution of quasistatic nonlinear peridynamics.
Debdeep Bhattacharya, Louisiana State University
Abstract: We consider the load-controlled quasistatic evolution of a nonlinear nonlocal continuum model, which can be viewed as a peridynamic equation. The well-posedness of the solution for all loads near the local minima of the peridynamic energy is proved in a suitable space perpendicular to rigid motions. Consequently, the local existence of a stable load path originating at the local minima is established. Although the local minima belong to the strength domain of the material, the evolution of the displacement, however, is not constrained to lie in the strength domain. Our method relies on a fixed-point argument, which differs from the approaches based on the global minimizer of the energy. The load-controlled evolution is shown to exhibit energy balance. A numerical method is implemented to solve the load-controlled evolution equation.

MS14-B-2: Convergence of Solutions for Linear Peridynamic Models. *Mikil Foss, University of Nebraska-Lincoln*
Abstract: Peridynamic models have been successfully employed to predict fractures and deformations for a variety of materials. In this talk, I will present some results on the convergence of solutions to a nonlocal state-based linear elastic model to their local counterparts as the interaction horizon vanishes. The results provide explicit rates of convergence that are sensitive to the compatibility of the nonlocal boundary data and the extension of the solution for the local model.

MS14-B-3: A Monotone Meshfree Finite Difference Method for Linear Elliptic PDEs via Nonlocal Relaxation.
Qihao Ye, University of California San Diego
Abstract: We design a monotone meshfree finite difference method for linear elliptic PDEs in non-divergence form on point clouds via a nonlocal relaxation method. Nonlocal approximations of linear elliptic PDEs are first introduced to which a meshfree finite difference method applies. Minimal positive stencils are obtained through a linear optimization procedure that automatically guarantees the stability and, therefore, the convergence of the meshfree discretization. The key to the success of the method relies on the existence of positive stencils for a given point cloud geometry. We provide sufficient conditions for the existence of positive stencils by finding neighbors within an ellipse surrounding each interior point, generalizing the study for the Poisson equation by Seibold in 2008. It is well-known that wide stencils, in general, are needed for the existence of positive weights when elliptic equations become degenerate (when the coercivity constant goes to zero). Our study allows judiciously selecting the neighboring points to reduce the computational cost for solving elliptic equations with small coercivity constants. Numerical experiments will be provided.

MS14-C-1: Convergence of nonlocal nonlinear conservation laws with respect to horizon.
Anh Vo, University of Nebraska-Lincoln
Abstract: In recent years, conservation laws involving nonlocal terms have been extensively studied due to their applications to several fields. These nonlocal operators capture long-range interactions and often have a finite horizon which is measured through the support of the kernel. In this study, we investigate nonlinear nonlocal conservation laws and the nonlocal divergence operator. We propose a requirement for the flux density so that the nonlocal divergence will converge to the traditional divergence operator. We then apply the result to study the convergence of the conservation laws.

MS14-C-2: Nonlocal Equations on the Boundary.
Mitch Haeuser, Iowa State University
Abstract: We will discuss regularity for a problem involving a fractional Dirichlet-to-Neumann operator associated to harmonic functions. In particular, we will define a fractional powers of the normal derivative, compatible Sobolev spaces, and consider various examples. We will further look at the extension problem characterization to obtain various estimates. This is joint work with Luis Caffarelli (UT Austin) and Pablo Raúl Stinga (Iowa State University)

MS14-C-3: On a semilinear nonlocal elliptic equation in the context of plasma physics.
Daniel E Restrepo Montoya, University of Texas Austin
Abstract: In this talk, we will discuss regularity, qualitative properties and uniqueness of solutions to a type of semilinear equations that arises in plasma physics as an approximation to Grad equations, which were introduced by Harold Grad, to model the behavior of plasma confined in a toroidal vessel. The difficulty of this problem lies on a right-hand side which involves the measure of the superlevel sets, making the problem nonlocal. This model also develops naturally a dead core which amounts, mathematically, to a new type of free boundary problem that will be commented briefly. This is a joint work with Luis Caffarelli and Ignacio Tomasetti from UT Austin.

MS14-C-4: Extension equation for fractional power of operator defined on Banach spaces.
Animesh Biswas, University of Nebraska-Lincoln
Abstract: In this talk, we show the extension (in spirit of Caffarelli-Silvestre) of fractional power of operators defined on Banach spaces. Starting with the Balakrishnan definition, we use semigroup method to prove the extension. This is a joint work with Pablo Raul Stinga.

MS15-A-1: Understanding reinforcement learning-based agents in self-organizing systems.
Bingling Huang, University of Southern California
Abstract: Complex systems can be applied to wide engineering fields, such as air force and navy systems. As the task environments become more unpredictable, it puts forwards higher requirements on the complex system design. Self-organization refers a process of organization to an arising overall order from members' local interactions in response to changing external circumstances. One advantage of self-organization approaches is that individual can be kept relatively simple, and the emergent behaviour of the overall system can be expected to be sophisticated enough to deal with various demanding tasks. Therefore, it has become a promising strategy for the complex system design. Reinforcement learning method has been proposed to let agents perform self-organization, where agents learn how to accomplish tasks by maximizing reward functions. However, several issues become sharper as the task complexity increases. Firstly, how to design effective reward functions to accomplish tasks with limited prior knowledge. Furthermore, how to conduct efficient trainings with predictable task performances and economic computational resources. Therefore, bridging the human's and agents' knowledge and understanding the mechanism inside a RL-based agent group are in big demands. Targeting at assisting the complex system design, the relevant contents and its applications in aerospace areas will be discussed in this talk.

MS15-A-2: Development of grid-based Vlasov method for kinetic studies of plasma flows in space engineering.
Chen Cui, University of Southern California
Abstract: We present the up-to-date development progress of the grid-based Vlasov method and the parallel, multi-dimensional grid-based Vlasov solver, Vlasolver for the plasma flow in space engineering. Numerical schemes and implementations are developed to solve

the Vlasov-Poisson and Vlasov-Darwin systems. Two example applications are presented. The first one is a re-evaluation of one-dimensional collisionless plasma expansion into vacuum. It is shown that the grid-based method allows us to extend the self-similar solution and resolve the electron time scale perturbations. The second one is a two-dimensional simulation of plasma plume emitted from plasma thrusters. The comparison of the results from the Vlasov and PIC simulations shows that, while both models agree well on overall plume density and electric potential, the Vlasov model is able to resolve high-order moment physical properties without the effects of statistical noise. A core region and a fan region can be found in the electron heat flux. Near-Maxwellian features are found in the v_x direction while top-hat shape features are found in the v_y direction for electron velocity distribution function. We find that the grid-based Vlasov method, though computationally more expensive than PIC, can be advantageous in applications requiring accurate eVDF and accurate small-scale physical properties.

MS15-A-3: Kinetic Simulations of Charging of Irregularly-Shaped Dust Grains in Space Plasmas.

David Lund, Missouri University of Science and Technology

Abstract: The objective of this study is to investigate a fully-kinetic numerical investigation of charging of irregularly-shaped dust particulates in low temperature collisionless plasmas. The recently developed Parallel Immersed-Finite-Element Particle-in-Cell (PIFE-PIC) code is utilized to self-consistently resolve the plasma environment and charging of immersed materials. This model explicitly includes the material property (dielectric constant) of dust grains. Multiple dust grain shapes/configurations will be considered and compared to find how multiple dust grains are charged in a collisionless plasmas.

MS15-A-4: Kinetic Modeling of Electrostatic Transport of Lunar Regolith Particles with Applications to In-Situ Resource Utilization.

Easton Ingram, Missouri University of Science and Technology

Abstract: Continuous human presence on the Moon will require materials made on-site / in-situ. Many of these can be made from calcium and aluminum, elements available in the lunar regolith. However, their mineral grains (called anorthite) must first be separated from the other mineral grains in the regolith. The concept of electrostatic sieving is promising for use under the lunar environment. In this study, we will model the working process of electrostatic sieving by tracking the trajectories of charged lunar regolith particles under the electric field generated by an array of electrodes. Effects of size separation and efficacy of this concept will be presented and discussed.

CT1-A-1: An age-and Phase-Structured Model of Malaria Parasite Replication in Erythrocytes and Anti-malarial Therapies.

Md Afsar Ali, Kansas Wesleyan University

Abstract: Replication of Plasmodium parasites within human erythrocytes initiates malaria symptoms in blood. The cell division cycle of these parasites, however, is still poorly understood. In other eukaryotes, different cell-cycle synchronization techniques have been used to shed light on the mechanisms underlying cell division and control. In plasmodium, there is currently no method for cell-cycle synchronization. We investigate whether DNA synthesis inhibitors, mitotic spindle inhibitors, or cell-cycle control elements (such as cyclin-dependent kinases) can be used to synchronize P. falciparum cultures to a particular cell-cycle phase. For this, we develop an age-and-phase structured cell population balance model of cells differentiated by their position within the cell division cycle. A system of partial differential equations governs the kinetics of cell densities in different phases of the cell division cycle dependent on time t (hours) and an age-like variable

a (hours) describing the time since arrival in a particular phase of the cell division cycle. The proposed structured model accounts for the essential in-host processes: parasite replication and its regulation by an antimalarial drug. The anti-malarial drug is incorporated in the model by an appropriate mathematical function and applied to a particular phase, namely, T-phase. The proposed cell transition and division intensity functions are capable of simulating near exponential parasite cell-mass growth (multiplication time of 48 days) while maintaining information regarding population age within each cell phase. Drug effect shows a significant parasite population reduction, leading to the recovery of malaria disease. Our simulation results also show that applying drug at T-phase might give the optimum reduction of parasitemia in the blood.

CT1-A-2: A Local Macroscopic Conservative (LoMaC) low-rank tensor method for the Vlasov Maxwell system.

Shadi Heenatigala, Texas Tech University

Abstract: The main computational challenges of solving the Vlasov-Maxwell (VM) system include the high dimensionality of the phase space, and inherent conservation properties, among others. In this paper, we develop a novel Local Macroscopic Conservative (LoMaC) low-rank tensor method for the VM system, as a continuation of our previous work (arXiv:2207.00518). Such a method employs the hierarchical Tuck decomposition to approximate the Vlasov solution tensor in high dimensions, mitigating the curse of dimensionality. Furthermore, the method simultaneously evolves the macroscopic conservation laws of mass, momentum, and energy using a flux-difference form with kinetic flux vector splitting alongside the Vlasov equation; then the LoMac property is realized by projecting the low-rank Vlasov solution onto a subspace that shares the same macroscopic observables by a conservative orthogonal projection. A collection of extensive numerical tests on the VM system are presented to demonstrate the algorithm's efficacy.

CT1-A-3: Coupling deep learning with full waveform inversion.

Lu Zhang, Columbia University

Abstract: Full waveform inversion (FWI) aims at reconstructing unknown physical coefficients in wave equations using the wave field data generated from multiple incoming sources. In this work, we propose an offline-online computational strategy for coupling classical least-squares based computational inversion with modern deep learning based approaches for FWI to achieve advantages that can not be achieved with only one of the components. In a nutshell, we develop an offline learning strategy to construct a robust approximation to the inverse operator and utilize it to design a new objective function for the online inversion with new datasets. We demonstrate through numerical simulations that our coupling strategy improves the computational efficiency of FWI with reliable offline training on moderate computational resources (in terms of both the size of the training dataset and the computational cost needed).

CT1-A-4: A new artificial viscosity approach for adaptive multiresolution discontinuous Galerkin method for hyperbolic conservation laws..

Jannatul Ferdous Ema, Texas Tech University

Abstract: The adaptive multi-resolution discontinuous Galerkin (DG) method for hyperbolic conservation laws is proven effective in capturing the complex solutions structures when coupling a conventional artificial viscosity technique, while the computational cost is large due to the hierarchical structures of the multi-wavelet basis used. We propose a novel artificial viscosity approach for controlling spurious oscillations under the multi-resolution DG framework. In particular, the high order accuracy is not much compromised because the viscosity is added only for small scales of wavelet basis. This

approach is easy to implement. The numerical evidence verifies the high order accuracy and the ability to control oscillations of the proposed approach.

CT1-B-1: Convergence Analysis For A Semi-discrete Energy Stable Scheme For Hydrodynamic Q-tensor Model.
Yukun Yue, Carnegie Mellon University
Abstract: We present convergence analysis of an unconditional energy-stable first-order semi-discrete numerical scheme designed for a hydrodynamic Q-tensor model based on Invariant Quadratization Method(IEQ). This model couples a Navier-Stokes system for the flows and a parabolic type Q-tensor system governing the nematic crystal director fields. We prove the stability properties of the scheme and show convergence to weak solutions of the coupled liquid crystal system.

CT1-B-2: Higher temporal accuracy for LES-C turbulent models.
Yasasya Batugedara Mohottalalage, Michigan Technological University
Abstract: Large Eddy Simulations (LES) are widely used in modeling turbulent flows. To reduce the modeling error in LES models, a method called Large Eddy Simulation with Correction (LES-C) was proposed in Labovsky(2020) using a 'predictor-corrector' scheme. To improve the model further by reducing the time discretization error, we propose a method that uses a defect-corrector scheme called Deferred correction. Since the method was obtained by adding additional terms to the LES -C model, we can obtain extra accuracy with no additional computational cost. The method is tested for the ADC model (a member of the LES -C family) and the full numerical test is carried out where a clear reduction of errors can be observed. We also performed the full numerical analysis of the method.

CT1-B-3: Melt pool formation by a moving heat source
Tianshi Lu, Wichita State University
Abstract: Rothensal solved the heat equation with a moving source analytically. Eagar and Tsai generalized the solution to Gaussian distributed heat sources. We extended their results to more general settings, and derived the asymptotic solution of a fast moving heat source. The results have been validated against simulations in the open-source CFD software OpenFOAM. We simulated the melting process of a metal block heated by a moving heat source, and compared the results with the prediction by the analytic solution to the heat equation. We also studied the melt pool formation in stacked metal beads heated by a moving laser beam, as in the Selective Laser Melting, the most advanced metal additive manufacturing process.

CT1-B-4: Optimal Ordering Policy For Forest Residues and Willow Biomass For Continuous Industrial Supply.
Md Abu Helal, Colorado State University
Abstract: The development of biomass energy projects and other bio-based businesses depends on effective and efficient biomass logistics and supply from forestry and agricultural operations. Improved inventory management practices can contribute to increased competitive advantage and improved organizational performance in every industrial sector. Despite the potential direct and favorable influence of optimized inventory management on biomass supply chain efficiency, inventory management methods are often disregarded in the literature in this area. In this study we proposed an optimal inventory ordering policy for sustainable biomass supply chain management in the Mid-Atlantic region of the United States in order to improve biomass logistics to meet demand at the lowest possible cost and reduce risk to investment.

CT2-A-1: Higher order Liouville weighted composition operators over the Fock space .
Himanshu Singh, University of South Florida
Abstract: In recent times, the Liouville operator theory has gradually became as one of the

dominant candidates for machine learning of dynamical processes for data driven methods. We intend to augment and study the Liouville operators theory and its interactions over reproducing kernel Hilbert spaces, in particular the Fock Space of analytic functions. This presentation continues the study of the Liouville weighted composition operators to higher dimension over the Fock space and hence the name: Higher order Liouville weighted composition operators. This discussion provides the basic definition of it in connection with the dynamical systems. It also provides various important operator theoretic properties such as closability, boundedness and compactness, as well as essential norm estimates of the operator over the Fock space.

CT2-A-2: Preliminary report on symmetric and asymmetric cell division and modeling of interacting cell populations in the colonic crypt.

Khoi Vo, University of California, Riverside

Abstract: Mathematical modeling can be used to describe the behavior of cells within the colonic crypt. The colon is made up of nearly 10 million crypts which are responsible for producing the epithelial cells within the colon. Symmetric and asymmetric stem cells and cycling cells produce the cells within the crypt and when this behavior becomes dysregulated it can lead to the development of colorectal cancer. This model aims to make a simple spatial and time-dependent model to describe the behavior of two types of cells within the colon. Both analytic and numerical solutions are presented for a range of initial conditions and time points. The model is then expanded for stochastic analysis to further examine the spatial relationships among the cell types.

CT2-A-3: Quasi-interpolation for the Helmholtz–Hodge decomposition.

Nicholas Fisher, Minnesota State University, Mankato

Abstract: We propose a computationally efficient and stable quasi-interpolation based method for numerically computing the Helmholtz-Hodge decomposition of a vector field. To this end, we first explicitly construct a matrix kernel in a general form from polyharmonic splines such that it includes divergence-free/curl-free/harmonic matrix kernels as special cases. Then we apply the matrix kernel to vector decomposition via a convolution technique together with the Helmholtz-Hodge decomposition. More precisely, we show that if we convolve a vector field with a scaled divergence-free (curl-free) matrix kernel, then the resulting divergence-free (curl-free) convolution sequence converges to the corresponding divergence-free (curl-free) part of the Helmholtz-Hodge decomposition of the field as the scale parameter tends to zero. Finally, by discretizing the convolution sequence via certain quadrature rule, we construct a family of (divergence-free/curl-free) quasi-interpolants (defined both in the whole space and over a bounded domain) for approximating divergence-free/curl-free part corresponding to the Helmholtz-Hodge decomposition of the field, respectively.

CT2-A-4: Forced oscillations of incompressible Navier-Stokes equation in a 2D bounded domain.

Taige Wang, University of Cincinnati

Abstract: We establish the existence of time-periodic solutions for incompressible Navier-Stokes equation (NSE) posed in 2D domain mainly in Sobolev space $H^s(\Omega)$, $s = 1$. In this situation, fluid is motivated by a time-periodic force in the domain, and generates the forced oscillation (periodic solutions) satisfying a Burgers equation. Further, local and global stability are achieved for this periodic solution.

CT2-B-1: Global well-posedness and exponential decay of a model of fluid-structure interaction.

Wojciech Ożański, Florida State University

Abstract: In the talk we will discuss the problem of a fluid-structure interaction, which consists of a incompressible, viscous fluid, described by the 3D Navier-Stokes equations, with a homogeneous Dirichlet boundary condition, and an elastic structure, described in Lagrangian coordinates by the wave equation with linear damping, and equipped with a homogeneous Dirichlet boundary condition. The elastic structure and the fluid interact via a common free boundary, on which we assume continuity of the displacement as well as continuity of the stresses. The most notable feature of the model is the lack of any artificial stabilization terms, which are often used to deduce local well-posedness of the system. It turns out that removing the stabilization terms can in principle cause the system not to decay to zero as time passes. We will discuss how one can analyze various notions of energies of the system to avoid the stability issues related to the lack of the stabilization terms. We will show that the system is globally well-posed for small data, and decays exponentially to a final state which is zero only thanks to the preservation of the volume of the system.

CT2-B-2: Densely Defined Multiplication Operators in a NARMAX-type Identification Scheme.

John Kyei, University of South Florida

Abstract: In this presentation, we shall discuss a parsimonious signal approximation technique based on the multiplication operator on a reproducing kernel Hilbert space. Valid trajectories of a dynamical system shall be encoded with occupation kernels in the domain of the adjoint multiplication operator. We shall explore an interaction between the adjoint operator and the above kernel that motivates an alternative formulation of the NARMAX system identification scheme. This research is conducted in collaboration with Himanshu Singh, Drs. Joel A. Rosenfeld and Benjamin P. Russo and is funded by AFOSR Award FA 9550-20-1-0127 and NSF award ECCS-2027976.

CT2-B-3: Mathematical modeling of the process of movement of arterial blood in the arteries for angioplasty and stenting of the coronary arteries.

Bakhyt Alipova, University of Kentucky, International IT University

Abstract: IBased on the general Navier-Stokes equations and convective heat conduction, a specific boundary value problem (BVP) of CFD is formulated, having determined the calculation area D with the initial and boundary conditions. For a 2-D problem of the flow of a viscous heat-conducting fluid in a channel with internal obstacles (blood particles), the momentum equations, the continuity equation, and the energy equation are considered.

The boundary of the region D is multiply connected, the channel (artery) walls are thermally insulated; To simplify the formulation of the BVP, reduce numerical calculations, and reduce the number of problem parameters, the problem is assumed to be dimensionless.

The numerical implementation of the problem is supposed to be performed by the finite difference method (FDM). It is supposed to build homogeneous and denser grids in time and space. For the selected grid function, a detailed discretization is performed, and the resulting system of linear algebraic equations is solved using the tridiagonal matrix method.

It is expected to develop an virtual reality simulator for angioplasty and coronary artery stenting: Develop an algorithm for the operation of tools, Develop an algorithm for the behavior of organic tissues etc.