Czech Academy of Sciences–Kanazawa University Workshop

Shiinoki Cultural Complex, Kanazawa City, Ishikawa
November 2–3, 2025

Day 1 Schedule

Time	Title of Talk / Speaker / Affiliation / Abstract
09:50–10:00	*Opening Remarks*, Masato Kimura, Kanazawa University
10:00–10:50	*Weak solutions to a full compressible magnetohydrodynamic flow interacting with thermoelastic structure and singular limits* Šárka Nečasová, Institute of Mathematics, Czech Academy of Sciences This talk addresses the interaction between a compressible, electrically conducting fluid and a thermoelastic shell in 2D. The shell is modeled by linear thermoelasticity equations and coupled with a fluid described by full compressible MHD equations. We establish existence of weak solutions via domain extension, operator splitting, decoupling, and penalization of interface conditions [1]. We also justify the incompressible inviscid limit under low Mach number, high Reynolds number, and well-prepared initial data for barotropic fluids [2]. This is a joint work with Kuntal Bhandari (Institute of Mathematics, Czech Academy of Sciences), Bingkang Huang (University of Technology, Hefei, China), Sourav Mitra (Indian Institute of Technology Indore, India), and Yadong Liu (Nanjing Normal University, China). **[1]** Kuntal Bhandari, Bingkang Huang, Šárka Nečasová, *Weak solutions to a full compressible magnetohydrodynamic flow interacting with thermoelastic structure*, arXiv:2505.23539, 2025. **[2]** Yadong Liu, Sourav Mitra, Šárka Nečasová, *Weak solutions and singular limits for a compressible fluid-structure interaction problem with slip boundary conditions*, arXiv:2405.09908, 2025.
10:50–11:05	*Non-axisymmetric Tornado-type Flow: Energy Transfer and Dynamics* Afifah Maya Iknaningrum, Kanazawa University While tornado-type flows have been extensively studied in straight cylindrical domains (e.g. [1]), the influence of curvature on vortex dynamics remains less understood. By incorporating curvature into 3D numerical simulations in a non-axisymmetric curved cylindrical domain, we reveal specific vortex dynamics responsible for energy transfer [2]. Recent studies related to scale-local energy transfer [3] and observational studies of real tornadoes [4] support the credibility of our numerical approach. This is a joint work with Pen-Yuan Hsu (Graduate School of Mathematical Science, The University of Tokyo, Japan), Tsuyoshi Yoneda (Graduate School of Economics, Hitotsubashi University, Japan), and Hirofumi Notsu (Faculty of Mathematics and Physics, Kanazawa University, Japan). **[1]** Hsu, P.Y., Notsu, H. and Yoneda, T., A local analysis of the axisymmetric Navier-Stokes flow near a saddle point and no-slip flat boundary, J. Fluid Mech., 729, pp. 444–459, 2016. **[2]** Iknaningrum, A.M., Hsu, P.Y., Yoneda, T., and Notsu, H., Energy Transfer Dynamics Generated by Non-Axisymmetric Tornado-Type Flows, [Under review], 2025. **[3]** Goto, S., Saito, Y. and Kawahara, G., Hierarchy of antiparallel vortex tubes in spatially periodic turbulence at high Reynolds numbers, Physical Review Fluids, 2, 064603, 2017. **[4]** Bluestein, H.B., Thiem, K.J., Snyder, J.C. and Houser, J.B., The Multiple-Vortex Structure of the El Reno, Oklahoma, Tornado on 31 May 2013, Monthly Weather Review, 146(8), pp. 2483–250, 2018.
11:05–11:20	Break

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<tr><th>Time</th><th>Title of Talk / Speaker / Affiliation / Abstract</th></tr>
<tr><td>11:20–11:35</td><td>

A variable time step Lagrange-Galerkin scheme with second-order accuracy in time for convection-diffusion problems

Yuki Karasawa, Kanazawa University

This presentation proposes a variable time step formulation of the Lagrange–Galerkin method with second-order accuracy in time for convection-diffusion problems. By employing the method of characteristics, the scheme reduces numerical diffusion and relaxes CFL restrictions [1]. Stability is demonstrated using ideas from [2] and [3], and norm error estimates are derived from the stability results.

[1] K. Futai, N. Kolbe, H. Notsu, and T. Suzuki, A mass-preserving two-step Lagrange–Galerkin scheme for convection-diffusion problems, Journal of Scientific Computing, 92(2):37, 2022.
[2] Liao, Hong-lin and Zhang, Zhimin, Analysis of adaptive BDF2 scheme for diffusion equations, Mathematics of Computation, 90, 1207–1226, 2021.
[3] W. Wang, M. Mao, and Z. Wang, Stability and error estimates for the variable step-size BDF2 method for linear and semilinear parabolic equations, Advances in Computational Mathematics, 47(1):8, 2021.

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<tr><td>11:35–11:50</td><td>

Dynamics of the wave-pinning model for cell polarity

Taikei Uechi, Kanazawa University

Motile eukaryotic cells establish polarity through the spatial segregation of their internal components. To describe this phenomenon, Mori et al. proposed the wave-pinning model, a bistable reaction–diffusion system [1]. Our matched asymptotic analysis of the model reveals that the segregation front exhibits two-timescale dynamics: a slow evolution driven by mean curvature and a fast wave propagation whose speed depends on an inactive species.

This is a joint work with Koya Sakakibara (Kanazawa University, Japan) and Shunsuke Kobayashi (University of Miyazaki, Japan).

[1] Y. Mori, A. Jilkine, and L. Edelstein-Keshet, *Wave-pinning and cell polarity from a bistable reaction–diffusion system*, *Biophysical Journal*, 94, 3684–3697, 2008.

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<tr><td>11:50–12:20</td><td>

A rate-independent model of droplet evolution

Norbert Požár, Kanazawa University

In this talk, we introduce a simplified model of a quasistatic droplet on a surface with contact angle hysteresis, based on a rate-independent evolution of the one-phase Bernoulli free boundary problem. By taking advantage of two notions of weak solutions—energy-based and comparison-principle-based—we study the dynamic contact angle of moving contact lines and the geometry of de-pinning. We show that these two notions of solutions coincide in a star-shaped setting, where we obtain (almost) optimal regularity of the contact line and convergence of a minimizing-movements scheme. In a general setting, the notions differ essentially in how they handle jumps, but both are shown to satisfy a weak motion law.

This is a joint work with Inwon Kim (UCLA, USA) and William M. Feldman (University of Utah, USA).

[1] W. M. Feldman, I. Kim, and N. Požár, *An obstacle approach to rate-independent droplet evolution*, arXiv:2410.06931, 2024.
[2] W. M. Feldman, I. Kim, and N. Požár, *On the geometry of rate-independent droplet evolution*, arXiv:2310.03656, 2023.
[3] W. M. Feldman and N. Požár, *On convex comparison for exterior Bernoulli problems with discontinuous anisotropy*, *Interfaces Free Bound.*, 27(3):459–468, 2025.

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<tr><td>12:20–14:00</td><td>Lunch Break</td></tr>
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Time	Title of Talk / Speaker / Affiliation / Abstract
14:00–14:30	*3 topics on many-particle limits* Patrick van Meurs, Kanazawa University In this talk, we introduce three main research topics in applied analysis. 1. The many-particle limit of particle systems described either by the minimizer of an interacting particle energy (as the equilibrium state) or as the gradient flow thereof. The challenge is that the particle interaction is singular. 2. A system of moving Coulomb charges with added noise, where the goal is to construct a well-defined solution concept for this system of singular SDEs and to understand the nature of possible collisions. 3. The derivation of several types of PDEs—such as (non)linear heat equations with a reaction term and the Navier–Stokes equations—as many-particle (hydrodynamic) limits of simple stochastic particle systems or cellular automata.
14:30–15:20	*Analysis of bi-fluid systems* Martin Kalousek, Institute of Mathematics, Czech Academy of Sciences This talk is devoted to bi-fluid systems. After their introduction, the focus will be on the existence analysis for two examples. Namely, we briefly discuss the global-in-time existence of a weak solution to the so-called one-velocity Baer–Nunziato system, and the existence of a weak solution to a bi-fluid system in a bounded domain with variable boundary. The presented results are based on joint works [1, 2]. **[1]** M. Kalousek, S. Mitra, and Š. Nečasová, *The existence of a weak solution for a compressible multicomponent fluid–structure interaction problem*, *J. Math. Pures Appl.*, 184:118–189, 2024. **[2]** M. Kalousek and Š. Nečasová, *On existence of weak solutions to a Baer–Nunziato type system*, *J. Differential Equations*, 452, 2026.
15:20–15:35	Break
15:35–15:50	*On the memory of the twin vortex computer for an optimized cylinder* Yuma Nakamura, Kanazawa University In recent years, forecasting certain phenomena based on given robust data has been of interest among mathematicians and allied scientists. Our focus lies on a method known as *Physical Reservoir Computing*, which is derived from the framework of recurrent neural networks. In particular, we consider the dynamics induced by the flow past a cylinder, as studied in [1]. In that work, the authors investigated the effect of varying the Reynolds number on the information processing capacity, and showed that when the twin-vortex—generated due to the periodically stable flow—appears, the physical reservoir computer achieves meaningful information processing and reaches peak capability at the bifurcation point of stability. In this talk, we present an ongoing study on the effect of varying the obstacle shape in the channel by means of shape optimization. The optimization problem is formulated to either maximize or minimize the L^2-norm of the curl of the velocity field, motivated by [1], which indicates that the vortex size influences computational capability. Using a traction method based on the gradient descent of the vorticity functional, we numerically solve the shape optimization problem and evaluate the performance of the physical reservoir computer on the optimized shapes. Our preliminary results show that the shapes generated by the minimization problem yield better performance than those from the maximization case. This is a joint work with John Sebastian H. Simon (RICAM, Austria), Tomoyuki Kubota and Kohei Nakajima (The University of Tokyo, Japan), and Hirofumi Notsu (Kanazawa University, Japan). **[1]** K. Goto, K. Nakajima, and H. Notsu, *Twin vortex computer in fluid flow*, *New J. Phys.*, 23:063051, 2021.

Time	Title of Talk / Speaker / Affiliation / Abstract
15:50–16:40	*On compressible fluids with shear-dependent viscosity* Václav Mácha, Institute of Mathematics, Czech Academy of Sciences We present recent developments concerning the existence of solutions to the generalized Navier–Stokes system describing the flow of a compressible fluid with shear-dependent viscosity. Establishing existence in this setting is particularly delicate, as the equations do not permit deriving sufficiently strong compactness properties to apply the standard Galerkin method for obtaining weak solutions. Instead, we discuss several results concerning measure-valued and strong solutions to the aforementioned system. During the talk, we will also present results obtained in collaboration with Martin Kalousek, Petr Ludvík, Šárka Nečasová, and Jan Slavík (all from the Institute of Mathematics, Czech Academy of Sciences).
16:40–16:55	Break
16:55–17:45	*On dissipative turbulent solutions to the compressible anisotropic Navier–Stokes equations in unbounded domains* Ondřej Kreml, Institute of Mathematics, Czech Academy of Sciences Inspired by Abbatiello, Feireisl, and Novotný [1], we prove the global existence of dissipative turbulent solutions for the compressible Navier–Stokes equations with an anisotropic viscous stress tensor on unbounded domains. Our work complements the result of Bresch and Jabin [2], who used a new compactness method to prove the existence of a weak solution to the same system in the 3D torus. By working with a larger class of dissipative turbulent solutions, we are able to relax assumptions on the anisotropic tensor coefficients and the pressure law coefficient, and we establish existence results on a large class of unbounded domains, which is more consistent with the physical context. We also prove the weak–strong uniqueness property of the obtained dissipative turbulent solutions. This is a joint work with Šárka Nečasová and Tong Tang. **[1]** A. Abbatiello, E. Feireisl, and A. Novotný, *Generalized solutions to models of compressible viscous fluids*, Discrete Contin. Dyn. Syst., 41, 1–28, 2021. **[2]** D. Bresch and P. E. Jabin, *Global existence of weak solutions for compressible Navier–Stokes equations: thermodynamically unstable pressure and anisotropic viscous stress tensor*, Ann. of Math., 188, 577–684, 2018.

Day 2 Schedule

Time	Title of Talk / Speaker / Affiliation / Abstract
09:30–10:20	*Equilibrium state of the 3D MHD equations with an arbitrary geometry* Hideo Kozono, Waseda University & Tohoku University In a 3-dimensional bounded domain Ω with smooth boundary $\partial\Omega$, we consider the stability problem of solutions to the MHD equations for $U = (u, B)$ denoting the velocity and magnetic field, respectively. Introducing the harmonic vector field $X_{\mathrm{har}}(\Omega) = \{h \in C^\infty(\bar{\Omega}) \mid \operatorname{div} h = 0, \operatorname{rot} h = 0, h \cdot \nu\|_{\partial\Omega} = 0\}$ with ν denoting the unit outer normal to $\partial\Omega$, we first show that $U^* = (0, B^*)$ with $B^* \in X_{\mathrm{har}}(\Omega)$ gives an equilibrium state. Next, we prove that if B^* is small in $L^1(\Omega)$ and the initial disturbance U_0 is sufficiently small in $L^3(\Omega)$, with $B_0 - B^*$ perpendicular to $X_{\mathrm{har}}(\Omega)$, then U^* is exponentially stable. This is a joint work with Senjo Shimizu (Kyoto University) and Taku Yanagisawa (Nara Women's University). **[1]** H. Kozono, T. Yanagisawa, *Variational inequality for vector fields and the Helmholtz–Weyl decomposition in bounded domains*, Indiana Univ. Math. J., 58, 1853–1920, 2009. **[2]** H. Kozono, S. Shimizu, T. Yanagisawa, *Stability of harmonic vector fields as an equilibrium of the 3D MHD equations in bounded domains with arbitrary geometry*, Math. Ann., 393, 923–952, 2025.
10:20–10:35	*Parameter Identification in Elliptic PDEs Using the Coupled Complex Boundary Method with Tikhonov Regularization* Sahat Pandapotan Nainggolan, Kanazawa University This talk investigates an inverse coefficient problem for a convection–reaction–diffusion equation, aiming to reconstruct a spatially varying diffusion coefficient from limited boundary measurements. Both Dirichlet and Neumann data are incorporated into a unified framework using the coupled complex boundary method (CCBM), encoding the Cauchy data as a complex Robin-type boundary condition and transferring the fitting condition into the domain interior. To stabilize the reconstruction, Tikhonov regularization is employed, ensuring well-posedness of the variational formulation. The forward and inverse problems are discretized using the finite element method and implemented in FreeFEM++. Numerical experiments demonstrate the feasibility and robustness of the proposed approach, showing accurate recovery of the diffusion coefficient even with noisy data. This is a joint work with Julius Fergy Tiongson Rabago and Hirofumi Notsu (Kanazawa University, Japan). **[1]** X. L. Cheng, R. F. Gong, W. Han, and X. Zheng, *A novel coupled complex boundary method for solving inverse source problems*, Inverse Problems, 30:055002, 2014. **[2]** H. W. Engl, M. Hanke, and A. Neubauer, *Regularization of Inverse Problems*, Springer, 1996. **[3]** R. F. Gong, X. L. Cheng, and W. Han, *A coupled complex boundary method for an inverse conductivity problem with one measurement*, Applicable Analysis, 96:869–885, 2017. **[4]** A. N. Tikhonov and V. Y. Arsenin, *Solutions of Ill-posed Problems*, Wiley, New York, 1977. **[5]** X. Zheng, X. Cheng, and R. Gong, *A coupled complex boundary method for parameter identification in elliptic problems*, International Journal of Computer Mathematics, 97:998–1015, 2020.
10:35–10:50	*Fracture phase field model with unilateral contact condition: energy dissipation identity and finite element simulations* Oussama Ounissi, Kanazawa University The fracture phase field model (PFM) is widely used to model fracture mechanics, but in certain scenarios the standard PFM fails to reproduce realistic crack propagation because it does not consider unilateral contact (non-penetration) conditions. In this talk, we present a variational formulation of the phase-field model that incorporates unilateral contact, and prove an energy-dissipation identity for both the standard and unilateral-contact formulations. We also illustrate the effect of the contact condition through numerical examples. This is a joint work with Masato Kimura (Kanazawa University, Japan), Md Mamun Miah (Khulna University of Engineering and Technology, Bangladesh), and Sayahdin Alfat (Halu Oleo University, Indonesia).

Time	Title of Talk / Speaker / Affiliation / Abstract
10:50–11:05	Break
11:05–11:20	*Lagrangian–Galerkin Moving Mesh Method* Kharisma Surya Putri, Kanazawa University In this research, our goal is to accurately capture high-concentration phenomena that lead to sharp spike patterns, such as those observed in cancer cell aggregation. These problems are typically modeled by convection-dominated PDEs, which require careful domain discretization to achieve high-resolution results. Adaptive mesh methods and optimal transport techniques have gained popularity as effective approaches for handling such challenges. We introduce the Lagrangian–Galerkin Moving Mesh Method (LGMM) as a low-cost computational alternative for handling high-concentration phenomena. LGMM extends the mass-conservative Lagrange–Galerkin (LG) framework into a moving mesh setting, where mesh nodes follow the underlying flow while preserving mass conservation. Optimal error estimates in the $\ell^\infty(L^2) \cap \ell^2(H_0^1)$ norms are established for linear elements, and numerical experiments validate the method and highlight advantages over standard fixed-mesh LG methods. This is a joint work with Niklas Kolbe (RWTH Aachen University, Germany), Tatsuki Mizuochi, and Hirofumi Notsu (Kanazawa University, Japan). **[1]** K.S. Putri, T. Mizuochi, N. Kolbe, and H. Notsu, *Error Estimates for First- and Second-Order Lagrange–Galerkin Moving Mesh Schemes for the One-Dimensional Convection–Diffusion Equation*, Journal of Scientific Computing, 101, 2024.
11:20–11:35	*Numerical modelling of human phonation process* Jan Valášek, Institute of Mathematics, Czech Academy of Sciences This contribution focuses on the fluid–structure–acoustic interaction (FSAI) problem with emphasis on human phonation. Phonation involves complex interactions between the vibrating elastic structure of the vocal folds, the unsteady airflow, and the resulting acoustics, together with their mutual couplings. A general mathematical model of the FSAI problem is introduced, followed by simplifications suitable for numerical treatment, e.g., approximating the FSAI problem by a fluid–structure interaction (FSI) problem with a forward-coupled aeroacoustic model. Special attention is devoted to mutual contact of the vocal folds, which occurs regularly during healthy phonation, increasing the problem's complexity. A contact treatment compatible with the finite element method is described [1]. The aeroacoustic problem is modeled using aeroacoustic analogies (perturbation approach), offering a computationally feasible alternative to full compressible Navier–Stokes equations. Two mathematical formulations—the Lighthill acoustic analogy and the Aeroacoustic Wave Equation (AWE)—are presented [2]. Finally, numerical simulations of flow-induced vocal fold vibrations and sound propagation through the human vocal tract are shown for the vowel [u:] [3]. This is a joint work with Petr Sváček (Czech Technical University in Prague, Czechia). **[1]** P. Sváček and J. Horáček, *FE numerical simulation of incompressible airflow in the glottal channel periodically closed by self-sustained vocal folds vibration*, J. Comput. Appl. Math., 393:113529, 2021. **[2]** S. Falk, S. Kniesburges, S. Schoder, et al., *3D-FV-FE aeroacoustic larynx model for investigation of functional based voice disorders*, Front. Physiol., 12:616985, 2021. **[3]** J. Valášek and P. Sváček, *Aeroacoustic simulation of human phonation based on flow-induced vocal fold vibrations including their contact*, Adv. Eng. Softw., 194:103652, 2024.
12:10–14:00	Lunch Break

Time	Title of Talk / Speaker / Affiliation / Abstract
14:00–14:30	*Well-posedness of the Langmuir film model* Koya Sakakibara, Kanazawa University, Japan A Langmuir film (or Langmuir monolayer) is a single molecular layer of amphiphilic molecules spread at the air–water interface, exhibiting two-dimensional fluid behavior coupled with the subphase hydrodynamics beneath it. We investigate the inviscid Langmuir layer–Stokes subfluid (ILLSS) model, which couples a two-dimensional, incompressible, inviscid film on $\partial B = \mathbb{R}^2$ with a three-dimensional Stokes flow in the subfluid $B = \mathbb{R}^2 \times (-1, 0)$. The governing system involves the velocity v, pressure p, film interface Γ, its curvature κ, and normal velocity U. In this talk, we derive the boundary integral equation (BIE) governing the evolution of Γ and establish a curve-shortening identity. We then prove the local-in-time existence of solutions to the BIE using maximal L^2-regularity in H^1. By obtaining a regularity result, we show that the ILLSS model is equivalent to the BIE formulation. Finally, several numerical experiments illustrating the dynamics are presented. This is a joint work with Yoichiro Mori (University of Pennsylvania, USA) and Shinya Okabe (Tohoku University, Japan). **[1]** J. C. Alexander, A. J. Bernoff, E. K. Mann, J. A. Mann, Jr., J. R. Wintersmith, and L. Zou, *Domain relaxation in Langmuir films*, J. Fluid Mech., 571:191–219, 2017. **[2]** K. B. Blodgett, *Films built by depositing successive monomolecular layers on a solid surface*, J. Am. Chem. Soc., 57:1007–1022, 1935. **[3]** I. Langmuir, *The constitution and fundamental properties of solids and liquids, II. Liquids*, J. Am. Chem. Soc., 39:1848–1906, 1917.
14:30–15:20	*Stability of bifurcating patterns in viscous compressible fluids* Yoshiyuki Kagei, Institute of Science, Tokyo, Japan In systems of equations for motion of viscous fluids, solutions often exhibit various interesting spatio-temporal periodic patterns. In this talk, we mainly consider the stability of the bifurcating spatially periodic patterns in the compressible Navier-Stokes system for the Couette-Taylor flows.
15:20–15:35	Break
15:35–15:50	*TBA* Naohiko Ogawa, Kanazawa University, Japan TBA. This is a joint work with Kouta Futai and Yuki Karasawa (Kanazawa University, Japan).
15:50–16:40	*Spatially adaptive stabilized Lagrange–Galerkin schemes for two-fluid flow and fluid-structure interaction problems* Hirofumi Notsu, Kanazawa University, Japan Lagrange–Galerkin (LG) schemes combined with pressure stabilization (PS), an adaptive mesh refinement (AMR) technique, and a level set method (LSM) are presented for two-fluid flow (TFF) and fluid-structure interaction (FSI) problems. LG schemes are robust for convection-dominated problems and provide symmetric approximations of the nonlinear material derivatives without artificial parameters, as they are based on the method of characteristics. An advantage of LG schemes, at least for problems with a linear convection term, is that no CFL condition is required; thus, the time increment can be chosen independently of the mesh size. LG schemes are therefore potentially compatible with AMR techniques. With the aid of PS, our schemes employ the simplest piecewise linear (P1) conforming finite element for all the unknowns—the velocity, pressure, and level set (signed distance) function. Consequently, the degrees of freedom can be easily controlled, and the schemes are particularly effective in three dimensions. As a foundation of this study, we introduce a second-order-in-time adaptive stabilized LG scheme with a mass-preserving approximation of the material derivative for the incompressible Oseen (linearized Navier–Stokes) equations, and we prove its theoretical properties, namely stability and error estimates. The proposed schemes for TFF and FSI problems are then presented. In these schemes, integrals over moving domains and boundaries are transformed into integrals over the entire domain, independent of time, by using approximate Heaviside step and Dirac delta functions. The AMR technique refines meshes near moving boundaries to accurately capture interface phenomena. Numerical results in two and three dimensions demonstrate the effectiveness of the proposed adaptive stabilized LG schemes. This is a joint work with Kouta Futai and Yuki Karasawa (Kanazawa University, Japan).
16:40–16:45	*Closing Remarks*, Hirofumi Notsu, Kanazawa University
16:30–18:00	Project / Free Discussion