Michael Zwolak

Biophysical Measurement | Scientific Computing | Quantitative Biology

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Summary

Biophysical measurement scientist and research leader integrating experiment, quantitative data analysis, mechanistic modeling, and scientific computing. At NIST, I direct the Biophysical and Biomedical Measurement Group, leading cross-scale programs from biomolecules to cells and tissues with physical scientists, biomedical engineers, and associate researchers. I work with experimental scientists from study design and data generation through quality assessment, analysis, and model development to establish reliable biological inference. Current programs connect this foundation to quantitative cytometry and interpretable biomolecular representations for predictive modeling and AI, while active computational-physics work develops algorithms and representations for classical and quantum many-body systems.

Relevant Expertise

Biological Measurement & Data
Fluorescence/FRET, cytometry, spectroscopy, nanopore and single-molecule measurements

Quantitative Methods
Statistics, time series, clustering, SVD, tensor networks, mechanistic modeling

Scientific Leadership
Cross-scale programs, team leadership, scientific strategy, and program building

Experience

***Group & Project Leader,* National Institute of Standards and Technology** 2014 – present

- Directing NIST's primary group for physical measurements in biology 2018 – present
- Setting multi-year strategy across programs spanning biomolecules, cells, and tissues and integrating biological measurement, quantitative data analysis, and mechanistic modeling
- Working with experimentalists from study design and data generation through quality assessment, analysis, modeling, and biological interpretation to produce reliable datasets for quantitative inference and prediction
- Developing quantitative frameworks connecting experimental signals to biological properties in FRET, biodosimetry, spectroscopy, cytometry, and structural ensembles
- Leading current work on measurement quality, comparability, uncertainty, and interpretable representations to make biological data more reliable for predictive modeling and AI
- Spearheaded clearer frameworks for funded collaborations with academic and clinical partners; Co-I on a Wake Forest-led NIH U01 in human biodosimetry

***Assistant Professor,* Oregon State University, Department of Physics** 2011 – 2014

- Pioneered thermal transport as a quantitative probe of biomolecular structural transitions; led an independent research program and taught graduate physics

***Feynman & Director's Fellow,* Los Alamos National Laboratory** 2007 – 2011

- Simulated electronic, thermal, and ionic transport in biomolecular systems and nanopores; developed methods for nonequilibrium open quantum systems

Education

Ph.D., Physics, California Institute of Technology (GPA: 4.0/4.0) 2008

M.S., Physics, Virginia Polytechnic Institute (GPA: 4.0/4.0) 2003

B.S., Chemical Engineering; B.S., Chemistry; B.A., Philosophy (Honors) 2002

Virginia Polytechnic Institute; minors in mathematics and physics

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Selected Data-to-Inference & Computational Contributions

- **Quantitative cytometry (current):** Developing analyses of how measurement quality and analytical choices propagate into inferred single-cell state distributions and downstream biological conclusions
- **Interpretable biomolecular representations:** Developed a secondary-structure distance metric and clustering framework that compresses DNA/RNA molecular-dynamics ensembles, distinguishes meaningful structural states, and can provide structured inputs for statistical or ML models
- **Quantitative DNA folding:** Integrated FRET measurements with thermodynamic modeling to infer folding yield and melting behavior, identify failure mechanisms, and improve melt-curve analysis
- **Single-molecule biodosimetry:** Formulated transfer-matrix and statistical models connecting DNA strand-break and fragment measurements to radiation dose and damage mechanisms
- **Time-resolved spectroscopy:** Created time-series analyses to infer energy-transport pathways and hidden energy-landscape structure from ultrafast biomolecular measurements
- **Finite-size scaling for molecular simulation:** Developed the golden-aspect-ratio construction that isolates access resistance in atomistic nanopore simulations and connects finite simulation cells to continuum transport
- **Tensor-network algorithms:** Identified the natural entanglement structure that overcomes the apparent exponential growth in quantum-transport simulation cost, devised the tensor-network representation that exploits it, and demonstrated efficient scaling for quadratic systems; *Entanglement at the Fermi Edge and Tensor Networks for Transport* is under review at *Physical Review Letters*

Technical and Leadership Skills

Biological measurement domains: fluorescence/FRET; flow cytometry; spectroscopy; DNA/RNA structure and ensembles; nanopore and single-molecule data; assay interpretation; measurement quality and uncertainty
Quantitative methods: statistical analysis; time-series analysis; clustering; singular-value decomposition; dimensional reduction; data compression; uncertainty analysis; mechanistic modeling
Computational methods: tensor networks; numerical linear algebra; information theory; algorithm analysis; molecular dynamics (NAMD/LAMMPS); Linux/HPC workflows; Fortran; Julia; MATLAB; Mathematica
Leadership: research strategy; multidisciplinary team leadership; cross-scale program development; experiment-computation integration

Selected Relevant Publications

- Clustering DNA and RNA molecular dynamics ensembles via secondary structure, *Biophys. J.* **125**, 515 (2026)
- Single-Molecule Biodosimetry, *Anal. Chem.* **97**, 22004 (2025)
- Best practice for improved accuracy: A critical reassessment of van't Hoff analysis of melt curves, *Biophys. J.* **121**, 1986 (2022)
- Failure mechanisms in DNA self-assembly: Barriers to single-fold yield, *ACS Nano* **15**, 3284 (2021)
- Performance of reservoir discretizations in quantum transport simulations, *J. Chem. Phys.* **155**, 124117 (2021)
- Breaking the entanglement barrier: Tensor network simulation of quantum transport, *Phys. Rev. Lett.* **124**, 137701 (2020)
- Revealing thermodynamics of DNA origami folding via affine transformations, *Nucleic Acids Res.* **48**, 5268 (2020)
- Topology, landscapes, and biomolecular energy transport, *Nat. Commun.* **10**, 4662 (2019)
- Optimal transport and colossal ionic mechano-conductance in graphene crown ethers, *Sci. Adv.* **5**, eaaw5478 (2019)
- Golden aspect ratio for ion transport simulation in nanopores, *Phys. Rev. E* **98**, 012404 (2018)