KEATON J. BURNS

MIT Dept. of Mathematics
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Cambridge, MA 02139

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RESEARCH INTERESTS

I develop numerical methods and open-source software for large-scale scientific simulations. My work focuses on high-order methods for PDEs and applying them to diverse problems in fluid dynamics. I am the lead developer of Dedalus, a parallel framework for solving PDEs with modern spectral methods.

EMPLOYMENT

Research Scientist 2023 – Present
Department of Mathematics, Massachusetts Institute of Technology

Visiting Scholar 2019 – Present
Center for Computational Astrophysics, Flatiron Institute

Instructor in Applied Mathematics 2019 – 2023
Department of Mathematics, Massachusetts Institute of Technology

Flatiron Research Fellow 2018 – 2019
Center for Computational Astrophysics, Flatiron Institute

EDUCATION

Ph.D. in Physics 2018
Massachusetts Institute of Technology

M.A.St. in Mathematics (Part III) 2013
Churchill College, University of Cambridge

B.A. in Applied Mathematics, Physics, and Astrophysics 2012
University of California Berkeley
    Highest Honors in Applied Mathematics, Physics
    Highest Distinction in General Scholarship

FELLOWSHIPS & AWARDS

NSF Graduate Research Fellow – MIT Physics 2012 – 2017
Geophysical Fluid Dynamics Fellow – Woods Hole Oceanographic Institute 2016
Kavli Graduate Fellow – MIT Kavli Institute 2013 – 2014
Department Citation – UC Berkeley Astronomy 2012
Stewardship Science Graduate Fellowship (Declined) – DOE NNSA 2012
Peirce Fellowship (Declined) – Harvard Astronomy 2012
Ernest Coleman Award for Scholarship and Citizenship – SLAC SULI Program 2011

Funding & Supported Collaborations

NASA OSTFL Grant 80NSSC22K1738 – PI ($550k) 2022-2024
"Supporting Dedalus, an open-source CFD framework with modern spectral methods."

NASA HTMS Grant 80NSSC20K1280 – Co-I with PI Daniel Lecoanet ($1.5M) 2020-2023
"MRI in the Sun? Global Radiation-MHD Simulations of the Near-Surface Shear Layer."

Canadian NFRF Explorations – Collab. with PI Adrian Liu ($250k) 2019-2022
"Next-generation astrophysical simulations using machine learning."

Teaching

Lecturer: Fast Methods for PDEs & IEs (MIT Math 18.336 / CS 6.7340) Fall 2019-2022

Lecturer: System Functions & Laplace Transform (MIT Math 18.031) Jan. 2021-2023

Recitation Instructor: Calculus (MIT Math 18.02A) Jan. 2020

Teaching Assistant: Astrophysics I (MIT Physics 8.901) Spring 2017, 2018

Teaching Assistant: Astrophysics II (MIT Physics 8.902) Fall 2017

Teaching Assistant: Radio Astronomy Laboratory (UC Berkeley Astro 121) Spring 2011

Service & Outreach

Reviewer – AMSES, GMD, JAMES, JCP, JORS, JOSS, PASC, Science Adv., SIURO, SINUM, WRR

Staff – WHOI Geophysical Fluid Dynamics Program 2022-2023

Co-organizer – MIT Numerical Methods for PDEs seminar 2021 – Present

Co-organizer – Flatiron-Wide Algorithms and Mathematics conference Oct. 2019

Co-organizer – CCA Plasma Astrophysics Summer School Summer 2019

Co-organizer – MIT Kavli Institute Journal Club 2015 - 2018

CFD Session Chair – APS Division of Fluid Dynamics Meeting #70 Nov. 2017

STEM Teaching Assistant – MIT Warrior Scholar Project Summer 2017

John Carlson Lecture Assistant – MIT & New England Aquarium Oct. 2016

Publications

* : first author or project supervisor

33. J. A. Jackson, N. Romeo, A. Mietke, **K. J. Burns**, J. F. Totz, A. C. Martin, J. Dunkel, and J. I. Alsous, "Scaling behaviour and control of nuclear wrinkling." Nature Physics, Sep. 2023.

32. E. Rojas, **K. J. Burns**, and D. Hysell, "Fluid models capturing Farley-Buneman instabilities." Annales Geophysicae, vol. 41, no. 2, pp. 281–287, Jul. 2023.

31. E. H. Anders, D. Lecoanet, M. Cantiello, **K. J. Burns**, B. A. Hyatt, E. Kaufman, R. H. D. Townsend, B. P. Brown, G. M. Vasil, J. S. Oishi, and A. S. Jermyn, "The photometric variability of massive stars due to gravity waves excited by core convection." Nature Astronomy, Jul. 2023.

30. G. L. Wagner, A. Hillier, N. C. Constantinou, S. Silvestri, A. Souza, **K. Burns**, A. Ramadhan, C. Hill, J.-M. Campin, J. Marshall, R. Ferrari. "CATKE: a turbulent-kinetic-energy-based parameterization for ocean microturbulence with dynamic convective adjustment." arxiv:2306.13204, Jun. 2023.

* 29. N. Romeo, J. Slomka, J. Dunkel, and **K. J. Burns**, "Vortex line entanglement in active Beltrami flows." arxiv:2306.01062, Jun. 2023.

* 28. **K. J. Burns**, D. Fortunato, K. Julien, and G. M. Vasil, "Corner Cases of the Generalized Tau Method." arXiv:2211.17259, Nov. 2022.

27. J. S. Oishi, **K. J. Burns**, J. B. Marston, and S. M. Tobias, "Direct statistical simulation of the Busse annulus." J Fluid Mech, vol. 949, p. R1, Oct. 2022.

* 26. S. J. Benavides, **K. J. Burns**, B. Gallet, and G. R. Flierl, "Effective Drag in Rotating, Poorly Conducting Plasma Turbulence." Astrophysical Journal, vol. 938, no. 2, p. 92, Oct. 2022.

25. B. Gallet, B. Miquel, G. Hadjerci, **K. J. Burns**, G. Flierl, and R. Ferrari, "Transport and emergent stratification in the equilibrated Eady model: the vortex gas scaling regime." J Fluid Mech, vol. 948, p. A31, Oct. 2022.

24. E. Kaufman, D. Lecoanet, E. A. Anders, B. P. Brown, G. M. Vasil, J. S. Oishi, and **K. J. Burns**, "The stability of Prendergast magnetic fields." MNRAS, vol. 517, no. 3, pp. 3332–3340, Oct. 2022.

23. V. Heinonen, A. J. Abraham, J. Slomka, **K. J. Burns**, P. J. Saenz, and J. Dunkel, "Emergent universal statistics in nonequilibrium systems with dynamical scale selection." arXiv:2205.01627, May 2022.

* 22. S. J. Benavides, **K. J. Burns**, B. Gallet, J. Y.-K. Cho, and G. R. Flierl, "Inverse cascade suppression and shear layer formation in MHD turbulence subject to a guide field and misaligned rotation." J Fluid Mech, vol. 935, Mar. 2022.

21. J S. Oishi, **K. J. Burns**, S. E. Clark, E. H. Anders, B. P. Brown, G. M. Vasil, and D. Lecoanet, "eigentools: A Python package for studying differential eigenvalue problems with an emphasis on robustness." Journal of Open Source Software, vol. 6, no. 62, p. 3079, June 2021.

20. E. W. Hester, G. M. Vasil, and **K. J. Burns**, "Improving accuracy of volume penalized fluid-solid interactions." Journal of Computational Physics, vol. 430, p. 110043, Apr. 2021.

19. E. W. Hester, L.-A. Couston, B. Favier, **K. J. Burns**, and G. M. Vasil, "Improved phase-field models of melting and dissolution in multi-component flows." Proc. R. Soc. A, vol. 476, no. 2242, p. 20200508, Oct. 2020.

18. B. P. Brown, J. S. Oishi, G. M. Vasil, D. Lecoanet, and **K. J. Burns**, "Single-hemisphere Dynamos in M-dwarf Stars." The Astrophysical Journal Letters, vol. 902, no. 1, p. L3, Oct. 2020.

17. R. Supekar, V. Heinonen, **K. J. Burns**, and J. Dunkel, "Linearly forced fluid flow on a rotating sphere." J. Fluid Mech., vol. 892, p. 1, Jun. 2020.

* 16. **K. J. Burns**, G. M. Vasil, J. S. Oishi, D. Lecoanet, and B. P. Brown, "Dedalus: A flexible framework for numerical simulations with spectral methods." Phys. Rev. Research, vol. 2, no. 2, p. 838, Apr. 2020.

15. J. S. Oishi, G. M. Vasil, M. Baxter, A. Swan, **K. J. Burns**, D. Lecoanet, and B. P. Brown, "The magnetorotational instability prefers three dimensions." Proc. R. Soc. A, vol. 476, no. 2233, p. 20190622, Jan. 2020.

14. D. Lecoanet, M. Cantiello, E. Quataert, L.-A. Couston, **K. J. Burns**, B. J. S. Pope, A. S. Jermyn, B. Favier, and M. Le Bars, "Low-frequency Variability in Massive Stars: Core Generation or Surface Phenomenon?" The Astrophysical Journal Letters, vol. 886, no. 1, p. L15, Nov. 2019.

13. V. Heinonen, **K. J. Burns**, and J. Dunkel, "Quantum hydrodynamics for supersolid crystals and quasicrystals." Phys. Rev. A, vol. 99, no. 6, p. 063621, June 2019.

* 12. **K. J. Burns**, D. Lecoanet, G. M. Vasil, J. S. Oishi, and B. P. Brown, "The "Sphered Cube": A New Method for the Solution of Partial Differential Equations in Cubical Geometry." arXiv:1903.12642, March 2019.

11. D. Lecoanet, G. M. Vasil, **K. J. Burns**, B. P. Brown, and J. S. Oishi, "Tensor calculus in spherical coordinates using Jacobi polynomials, Part-II: Implementation and Examples." Journal of Computational Physics: X, p. 100012, March 2019.

10. G. Vasil, D. Lecoanet, **K. Burns**, J. Oishi, and B. Brown, "Tensor calculus in spherical coordinates using Jacobi polynomials. Part-I: Mathematical analysis and derivations." Journal of Computational Physics: X, p. 100013, March 2019.

9. O. Mickelin, J. Słomka, **K. J. Burns**, D. Lecoanet, G. M. Vasil, L. M. Faria, and J. Dunkel, "Anomalous Chained Turbulence in Actively Driven Flows on Spheres." Phys. Rev. Lett., vol. 120, no. 16, p. 164503, Apr. 2018.

* 8. **K. J. Burns**, N. J. Balmforth, and I. J. Hewitt, "Rolling resistance of shallow granular deformation." Proc. R. Soc. A, vol. 473, no. 2207, p. 20170375, Nov. 2017.

7. D. Lecoanet, G. M. Vasil, J. Fuller, M. Cantiello, and **K. J. Burns**, "Conversion of internal gravity waves into magnetic waves." MNRAS, vol. 466, no. 2, pp. 2181-2193, Apr. 2017.

6. D. Lecoanet, J. Schwab, E. Quataert, L. Bildsten, F. X. Timmes, **K. J. Burns**, G. M. Vasil, J. S. Oishi, and B. P. Brown, "Turbulent Chemical Diffusion in Convectively Bounded Carbon Flames." ApJ, vol. 832, no. 1, p. 71, Nov. 2016.

5. G. M. Vasil, **K. J. Burns**, D. Lecoanet, S. Olver, B. P. Brown, and J. S. Oishi, "Tensor calculus in polar coordinates using Jacobi polynomials." Journal of Computational Physics, vol. 325, pp. 53-73, Nov. 2016.

4. D. Lecoanet, M. McCourt, E. Quataert, **K. J. Burns**, G. M. Vasil, J. S. Oishi, B. P. Brown, J. M. Stone, and R. M. O'Leary, "A validated non-linear Kelvin-Helmholtz benchmark for numerical hydrodynamics." MNRAS, vol. 455, no. 4, pp. 4274-4288, Feb. 2016.

3. D. Lecoanet, M. Le Bars, **K. J. Burns**, G. M. Vasil, B. P. Brown, E. Quataert, and J. S. Oishi, "Numerical simulations of internal wave generation by convection in water." Phys. Rev. E, vol. 91, no. 6, p. 063016, Jun. 2015.

2. D. Lecoanet, B. P. Brown, E. G. Zweibel, **K. J. Burns**, J. S. Oishi, and G. M. Vasil, "Conduction in Low Mach Number Flows. I. Linear and Weakly Nonlinear Regimes." ApJ, vol. 797, no. 2, p. 94, Dec. 2014.

1. E. Huby, G. Perrin, F. Marchis, S. Lacour, T. Kotani, G. Duchêne, E. Choquet, E. L. Gates, J. M. Woillez, O. Lai, P. Fédou, C. Collin, F. Chapron, V. Arslanyan, and **K. J. Burns**, "FIRST, a fibered aperture masking instrument. I. First on-sky test results." Astronomy & Astrophysics, vol. 541, p. A55, May 2012.

35. "Solving PDEs exactly over polynomials."
Applied and Computational Analysis Seminar, Cambridge DAMTP, November 2023.
34. "Solving PDEs exactly over polynomials."
Applied Mathematics Seminar, Yale Mathematics, October 2023.
33. "Introduction to spectral methods and Dedalus."
Fluid Dynamics Summer School, Flatiron Institute, August 2023.
32. "Experimental numerical methods for Navier-Stokes."
Geophysical Fluid Dynamics Program, Woods Hole Oceanographic Institute, August 2023.
31. "Introduction to spectral methods and Dedalus."
Geophysical Fluid Dynamics Program, Woods Hole Oceanographic Institute, June 2023.
30. "Introduction to spectral methods and Dedalus."
Biophysical Modeling Summer School, Flatiron Institute, June 2023.
29. "Solving PDEs exactly over polynomials."
Applied Mathematics Seminar, UC Santa Cruz Applied Math, May 2023.
28. "Practical sessions on Dedalus and spectral methods."
Fluid Mechanics of Stars and Planets, CISM, April 2023.
27. "Solving PDEs exactly over polynomials."
Physical Mathematics Seminar, MIT Mathematics, March 2023.
26. "A Generalized Tau Method for Spectral Boundary Conditions in Multiple Dimensions."
SIAM Computational Science and Engineering, March 2023.
25. "Solving partial differential equations exactly over polynomials."
Applied Mathematics Colloquium, Northwestern University, February 2023.
24. "Modern Spectral Methods for PDEs."
Geophysical Fluid Dynamics Program, Woods Hole Oceanographic Institute, August 2022.
23. "Sparse spectral methods for PDEs in curvilinear domains with Dedalus."
Applied & Computational Math Seminar, Dartmouth Mathematics, September 2021.
22. "Generalization and performance of machine-learned turbulence closures."
Geophysical & Astrophysical Fluid Dynamics Seminar, UC Santa Cruz Applied Math, May 2021.
21. "Generalization and performance of machine-learned turbulence closures."
Geophysical/Astrophysical Fluid Dynamics Seminar, CU Boulder Applied Math, April 2021.
20. "Dedalus Project & Modern Spectral Methods for DNS."
New Challenges in Turbulence Research IV, Physics School of Les Houches, February 2021.
19. "Flexible spectral methods and high-level programming for PDEs."
Mathematical & Computational Engineering Seminar, PUC Chile IMC, December 2020.
18. "Challenges in the large-scale solution of PDEs with modern spectral methods."
Scientific Computing and Numerics Seminar, Cornell CSE, October 2020.
17. "Flexible spectral methods and high-level programming for PDEs."
Applied and Computational Mathematics Seminar, UW Madison Mathematics, April 2020.

16. “Flexible spectral methods and high-level programming for PDEs.”
Special Colloquium, Princeton PACM, March 2020.
15. “Inside Stars and Planets: Meeting the Challenges of Low-Mach-Number Astrophysics.”
Joint IAS/PU Astrophysics Colloquium, Princeton Astrophysics, March 2020.
14. “Flexible spectral simulations of low-Mach-number astrophysical fluids.”
Fluid Dynamics Seminar, Harvard CMSA, February 2020.
13. “Flexible spectral methods and high-level programming for PDEs.”
Sydney Dynamics Group, Univ. of Sydney Mathematics & Statistics, February 2020.
12. “Methods to solve differential equations.”
Flatiron-Wide Algorithms and Mathematics, Flatiron Institute, October 2019.
11. “Spectral Methods for PDEs.”
AstroNYC Summer School, Flatiron Institute, June 2019.
10. “Flexible algorithms for solving PDEs with spectral methods.”
Applied Mathematics Colloquium, Columbia APAM, December 2018.
9. “Dedalus: A flexible framework for solving differential equations using spectral methods.”
Flatiron Institute Software Review, Flatiron Institute, October 2018.
8. “Dedalus: Implementation.”
Spectral Methods Workshop, Imperial College London, July 2018.
7. “Glacial meltwater plumes.”
Convection in Nature Workshop, Princeton Center for Theoretical Science, February 2018.
6. “Dedalus: A flexible spectral solver for partial differential equations.”
Flatiron Seminar, Flatiron Institute, November 2017.
5. “Dedalus: A flexible spectral solver for fluid dynamics.”
Physical Mathematics Seminar, MIT Mathematics, October 2017.
4. “Flexible Spectral Methods for Geophysical Flows.”
Mathematical Geoscience Seminar, Oxford Mathematics, June 2017.
3. “Simulations of turbulent meltwater plumes.”
Physical Oceanography Group Meeting, Oxford Earth Sciences, May 2017.
2. “Rolling Resistance on Sand.”
GFD Fellow Presentations, Woods Hole Oceanographic Institute, August 2016.
1. “Multivariate Chebyshev Discretizations of Incompressible Hydrodynamics.”
Spectral Methods Workshop, Univ. of Sydney Mathematics & Statistics, February 2016.

CONTRIBUTED PRESENTATIONS

17. “Simulating convection at extreme parameters on a logarithmic Fourier lattice.”
APS Division of Fluid Dynamics Meeting #76, November 2023.
16. “Corner cases of the generalized tau method.”
Numerical Analysis in the 21st Century, August 2023.

15. “Automatic spectral methods for non-radial structure and stability problems.”
APS Division of Fluid Dynamics Meeting #75, November 2022.

14. “Simulating general flows in curvilinear domains with Dedalus.”
APS Division of Fluid Dynamics Meeting #74, November 2021.

13. “Sparse spectral methods for curvilinear domains in the Dedalus code.”
International Conference on Spectral and High Order Methods, July 2021.

12. “Pivoting for fast direct spectral PDE solvers.”
SIAM Computational Science and Engineering, March 2021.

11. “Designing networks to accurately learn 2D turbulence closures.”
APS Division of Fluid Dynamics Meeting #73, November 2020.

10. “The Sphered Cube and other applications of sparse spectral methods in spheres.”
APS Division of Fluid Dynamics Meeting #72, November 2019.

9. “The Automatic Sparse Spectral Discretization of Tensorial PDEs”
North American High Order Methods Conference, June 2019.

8. “Nonlinear tidal instabilities in compressible atmospheres.”
APS Division of Fluid Dynamics Meeting #71, November 2018.

7. “Dedalus: A parallel spectral framework for multidimensional PDEs.”
International Conference on Spectral and High Order Methods, July 2018.

6. “Turbulent Heat Transfer from a Thermally Forced Boundary in a Stratified Fluid.”
American Geophysical Union Fall Meeting, December 2017.

5. “Dedalus: A spectral solver for PDEs with diverse applications to CFD.”
APS Division of Fluid Dynamics Meeting #70, November 2017.

4. “Sidewall-driven convection in a thermally and compositionally stratified fluid.”
APS Division of Fluid Dynamics Meeting #69, November 2016.

3. “Turbulent structures in convection from a heated sidewall in a stratified fluid.”
APS Division of Fluid Dynamics Meeting #68, November 2015.

2. “Numerical Simulations of Nonlinear Wall-Mode Convection.”
American Geophysical Union Fall Meeting, December 2014.

1. “Orbital Stability of Spacecraft Exploring Multiple Asteroid Systems.”
American Astronomical Society Meeting #218, May 2011.

Whitepapers, Theses, Essays

5. N. A. Featherstone, **et al.**, “The Puzzling Structure of Solar Convection: Window into the Dynamo.” arXiv:2305.08823, May 2023.

4. **K. J. Burns**, “Flexible algorithms for simulating astrophysical and geophysical flows.” MIT PhD thesis advised by N. Weinberg & G. Flierl, May 2018.

3. J. S. Oishi, B. P. Brown, **K. J. Burns**, D. Lecoanet, and G. M. Vasil, “Perspectives on Reproducibility and Sustainability of Open-Source Scientific Software from Seven Years of the Dedalus Project.” arXiv:1801.08200, Jan. 2018.

2. **K. J. Burns**, “Chebyshev Spectral Methods with Applications to Astrophysical Fluid Dynamics.” Cambridge Part III essay advised by H. Latter, May 2013.
1. **K. J. Burns**, “Tidal Effects in Binary Star Systems.” UC Berkeley senior thesis advised by E. Quataert, June 2012.