MATTHEW HEADRICK

Title Associate Professor of Physics, Brandeis University

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Research interests String theory, quantum field theory, quantum gravity, general relativity, geometry, quantum information theory, statistical mechanics

Employment & education

Brandeis University, 2008–present
Associate Professor, Martin Fisher School of Physics (2015–present)
Assistant Professor, Martin Fisher School of Physics (2008–2015)

Undergraduate courses taught:
Mathematical Physics
Quantum Theory I
Quantum Theory II

Graduate courses taught:
Quantum Mechanics I
Quantum Mechanics II
Quantum Field Theory

Long-term visitor:
Center for Theoretical Physics, Massachusetts Institute of Technology (spring & fall 2017)
Visitor, Center for the Fundamental Laws of Nature, Harvard University (fall 2012)
Visitor, Center for the Fundamental Laws of Nature, Harvard University (fall 2009)

Stanford University, 2006–2008
Postdoctoral Scholar, Stanford Institute for Theoretical Physics

Massachusetts Institute of Technology, 2003–2006
Pappalardo Fellow, Center for Theoretical Physics

Tata Institute of Fundamental Research, Mumbai, 2002–2003
Visiting Fellow, Department of Theoretical Physics

Harvard University, 1996–2002
Ph.D. in Physics (March 2003)

Thesis: "Noncommutative solitons and closed string tachyons"
Advisor: S. Minwalla
Harold T. White Prize for Excellence in the Teaching of Physics (May 2002)
Certificate of Distinction in Teaching (May 2001)
Exchange scholar, Princeton University (spring 1999)
M.A. in Physics (June 1998)

Lycée d'Etat de Ndendé, Gabon, 1994–1996
Peace Corps Volunteer
Secondary-school mathematics, physics, and chemistry teacher

Princeton University, 1990–1994
A.B. in Physics with Highest Honors (June 1994)
Thesis: "$(2+1)$-dimensional spacetimes containing closed timelike curves"
Advisor: J.R. Gott III
Inducted into Phi Beta Kappa and Sigma Xi (May 1994)
Kusaka Memorial Prize in Physics (May 1994)
Kusaka Memorial Prize in Physics (May 1993) Exchange scholar, Ecole Normale Supérieure de Lyon (fall 1992)

Funding

Simons Fellow in Theoretical Physics (Simons Foundation), 2017

Co-principal Investigator: DOE Office of High-Energy Physics Award DE-SC0009987, "Research in Quantum Field Theory, Cosmology, and String Theory," 2016–present

Co-principal Investigator: Simons Collaboration in Mathematics and the Physical Sciences (Simons Foundation), "It from Qubit: Quantum Fields, Gravity, and Information," 2015–present

Principal Investigator: NSF Award PHY-1053842, "CAREER: Holography, Quantum Information, and Elliptic Relativity," 2011–2017

Co-principal Investigator: NSF Award IIA-1243369, "U.S.-India Advanced Studies Institute on Thermalization: From Glasses to Black Holes, Bangalore, Summer 2013," 2012–2014

Co-principal Investigator: DOE Office of High-Energy Physics Award DE-FG02-92ER40706, 2010–2011

Affiliated faculty: NSF Award DMS-1159049, "FRG: Collaborative Research: Generalized Geometry, String Theory and Deformations", 2012–present

Affiliated faculty: NSF Award DGE-1068620, "IGERT: Geometry and Dynamics—Integrated Education in the Mathematical Sciences", 2011–present

Affiliated faculty: NSF Award DMS-0854965, "FRG: Collaborative Research: Generalized Geometries in String Theory", 2009–13

NSF Graduate Research Fellowship, 1996–1999

Professional activities

Deputy Director, Simons Collaboration in Mathematics and the Physical Sciences (Simons Foundation), "It from Qubit: Quantum Fields, Gravity, and Information," 2015–present

Co-organizer of the following workshops and schools:

- *It from Qubit Annual Meeting*, Simons Foundation, December 2017
- *It from Qubit Annual Meeting*, Simons Foundation, December 2016
- *Entanglement in Field Theory and Gravity*, Simons Center for Geometry and Physics, Stony Brook University, Decemember 2016
- *It from Qubit School/Workshop*, Perimeter Institute for Theoretical Physics, July 2016
- *Entanglement in Strongly-Correlated Quantum Matter*, Kavli Institute for Theoretical Physics, University of California, Santa Barbara, April–July 2015
- *US-India Advanced Studies Institute on Thermalization: From Glasses to Black Holes*, International Center for Theoretical Sciences, Bangalore, June 2013
- *RG Flows, Holography, and Entanglement Entropy*, Michigan Center for Theoretical Physics, University of Michigan, September 2012
- *Quantum Information in Quantum Gravity and Condensed-Matter Physics*, Aspen Center for Physics, May–June 2011

Referee for the journals *Science*, *JHEP*, *JSTAT*, *Comm. Math. Phys.*, *Class. Quant. Grav.*, *Phys. Lett. B*, *Phys. Rev. Let.*, *Phys. Rev.* D, *Prog. Theor. Exp. Phys.*, *J. Phys. A*, and *New Jour. Phys.*
Named an "Outstanding Referee for the Journals of the Americal Physical Society", 2017

Grant reviewer and panelist for National Science Foundation

Grant reviewer for US Department of Energy, Chilean National Science and Technology Commission, US-Israel Binational Science Foundation, UK Royal Society, Austrian Science Fund, Swiss National Science Foundation, Netherlands Organisation for Scientific Research, and Deutsche Forschungsgemeinschaft (German Research Foundation)

External examiner for doctoral dissertation, University of British Columbia

Author of *Mathematica* packages `diffgeo`, `grassmann`, and `Virasoro`

Participant in TheoryNet, an NSF-sponsored program in which theoretical physicists visit and make presentations to Boston-area high-school science classes; visited Reading High School, Andover High School, Groton-Dunstable Regional High School, and Roxbury Latin School

Consultant in the preparation of *Lectures on Quantum Field Theory* by S. Coleman (World Scientific, 2018) and *Advanced Quantum Mechanics*, 2nd ed., by F. Dyson (World Scientific, 2011), both transcribed by D. Derbes

Technical reviewer, *String Theory for Dummies* by A. Z. Jones and D. Robbins (Wiley Publishing, 2009)

Advisees

Undergraduate:
Skyler Kasko (2013–2014)
Robert Callan (2010–2011)
Netta Engelhardt (2010–2011)

Graduate:
Zhibin Li (visiting, 2018–present)
Jonathan Harper (2017–present)
Andrew Rolph (2016–present)
César Agón (2013–2017)

Postdoctoral:
Brian Swingle (2016)
Bogdan Stoica (2016–present)
Ida Zadeh (2013–2016)
Masoud Soroush (2013–2015)
Jianyang He (2011–2013)
Hajar Ebrahim (2008–2010)

Invited talks & lectures

"Bit threads and holographic monogamy"
Southwest Holography Meeting, University of Texas, Austin (March 2018)
University of Pennsylvania (February 2018)

"Bit threads in space and time"
Boston University (January 2018)
Entangle This: Tensor Networks and Gravity, Instituto de Física Teórica UAM-CSIC, Madrid (May 2017)
Simons Symposium on Quantum Entanglement, Schloss Elmau, Germany (May 2017)

"Lectures on entanglement in field theory and holography"
Theory Winter School, National High Magnetic Field Laboratory, Tallahassee (January 2018)
Theoretical Advanced Summer Institute: Physics at the Fundamental Frontier, University of Colorado, Boulder (June 2017)

"Bit threads and holographic entanglement"
Columbia University (December 2017)
Frontiers of Quantum Information Physics, Kavli Institute for Theoretical Physics, University of California, Santa Barbara (October 2017)
String Club, Center for Theoretical Physics, Massachusetts Institute of Technology (February and April 2017)

"Introduction to entanglement entropy in field theory and holography"
Theory Seminar, University of Massachusetts, Lowell (November 2017)
Geometry and String Theory Seminar, University of Texas, Austin (February 2017)

"Flow-cut theorems & covariant bit threads"
Gravity, Quantum Fields and Information Seminar, Albert Einstein Institute, Potsdam (November 2017)
Quantum Information in Quantum Gravity III, University of British Columbia (August 2017)

"Quantum entanglement and the geometry of spacetime"
Bates College Physics Colloquium (November 2017)
University of Massachusetts, Boston Physics Colloquium (October 2017)

Carnegie-Mellon University–University of Pittsburgh Joint Physics Colloquium (February 2017)
City College of New York Physics Colloquium (February 2017)
University of Massachusetts, Lowell Physics & Applied Physics Colloquium (February 2016)
Brandeis University Physics Colloquium (September 2014)

"Quantum entanglement, classical gravity, and convex programming: New connections"
Center for Mathematical Sciences and Applications Colloquium, Harvard University (February 2017)

"A new perspective on holographic entanglement"
String Theory: Past and Present, International Center for Theoretical Sciences, Bangalore (January 2017)
Quantum Spacetime Seminar, Tata Institute of Fundamental Research, Mumbai (January 2017)
Strings 2016, Tsinghua University, Beijing (August 2016)
It from Qubit School/Workshop, Perimeter Institute (July 2016)
Quantum Matter, Spacetime and Information conference, Yukawa Institute for Theoretical Physics, Kyoto University (June 2016)
Northeast Gravity Meeting, Amherst Center for Fundamental Interactions, University of Massachusetts, Amherst (April 2016)
New Frontiers in Entanglement workshop, University of Pennsylvania (April 2016)
Boston University (February 2016)
Berkeley Center for Theoretical Physics, University of California, Berkeley (October 2015)
Perimeter Institute (August 2015)
California Institute of Technology (June 2015)
Kavli Institute for Theoretical Physics, University of California, Santa Barbara (June 2015)
Simons Symposium on Quantum Entanglement, Puerto Rico (March 2015)

"Lectures on entanglement entropy, quantum field theory, and holography"
U.S.–India Advanced Studies Institute: Classical And Quantum Information, International Center for Theoretical Sciences, Bangalore (January 2017)

"Covariant bit threads: progress report"
It from Qubit Annual Meeting, Simons Foundation, New York (December 2016)

"Holography, entanglement entropy, and bit threads",
Condensed Matter Physics Seminar, Harvard University (April 2016)

"Entanglement entropy, quantum field theory, and holography"
Centre for Particle Theory Colloquium, Durham University (December 2014)
YITP Workshop on Quantum Information Physics, Yukawa Institute for Theoretical Physics, Kyoto University (August 2014)

"Holographic holes and differential entropy"
Centre for Particle Theory, Durham University (December 2014)
Emergent Spacetime in String Theory workshop, Aspen Center for Physics (July 2014)

"Causality, holography, and entanglement entropy"
Sixth New England String Meeting, Brown University (October 2014)
Kyoto University (August 2014)
Yale University (April 2014)
New Perspectives on Thermalization conference, Aspen Center for Physics (March 2014)
Perimeter Institute (February 2014)
Princeton University (February 2014)
Brown University (February 2014)

"Overview: Entanglement entropy"
Quantum Fields Beyond Perturbation Theory conference, Kavli Institute for Theoretical Physics, University of California, Santa Barbara (January 2014)

"What can entanglement entropy teach us about general relativity?"
Holography: From Gravity to Quantum Matter conference, Isaac Newton Institute, Cambridge University (September 2013)

"Are quantum field theories characterized by their entanglement entropies?"
Tata Institute of Fundamental Research, Mumbai (June 2013)
University of Toronto (April 2013)
University of Amsterdam (April 2013)
Edinburgh Mathematical Physics Group (March 2013)
Entanglement in Discrete and Continuous Quantum Systems program, Princeton Center for Theoretical Science (October 2012)

"Properties of entropy in holographic theories"
Austin Holography Workshop, University of Texas, Austin (May 2013)
Harvard University (November 2012)
RG Flows, Holography, and Entanglement Entropy workshop, Michigan Center for Theoretical Physics, University of Michigan (September 2012)

"Bose-Fermi duality and entanglement entropies"
Massachusetts Institute of Technology (October 2012)

"Quantum information and entanglement in holographic theories"
Mextrings '12 conference, National University of Mexico (UNAM) (May 2012)
Bits, Branes, and Black Holes program, Kavli Institute for Theoretical Physics, University of California, Santa Barbara (May 2012)
University of Massachusetts, Amherst (October 2011)
University of Texas, Austin (October 2011)
Quantum Information in Quantum Gravity and Condensed-Matter Physics workshop, Aspen Center for Physics (May 2011)
Massachusetts Institute of Technology (April 2011)
University of Michigan (January 2011)
University of New Hampshire (December 2010)
Applications of AdS/CFT to Condensed Matter Systems conference, Galileo Galilei Institute, Florence (November 2010)
SUNY Stony Brook (October 2010)
McGill University (September 2010)
Massachusetts Institute of Technology (June 2010)
Korea Institute for Advanced Study (May 2010)

"Gravity, entropy, and entanglement"
Pappalardo Symposium, Massachusetts Institute of Technology (October 2010)
Brandeis University Physics Colloquium (October 2010)

"Calabi-Yau metrics for dummies"
Institute for the Physics and Mathematics of the Universe, Tokyo University (June 2010)
Massachusetts Institute of Technology (March 2010)
Durham University (November 2009)
Dublin Institute for Advanced Studies (October 2009)
Tata Institute of Fundamental Research, Mumbai (October 2009)
Harvard University (September 2009)

"Progress on numerical Calabi-Yau metrics"
Quantum Theory and Symmetries conference, University of Kentucky (July 2009)

"Tachyon actions in string theory: a no-go theorem"
Fundamental Aspects of Superstring Theory program, Kavli Institute for Theoretical Physics, University of California, Santa Barbara (May 2009)
Massachusetts Institute of Technology (December 2008)
Brown University (October 2008)

"New approaches to numerical Calabi-Yau metrics"
Boston University Geometry Seminar (April 2009)

"Ricci flow, and some applications"
Everytopic Seminar, Brandeis University Mathematics Department (November 2008)

"Ricci flow, Kähler-Einstein manifolds, and numerical geometry"
University of California, Santa Cruz mathematics graduate colloquium (May 2008)

"Hedgehog black holes and the deconfinement transition"
Pacific Northwest String Seminar, Pacific Institute for the Mathematical Sciences, University of British Columbia (April 2008)
University of California, Davis (November 2007)
University of Oxford Mathematical Institute (November 2007)
Strong fields, integrability, and strings program, Isaac Newton Institute (November 2007)
Queen Mary, University of London (November 2007)
Tata Institute of Fundamental Research, Mumbai (October 2007)
Imperial College London (June 2007)

"The uses of Ricci flow"
University of Texas, Austin (March 2007)
Stanford Linear Accelerator Center (March 2007)
Brandeis University (February 2007)
University of California, Berkeley (January 2007)

"Scale transformations and the dynamics of string theory"
Brandeis University Physics Colloquium (February 2007)

"Ricci flow and black holes"

Massachusetts Institute of Technology (October 2006)
Southern California Strings Seminar, University of Southern California (September 2006)
University of California, Santa Barbara (September 2006)
Recent Advances in Black Holes in String Theory workshop, Aspen Center for Physics (August 2006)
University of Chicago (August 2006)
Brown University (April 2006)

"On time dependence in string theory"
Cambridge University (May 2006)
Johns Hopkins University (April 2006)
University of Kentucky (March 2006)

"The shape of the extra dimensions"
University of Wisconsin, Milwaukee Physics Colloquium (April 2006)
Massachusetts Institute of Technology Pappalardo Symposium (May 2005)

"A string theorist's adventures in numerical relativity"
University of Kentucky Center for Computational Sciences (March 2006)

"Closed string tachyon dynamics"
Perimeter Institute (December 2005)

"Numerical Ricci-flat metrics on K3"
Biséminaire ENS/IHP de Physique et de Mathématiques, Paris (July 2005)
Zhejiang University Center of Mathematical Sciences (April 2005)
Brandeis University Math/CS/Physics Everyperson Seminar (February 2005)
Harish-Chandra Research Institute (December 2004)

"Closed string tachyon condensation on C/Z_n"
Modern Trends in String Theory II, Porto (June 2004)
Harvard University (March 2004)
University of Texas, Austin (February 2004)

"Progress in closed string tachyon condensation"
IPM String Workshop, Anzali, Iran (October 2003)
Theoretical Physics Colloquium, Tata Institute of Fundamental Research, Mumbai (September 2003)
Harish-Chandra Research Institute (September 2003)

"Spacetime energy decreases under world-sheet RG flow"
University of Chicago (December 2002)
Perimeter Institute (November 2002)

"String interactions from perturbative Yang-Mills theory"
Stanford University (October 2002)

"String interactions in the BMN correspondence"
Massachusetts Institute of Technology (October 2002)
University of Pennsylvania (September 2002)

"Time travel in general relativity"
MIT Media Lab (March 1997)

Publications

M. Headrick and R.C. Myers, "Conference report on *Quantum Information in Quantum Gravity III*," in *Matters of Gravity*, arXiv:1712.09422 [gr-qc] (2017)

M. Headrick and V.E. Hubeny, "Riemannian and Lorentzian flow-cut theorems," arXiv:1710.09516 [hep-th], accepted for publication in *Class. Quant. Grav.* (2017)

M. Freedman and M. Headrick, "Bit threads and holographic entanglement," arXiv: 1604.00354 [hep-th], *Comm. Math. Phys.* 352, 407 (2017)

M. Headrick, A. Maloney, E. Perlmutter, and I.G. Zadeh, "Rényi entropies, the analytic bootstrap, and 3D quantum gravity at higher genus," arXiv:1503.07111 [hep-th], *JHEP* 07: 059 (2015)

M. Headrick, V.E. Hubeny, A. Lawrence, and M. Rangamani, "Causality and holographic entanglement entropy," arXiv:1408.6300 [hep-th], *JHEP* 12: 162 (2014)

M. Headrick, R.C. Myers, and J. Wien, "Holographic holes and differential entropy," arXiv:1408.4770 [hep-th], *JHEP* 10: 149 (2014)

M. Headrick, "General properties of holographic entanglement entropy," arXiv:1312. 6717 [hep-th], *JHEP* 03: 085 (2014)

C.A. Agón, M. Headrick, D.L. Jafferis, and S. Kasko, "Disk entanglement entropy for a Maxwell field," arXiv:1310.4886 [hep-th], *Phys. Rev.* D89: 025018 (2014)

M. Headrick, A. Lawrence, and M.M. Roberts, "Bose-Fermi duality and entanglement entropies," arXiv:1209.2428 [hep-th], *J. Stat. Mech.* P02022 (2013)

R. Callan, J. He, and M. Headrick, "Strong subadditivity and the covariant holographic entanglement entropy formula," arXiv:1204.2309 [hep-th], *JHEP* 06: 81 (2012)

P. Hayden, M. Headrick, and A. Maloney, "Holographic mutual information is monogamous," arXiv:1107.2940 [hep-th], *Phys. Rev.* D87: 046003 (2013)

H. Ebrahim and M. Headrick, "Instantaneous thermalization in holographic plasmas," arXiv:1010.5443 [hep-th]

M. Headrick, "Entanglement Rényi entropies in holographic theories," arXiv:1006. 0047 [hep-th], *Phys. Rev.* D82: 126010 (2010)

M. Headrick and A. Nassar, "Energy functionals for Calabi-Yau metrics," arXiv: 0908.2635 [hep-th], *Adv. Theor. Math. Phys.* 17: 867 (2013)

M. Headrick and A. Nassar "Energy functionals for Calabi-Yau metrics," *Proceedings of the 6th Annual Symposium on Quantum Theory and Symmetries*, *Journal of Physics: Conference Series* 462, 012019 (2013)

M. Headrick, S. Kitchen, and T. Wiseman, "A new approach to static numerical relativity, and its application to Kaluza-Klein black holes," arXiv:0905.1822 [gr-qc], *Class. Quant. Grav.* 27: 035002 (2010) [chosen by the editors as an IOPselect article and included in the annual highlights collection for 2009–2010]

M. Headrick, "A solution manual for Polchinski's *String Theory*," arXiv:0812.4408 [hep-th]

M. Headrick, "A note on tachyon actions in string theory," arXiv:0810.2809 [hep-th], *Phys. Rev.* D79: 046009 (2009)

M. Headrick, "Hedgehog black holes and the Polyakov loop at strong coupling," arXiv:0712.4155 [hep-th], *Phys. Rev.* D77: 105017 (2008)

M. Headrick and T. Wiseman, "Numerical Kähler-Ricci soliton on the second del Pezzo," arXiv:0706.2329 [math.DG]

M. Headrick and T. Takayanagi, "A holographic proof of the strong subadditivity of entanglement entropy," arXiv:0704.3719 [hep-th], *Phys. Rev.* D76: 106013 (2007)

C. Doran, M. Headrick, C.P. Herzog, J. Kantor, and T. Wiseman, "Numerical Kähler-Einstein metric on the third del Pezzo," arXiv:hep-th/0703057, *Comm. Math. Phys.* 282, 357 (2008)

M. Headrick and T. Wiseman, "Ricci flow and black holes," arXiv:hep-th/0606086, *Class. Quant. Grav.* 23: 6683 (2006)

D.Z. Freedman, M. Headrick, and A. Lawrence, "On closed string tachyon dynamics," arXiv:hep-th/0510126, *Phys. Rev.* D73: 066015 (2006)

M. Headrick and T. Wiseman, "Numerical Ricci-flat metrics on K3," arXiv:hep-th/0506129, *Class. Quant. Grav.* 22: 4931 (2005) [included in the annual highlights collection for 2005–2006]

M. Headrick and J. Raeymaekers, "The large N limit of C/Z_N and supergravity," arXiv:hep-th/0411148, *JHEP* 0502:054 (2005)

M. Headrick, S. Minwalla, and T. Takayanagi, "Closed string tachyon condensation: An overview," arXiv:hep-th/0405064, *Class. Quant. Grav.* 21: S1539 (2004)

M. Headrick, "Decay of C/Z_n: exact supergravity solutions," arXiv:hep-th/0312213, *JHEP* 0403:025 (2004)

M. Gutperle, M. Headrick, S. Minwalla, and V. Schomerus, "Spacetime energy decreases under world-sheet RG flow," arXiv:hep-th/0211063, *JHEP* 0301:073 (2003)

N.R. Constable, D.Z. Freedman, M. Headrick, and S. Minwalla, "Operator mixing and the BMN correspondence," arXiv:hep-th/0209002, *JHEP* 0210:068 (2002)

N.R. Constable, D.Z. Freedman, M. Headrick, S. Minwalla, L. Motl, A. Postnikov, and W. Skiba, "PP-wave string interactions from perturbative Yang-Mills theory," arXiv:hep-th/0205089, *JHEP* 0207:017 (2002)

J.R. David, M. Gutperle, M. Headrick, and S. Minwalla, "Tachyon condensation on twisted circles," arXiv:hep-th/0111212, *JHEP* 0202:041 (2002)

R. Gopakumar, M. Headrick, and M. Spradlin, "On noncommutative multi-solitons," arXiv:hep-th/0103256, *Comm. Math. Phys.* 233: 355 (2003)

R. Gopakumar, M. Headrick, and M. Spradlin, "Noncommutative solitons I," *Proceedings of Strings 2001, Mumbai* (2002)

M. Headrick and J.R. Gott III, "(2+1)-dimensional spacetimes containing closed timelike curves," *Phys. Rev.* D50: 7244 (1994)