

# Arvind Murugan

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## Employment

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Assistant Professor	<b>University of Chicago</b> , Chicago, IL Physics + James Franck Institute	July 15 - (present)
Postdoc	<b>Harvard University</b> , Cambridge, MA School of Engineering and Applied Sciences	Sep 12 - Sep 15
Member	<b>Institute for Advanced Study</b> , Princeton, NJ School of Natural Sciences	Aug 09 - Aug 12
Visiting Researcher	<b>Rockefeller University</b> , NYC, NY Laboratory of Living Matter	Aug 09 - Aug 12

## Education

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Ph.D. (Physics)	<b>Princeton University</b> , Princeton, NJ Thesis: "Gauge-gravity duality with renormalization group flow and reduced supersymmetry." <i>Advisor: Igor R. Klebanov</i>	Sep 04 - Jul 09
M.S. (Physics)	<b>California Institute of Technology</b> , Pasadena, CA. <i>Advisor: Anton Kapustin</i>	Sep 00- Jun 04
B.S. (Mathematics)	<b>California Institute of Technology</b> , <i>w/ honors</i> Pasadena, CA.	Sep 00- Jun 04

## Awards

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NSF Career Award, 2023 - 2028

Simons Investigator, 2017- 2022

Addie and Harold Broitman Member in Biology, IAS 2010 - 2011.

Princeton University Graduate Centennial Fellowship 2004 - 2009.

## Research articles

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- \* M J. Falk, F D. Roach, W Gilpin, [A Murugan](#)  
Curiosity-driven search for novel non-equilibrium behaviors  
arXiv (2023)
- \* A Goyal, A Flamholz, A Petroff, [A Murugan](#)  
Closed ecosystems extract energy through self-organized nutrient cycles,  
arXiv (2023)
- \* CG Evans, J O'Brien, E Winfree, [A Murugan](#)  
Pattern recognition in the nucleation kinetics of non-equilibrium self-assembly.  
arXiv (2022)
- 38 M J. Falk, J Wu, A Matthews, V Sachdeva, N Pashine, M Gardel, S Nagel, [A Murugan](#)  
Learning to learn: Non-equilibrium design protocols for adaptable materials  
PNAS (2023)
- 37 J Devany, M J Falk, L J Holt, [A Murugan](#), M L Gardel  
Epithelial tissue confinement inhibits cell growth and leads to volume-reducing divisions  
Developmental Cell 2023
- 36 Arinze C, Stern M, Nagel SR, [Murugan A.](#)  
Learning to self-fold at a bifurcation  
Physical Review E (2023)
- 35 N. Stern, [A. Murugan](#)  
Learning without neurons in physical systems  
Annual Reviews of Condensed Matter Physics (2023)
- 34 S W. Schaffter, K-L Chen, J O'Brien, M Noble, [A Murugan](#), R Schulman  
Standardized excitable elements for scalable engineering of far-from-equilibrium  
chemical networks  
Nature Chemistry, 2022
- 33 Ligand-receptor promiscuity enables cellular addressing  
C Su, [A Murugan](#), J Linton, A Yeluri, J Bois, H Klumpe, Y Antebi, M Elowitz  
Cell Systems, 2022
- 32 M.Falk, V. Alizadehyazdi, H. Jaeger, [A. Murugan](#)  
Learning to control active matter  
Physical Review Research, 2021
- 31 [A. Murugan et al.](#),  
Roadmap on biology in time varying environments  
Physical Biology, 2021
- 30 M.Son, A.Wang, M.Metzig,P. Patel,K. Husain,H.Tu,J. Lin, [A.Murugan.](#)  
A.Hoffmann,S.Tay  
NF- $\kappa$ B responds to absolute differences in cytokine concentrations

Science Signaling Vol. 14, Issue 666, eaaz4382

- 29 V Galstyan, K Husain, F Xiao, [A. Murugan+](#), R Phillips+  
Proofreading through spatial gradients  
eLife 2020; 9:e60415
- 28 K. Husain, [A. Murugan](#)  
Physical constraints on epistasis  
*Molecular Biology and Evolution (MBE) (2020)*
- 27 M. Stern, C. Arinze, L. Perez, S. Palmer, [A. Murugan](#)  
Supervised learning in a mechanical system  
*PNAS 2020*
- 26 M. Stern, M. Pinson, [A. Murugan](#)  
Continual learning of multiple memories in mechanical networks  
*PRX 2020*
- 25 V. Sachdeva\*, K. Husain\*, J. Sheng, S. Wang+, [A. Murugan+](#)  
Tuning environmental timescales to evolve and maintain generalists  
*PNAS 2020*
- 24 W. Zhong, Z. Lu, D. Schwab+, [A. Murugan+](#)  
“Non-equilibrium statistical mechanics of continuous attractors”  
*Neural Computation (2020)*
- 23 K Husain, W Pittayakanchit, G Pattanayak, M Rust, [A. Murugan](#)  
“Kalman-like self-tuned sensitivity of circadian clocks”,  
*Cell Systems (2019)*
- 22 J. O’Brien, [A. Murugan](#)  
“Temporal pattern recognition through analog molecular computation”  
*ACS Synthetic Biology (2019)*
- 21 [A. Murugan A](#), H. Jaegger  
“Bioinspired nonequilibrium search for novel materials”,  
*MRS Bulletin 44(2):96-105 (2019)*
- 20 M. Stern, V. Jayaram, [A. Murugan](#)  
“Shaping the topology of folding pathways in mechanical systems”  
*Nature Communications 9: 4303 (2018)*
- 19 W. Pittayakanchit, Z. Lu, J. Chew, M. Rust, [A. Murugan](#)  
“Biophysical clocks face a trade-off between internal and external noise resistance”,  
eLife (2018);7:e37624
- 19 J. Chew, E. Leypunskiy, J. Lin, [A. Murugan](#), M. Rust  
“High Protein Copy Number Is Required to Suppress Stochasticity in the  
Cyanobacterial Circadian Clock”  
*Nature Communications (June 2018)*
- 18 N. Stern, M. Pinson, [A. Murugan](#),  
“The complexity of folding self-folding origami”

- Physical Review X 7, 041070 (2017)
- 17 W. Zhong, D. Schwab, A. Murugan  
“Associative pattern recognition through macro-molecular self-assembly”  
Journal of Statistical Physics, 167, Issue 3–4, (2017)
  - 16 M. Pinson, M. Stern, A. Carruthers, B. Chen, A. Murugan,  
“Self-folding origami at any energy scale”  
Nature Communications 8:15477 (2017)
  - 15 A. Murugan, S. Vaikuntanathan,  
“Topologically protected modes in non-equilibrium stochastic systems”  
Nature Communications 8, 13881 (2017)
  - 14 M. Huntley\*, A. Murugan\*, M. Brenner (\* = first authors)  
“The Information Capacity of Specific Interactions”,  
Proceedings of the National Academy of Sciences 113 (21) 5841-5846 (2016)
  - 13 D. Zwicker, A. Murugan\*, M. Brenner\* (\* = corresponding authors)  
“Receptor arrays optimized for natural odor statistics”,  
Proceedings of the National Academy of Sciences 113(20) 5570-5575 (2016)
  - 12 A. Murugan, S. Vaikuntanathan,  
“Biological implications of dynamical phases in non-equilibrium networks”  
Journal of Statistical Physics special issue (2016, 162 (6))
  - 11 A. Murugan\*, Z. Zeravcic\*, S. Leibler, M. Brenner, (\* = first authors)  
“Multifarious Assembly Mixtures: Systems Allowing Retrieval of Diverse Stored Structures”,  
Proceedings of the National Academy of Sciences 112(1) 54-59 (2015)
  - 10 A. Murugan\*, J. Zou\*, and M. Brenner, (\* = first authors)  
“Undesired Usage and the Robust Self-Assembly of Heterogeneous Structures”  
Nature Communications 6, 6203 (Jan 2015)
  - 9 A. Murugan, D.A. Huse, S. Leibler,  
“Discriminatory proofreading regimes in non-equilibrium systems”  
Physical Review X 4 (2), 021016
  - 8 A. Murugan, D.A. Huse, S. Leibler  
“Speed, dissipation, and error in kinetic proofreading”  
Proceedings of the National Academy of Sciences 109(30):12034-9 (2012)
  - 7 I.R.Klebanov, T.Klose, A. Murugan  
“AdS4/CFT3 – squashed, stretched and warped”  
Journal of High Energy Physics 0903 140 (2009) arxiv:0809.3773 [hep-th]
  - 6 I. R. Klebanov, A. Murugan, D. Rodriguez-Gomez, J. Ward  
“Goldstone Bosons and Global Strings in a Warped Resolved Conifold”  
Journal of High Energy Physics 0805, 090 (2008), arXiv:0712.2224 [hep-th]

- 5 I. R. Klebanov, D. Kutasov, [A. Murugan](#)  
*"Entanglement as a Probe of Confinement"*  
 Nuclear Physics B 796, 274 (2008), arXiv:0709.2140 [hep-th]
- 4 I. R. Klebanov, [A. Murugan](#).  
*"Gauge/Gravity Duality and Warped Resolved Conifold"*  
 Journal of High Energy Physics 0703, 042 (2007), arXiv:hep-th/0701064
- 3 D. Baumann, A. Dymarsky, I. R. Klebanov, J. M. Maldacena, L. McAllister, [A. Murugan](#)  
*"On D3-brane potentials in compactifications with fluxes and wrapped D-branes"*  
 Journal of High Energy Physics 0611, 031 (2006), arXiv:hep-th/0607050
- 2 A. Kapustin, [A. Murugan](#)  
*"Fatgraph expansion for noncritical superstrings"*  
 arXiv:hep-th/0404238
- 1 Hauksson, Egill, [A. Murugan](#)  
*"A new 3-D Regional Velocity Model for Real-time Hypocenter Determinations in Southern California"*  
 Proceedings of the Southern California Earthquake Center (Annual Meeting), 2002

## Invited talks

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University of Michigan, Ann Arbor, MI	"Learning and computation without neurons"	Jul'23
Molecular Mechanisms of Evolution, Gordon Conference	"Evolution of kinetic proofreading"	Jun'23
QBio symposium, Northwestern, Chicago, IL	"Dimensionality reduction in biology"	Jun'23
Physics colloquium NYU, New York, NY	"Learning without neurons"	Mar'23
GSNP Tutorial APS Meeting, Las Vegas, LV	"Learning and computation without neurons"	Mar'23
Theory chalk talk, Harvard Medical School	"Learning without neurons"	Feb'23
Caltech alumnus meetup	"Learning without neurons"	Feb'23
Stochastic Physics in Biology, Gordon Conference	"Origin of non-equilibrium order"	Jan'23
Physics Colloquium AMOLF, Netherlands	"Origin of Maxwell Demons"	Nov'22

Workshop on information processing, AMOLF, Netherlands	“Neural computation with molecules”	Nov’22
Physics/Chemistry Colloquium, TU Eindhoven	“Neural computation with molecules”	Nov’22
Coherent Network Computing, Stanford, CA	“Pattern recognition through nucleation”	Oct’22
Cargese Summer School, Corsica, France	“Origin of kinetic proofreading”	Sep’22
Simons Center for Geometry and Physics, Stony Brook, NY	“Pattern recognition through nucleation”	May’22
Johns Hopkins, Baltimore, MD	“Pattern recognition through nucleation”	May’22
Harvard University, Cambridge, MA	“Learning without neurons”	Apr’22
Illinois Institute of Technology, Chicago, IL	“Pattern recognition through nucleation”	Apr’22
APS March Meeting Chicago, IL	“Learning without neurons” Invited talk	Mar’22
University of Michigan, Ann Arbor, MI	“Pattern recognition through nucleation”	Sep’21
Cold Spring Harbor (Virtual)	“Clocks, Hourglasses, and History-dependent Clocks”	May’21
University of Amsterdam (Virtual)	“Materials that learn from examples”	May’21
Biological Physics/Physical Biology (BP/PB) series (Virtual)	“Neural network-like collective dynamics of molecules”	Apr’21
qEvo 2021 (Virtual)	“Physical constraints on epistasis”	Jan’21
Max Planck Institute, Gottingen, Germany	“Neural network-like collective dynamics in molecules”	Dec’20

Imperial College London, UK	Physics of life series, "Neural network-like collective dynamics in molecules"	Nov'20
Tel Aviv University (Virtual/zoom)	Workshop on Pathways, Sequence and Memory "Supervised learning in mechanics"	June'20
BIRS, Banff, Canada	Workshop on gene regulation, "Self-tuned sensitivity"	Feb' 20
MIT, Cambridge, MA	Physics seminar, "Neural network-like collect dynamics in matter"	Jan' 20
EPFL, Lausanne, Switzerland	CECAM workshop, "Learning in matter"	Jan' 20
UCLA, Los Angeles, CA	Physics seminar "Learning from examples"	Oct' 19
NSF, Alexandria, VA	MRSEC Directors meeting, "Learning from examples"	Sep' 19
U Penn, Philadelphia, PA	Physics seminar, "Learning from examples"	Sep' 19
Aspen, CO	Information processing in cells "Self-tuned sensitivity"	Jul' 19
Paros, Greece	Frontiers of Biophysics, "Interrupted transients"	Jun' 19
Chan-Zuckerberg Biohub, San Francisco, CA	Theory in Biology day "Interrupted Transients"	Mar'19
Gordon Conference, Invited talk Ventura, CA	Stochastic Physics and Biology "Self-tuned trust in clocks"	Jan'19
UIUC, Urbana Champaign, IL	Physics seminar "Transients in physics and biology"	Nov'18
Peking University, China	Center for Quantitative Biology, "Transients in physics and biology"	Oct'18
DNA 24, Dajin, China	DNA Computing and Molecular Programming, Invited plenary talk	Oct'18
Penn State, College Station, PA	Physics seminar, "Internal models of the external world"	Oct'18
Emory University, Atlanta, GA	Physics colloquium, "Associative memory in materials"	Apr'18
Simons Foundation,	Invited talk, Theory & Biology Conference	Apr'18

NYC, NY	``Internal models of the external world''	
Rice University, Houston, TX	Physics seminar ``Internal models of the external world''	Apr'18
APS Invited talk Los Angeles, CA	``Towards a theory of self-folding''	Mar'18
KITP, Santa Barbara, CA	Invited talk, Memories 2018 conference ``Associative memory in frustrated materials''	Feb'18
Princeton University, Princeton, NJ	Invited talk, PCTS workshop ``Associative memory in frustrated materials''	Nov'17
MIT Physics, Cambridge, MA	Physics seminar ``Internal models of the external world''	Oct'17
UT Southwestern, Dallas, TX	Systems Biology seminar ``Internal models of the external world''	Oct'17
Washington U. St Louis, MO	Physics seminar, ``Internal models of the external world''	Sep'17
QBio workshop, New Brunswick, NJ	``Continuous attractors as unreliable estimators''	Jul'17
CNLS conference Santa Fe, NM	Los Alamos NL annual conference "Fitting internal models to the external world"	May'17
Harvard University, Cambridge, MA	Widely Applied Math seminar "Fitting internal models to the external world"	Mar'17
Northwestern University, Chicago, IL	Mechanical Engineering, "When is something self-folding?"	Jan' 17
Harvard University, Cambridge, MA	Workshop on Aging and Failure in biology "Error correction through catastrophes"	May'16
Foundations of Nanoscience (FNANO), Snowbird, UT	Invited speaker "Control of heterogeneous self-assembly"	Apr'16
University of Illinois, Urbana-Champaign, IL	Urbana cond-mat Symposium, "Associative memory: A forgotten property of frustrated disordered materials"	Mar'16
Santa Fe Institute, Santa Fe, NM	Kinetic Networks: from Topology to Design, "More computation by matter"	Sep'15
Rockefeller University, New York, NY	Center for Studies in Physics and Biology, ``Control vs multi-functionality in disordered frustrated systems"	Apr'15
University of Colorado,	Department of Physics, Colloquium "Design	Mar'15



Boulder, CO	principles for heterogeneous structure synthesis: Lessons from biology	
University of Colorado, Boulder, CO	Department of Physics, Seminar “Non-equilibrium error correction in biological and synthetic systems”	Mar’15
APS Invited Talk, San Antonio, TX	“Non-equilibrium error correction in biological and synthetic systems”	Mar’15
University of Massachusetts, Amherst, Amherst, MA	Department of Physics, “Design principles for heterogeneous structure synthesis: Lessons from biology”	Mar’15
University of San Diego, San Diego, CA	Department of Physics, “Design principles for heterogeneous structures”	Feb’15
MIT, Cambridge, MA	Department of Physics, “Design principles for heterogeneous structure synthesis: Lessons from biology	Feb’15
Aspen Institute for Physics, Aspen, CO	Unified Concepts in Glass Physics VI, “Associative memory: A forgotten property of marginal frustrated systems”	Feb’15
Cornell, Ithaca, NY	LASSP and Applied Physics seminar, “Design principles for heterogeneous structure synthesis: Lessons from biology”	Jan’15
University of Chicago, Chicago, IL	James Franck Institute, “Design principles for heterogeneous structure synthesis: Lessons from biology”	Jan’15
Princeton University, Princeton, NJ	Department of Chemistry, “Design principles for heterogeneous structure synthesis: Lessons from biology”	Dec’14
Universite Joseph Fourier, Grenoble, France	Laboratory of Interdisciplinary Physics, “Associative memory and bottom-up materials synthesis	Jul’14
University of Nice, Nice, France	Laboratory of Condensed Matter Physics, “Associative memory and bottom-up materials synthesis”	Jun’14
Ecole Superieure de Physique et de Chimie Industrielles (ESPCI) , Paris	jointly with Ecole Normale Superieure (ENS), “Associative memory and bottom-up materials synthesis”	Jun’14
Brandeis, Waltham, MA	Physics Department “Design principles for heterogeneous materials synthesis: Lessons from biology”	Jun’14

University of Chicago, Chicago, IL	Computations in Science Seminar, “Design principles for heterogeneous materials synthesis: Lessons from biology.”	May’14
University of Maryland College Park, MD	Institute for Physical Science and Technology, “Design principles for material synthesis : Lessons from biology”	Apr’14
Northwestern, Evanston, IL	Applied Math Colloquium “Design principles for material synthesis : Lessons from biology”	Jan’14
Boston Physical Biology Hangout, MIT	“Principles of non-equilibrium error-correction”	Dec’13
Harvard University, Cambridge, MA	Bauer Forum “Self-assembly in imperfect conditions”	Nov’13
	Condensed Matter Kids Seminar	Oct’12
	“Kinetic Proofreading and Non-Equilibrium Occupancy of States”	Dec’11
Perimeter Institute for Theoretical Physics, Ontario	Young Researchers Conference, “Gauge-gravity duality in 2 + 1 dimensions”	Dec’08
Institute for Nuclear Theory, U. Washington, Seattle, WA	String Theory Methods in the Real World, “Entanglement as a probe of confinement”	May’08
Princeton University, Princeton, NJ	High-energy theory group seminar, “Entanglement and Confinement”	Apr’08
Cornell University, Ithaca, NY	High-energy theory group seminar, “Entanglement and Confinement”	Apr’08
University of Chicago, Chicago, IL	High-energy theory group seminar, “Entanglement as a measure of confinement”	Nov’07

## Teaching experience

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- Fall 19, 21 **General Physics**  
Newtonian mechanics and fluid dynamics for non-physics majors
- Fall 16, 17, 19, 20 **Mathematical Methods for Physicists**, (U Chicago)  
Introductory mathematical methods for PhD students
- Fall 15, 17, **Principles of Biophysics**, (U Chicago)  
Spring 18, 20, 23 Introduction to quantitative biology for physics grad + undergrads

## Service/outreach

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- eLife, Board of Reviewing Editors
- Referee Referee for Nature, Science Advances, Nature Communications, PNAS, Physical Biology”, “Biophysical Journal”, “PLoS One”, “Journal of the Royal Society Interface”, “Journal of High Energy Physics”, “Nuclear Physics B”, “Physical Review Letters, D, X”, “Journal of Statistical Physics”, “Quantum Information Processing”
- Organizer Chair line, Gordon Conference Stochastic Physics in Biology (2022 - )  
Program committee for the yearly QBio meeting **(20?? - 20??)**  
Midwest QBio meeting (Nov 2015) at U Chicago.  
Organizer of APS March meeting (2017, 2019, 2021) sessions on information processing and learning in biology.
- Other outreach `Theory alley` display for high school students at annual Physics with a Bang U Chicago outreach event (2015 - 2017)  
Workshop for science teachers at KITP, Santa Barbara (2018)