

Sean M. Carroll

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Current Position

California Institute of Technology

2014- Research Professor
2006-2014 Senior Research Associate
Department of Physics and Walter Burke Institute of Theoretical Physics

Research Interests

Theoretical physics. Quantum spacetime, quantum information cosmology, field theory, particle physics, general relativity, statistical mechanics, and complexity.

Philosophy of science. Foundations of quantum mechanics and statistical mechanics, philosophy of cosmology, philosophical naturalism, metaphysics and ontology, emergence, causation.

Education

1984-1988 **Villanova University**
B.S. Astronomy and Astrophysics, B.A. Honors Program
Magna Cum Laude; Minors in Physics, Philosophy

1988-1993 **Harvard University**
Ph.D. Astronomy (George Field, advisor)
Thesis: *Cosmological Consequences of Topological and Geometric Phenomena in Field Theories*

Previous Positions

1993-1996 **Massachusetts Institute of Technology**
Postdoctoral Researcher, Center for Theoretical Physics, and Lecturer, Physics

1996-1999 **Institute for Theoretical Physics, UC Santa Barbara**
Postdoctoral Researcher

1999-2006 **University of Chicago**
Assistant Professor, Physics and Enrico Fermi Institute

Research Highlights

Spacetime Symmetries Possible violations of spacetime symmetries provide uniquely precise tests of new physics at high energies. I pioneered the study of Lorentz violation through low-energy effective Lagrangians, including proposed observational tests [1, 18]. I also proposed some of the first experimental limits on non-commutative modifications of electromagnetism [29], and constraints on dynamical Lorentz-violating fields [35, 45, 52, 53]. On cosmological scales, I have developed frameworks in which to analyze possible large-scale deviations from cosmological isotropy [44, 46, 48, 50].

Dark Matter, Dark Energy, Dark Forces I proposed experimental constraints on dynamical dark energy through its coupling to other fields, as well as suggesting how to avoid those constraints by imposing symmetries [22]. The best-motivated models of dark energy predict cosmological birefringence at a potentially observable level, which is currently being searched for observationally. I also pioneered theories of dark matter coupled to long-range forces [19, 47, 55, 61], including the possibility of an unbroken analogue of electromagnetism in the dark sector [49].

Modified Gravity Understanding the acceleration of the universe, usually attributed to dark energy, is one of the major challenges in theoretical physics today. Since our evidence for dark energy is exclusively through its gravitational effects, I suggested that a simple modification of Einstein's equation, known as $f(R)$ gravity, could cause acceleration without dark energy [34, 37, 43]. This idea now serves as a popular testing ground for cosmological deviations from general relativity. I explored modifications of GR due to extra dimensions [28, 33, 41] and proposed observational tests [23, 30].

Origin of the Universe & the Arrow of Time One major clue to the origin of the universe is the low entropy of the early state, responsible for the arrow of time. I proposed the first time-symmetric model of a multiverse in which the thermodynamic arrow of time arises naturally [38,39]. I have developed measures of cosmological fine-tuning [59, 63, 67, 70], and studied the possibility of the universe fluctuating into a proto-inflationary state [60]. I showed for the first time how cosmic evolution could spontaneously compactify dimensions of spacetime [56].

Foundations of Quantum Mechanics In the Everett or Many-Worlds formulation of quantum mechanics, the Born rule, that probabilities are given by the amplitude squared, must be derived rather than postulated. I proposed a new solution to this problem based on the notion of self-locating uncertainty [65, 69]. Applying the Everett formulation to cosmology, I argued that it is possible to sidestep the Boltzmann Brain problem if Hilbert space is infinite-dimensional [66]. I suggested a way of finding emergent spatial structure from the entanglement of an abstract quantum state [76].

Statistical Mechanics and Complexity I have argued that, while entropy increases in closed systems, natural measures of "complexity" first increase and then decrease [68]. I have proposed a new Bayesian formulation of the Second Law of Thermodynamics, which incorporates the outcomes of measurements into a tighter inequality obeyed by the evolution of open systems [74].

Honors and Awards

- Named Lectures Malmstrom Lecturer, Hamline University, 2003; Resnick Lecturer, Rensselaer Polytechnic Institute, 2003; National Science Foundation NSF Distinguished Lecturer, 2007; Kieval Lecturer, Cornell University, 2011; Brattain Lecturer, Whitman College, 2014; Keynote Address, American Humanist Association, 2014; Schrödinger Colloquium, Universität Zürich, 2014; Gifford Lectures in Natural Theology, Glasgow, 2016; Beyond Annual Lecture, Arizona State University, 2017
- 1984-1988 Villanova University Presidential Scholar
- 1988 Phi Beta Kappa
- 1988 Villanova University Academic Medallion: Bachelor of Science, Astronomy and Astrophysics; Bachelor of Arts, Honors Program
- 1988-1991 National Science Foundation Graduate Fellowship
- 1991-1993 National Aeronautics and Space Administration Graduate Fellowship
- 1996 MIT Graduate Student Council Teaching Award
- 1997 American Physical Society Congressional Fellowship (declined)
- 2000-2002 Alfred P. Sloan Foundation Fellowship
- 2000-2005 David and Lucile Packard Foundation Fellowship for Science and Engineering
- 2005 Second Place (with Jennifer Chen), Gravitational Research Foundation Essay Competition
- 2006 Villanova University College of Liberal Arts and Sciences Alumni Medallion
- 2006 Spherical Cow Award for Graduate Physics Teaching, University of Chicago
- 2009 Second Place, Foundational Questions Institute Essay Competition
- 2010 Fellow, American Physical Society
- 2010 *From Eternity to Here*: Best books of 2010, *Wilson Quarterly*
- 2013 *The Particle at the End of the Universe*: Best books of the year, *Financial Times*, *The Guardian*, *New Scientist*, Phi Beta Kappa, *Physics World*, *The Times* (UK)
- 2013 Royal Society Winton Prize for Science Books
- 2013-15 100 Global Thought Leaders, Gottlieb Duttweiler Institute
- 2014 Emperor Has No Clothes Award, Freedom From Religion Foundation
- 2014 Andrew Gemant Award, American Institute of Physics
- 2015 Fellowship, John Simon Guggenheim Foundation
- 2016 *The Big Picture*: *New York Times* bestseller list, *AudioFile* Earphones Award, Best books of the year: Amazon.com, Goodreads, *Kirkus*, *Science Friday*, *Financial Times*, *Forbes*

Activities

- Professional Societies American Physical Society, American Association for the Advancement of Science, Philosophy of Science Association, Authors Guild, Foundational Questions Institute
- 2002 JPL Advisory Committee on Gravitation and Fundamental Physics
- 2001-2002 Roadmap Team Member, NASA Structure and Evolution of the Universe Theme
- 2001-2005 Theory MRC Leader, Kavli Institute for Cosmological Physics

(activities cont.)

- 2004-2007 Executive Committee, APS Topical Group on Gravitation
- 2005-2012 Co-founder and contributor, *Cosmic Variance* blog
- 2007-2009 APS Committee on Informing the Public
- 2010-2012 Contributing Editor, *Discover* Magazine
 - 2011 Juror, Alfred P. Sloan Prize, Sundance Film Festival
- 2012-2013 “Discoverers” consultant, Discovery Communications
 - 2012 Judge, 3 Quarks Daily Science Blogging Prize
- 2013-present Board of Advisors, *Nautilus* magazine
 - 2013 JPL Futures Strategy Committee
- 2014-2016 Judge, Buchalter Cosmology Prize
- 2014-2016 Advisory Panel, The Science Channel
- 2016-present Editor (gravitation theory), *Foundations of Physics*
- 2016-present Member, California Quantum Interpretation Network

Organizing

- 1997 Organizer, 13th Pacific Coast Gravity Meeting, Santa Barbara
- 1999 Session Organizer, Cosmic Genesis and Fundamental Physics, Sonoma
- 2001 Scientific Organizing Committee, GR16, Durban, South Africa
- 2001 Working Group Co-Convenor (Astro/Cosmo/Particle Physics), Snowmass 2001: The Future of Particle Physics.
- 2001 Organizer, EFI Mini-Symposium: String Theory and Experiment, University of Chicago
- 2001 Local Organizing Committee, Workshop on Cosmological Probes of Dark Energy, Chicago
- 2002 Co-Chair, Local Organizing Committee, Cosmo-02 International Workshop on Particle Physics and the Early Universe, Chicago
- 2003 Co-Director, Short Course on Origin of Structure in the Universe, Center for Cosmological Physics, Chicago
- 2003 Program Co-Organizer, Kavli ITP Program on Superstring Cosmology, Santa Barbara
- 2004 Program Committee, Moriond Conference on Exploring the Universe, La Thuile, Italy
- 2004 Scientific Organizing Committee, GR17, Dublin, Ireland
- 2005 Organizer, AAAS Symposium on Understanding Dark Energy, Washington, D.C.
- 2005 Organizer, APS April Meeting Symposium on Cosmological Constraints on Gravitation and Fundamental Physics, Tampa
- 2005 Organizing Committee, Symposium on *Why So Few Women in Science?*, University of Chicago
- 2010 Organizer, AAAS Symposium on The Arrow of Time, San Diego
- 2011 Organizing Committee, Challenges for Early Universe Cosmology, Perimeter Institute
- 2011 Organizing Committee, Foundational Questions Institute Conference, *Setting Time Aright*, Bergen/Copenhagen

(organizing cont.)

- 2012 Organizer, Moving Naturalism Forward workshop, Stockbridge, MA
- 2014 Organizing Committee, Primordial Gravitational Waves & Cosmology Workshop, Caltech
- 2016 Organizing Committee, Reconciling Tests of Gravity Workshop, Caltech

Advising

**Summer
undergrad
research
students** Teodora Beloreshka (Caltech, 2000), Augusta Abrahamse (American University, 2002), Suz Tolwinski (Brown, 2004), Nicholas Scianmarello (Caltech, 2010), Aliza Malz (Caltech, 2010)

**Undergrad
Thesis Students** Ethan Honda (MIT, 1996), Monica Guica (Chicago, 2003), Stefan Mendez-Diez (Chicago, 2004), Abhishek Kumar (Chicago, 2004), Kevin Kuns (Caltech, 2012), Mengshuen Chua (Caltech [philosophy], 2015)

**Ph.D. Students
Supervised** Mark Hoffman (Chicago, 2003), Eugene Lim (Chicago, 2004), Jennifer Chen (Chicago, 2005), Ignacy Sawicky (Chicago, 2007), Lotty Ackerman (Caltech, 2009), Heywood Tam (Caltech, 2010), Chien-Yao Tseng (Caltech, 2013), Kimberly Boddy (Caltech, 2014), Jason Pollack (Caltech, 2017), Grant Remmen (Caltech, 2017), Aidan Chatwin-Davies (Caltech, current), ChunJun Cao (Caltech, current), Ashmeet Singh (Caltech, current)

**Ph.D. Students
co-supervised or
closely worked
with** Simeon Hellerman (UCSB, 2001), Laura Mersini (Wisconsin-Milwaukee, 2000), Takemi Okamoto (Chicago, 2004), James Geddes (Chicago, 2005), Vikram Duvvuri (Chicago, 2007), Jing Shu (Chicago, 2008), Adrienne Erickcek (Caltech, 2009), Moira Gresham (Caltech, 2010), Timothy Dulaney (Caltech, 2011), Charles Sebens (Michigan, 2015), Anthony Bartolotta (Caltech, current)

**Postdocs
Supervised** Manoj Kaplinghat (Chicago, 1999-2002), Cristian Armendariz-Picon (Chicago, 2001-2004), Geraldine Servant (Chicago/Argonne, 2001-2004), Matthew Johnson (Caltech, 2007-2010), Ingunn Wehus (Caltech, 2007-2010), Matthew Buckley (Caltech, 2008-2010), Stefan Leichenauer (Caltech, 2011-2014), Ning Bao (Caltech, 2014-2017)

Courses Taught

Harvard University

- 1989 Astronomy 300, General Relativity Seminary (graduate)

Massachusetts Institute of Technology

- 1996 Physics 8.962, General Relativity (graduate)

University of Chicago

- 2002, 2004, 2005 Physics 264, Spacetime and Black Holes (undergraduate)
- 2002, 2004 Physics 300, The Teaching and Learning of Physics (graduate)
- 2000, 2001 Physics 363, Particle Physics (graduate)
- 2001, 2003, 2005 Physics 364, General Relativity (graduate)
- 2001, 2006 Physics 371, Introduction to Cosmology (graduate)
- 2004 Big Problems 246, Moments in Atheism (undergraduate)

(courses taught cont.)

California Institute of Technology

2017 Physics 125c, Quantum Mechanics (undergraduate)

Notable Broadcast Media

2000-01, 2003-04 *Odyssey* with Gretchen Helfrich, WBEZ Radio, Chicago
2006, 2010, 2012, *Science Friday* with Ira Flatow, NPR/Public Radio
2013, 2015
2007, 2009, 2012 *Quirks and Quarks*, CBC Radio
2006-07, 2010, *Coast to Coast AM*
2012
2008, 2012 *The Universe*, History Channel
2009, 2010 DVD Extras: *LOST*, *The Day the Earth Stood Still*, *The Justice League*
2009 *Known Universe*, National Geographic Channel
2009 *Naked Science*, National Geographic Channel
2010 *BookTV*, C-SPAN
2010, 2012 *The Colbert Report*, Comedy Central
2010, 2013 *On Point*, NPR
2010-12, 2014 *Through the Wormhole with Morgan Freeman*
2011, 2014 *Closer to Truth* with Robert Kuhn
2011 *Prophets of Science Fiction*, The Science Channel
2011 *Curiosity Conversations: God and Cosmology*, Discovery Channel
2011, 2015 *NOVA*, PBS
2012, 2015 *Horizon*, BBC
2012 *The Agenda with Steve Paikin*, TVO Canada
2013 *101 Objects That Changed the World*, History Channel
2013 *The Fantastic Mr. Feynman*, BBC-TV
2013 *Catalyst*, ABC TV (Australia)
2014 *Friday Night Spotlight: Science in the Movies* (Host), Turner Classic Movies
2014 *PBS NewsHour*
2014 *The Science of Interstellar*, Science Channel
2015 *A Better Life: An Exploration of Joy & Meaning in a World Without God*
2015 *How the Universe Works*, Discovery Channel

Film/Television Consulting (with main contacts)

2007 *Angels and Demons* (Ron Howard, director; Brian Grazer, producer)
2008, 2013 *Bones* (Janet Lin, writer; Emily Silver, writer)
2009 *TRON: Legacy* (Jeffrey Silver, producer; Joseph Kosinski, director)
2009 *Thor* (Kevin Feige, producer; Kenneth Branagh, director; Don Payne, writer)

(film/television consulting cont.)

- 2011 *Fringe* (Glen Whitman, writer)
- 2013 *Thor: The Dark World* (Kevin Feige, producer; Alan Taylor, director)
- 2014 *Big Hero Six* (Don Hall, director)
- 2015 *Terminator: Genysis* (Alan Taylor, director)
- 2016 *Spectral* (George Nolfi, writer)

Research Publications

1. S.M. Carroll, G.B. Field and R. Jackiw, 1990, "Limits on A Lorentz and Parity-Violating Modification of Electrodynamics," *Phys. Rev. D* **41**, 1231.
2. E.F. Guinan and S.M. Carroll, 1990, "Eclipsing Binaries as Astrophysical Laboratories and the Strange Case of Epsilon Aurigae," in *Active Close Binaries: NATO ASI meeting at Kudasi, Turkey*, ed. C. Ibanoglu and I. Yavuz (Kluwer: Dordrecht), 7.
3. S.M. Carroll, E.F. Guinan, G.P. McCook and R.A. Donahue, 1991, "Interpreting Epsilon Aurigae," *Astrophys. J.* **367**, 278.
4. S.M. Carroll and G.B. Field, 1991, "The Einstein Equivalence Principle and the Polarization of Radio Galaxies," *Phys. Rev. D* **43**, 3789.
5. S.M. Carroll, E. Farhi and A.H. Guth, 1992, "An Obstacle to Building a Time Machine," *Phys. Rev. Lett.* **68**, 263; Erratum: **68**, 3368.
6. W.D. Garretson, G.B. Field and S.M. Carroll, 1992, "Primordial Magnetic Fields from Pseudo-Goldstone Bosons," *Phys. Rev. D* **46**, 5346; [hep-ph/9209238](#).
7. J.A. Bryan, S.M. Carroll and T. Pyne, 1994, "A Texture Bestiary," *Phys. Rev. D* **50**, 2806; [hep-ph/9312254](#).
8. S.M. Carroll, D.Z. Freedman, M.E. Ortiz, and D.N. Page, 1994, "Physical States in Canonically Quantized Supergravity," *Nucl. Phys.* **B423**, 661; [hep-th/9401155](#).
9. S.M. Carroll and G.B. Field, 1994, "Consequences of Propagating Torsion in Connection Dynamic Theories of Gravity," *Phys. Rev. D* **50**, 3867; [gr-qc/9403058](#).
10. S.M. Carroll, E. Farhi, A.H. Guth and K.D. Olum, 1994, "Energy-Momentum Restrictions on the Creation of Gott Time Machines," *Phys. Rev. D* **50**, 6190; [gr-qc/9404065](#).
11. S.M. Carroll, D.Z. Freedman, M.E. Ortiz and D.N. Page, 1995, "Bosonic Physical States in $N = 1$ Supergravity?," in *Proceedings of the 7th Marcel Grossmann Meeting*, ed. R. Ruffini and M. Keiser (World Scientific); [gr-qc/9410005](#).
12. S.L. Baliunas *et al.* [27 authors], 1995, "Chromospheric Variations in Main-Sequence Stars. II," *Astrophys. J.* **438**, 269.
13. S.M. Carroll, M.E. Ortiz and W. Taylor IV, 1996, "A Geometric Approach to Free Variable Loop Equations in Discretized Theories of 2D Gravity," *Nucl. Phys.* **B468**, 383; [hep-th/9510199](#).
14. S.M. Carroll, M.E. Ortiz and W. Taylor IV, 1996, "Spin/Disorder Correlations and Duality in the $c = 1/2$ String," *Nucl. Phys.* **B468**, 420; [hep-th/9510208](#).
15. T. Pyne and S.M. Carroll, 1996, "Higher-Order Gravitational Perturbations of the Cosmic Microwave Background," *Phys. Rev. D* **53**, 2920; [astro-ph/9510041](#).
16. S.M. Carroll, M.E. Ortiz and W. Taylor IV, 1996, "The Ising Model with a Boundary Magnetic Field on a Random Surface," *Phys. Rev. Lett.* **77**, 3947; [hep-th/9605169](#).
17. A. Sornborger, S.M. Carroll and T. Pyne, 1997, "The Collapse of Exotic Textures," *Phys. Rev. D* **55**, 6454; [hep-ph/9701351](#).
18. S.M. Carroll and G.B. Field, 1997, "Is There Evidence for Cosmic Anisotropy in the Polarization of Distant Radio Sources?," *Phys. Rev. Lett.* **79**, 2394; [astro-ph/9704263](#).

(research publications cont.)

19. G.W. Anderson and S.M. Carroll, 1997, "Dark Matter with Time-Dependent Mass," in *Cosmo-97, International Workshop on Particle Physics and the Early Universe*, ed. L. Roszkowski (World Scientific: Singapore), p. 227; [astro-ph/9711288](#).
20. S.M. Carroll, M.E. Ortiz and W. Taylor IV, 1998, "Boundary Fields and Renormalization Group Flow in the Two-Matrix Model," *Phys. Rev. D* **58**, 046006; [hep-th/9711008](#).
21. S.M. Carroll and M. Trodden, 1998, "Dirichlet Topological Defects," *Phys. Rev. D* **57**, 5189; [hep-th/9711099](#).
22. S.M. Carroll, 1998, "Quintessence and the Rest of the World," *Phys. Rev. Lett.* **81**, 3067; [astro-ph/9806099](#).
23. P.M. Garnavich *et al.* [21 authors], 1998, "Supernova Limits on the Cosmic Equation of State," *Astrophys. J.* **509**, 74; [astro-ph/9806396](#).
24. S.M. Carroll and G.B. Field, 1998, "Primordial Magnetic Fields that Last?," in *33rd Rencontres de Moriond: Fundamental Parameters in Cosmology*, 17-24 January 1998, Les Arcs, France; [astro-ph/9807159](#).
25. G.B. Field and S.M. Carroll, 2000, "Cosmological Magnetic Fields from Primordial Helicity," *Phys. Rev. D* **62**, 103008; [astro-ph/9811206](#).
26. S.M. Carroll, S. Hellerman, and M. Trodden, 2000, "Domain Wall Junctions are 1/4-BPS States," *Phys. Rev. D* **61**, 65001; [hep-th/9905217](#).
27. S.M. Carroll, S. Hellerman, and M. Trodden, 2000, "BPS Domain Wall Junctions in Infinitely Large Extra Dimensions," *Phys. Rev. D* **62**, 044049; [hep-th/9911083](#).
28. S.M. Carroll and L. Mersini, 2001, "Can We Live in a Self-Tuning Universe?," *Phys. Rev. D* **64**, 124008; [hep-th/0105007](#).
29. S.M. Carroll, J.A. Harvey, V.A. Kostelecký, C.D. Lane, and T. Okamoto, 2001, "Noncommutative Field Theory and Lorentz Violation," *Phys. Rev. Lett.* **87**, 141601; [hep-th/0105082](#).
30. S.M. Carroll and M. Kaplinghat, 2001, "Testing the Friedmann Equation: The Expansion of the Universe During Big-Bang Nucleosynthesis," *Phys. Rev. D* **65**, 063507; [astro-ph/0108002](#).
31. S.M. Carroll, J. Geddes, M.B. Hoffman, and R.M. Wald, 2002, "Classical Stabilization of Homogeneous Extra Dimensions," *Phys. Rev. D* **66**, 024036; [hep-th/0110149](#).
32. S.M. Carroll, M.B. Hoffman, and M. Trodden, 2003, "Can the dark energy equation-of-state parameter w be less than -1 ?," *Phys. Rev. D* **68**, 023509; [astro-ph/0301273](#).
33. S.M. Carroll and M.M. Guica, 2003, "Sidestepping the Cosmological Constant with Football-Shaped Extra Dimensions", [hep-th/0302067](#).
34. S.M. Carroll, V. Duvvuri, M. Trodden and M.S. Turner, 2004, "Is Cosmic Speed-Up Due to New Gravitational Physics?," *Phys. Rev. D* **70**, 043528; [astro-ph/0306438](#).
35. S.M. Carroll and E.A. Lim, 2004, "Lorentz-Violating Vector Fields Slow the Universe Down," *Phys. Rev. D* **70**, 123525; [hep-th/0407149](#).
36. S.M. Carroll, A. De Felice, and M. Trodden, 2005, "Can we be tricked into thinking that w is less than -1 ?," *Phys. Rev. D* **71**, 023525; [astro-ph/0408081](#).
37. S.M. Carroll, A. De Felice, V. Duvvuri, D.A. Easson, M. Trodden, and M.S. Turner, 2004, "The Cosmology of Generalized Modified Gravity Models", *Phys. Rev. D* **71**, 063513; [astro-ph/0410031](#).

(research publications cont.)

38. S.M. Carroll and J. Chen, 2004, "Spontaneous Inflation and the Origin of the Arrow of Time", [hep-th/0410270](#).
39. S.M. Carroll and J. Chen, 2005, "Does inflation provide natural initial conditions for the universe?," *Gen. Rel. Grav.* **37**, 1671; [gr-qc/0505037](#).
40. S.M. Carroll and J. Shu, 2005, "Models of Baryogenesis via Spontaneous Lorentz Violation," *Phys. Rev. D* **73**, 103515; [hep-ph/0510081](#).
41. I. Sawicki and S.M. Carroll, 2005, "Cosmological Structure Evolution and CMB Anisotropies in DGP Braneworlds," [astro-ph/0510364](#).
42. S.M. Carroll, 2006, "Is our universe natural?," *Nature*, 440, 1132; [hep-th/0512148](#).
43. S.M. Carroll, I. Sawicki, A. Silvestri, and M. Trodden, 2006, "Modified-Constraint Gravity and Cosmological Structure Formation," *New J. Phys.*, **8**, 323; [astro-ph/0607458](#).
44. L. Ackerman, S.M. Carroll and M.B. Wise, 2007, "Imprints of a Primordial Preferred Direction on the Microwave Background," *Phys. Rev. D* **75**, 083502; [astro-ph/0701357](#).
45. S. M. Carroll and H. Tam, 2008, "Aether Compactification," *Phys. Rev. D* **78**, 044047; [arXiv:0802.0521](#).
46. A.L. Erickcek, M. Kamionkowski and S.M. Carroll, 2008, "A Hemispherical Power Asymmetry from Inflation," *Phys. Rev. D* **78**, 123520; [arxiv:0806.0377](#).
47. S.M. Carroll, S. Mantry, M.J. Ramsey-Musolf, and C.W. Stubbs, 2008, "Dark-Matter-Induced Weak Equivalence Principle Violation," *Phys. Rev. Lett.* **103**, 011301; [arxiv:0807.4363](#).
48. A.L. Erickcek, S.M. Carroll, and M. Kamionkowski, 2008, "Superhorizon Perturbations and the Cosmic Microwave Background," *Phys. Rev. D* **78**, 083012; [arxiv:0808.1570](#).
49. L. Ackerman, M.R. Buckley, S.M. Carroll, and M. Kamionkowski, 2008, "Dark Matter and Dark Radiation," *Phys. Rev. D* **79**, 023519; [arxiv:0810.5126](#).
50. S.M. Carroll, C.-Y. Tseng, and M.B. Wise, 2008, "Translational Invariance and the Anisotropy of the Cosmic Microwave Background," *Phys. Rev. D* **81**, 083501; [arxiv:0811.1086](#).
51. S.M. Carroll, 2008, "What if Time Really Exists?," entry in the Foundational Questions Institute Essay Competition on the Nature of Time; [arxiv:0811.3722](#).
52. S.M. Carroll, T.R. Dulaney, M. Gresham, and H. Tam, 2008, "Instabilities in the Aether", *Phys. Rev. D*, **79**, 065011; [arxiv:0812.1049](#).
53. S.M. Carroll, T.R. Dulaney, M. Gresham, and H. Tam, 2008, "Sigma-Model Aether", *Phys. Rev. D* **79**, 065012; [arxiv:0812.1050](#).
54. S.M. Carroll, M.C. Johnson, and L. Randall, 2009, "Extremal Limits and Black Hole Entropy," *JHEP* **0911**, 109; [arxiv:0901.0931](#).
55. S.M. Carroll, S. Mantry, and M.J. Ramsey-Musolf, 2009, "Implications of a Scalar Dark Force for Terrestrial Experiments," *Phys. Rev. D* **81**, 063507; [arxiv:0902.4461](#).
56. S.M. Carroll, M.C. Johnson, and L. Randall, 2009, "Dynamical compactification from de Sitter space," *JHEP* **0911**, 094; [arxiv:0904.3115](#).
57. S.M. Carroll, H. Tam, and I.K. Wehus, 2009, "Lorentz Violation in Goldstone Gravity," *Phys. Rev. D* **80**, 025020; [arxiv:0904.4680](#).

(research publications cont.)

58. B. Kloppenborg *et al.* [17 authors], 2010, "In the Shadow of the Transiting Disk: Imaging epsilon Aurigae in Eclipse," *Nature* **464**, 870; [arxiv:1004.2464](#).
59. S.M. Carroll and H. Tam, 2010, "Unitary Evolution and Cosmological Fine-Tuning," [arxiv:1007.1417](#).
60. A. Aguirre, S.M. Carroll, and M.C. Johnson, 2011, "Out of equilibrium: understanding cosmological evolution to lower-entropy states," *JCAP* **1202**, 024; [arxiv:1108.0417](#).
61. K. Boddy, S.M. Carroll, and M. Trodden, 2012, "Dark Matter with Density-Dependent Interactions," *Phys. Rev. D*, **86**, 123529; [arxiv:1208.4376](#).
62. K.K. Boddy and S.M. Carroll, 2013, "Can the Higgs Boson Save Us From the Menace of the Boltzmann Brains?" [arxiv:1308.4686](#).
63. G.N. Remmen and S.M. Carroll, 2013, "Attractor Solutions in Scalar-Field Cosmology," *Phys. Rev. D* **88**, 083518; [arxiv:1309.2611](#).
64. S.M. Carroll, S. Leichenauer, and J. Pollack, 2013, "A Consistent Effective Theory of Long-Wavelength Cosmological Perturbations," *Phys. Rev. D* **90**, 023518; [arxiv:1310.2920](#).
65. S.M. Carroll and C.T. Sebens, 2013, "Many Worlds, The Born Rule, and Self-Locating Uncertainty," in *Quantum Theory: A Two-Time Success Story, Yakir Aharonov Festschrift*, D.C. Struppa, J.M. Tollaksen, eds. (Springer-Verlag), p. 157; [arxiv:1405.7907](#).
66. K.K. Boddy, S.M. Carroll, and J. Pollack, 2014, "De Sitter Space Without Dynamical Quantum Fluctuations," *Found. Phys.* **46**, 702; [arxiv:1405.0298](#).
67. G.N. Remmen and S.M. Carroll, 2014, "How Many e -Folds Should We Expect from High-Scale Inflation?" *Phys. Rev. D* **90**, 063517; [arxiv:1405.5538](#).
68. S. Aaronson, S.M. Carroll, and L. Ouellette, 2014, "Quantifying the Rise and Fall of Complexity in Closed Systems: The Coffee Automaton," [arxiv:1405.6903](#).
69. C.T. Sebens and S.M. Carroll, 2014, "Self-Locating Uncertainty and the Origin of Probability in Everettian Quantum Mechanics," *The British Journal for the Philosophy of Science*, in press; [arxiv:1405.7577](#).
70. S.M. Carroll, 2014, "In What Sense Is the Early Universe Fine-Tuned?", to appear in *Time's Arrows and the Probability Structure of the World*, B. Loewer, E. Winsberg and B. Weslake, eds.; [arxiv:1406.3057](#).
71. N. Bao, C. Cao, S.M. Carroll, A. Chatwin-Davies, N. Hunter-Jones, J. Pollack, and G.N. Remmen, 2015, "Consistency Conditions for an AdS/MERA Correspondence," *Phys. Rev. D* **91**, 125036; [arxiv:1504.06632](#).
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