

Data-driven methods for partial differential equations



Report of Contributions

Contribution ID: 2

Type: **Contributed poster**

Neural semi-Lagrangian method for high-dimensional advection-diffusion problems

Monday, March 2, 2026 6:15 PM (3 minutes)

We are interested in numerically solving high-dimensional advection-diffusion equations, such as kinetic equations or parametric problems. Traditional numerical methods suffer from the curse of dimensionality, as the number of degrees of freedom grows exponentially with dimension. Recently, methods based on neural networks have proven effective in reducing the number of degrees of freedom by enriching classical approximation spaces. In this presentation, we will introduce a semi-Lagrangian neural method: at each time step, it consists of advecting the solution exactly, following the characteristic curves of the equation, and projecting it onto the neural approximation space. We provide rough error estimates and present several high-dimensional numerical experiments to evaluate the performance of the method. This is a joint work with Emmanuel Franck, Victor Michel-Dansac and Vincent Vigon.

Authors: Mr FRANCK, Emmanuel (Inria, University of Strasbourg); Mr MICHEL-DANSAC, Victor (Inria, University of Strasbourg); NAVORET, Laurent (University of Strasbourg, Inria); Mr VIGON, Vincent (University of Strasbourg, Inria)

Presenter: NAVORET, Laurent (University of Strasbourg, Inria)

Session Classification: Poster blitz, poster session, and welcome reception

Contribution ID: 3

Type: **Invited talk**

On gradient stability in nonlinear PDE models and inference in interacting particle systems

Wednesday, March 4, 2026 8:30 AM (45 minutes)

We consider general parameter to solution maps $\theta \mapsto \mathcal{G}(\theta)$ of non-linear partial differential equations and describe an approach based on a Banach space version of the implicit function theorem to verify the gradient stability condition of Nickl & Wang (JEMS 2024) for the underlying non-linear inverse problem, providing also injectivity estimates and corresponding statistical identifiability results. We illustrate our methods in two examples involving a non-linear reaction diffusion system as well as a McKean–Vlasov interacting particle model, both with periodic boundary conditions. We apply our results to prove the polynomial time convergence of a Langevin-type algorithm sampling the posterior measure of the interaction potential arising from a discrete aggregate measurement of the interacting particle system.

Authors: CASTRE, Aurélien (University of Cambridge, DPMMS); NICKL, Richard

Presenter: CASTRE, Aurélien (University of Cambridge, DPMMS)

Session Classification: Invited talks 7

Contribution ID: 4

Type: **Invited talk**

Data-Driven Methods to Solve Maxwell's equations

Wednesday, March 4, 2026 9:15 AM (45 minutes)

Understanding and predicting solutions to Maxwell's equations lies at the heart of research in optics and photonics. Traditionally, mostly physics-based approaches were used for that purpose, i.e., analytical and, very often, numerical methods. However, over time, we have been accumulating plenty of data on structure-property relations, i.e., we know how a given optical structure responds to illumination. This growing resource opens the door to complementary, data-driven approaches for exploring electromagnetic scattering phenomena.

In this talk, we present an overview of our recent efforts to leverage such data for solving and interpreting optical scattering problems. We describe our progress in developing standardized formats for storing Maxwell-related data and in building a web-based database that enables broad access to curated scattering datasets. We further highlight several data-driven methodologies that range from surrogate modeling to generalization strategies, which exploit these datasets to address forward and inverse scattering tasks.

Our work is carried out in close collaboration with the wider optics community, with the goal of establishing shared infrastructure and best practices that advance data-centric research in photonics.

Authors: ROCKSTUHL, Carsten; Dr BOUSSAOURD, Kaoutar (Karlsruhe Institute of Technology); TRISTRAM, Frank (KIT); MEYER, Jörg (KIT); Ms ASADOVA, Nigar (Karlsruhe Institute of Technology)

Presenter: ROCKSTUHL, Carsten

Session Classification: Invited talks 7

Contribution ID: 5

Type: **Contributed poster**

Posterior contraction under misspecification and heteroskedasticity in non-linear inverse problems

Monday, March 2, 2026 6:21 PM (3 minutes)

In many practical and numerical inverse problems, the exact data log-likelihood is not fully accessible, motivating the use of surrogate likelihoods. We study heteroscedastic statistical nonparametric nonlinear inverse problems and establish posterior contraction results when inference is based on a surrogate log-likelihood constructed from proxy error variances and an approximate forward map. Under general assumptions on the approximation quality, we show that the resulting surrogate posterior is statistically reliable and contracts at rates comparable to those of the exact posterior. The analysis leverages consistency properties of the maximum a posteriori (MAP) estimator to effectively handle heteroscedastic noise and to control the impact of likelihood approximation errors. We apply the framework to PDE-constrained regression problems for a reaction–diffusion equation and the two-dimensional Navier–Stokes equations. In the latter case, we consider misspecified viscosity and forcing terms as well as Oseen-type linearization models, highlighting relevance for numerical analysis applications.

Authors: Ms SEIZILLES, Fanny (University of Cambridge); SIEBEL, Maximilian (Heidelberg University)

Presenter: SIEBEL, Maximilian (Heidelberg University)

Session Classification: Poster blitz, poster session, and welcome reception

Contribution ID: 6

Type: **Contributed poster**

Prediction error certification for PINNs: Theory, computation and application

Monday, March 2, 2026 6:18 PM (3 minutes)

We present two residual-based a posteriori error estimators for physics-informed neural networks (PINNs) that are applicable to the approximation of solutions of partial differential equations (PDEs) on complex geometries. Building on the semigroup-based framework introduced previously, we incorporate the concept of input-to-state stability (ISS), or suitable modifications thereof, to quantify how boundary residuals contribute to the overall prediction error. All quantities required by the estimators (semigroup decay rates, ISS gains, etc.) are extracted from a standard spatial discretization of the PDE and its associated operators. The approach is illustrated on two problems: the heat equation on a line, where the required parameters can be verified against analytically derived bounds, and the Stokes flow around a cylinder.

Authors: UNGER, Benjamin (Karlsruhe Institute of Technology); HILLEBRECHT, Birgit (KIT)

Presenter: HILLEBRECHT, Birgit (KIT)

Session Classification: Poster blitz, poster session, and welcome reception

Contribution ID: 7

Type: **Contributed poster**

Geometric Optimization in Scientific Machine Learning

Monday, March 2, 2026 6:24 PM (3 minutes)

We discuss an “optimize-then-project” approach for applications in scientific machine learning. The key idea is to design algorithms at the infinite-dimensional level and subsequently discretize them in the tangent space of the neural network ansatz, similar to a natural gradient style ansatz. We illustrate this approach in the context of the variational Monte Carlo method for quantum many-body problems, where neural quantum states have recently emerged as powerful representations of high-dimensional wavefunctions. In this setting, we recover the celebrated stochastic reconfiguration algorithm, interpreting it as a projected Riemannian L^2 gradient descent method. We further explore extensions to Riemannian Newton methods, and conclude with considerations related to the scalability of these schemes.

Author: MÜLLER, Johannes**Co-authors:** ZHANG, Hang (ETH Zurich); NYS, Jannes (ETH Zurich); CARRASQUILLA, Juan (ETH Zurich); ZEINHOFER, Marius (ETH Zurich); MISHRA, Siddhartha (ETH Zurich); ARMEGIOIU, Victor (ETH Zurich)**Presenter:** MÜLLER, Johannes**Session Classification:** Poster blitz, poster session, and welcome reception

Contribution ID: 8

Type: **Contributed poster**

Exploratory computation of statistical Navier–Stokes solutions

Monday, March 2, 2026 6:30 PM (3 minutes)

Global well-posedness for three-dimensional fluid flow equations remains a profound open problem. Recent efforts have shifted toward statistical solutions as a robust framework for describing turbulence, yet efficient computational tools to explore these solutions in three dimensions are scarce.

We develop novel stochastic numerical schemes to compute and analyze statistical solutions for three-dimensional incompressible flows. We combine entropy-stable lattice Boltzmann methods with Monte Carlo and stochastic Galerkin methods. By leveraging platform-agnostic development on heterogeneous high-performance computing systems, we efficiently target application-relevant flow configurations.

We present numerical results demonstrating the computational exploration of statistical solutions and their associated observables, including energy spectra, structure functions, and Wasserstein distances. Our goal is to validate the convergence of these statistical measures in regimes where deterministic simulations are nonunique. All developed methodologies are implemented in the open-source framework OpenLB to ensure public accessibility and sustainable reusability, including applications in training generative diffusion models and addressing complex engineering problems.

Authors: SIMONIS, Stephan (ETH Zurich); Mr GRAFEN, Johannes (Karlsruhe Institute of Technology)

Co-authors: Mr ROHNER, Tobias (ETH Zurich); Mr KUMBHAT, Arsh (ETH Zurich); Dr KRAUSE, Mathias (Karlsruhe Institute of Technology); Prof. FRANK, Martin (Karlsruhe Institute of Technology); Prof. MISHRA, Siddhartha (ETH Zurich)

Presenter: SIMONIS, Stephan (ETH Zurich)

Session Classification: Poster blitz, poster session, and welcome reception

Contribution ID: 9

Type: **Invited talk**

Learning stochastic reduced order models from data

Tuesday, March 3, 2026 4:00 PM (45 minutes)

We propose a non-intrusive model order reduction technique for stochastic differential equations with additive Gaussian noise. The method extends the operator inference framework and focuses on inferring reduced-order drift and diffusion coefficients by formulating and solving suitable least-squares problems based on observational data. Various subspace constructions based on the available data are compared.

We demonstrate that the reduced order model produced by the proposed non-intrusive approach closely approximates the intrusive ROM generated using proper orthogonal decomposition. Numerical experiments illustrate the performance by analyzing errors in expectation and covariance. This is joint work with Martin Nicolaus (Potsdam) and Martin Redmann (Rostock).

Author: FREITAG, Melina (University of Potsdam)

Presenter: FREITAG, Melina (University of Potsdam)

Session Classification: Invited talks 6

Contribution ID: 10

Type: **Contributed poster**

Hyperbolic Traffic Models with Uncertain Accident Dynamics

Monday, March 2, 2026 6:27 PM (3 minutes)

We consider hyperbolic partial differential equations (PDEs) with a space-dependent flux function to describe traffic flow dynamics. The PDE is coupled with a stochastic process modeling traffic accidents, thereby capturing the interplay between traffic dynamics and accident occurrence. This framework enables the analysis of accident risk and its consequences in road networks.

A key aspect of the modeling approach is the comparison of different stochastic processes for accident occurrence. Beyond a baseline accident risk, these processes allow for the modeling of short- and medium-term accident characteristics as well as subsequent accidents. In particular, we employ a self-exciting Hawkes process, originally introduced in earthquake modeling, as well as related process classes.

In this talk, we present numerical methods for solving the coupled system, with a focus on the statistical moments and long-time behavior of the accident process. The effectiveness of the proposed methods is demonstrated through numerical simulations. Finally, we validate the model using real-world accident data, highlighting the impact of self-excitation on traffic risk assessment.

Authors: TOSIN, Andrea; Prof. GÖTLICH, Simone; SCHILLINGER, Thomas (University of Mannheim)

Presenter: SCHILLINGER, Thomas (University of Mannheim)

Session Classification: Poster blitz, poster session, and welcome reception

Contribution ID: 11

Type: **Invited talk**

Finite-precision arithmetic in deep learning for scientific computing

Tuesday, March 3, 2026 8:30 AM (45 minutes)

Deep learning methods are increasingly deployed using low-precision arithmetic, primarily driven by memory, energy, and throughput constraints. At the same time, deep neural networks are highly compositional systems, a structure that naturally raises concerns about the amplification and accumulation of numerical errors across layers and operations. Nonetheless, such models are being applied at an increasing scale to problems in applied mathematics and engineering, where reliability and high numerical accuracy are essential. In this talk, we provide a broad overview of the challenges posed by finite-precision arithmetic in deep learning, identify scenarios in which reduced precision can lead to problematic behavior, and discuss strategies for mitigating associated risks.

Author: PETERSEN, Philipp (Universität Wien)

Presenter: PETERSEN, Philipp (Universität Wien)

Session Classification: Invited talks 3

Contribution ID: 12

Type: **Invited talk**

Data-driven reduced modeling of chaotic, turbulent, and stochastic systems via population dynamics

Tuesday, March 3, 2026 11:15 AM (45 minutes)

Learning models of time-dependent processes that generalize across initial conditions and parameter regimes is a key challenge in machine learning and the computational sciences. For chaotic, turbulent, and stochastic systems, modeling the dynamics of individual trajectories can be exceedingly challenging because trajectories can be erratic and irregular, and in stochastic settings may even be nowhere differentiable. Instead, we focus on learning population dynamics, which model how the distribution of the system states evolves over time. By learning population dynamics, we deliberately discard trajectory-specific information to obtain dynamics that are smoother and more well behaved than the underlying sample trajectories. We argue that this loss of information is an acceptable, principled form of reduced modeling because population-level statistics are maintained, and these are often the quantities that are of interest in scientific and engineering settings.

Author: PEHERSTORFER, Benjamin (Courant Institute of Mathematical Sciences, New York University)

Presenter: PEHERSTORFER, Benjamin (Courant Institute of Mathematical Sciences, New York University)

Session Classification: Invited talks 4

Contribution ID: 13

Type: **Invited talk**

A statistical tour of physics-informed learning

Monday, March 2, 2026 3:15 PM (45 minutes)

We will begin by discussing the limitations inherent in the training of Physics-Informed Neural Networks (PINNs), which, despite their conceptual appeal, often face practical challenges (such as convergence issues, sensitivity to hyperparameters, and the need of large data volume). In a second step, we will recast and characterize the problem of physics-informed learning as a kernel method. This reformulation allows us to draw upon the rich body of work in statistical learning theory, particularly kernel methods, to gain deeper theoretical insights into favorable mechanisms in physics-informed learning. Furthermore, it opens the door to the development of alternative approaches. In particular, it motivates the Physics-Informed Kernel Learning (PIKL) algorithm, which integrates PDE priors into the learning process in a more principled, theoretically grounded and potentially more robust manner. Finally, we have also developed a GPU-compatible implementation of PIKL, enabling large-scale learning and making the method practical for real-world scientific applications.

Author: Prof. BOYER, Claire (Université Paris-Saclay)

Presenter: Prof. BOYER, Claire (Université Paris-Saclay)

Session Classification: Invited talks 2

Contribution ID: 14

Type: **Invited talk**

Data assimilation with dissipative nonlinear dynamical systems: Optimal Gaussian asymptotics for the posterior measure

Tuesday, March 3, 2026 2:45 PM (45 minutes)

We consider a Bayesian update procedure to predict future states of infinite-dimensional non-linear dynamical systems. We focus on dissipative systems, in which information is lost exponentially fast over time. While, from an inverse problem perspective, this is expected to make inference difficult, it turns out to be extremely useful from a statistical perspective. When a Gaussian process prior is assigned to the initial condition of the system, we will explain how the posterior measure, which provides the update in the space of all trajectories arising from a discrete sample of the dynamics, is approximated by a Gaussian random field obtained as the solution to a linear parabolic PDE with Gaussian initial condition. This approximation holds in the strong sense of the supremum norm on the regression functions, showing that predicting future states of such systems admits root(N)-consistent estimators, even when a nonparametric model for the parameter is maintained. We further derive a functional minimax theorem that describes the Cramer-Rao lower bound for estimating the states of the system, which is attained by our data assimilation algorithm.

Author: KONEN, Dimitri (University of Cambridge)

Co-author: Prof. NICKL, Richard (University of Cambridge)

Presenter: KONEN, Dimitri (University of Cambridge)

Session Classification: Invited talks 5

Contribution ID: 16

Type: **Invited talk**

Solving time-dependent PDEs with random feature models

Monday, March 2, 2026 2:00 PM (45 minutes)

We discuss a sampling scheme for a data-dependent probability distribution of the parameters of neural networks. Such sampled networks are provably dense in the continuous functions, and have a convergence rate in the number of neurons that is independent of the input dimension. Using sampled neurons as basis functions in an ansatz allow us to use separation of variable schemes and effectively solve time-dependent partial differential equations. In computational experiments comparing training speed and accuracy, the sampling scheme outperforms iterative, gradient-based optimization by several orders of magnitude.

Author: DIETRICH, Felix

Presenter: DIETRICH, Felix

Session Classification: Invited talks 1

Contribution ID: 17

Type: **Invited talk**

AI for Efficient Simulations of PDEs

Monday, March 2, 2026 1:15 PM (45 minutes)

tba

Author: MISHRA, Siddhartha (ETH Zurich)

Presenter: MISHRA, Siddhartha (ETH Zurich)

Session Classification: Invited talks 1

Contribution ID: 18

Type: **Invited talk**

When do World Models Successfully Learn Dynamic Systems?

Monday, March 2, 2026 4:00 PM (45 minutes)

In this work, we explore the use of compact latent representations with learned time dynamics ('World Models') to simulate physical systems. Drawing on concepts from control theory, we propose a theoretical framework that explains why projecting time slices into a low-dimensional space and then concatenating to form a history ('Tokenization') is so effective at learning physics datasets, and characterise when exactly the underlying dynamics admit a reconstruction mapping from the history of previous tokenized frames to the next. To validate these claims, we develop a sequence of models with increasing complexity, starting with least-squares regression and progressing through simple linear layers, shallow adversarial learners, and ultimately full-scale generative adversarial networks (GANs). We evaluate these models on a variety of datasets, including modified forms of the heat and wave equations, the chaotic regime 2D Kuramoto-Sivashinsky equation, and a challenging computational fluid dynamics (CFD) dataset of a 2D Kármán vortex street around a fixed cylinder, where our model is successfully able to recreate the flow.

Author: GOTTSCHALK, Hanno (TU Berlin)

Presenter: GOTTSCHALK, Hanno (TU Berlin)

Session Classification: Invited talks 2

Contribution ID: 19

Type: **Invited talk**

Optimal Sensor Placement for Linear Inverse Problems via Measure Optimisation

Tuesday, March 3, 2026 9:15 AM (45 minutes)

In PDE-based inverse problems, only a limited number of sensors can be deployed, so choosing measurement locations is crucial, but the resulting design problem is highly nonconvex. This talk explores how we can lift sensor placement from selecting B points to optimising over probability measures on the design domain, giving a tractable relaxation with a Bayesian interpretation. We then solve the measure problem using particle-based Wasserstein gradient flows. We illustrate the approach on representative PDE-driven inverse problems.

Author: DUNCAN, Andrew (Imperial College London)

Presenter: DUNCAN, Andrew (Imperial College London)

Session Classification: Invited talks 3

Contribution ID: 20

Type: **Invited talk**

Structure-preserving model reduction: From the formulation on manifolds to data-driven realizations

Tuesday, March 3, 2026 10:30 AM (45 minutes)

Capturing and preserving physical properties, e.g., system energy, stability, and passivity, using data-driven methods is currently a highly researched topic in surrogate modeling. To ensure that the desired physical properties are retained, structure-preserving projection techniques are used in model order reduction (MOR).

In this talk, we present structure-preserving MOR with nonlinear projections, which are needed for problems with slowly decaying Kolmogorov n -widths. To precisely define and highlight the quantities we would like to retain, we start with a formulation of initial-value problems on manifolds, which we consider the full-order model (FOM). Already at this level, we define what we mean by adding structure to the FOM and how this can be detailed geometrically. This formalism allows to introduce a novel projection technique, the generalized manifold Galerkin (GMG). By adapting the underlying non-degenerate tensor field, this GMG projection can be used for a structure-preserving reduction of various initial value problems that give rise to interesting physical properties, including, but not limited to, Lagrangian and (port-)Hamiltonian systems.

Once we have derived the geometric formulation, we focus on data-driven ansatzes to realize the presented reduction methods. In this part of the talk, we will connect several existing data-driven techniques with GMG projections.

Author: GLAS, Silke (University of Twente)

Presenter: GLAS, Silke (University of Twente)

Session Classification: Invited talks 4

Contribution ID: 21

Type: **Invited talk**

Statistical Guarantees for Denoising Reflected Diffusion Models

Tuesday, March 3, 2026 4:45 PM (45 minutes)

Denoising diffusion models can be interpreted through stochastic dynamics closely related to time-dependent PDEs, yet their practical implementations often rely on truncation heuristics that lack theoretical justification. We study denoising diffusion models driven by reflected diffusions, which naturally confine the dynamics to bounded domains and remove this mismatch between theory and practice. Under Sobolev smoothness assumptions, we establish minimax-optimal convergence rates in total variation distance, up to polylogarithmic factors. The analysis combines spectral methods with quantitative neural network approximation results, yielding rigorous statistical guarantees for this class of data-driven stochastic models.

Author: STRAUCH, Claudia**Presenter:** STRAUCH, Claudia**Session Classification:** Invited talks 6

Contribution ID: 22

Type: **Invited talk**

Ensemble Kalman Methods for Optimization: Subspace Control, Subsampling, and Applications in Machine Learning and Optimal Control

Tuesday, March 3, 2026 2:00 PM (45 minutes)

tba

Author: SCHILLINGS, Claudia (FU Berlin)

Presenter: SCHILLINGS, Claudia (FU Berlin)

Session Classification: Invited talks 5