Ruiwen Shu – Curriculum Vitae

Address	4176 Campus Drive, College Park, MD 20742	**Email** **Website**	rshu at cscamm dot umd dot edu shuruiwen dot com

Education

2018-present Postdoctoral fellow - Department of Mathematics, University of Maryland, College Park

2014-2018 PhD - Department of Mathematics, University of Wisconsin-Madison
Major: Mathematics
Advisor: Prof. Shi Jin

2010-2014 Bachelor of Mathematics - School of Mathematical Sciences, Peking University
Major: Mathematics

Honors and awards

Nov 2017 **Excellence in Research Award** (UW-Madison)
for significant and substantial contributions to research in mathematics

July 2013 **Bronze Medal, L. -K. Hua Awards (Analysis)**
S.-T. Yau College Student Mathematics Contests
(Gold/Silver/Bronze=1/3/6)

Oct 2013 **Huirong Li Scholarship** (Peking University)

Oct 2012 **Wengang Li Scholarship** (Peking University)

Oct 2011 **Wusi Scholarship** (Peking University)

Sept 2010 **Outstanding Freshman Scholarship** (Peking University)

July 2009 **Silver Medal**, National Olympiad in Informatics (China)

Research interest

My research interests include uncertainty quantification and numerical methods for kinetic and hyperbolic problems.

Publications

[9] Jingwei Hu and Ruiwen Shu, *A second-order asymptotic-preserving and positivity-preserving exponential Runge-Kutta method for a class of stiff kinetic equations*, SIAM J. Sci. Comput., submitted.

We introduce a second-order time discretization method for stiff kinetic equations. The method is asymptotic-preserving (AP) – can capture the Euler limit without numerically resolving the small Knudsen number; and positivity-preserving – can preserve the non-negativity of the solution which is a probability density function for arbitrary Knudsen numbers. The method is based on a new formulation of the exponential Runge-Kutta method and can be applied to a large class of stiff kinetic equations including the BGK equation (relaxation type), the Fokker-Planck equation (diffusion type), and even the full Boltzmann equation (nonlinear integral type). Furthermore, we show that when coupled with suitable spatial discretizations the fully discrete scheme satisfies an entropy-decay property. Various numerical results are provided to demonstrate the theoretical properties of the method.

[8] Ruiwen Shu and Shi Jin, *A study of Landau damping with random initial inputs*, submitted.

For the Vlasov-Poisson equation with random uncertain initial data, we prove that the Landau damping solution given by the deterministic counterpart (Caglioti and Maffei, J. Stat. Phys., 92:301-323, 1998) depends smoothly on the random variable if the time asymptotic profile does, under the smoothness and smallness assumptions similar to the deterministic case. The main idea is to generalize the deterministic contraction argument to more complicated function spaces to estimate derivatives in space, velocity and random variables. This result suggests that the random space regularity can persist in long-time even in time-reversible nonlinear kinetic equations.

[7] Jingwei Hu, Ruiwen Shu and Xiangxiong Zhang, *Asymptotic-preserving and positivity-preserving implicit-explicit schemes for the stiff BGK equation*, SIAM J. Numer. Anal., to appear.

We develop a family of second-order implicit-explicit (IMEX) schemes for the stiff BGK kinetic equation. The method is asymptotic-preserving (can capture the Euler limit without numerically resolving the small Knudsen number) as well as positivity-preserving — a feature that is not possessed by any of the existing second or high order IMEX schemes. The method is based on the usual IMEX Runge-Kutta framework plus a key correction step utilizing the special structure of the BGK operator. Formal analysis is presented to demonstrate the property of the method and is supported by various numerical results. Moreover, we show that the method satisfies an entropy-decay property when coupled with suitable spatial discretizations. Additionally, we discuss the generalization of the method to some hyperbolic relaxation system and provide a strategy to extend the method to third order.

[6] Qin Li, Jian-Guo Liu and Ruiwen Shu, *Polynomial interpolation of Burgers' equation with randomness*, SIAM/ASA J. Uncertainty Quantification, submitted.

Generalized polynomial chaos (gPC) has been extensively used in uncertainty quantification problems to handle random variables. For gPC to be valid, one requires high regularity on the random space that hyperbolic type problems usually cannot provide, and thus it is believed to behave poorly in those systems. We provide a counter-argument in this paper, and show that despite the solution profile itself develops singularities in the random space, which prevents the use of gPC, the physical quantities such as shock emergence time, shock location, and shock width are all smooth functions of random variables in the initial data: with proper shifting, the solution's polynomial interpolation approximates with high accuracy. The studies were inspired by the stability results from hyperbolic systems. We use the Burgers' equation as an example for thorough analysis, and the analysis could be extended to general conservation laws with convex fluxes.

[5] Qin Li, Ruiwen Shu and Li Wang, *A new numerical approach to inverse transport equation with error analysis*, SIAM J. Numer. Anal., to appear.

The inverse radiative transfer problem finds broad applications in medical imaging, atmospheric science, astronomy, and many other areas. This problem intends to recover the optical properties, denoted as absorption and scattering coefficient of the media, through the source-measurement pairs. A typical computational approach is to form the inverse problem as a PDE-constraint optimization, with the minimizer being the to-be-recovered coefficients. The method is tested to be efficient in practice, but lacks analytical justification: there is no guarantee of the existence or uniqueness of the minimizer, and the error is hard to quantify. In this paper, we provide a different algorithm by levering the ideas from singular decomposition analysis. Our approach is to decompose the measurements into three components, two out of which encode the information of the two coefficients respectively. We then split the optimization problem into two subproblems and use those two components to recover the absorption and scattering coefficients separately. In this regard, we prove the well-posedness of the new optimization, and the error could be quantified with better precision. In the end, we incorporate the diffusive scaling and show that the error is harder to control in the diffusive limit.

[4] Ruiwen Shu and Shi Jin, *Uniform regularity in the random space and spectral accuracy of the stochastic Galerkin method for a kinetic-fluid two-phase flow model with random initial inputs in the light particle regime*, ESAIM Math. Model. Numer. Anal., to appear.

We consider a kinetic-fluid model with random initial inputs which describes disperse two-phase flows. In the light particle regime, using energy estimates, we prove the uniform regularity in the random space of the model for random initial data near the global equilibrium in some suitable Sobolev spaces, with the randomness in the initial particle distribution and fluid velocity. By hypocoercivity arguments, we prove that *the energy decays exponentially in time, which means that the long time behavior of the solution is insensitive to such randomness in the initial data. Then we consider the generalized polynomial chaos stochastic Galerkin method (gPC-sG) for the same model. For initial data near the global equilibrium and smooth enough in the physical and random spaces, we prove that the gPC-sG method has spectral accuracy, uniformly in time and the Knudsen number, and the error decays exponentially in time.*

[3] Jingwei Hu, Shi Jin and Ruiwen Shu, *A stochastic Galerkin method for the Fokker-Planck-Landau equation with random uncertainties*, Proc. 16th Int'l Conf. on Hyperbolic Problems, to appear.

We propose a generalized polynomial chaos based stochastic Galerkin method (gPC-sG) for the Fokker-Planck-Landau (FPL) equation with random uncertainties. The method can handle uncertainties from initial or boundary data and the neutralizing background. By a gPC expansion and the Galerkin projection, we convert the FPL equation with uncertainty into a system of deterministic equations. A consistency result is proven for the approximation of the collision operator. To compute efficiently the collision kernel under the gPC expansion, we use a singular value decomposition (SVD) combined with a fast spectral method for the collision operator. For high dimensional random inputs, we adopt a sparse basis and use the sparsity of a set of basis related coefficients and the Lax-Friedrichs splitting to avoid all the SVD involved. Numerical experiments verify the efficiency of the gPC-sG method.

[2] Ruiwen Shu, Jingwei Hu and Shi Jin, *A Stochastic Galerkin Method for the Boltzmann Equation with multi-dimensional random inputs using sparse wavelet bases*, Numer. Math. Theor. Meth. Appl. (NMTMA) 10, 465-488, 2017. (A special issue in honor of the 80th birthday of Prof. Zhenhuan Teng)

We propose a stochastic Galerkin method using sparse wavelet bases for the Boltzmann equation with multi-dimensional random inputs. The method uses locally supported piecewise polynomials as an orthonormal basis of the random space. By a sparse approach, only a moderate number of basis functions is required to achieve good accuracy in multi-dimensional random spaces. We discover a sparse structure of a set of basis-related coefficients, which allows us to accelerate the computation of the collision operator. Regularity of the solution of the Boltzmann equation in the random space and an accuracy result of the stochastic Galerkin method are proved in multi-dimensional cases. The efficiency of the method is illustrated by numerical examples with uncertainties from the initial data, boundary data and collision kernel.

[1] Shi Jin and Ruiwen Shu, *A stochastic Asymptotic-Preserving scheme for a kinetic-fluid model for disperse two-phase flows with uncertainty*, J. Comput. Phys., 335, 905-924, 2017.

In this paper we consider a kinetic-fluid model for disperse two-phase flows with uncertainty. We propose a stochastic asymptotic-preserving (s-AP) scheme in the generalized polynomial chaos stochastic Galerkin (gPC-sG) framework, which allows the efficient computation of the problem in both kinetic and hydrodynamic regimes. The s-AP property is proved by deriving the equilibrium of the gPC version of the Fokker-Planck operator. The coefficient matrices that arise in a Helmholtz equation and a Poisson equation, essential ingredients of the algorithms, are proved to be positive definite under reasonable and mild assumptions. The computation of the gPC version of a translation operator that arises in the inversion of the Fokker-Planck operator is accelerated by a spectrally accurate splitting method. Numerical examples illustrate the s-AP property and the efficiency of the gPC-sG method in various asymptotic regimes.

Invited conference talks

2018 Feb Young Researchers Workshop: Kinetic models in biology and social sciences, Arizona State University

2017 Oct Hypocoercivity and Sensitivity Analysis in Kinetic Equations and Uncertainty Quantification, UW-Madison

2017 July International Conference on Uncertainty Quantification in Computational Fluid Dynamics, SJTU, China

2017 Feb 2017 SIAM Conference on Computational Science and Engineering, Atlanta, GA (minisymposium)

Contributed conference talks

2016 Aug	XVI International Conference on Hyperbolic Problems, Aachen, Germany

Attended conferences and summer schools

2018 Jun	International workshop on Kinetic Theory and Related Topics, TSIMF, China
2018 Mar	Workshop on kinetic and fluid Partial Differential Equations, Univ. Paris Descartes and Univ. Paris Diderot, France
2017 July	Summer School on Applied and Stochastic Analysis for Partial Differential Equations, SJTU, China
2017 Apr	Pre-School on Stochastic Dynamics out of Equilibrium, CIRM, France
2017 Jan	IPAM Big Data Meets Computation Program, UCLA
2016 July	Conference on Quantum and Kinetic Transport, SJTU, China
2016 Jun	Summer School on Quantum and Kinetic Theory for Complex Systems, UCSB
2016 Apr	Boundary Value Problems and Multiscale Coupling Methods for Kinetic Equations, UW-Madison
2016 Feb	Advances in Kinetic and Fluid Dynamics Transport: Analysis and Approximations, UT-Austin
2015 Nov	Young Researchers Workshop: Kinetic Theory with Applications in Physical Sciences, CSCAMM
2015 May	Asymptotic Preserving and Multiscale Methods for Kinetic and Hyperbolic Problems, UW-Madison

Teaching (as teaching assistant, at UW-Madison)

Fall 2017-2018	Math 234 (Calculus 3)
Fall 2016-2017	Math 222 (Calculus 2), rated ’Superior’
Fall 2015-2016	Math 234 (Calculus 3), rated ’Superior’
Spring 2014-2015	Math 221 (Calculus 1), rated ’Satisfactory Plus’
Fall 2014-2015	Math 221 (Calculus 1), rated ’Satisfactory Plus’