Zachary G. Nicolaou

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Research interests

My research focuses on the emergence of complexity, with particular emphasis on synchronization and pattern formation in networks, condensed matter, and fluid mechanical systems. I utilize tools in nonlinear dynamics and symmetry analysis to discover mechanisms behind complex phenomena. As a master's student at Cambridge, I published work in Nature Materials proposing an early and seminal mechanical metamaterial that counterintuitively contracts under tension (or expands under pressure) as a result of a stress-induced, solid-to-solid phase transition. As a graduate student at Caltech, I studied thin fluid films driven by interfacial forces which arise in a myriad of natural and technological systems, focusing on symmetry and variational analyses and deriving new symmetry reductions and stability results for driven droplets. As a postdoctoral fellow at Northwestern University, I studied synchronization and pattern formation in networks and driven fluid systems. Current topics of interest are symmetry concepts (including chimera states and converse symmetry breaking), critical dynamics, novel states appearing around band gaps, and the kinetics of topological defects.

Education and employment

University of Massachusetts Boston, 09/01/2020–02/28/2021

> Postdoctoral researcher in the group of Jason R. Green

Northwestern University, 10/01/2016–07/31/2020

> Postdoctoral researcher in the group of Adilson E. Motter

California Institute of Technology, 2011-2017

> Doctor of philosophy in Physics, conferred July 2017
>> Dissertation: Symmetry and variational analyses of fluid interface equations in the thin film limit
>> Advisor: Professor Sandra M. Troian
>
> Graduate Teaching and Research Assistant, Department of Physics and Department of Applied Physics, 2013-2016

University of Cambridge, 2010-11

> Master's of Advanced Study in Applied Mathematics and Theoretical Physics
>
> Graduated with Merit, 2011

Northwestern University, 2006-10

> Bachelor's of Arts in Physics, Mathematics, and the Integrated Science Program
> GPA: 3.83/4.0
>
> Programming Instructor. Northwestern Integrated Science Program A01/ISP101 Computer Programming, 2009-10
>
> Undergraduate Research, Professor Adilson E. Motter, Department of Physics, 2008-2010
>
> Programming Tutor. Northwestern Integrated Science Program A01/ISP101 Computer Programming, 2008-09

Honors and awards

Washington Research Foundation Postdoctoral Fellowship award, 2021-2024.

First place, 2019 Scientific Images Contest, Northwestern Science in Society, 2019.

Full membership in Sigma Xi, 2019.

Finalist in the GSNP student speaker award at the 2016 APS March Meeting, 2016.

National Science Foundation Graduate Research Fellowship Program, 2010-13.

University of Cambridge Part III Mathematics graduate with Merit, 2011.

Outstanding Senior Thesis in Physics and Astronomy, Northwestern University, 2010.

Undergraduate Research Internship, Northwestern University Materials Research Science and Engineering Center, 2008-09 and 2009-10.

Summer Research Grant, Northwestern University, Summer, 2009.

Barry M. Goldwater Scholarship, 2009.

Katherine L. Krieghbaum Scholarship, Northwestern University, 2009.

Phi Beta Kappa Honor Society (inducted as Junior), 2009.

Sigma Pi Sigma Physics Honor Society (inducted as Junior), 2009.

Best Junior in Physics, Northwestern University Physics Department, 2009.

Outstanding Achievement in Mathematics by a Junior, Northwestern University Mathematics Department, 2009.

Scientific publications

Z. G. Nicolaou, S. B. Nicholson, and J. R. Green, Prevalence and persistence of dynamical complexity in driven chemical networks, in preparation.

Z. G. Nicolaou, D. Case, E. B. van der Wee, M. M. Driscoll, and A. E. Motter, Heterogeneity-stabilized homogeneous states in driven media, under review in Nat. Commun.

Z. G. Nicolaou and A. E. Motter, Anharmonic classical time crystals, to appear in Phys. Rev. Research (2021).

Z. G. Nicolaou, T. Nishikawa, S. B. Nicholson, J. R. Green, and A. E. Motter, Non-normality and non-monotonic dynamics in complex reaction networks, Phys. Rev. Research **2**, 043059 (2020).

Z. G. Nicolaou, and A. E. Motter, Missing links as a source of variable constants in complex networks, Phys. Rev. Research **2**, 043135(2020).

Z. G. Nicolaou, M. Sebek, I. Z. Kiss, and A. E. Motter, Coherent dynamics induced by uncorrelated noise, Phys. Rev. Lett. **125**, 094101 (2020).

Y. Zhang, Z. G. Nicolaou, J. D. Hart, R. Roy, and A. E. Motter, Critical Switching Behavior in Globally Attractive Chimeras, Phys. Rev. X **10**, 011044 (2020).

Z. G. Nicolaou, D. Eroglu, and A. E. Motter, Multifaceted dynamics of Janus oscillator networks, Phys. Rev. X **9**, 011017 (2019).

Z. G. Nicolaou, B. Xu, & Adilson E. Motter, Minimal scattering entanglement in one-dimensional trapped gases, Phys. Rev. A **99**, 012316 (2019).

Z. G. Nicolaou, Stability and instability of axisymmetric droplets in thermocapillary-driven thin films, Nonlinearity **31**, 1009 (2018).

Z. G. Nicolaou, H. Riecke, & A. E. Motter, Chimera States in Continuous Media: Existence and Distinctness, Phys. Rev. Lett. **119**, 244101 (2017).

Z. G. Nicolaou, Symmetry and variational analyses of thin film partial differential equations, Caltech dissertation (2016).

Z. G. Nicolaou and A. E. Motter, Longitudinal inverted compressibility in super-strained metamaterials, J. Stat. Phys. **151**, 1162 (2013).

Z. G. Nicolaou and A. E. Motter, Mechanical metamaterials with negative compressibility transitions, Nature Materials **11**, 608 (2012).

Technical skills

Analytic approaches

Symmetry analysis, dimension reduction, and similarity solutions
Lyapunov functions and variational methods
Linear stability analysis, asymptotic approaches, and bifurcation analysis

Numerical simulations

Programming in Python, C, C++, Mathematica, Matlab
ODE integration with adaptive timestepping, stiffness switching
PDE integration with finite elements, finite differences, and (pseudo)spectral methods
Parallelization with OpenMP, BLAS optimization, and Bash scripting with Slurm clusters

Conference organization and peer review

NetSci 2020 program committee member, Rome, Italy 2020.

NetSci-X 2020 program committee member, Tokyo, Japan 2020.

International School and Conference on Network Science 2018, program committee member, Paris, 2018.

9th International Conference on Complex Networks, program committee member, New England Complex Systems Institute, 2018.

APS March Meeting 2018, focus session organizer (Session V47), Los Angeles, 2018.

Network Frontier Workshop, organizing committee and emcee, Northwestern University, 2017.

Nature Materials, reviewer.

Phys. Rev. Research, reviewer.

ACS Nano, reviewer.

Nonlinearity, reviewer.

Physica A: Statistical Mechanics and its Applications, reviewer.

Chaos: An Interdisciplinary Journal of Nonlinear Science, reviewer.

Communications in Nonlinear Science and Numerical Simulation, reviewer.

Journal of Complex Networks, reviewer.

Journal of Nonlinear Science, reviewer.

Seminars and selected presentations

Diverse effects of noise in oscillator networks (invited seminar talk). Kadir Has University Faculty Seminar, Turkey (November 2020).

Critical switching behavior in globally attractive chimeras (invited seminar talk). Syndey Dynamics Group Seminar, University of Sydney (May 2020).

Symmetry and asymmetry in oscillatory patterns (invited seminar talk). LANS informal seminar, Argonne National Laboratory (September 2019).

Multifaceted dynamics of Janus oscillator networks (invited minisymposium). SIAM Conference on Applications of Dynamical Systems (May 2019).

Computational physics inspires new insights in nature and technology (invited seminar). Physics seminar, Physics Department at University of Wisconsin Whitewater (September 2018).

Chimera states in continuous media (invited talk). Topical Problems in Nonlinear Wave Physics, Moscow-St. Petersburg, Russia (July 2017).

Chimera States in Continuous Media, SIAM Conference on Applications of Dynamical Systems, Snowbird, UT (May 2017).

Lie algebraic analysis of thin film Marangoni flows: multiplicity of self-similar solutions. APS March Meeting 2016, Baltimore, MD (March 2016).

Features of the interface equation coupling thin and thick film regimes in conduction-triggered thermocapillary flows. 68th Annual Meeting of the APS Division of Fluid Dynamics, Boston MA (November 2015).

Lyapunov based predictions of droplet shapes in thermocapillary driven nanofilms. APS March Meeting 2015, San Antonio TX (March 2015).

Lie group reduction analysis of the moving boundary problem governing Bénard-like fluctuations in nanofilms. APS March Meeting 2014 , Denver CO (March 2014).

Network destabilizations with inverted mechanical responses. APS March Meeting 2010, Portland OR (March 2010).

Mentoring and outreach

Teaching assistant at Northwestern and Caltech with excellent reviews

"Zac is a fantastic TA, and was always available to answer questions about the problem set, the course, or physics in general. He has a broad base of knowledge and never hesitates to explain things in ways deeper than you might have first imagined."

"Zach was an excellent TA. He was always willing to talk about the homework and class material when he was in his office (which was most of the morning and afternoon), and he was very knowledgeable about the subject. He definitely put in quite a bit more time than most other TA's will spend on classes. He was also quite approachable, which is always refreshing."

"Zach was not only extremely helpful outside of class, but also in lecture as he would interject to clarify points or answer students' questions with infallibly perceptive and insightful comments. His office hours were 'by appointment,' which effectively meant 'any time–day or night'. He is a genuinely nice person and always seemed happy to help, no matter how long it took."

Volunteer tutoring with special needs students in Caltech Y Rise program

Two hours per week for one year in high school physics and chemistry

Student and research mentor in the Motter group at Northwestern

    Undergraduate student Bohan Xu in quantum decoherence (published in *Phys. Rev. A*)

    Graduate student Phalguni Shah in ecological systems (in preparation)

    Graduate student Daniel Case in Faraday wave instabilities (in preparation)

    Graduate student Yuanzhao Zhang in chimera states (published in *Phys. Rev. X*)

Co-founder (with Sarah Wellons) of informal postdoc mentoring program at Northwestern

    Organized ice cream social events to introduce postdocs and students

    Matched 15 Physics and Astronomy grad students with postdocs from other groups