Semyon V. Tsynkov
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https://orcid.org/0000-0003-1069-9612 LinkedIn Web of Science ResearcherID: X-5528-2019

ONE PAGE CV SUMMARY

Education

MSc (1989), PhD (1992), Doctor of Science (2004)

Current Research Topics

- Partial differential equations (PDEs), numerical analysis of PDEs, scientific computation.
- Numerical methods for problems on unbounded domains, artificial boundary conditions.
- Non-deteriorating methods for long-time numerical simulation of large-scale 3D unsteady problems.
- Applied problems of wave propagation, including acoustics, electromagnetism, optics, and plasma.
- Statistical analysis of the propagation of waves in random media.
- Inverse problems, including remote sensing (radar imaging) and active control of sound.
- Machine learning for remote sensing applications.
- Topological electromagnetic fields.

Summary of Research Funding

Overall funding awarded/directed	**$12,905,000**
Currently active projects	**Three**
Current budget at NC State (as PI)	**$1,230,000**
Current budget w/partners	**$1,980,000**

Summary of Publications

Graduate textbooks	**1**	 https://www.crcpress.com/A-Theoretical-Introduction-to-Numerical-Analysis/
Research monographs	**1**	 http://www.springer.com/us/book/9783319521251
Journal articles	**92**	
Book chapters	**8**	
Peer reviewed preprints	**13**	
Peer reviewed conference papers	**38**	
Other publications	**2**	
Accepted	**1**	

Summary of Advising/Mentoring

Present	Currently supervise ***a group of four*** junior researchers
Current junior faculty mentees	**1**
Previous graduate students	**14**
Previous postdocs/RAPs	**4**

Summary of Service

Larry Norris Faculty Award Honoring Faculty Service (NC State), Spring of 2021.

Editorial boards, a large number of committees at NC State, refereeing for journals (outstanding reviewer), publishing houses, and funding agencies, member of grant review panels, external evaluator on faculty promotions, conference organizer:

Intnl. Conf. *Difference schemes and applications* in Honor of the 90-th Birthday of Prof V.S. Ryaben'kii
International Conference *Advances in Applied Mathematics* in memoriam of Prof Saul Abarbanel
Smart Computational Methods in Continuum Mechanics 2021

Triangle Computational and Applied Mathematics Symposium (TriCAMS): 2022, 2023, 2024

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Academic Degrees

June 1989	***MSc (with Honors)*** [Diploma of Higher Education] in Engineering Physics (Aerodynamics and Thermodynamics) from Moscow Institute for Physics and Technology (Russia);
May 1992	***PhD*** [Candidate of Science] in Computational Mathematics from Russian Academy of Sciences (Moscow), advisor: Professor V. S. Ryaben'kii;
May 2004	***Doctor of Science*** [Habilitation, an advanced post-PhD degree] in Computational Mathematics from Russian Academy of Sciences (Moscow).

Professional Background

July 1991 – Sept 1992	Russian Academy of Sciences (Moscow), ***Research Scientist;***
Oct 1992 – Sept 1994	Department of Applied Mathematics, Tel-Aviv University (Israel), ***Postdoc;***
Oct 1994 – Sept 1997	NASA Langley Research Center (Hampton, VA, USA), *National Research Council* ***Resident Research Associate*** (Aerodynamic and Acoustic Methods Branch);
Oct 1997 – Sept 2002	Dept. of Applied Mathematics, Tel-Aviv University (Israel), ***Senior Lecturer;***
Oct 1997 – Dec 2002	NASA Langley Research Center (Hampton, VA, USA), ***Consultant*** for ICASE;
Aug 2000 – ***present***	Department of Mathematics, North Carolina State University (Raleigh, NC, USA), ***Associate Professor, Professor;***
Mar 2008 – Feb 2012	Computational Sciences, LLC (Madison, AL), ***Consultant;***
Sept 2012 – Mar 2017	Computational Sciences, LLC (Madison, AL), ***Academic partner on STTR;***
Nov 2012 – Dec 2018	Moscow Institute of Physics and Technology (Russia), ***Adjunct Professor;***
Dec 2018 – Feb 2022	ADED, LLC (San Antonio, TX), ***Academic partner on STTR.***
Sep 2020 – ***present***	Center for Research in Scientific Computation (CRSC), North Carolina State University (Raleigh, NC, USA), ***Associate Director.***

Current Research Topics

- Partial differential equations (PDEs), numerical analysis of PDEs, scientific computation.
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- Non-deteriorating methods for long-time numerical simulation of large-scale 3D unsteady problems.
- Applied problems of wave propagation, including acoustics, electromagnetism, optics, and plasma.
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Research Funding Summary

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Currently active projects	**Three**
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Federal Research Grants (STTR/SBIR with industry)

2008 — 2009 US Air Force Research Laboratory (Kirtland AFB), NC State **co-PI** on **Phase I SBIR** research grant: *Accurate and Efficient Computation of Electromagnetic Fields and Waves over Unbounded Regions in 3D,* **$150,000.**
Prime contractor: **Computational Sciences, LLC** (Madison, AL).
Other performing organizations: **U. of Akron, U. of Washington.**

2009 — 2011 US Air Force Research Laboratory (Kirtland AFB), NC State **co-PI** on **Phase II SBIR** research grant: *Accurate and Efficient Computation of Electromagnetic Fields and Waves over Unbounded Regions in 3D,* **$750,000.**
Prime contractor: **Computational Sciences, LLC** (Madison, AL).
Other performing organizations: **U. of Akron, U. of Washington.**

2011 — 2012 US Army Research Office (ARO), NC State **co-PI** on **Phase I STTR** research grant for the project: *A Priori Error-Controlled Simulations of Electromagnetic Phenomena for HPC,* **$100,000.**
Prime contractor: **Computational Sciences, LLC** (Madison, AL).
Other performing organizations: **LLNL, U. of Washington.**
Endorsements: **Boeing, Lockheed-Martin.**

2013 — 2014 US Army Research Office (ARO), NC State **co-PI** on **Phase I STTR** research grant for the project: *A Universal Framework for Non-Deteriorating Time-Domain Numerical Algorithms in Maxwell's Electrodynamics,* **$150,000.**
Prime contractor: **Computational Sciences, LLC** (Madison, AL).
Other performing organizations: **LLNL, RPI, U. of Washington.**
Endorsements: **Kirtland AFB, Boeing, Lockheed-Martin.**

2014 — 2017 US Army Research Office (ARO), NC State **co-PI** on **Phase II STTR** research grant for the project: *A Universal Framework for Non-Deteriorating Time-Domain Numerical Algorithms in Maxwell's Electrodynamics,* **$1,000,000.**
Prime contractor: **Computational Sciences, LLC** (Madison, AL).
Other performing organizations: **RPI, U. of Washington.**
Endorsements: **Kirtland AFB, Lockheed-Martin, Raytheon, Northrop Grumman, Boeing.**

2018 — 2019 US Army Research Office (ARO), NC State **co-PI** on **Phase I STTR** research grant for the project: *Analysis and Design of Adaptive Multi-Function Antenna Systems Based on Signal Fragmentation,* **$150,000.**
Prime contractor: **ADED, LLC** (San Antonio, TX).
Other performing organizations: **Ultra Quantum, Inc.** (Madison, AL).
Endorsements: **Expedition Technologies, Inc.** (Dulles, VA).

2019 — 2022 US Army Research Office (ARO), NC State **co-PI** on **Phase II STTR** research grant for the project: *Wavelet-Based Adaptive Antenna Systems* **$1,025,000.**
Prime contractor: **ADED, LLC** (San Antonio, TX).
Other performing organizations: **Ultra Quantum, Inc.** (Madison, AL).

Federal Research Grants (Academic)

1998 — 2000	NASA Langley Research Center (USA) Director's Discretionary Fund, **PI** on the research grant for the project: *Global Boundary Conditions for Aerodynamic and Aeroacoustic Computations*, **$300,000.**
2000 — 2001	NASA Langley Research Center (USA) Creativity & Innovation Program, **PI** on the research grant for the project: *Active Shielding and Control of Environmental Noise*, **$200,000.**
2001	North Carolina State University, Faculty Research and Professional Development Fund, **PI** on the research grant for the project: *Non-Deteriorating Numerical Algorithms for Wave Propagation Problems*, **$5,000.**
2001 — 2004	US Air Force Office for Scientific Research, **PI** on the research grant for the project: *Non-Deteriorating Numerical Methods and Artificial Boundary Conditions for the Long-Term Integration of Maxwell's Equations*, **$115,000.**
2001 — 2005	National Science Foundation, USA, **PI** on the research grant for the project: *Temporally Uniform Grid Convergence of Discrete Approximations and Numerical Simulations in the Problems of Wave Propagation over Unbounded Domains*, **$95,000.**
2004 — 2007	US Air Force Office for Scientific Research, **PI** on the research grant for the project: *Lacunae-Based Methods for Problems in Electromagnetics*, **$185,000.**
2005 — 2008	National Science Foundation, USA, **PI** on the research grant for the project: *High-Order Numerical Simulation of Focusing Nonlinear Waves in the Non-Paraxial Regime,* **$105,000.**
2007 — 2010	US Air Force Office for Scientific Research, **PI** on the research grant for the project: *Determination of the Ionosphere Parameters by Analyzing the Propagation After-Effects,* **$300,000.**
2008 — 2011	National Science Foundation, USA, **PI** on the research grant for the project: *High-Order Numerical Solution of Wave-Type Equations with Discontinuous Coefficients,* **$200,000.**
2009 — 2013	US–Israel Binational Science Foundation (BSF), American **co-PI** (jointly with Professor E. Turkel of Tel Aviv University) on the research grant for the project: *Numerical Simulation of Waves in Piecewise Continuous Media with High Order Accuracy,* **$100,000.**
2010 — 2013	US Air Force Office for Scientific Research, **PI** on the research grant for the project: *SAR Imaging through the Earth's Ionosphere,* **$760,000.**
2011 — 2016	US Army Research Office, **PI** on the research grant for the project: *Singularity-free high order boundary methods for heterogeneous wave problems,* **$511,000.**
2013 — 2014	US Army Research Office, **PI** on the grant: *Difference Schemes and Applications — A Conference Support Proposal,* **$5,000.**
2013 — 2014	European Office of Aerospace Research and Development (EOARD), **PI** on the grant: *Difference Schemes and Applications — A Conference Support Proposal,* **$10,000.**
2014 — 2017	US Air Force Office for Scientific Research, **PI** on the research grant for the project: *Transionospheric Synthetic Aperture Imaging,* **$670,000;**
2015 — 2019	US–Israel Binational Science Foundation (BSF), American **co-PI** (jointly with Professor E. Turkel of Tel Aviv University) on the research grant for the project: *High Order Numerical Computation of Unsteady Waves with Non-Conforming Interfaces,* **$126,000.**
2016 — 2021	US Army Research Office, **PI** on the research grant for the project: *Numerical Simulation of Time-Dependent Waves with High Order Accuracy and Interfaces of General Shape,* **$662,000.**

2017 — 2021	US Air Force Office for Scientific Research, **PI** on the research grant for the project: *A New Generation of Models for Radar Targets,* **$983,000.**
2018 — 2019	US Army Research Office, **PI** on the grant: *Advances in Applied Mathematics — A Conference Support Proposal,* **$17,600.**
2018 — 2019	US AFOSR, **co-PI** on the grant: *Advances in Applied Mathematics — A Conference Support Proposal,* **$19,800.**
2021 — 2023	US Air Force Office for Scientific Research, **PI** on the research grant for the project: *Mitigation of Ionospheric Distortions for Spaceborne Synthetic Aperture Radar Images,* **$900,000.**
2021 — 2025 (current)	US–Israel Binational Science Foundation (BSF), American **co-PI** (jointly with Professor E. Turkel of Tel Aviv University) on the research grant for the project: *High Order Accurate Three Dimensional Numerical Simulation of Unsteady Broadband Electromagnetic Propagation,* **$200,000.**
2023 — 2025	US Air Force Office for Scientific Research, **PI** on the DURIP: *Increased deep learning computing capacity for radar applications,* **$228,000.**
2024 — 2027 (current)	US Air Force Office for Scientific Research, **PI** on the research grant for the project: *Spaceborne SAR reconstruction through a turbulent ionosphere: Conventional and data-driven methods for autofocus development and target analysis,* **$780,000.**
2024 — 2026 (current)	US Army Research Office/Princeton University, **PI** on the research grant for the project: *Analysis and Computation of Topological Electromagnetic Fields and Accelerating Waves*, **$1,000,000.**

Awards (including advisees)

1994 — 1996	National Research Council Research Associateship Award (USA).
1996	Alexander von Humboldt Research Fellowship (Germany), later declined.
1997 — 2000	Alon Fellowship (young faculty award by the government of Israel — — an equivalent of the Presidential Young Investigator Award in the US).
2006 (June–July)	Sackler Visiting Chair, Tel Aviv University.
June 2008	Best student paper by G. Baruch (PhD advisee) at the international conference on Nonlinear Waves — Theory and Applications, Beijing, China.
2008 — 2010	Invited Project Director for the research project *Methods, Algorithms, and Software for Computing the Diffraction of Waves in Heterogeneous Media on Multiprocessor Computer Platforms*, Russian Academy of Sciences.
2015 — 2017	Fulbright Postdoctoral Fellowship award to Steven Britt (PhD advisee).
2021	Larry Norris Faculty Award Honoring Faculty Service (NC State).
2024	North Carolina Space Grant award to Patrick Haughey (PhD advisee).

Research Leadership

1997 — 2002	Research group leader at ICASE, NASA Langley Research Center, Hampton, VA.
2008 — 2010	Research group leader (invited foreign project director) at Russian Academy of Sciences, Moscow, Russia.
2010 — present	Initiator and leader of the research program at NC State Mathematics Department on *Mathematics of radar imaging.*
Present	Currently supervise ***a group of four*** junior researchers (Graduate students and Research Assistant/Associate Professors (RAPs)).
Sept. 2020 – present	Associate Director for the Center of Research in Scientific Computation (CRSC).

Research Topics & Collaborations (current and past)

CFD	S. Abarbanel, J. Nordström, V. Ryaben'kii, E. Turkel, V. Vatsa, D. Sidilkover, T. Roberts. Support: NASA.
Electromagnetism, PML	S. Abarbanel, E. Kashdan, E. Turkel, H. Qasimov, S. Petropavlovsky, I. Tsukerman, U. Shumlak, M. Osintcev, A. Fedoseyev, W. Henshaw, F. Smith, A. Kahana, I. Versano Support: Israeli DoD, AFOSR, ARO.
Acoustics, noise control	J. Lončaric, A. Peterson, V. Ryaben'kii, S. Utyuzhnikov. Support: NASA.
Unsteady waves, lacunae, non-deteriorating methods	H. Qasimov, V. Ryaben'kii, V. Turchaninov, S. Petropavlovsky, E. Kansa, I. Tsukerman, U. Shumlak, M. Osintcev, A. Fedoseyev, W. Henshaw, F. Smith, A. Chertock, C. Leonard. Support: AFOSR, NSF, ARO.
Nonlinear waves	G. Baruch, G. Fibich, B. Ilan. Support: NSF.
Waves in discontinuous media	E. Turkel, G. Fibich, G. Baruch, S. Britt, M. Medvinsky, S. Petropavlovsky, D. Gordon, R. Gordon, S. Magura, F. Smith. Support: NSF, BSF, ARO.
Synthetic aperture radar (SAR) imaging	E. Smith, M. Gilman, J. Lagergen, K. Flores, R. Sah, V. Chidara, P. Haughey, H. Outlaw. Support: AFOSR.
Machine learning for SAR	M. Gilman, J. Lagergen, K. Flores, R. Sah, V. Chidara, H. Outlaw, D. Ray, Y. Shin. Support: AFOSR.
Numerical simulation of FRC plasmas	E. Kansa, U. Shumlak, I. Tsukerman Support: AFRL.
Multi-function antennas	R. Albanese, A. Fedoseyev, R. Medina, J.-J. Malosse Support: ARO.
Machine learning (ML) in scientific computation	A. Kahana, O. Ovadia, E. Turkel, I. Versano Support: BSF.
Topological electromagnetic fields	K. Sengupta, R. Sazdanovic, P. Spears Support: ARO.

Supervision of Students

B. Ilan	PhD 2002 (co-advised), postdoc at UC Boulder, currently Professor at the University of California, Merced.
D. Warren	senior undergraduate, 2005–2006.
L. Bilbro	senior undergraduate, 2006.
A. Peterson	MSc 2006, currently Systems Engineer – Capital Markets at SAS Institute.
H. Qasimov	PhD 2008 (100% RA AFOSR/NSF), postdoc at the Max Plank Institute, Director of Risk Management at PASHA Bank, The Netherlands, Model validation at M&T Bank, Buffalo, NY, USA, currently at Federal Reserve Bank of Chicago, IL, USA.
G. Baruch	PhD 2010 (co-advised), postdoc at Caltech, researcher at Google, Yahoo, founder at Virtual Drimia, Senior Data Scientist, Intensix, currently at Seor Technologies, Israel.
M. Medvinsky	PhD 2013 (co-advised, 100% FTE support NSF), postdoc at U. of Utah, then Research Assistant Professor/Lecturer, Department of Mathematics, NC State.
E. Smith	PhD 2013 (100% FTE RA support AFOSR), currently Research Mathematician at the US Naval Research Laboratory (NRL), Washington, DC.
S. Britt	PhD 2015 (100% RA support NSF/BSF/ARO), then Fulbright postdoctoral scholar, Department of Applied Mathematics, Tel Aviv University, Israel, currently at Mercer Engineering Research Center in Warner Robins, GA.
S. Magura	MSc 2017 (75% FTE RA support ARO), then Software Developer for Interface

	Technologies, currently Staff Software Engineer at Spot, Raleigh, NC.
J. Lagergren	PhD 2020 (co-advised, 25% FTE RA support AFOSR), currently a postdoc at Oak Ridge National Laboratory, Knoxville, TN.
F. Smith	PhD 2022 (100% FTE RA support ARO/BSF), currently a Research Geophysicist at CGG in Houston, TX.
E. North	PhD 2022 (100% FTE RA support ARO/BSF), currently a Sr. Associate Analytics Software Tester at SAS Institute in Cary, NC.
C. Leonard	PhD 2022 (co-advised), currently a Machine Learning Engineer III at Vadum, Inc., in Raleigh, NC.
R. Sah	MSc 2022 (100% FTE RA support AFOSR).
V. Chidara	MSc 2022, (100% FTE RA support AFOSR).
P. Haughey	PhD expected 2026, (100% FTE RA support AFOSR).
P. Spears	PhD expected 2027, (100% FTE RA support ARO).
H. Outlaw	PhD expected 2028, (100% FTE RA support BSF/AFOSR).

Supervision/Mentoring of Postdocs/Junior Researchers and Faculty

Mark Hoefer	NSF Postdoc during the Academic Year 2009–2010, currently Professor at the University of Colorado, Boulder.
Mikhail Gilman	Research Assistant Professor, Jan. 2011 — June 2022 (100% FTE support, AFOSR), Research Associate Professor, July 2022 — present (100% FTE support, AFOSR).
Sergey Petropavlovsky	Research Assistant Professor, Jan. 2013 — 2024 (100% FTE support in residence, ARO).
Mikhail Osintcev	Research Assistant Professor, Apr. 2015 — Mar. 2017 (100% FTE support, ARO).
Michael Medvinsky	Research Assistant Professor, Jan. 2016 — May 2021 (75% FTE support, ARO), currently Lecturer at the Department of Mathematics, NC State.
Andrew Papanicolaou	Tenure-Track Assistant Professor of Mathematics, Aug. 2020 — May 2023.
Hangjie Jie	Tenure-Track Assistant Professor of Mathematics, Aug. 2021 — present.

Editorial Boards

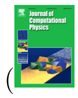
2005 — present	Applied Numerical Mathematics (Elsevier).
2014 — 2016	Royal Society Open Science (Royal Society Publishing).
2014 — 2015	Managing Guest Editor for the Special Issue of Applied Numerical Mathematics covering the International Conference ***Difference Schemes and Applications*** in Honor of the 90-th Birthday of Professor V. S. Ryaben'kii (vol. 93, 2015).
2018 — 2019	Guest Editor for the Special Issue of the Journal of Scientific Computing dedicated to the memory of Professor Saul Abarbanel.

Professional Societies

2002 — present	Member of the American Mathematical Society (AMS).

Service (since coming to NC State in 2000)

Larry Norris Faculty Award Honoring Faculty Service (NC State), Spring 2021.

– Reviewer for various research Journals, including the **Journal of Computational Physics** (

outstanding reviewer), SIAM Journal on Numerical Analysis, SIAM Journal on Scientific Computing, AIAA Journal, Computers & Fluids, Journal of Approximation Theory, Mathematics of Computation, Journal of Scientific Computing, Computer Methods in Applied Mechanics and Engineering, Journal of Sound and Vibration, Journal of Computational and Applied Mathematics, Mathematics and Computers in Simulation, IEEE Transactions on Control Systems Technology, Journal of Computational Acoustics, Numerical Methods for Partial Differential Equations, Numerical Algorithms, Applied Mathematics and Computation, Applied Mathematical Modeling, and others.

– Reviewer of book proposals for various Publishing Houses, including Wiley, CRC, and Springer.

– Reviewer of grant proposal applications for various funding agencies, including US–Israel BSF, AFOSR, ARO, and others.

– Mathematical Sciences Branch of the Army Research Office (ARO) triennial Strategy Planning meeting, invited participant, April 2021.

– Member of grant review panels for DoD sponsors (also NSF in the past).

– External evaluator on faculty promotions at various other Universities.

– Chair/Member (past and current) of a large number of the various committees at NC State University (standing committees, hiring committees, advisory committees).

– Coordinator of teaching assignments in Numerical Analysis for the Department of Mathematics.

– Organizer of conferences:

- International Conference *Difference schemes and applications* in Honor of the 90-th Birthday of Prof V.S. Ryaben'kii.
- International Conference *Advances in Applied Mathematics* in memoriam of Prof Saul Abarbanel.
- *Smart Computational Methods in Continuum Mechanics 2021* in memoriam of Academician O. M. Belotserkovski.
- First Triangle Computational and Applied Mathematics Symposium (TriCAMS), September 2022.
- Second Triangle Computational and Applied Mathematics Symposium (TriCAMS), November 2023.
- Third Triangle Computational and Applied Mathematics Symposium (TriCAMS), October 2024.

Research Conferences (since coming to NC State in 2000)

June 2001	International Conference on Spectral and High Order Methods, Uppsala, Sweden (1 invited & 1 contributed).
November 2001	South East Conference on Applied Mathematics, Raleigh, NC, USA (contributed).
January 2002	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited).
May 2002	SIAM Conference on Optimization, Toronto, Canada (contributed).
January 2003	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited).
February 2003	IPAM Conference on Emerging Applications of the Nonlinear Schrödinger Equations, Los Angeles, CA, USA (invited).
April 2003	AMS Spring Eastern Sectional Meeting, New York, NY, USA (invited).
May 2003	International Conference on Computational Science and its Applications, Montreal, Canada (invited).
June–July 2003	The Sixth International Conference on Mathematical and Numerical Aspects of Wave Propagation, Jyväskylä, Finland (contributed).
January 2004	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited).
October 2004	SIAM Conference on Nonlinear Waves, Orlando, FL, USA (invited).
January 2005	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited).
June 2005	The Seventh International Conference on Mathematical and Numerical Aspects of Wave Propagation, Providence, RI, USA (contributed).
July 2005	SIAM Annual Meeting, New Orleans, LA (minisymposium organizer).
January 2006	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited).
February 2006	Workshop on Advances in Computational Scattering, Banff International Research Station (BIRS), Banff, Alberta, Canada (invited).
March 2006	Progress in Electromagnetics Research Symposium, Cambridge, MA, USA (invited).
April 2006	AMS Spring Central Sectional Meeting, Notre Dame, IN, USA (invited).
January 2007	AMS Joint Mathematics Meetings, New Orleans, LA, USA (invited).
January 2007	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited).
June 2007	International Conference on Spectral and High Order Methods, (ICOSAHOM'07) Beijing, China (contributed).
July 2007	The Eighth International Conference on Mathematical and Numerical Aspects of Wave Propagation, Reading, UK (two contributed).
September 2007	Nonlinear Photonics, Quebec City, Canada (invited).
January 2008	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited).
June 2008	Nonlinear Waves — Theory and Applications, Beijing, China (minisymposium organizer).
September 2008	Numerical Methods for Aeroacoustics, Svetlogorsk, Russia (invited).
January 2009	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited).
March 2009	The 6th IMACS International Conference on Nonlinear Evolution Equations and Wave Phenomena: Computation and Theory, Athens, GA, USA (invited).
June 2009	The Ninth International Conference on Mathematical and Numerical Aspects of Wave Propagation, Pau, France (two contributed).
June 2009	International Conference on Spectral and High Order Methods, (ICOSAHOM'09) Trondheim, Norway (2 invited).
July 2009	International Conference in Honor of Professor Godunov's 80th Birthday, Novosibirsk, Russia (invited).
September 2009	Air Force workshop "Radar and the Ionosphere," Wright-Patterson Air Force Base, Dayton, OH (invited).
January 2010	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited).
January 2010	Air Force Orbital Resources Ionosphere (ORION) Conference, Dayton, OH, USA (invited).

June 2010	Second International Conference on Nonlinear Waves — Theory and Applications, Beijing, China (minisymposium organizer & invited talk).
November 2010	AMS Fall Central Sectional Meeting, Notre Dame, IN, USA (invited).
January 2011	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited).
June 2011	International Conference in Honor of Prof. Saul Abarbanel's 80th Birthday, Tel-Aviv, Israel (invited).
July 2011	The Tenth International Conference on Mathematical and Numerical Aspects of Wave Propagation, Vancouver, Canada (contributed).
January 2012	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited).
February 2012	IPAM Workshop on Challenges in Synthetic Aperture Radar, Los Angeles, CA, USA (invited).
May 2012	SIAM Conference on Imaging Science, Philadelphia, PA, USA (invited).
June 2012	7th International Workshop on Parallel Matrix Algorithms and Applications, London, UK (contributed).
January 2013	AFOSR Electromagnetics Workshop (invited).
May 2013	Difference Schemes and Applications, Moscow, Russia (organizer) https://stsynkov.math.ncsu.edu/Ryabenkii-90/en/index.html.
July 2013	SIAM Annual Meeting, San Diego, CA, USA (invited).
July 2013	12th US National Congress on Computational Mechanics (USNCCM12), Raleigh, NC, USA (2 contributed).
January 2014	AFOSR Electromagnetics Workshop, Arlington VA, USA (invited).
June 2014	10th European Conference on Synthetic Aperture Radar (contributed).
June 2014	International Conference on Spectral and High Order Methods, (ICOSAHOM'14) Salt Lake City, Utah (speaker & minisymposium organizer).
January 2015	AFOSR Electromagnetics Workshop, Arlington VA, USA (invited).
February 2015	ARL/ARO grantees program review, Adelphi, MD, USA (invited).
July 2015	The 12th International Conference on Mathematical and Numerical Aspects of Wave Propagation, Karlsruhe, Germany (contributed).
January 2016	AFOSR Electromagnetics Workshop, Arlington VA, USA (invited).
January 2016	ARL/ARO grantees program review, Adelphi, MD, USA (invited).
May 2016	SIAM Conference on Imaging Science, Albuquerque, NM, USA (invited).
June 2016	International Conference on Spectral and High Order Methods, (ICOSAHOM'16) Rio de Janeiro, Brazil (contributed).
June 2016	Eighth Conference of the Euro-American Consortium for Promoting the Application of Mathematics in Technical and Natural Sciences, AMiTaNS'16, Albena, Bulgaria (invited).
January 2017	AFOSR Electromagnetics Workshop, Arlington VA, USA (invited).
May 2017	The 13th International Conference on Mathematical and Numerical Aspects of Wave Propagation, Twin Cities, MN, USA (5 contributed).
June 2017	Ninth International Conference of the Euro-American Consortium for Promoting the Application of Mathematics in Technical and Natural Sciences, AMiTaNS'17, Albena, Bulgaria (invited).
Fall 2017	ICERM Semester Program on "Mathematical and Computational Challenges in Radar and Seismic Reconstruction" (invited).
January 2018	AFOSR Electromagnetics Workshop, Arlington VA, USA (invited).
July 2018	International Conference on Spectral and High Order Methods, (ICOSAHOM'18) London, United Kingdom (two invited).
August 2018	ICERM (Brown University) Workshop on "Advances in PDEs: Theory, Computation and Application to CFD" (invited).
September 2018	2018 IEEE Conference on Antenna Measurements & Applications, Västerås, Sweden (invited).

December 2018	International conference "Advances in Applied Mathematics," Tel Aviv University, Israel (organizer and invited speaker), https://stsynkov.math.ncsu.edu/Memorial-Conference/index.html.
January 2019	AFOSR Electromagnetics Workshop, Arlington VA, USA (invited).
August 2019	International Conference "Mathematics and Its Applications" in honor of the 90th birthday of Sergei K. Godunov, Novosibirsk, Russia (invited).
August 2019	The 14th International Conference on Mathematical and Numerical Aspects of Wave Propagation, Vienna, Austria (2 contributed).
January 2020	AFOSR Electromagnetics Workshop, Arlington VA, USA (invited).
July 2020	SIAM Conference on Imaging Science, virtual delivery (invited).
January 2021	AFOSR Electromagnetics Workshop, virtual delivery (invited).
January 2021	Joint Mathematics Meetings, virtual delivery (invited).
January 2021	14th World Congress of Computational Mechanics (WCM) and European Community on Computational Methods in Applied Science (ECCOMAS) 2020 Congress, virtual delivery (contributed).
March 2021	AMS 2021 Spring Southeastern Sectional Meeting, virtual delivery (invited).
May 2021	International Conference "P. Chebyshev Mathematical Ideas and Their Applications to Natural Sciences," virtual delivery (contributed).
June 2021	SIAM Conference on Mathematical & Computational Issues in the Geosciences, virtual delivery (invited).
July 2021	International Conference on Spectral and High Order Methods, (ICOSAHOM'20-21) virtual delivery (one invited, one contributed).
July 2021	SIAM Annual Meeting, virtual delivery (invited).
August 2021	International Applied Computational Electromagnetics Society (ACES) Symposium, virtual delivery (invited).
October 2021	Smart Computational Methods in Continuum Mechanics (CMCM 2021), virtual delivery (organizer and invited speaker), https://cmcm2021.mipt.ru/.
January 2022	AFOSR Electromagnetics Workshop, virtual delivery, Washington, DC (invited).
June 2022	Fourteenth International Conference of the Euro-American Consortium for Promoting the Application of Mathematics in Technical and Natural Sciences, AMiTaNS'22, virtual delivery, Albena, Bulgaria (invited).
September 2022	Triangle Applied and Computational Mathematics Symposium (TriCAMS, member of the Organizing Committee).
January 2023	AFOSR Electromagnetics Workshop, Washington, DC (invited).
July 2023	17th US National Congress on Computational Mechanics (USNCCM17), Albuquerque, NM, USA (2 invited).
October 2023	International Conference on Electromagnetics in Advanced Applications (ICEAA '23), Venice, Italy (contributed).
November 2023	Triangle Applied and Computational Mathematics Symposium (TriCAMS, member of the Organizing Committee).
November 2023	Defense TechConnect, Washington, DC (contributed).
January 2024	AFOSR Electromagnetics Workshop, Washington, DC (invited).
July 2024	The 16th International Conference on Mathematical and Numerical Aspects of Wave Propagation (WAVES 2024), Berlin, Germany (2 contributed).
July 2024	2024 IEEE International Geoscience and Remote Sensing Symposium (IGARSS 2024), Athens, Greece (2 contributed).
December 2024	2024 Abarbanel Workshop on Applied and Computational Mathematics, Tel Aviv University, Israel (invited).
January 2025	AFOSR Electromagnetics Workshop, Washington, DC (invited).

Invited Seminars & Colloquia (since coming to NC State in 2000)

February 2001	Department of Mathematics, UCLA.
February 2001	NASA Ames Research Center.
February 2001	Department of Aerospace Engineering, University of California, Davis.
February 2001	Department of Mathematics, Stanford University.
February 2002	Department of Applied Physics and Applied Mathematics, Columbia Univ.
February 2002	Courant Institute of Mathematical Sciences.
March 2002	Department of Engineering Sciences and Applied Mathematics, Northwestern University.
October 2002	Center for Scientific Computing and Applied Mathematics, University of Maryland.
February 2003	Department of Mathematics, University of Southern California.
February 2003	Department of Applied Mathematics, Illinois Institute of Technology.
February 2003	Department of Mathematical Sciences, Indiana University — Purdue University, Indianapolis.
May 2003	Department of Mathematics, University of North Carolina, Charlotte.
October 2003	Joint Colloquium of the Keldysh Institute for Applied Mathematics and Institute for Mathematical Modeling, Russian Acad. Sci., Moscow, Russia.
February 2004	Public defense of the Doctor of Science Dissertation, Institute for Mathematical Modeling, Russian Academy of Sciences, Moscow, Russia.
March 2004	Department of Mathematics, Duke University.
March 2004	Department of Mathematics, University of Connecticut.
June 2004	Department of Mathematics, Stanford University.
October 2004	Department of Applied Mathematics, Caltech.
October 2004	Department of Mathematics, UCLA.
October 2004	Department of Applied Mathematics, Tel Aviv University, Israel.
November 2004	Courant Institute of Mathematical Sciences.
November 2004	Department of Mathematics, University of North Carolina, Charlotte.
February 2005	Center for Optoelectronics, University of North Carolina, Charlotte.
March 2005	NASA Langley Research Center.
March 2005	Department of Mathematics, University of California, Berkeley.
November 2005	Department of Applied Mathematics, Columbia University.
November 2005	Department of Mathematics, New Jersey Institute of Technology.
March 2006	Department of Mathematics, California State University, Northridge.
April 2006	ICES, University of Texas, Austin.
October 2006	Department of Mathematics, Georgia Institute of Technology.
January 2007	Department of Mathematics, Northeastern University.
February 2008	Department of Mathematics, University of Nevada, Reno.
June 2008	Mathematical Institute, Oxford University, UK.
January 2009	Department of Mathematics, the University of Sussex, UK.
February 2009	Keldysh Institute for Applied Mathematics, Moscow, Russia.
March 2009	Institute for Mathematical Modeling, Moscow, Russia.
March 2009	US Naval Research Laboratory, Washington, DC.
May 2010	Department of Applied Mathematics, Northwestern University.
September 2012	Department of Mathematics, University of Houston.
December 2012	Department of Mathematics, University of Utah.
March 2013	Department of Mathematical Sciences, University of Texas, Dallas.
March 2013	Department of Mathematics and Statistics, Old Dominion University.
January 2014	School of Mathematics, Tel Aviv University, Israel.
September 2014	CSCAMM, University of Maryland, College Park.
March 2015	Department of Mathematics, University of California, Riverside, CA.
November 2016	National Reconnaissance Office (NRO) Technology Seminar Series,

	Washington, DC.
March 2017	Department of Mathematics, Southern Methodist University, Dallas, TX.
April 2017	School of Mathematical and Statistical Sciences, Arizona State University, Tempe, AZ.
March 2019	Department of Mathematics, Brigham Young University, Provo, UT.
April 2022	Department of Mathematics Colloquium, NC State, Raleigh, NC.
April 2022	Applied Mathematics Colloquium, UNC Chapel Hill, Chapel Hill, NC.

Books

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https://www.crcpress.com/A-Theoretical-Introduction-to-Numerical-Analysis/

[2]  M. Gilman, E. Smith, and S. Tsynkov, *Transionospheric Synthetic Aperture Imaging,* Series: *Applied and Numerical Harmonic Analysis,* Birkhäuser, Cham, Switzerland, xxiii+458 pages, 2017. http://www.springer.com/us/book/9783319521251

Refereed Journal Articles

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Research Summary

My general research area is applied and computational mathematics, with emphasis on numerical analysis of PDEs and scientific computation, as well as inverse problems (remote sensing and control). I am interested in various aspects of wave propagation, including stochastic formulations for random media. I have worked on applications in fluids, acoustics, electromagnetism, optics, plasma, and other areas. I am also interested in the development of machine learning techniques for remote sensing applications (radar imaging).

Current projects

A key direction of our current work is mathematical analysis of synthetic aperture radar (SAR) imaging (supported by AFOSR). Mathematically, this is a certain class of inverse problems for wave-type equations. The initial focus of the project was on how the dispersion of radio waves in the Earth ionosphere affects the performance of spaceborne SAR sensors. The ionosphere is modeled as cold plasma, which may, in particular, be turbulent. The latter case requires statistical analysis of the propagation of waves through a random medium. The ionospheric phenomena, both deterministic and random, are shown to affect the azimuthal resolution of a SAR sensor stronger than the range resolution. In [41], we estimate the magnitude of some key effects, and identify the probing on two carrier frequencies as a possible venue for compensating for the ionospheric distortions. In [44], we analyze the effect of a commonly used approximation, known as start-stop, on the quality of the image by a spaceborne radar. Additional results related to the start-stop approximation and the Doppler effect for SAR are presented in [137]. In [47], we show that if the matched filter of a spaceborne SAR sensor is corrected using dual carrier probing, as suggested in [41], then the performance of the radar improves, i.e., the distortions of the image due to the ionosphere are reduced. Subsequent work includes some aspects of polarimetric imaging [53], development of an algorithm with improved robustness based on image registration [51], taking into account the Faraday rotation in the ionosphere, which is due to the gyrotropy of a magnetized plasma [58], detection of material dispersion by means of SAR [133], as well as the analysis of the linearized scattering beyond the first Born approximation [59]. A comprehensive account of our effort on the mathematical analysis of SAR imaging up to 2016 is available in the new monograph [2] (http://www.springer.com/us/book/9783319521251). Recent extensions of this effort include a more detailed analysis of SAR imaging through a turbulent ionosphere [142], analysis of Faraday rotation for polarimetric imaging that takes into account the variation of the rotation angle over the length of the interrogating signal (called differential Faraday rotation) [67, 143], detection of target dispersion in SAR images [71, 76, 77, 145], including that with the help of machine learning [80, 92], analysis of the cross-track SAR interferometry [78], analysis of the effect of differential Faraday rotation on polarimetric SAR interferometry [82], vertical autofocus algorithm [84] for determining the elevation of the phase screen, and optimization-based transionospheric autofocus algorithm [87, 151] for deriving the phase correction for SAR imaging through a turbulent cold plasma that shows superior performance [93] compared to the more conventional techniques, such as the phase curvature autofocus [153] or screen projection. A justification for using the phase screens for implementing the ionospheric corrections in spaceborne SAR imaging is presented in [89, 152], while the results of a statistical study of autofocus performance are reported in [94, 154]. An additional development is the application of advanced numerical convolution algorithms based on tensor train decomposition to SAR signal processing, which yields denoising and may offer speed-up gains [88].

Another current project focuses on the design of high order accurate numerical methods for the numerical simulation of waves. This work is supported by ARO and the US–Israel Binational Science Foundation (BSF — jointly with Prof. E. Turkel of Tel Aviv University). Examples include the propagation of waves through the media with sharply varying material characteristics, such as the speed of sound undergoing jumps in acoustics or the index of refraction undergoing jumps in electromagnetism/optics. The key objective is to develop a methodology that would not lose its high order accuracy because of those discontinuities, and at the same time would be capable of handling the interfaces of arbitrary shape. In [46, 48, 56], we have proposed a family of compact high order accurate finite difference schemes for the time-harmonic formulation that involves variable yet smooth coefficients. An important advantage of these schemes is that because of the compact stencils they do not need any additional boundary conditions beyond those required by the differential equation itself. They have also proven to be a very economical way of attaining high order accuracy, because the number of degrees of freedom is the same as that for the standard second order schemes. The material discontinuities are addressed by combining the compact schemes with discrete Calderon's operators and the method of difference potentials [54, 55, 57, 131, 132]. A key merit of this approach is that it allows to build the discretization on a regular structured grid and at the same time take care of the non-conforming interfaces with no loss of accuracy. Compared to the methods based on the boundary integral equations, discrete Calderon's operators do not involve singular integrals and handle variable coefficients with the same ease as constant coefficients (in the regions of smoothness). They also offer a considerably more straightforward computational procedure [62, 134] than high order methods based on weak formulations, such as isoparametric finite elements. In addition, the method of difference potentials allows one to easily consider problems with non-standard boundary conditions, e.g., those of the mixed type [55] and solve multiple related problems at a very low individual cost per problem (e.g., fixed geometry but different boundary conditions) [55, 60]. If combined with proper asymptotic analysis, it also enables an efficient computation of solutions with singularities [60, 65, 141]. In 3D, the method of difference potentials also enables an elegant implementation of high order Bayliss-Gunzburger-Turkel artificial boundary conditions that requires neither the discrete approximation of high oder derivatives nor introduction of auxiliary variables [70]. A recent application involves solution of 3D multiple scattering problems [79], as well as non-iterative domain decomposition [81] with application to computing the photonic crystal ring resonators [85].

A key part of the simulation of waves project is the extension to time-dependent propagation, which is also supported by the ARO and BSF. A compact fourth order accurate finite difference approximation to the unsteady wave (d'Alembert) equation is proposed in [66]. Its extension to three space dimensions is given in [72] and to Maxwell's equations — in [90]. For initial boundary value problems, we are pursuing two parallel approaches. One is to interpret the upper time level of an implicit scheme as an elliptic equation and employ the method of difference potentials in much the same way as done for time-harmonic problems [68, 101, 140]. This approach requires special termination at the artificial outer boundary, which can be achieved by means of any appropriate ABC or absorbing layer, in particular, the sponge layer of [83]. The other approach is to use the full-fledged time-dependent formulation [69, 74, 75, 100, 138, 144, 146–148] and take advantage of the Huygens' principle and lacunae [50, 102] as done in our work on unsteady ABCs [16, 20, 26, 28, 49, 50, 64, 136, 139, 155]. In the second approach, the solution can be updated only at the boundary of the computational domain as the time elapses. As a result, it offers sub-linear computational complexity for long simulation times. The latest development in this area is our work [86] where we handle 3D complex non-conforming geometries on Cartesian grids using patched parameterizations of surfaces, as well a similar development for Maxwell's equations in second-order form [91], where the electromagnetic scattering about generally shaped perfectly electric conducting bodies is addressed. The time-dependent methodology can be modified accordingly (simplified) and applied to the time-harmonic case, which yields an algorithm with exact treatment of artificial outer boundaries (no reflection error) [150]. A separate turn of this project is the application of artificial neural networks to determining the shape of lacunae in the solutions of the wave equation [102].

A recently completed project on multi-function antennas was supported by the Army STTR (Phase I/II). Small antennas that radiate wavelengths which are long compared to the antenna size have been developed previously. However, these antennas are generally narrow-band in their operation. The objective of this project is to provide the Army with a new antenna technology capable of emitting a broad frequency band of electromagnetic (EM) radiation in one compact package. The central idea is to represent the desired long-wavelength signal as a superposition of compactly supported short pulses. These pulses are shifted with an overlap with respect to one another and are radiated in a predetermined sequence by an array of small antennas. The possibility of such a representation is facilitated by results from Shannon's sampling theory, Fourier analysis, the theory of analytic functions, and frame theory. As often is the case for STTRs, the focus of the project was more on achieving its goals rather than publications. Yet a small sample of the results has recently been published in [149].

The most recent addition to my portfolio of research projects is the collaborative effort with Princeton University (supported by US Army) on the analysis and computation of exotic electromagnetic fields in terahertz regimes, including unsteady topological solutions to Maxwell's equations, paraxial knotted fields, and accelerating beams.

Prior accomplishments

I was trained in Moscow, Russia, at the Moscow Institute for Physics and Technology and subsequently Russian Academy of Sciences, where I have completed my PhD in December 1991. The subject of my PhD was development of numerical methods for solving fluid flow problems on the domains of irregular shape; and the thesis included the three key elements that pertain to every full-fledged algorithm designed for this purpose. Those are the grid, the scheme, and the boundary conditions. As a part of the PhD, I have developed and implemented a collection of numerical algorithms for the generation of conformal [105] and quasi-conformal [107] two-dimensional grids around curvilinear shapes, like airfoils, etc. This was done by solving the Cauchy-Riemann and Beltrami equations, respectively, using the method of difference potentials by Ryaben'kii. Another part of the thesis was devoted to building the Euler and Navier-Stokes schemes based on kinetic models [3,103,104]. Such schemes often have better properties as far as capturing some "borderline" fluid physics phenomena, like those pertinent to rarefied gases (e.g., re-entry conditions). In doing so, special attention was paid to obtaining the schemes with the same boundary-layer limit as that of the standard Navier-Stokes equations. In the third part of my thesis, I developed highly accurate nonlocal artificial boundary conditions (ABCs) for the numerical integration of external compressible inviscid flows [106,108, 109,116]. The ABCs help truncate the problem originally formulated on an unbounded domain. They provide a closure for the truncated formulation that enables construction of a finite-dimensional discretization so that the problem can be solved on the computer. The issue of ABCs appears critical in many areas of scientific computing, e.g., in acoustics, electrodynamics, solid mechanics, and fluid dynamics. In my PhD thesis, I have constructed global ABCs under the assumption of a linearized potential flow in the far field, and implemented these boundary conditions for simulating a variety of compressible Euler flows. The new ABCs provided for a very substantial reduction of the required computer resources through the shrinkage of the computational domain, while still guaranteeing high accuracy of the numerical solution.

In work [110, 111] we have used the method of difference potentials to build a class of domain decomposition algorithms that did not require the overlap of subdomains for convergence (unlike many traditional techniques based on the Schwartz algorithm). After many years, those ideas are currently revisited in [81].

The design of ABCs for the numerical solution of external flow problems was in the focus of my research for a number of years after the PhD. This work was supported by NASA. External problems represent a wide class of important formulations in computational fluid dynamics, and the proper treatment of external boundaries may have a profound impact on the quality and performance of numerical algorithms and interpretation of the results. Existing ABCs' techniques can basically be classified into two groups. Global ABCs usually provide high accuracy and robustness of the numerical procedure but often appear fairly cumbersome and computationally expensive. Local ABCs are algorithmically simple, numerically inexpensive, and geometrically universal; however, they usually lack the accuracy of computations. In a series of papers written between 1993 and 2000, see [4–11, 13, 95, 96, 112, 113, 117–122], we have developed new ABCs for the steady-state compressible viscous flows that combine the advantages of local and global methods.

The approach of [4–11, 13, 95, 96, 112, 113, 117–122] is based on application of the method of difference potentials. It allows one to obtain highly accurate ABCs in the form of certain nonlocal boundary operator equations. The operators involved are analogous to the pseudodifferential boundary projections first introduced by A. Calderon and then also studied by R. Seeley. In spite of their nonlocal nature, the new boundary conditions are geometrically universal, numerically inexpensive, and easy to implement along with the existing interior solvers. These ABCs allow one to drastically improve the treatment of external artificial boundaries for a variety of flow configurations and regimes. They have been constructed for both two and three space dimensions, and successfully implemented along with the NASA-developed production flow solver `TLNS3D`. The actual cases analyzed using the new ABCs include subsonic and transonic, laminar and turbulent, two- and three-dimensional flows. A case of particular interest from the standpoint of flow physics involves the jet exhaust, see [13, 122]. In all these cases, the new ABCs have systematically outperformed the standard existing methods; they have provided for a better accuracy and much smaller computational domains, which translated into very substantial savings of computer resources. Besides, the nonlocal ABCs could noticeably speed up the convergence of multigrid iterations, see [121].

Based on my deep involvement in the area of numerical methods for unbounded domains, I wrote a comprehensive survey article on the subject that was solicited by Applied Numerical Mathematics and published in 1998, see [12]. This paper includes, among other things, a comparative assessment of different existing methods for constructing the ABCs. By now, it has become a standard source of reference in the field. I also wrote a survey chapter on ABCs and the method of difference potentials for the research monograph by V. Ryaben'kii [98, Part V, Chapter 2].

As an extension of work on ABCs for the steady-state external fluid flows, we have developed and implemented a unified flow solver [18] that combines the advantages of the global far-field ABCs with those of the so-called factorizable schemes for hydrodynamics; these schemes facilitate the construction of optimally convergent multigrid algorithms. Global ABCs do not hamper the optimal multigrid convergence of the solver. At the same time, contrary to the standard local ABCs, the solution accuracy provided by the global ABCs deteriorates very slightly or does not deteriorate at all when the computational domain shrinks, which enables substantial savings of computer resources.

A subsequent development on ABCs based on Calderon's operators is the work done under the AFRL Phase I and II SBIR grants with Computational Sciences, LLC, on computing the exterior magnetic fields for the field reversed configurations (FRC) in plasma (a promising approach to fusion), see [52].

More recently, the focus of my research work has shifted toward wave propagation problems, with applications primarily in acoustics, electromagnetism, optics, and plasma. This involves both time-harmonic (monochromatic) and time-dependent (broad-band) waves. In [97], we considered the Helmholtz equation and studied an alternative way of handling the artificial outer boundary — by means of the so-called perfectly matched layer (PML) that damps the outgoing waves and prevents their reflection back into the computational domain. Using energy-type estimates and the separation of variables, we analyzed the solvability, uniqueness, and limit properties (with respect to the thickness of the layer) of several PMLs. We also considered numerical approximations, including those of high order accuracy, and discussed iterative methods and preconditioning for solving the Helmholtz equation with a PML.

In a series of papers [14–16,20,114] we introduced a non-deteriorating algorithm for the long-time computation of unsteady waves, and subsequently used it to obtain global highly accurate ABCs for the numerical simulation of waves on unbounded domains. This work was supported by the NSF and AFOSR. The algorithm exploits the presence of lacunae, i.e., sharp aft fronts of the waves, in the solutions (equivalent to the strong Huygens' principle). It is inherently three-dimensional and guarantees a temporally uniform grid convergence of the solution driven by a given continuously operating source on arbitrarily long time intervals. Moreover, the algorithm has a linear computational complexity with respect to the grid dimension. The design of numerical schemes that would converge uniformly in time has been an outstanding question in numerical analysis of PDEs for many years, since the first studies on stability and convergence of the discrete approximations have been conducted in the 1950-ies.

The non-deteriorating numerical algorithm of [14–16,20,114] can, in fact, be built as a modification on top of any consistent and stable finite-difference scheme, making its grid convergence uniform in time and at the same time keeping the rate of convergence the same as that of the non-modified scheme. The corresponding lacunae-based ABCs are obtained directly for the discrete formulation of the problem and do not require a discretization of the continuous boundary conditions. The extent of their temporal nonlocality is fixed and limited. In addition, the ABCs can handle artificial boundaries of irregular shape on regular grids with no loss of accuracy. Moreover, the approach of [14–16, 20, 114] allows one to consider the radiation of waves by moving sources (e.,g., radiation/scattering by a maneuvering aircraft).

The lacunae-based approach originally developed for the scalar wave equation can be extended to the systems of equations of acoustics and electromagnetism, see [26, 28, 124, 155]. Extension to electromagnetic waves is particularly non-trivial because of the additional constraints due to the continuity equation for currents and charges. An important application of the work on lacunae is the stabilization of time-dependent PMLs [36,127] known to suffer from the long-time error buildup. A subsequent extension involves the concept of quasi-lacunae [49, 50] that generalize the notion of classical lacunae for Maxwell's equations, and allow for a non-zero electrostatic solution behind aft fronts of the propagating waves. Quasi-lacunae facilitate the development of a universal algorithm for long-time electromagnetic simulations (stabilization of any ABC or PML). This project was supported by the US Army Phase II STTR, see [136]. The applications to problems with a non-Huygen's interior region are reported in [64, 139].

My work on lacunae also involved the study of a weakly dispersive propagation of electromagnetic waves in the ionosphere, with the goal of identifying the aft fronts of the waves in some approximate sense [33]. We have shown that the "depth" of the weak lacunae in dilute plasma is proportional to the ratio of the Langmuir frequency to the carrier frequency of the wave. Also in [33], we have analyzed the case with gyrotropy and shown that for the typical ionospheric conditions the additional effect on lacunae was small.

In work [17, 22–24, 27, 123], we studied the problem of active control of sound for time-harmonic wave fields formulated as a special type of the inverse source problem for elliptic PDEs. This work was supported by NASA. Unlike many existing methodologies, the approach of [17] provides for the exact volumetric cancellation of the unwanted noise on a given predetermined region of space, while leaving unaltered those components of the total acoustic field that are deemed friendly. It turns out that for eliminating the noise one needs to know nothing about either its sources or the properties of the medium across which it propagates. The controls are built based solely on the measurements performed at the boundary of the domain to be protected from noise. Perhaps as important, the measured quantities can refer to the total acoustic field rather than to its unwanted component only, and the methodology can automatically distinguish between the two. In [17], we have constructed the general solution to this noise control problem using the concepts of generalized potentials and boundary projections of Calderon's type. For a given wave field, the application of a Calderon's projection allows one to definitively tell between its incoming and outgoing components with respect to a particular domain of interest. Then, the controls are designed so that they suppress the incoming component for the domain to be shielded or alternatively, the outgoing component for the domain, which is complementary to the one to be shielded.

In [22], we have constructed special types of discrete surface control sources that correspond to the continuous densities of the single- and double-layer potentials. In [23, 24, 27, 123], we focused on optimizing the control sources with respect to different criteria: L_2, power, and acoustic source strength. The latter translates into a challenging numerical problem of a constrained L_1 minimization for complex-valued functions. Our central result in [23] is that the global L_1-optimal solution can, in fact, be obtained without solving the numerical optimization problem; it is given by a special layer of monopoles at the boundary of the protected region. A subsequent addition to this work is active control of sound for multiply connected regions [30, 32, 34], as well as that with variable degree of cancellation [43, 45]. Besides shielding the given multiply connected region from the exterior noise, the approach allows its different parts to selectively hear or not hear each other. Yet another extension is experimental verification and validation of the proposed noise control methodology, which is reported in [38].

In our work [19, 21, 25], we analyzed the mathematical and numerical aspects of the propagation of electromagnetic waves (intense laser beams) in nonlinear Kerr media. This work was supported by NSF. A standard model for describing this class of phenomena is the nonlinear Schrödinger equation (NLS). It is derived from the more comprehensive nonlinear Helmholtz equation (NLH) by employing the paraxial approximation and neglecting the backscattered waves. In [19], we used a high-order finite-difference method supplemented by the nonlocal two-way ABCs to solve the NLH as a true boundary value problem. As the propagation equation is nonlinear, the impinging and scattered waves cannot be separated, and the problem has to be solved in its entirety. In doing so, the boundary should transmit the given incoming waves in one direction and simultaneously be transparent to all the outgoing waves that travel in the opposite direction. The two-way ABCs in [19] were obtained directly for the fourth order accurate scheme that we used to approximate the NLH. Our numerical methodology allows for a direct comparison of the NLH and NLS models and, apparently for the first time ever, for an accurate quantitative assessment of the backscattered signal in nonlinear self-focusing. In [21], we have been able to match the numerical predictions of nonlinear backscattering with the results of the asymptotic theory. In [25], we have introduced linear damping into the model and could show that the NLH requires less damping than the NLS to prevent the blow-up of the solution for high input powers. This is an indication that nonparaxiality and backscattering can help suppress the formation of singularities. In our subsequent papers on the subject [29, 99, 125], we employed the Sommerfeld-type local radiation boundary conditions in the cross-range direction, instead of the previously used Dirichlet boundary conditions. The modified algorithm offers a considerable improvement as far as its numerical performance and the scope of physical phenomena that it is capable of simulating. An extension of this approach to the case of cylindrical geometry is addressed in [31]. In [35, 126], a major progress was made by constructing a new finite volume compact scheme for the analysis of material discontinuities, and by introducing a Newton-based nonlinear solver. Newton's linearization is nontrivial since the Kerr nonlinearity is Frechet non-differentiable for complex-valued solutions. Thus, the NLH has to be recast as a system of two real equations, in which case Newton's method converges rapidly and enables computations for very high levels of nonlinearity, beyond the actual threshold of material breakdown. An extension of this work in the general context of high order accurate schemes for wave propagation problems with discontinuities is presented in [39]. The results of multi-dimensional simulations of the NLH by means of compact approximations and Newton's solver are summarized in [37, 42].