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A High Order Multi-Scale Numerical Approach for Kinetic Simulations

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UNIVERSITY OF HOUSTON SYSTEM

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Final Report

Air Force Research Laboratory
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14. ABSTRACT

The PI has made her eort in developing robust, ecient and high order multi-scale numerical algorithms for kinetic equations with her group members. Truly multi-scale and multi-dimensional approaches have been developed for the kinetic simulations with potential applications to plasma physics and rareed gas dynamics. During 2012-2015, the PI and her group members have published/submitted sixteen papers in top journals in the eld. These include eight papers published in Journal of Computational Physics, two papers published in Journal of Scientic Computing, one paper published in SIAM Journal on Scientic Computing, one paper published in SIAM Journal on Numerical analysis, one paper published in Monthly Weather Review, and three papers being submitted/under revision.

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Final Performance Report:
A High Order Multi-scale Numerical Approach for Kinetic Simulations

FA9550-12-1-0318 (YIP)

Jing-Mei Qiu
Department of Mathematics
University of Houston

Status/Progress of the Project FA9550-12-1-0318 (08/01/2012-06/14/2015)

Objectives. This is a three-year YIP project from Dr. Jing-Mei Qiu from University of Houston. We propose to develop a very high order mesh-based numerical method for multi-scale kinetic simulations.

Status of effort. The PI has made her effort in developing robust, efficient and high order multi-scale numerical algorithms for kinetic equations with her group members. Truly multi-scale and multi-dimensional approaches have been developed for the kinetic simulations with potential applications to plasma physics and rarefied gas dynamics. During 2012-2015, the PI and her group members have published/submitted sixteen papers in top journals in the field. These include eight papers published in Journal of Computational Physics, two papers published in Journal of Scientific Computing, one paper published in SIAM Journal on Scientific Computing, one paper published in SIAM Journal on Numerical analysis, one paper published in Monthly Weather Review, and three papers being submitted/under revision.

Accomplishments/New Findings. The PI, together with her group members, have been involved in the following research activities in the development, analysis and applications of efficient, robust and high order numerical approaches for kinetic-scale, hydrodynamic-scale and multi-scale simulations. In particular, the following topics are being pursued.

1. Development and analysis of high order asymptotic preserving schemes for kinetic equations in the diffusive and hyperbolic limits, see our publications [7, 11, 16].

2. Development and analysis of high order maximum principle preserving and positivity preserving methods for convection-diffusion equations. Specific schemes we consider include the high order finite difference, finite volume and finite element DG methods, see our publications [4, 12, 13, 14].

3. Development of high order DG schemes with kinetic fluxes for Navier-Stokes (NS) equations, see our publications [8].

4. Development of semi-Lagrangian discontinuous Galerkin (DG) on the cubed sphere on global transport problem, see our publications [5].

5. Error analysis of integral deferred correction method for solving stiff problems, such as singular perturbation problems. Specific schemes we consider are implicit Runge-Kutta (RK) methods for stiff problems and implicit-explicit RK methods for temporal multi-scale problems, see our publications [10].

Personnel Supported. The PI is supported by this grant via one month summer salary per year. Besides, one postdoc associate (Dr. Tao Xiong), one research associates (Dr. Hongqiang Zhu) and one graduate student (Mr. Xiaofeng Cai) are either fully or partially supported by this grant.

Publications. There are thirteen papers published/accepted in top journals in the field, since the project has been funded in 2012.

1. Hybrid semi-Lagrangian finite element-finite difference methods for the Vlasov equation, W. Guo and J.-M. Qiu, Journal of Computational Physics, v234 (2013), Pages 108-132.

2. Superconvergence of discontinuous Galerkin and local discontinuous Galerkin methods: eigen-structure analysis based on Fourier approach , W. Guo, X.-H. Zhong and J.-M. Qiu, Journal of Computational Physics, v235(2013), Pages 458-485.

3. A Conservative Semi-Lagrangian Discontinuous Galerkin Scheme on the Cubed-Sphere, W. Guo, R. Nair and J.-M. Qiu, Monthly Weather Review, 142 (2014), Pages 457-475.

4. A parametrized maximum principle preserving flux limiter for finite difference RK-WENO schemes with applications in incompressible flows, T. Xiong, J.-M. Qiu and Z. Xu, Journal of Computational Physics, v252(2013), Pages 310-331.

5. A Conservative Semi-Lagrangian Discontinuous Galerkin Scheme on the Cubed-Sphere, W. Guo, R. Nair and J.-M. Qiu, Monthly Weather Review, 142 (2014), Pages 457-475.

6. A High Order Time Splitting Method Based on Integral Deferred Correction for Semi-Lagrangian Vlasov Simulations, A. Christlieb, W. Guo, M. Morton, J.-M. Qiu, Journal of Computational Physics, v267(2014), Pages 7-27.

7. Analysis of Asymptotic Preserving DG-IMEX Schemes for Linear Kinetic Transport Equations in a Diffusive Scaling, J. Jang, F. Li, J.-M. Qiu, T. Xiong, SIAM Numerical Analysis, v52 (2014), pp. 1497-2206.

8. Runge-Kutta Central Discontinuous Galerkin BGK Method for the Navier-Stokes Equations, T. Ren, J. Hu, T.Xiong and J.-M. Qiu, Journal of Computational Physics, v274 (2014), Pages 592610. .

9. Runge-Kutta Discontinuous Galerkin Method for Traffic Flow Model on Networks, S. Canic, B. Piccoli, J.-M. Qiu and T. Ren, Journal of Scientific Computing, accepted.

10. High Order Asymptotic Preserving Discontinuous Galerkin Schemes for Discrete-Velocity Kinetic Equations in the Diffusive Scaling, J. Jang, F. Li, J.-M. Qiu, T. Xiong, Journal of Computational Physics, v281 (2015), Pages 199224.

11. High order maximum principle preserving discontinuous Galerkin method for convection-diffusion equations, T. Xiong, J.-M. Qiu and Z. Xu, SIAM Journal on Scientific Computing, v37(2), 2015, Pages 583-608.

12. A New Lax-Wendroff Discontinuous Galerkin Method with Superconvergence, W. Guo, J.-M. Qiu and J.-X. Qiu, Journal of Scientific Computing, accepted.

13. High Order Asymptotic Preserving Nodal Discontinuous Galerkin IMEX Schemes for the BGK Equation, T. Xiong, J. Jang, F. Li and J.-M. Qiu, Journal of Computational Physics, v284 (2015), Pages 7094.

In addition, there are three papers that are under revision.

14. Error Estimate of Integral Deferred Correction Implicit Runge-Kutta method for Stiff Problems, S. Boscarino, J.-M. Qiu, in revision, M2AN.

15. Parametrized Positivity Preserving Flux Limiters for the High Order Finite Difference WENO Scheme Solving Compressible Euler Equations, in revision, T. Xiong, J.-M. Qiu, Z. Xu, submitted.

16. High order maximum principle preserving finite volume method for convection dominated problems, P. Yang, T. Xiong, J.-M. Qiu and Z. Xu, submitted.

Participation/presentations at meetings, conferences, seminars, etc. The PI has actively participated in national and international conferences and meetings, especially those related to the topic of the proposed project on "kinetic and plasma simulations". These include the following.

1. 2012 Young Researchers Workshop: Kinetic Description of Model Scale phonomena, Department of Mathematics, University of Wisconsin-Madison, Madison, WI, Oct. 10-13, 2012.

2. Colloquium, Rice University, Houston, TX, Nov. 26th, 2012.

3. AMS Spring Central Section at Iowa State University (ISU), IA, April 28th, 2013.

4. The Second Workshop on Development and Application of High-Order Numerical Methods, Xiamen, China, May 18-21, 2013.

5. The Mathematics of Finite Elements and Applications, Brunel University, England, June 11-14th, 2013.

6. Program review, Air Force Office of Scientific Research Computational Mathematics, Arlington, VA, July 29, 2013.

7. Invited speaker, SIAM Conference on Analysis of Partial Differential Equations, Orlando, FL, December 7-10, 2013.

8. Colloquium speaker, University of Maryland, Baltimore County, MD, Feb. 18th, 2014.

9. Colloquium speaker, University of Kentucky, KY, Feb. 20th, 2014.

10. Invited speaker, Algorithm and Model Verification and Validation For Kinetic and Gyrokinetic Plasma Simulation Codes, Max-Plank Institute for plasma physics, Garching, Germany, April 8-10, 2014.

11. Invited speaker, Numerical methods for stiff problems in partial differential equations, ECMI 2014 - European Consortium for Mathematics in Industry, Taormina, Italy, June 9 - 13, 2014.

12. Program review, Air Force Office of Scientific Research Computational Mathematics, Arlington, VA, July 31st, 2014.

13. Scientific Computing Seminar, Texas A&M University, College State, TX, January 28th, 2015.

14. Graduate colloquium, University of Houston, Houston, TX, Feburary 20th, 2015.

15. Colloquium speaker, Indiana University at Bloomington, Bloomington, IN, Feb. 26th, 2015.

16. Colloquium speaker, Michigan State University, East Lansing, MI, March 4th, 2015.

17. Program review, Air Force Office of Scientific Research Computational Mathematics, Arlington, VA, August 5th, 2015.

From:	Jingmei Qiu
To:	AFRL/AFOSR Technical Reports; CAMBIER, JEANLUC DR-04 USAF AFMC AFOSR/RTA2
Cc:	Jingmei Qiu
Subject:	Performance Report to Dr. Jean-Luc Cambier (FA9550-12-1-0318 (YIP))
Date:	Tuesday, August 11, 2015 2:07:26 PM
Attachments:	report_Qiu_YIP_2015.pdf

Dear Jean-Luc,

Attached please find my performance report for the YIP project. This email is also sent to technicalreports@afosr.af.mil . If you need additional information, please let me know.

Thank you very much for the support for our research!!!

Best regards,
Jingmei