# CURRICULUM VITAE ET STUDIORUM

of GIOVANNI RUSSO

July 17, 2014

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## 1 Personal data

Born in Palermo, Italy, on January 11, 1958.
Full professor of Numerical Analysis, Faculty of Science, University of Catania, Italy


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## 2 Education and employment

2000-present Full professor of Numerical analysis, University of Catania.

2001-2006 Member of the editorial board of SIAM J. Numer. Anal.

1992-2000 Associate professor of Numerical Analysis and Applied Mathematics, Faculty of Science, University of L'Aquila, Italy.

1990-1992 Researcher in Mathematical Physics, Faculty of Science, University of L'Aquila, Italy.

1987-1990 Post-doctoral position at the Courant Institute of Mathematical Science, New York University.

1987 Philosophy Doctor in Phyisics, University of Catania, Italy. Supervisor, prof. A.M.Anile.

1982-1983 Post graduate research in Solid State Physics, Physics Institute, University of Catania (supervision prof. E.Rimini).

1982 Laurea degree, *Magna cum Laude*, in Nuclear Engineering, Politecnico di Milano, Milano, Italy.

## 3 Teaching activity

### 3.1 Courses, for each year

1990-91 Teaching assistence (in Italian *Esercitazioni*) in Classical Mechanics for students in Physics;

1991-92 Teaching assistence in Classical Mechanics for students in Physics;

1992-93 one year course on Approximation Methods (lectures and exercises) for students in Computer Science and Mathematics.

1993-94 one year course on Approximation Methods (lectures and exercises) for students in Computer Science and Mathematics, one six-month course of Basic Numerical Analysis (only lectures) for students in Computer Science;

1993-94 one year course on Approximation Methods (lectures and exercises) for students in Computer Science and Mathematics, one six-month course of Basic Numerical Analysis (only lectures) for students in Computer Science;

1994-95 one year course on Approximation Methods (lectures and exercises) for students in Computer Science and Mathematics, one six-month course of Basic Numerical Analysis (only lectures) for students in Computer Science;

1995-96 one year course on Approximation Methods (lectures and exercises) for students in Computer Science and Mathematics, one six-month course of Basic Numerical Analysis (only lectures) for students in Computer Science

1996-97 two six-month courses in Numerical Analysis for students in Mathematics (lectures and exercises) and one six-month course in Numerical Analysis I for students in Computer Science;

1997-98 two six-month courses in Approximation Methods (I and II) for students Informatics and Mathematics, one six-month course in Numerical Analysis II (only lectures) for students in Informatics and Mathematics, one six-month course in Basic Numerical Methods II for *Diplima* in Material Science.

1998-99 two six-month courses in Approximation Methods (I and II) for students Informatics and Mathematics, one six-month course in Numerical Analysis II (only lectures) for students in Informatics and Mathematics, one six-month course in Basic Numerical Methods II for *Diploma* in Material Science.

1999-2000 two six-month courses in Approximation Methods (I and II) for students Informatics and Mathematics, one six-month course in Numerical Analysis II (only lectures) for students in Informatics and Mathematics, two six-month course in Basic Numerical Methods (I and II) for *Diplima* in Material Science.

2000 Short course on Numerical Methods (30 hours) for the students of *Scuola Superiore per la Formazione d'Eccellenza* (SSC), University of Catania.

2000-2001 One year course in Numerical Analysis (lectures and exercises) for students in Mathematics.

2001-2002 One year course in Numerical Analysis (lectures and exercises) for students in Mathematics.

2002 Short course on Numerical Methods (30 hours) for the students of *Scuola Superiore per la Formazione d'Eccellenza* (SSC), University of Catania.

2002 Six-month (50 hour) course on *Analysis, design, and didactic simulation in Mathematics, II*, in the framework of the courses for high school teachers *Scuola Interuniversitaria Siciliana di Specializzazione per l'Insegnamento nella Scuola Secondaria* (SISSIS).

2002-2003 One year course in Numerical Analysis (lectures and exercises) for students in Mathematics. One six-month course in Numerical Analysis II for students in Informatics.

2003 Short course on Numerical Methods (30 hours) for the students of *Scuola Superiore per la Formazione d'Eccellenza* (SSC), University of Catania.

2002 Three-month (25 hour) course on *Topics in Numerical Analyis*, in the framework of the courses for high school teachers (SISSIS).

2003-2004 One six-month course in Numerical Analysis (lectures and exercises) for students in Mathematics and Informatics.

2004 Short course on Numerical Methods (30 hours) for the students of *Scuola Superiore per la Formazione d'Eccellenza* (SSC), University of Catania.

2004 Three-month (25 hour) course on *Topics in Numerical Analyis*, in the framework of the courses for high school teachers (SISSIS).

2004 Four month course in Numerical Methods in Engineering, Math#371 (two sessions) at the University of Michigan, Ann Arbor, Michigan.

2004-2005 Six-month course on *Computer programming and numerical methods*, for the students of Mathematics.

2005 Short course on Numerical Methods (30 hours) for the students of *Scuola Superiore per la Formazione d'Eccellenza* (SSC), University of Catania.

2005 Short course (12 hours) on numerical methods for partial differential equation, for PhD students in Engineering.

2005 Three-month (25 hour) course on *Topics in Numerical Analyis*, in the framework of the courses for high school teachers (SISSIS).

2005-2006 Six-month course on *Computer programming and numerical methods*, for the students of Mathematics.

2005-2006 One six-month course in Numerical Analysis (lectures and exercises) for students in Mathematics.

2006 Short course on Numerical Methods (30 hours) for the students of *Scuola Superiore per la Formazione d'Eccellenza* (SSC), University of Catania.

2006 Three-month (25 hour) course on *Topics in Numerical Analyis*, in the framework of the courses for high school teachers (SISSIS).

2006 Short course (12 hours) on numerical methods for partial differential equation, for the PhD program in Mathematics for Technology.

2006-2007 One six-month course in Approximation Methods (lectures and exercises) for students in Mathematics.

2006-2007 One six-month course in Numerical Analysis II (lectures and exercises) for students in Mathematics.

2006-2007 One six-month course in Numerical Analysis (lectures and exercises) for students in Mathematics.

2007 Short course on Numerical Methods (30 hours) for the students of *Scuola Superiore per la Formazione d'Eccellenza* (SSC), University of Catania.

2007 Three-month (25 hour) course on *Topics in Numerical Analyis*, in the framework of the courses for high school teachers (SISSIS).

2007-2008 One six-month course in Numerical Analysis (lectures and exercises) for students in Mathematics.

2008 Short course on Computational Mathematics (30 hours) for the students of *Scuola Superiore per la Formazione d'Eccellenza* (SSC), University of Catania.

2008 Three-month (25 hour) course on *Topics in Numerical Analyis*, in the framework of the courses for high school teachers (SISSIS).

2008-2009 One six-month course in Numerical Analysis (lectures and exercises) for students in Mathematics.

2009 Three-month (25 hour) course on *Topics in Numerical Analyis*, in the framework of the courses for high school teachers (SISSIS).

2009-2010 One six-month course in Numerical Analysis (lectures and exercises) for students in Mathematics.

2010 Short course on Computational Mathematics (30 hours) for the students of *Scuola Superiore per la Formazione d'Eccellenza* (SSC), University of Catania.

2010-2011 One six-month course in Numerical Analysis (lectures and exercises) for students in Mathematics, and one six-moth master course on numerical methods for ordinary and partial differentiale equations for students in Mathematics.

2011 Short course on Computational Mathematics (30 hours) for the students of *Scuola Superiore per la Formazione d'Eccellenza* (SSC), University of Catania.

2011-2012 One six-month course in Numerical Analysis (lectures and exercises) for students in Mathematics, and one six-moth master course on numerical methods for ordinary and partial differentiale equations for students in Mathematics.

2012 Short course on Numerical Methods for Ordinary and Partial Differential Equations (30 hours) for the students of *Scuola Superiore per la Formazione d'Eccellenza* (SSC), University of Catania.

# 4 Scientific activity

## 4.1 Experience abroad

1987-1990 *Post doctoral position*, Courant Institute of Mathematical Sciences, New York University, New York.

1987 October: *visiting* by the Fachbereich Mathematik, Universität Kaiserslautern.

1991-1992 October 1991 - January 1992, and August-September 1992: *post-doctoral position*, Department of Mathematics, University of California, Los Angeles, invited by Prof. Caflisch. January 1992: (one week) Institute for Advanced, Study, Princeton, NJ, invited by Prof. J. Strain. July 1992: *visiting*, Fachbereich Mathematik, Universität Kaiserslautern, invited by Prof. H. Neunzert.

1993 July-August: *visiting*, Department of Mathematics, University of California, Los Angeles. August: Department of Mathematrics, University of Wyoming, Laramie, WY, USA, invited by del Prof. T. Mathew. September-October: *visiting*, Fachbereich Mathematik, Universität Kaiserslautern.

1994 July-August: *visiting*, Department of Mathematics, University of California, Los Angeles.

1995 Febbraio-Marzo: Institute for Advanced Study di Priceton, NJ, invited by Prof. David Levermore. July-August: *visiting*, Department of Mathematics, University of Michigan, invited by Prof. P. Smereka. October: *visiting*, Fachbereich Mathematik, Universität Kaiserslautern.

1996 July-August: *visiting*, Department of Mathematics, University of Michigan.

1997 July-August: *visiting*, Department of Mathematics, University of Michigan. September: two-week visit, l'Université Paris VI, invited by Prof. B. Perthame.

1998 January: *visiting* , Department of Mathematics, University of California, Los Angeles. February: *visiting*, Université Paul Sabatier, Toulouse, France, invited by Prof. Pierre Degond. July-August: *visiting*, Department of Mathematics, University of Michigan; Department of Mathematics, University of California, Los Angeles; Department of Mathematics, University of Wyoming.

1998-99 October 1998-February 1999: *visiting* , Department of Mathematics, University of Michigan.

1999 August-September: *visiting* , Department of Mathematics, University of Michigan.

2001 July-August: Department of Mathematics, University of Michigan; Department of Mathematics, University of California, Berkeley (one week), invited by Prof. Strain.

2002 May: Department of Mathematics, University of Michigan.

2003 August: Department of Mathematics, University of Michigan.

2004 September-December: visiting professor, Department of Mathematics, University of Michigan.

2005 February, June, September (one week each time): invited by Prof. Ernst Hairer, Department of Mathematics, University of Geneva, Switzerland.
July: Department of Mathematics, University of Michigan.

2006 March (two weeks): invited by Prof. Kazuo Aoki, Department of Aeronautics and Astronautics, Faculty of Engineering, Kyoto University, Kyoto, Japan.
August: Department of Mathematics, University of Michigan.

2007 February-March (one month): visiting professor, Department of Mathematics, University of Lyon, France, invited by Prof. Francis Filbet.
August: Department of Mathematics, University of Michigan.

2008 June (one week): visiting, Department of Mathematics, University of Michigan.

2009 August (one month): visiting professor, Department of Mathematics, University of Michigan.

2010 August (one month): visiting professor, Department of Mathematics, University of Michigan.

2011 August (three weeks): visiting professor, Department of Mathematics, University of Michigan.

2012 August (three weeks): visiting professor, Department of Mathematics, University of Michigan.

## 4.2 Conferences

Prof. Russo participated to several conferences and summer schools.
The list of invited talks follows.

1. Invited: "A particle method for collisional kinetic equation", 1988 AMS SIAM Summer Seminar, Colorado State University, Fort Collins, Colorado, 18-29 Luglio, 1988.

2. Seminar: "A Lagrangian Scheme for Collisional Kinetic Equations", Numerical Analysis Seminar, Courant Institute of Marhematical Sciences, New York, 11 Novembre 1988.

3. Invited: "Implicit Particle Methods for the Heat and Navier-Stokes Equations", International Conference on "Preconditioning techniques on large sparse linear systems", Cortona, Italy, September 28–October 2,1992.

4. Invited: "Fast Triangulated Vortex Methods for the 2D Euler Equations", Eutomech 305, Ercoftac workshop on "Dynamics and Geometry of Vortical Structures", Cortona, June 28–July 2, 1993.

5. Minisymposium: "Free Lagrangian Vortex Methods for Incompressible Euler and Navier-Stokes Equations", 1993 SIAM Annual Meeting, Philadelphia, PA, July 12-16, 1993.

6. Invited: "Kinetic Theory of Bubbly Flow", Workshop on "Exotic application of kinetic theory", Kaiserslautern, September 27–29, 1993.

7. Invited: "Kinetic Theory for Bubbly Flow", International Conference on "Nonlinear Equations in Many-Particle Systems", Mathematisches Forschungsinstitut Oberwolfach, Oberwolfach, Germany, November 28–December 3, 1993.

8. Minisymposium: "Uniformly Accurate Schemes for Hyperbolic Systems with Relaxation", 1994 SIAM Annual Meeting, San Diego, CA, July 25-29, 1996.

9. Invited: "Schemi uniformemente accurati per sistemi iperbolici con rilassamento", Giornate di studio su problemi iperbolici, Milano, Italy, October 6–7, 1994.

10. Invited: "A Lagrangian Numerical Method for Fluid-Membrane Interaction in 2D and 3D", Forum on Vortex Mathods for Engineering Applications, Albuquerque, New Mexico, February 22–24, 1995.

11. Invited: "Kinetic Theory of Bubbly Flow", French workshop "Couplage Equations", Saint Malo, March 20–21, 1995.

12. Invited: "Metodi numerici basati su una formulazione Hamiltoniana per il trattamento della interazione fluido-membrana in 2D e 3D", Giornate di studio su problemi differenziali iperbolici, Bologna, 9–10 Novembre 1995.

13. Minisymposium: "High Order Methods for Balance Laws", 1996 SIAM Annual Meeting, Kansas City, Missouri, July 22-26, 1996.

14. Invited: "A Vlasov-Boltzmann Equation for Bubbly Flow", Analytische und numerische Approximationsmethoden für Probleme der Plasmaphysik, der Physik verdünnter Gase und von Halbleitern, Mathematisches Forschungsinstitut Oberwolfach, Oberwolfach, Germany, May 12–18, 1996.

15. Minisymposium: "Metodi Numerici per Modelli Idrodinamici dei Semiconduttori", III Congresso Nazionale della SIMAI, Salice Terme (Pavia), May 27-31, 1996.

16. Minisymposium: "Metodi Numerici per Sistemi Iperbolici con Rilassamento", III Congresso Nazionale della SIMAI, Salice Terme (Pavia), 27-31 Maggio 1996.

17. Invited: "High order methods for balance laws", workshop on Numerical Methods for Kinetic Equations, Weierstrass-Institut für Angewandte Analysis und Stochastik, Berlin, September 1–5, 1997.

18. Minisymposium: "On the impulse formulation of the Euler equations", IX International Conference on Waves and Stability in Continuous Media, Bari, Octber 6–11, 1997.

19. Invited: "High order central schemes for hyperbolic systems of conservation laws", IPERAQ97, V Incontro Nazionale sui Problemi di tipo Iperbolico, L'Aquila, November 11–13, 1997.

20. Invited: "High order central schemes for hyperbolic systems of conservation laws", International school on "Problemes non lineaires appliques 1998, Systemes hyperboliques: Noveaux Schemas et nouvelles applications", INRIA Rocquencourt, France, March 16–19, 1998.

21. Invited: "Hydrodynamic models for semiconductor device simulations", Workshop on "Hyperbolic aspects of moment closure problems", FORTH, Heraklion, Crete, Greece, April 1–4, 1998.

22. Invited: "Hydrodynamic models for semiconductor device simulations", First European Symposium on Applied Kinetic Theory, Toulouse, May 6–7, 1998.

23. Invited: "Kinetc Theory of Bubbly Flow", IV Congresso Nazionale SIMAI, Giardini di Naxos (ME), Italy, June 1–5, 1998.

24. Invited: "An Implicit Monte Carlo Method for Rarefied Gas Dynamics", Fifth International Workhop on Mathematical Aspects of Fluid and Plasma Dynamics, Wailea, Maui, Hawaii, June 28–July 3, 1998.

25. Plenary: "Schemi centrali per leggi di bilancio", IPERPV98, VI Incontro Nazionale sui Problemi di Tipo Iperbolico, Pavia, Italy, October 1–3, 1998.

26. Invited: "Implicit Monte Carlo Methods for Rarefied Gas Dynamics", workshop on "Analytical techniques and asymptotic methods for kinetic problems", Vienna, October 5–8, 1998.

27. Minisymposium: "Impulse formulation of the Euler equations and fluid-membrane interaction", International Conference on Industrial and Applied Mathematics (ICIAM) '99, Edimburgh, July 5–9, 1999.

28. Minisymposium: "Spectral methods for the Boltzmann equation", ICIAM '99, Edimburgh, July 5–9, 1999.

29. Invited: "Time relaxed Monte Carlo methods for the Boltzmann equation", International Congress on "Nonlinear Equations in Many-Particle Systems", Mathematisches Forschungsinstitut Oberwolfach, Oberwolfach, Germany, December 5–11, 1999.

30. Invited: "Numerical methods for the Boltzmann equation", International Workshop for numerical methods for Kinetic and Hyperbolic Equations, Ferrara, December 17–18, 1999.

31. Plenary: "Central schemes for balance laws", HYP2000, Eighth International Conference on Hyperbolic Problems, Theory, Numerics, Applications, Otto-von-Guericke-Universität Magdeburg, February 28–March 3, 2000.

32. Invited: "Central schemes for balance laws", HCL2000, TMR Workshop on Numerical Methods for Hyperbolic Conservation Laws, Valencia, Spain, May 10–12, 2000.

33. Minisymposium: "Implicit-Explicit Runge-Kutta schemes for stiff systems of partial differential dquations", WCNA2000, World Congress of Nonlinear Analysis, Catania, Italy, July 19–26, 2000.

34. Invited: "Implicit-Explicit Runge-Kutta schemes for stiff systems of partial differential equations", final meeting of the European Network for Training, Mobility, and Research on Nonlinear Hyperbolic Problems, September 11–13, 2000, Ecole Normale SupÃ©rieure, Paris.

35. Invited: "Implicit-Explicit schemes for balance laws", TMR workshop on "Advances in Mathematical Semiconductor Modeling", Pavia, Italy, September 22–23, 2000.

36. Minisymposium: "Central Schemes for balance laws", 11th ECMI Conference, Torre Normanna, Altavilla Milicia (Palremo), Italy, September 26–30, 2000.

37. Plenary: "Central schemes for balance laws", IPERBS 2000 Problemi di Tipo Iperbolico VIII Incontro Nazionale, Brescia, Italy, November 30–December, 2000.

38. Invited: "Metodi numerici per equazioni iperboliche e cinetiche", Convegno del Gruppo Nazionale per Informatica Matematica, Bertinoro, December 11–13, 2000.

39. Invited lecture: "Central schemes for systems with source and for two fluid flows", THREE-DAY WORKSHOP on "Nonlinear Hyperbolic Systems of Conservation Laws", ETH Zürich, January 24-26, 2001.

40. Invited lecture: "Central WENO schemes for conservation laws", THREE-DAY WORKSHOP on "Nonlinear Hyperbolic Systems of Conservation Laws", ETH Zürich, January 24-26, 2001.

41. Summer School: "Central Schemes and Systems of Balance Laws", series of lectures for the Summer School on Hyperbolic Partial Differential Equations, Technical University of Hamburg-Harburg, Hamburg, March 2001.

42. Invited: "Central schemes for balance laws", WASCOM 2001, Porto Ercole (Grosseto), Italy, June 3–9, 2001.

43. Minisymposium: "IMEX Runge-Kutta schemes for hyperbolic systems with relaxation", 2001 SIAM Annual Meeting, San Diego, California, July 3–13, 2001.

44. Invited: "Time Relaxed Monte Carlo Schemes for the Boltzmann Equation", Granada Euroconference on Asymptotic Methods and Applications in Kinetic and Quantum Kinetic Theory, September 17–21, 2001.

45. Invited: "Spectral methods for kinetic equations", TMR Workshop *Numerical and asymptotic methods for kinetic equations*, Universität Saarlandes, Saarbruecken, November 29–December 1, 2001.

46. Invited: "Well balanced central schemes on staggered grid", JournÃ©es Savoisiennes de mathÃ©matiques appliquÃ©es, EQUATIONS DE SAINT VENANT, ThÃ©orie et applications, Chambery, France, May 16–17, 2002.

47. Invited: "Level set methods for the evolution of faceted crystals", Conference on "Fronts, Fluctuations, & Growth Conference", Michigan Center for Theoretical Physics University of Michigan, Ann Arbor, May 20–25, 2002.

48. Minisymposium: "Numerical methods for crystal growth", AMS-UMI Joint International Meeting, June 12-16, 2002.

49. Invited: "Spectral methods for the time dependent, space non-homogeneous Boltzmann equation", 2nd International Workshop on Kinetic Theory & Applications, Karlstad University, September 1–3, 2002.

50. Summer School: "Numerical methods for Conservation Laws", series of lectures for the XXVII Summer School on Mathematical Physics, Ravello, Italy, September 9-21, 2002.

51. Talk in a summer school: "Spectral Methods for the Boltzmann Equation", given at the XX School of Computational Mathematics: Computational Aspects in Kinetic Models, Piano di Sorrento, Napoli (Italy), September 22-28, 2002.

52. Invited: "Central Schemes for Balance Laws with Application to Shallow Water Equations", Symposium on Trends and Applications of Mathematics to Mechanics, STAMM2002, Maiori, September 29-October 4, 2002.

53. Session: "Numerical methods for balance laws and kinetic equations", "Around HYperbolic and Kinetic Equations", First annual meeting of the HYKE network, Vienna, Austria, February 24–28, 2003.

54. Invited: "Hydrodynamical models for semiconductor device simulation", workshop on"Analysis and Numerics for Modeling Semiconductor Devices and Biological Channels", CSCAMM, Niversity of Maryland, College Park, MD, May 19–23, 2003.

55. Invited: "High-order central Runge-Kutta schemes for conservation laws", international workshop on "Very High-Order Numerical Schemes for Conservation Laws", Newton Institute, Cambridge, UK, May 27–30, 2003.

56. Invited: "Time Relaxed Monte Carlo Methods: effective time discretization for large range of mean free path", international workshop on "Direct Simulation Monte Carlo: The Past 40 Years and the Future", Milano, Italy, June 2–5, 2003.

57. Invited: "Variable grid methods for kinetic equations", 3-rd Workshop on Kinetic Theory and Applications, Karlstad University, Sweden, 15–17 June 2003.

58. Invited: "Implicit-Explicit Runge-Kutta schemes and applications to hyperbilic systems with relaxation", international workshop on "Advances and challenges in time integration of PDE's", Brown University, Providence, RI, August 18–20, 2003.

59. Minisymposium: "Finite difference staggered central schemes for conservation laws, Icosahom 2004, Brown University, June 2004.

60. Invited: "Kinetic Monte Carlo methods for strained epitaxial growth", Workshop on *Issues on computational transport in meso and nano scales*, March 4 & 5, 2005, Center for Numerical Analysis, Institute for Computational Engineering and Sciences (ICES), The University of Texas at Austin, Austin, Texas, USA.

61. Invited seminar: "Computation of Strained Epitaxial Growth in Three Dimensions by Kinetic Monte Carlo", Center for Scientific Computation and Mathematical Modeling, University of Maryland, College Park, March 9, 2005.

62. Invited: "Kinetic Monte Carlo methods for strained epitaxial growth", First Mediterranean Conference in Applied Mathematics, Tozeur, Tunisia, March 23-25, 2005.

63. Invited: "High Order Finite Volume Schemes for Balance Laws with Stiff Source", Workshop on Foundations of Numerical PDEs, July 7 - July 9, 2005, Foundations of Computational Mathematics (FoCM2005), Universidad de Cantabria in Santander, Spain.

64. Invited: "Finite volume shock capturing schemes for balance laws", workshop on *New trends on shock wave theory for hyperbolic dissipative systems*, Royal Palace Hotel, Messina, June 17–18, 2005.

65. Minisymposium: "Kinetic Monte Carlo Simulations of Heteroepitaxial Growth in Three Dimensions", *Elastic effects in Epitaxially Grown Thin Films*, 2005 SIAM Annual Meeting, July 11–15, 2005, Hilton New Orleans, New Orleans, LA, USA.

66. Invited: "Kinetic Monte Carlo Simulation of Elastic Effects in Heteroepitaxial Growth", SEMIC2006, Recent Advances in Modeling and Simulation of Semiconductor Devices and Circuits, Vienna University of Technology, Technische Universität Wien, February 16-17, 2006.

67. minisymposium: "Introduction to Level Set Methods", minisymposium M27, VIII SIMAI Conference, Baia Samuele (RG), Italy, May 22–26, 2006.

68. Invited: "Time relaxed Monte Carlo methods for the Boltzmann equation", RGD25, 25 th International symposium on Rarefied Gas Dynamics, Saint Petersburg, Russia, July 15–21, 2006.

69. Invited: "Central Runge-Kutta finite volume schemes for balance laws", IPERPD2006 - 12th Meeting on Hyperbolic Equations, Padova, Italy, September 13-15, 2006.

70. Invited: "A Multigrid-Fourier Method for the Computation of Elastic Fields with Application to Heteroepitaxy", International Workshop on Kinetic Theory and Applications, Karlstad University, June 10-12, 2007.

71. Minisymposium: High-order well-balanced central schems on staggered grids, with application to shallow-water equations, IC/MP253/025: High-order shock capturing methods for non-linear hyperbolic partial differential equations, ICIAM 2007, Zürich, 16–20 July 2007.

72. Minisymposium: ADER RungeÂ–Kutta methods for conservation laws, IC/MP840/025: High-order methods for wave propagation and flow problems in complex geometries, ICIAM 2007, Zürich, 16–20 July 2007.

73. Minisymposium: High order implicit semilagrangian WENO schemes for the BGK model of rarefied gas dynamics, Minisymposium MS6, 7th International Conference on Spectral and High-Order Methods (ICOSAHOM'07) June 18-22, 2007, Beijing.

74. Invited: "A multigrid-Fourier method for energy computation in strained epitaxial growth", presented at the international workshop "Facets of Heteroepitaxy: Theory, Experiment, and Computation", Banff International Research Center, Banff, Canada, February 10–15, 2008.

75. Minisymposium: "High Order Well Balanced Schemes for Systems of Balance Laws", [MS062] Numerical Modelling of Hydrodynamic Geophysical Flows. Honouring Fausto Saleri, ECCOMAS 2008, 30 June, 4 July 2008, Venice, Italy.

76. Invited: "High order semilagrangian schemes for the BGK equation", presented at the International workshop on "Numerics for kinetic equations", Oberwolfach, November 16-22, 2008.

77. Invited: "Semilagrangian schemes for the BGK Model of the Boltzmann Equation", Quantum and Kinetic Transport: Analysis, Computations, and New Applications, Workshop I: Computational Kinetic Transport and Hybrid Methods, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, March 30 - April 3, 2009.

78. Minisymposium: "Moving boundary problems for the BGK model of rarefied gas dynamics", PhysCon09, 4th International Scientific Conference on Physics and Control www.physcon2009.diees.unict.it September 1 Â– 4, 2009, FacoltÃ  di Ingegneria, UniversitÃ  degli Studi di Catania, Italy.

79. Invited: "High order well-balanced schemes for balance laws", at NumHyp2009, Numerical approximations of hyperbolic systems with source terms and applications, Castro Urdiales, Spain, September 7-11, 2009.

80. Invited: "High order well balances schemes for hyperbolic systems with source", Intensive Research Month on Hyperbolic Conservation Laws and Fluid Dynamics, Parma, February 15-19, 2010.

81. Emerging Topics in Dynamical Systems and Partial Differential Equations, DSPDEs'10, Barcelona, Spain, May 31- June 4, 2010: invited talks at two minisymposia: High order semilagrangian methods for kinetic equations, and IMEX schemes for hyperbolic systems with stiff relaxation

82. Invited: "Implicit-Explicit Runge-Kutta schemes for hyperbolic systems with stiff relaxation in the hyperbolic and diffusive limit", CICAM5, Fifth China-Italy Colloquium on Applied Mathematics, Capo Mulini (Catania), Italy September 27-30, 2010.

83. Invited lecture: "Deterministic methods for the Boltzmann equation", in Models and Computational Methods for Rarefied Flows, von Karman Institute, Rhode-St-GenÃ¨se, Belgium January 24-28, 2011.

84. Invited: "Implicit-Explicit Runge-Kutta schemes for hyperbolic systems with stiff relaxation in the hyperbolic and diffusive limit", SAMHYP2011, Numerical methods for hyperbolic equations: recent trends and future directions, ETH Zürich, February 18-19, 2011.

85. Invited: "High order semilagrangian schemes for the BGK model", Workshop on Kinetic Theory and Computation, Kyoto, MArch 21-25, 2011.

86. Invited speaker, Sevilla Numerica meeting, Sevilla (Spain) from 20 to 24 June 2011.

87. Invited speaker: Workshop "Nonlinear Hyperbolic Systems of Balance Laws in Extended Thermodynamics and Kinetic Theory", Cortona, Italy, September 4-9, 2011.

88. Invited speaker: workshop "Vlasov Models in Kinetic Theory", Institute for Computational and Experimental Research in Mathematics (ICERM), Brown, RI, September 19 - 23, 2011.

89. Invited speaker: workshop "Recent advances on theory and applications of Semi-Lagrangian methods", Rome, December 5-6, 2011.

90. Plenary speaker, ICOSAHOM 2012, International Conference on Spectral and High Order Methods, June 25-29, 2012, at Hotel Ramada Plaza (Gammarth, Tunisia) `http://icosahom.enscbp.fr`

91. Plenary speaker, HYP2012, 14th International Conference on Hyperbolic Problems: Theory, Numerics and Applications, Padova (Italy), June 24-29, 2012. `http://www.hyp2012.eu`

92. Invited talk, I3MS Seminar Series 2013, RWTH Aachen University, June 10, 2013 `http://www.aices.rwth-aachen.de/news-events/ims/seminar-series-ss-2013/` Title of the talk: Ghost-Point Finite Difference Level Set Methods on Cartesian Mesh for Elliptic and Hyperbolic Problems.

93. Invited talk: INDAM Workshop on ÒMathematical Paradigms of Climate ScienceÓ Roma, June 24-28, 2013 Istituto Nazionale di Alta Matematica INDAM.

94. Invited speaker, Conference on "Mathematical topics in Kinetic Theory", University of Cambridge, 17th-21st June 2013 `http://math.univ-lyon1.fr/homes-www/filbet/nusikimo/CBG2013/`. Title of the talk: On semilagrangian methods for kinetic equations.

95. Invited talk, Applied Interdisciplinary Mathematics, Department of Mathematics, University of Michigan, Ann Arbor, Michigan, September 20, 2013. `http://www.math.lsa.umich.edu/seminars_events/events.php?eventdefid=3&dt_begin=2013-07-01&dt_end=2014-06-30`. Title of the talk: Ghost point finite difference level set methods on Cartesian mesh for elliptic and hyperbolic problems.

96. Invited talk, Differential Equation Seminar, Department of Mathematics, University of Michigan, Ann Arbor, Michigan, October 17, `http://www.math.lsa.umich.edu/seminars_events/events.php?eventdefid=7&dt_begin=2013-07-01&dt_end=2014-06-30`. Title of the talk: Implicit-Explicit schemes for hyperbolic systems with diffusive relaxation.

97. Invited talk, Numerical Analysis Seminar, Department of Mathematics, North Carolina State University, October 27, 2013, `http://www.math.ncsu.edu/events` Title of the talk: On semilagrangian methods for kinetic equations.

98. Invited talk, Mathematics Colloquium, Fall 2013, room: PGH 646, Department of Mathematics, University of Houston, Houston, Texas, November 6, 2013. Title of the talk: Ghost point finite difference level set methods on Cartesian mesh for elliptic and hyperbolic problems.

99. Invited talk, Joint CSCAMM/KI-Net Seminar, Center for Scientific Computation and Mathematical Modeling (CSCAMM), University of Maryland, College Park, Nov. 20, 2013 `http://www.cscamm.umd.edu/seminars/fall13/`. Title of the talk: On semilagrangian methods for kinetic equations.

100. Invited talk at the international workshop "Cartesian Grid, Level-set & Immersed Boundary", Bordeaux, France, March 25–27, 2014.

## 4.3 Conference organization

Prof. Russo organized several international workshops, conferences, and research periods.

1. International workshop on "Mathematical Methods for Semiconductors", L'Aquila 3–5 May 1995 (together with Prof. P.Marcati, University of L'Aquila.)

2. Mimisymposiym "Metodi Numerici per Fenomeni di Propagazione", IV Congresso Nazionale SIMAI, Giardini di Naxos (Messina), 1-5 June, 1998.

3. International workshop"Numerical methods for Hyperbolic and Kinetic Equations", Department of Mathematics, University of Catania, February 8-10, 2001.

4. Minisymposium "Numerical methods for hyperbolic systems with source terms", presso il 2001 SIAM Annual Meeting, Town and Country Hotel, San Diego, California, July 9-13, 2001 (joint with Prof. Pareschi, University of Ferrara.)

5. National workshop "IPERCT2001, Problemi di Tipo Iperbolico", Santa Tecla Palace Hotel, Acireale (CT), Italy, November 22-24 2001.

6. September 2002, XX Summer School of Computational Mathematics, "Computational aspects in kinetic theory", Piano di Sorrento, Napoli, Italy, September 22–28, 2002.

7. International conference (together with L.Pareschi and G.Toscani) "Modeling and Numerics of Kinetic Dissipative Systems", May 31 - June 4, 2004, Lipari, Italy.

8. Minisymposium (with A.Majorana) on "Mathematical and computational aspects of kinetic models" at 5th International ISAAC Congress, July 25-30, 2005, Department of Mathematics and Informatics, University of Catania Catania, Sicily, Italy.

9. Two minisymposia: Multiscale evolutionary problems, and "shallow water models: numerical methods and applications" (in collaboration with prof. R. Fazio), at the "VIII SIMAI Conference", Baia Samuele (Ragusa, Italy), 22-26 May 2006.

10. Minisymposium on "Numerical methods for conservation laws", ECMI 2006, July 10–14 2006, University of Madrid Carlos III, Madrid, Spain.

11. Minisymposium on "Stiff problems", SCICADE 2007, Saint Malo, France, 9-13 July 2007.

12. Member of the scientific committee of the conference "Modeling and computational methods in fluid dynamics and material science: towards the challenge of the nanoscales", Bressanone, Italy, December 19–22, 2007.

13. Minisymposium: M27 on Optimization problems in industry (coorganized with Giuseppe Nicosia, University of Catania), SIMAI 9th Congress, Rome, September 15-19, 2008.

14. Minisymposium: M23: Level Set Methods and Related Problems (coorganized with Roberto Ferretti, University of Rome 3), SIMAI 9th Congress, Rome, September 15-19, 2008.

15. Member of the Scientific Commettee of Iperba09: XIII Incontro Nazionale sui Problemi di Tipo Iperbolico, Bari, February 11-13, 2009.

16. C.I.M.E. Summer School Multiscale and Adaptivity: Modeling, Numerics and Applications, CIME-EMS Summer School in applied mathematics July 6 - July 11, 2009 - Cetraro (CS) Lecturers: Silvia Bertoluzza, Bjorn Engquist, Ricardo Nochetto, Alfio Quarteroni, Kunibert Siebert, Andreas Veeser. For more information see `http://php.math.unifi.it/users/cime/`.

17. Minisymposium on "stiff problems", ICNAAM conference, Crete, September 17-23, 2009.

18. INdAM two month intensive period on "Analytical and Numerical Problems in Fluid Dynamics and Applications", April 12-June12, 2010 (see `http://www.dmi.unict.it/INDAM2010/index.html`): focused period with about ten lecturers giving short courses, and more than twenty speakers giving invited talks.

19. Minisymposia MSP40 "Numerical methods for hyperbolic systems in non-conservative form and environmental applications", and MSP22 "Mathematical models and methods for volcano physics", SIMAI 2010, Cagliari, June 21, 2010 – June 25, 2010.

20. Member of the Scientific Commettee of IPERME2011, workshop on hyperbolic equations, Messina, February 16-18, 2011.

## 4.4 Summer Schools

Prof. Russo has been one of the main lecturers in several summer schools. Among these we recall

July 1999, "Numerical methods for kinetic equations", CEMRACS courses, INRIA, Rocquencourt, France.

March 2001, "Central schemes and Systems of Conservation Laws", Summer School on Hyperbolic Partial Differential Equations, Technische Universitaet Hamburg-Harburg.

September 2002: Ravello summer school on Mathematical Physics, one week short course on "Numerical methods for Conservation Laws".

June 2004: Summer school on "Methods and Models of Kinetic Theory", one week short course on numerical methods for the Boltzmann equation, Porto Ercole, Grosseto, Italy, June 4–10, 2004.

November 2007: Short course on "High order shock capturing schemes for balance laws", in the summer school *Advanced School on Numerical Solutions of Partial Differential Equations New Trends and Applications*, Centre de Recerca Matematica, University of Barcelona, Spain, November 15 to 21, 2007.

## 4.5 Referee activity

Since December 2000, Prof. Russo is a member of the editorial board of SIAM Journal of Numerical Analysis.

Since 2002 he is a member of the scientific commettee of the journal "Le Matematiche", editet by the University of Catania.

He has been referees of papers submitted to the following journals

1. SIAM Journal of Numerical Analisys
2. SIAM Journal of Applied Mathematics
3. SIAM Journal of Scientific Computing
4. Journal of Computational Physics
5. Mathematical Models and Methods in Applied Sciences
6. Computers and Fluids
7. Journal of Difference Equations and Applications
8. COMPEL
9. Transport Theory and Statistical Physics
10. Mathematical Models and Numerical Analysis
11. Numerical Methods for Partial Differential Equations
12. Journal of Computational Electronics
13. Communications in Mathematical Sciences
14. Journal of Scientific Computing
15. Journal of Computation and Applied Mathematics
16. Calcolo
17. Le Matematiche
18. Kinetic and Reated Models

19. Communications in Computational Physics

20. Applied Numerical Mathematics

He has been reviewer of several PhD thesis.

## 4.6 Editorial Board

G.Russo has been associate editor of SIAM J. Numer. Anal. from 2001 to 2006.

He is presently member of the Editorial Board of "Le Matematiche", a general mathematical journal published by the University of Catania.

## 4.7 Scientific Commettees

Prof. Russo is presently a member of the Council of the European Consortium of Mathematics in Industry (ECMI).

He has been in the Scientific Commettee of several conference; in particular, he has been in the scientific board of the the biannual italian conference on hyperbolic problems several times.

Prof. Russo has been member of several commettee for university positions. In particular we recall the following.

**PhD defence in Italy** ten times, 1997, 1998, twice in 2003, 2006, twice in 2007, 2009, 2010, 2011.

**PhD defence in Sweeden** once, (Karlstad, 2008).

**PhD defence in France** once, (Lyon, 2012).

**Researcher position** three times, 1995, 1998, 1999.

**Confirmation associate professors** once, in 2002.

**Confirmation researchers** once, in 1994.

**Foreigner habilitation** twice, for the french *Habilitation a diriger des recherches*

**Full professorship** once, in 2005.

## 4.8 Research projects

**Bilateral project USA-Italy** duration: three years (1996-98), financed by Italian *Consiglio Nazionale delle Ricerche* American National Science Foundation. Title of teh project: "Numerical and analytical methods for the simulation and control of fluids". Universities involved: University of L'Aquila, University of Rome, "La Sapienza", University of California, Los Angeles. Principal investigators: Giovanni Russo (University of L'Aquila) and Russel E. Caflisch (UCLA).

**National project 40% (now PRIN)** G.Russo has been Scientific Responsible of local units in several occasions: 1994, 1999 (contribution of the Ministry of Education [MURST]: 28 million lira), 2001 (MURST contribution: 59 million lira), 2004 (MURST contribution 36,700 Euros).

**Vigoni program 1998-99** For collaboration between Italian and German Universities. Joint project between University of L'Aquila (G.Russo) and Universität des Saarlandes (prof.S.Rjasanow).

**GNIM project 2000** National project on *Numerical methos for hyperbolic and kinetic equations.*

**INDAM project 2004 and 2005** National project on *Numerical methods for multiscale evolutionary problems* (14,500 Euros each year).

**INTAS 2000** Principal investigator of INTAS project (868) for sponsoring research in former soviet countries. Title of the project: "Conservation laws of mechanics of continua". Duration: 2 years. Total financial support: 60,000 Euros (80% of which goes to former soviet institutions). Universities involved: University of L'Aquila (then Catania after G.Russo moved to Catania), Italy, Ecole Polytechnique, France, Lavrentyev Institute of Hydrodynamics, and Sobolev's Institute od Mathematics Novosibirsk, Russia.

**LIMA project 2005-2007** Born in collaboration with LIMA S.R.L., an industrial partner from San Daniele del Friuli, Italy, the project was aimed to the collaboration between university and industry, for the construction of a prototypal software that assists the surgeon in the bone prosthesys transplant. Partners: University of Catania (Department of Mathematics and Computer Science, Department of Mechanical Engineering), Vittorio Emanuele hospital (Catania), Consorzio Catania Ricerche (Catania), LIMA group SRL, Fraunhofer ITWM (Kaiserslautern).

**POKER project 2008-2010** Born in collaboration with Infracom Italia S.P.A., University of Catania (Department of Mathematics and Computer Science), and Fraunhofer ITWM (Kaiserslautern), the research project has the objective of constructing a prototypal software that assists small investors proposing portfolio options tailored to them.

**Galileo 2008/2009** Galileo project for the collaboration between Italy and France. Title of the project: MONUMENT (MOdellizzazione NUmerica in MEms ed in Nano Tecnologie). Duration: one year. Italian P.I.: Giovanni Russo, University of Catania. French P.I.: Francis Filber, Université Claude Bernarde, Lyon. Research groups involved: Department of Mathematics and Informatics, University of Catania; MOX, Polytechnic of Milano; Department of Mathematics, Université Claude Bernarde, Lyon. Budget: 10800 Euros.

**Azioni integrate Italia-Spagna 2009** Title of the project: "Metodi numerici per sistemi iperbolici in forma non conservativa, con applicazioni ambientali". Duration of the project: two years. Italian P.I.: Giovanni Russo, Spanish P.I., Carlos Pares, Universidad de Malága. Universities involved: University of Catania, University of Trento, Polytechnic of Torino. The budget is 10,800 Euros.

**Lava project** LAVA is a project that the Civil Protection commissioned to the National Institute for Geophysics and Volcanology (INGV). The duration of the project is two years (2008-2010). Prof. Russo is responsible of Research Unit n.8, in charge of "Simulation of lava flows". Budget of the unit: 48,000 Euros.

**PRIN 2009** In July 2011 the National Project "Innovative Numerical Methods for Hyperbolic Problems with Applications to Fluid dynamics, Kinetic Theory and Computational Biology" was accepted and funded by Italian Ministry of Education, University and Research (MIUR). The project, coordinated by Giovanni Russo, is composed by three research units, located respectively in Catania, Milano, and Ferrara. It lasts two years, with a total budget of 165,391 Euros, of which 115,774 coming from MIUR.

## 4.9 PhD Programs

2002–2008, G.Russo has been coordinator of the PhD program in "Mathematics for Technology", University of Catania. Information about the PhD program can be found at
http://www.dmi.unict.it/~russo/DotMatTec/index.htm

In 2009 the three PhD programs in "Mathematics for Technology", "Mathematics for Engineering", and "Mathematics for Decisions in Economics and in Finance", of the University of Catania, merged into a single PhD program in Applied Mathematics, still coordinated by G.Russo.

In 2010 the PhD program in "Applied Mathematics" and the PhD program in "Mathematics" merged into a single PhD program in "Pure and Applied Mathematics", coordinated by G.Russo.

# 5 Scientific production

In this document I will try to summarize my research activity so far, and to briefly describe some of the present research project I am involved at present. The numbering of the papers refer to the list of publications, presented in a different pdf document.

From 1982 to 2010 I worked on several research fields, published about one hundred papers and conference proceedings in international journals, and several chapters in books.

## 5.1 h-index

According to google scholar my citations and h-index are as follows (as of Dec 3rd 2013)

| | All | Since 2008 |
|---|---|---|
| Citations | 3210 | 1508 |
| h-index | 31 | 22 |
| i10-index | 64 | 40 |

According to the ISI-web of knowledge my h-index is approximately 21 (it is difficult to compute the exact value because "russo g*" is very common in Italy)

The main research topics I worked on are the following.

1. Experimental and theoretical study of laser annealing induced by picosecond laser pulses
2. Asymptotic methods in wave propagation
3. Particle methods
4. Computational fluid dynamics
5. Kinetic models for bubbly flow
6. Hydrodynamical models of semiconductors
7. Numerical methods for kinetic equations
8. Numerical methods for balance laws
9. Mathematical modeling and simulation of crystal growth
10. High Frequency Waves
11. Complex networks

A brief description of the contribution of the author in the various fields is provided here, starting from the current research interest.

## 5.2 Current research projects

I am continuing working on some of the research field in which I have been working during my career, whose work is reported in detail later. In this section I will mainly concentrate in describing my main current research activity.

**Semilagrangian schemes for kinetic equations, Refs. [115, 128]** In particular, I am continuing my research on semi-Lagrangian methods for kinetic equations, in collaboration with Dr. Santagati and Prof. Filbet, and possibly with a young PhD student. The emphasis is to extend the method to treat problems with moving boundaries, in more space dimensions, and with more general boundary conditions than the ones treated in paper [115]. Another line of research in this direction consists in exploring the schemes that are obtained when the following restriction on the grid spacing is satisfied: $\Delta v \Delta t = s\Delta x$, where $s$ is an integer. In this case no interpolation is needed in the semi-Lagrangian method, and one could construct a high order scheme which resembles a lattice-Boltzmann scheme, but that can be used to solve the kinetic equation, not only the Navier-Stokes equation. On a more theoretical level, paper [128], recently accepted on SINUM, deals with the proof of convergence of the semilagrangian scheme introduced in the PhD thesis of my former PhD student P.Santagati, for the BGK model.

**Well balanced schemes, Ref. [131]** In the field of shock capturing schemes for balance laws, I am working on the construction of high order well-balanced schemes for hyperbolic systems with source terms and on treatment of dry states in shallow water equation, the latter research in collaboration with Gabriella Puppo. Another topic I am working, in collaboration with the group of Prof. Carlos Parés from Malaga, is the development of central schemes applied for problems which do not admit a conservation form (see paper [131], recently accepted); several problems of interest for application, such as multilayer shallow water systems, of shallow water with sedimentation, are described by hyperbolic equations which do not admit a conservative form (at least not in the correct physical variables), and therefore one cannot use the standard theory of conservation laws to define weak solutions (which arise naturally, because of the non linearity of the system). The theory of Dal Maso, Le Floch and Murat, based on the choice of a family of paths joining states across a discontinuity, can be used to define weak solutions in such cases. The group of Malaga constructed numerical schemes making use of such theory. In [131] we coupled central schemes with the path conservative schemes, thus exploiting the advantages of central schemes in this context.

**Parabolic relaxation, Ref. [129, 130, 135]** For problems with stiff terms, a research in collaboration mainly with Dr. Sebastiano Boscarino, an assistant professor from my Department, and with various external collaborators (Pareschi, LeFloch, Torrilhon) is conducted to develop numerical methods that are able to capture the so called diffusion limit, which is the scaling one uses when interested in the long time behavior of the solution of a hyperbolic system with relaxation, in which one is interested in the small diffusive effect. In paper [129] we construct a method for hyperbolic systems with diffusive relaxation that, in the limit of zero relaxation time, becomes a consistent implicit discretization of the limit diffusion equation, thus overcoming the classical parabolic CFL condition. The paper [130] deals with the construction and analysis of IMEX-Runge-Kutta schemes for hyperbolic systems with parabolic relaxation, in which the flux term is treated explicitly. The task is non-trivial because of the divergence of the characteristic speeds. It is shown that if the IMEX scheme satisfies some additional conditions, then it is *Asymptotic Preserving*, i.e. it is able to capture the solution of the limit parabolic equation. When the limit diffusive equation is non-linear, new difficulties appear, because the schemes for the solution of the hyperbolic systems are based on an effective solver of the limit equation. This problem is treated in the paper [135], recently submitted, in which a suitable modification of the IMEX schemes derived in the two papers previously mentioned allows the construction of very effective solvers for such hyperbolic systems with non-linear parabolic diffusion limit.

**Ghost point methods [122, 132]** Among my new research interests, I mention the developments of numerical methods for treating problems with moving boundaries, using discretization on regular grid. In the case of fixed boundaries, the domain is identified by a time independent level set function. The numerical value of the unknowns have to be defined on the grid points inside the domain, and on those outside of the domain, near the boundary (ghost points). The equation of motion is used to evolve the unknowns inside the domain, while boundary conditions are used to define the value of the unknown at the ghost points. This procedure can be extended to domain with moving boundary, in which case the domain will be described by a time dependent level set function. In case the function is not known a priori (free boundary problem), a suitable

evolution equation of level set type is used to evolve the level set function, and therefore to change the domain. As a starting point, multigrid solvers for elliptic problems in arbitrary domains embedded in a Cartesian gris have been developed [122, 132]. The research is conducted with my former student Armando Coco. Three new ingredients are proposed in paper [132]: i) a systematic technique to impose various types of boundary conditions (Dirichlet, Neumann, mixed, Robin) to high order (although only second order is implemented); ii) a relaxation technique is proposed as a multigrid smoother, which is based on relaxing the equation and the boundary condition by suitable time dependent equations; iii) the transfer operators are constructed by taking into account the smooth property of the error and the lack of smoothness of the residue. Several tests cases show the robustness, efficiency and accuracy of the method.

We plan to apply this approach to several context, namely gas dynamics in domain with moving objects (research conducted in collaboration with Alina Chertock, from North Carolina State, Alexander Kurganov, Tulane University, and Armando Coco), or shallow water equation in a domain with moving objects. The latter research is conducted together with Dr. Edie Miglio, from Polytechnic of Milan, Italy. Another application I have in mind is the numerical simulation of lava flow, which I describe below.

**Numerical simulation of lava flow [123, 124, 127]** In the region near Catania there is a great attention to monitor the activity of mount Etna, the largest active volcano in Europe. An important aspect, for the obvious application for the civil protection, is the possibility of being able to predict with some detail the regions covered by lava flow as a consequence of an eruption. One of the research project I am involved in concerns exactly this issue (see Section 4.8) in my CV. Lava can be modeled as a strongly viscous non Newtonian incompressible fluid, and it evolution can be described by the numerical solution of Navier-Stokes equations for such a fluid, with free boundary. The equations are strongly coupled with the equation for the temperature, because the rheological properties of the lava depends on the temperature (and on the shear stress). When lava flows on a sloping side of the volcano, subject to gravity, the surface which is exposed to air dissipates heat, the main contribution being due to radiation. When the lava cools down, a crust is formed on the surface, preventing new melted lava from being exposed to air. The mechanism by which the crust forms depends on the flow rate. In any case, the main effect is that a tube of lava forms, and the lava may flow inside the tube to distances much larger than expected if this crust formation is not taken into account. During its evolution the lava may carry with itself debris or pieces of crust.

Several techniques are possible for the numerical simulation of such complex flow. Among the various possibilities, we chose two complementary alternatives. The first one consists in the use of purely Lagrangian methods, based on Smoothed Particle Hydrodynamics (SPH). Such approach has the advantage of not requiring a (possibly moving) grid, and it is rather natural for treating free boundaries and complex geometries. In collaboration with researchers from INGV (the Italian National Institute of Geophysics and Volcanology), and with my post-doctoral fellow Giuseppe Bilotta, we are developing an SPH method for the numerical simulation of lava flow on a complex geometry, possibly in presence of debris, which are treated as solid objects carried by the fluid. Right now there is a recently published paper on the topic [124], dealing with the use of moving least square techniques (MLS) to improve the performance of SPH methods. In the paper [127], sensitivity analysis of the main parameters determining the region invaded by the lava has been considered. The parameters considered are the solidification temperature of the lava, and the effusion temperature, and the water concentration. It is shown that the latter is the most critical parameter in determining the rheology, and therefore the final displacement of the lava. Other papers in press deal with different aspects of the problem. In order to avoid the burden of the elliptic solver for the pressure, in the present code the lava is treated as weakly compressible, with a fictitious sound speed being chosen to be about ten times the maximum fluid speed. The code is then completely explicit in time. It is our intention to perform a comparison of the weakly compressible approach with the fully incompressible approach employed by other authors. In order to reduce computer time, the codes are implemented on GPU architecture, obtaining two orders of magnitude speed-up with respect to a single core computer. Results on the GPU implementation of SPH are reported in [123].

The second approach we are exploring consists in discretizing the incompressible Navier-Stokes equation with a free boundary problem in primitive variables on a fixed Cartesian grid, describing the evolution of the free surface by a level set equation. This approach is very promising, mainly because in this case there would be no difficulty in treating some terms implicitly (for example the pressure term or the diffusion terms). In

addition to having the possibility of comparing results obtained with completely different methods, we hope that with this latter approach it will be easier to describe the phenomenon of crust formation.

A preliminary work in this direction is almost ready for publication. It is a paper on a novel technique to solve Poisson equation with mixed or Robin conditions, on a regular grid in an arbitrary domain described by a level set function [132], using Jacobi iteration accelerated by multigrid.

**High frequency waves [133, 134]** I am presently working on numerical methods for high frequency waves or for the solution of the Schrödinger equation (SE) near the semiclassical limit. The research is conducted in collaboration with prof. Peter Smereka, University of Michigan. We started considering the Schrödinger equation. The methods we are looking for should become almost as efficient as the description in term of the so called *Gaussian beams* (GB), when the solution is well represented as a superposition of such GB's, but they should be much more flexible than GB, in the sense that they provide a numerical methods for the solution of (SE), whose accuracy depends on the discretization parameters (size of the grid in space, and time step), while GB provide an asymptotic method, whose accuracy improves as the non-dimensional Plank's constant becomes smaller and smaller. The objective is reached by a transformation, called Wave Packet Transform, which maps the original Schrödinger equation in another Schrödinger equation more amenable to numerical solution. A first paper, presenting the formulation and numerical tests in one space dimension, has been recently accepted ([133]), while a second paper, dealing with the more interesting case of multidimensional problems, has been recently submitted ([133]).

**Complex Networks [125, 126]** In the last few years, under the influence of my colleague Vito Latora, now at the Department of Mathematics, Queen Mary University, London, I started being interested in Complex Networks. Complex networks are the backbone of a complex systems, and they are able to describe the gross features of a huge variety of systems, ranging from computer network to social networks. The mathematical structure of a network is a graph, which in turn is defined by means of its adjacency matrix. After several discussions, we decided to start writing a textbook together [136], in which my main contribution is to take care of the mathematical and algorithmical aspects of the treatment of complex networks (graph theory, algebraic description of sparse graphs and related numerical linear algebra, algorithms for graph exploration and for the computation of the so-called *centrality measures*, and so on.)

Being involved in writing the book has been an excuse to learn about this fascinating subject, and collaborate with Latora and his group on problems related to them. Of the various problems connected to complex network, we started interacting on problems related to eigenvector centrality, which is related to the celebrated Page Rank that Google used to select the most interesting pages among the many (even thousands or million) pages containing a given string. The research, conducted in collaboration with R.Criado from the Universidad Rey Juan Carlos de Madrid, Spain, produced the paper [125], published this year on Scientific Reports.

A second paper, dealing with time dependent networks, recently appeared on Chaos [126]. For such networks, the tools usually adopted for static graphs are not always appropriate. Even straightforward techniques, consisting for example in considering the static graph obtained by aggregating all the links as if they occurred at the same time, does not provide satisfactory answers to simple problems, such as the ability of transmitting a message from one note to another. In the paper the notion of connectedness (and the associated notion of component) is extended to time-varying graphs, represented as time-ordered sequences of graphs defined over a fixed set of nodes. As a practical example, we have performed a temporal component analysis of time-varying graphs constructed from three data sets of human interactions. The results show that taking time into account in the definition of graph components allows to capture important features of real systems.

## 5.3 Previous research activity

### Experimental and theoretical study of laser annealing induced by picosecond laser pulses [13, 14, 15, 16, 17]

This topic was the subject of the master thesis and of the first year of research activity, during 1982-83. The research was carried on with the experimental group of prof. Emanuele Rimini, from the Physics Department of

the University of Catania. Papers [13, 14, 15, 16, 17] are on this subject. The first two are experimental papers conducted in collaboration with the CISE Laboratory of Milano, on the impurity redistribution if implanted Silicon after laser pulse irradiation with pulses of the duration of few hundreds of picoseconds, the third one is a review paper on the subject, and in the fourth one G.Russo contributed with the numerical simulation of charge dynamics under picosecond laser pulse irradiation, with a model developed by Lieitoila and Baeri.

## Asymptotic methods in wave propagation [18, 19, 20, 21, 26, 28, 39, 22, 24, 25, 27, 30, 33]

This topic was the subject of the graduate research studies of Giovanni Russo for his PhD in Physics, conducted under the supervision of prof. Angelo Marcello Anile, at the University Catania. The two main field of research consisted in the development of approximate asymptotic methods for the propagation of shock waves (papers [18, 19, 20, 21, 26, 28, 39], and in the study of shock wave stability on various contexts (papers [22, 24, 25, 27, 30, 33]).

An asymptotic method for the propagation of weak shock waves, called Generalized Wavefront Expansion (GWE), was derived and analyzed in [18, 19, 20, 21]; the results obtained by the analytical methods were compared with the numerical solutions obtained using the shock capturing methods available at that time, and applied to gas dynamics. The connection between GWE and the theory of weakly non-linear high frequency waves, developed during that period by J.K.Hunter and J.B.Keller, was established in the paper [39]. Approximate methods for a different kind of shocks, called step shocks, was considered in [21].

Probably the major contribution of the research during the PhD has been the study of shock wave stability, and its application to astrophysics. Several kinds of stability of plane shocks were available in the literature, such as corrugation stability, linear stability, stability against reflection of acoustic waves on a shock, and so on. Most of them were developed and applied in the context of shock waves for the Euler equations of classical gas dynamics. The various stability conditions are expressed by a relation that has to be satisfied by the equation of state of the gas relating, for example, the pressure to the density and internal energy. In a series of papers, the various kinds of stability have been considered for the relativistic Euler equations, and the conditions on the equation of state of the relativistic gas has been established [22, 24, 25], and applied to the study of shock wave stability for relativistic gas of interest in astrophysics, such as compact objects (white dwarfs and neutron stars) [27]. New application to classical gases have been presented in [33] and the definition of corrugation stability has been applied to shock waves in MHD in [30]. Most of the results published in the papers appear in the PhD thesis [1].

## Particle methods (Ref.[29, 31, 32, 34, 35, 36, 37, 42])

During his PhD and subsequently during his post-doctoral position at the Courant Institute of Mathematical Sciences, G.Russo worked on particle methods applied to various kinds of transport equations. Particle methods were very popular at that time. In plasma physics they were the main tool for the simulation of charge transport, and in fluid dynamics the vortex-blob method appeared to be very appealing for the solution of the inviscid incompressible Euler equation, because it did not introduce any spurious numerical viscosity. The first two papers on particle methods, [29, 31] are mainly of theoretical value. It is shown that in a space homogeneous linear collisional kinetic equation, is possible to give a particle approximation, in which all the particles have the same mass. The collision term has the effect of changing the momentum of each particle. A technique based on weak convergence of measures is used to prove the convergence of the particle method to the exact solution of the linear transport equation. In paper [32] this idea of approximating a source by a flux is further investigated and applied to the one dimensional heat equation. It is shown that a pure particle approximation is possible of the heat equation, with accuracy and stability properties very similar to the classical finite difference scheme for the one dimensional heat equation. A second order linearly implicit scheme is proposed. In paper [35] the ambitious program of replacing a diffusion term in a convection-diffusion equation by a drift term obtained by a suitable discretization of the osmotic velocity is considered. An innovative technique based on the approximation of the gradient operator on unstructured grids is introduced, and the results of the technique are favorably compared with other particle approximations of convection-diffusion equation, obtained by using a

smooth kernel. The main motivations for using particle methods for convection-diffusion equation is that when the viscosity vanishes, the methods smoothly become a particle method for a convection equation, providing an exact measure-value solution of the equation (solution along the characteristics). Applications have been presented at various conferences [34, 36, 37]. A deterministic vortex method for the numerical solution of the incompressible Navier-Stokes equation in two space dimensions has been presented in [42]. The equations are written in the vorticity formulation, and the flow field is approximated by a superposition of vortex-blobs. Each vortex is convected by a velocity reconstructed from the vorticity distribution by the Biot-Savart law, while the vorticity itself (or, better, the circulation) is diffused by solving a diffusion equation in which the Laplacian is a approximated on the unstructured free Lagrangian grid of the particles (a Voronoi diagram, updated at each time step, has been used). The resulting scheme has the following remarkable properties: i) as the viscosity vanishes the scheme reduces ti the classical vortex-blob method for the incompressible Euler equations, ii) the method provides the exact evolution law of the total circulation (at variance with the random vortex method, that introduces strong statistical fluctuations in the total circulation).

## Computational fluid dynamics [44, 45, 51, 63, 56]

Several methods have been proposed and analyzed for the numerical solution of incompressible Euler equation. In particular, in paper [44], a vortex methods has been proposed for the numerical solution of the two dimensional incompressible Euler equations. The method works as follows. At a given time the vorticity field is approximated by a piecewise liner reconstruction obtained on the Delaunay triangulation associated to the vortex points. The velocity at each vortex location is then computed by integrating the Biot-Savart kernel on the piecewise vorticity. The convergence of such method on a fixed topology triangulation was previously proved by T.Chacon and T.Hou in 1990. The novelty of the approach in the present paper were the use of Delaunay triangulation, and the use of the fast-multipole method, suitably adapted on a piecewise linar distribution, to speed up the velocity computation. The system of ordinary differential equations for the vortex location is then solved by a suitable ode solver. Another advantage of approximating the vorticity on a triangulation is the great flexibility in grid adaptation, that allows to evolve both smooth distribution as well as vortex patches. Several numerical tests have been performed that show the effectiveness of the approach.

In the other papers, the so called *impulse formulation* of incompressible fluid dynamics has been considered. The impulse field $\mathbf{p}$ provides an alternative way describe the evolution of incompressible Euler and Navier-Stokes equations in two and three space dimensions. In the case of the Euler equations, for example, the impulse equations are written as $\partial\mathbf{p}/\partial t - \mathbf{u} \times (\nabla \times \mathbf{p}) = \nabla\Lambda$, where $\mathbf{u}$ is the divergence free projection of $\mathbf{p}$, and $\Lambda$ is an arbitrary gauge, that may be suitably chosen in order to simplify the treatment. In [63] the impulse formulation of the Euler equation is revised, pointing out the physical and geometrical implication of the most commonly chosen gauges, and some of the difficulties encountered when the impulse variable is directly used in a numerical method. In paper [51] an application of the impulse formulation in the study of the interaction between an incompressible inviscid fluid and an elastic membrane in two and three space dimensions is presented. The numerical results are then compared with the linear theory, in the case of small amplitude oscillations.

Recently, a new interest in computational fluid dynamics arose, mainly in conjunction with environmental applications (see the section 5.2 on the current research projects).

## Kinetic models for bubbly flow [46, 47, 93]

The goal of the papers is to derive the equations describing collective motion of spherical identical bubbles in an inviscid incompressible liquid. The first paper deals with the kinetic regime, while the second paper deals with the fluid dynamic limit. The starting point is the dynamics of a collection of $N$ spheres in a perfect fluid. Once the position and velocity of all the spheres are known at a given instant of time, one can in principle compute the motion of the fluid in the region occupied by the fluid. Without external forces, the total kinetic energy of the fluid is equal to the Lagrangian of the system, and can be computed, in principle, as a function of the coordinates of the spheres and their velocities. Because of this, the equation of motion of the spheres are given by Euler-Lagrange equation. In the case the volume fraction $\varepsilon$ of the sphere is very small, one can develop an

asymptotic theory in such a parameter. The expansion in the small parameter is equivalent to an expansion of the velocity field into dipole fields (the velocity field induced by a single sphere in motion in an infinite fluid is a dipole field). This allows some analytical manipulation of the problem. In particular, to the first order in the small parameter, it is possible to write explicitly the expression of the Hamiltonian of the system. From the Hamiltonian, one can use a standard approach, based on the Liouville equation and on the BBGKY hierarchy describing the evolution of $m-$particle distribution function to derive a self-consistent Vlasov-Poisson type equation for the one particle distribution function using the assumption of molecular chaos (*Stosszahlansatz*). Some of the properties of the equations are discussed in the paper, including onset of instability for the initial value problem, and construction of suitable particle schemes for the numerical solution of the equations.

In the first paper the binary collisions among the spheres were neglected, and only the mean field term induced by the dipole field was considered. In the second paper, on the contrary, one considers that the effect of the collisions is dominant, and relaxes the distribution to a Maxwellian. Under such an assumption, taking moments of the kinetic equations, one obtains a closed set of fluid dynamics equations describing the evolution of mass, momentum, and energy density of the distribution.

Later, several researchers, including Benoit Perthame, and Vladimir Teshukov, extended the theory in several directions. In particular, Vladimir Teshukov showed that the kinetic equation of bubbly flow in one space dimension can be interpreted as an infinite-dimensional hyperbolic system, and the instability of the solution for some initial value problem is interpreted as the lack of hyperbolicity of the system. The collaboration with the group of prof. Teshukov lead to a few papers, one of which related to the theory of bubbly flow [93].

## Hydrodynamical models of semiconductors [38, 43, 57, 59, 69, 72, 75, 10]

The work on semiconductor modeling dealt both with the analysis of the properties of some hydrodynamical model for semiconductor device simulation, and on the numerical solution of the equations. Several mathematical models are possible for the description of charge transport in semiconductors. The choice of the model depends on the level of physical detailed needed in the treatment, and in the computational resources available. Up to about twenty five years ago, the so-called *drift-diffusion* model was more than appropriate to describe charge transport in devices in which the typical characteristic lengths were well above the micron. When the technology allowed the production of smaller devices, such models became inappropriate to describe some effects (for example inertial effects of the carriers). A more detailed treatment of the charge transport dynamics is given by a kinetic description: the charges (electrons and holes) are described by a density function in phase space, that satisfies a complicated integro-differential equation, describing the interaction between the charges and the lattice (manly scattering with phonons) and the influence of the self-consistent electric field. Such kinetic models provide a very accurate physical description of charge transport in sub-micron channel devices, and, with suitable modifications, are able to take into account quantum effects (semiclassical description). Kinetic models are however very demanding from a computational point of view, mainly because of the dimensionality of the problem (in the full three dimensional case the density function depends on seven independent variables: three space coordinates, three momentum coordinates, and time). An intermediate level of description is given by the so-called hydrodynamical models. Such models are usually derived by taking some moments of the kinetic equations, and closing the hierarchy of equations using suitable mathematical techniques (for example *Maximum Entropy Theory* or *Extended Thermodynamics*).

In papers [38] and [43] an analysis is provided of an hydrodynamical model describing charge transport in a one dimensional model of a diode. In particular, in [43] a qualitative analysis of the solution of the equation is performed using techniques from the mathematical theory of ordinary differential equations. A comparison is then performed between the solution of the invistid model and the solution of a regularized viscous model.

Numerical solution of hydrodynamical models presents several computational challenges, because such systems have the structure of hyperbolic quasilinear systems of balance laws, with possibly stiff source terms, and with a term containing the electric field, coupled to the balance equations via a self-consistent Poisson equation.

One additional difficulty is that the characteristic structure of the hyperbolic part (eigenvalues and eigenvectors of the Jacobian matrix) is not explicitly known, and, of course, the solution of the so called *Riemann problem*, is not known for such systems. This motivates the use of shock-capturing numerical methods that do not require the knowledge of (exact or approximate) Riemann solvers.

The research developed in the context of semiconductor modeling motivated the research for the development of high order shock capturing central schemes, with or without stiff source terms (see section on numerical methods for balance laws).

In paper [69] the one dimensional equations of the hydrodynamical model have been solved by central finite volume scheme, which is the generalization of the well-known Nessyahu-Tadmor second order central scheme on staggered grid. The hydrodynamical model in one space dimension is described by a set of five pde's for the balance of density, momentum, energy, stress (a scalar in one dimension) and heat flux, coupled with the Poisson equation. Numerical simulations of a typical junction diode are performed, and the results are compared with those obtained by a sophisticated Monte Carlo code (Damocles, developed at the IBM T.J.Watson Research Center), which is physically much more accurate, but computationally extremely expensive.

Paper [72] deals with the numerical solution of a reduced hydrodynamical model, coupled with the Poisson equation. The second order of accuracy of the scheme has been tested with tests performed on smooth solution, and the reliability of the model has been assessed by a detailed comparison with sophisticated Monte Carlo simulation.

Paper [75] deals with the comparison between two different methods for the numerical solution of the hydrodynamical models of semiconductors. In particular, solutions obtained by a finite volume central scheme are compared with solutions obtained by a kinetic scheme. The cross-validation of different schemes is important in such problems, since exact solutions are not known. The excellent agreement between the two different approaches is a good indication of the reliability of the two methods.

## Numerical methods for kinetic equations [40, 41, 7, 79, 11, 64, 70, 67, 76, 82, 71, 86, 89, 9, 95, 109, 115, 100, 101, 107]

Together with the development of numerical methods for balance laws, this is one of the main research areas of G.Russo. The numerical solution of kinetic equations presents several difficulties, such as the dimensionality of the problem, the complexity of the collision integral in the case of the Boltzmann equation of rarefied gas dynamics, the stiffness of the collision term when the system is close to the fluid regime, just to mention some of them.

Conference proceedings [40] and [41] were a first attempt to deal with the stiffness of the collision term of a kinetic equation near the fluid dynamic limit. The research was conducted while G.Russo was a post-doc at UCLA, working with prof. R.Caflisch. A similar problem has been treated in the context of hyperbolic systems with stiff relaxation terms, leading to one of the most cited papers of G.Russo [49].

References [7, 79, 11] are lecture notes prepared for short courses on the numerical solution of the Boltzmann and related equations, delivered at several summer schools. They were all prepared in collaboration with Prof. Lorenzo Pareschi, from the University of Ferrara. In particular, the last one gives a nice overview of deterministic and Monte Carlo methods for the numerical solution of the Boltzmann and related equations, including the most recent developments at the time of publication.

Spectral methods for the numerical solution of the Boltzmann and Fokker-Planck-Landau equations are considered in a series of papers. In paper [64] a method is presented for the space homogeneous Boltzmann equation. Under the assumption that the distribution function decays fast in velocity, the equation is first periodized in velocity space; then, by taking the Fourier transform, the evolution equation is converted into an infinite set of equations for the Fourier coefficients. The truncation of the Fourier series gives a spectral-Fourier method for the Boltzmann equation. The computational complexity for the computation of the right-hand side of the equation is quadratic, because of the quadratic nature of the Boltzmann equation. However, there are two great advantages of this approach: first the Fourier coefficients that describe the collision operator can be computed at the beginning of the time integration, by integrating over the angles, and in many interesting cases have an explicit analytical expression (this makes the computational complexity lower than other deterministic schemes available at the time of the publication of the paper, in which also the angles in the collision integral have to be discretized), and the method presents a spectral accuracy, providing extremely accurate solutions with a reasonable number of Fourier modes (if the solution itself is quite smooth, which unfortunately is not always the case). The large accuracy of the scheme makes it a good choice when a very accurate solution is requires in special cases, for example when one wants to formulate conjectures on some properties of the solution

in special cases.

The scheme does not preserves momentum and energy exactly, but it preserves them with spectral accuracy. Not even positivity is preserved, although the violation of positivity of the solution is extremely small. With a suitable modification, the spectral method may be made positive using suitable filtering techniques in Fourier space [70], however this is done at the cost of losing spectral accuracy.

The spectral method has been extended to space non homogeneous problems in [86]. A fractional-step method is used for the time discretization: the convection step is solved by a Positive-Flux Conservative method, derived by Filbet in his PhD thesis, which is third order accurate in space, and the collision term is treated by the spectral method introduced in [64], where the space homogeneous Boltzmann equation is solved in each space cell. The accuracy in time is second order, obtained by using the classical symmetric Strang-splitting. An interesting feature of the splitting approach is that in this way the code is easily parallelizable: during the convection step each velocity is independent and parallelization is possible in velocity space, while during the collision step, each space cell is independent, and parallelization is possible in physical space.

A spectral method can be effectively used to compute the right-hand side of the Fokker-Planck-Landau equation. This is done in the two papers [67, 76]. By periodizing the FPL equation in velocity, and taking the Fourier transform, because of the very special structure of the equation, the right-hand side can be computed as the sum of seven convolutions, making the computa $\Delta v$ is the grid size in velocity space.

In addition to deterministic methods, Monte Carlo methods have been considered. MC methods are extensively used in rarefied gas dynamics. In fact, they are the most suitable methods for general purpose RGD computation, in presence of complex geometries, especially if the system is quite far from local thermodynamical equilibrium. Near local thermodynamical equilibrium (fluid regime) MC methods are usually not very effective: the main effect of collision is to relax the distribution function toward a Maxwellian, and the small deviation from equilibrium are hard to observe because they are masked by the large statistical noise intrinsic in the MC method.

The problem of designing a Monte Carlo method which is effective even near the fluid regime is treated in paper [82]. The method is based on a formal expansion in time of the numerical solution of a Boltzmann-type equation, called Wild sum, in which the solution at time $t + \Delta t$ is written as a series of positive terms. Because of the positivity of the terms, the series has a natural probabilistic interpretation, that leads to a Monte Carlo scheme. Furthermore, by truncating the series, and replacing the reminder by a local Maxwellian, one obtains a scheme that is able to work even in the fluid dynamic regime: in such a case the scheme becomes a sort of Monte-Carlo kinetic scheme for the underlying compressible Euler equation of a monoatomic gas, in which particles are sampled from a Maxwellian with the moment computed with the local distribution of particles, and then are convected by free flow during one time step. This approach, called Time-Relaxed Monte Carlo (TRMC) had several extensions, mainly by Pareschi and his students, in particular in the direction of removing the fluctuations by exploiting the fact that near the fluid dynamic regime the behavior of the system approaches a continuous equation that can be solved by a deterministic scheme.

Some variation of TRMC has been compared with other Monte Carlo methods developed by the group of Prof. Ivanov in Novosibirsk ([100, 101]) and with other methods for the numerical solution of the Boltzmann equation, as is done in [109]. In this paper, the numerical solution of the Boltzmann equation is compared also with real experiments conducted on an expansion of gas in a shock tube, using Argon.

A different problem has been considered in paper [89]. In this paper a non linear differential equation of degree four is considered, describing the so called *Hele-Shaw cells*. Making use of the positivity of the solution and the conservation of the $L^1$ norm of the solution, which are guaranteed by the special nature of the equation, in the paper a novel discretization of the equation is proposed, which has a kinetic interpretation. A Monte Carlo method is then adopted to approximate the solution of the kinetic equation and therefore of the fourth-order equation. The scheme preserves some of the properties of the original equation (positivity, $L^1$ norm preservation).

One of the drawbacks of most deterministic schemes for kinetic equation is that a grid in velocity space that is adequate in a region in space may be not adequate in a different region. Usually in space homogeneous equations this problem does not appear. There are, however, cases in which the kinetic equation does not conserve energy, and the distribution function approaches a Dirac mass concentrated at the origin (homogeneous cooling). This is the case, for example, of the Boltzmann equation for granular gases. In paper [95] an automatic rescaling

technique is proposed that is able to capture the long time behavior of such space homogeneous solutions. The technique is based on a change of coordinates in velocity space. The grid is rescaled by the thermal speed, i.e. the square root of the temperature. An evolution equation for the latter is then derived, and the coupled system describing the evolution of the temperature and the rescaled distribution function is solved numerically by a spectral method, suitably adapted to the problem (a drift term appears in the equation because of the change of coordinates). An application of a similar technique is proposed in [107], in which the semiconductor Boltzmann transport equation (BTE) is first rewritten in a rescaled energy variable, discretized in the new variable, and finally the coupled system (BTE and temperature) is solved numerically. Because of the more efficient discretization, this approach is able to provide an overall more efficient scheme, in spite of the additional drift term that appears in the equation written in the rescaled variables.

More recently, deterministic semi-Lagrangian schemes have been derived for the numerical solution of the BGK model of the Boltzmann equation. In a paper, still in preparation, [137], a large time step, high order accurate semi-Lagrangian scheme on a regular grid, for the numerical solution of the BGK model is presented. High order accuracy is obtained by using WENO reconstruction in space, and high order implicit Runge-Kutta along the characteristics. Due to a special property of the BGK operator, the implicit step can be explicitly solved. Because of the implicit nature of the time solver, the method is able to treat the problem even in the fluid dynamic regime, when the relaxation time vanishes, although in this case the method reduces to first order in time. Some of the results presented in the paper are contained in the PhD thesis of Pietro Santagati, who obtained his PhD in 2007, under the supervision of G.Russo.

Theoretical results about the scheme, including a convergence proof, will be presented in a forthcoming paper, still in preparation [128].

A similar semi-Lagrangian, large time step method has been used in [115], in which the BGK equation has been solved on a fixed grid in space in a region that depends on time (piston problem). Reflecting boundary conditions on the piston are used to define the value of the distribution function at *ghost cells*. A comparison between the results obtained by this method and the numerical solution of the Euler equation of gas dynamics is performed for a very small Knudsen number (fluid regime).

## Numerical methods for balance laws

The research in this field had three main objectives:

1. construction of high order finite volume and finite difference shock capturing schemes for conservation laws which do not rely on Riemann solvers
2. development of high order schemes for balance laws with stiff source terms
3. shallow water equations and well balanced schemes for hyperbolic systems with source

The first and second topic were originally motivated by the application to the hydrodynamical model of semiconductors. In such models, in fact, the characteristic structure is not know, and therefore it is very difficult to use schemes that require the solution of the Riemann problem. Furthermore, such systems may contain stiff source terms that are better treated by an implicit scheme. Several other mathematical models, such as discrete velocity models from kinetic theory, have the structure of a hyperbolic system with relaxation: when a small parameter (that can be interpreted as a relaxation time) vanishes, the source term becomes an algebraic relation between the variables, and the original hyperbolic system with source relaxes to a hyperbolic systems with a smaller number of unknowns. The original motivation to work on such problems was to develop efficient schemes for kinetic equations that work also in the fluid regime.

The third topic was motivated first by the construction of well balanced central schemes for shallow water equations, and later by the desire of construct high order well-balanced finite volume schemes for generic systems of balance laws.

### High order schemes for conservation laws [61, 62, 65, 66, 68, 84, 91, 103, 60, 8, 12, 99, 80, 121]

Central schemes on staggered grids have two great advantages: the staggering process avoids the need of Riemann solvers, and it increases the resolution for the same order of accuracy and grid size. The first advantage is shared

by standard non staggered schemes, when a numerical flux function that does not require Riemann solver is used, for example the local Lax-Friedrichs flux. The second advantage in some cases may compensate the disadvantages introduced by the staggering (for example it is slightly more cumbersome to assign boundary conditions in a scheme on staggered grids).

The first paper on high order central schemes is [61]. In this paper a general technique is introduced to extended the second order central scheme by Nessyahu and Tadmor to arbitrarily high order finite volume central schemes on staggered grid. A fourth order scheme was presented in the paper. Two main ingredients were used. First, Essentially Non Oscillatory reconstruction (ENO), introduced by Osher and coworkers, and adapted to the central context, allowed to compute point-wise values at the center of the cell, and the staggered cell average. The use of a staggered grid avoids the need of a Riemann solver. Second, the integral of the flux is computed by Simpson's rule, and the approximation of the flux on the nodes is obtained by Runge-Kutta schemes with the aid of so called Natural Continuous Extension (or dense output). In a next paper, [62], the use of Weighted ENO reconstruction (WENO), originally introduced by Liu, Osher and Chan in the context of upwind schemes, and suitably adapted here to the central context, allowed the computation of fourth order schemes (CWENO schemes) with a more compact stencil than the one required by the ENO reconstruction. Numerical experiments on the TVD (Total Variation Diminishing) property of the recently developed CWENO schemes was presented at the ICOSAHOM conference in Israel in 1998 [65]. A third order CWENO scheme in two space dimensions were presented in [66], and a version with a more compact stencil was presented in [68]. A fourth order CWENO scheme in two space dimensions was presented in [84].

In my opinion, the best paper on high order central schemes for conservation laws is the one developed with Pareschi and Puppo on Central-Runge-Kutta schemes (CRK) [91]. It introduces a new technique to construct high order central schemes on staggered grids. The method is based on integrating the evolution equation for the staggered cell average for one time step, by an ingenious use or a Runge-Kutta approach: the numerical solution is computed for the staggered cell averages, so that the resulting scheme is conservative, while the so called stage values are computed (point wise) along the center of the non staggered cell, by a scheme which is not necessarily in conservative form, since these values are used to evaluate the flux when constructing the (conservative) numerical solution. In addition, the schemes obtained in this fashion have a simpler structure than previous central schemes. For high order schemes, this simplification results in higher computational efficiency. In this work, schemes of order 2 to 5 are proposed and tested, although central Runge–Kutta schemes of any order of accuracy can be constructed in principle. The application to systems of equations is carefully studied, comparing algorithms based on a component wise extension of the scalar scheme with those based on projection along characteristic directions.

In paper [103] conservative finite difference shock capturing scheme, originally developed by Osher and Shu on non staggered grids, are extended to staggered grids. The finite difference approach has some advantages over finite volume: it is simpler and more efficient in several space dimensions, and it is more natural for systems with a source term, if high order accuracy is desired (it has however the drawback of being less flexible in terms of space discretization).

Paper [60] deals with the development of efficient shock capturing schemes, having in mind applications to magneto-hydro-dynamics. When developing high order schemes, a numerical flux function that is often used is an improvement of the local-Lax-Friedrichs (LLF) flux, which involves the use of the absolute value of the Jacobian matrix of the system (while the simple LLF flux uses the spectral radius of the matrix), which in turn requires the diagonalization of the matrix. An intermediate approach is obtained by approximate the absolute value of a matrix by a function of the matrix that approximates the absolute value. The use of such numerical flux function provides a resolution which is better than the one obtained by LLF flux, and it is much simpler than the use of the absolute value of the matrix.

Several lecture notes have been written on the topic of shock capturing schemes for conservation laws. Among these we recall the chapters written for books: [8] and [12], for lectures given respectively at a summer school in Hamburg in 2001 and a summer school in Barcelona in 2007, both on numerical methods for balance laws.

Paper [99] deals with the application of (WENO) reconstructions to a class of semi-Lagrangian schemes for first order time-dependent Hamilton–Jacobi equations. In particular, we derive a general form of the scheme, study sufficient conditions for its convergence with high-order reconstructions, and perform numerical tests to

study its efficiency. In addition, we prove that the weights of the WENO interpolants are positive for any order.

In this section I include two papers on numerical methods for problems with moving boundaries. The first one is [80], in which a central scheme for the solution of one dimensional gas dynamics in Lagrangian coordinates was presented, which was able to deal with a system with two fluids separated by an interface. More recently, in paper [121], a second order boundary condition on a moving piston is presented, and the results of the piston problem are compared with those obtained by a moving mesh methods in Eulerian coordinates.

**Numerical schemes for hyperbolic systems with stiff relaxation [49, 50, 77, 55, 78, 88, 98, 106, 105, 103, 110, 113]**

Motivated by the goal of finding efficient schemes for kinetic equations that are able to capture the fluid dynamic limit without resolving the small collision mean free time, this research lead to some of the most cited papers of G.Russo.

In paper [49], which turned out to be the most cited paper, the authors study the problem of developing high-resolution shock-capturing numerical schemes for hyperbolic systems with relaxation. In such systems the relaxation time may vary from order one to much less than unity. When the relaxation time is small, the relaxation term becomes very strong and highly stiff, and under resolved numerical schemes may produce spurious results. Usually one cannot decouple the problem into separate regimes and handle different regimes with different methods. Thus it is important to have a scheme that works uniformly with respect to the relaxation time. Using the Broadwell model of the nonlinear Boltzmann equation, a second-order scheme that works effectively, with a fixed spatial and temporal discretization, for all ranges of the mean free path is derived. Formal uniform consistency proof for a first-order scheme and numerical convergence proof for the second-order scheme are also presented. Later, the scheme for the time evolution was recognized to be an Implicit-Explicit Runge-Kutta scheme applied to a hyperbolic system with stiff relaxation. Notice that the paper of Ascher, Ruuth and Spiteri on IMEX schemes for pde's appeared the same year.

The accuracy of the methods was restricted to second order in time. A third order accurate shock capturing finite volume scheme that made use of an extrapolation technique was presented in [50]. Later, more effective ways to obtain higher order *finite difference* schemes using IMEX are considered.

In paper [77] and in the proceeding paper [55] a second order central scheme on staggered grids for hyperbolic systems with stiff relaxation is presented. The scheme guarantees second order accuracy both in the non stiff regime and in the very stiff regime, with a small degradation of the accuracy for the intermediate cases.

In a series of papers, Pareschi and Russo studied high order shock capturing finite difference methods based on IMEX time discretization for the numerical solution of hyperbolic systems with relaxation. IMEX time discretization is a natural thing to do when dealing with hyperbolic systems with relaxation. In fact, the hyperbolic term is usually not stiff (if one wants to resolve all the waves of the system), and it does not need to be treated implicitly, while the relaxation term may be very stiff, and an explicit treatment would impose a restriction on the time step which is much more severe than the standard CFL condition.

In [78] new IMEX Runge-Kutta schemes are introduced, analyzed, and compared with existing IMEX schemes. A stability analysis that generalized the A-stability or Runge-Kutta schemes is performed. The treatment is restricted to systems of ordinary differential equations. In the conference proceeding [88] IMEX-Runge Kutta schemes are presented for the numerical solution of hyperbolic systems with stiff relaxation. Such schemes are constructed by combining explicit Strongly-Stability-Preserving schemes (SSP), which are commonly used for the time discretization of high order semidiscrete finite difference shock capturing schemes, with L-stable schemes for the relaxation part, which are stable enough to give the proper asymptotic limit, in the case of infinite stiffness. The properties of such IMEX-SSP schemes and of several other new schemes are analyzed in paper [98], and the effectiveness of the schemes was tested by applying them to various hyperbolic systems with relaxation, including the Broadwell model of the Boltzmann equation, shallow water equation with friction, hydrodynamical models for granular gases, and traffic flow models.

Paper [106] deals with the numerical solution of some parabolic integro-differential equations used in finance. They are models of option pricing generalizing the Black-Scholes equation, when the processes which generate the underlying stock returns may contain both a continuous part and jumps. Due to the non-local nature of the integral term, unconditionally stable implicit difference schemes are not practically feasible. IMEX schemes

seem to provide a very effective way to treat such problems.

In two papers in collaboration with G.Puppo, IMEX schemes are coupled with staggered finite difference and finite volume schemes. The first one, [105], is an extension of [103] to problems with stiff source, i.e. it presents a construction of high-order shock-capturing finite-difference schemes on staggered grids for hyperbolic systems with a stiff source term, obtained using IMEX time discretization. In paper [110] Central Rungr-Kutta and IMEX schemes are combined to provide the first general purpose high order shock capturing finite volume scheme for hyperbolic systems with stiff source term

Paper [113] deals with the problem of developing IMEX schemes which are uniformly accurate in the stiffness parameter, and applying them to hyperbolic systems with stiff relaxation. The problem of the uniform accuracy of IMEX schemes for systems of ordinary differential equation has been the topic of the PhD thesis of Dr. Sebastiano Boscarino, who obtained his PhD in 2006 under the supervision of G.Russo. In that thesis many ideas from implicit schemes applied to stiff systems and to differential-algebraic systems have been applied to the analysis of IMEX schemes. Even if the IMEX scheme preserves the theoretical order of accuracy $p$ in the limit of infinite stiffness, a strong degradation of the accuracy for intermediate values of the stiffness parameter is observed. The analysis of this effect is conducted by performing an asymptotic expansion in the stiffness parameter. To the various orders, one obtains a hierarchy of differential-algebraic systems of increasing index. The formal expansion can be performed both for the exact solution of the differential system, and for numerical solution obtained by the IMEX method. The lack of matching of the terms at positive orders in $\varepsilon$ is the cause of the degradation of the accuracy. The uniformity of the accuracy can be improved by matching some terms of the exact and numerical solution in the expansion in $\varepsilon$. This matching leads to new "order conditions" that have to be satisfied in addition to the classical order condition for IMEX schemes. In the paper in question, the new conditions, derived in the PhD thesis of Boscarino, have been applied to derive novel schemes that show a more uniform accuracy for hyperbolic systems with stiff relaxation, than the schemes known in the literature.

**Shallow water equations and well-balanced schemes [23, 81, 96, 92, 114, 119, 120]**

Some papers deal with the numerical solution of shallow water equation, and with the problem or constructing well-balanced schemes.

In an early paper, [23], several numerical schemes available at the time were tested with the purpose of computing the time at which shallow water waves break on a sloping beach. The most effective way was to use methods based on characteristics.

A numerical scheme is called *well-balanced* if it is able to maintain stationary states at a discrete level. This property is very important when one is interested in observing a solution which is a small perturbation of a stationary one. If a scheme is not well-balanced, spurious artifacts, of the order of the truncation error, may mask the small signal one is interested in.

At the hyperbolic conference in Magdeburg in 2000 [81] G.Russo presented the first well-balanced second order central scheme on staggered grid, two years earlier than a work that introduced well-balanced schemes for non-staggered central schemes using essentially the same ingredients. The scheme preserved only equilibria at rest, i.e. solutions for which the water flux is zero.

At a conference in Chambery in 2002, G.Russo presented a well-balanced staggered central scheme that preserves also non stationary equilibria, and which works for Saint-Venant model in the case of channels with variable cross section. The results have been published in [96].

For many years, well-balanced schemes were restricted to second order. Recently, several authors presented various techniques to construct high order, well balanced schemes. At the hyperbolic conference in Maryland, in 2008, G.Russo presented a general technique, developed in collaboration with Alexander Khe, to construct high order, well balanced schemes for systems with source, and applied it to one dimensional shallow water equations [114]. The technique is based on the use of equilibrium variables in the reconstruction step. In this formulation, the method is based on an analytical knowledge of the mapping between conservative and equilibrium variables. A more robust method, which is based on the numerical reconstruction of local equilibrium stares, has been presented at the international workshop NumHyp2009 held in Castro Urdiales in September 2009, and is being published in [119].

Finally, in paper [120] a well balanced scheme for Saint-Venant equations that includes the friction term with the bottom is presented.

Paper [92] deals with inifinite-layer formulation of shallow water. This constitute a generalization of standard Saint Venant equation for shallow water, and applies when the effect of the vorticity cannot be neglected. The system describing infinite-layer shallow water is an integrodifferential system, that has the mathematical structure of a hyperbolic system of infinite dimension. The goals of the paper were: to study a class of exact solution for such system, to propose a numerical methods for the approximation of it solutions, and to compare the solution of the infinite-layer model with the solution of classical Saint-Venant equations, to assess the validity of the latter.

## Numerical simulation of crystal growth

This research has been conducted in collaboration with Prof. Peter Smereka, from the University of Michigan. The goal is to develop models and methods for effective simulation of crystal growth, under various regimes. In paper based on macroscopic description of crystal growth, level set techniques have been used, while more microscopic modeling of epitaxial growth is obtained using Kinetic Monte Carlo techniques. The first paper on crystal growth is [73], in which the co-called van der Drift model for crystal growth is considered here. We present a new method for simulating van der Drift growth, both for single crystals and polycrystals. In the simulation of polycrystals, each grain is described by a level set function, which is defined only in a narrow band around the zero level set, defining grain boundary. In this way the total memory occupation is simply proportional to the total grid size. The computational domain of each grain is updated dynamically at each time step using a *signed distance function*. In a subsequent paper [90] the methods has been applied to the simulation of polycrystal, allowing to predict several macroscopic parameters of the polycrystal, such as morphology and surface roughness. The prediction of the model are in good agreement with experimental results.

In [74] we pointed out that the usual schemes based on PDE for the construction of signed distance function does not maintain the zero level set. After several iterations the error accumulates, and the zero level set suffers a spurious drift. We observed that this is due to the lacking of strict unwinding across the interface, and proposed a simple technique to fix this problem. First and second order accurate schemes were presented. In spite of its relative simplicity, this paper was a rather successful one, and became the second most cited paper of G.Russo.

In the next papers simulation of epitaxial growth has been considered.

In paper [94] the authors consider mathematical model for epitaxial growth, which is called *island dynamics*, which is a macroscopic model, in which the island formed over a substrate as a consequence of attachment after chemical vapor deposition, grows according to a velocity which is computed by solving a suitable Stephan problem. The level set defining the island is then moved according to such velocity. A hybrid model is considered in the paper: the velocity is computed by solving a pde, and then its value is interpreted as attachment probability, and particles are attached (or detached in case of negative velocity) with a rate proportional to the velocity itself. This approach provides some of the effects which are due to the statistical fluctuation of the problem, and which is impossible to observe with the macroscopic model. This idea, however, has not being pursued further, since at the end the method was not faster than the purely microscopic Kinetic Monte Carlo.

The goal of paper [102] is to construct an effective Kinetic Monte Carlo method for the simulation of etheroepitaxy. When depositing atoms of one species on atoms of a (not so) different species, say Germanium on Silicon, epitaxy is still possible since the external electronic structure of the two atoms is rather similar, and their size is not so different. However, lattice spacing in Germanium is about 4% greater, therefore when Ge atoms are forced to stay on the smaller Si substrate, the deposited layers are affected by compression stress. The overall effect is that the simple planar configuration, which is thermodynamically favorable in homogeneous epitaxy, is no longer the one that minimizes total energy (bond enerdy + elastic energy), and after a few monolayer the formation of mounds is observed experimentally. In KMC simulation, single adatoms are deposited one at time. Once the atoms reach the substrate they hop, with a rate that is approximately given by an attempt frequency times a Boltzmann factor that takes into account the energy barrier needed to perform the hop. In the computation of such energy barrier, necessary to perform KMC, the bottleneck is the computation of the elastic energy, since removing a single atom has a global change in the equilibrium

configuration of the lattice. In this paper we introduce a very effective way to compute the elastic energy of a configuration. The novelty of the method is that the contribution of the lattice is taken into account semi-analytically by decomposing the displacement of substrate atoms into Fourier modes, which can be computed analytically. The problem is transformed into large sparse symmetric positive definite linear system, which is then solved by conjugate gradient method. In a subsequent paper, [104], the method is made much more efficient by a non trivial use of a multigrid approach. The resulting scheme was orders of magniture faster than other schemes adopted, for example, by the group of UCLA interested in etheroepitaxy, and at the end this group decided to incorporate our method into their simulator.

## Other papers

G.Russo worked on a few other topics which are not directly related with what has been described before.

In [52] a domain decomposition method for the solution of parabolic problems is presented, which may be considered analogue to the classical ADI methods or fractional step methods for the solution of a large sparse linear system in several space dimensions, which are obtained when using an implicit scheme for the solution of the heat equation. Usually, the elliptic operator is fractioned along the coordinate axes, leading to sequence of tridiagonal systems (if the grids are uniform and the operator has no mixed second derivatives). In this paper a partition of unit is used, which is based on a domain decomposition, and it is applicable also to non uniform grids, and to operators containing mixed derivatives. For such methods, theoretical estimates of the truncation error are performed, and a comparison is made, both theoretical and numerical, between the new approach and the traditional ones.

Paper [87] deals with maximum norm stability and accuracy of a finite difference discretization of parabolic equations on overset non matching space time grids in space time. The resulting global discretization yields a large system of coupled equations, which is solved by Schwarz iterative procedure. The analysis employs contraction mapping arguments.

In [53] an optimization problem is considered. The goal is to construct a numerical approximation of a function which is implicitly defined by an integral equation. The minimization problem is treated by looking for a function of a suitable form, depending (nonlinearly) on five fitting parameters. The solution found in the paper is simpler and much more accurate than the one determined by other authors in a previous paper which the present paper refers to.

Paper [112] is the outcome of a project with an industrial partner, aimed to the development of a prototype software, KneeMech, developed to assist the surgeon by simulating the structural strain and stress distribution in a bone-prosthesis system of a knee, under various load conditions. The project saw a collaboration between the LIMA group S.R.L. and the University of Catania. The objective was to provide a tool that is able to simulate the stress distribution in the prosthesis and in the bones as a result of the implantation of a knee prosthesis. The result depends on a large set of parameters, such as the mechanical properties of the bone and the geometry of the cut. The initiative was so complex that several groups were involved in the project: the LIMA S.R.L., two Departments of the University of Catania (Department of Mathematics and Computer Science and Department of Mechanical Engineering). The research was carried on with the help of a foreign partner, the Fraunhofer Institute ITWM from Kaiserslautern, with the group conducted by Dr. Heiko Andrä. The Vittorio Emanuele hospital in Catania, Sicily, was involved in the project, providing CAT scan of the bones, and consulting about the surgical process. The bone is modeled as a five parameter viscoelastic material, which were determined by fitting the measured response using the analytical solution of the relaxation predicted by the model. A three dimensional geometric model of the bone was constructed by the image processing group from several 2D section images obtained from CAT scan. The geometrical data were integrated with the mechanical properties of the bone, obtaining a complete 3D description of the object. A great care has been used in the modeling of the bone-prosthesis contact: a highly accurate multi-scale modeling provides the determination of effective parameters to be used in the numerical simulation. The final problem is discretized using finite element on a tetrahedral mesh, obtained from the voxel representation of the bone. For the prototype, only an elastic model has actually been implemented. The final large sparse linear system is then solved by preconditioned conjugate gradient method. Once the displacement vector and stress tensor have been computed, the results can be displayed on arbitrary cross section of the bone (see screen shot figure).

An important aspect of the package is the possibility of performing uncertainty analysis, to establish the range of variation of the results upon uncertainty in the knowledge of some parameters, such as, for example, Young modulus of the bone. A suitably adapted affine arithmetic technique has been used for such purpose.

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