

# Biochemical Networks, P. R. ten Wolde (2017-2022)

## Biography



Pieter Rein ten Wolde was born on March 23, 1970, in Groningen, The Netherlands. He did his PhD in the group of Prof. dr. Daan Frenkel, at AMOLF, graduating cum laude in 1998. He then did a postdoc from 1991 – 2021 in the group of Prof. dr. David Chandler, at the University of California at Berkeley. After his postdoc he returned to AMOLF to set up the group “Biochemical Networks”. From 2008 he is also a professor at the VU Amsterdam. He is a recipient of a VICI grant and an ERC Advanced grant, and fellow of the American Physical Society.

The mission of his research group is to elucidate the design principles of biochemical networks by combining rigorous theory with innovative computational techniques. He has made seminal contributions to the understanding of rare events in equilibrium and non-equilibrium systems, the spatial design principles of intracellular biochemical networks, circadian rhythms and the bacterial cell cycle. He has pioneered the application of ideas from information theory and stochastic thermodynamics to cellular sensing and signaling. He currently aims to understand how accurate single-celled organisms can predict future changes in their environment.

## Group output

### Peer reviewed Publications 2017-2022

#### 2017

1. M. Braun, Z. Lansky, A. Szuba, F.W. Schwarz, A. Mitra, M. Gao, A. Lüdecke, P.R. ten Wolde and S. Diez, *Changes in microtubule overlap length regulate kinesin-14-driven microtubule sliding*, Nature Chem. Biol. **13**, 1245–1252 (2017).
2. A. Vijaykumar, P. R. ten Wolde and P. G. Bolhuis, *The magnitude of the intrinsic rate constant: How deep can association reactions be in the diffusion limited regime?*, J. Chem. Phys. **147**, 184108: 1-11 (2017)
3. J. Pajmans, D. K. Lubensky and P. R. ten Wolde, *Period Robustness and Entrainability of the Kai System to Changing Nucleotide Concentrations*, Biophys. J. **113**, 157-173 (2017)
4. J. Pajmans, D. K. Lubensky and P. R. ten Wolde, *Robustness of synthetic oscillators in growing and dividing cells*, Phys. Rev. E **95**, 052403: 1- (2017)
5. T. E. Ouldridge and P. R. ten Wolde, *Fundamental costs in the production and destruction of persistent polymer copies*, Phys. Rev. Lett. **118**, 158103: 1-5 (2017)
6. T. E. Ouldridge, C. C. Govern and P. R. ten Wolde, *Thermodynamics of Computational Copying in Biochemical Systems*, Phys. Rev. X **7**, 021004: 1-13 (2017)
7. A. Vijaykumar, T. E. Ouldridge, P. R. ten Wolde and P. G. Bolhuis, *Multiscale simulations of anisotropic particles combining molecular dynamics and Green's function reaction dynamics*, J. Chem. Phys. **146**, 114106: 1-12 (2017)
8. J. Pajmans, D. K. Lubensky and P. R. ten Wolde, *A thermodynamically consistent model of the post-translational Kai circadian clock*, PLoS Comput. Biol. **13**, e1005415: 1-43 (2017)
9. T. McGrath, N.S. Jones, P. R. ten Wolde and T. E. Ouldridge, *Biochemical Machines for the Interconversion of Mutual Information and Work*, Phys. Rev. Lett. **118**, 028101: 1-5 (2017)

## 2018

1. M. Monti, D. K. Lubensky and P. R. ten Wolde, *Robustness of Clocks to Input Noise*, Phys. Rev. Lett. **121**, 078101: 1-6 (2018). **Green OA**
2. A. Vijaykumar, P. R. ten Wolde and P. G. Bolhuis, *Generalised expressions for the association and dissociation rate constants of molecules with multiple binding sites*, Mol. Phys. **116**, 21-22: 3042-3054 (2018). **Gold OA**
3. H. Wierenga, P. R. ten Wolde and N. Becker, *Quantifying fluctuations in reversible enzymatic cycles and clocks*, Phys. Rev. E **97**, 042404: 1-6 (2018). **Green OA**
4. A. Vijaykumar, P. R. ten Wolde and P. G. Bolhuis, *Rate constants for proteins binding to substrates with multiple binding sites using a generalized forward flux sampling expression*, J. Chem. Phys. **148**, 124109: 1-11 (2018). **Green OA**
5. M. Monti, D. K. Lubensky and P. R. ten Wolde, *Optimal entrainment of circadian clocks in the presence of noise*, Phys. Rev. E **97**, 032405: 1-23 (2018). **Green OA**
6. T. E Ouldridge, R.A Brittain, and P. R ten Wolde, *The power of being explicit: demystifying work, heat, and free energy in the physics of computation*, in The Energetics of Computing in Life and Machines, SFI Press, 2018. **Green OA**

## 2019

1. Y. Li and P.R. ten Wolde, *Shape Transformations of Vesicles Induced by Swim Pressure*, Phys.Rev.Lett. **123**, 148003: 1-6, (2019). **Green OA**
2. K. Bielec, K. Sozansky, M. Seynen, Z. Dziekan, P.R. ten Wolde and R. Holyst, *Kinetics and equilibrium constants of oligonucleotides at low concentrations. Hybridization and melting study*, Phys. Chem. Chem. Phys. **21**, 10798-10807 (2019). **Not OA**
3. Y. Mulla, H. Wierenga, C. Alkemade, P.R. ten Wolde and G.H. Koenderink, *Frustrated binding of biopolymer crosslinkers*, Soft Matter **15**, 3036-3042 (2019). **Green OA**
4. T.R. Sokolowski, J. Pajmans, L. Bossen, T. Miedema, M. Wehrens, N.B. Becker, K. Kaizu, K. Takahashi, M. Dogterom and P.R. ten Wolde, *eGFRD in all dimensions*, J. Chem. Phys. **150** (5), 054108: 1-24 (2019). **Green OA**
5. J.M. Poulton, P.R. ten Wolde and T.E. Ouldridge, *Nonequilibrium correlations in minimal dynamical models of polymer copying*, PNAS **116** (6), 1946-1951 (2019). **Green OA**

## 2020

1. H. Wierenga and P. R. ten Wolde, *"Diffusible Crosslinkers Cause Superexponential Friction Forces"*, Phys. Rev. Lett. **125**, 078101 (2020), **Green OA**.

## 2021

1. L. Olivi, M. Berger, R.N.P. Creighton, N. De Franceschi, C. Dekker, B.M. Mulder, N.J. Claassens, P.R. ten Wolde and J. van der Oost, *Towards a synthetic cell cycle*, Nature Commun. **12**, 4531: 1-11 (2021) **Gold OA**
2. G. Malaguti and P.R. ten Wolde, *Theory for the optimal detection of time-varying signals in cellular sensing systems*, eLife **10**, e62574: 1-26 (2021) **Gold OA**
3. M. Meijers, S. Ito and P.R. ten Wolde, *Behavior of information flow near criticality*, Phys. Rev. E **103**, L010102 : 1-5 (2021) **Green OA**

## 2022

1. M. Berger and P.R. ten Wolde, *Robust replication initiation from coupled homeostatic mechanisms*, Nature Commun. **13**, (1), 6556: 1-13 (2022) **Gold OA**
2. H. Wierenga and P.R. ten Wolde, *Energetic constraints on filament-mediated cell polarization*, Phys. Rev. E **105**, 064406: 1-14 (2022) **Green OA**
3. G. Malaguti and P.R. ten Wolde, *Receptor time integration via discrete sampling*, Phys. Rev. E **105**, 054406: 1-16 (2022) **Green OA**

4. C. Alkemade, H. Wierenga, V.A. Volkov, M. Preciado López, A. Akhmanova, P.R. ten Wolde, M. Dogterom and G.H. Koenderink, *Cross-linkers at growing microtubule ends generate forces that drive actin transport*, PNAS **119**, e2112799119 : 1-12 (2022) Hybrid OA
5. J. Juritz, J.M. Poulton and T.E. Ouldrige, *Minimal mechanism for cyclic templating of length-controlled copolymers under isothermal conditions*, J. Chem. Phys. **156**, 074103: 1-21 (2022) Hybrid OA
6. A. Cumberworth, D. Frenkel and A. Reinhardt, *Simulations of DNA-Origami Self-Assembly Reveal Design-Dependent Nucleation Barriers*, Nano Lett. **22**, 6916-6922 (2022) Hybrid OA

## Contributions to scientific books (chapters or entire book) 2017-2022

N/A

## PhD theses 2017-2022

### 2017

1. A. Vijaykumar, *Multi-Scale simulation of reaction-diffusion systems*, University of Amsterdam, October 24, 2017
2. J. Paijmans, *A computational study of the robustness of cellular oscillators*, VU University of Amsterdam, January 20, 2017

### 2018

1. M. Monti, *A theoretical study of circadian clocks and circadian metabolism*, VU University Amsterdam, 2018-04-12.

### 2021

1. H. Wierenga, *Statistical Mechanics of Cytoskeletal Filaments*, 17/05/2021, VU Amsterdam.

## Masters and Bachelors theses 2017-2022

### 2017

1. Maarten van den Ende, *Circadian Metabolism, Modeling the metabolic states of circadian cells*, Masters thesis, VU-UvA, January, 2022

### 2018

1. Matthijs Meijers, *The behaviour of information flow near criticality*, Masters thesis VU – UvA, June, 2018

### 2019

1. Jeroen Goedhart, *Measuring the past, predicting the future: the push-pull network*, Masters thesis MSc Physics, UvA, September, 2019
2. Ramses Kools, *A mechanism for cell polarization based on active transport*, Masters thesis MSc Chemistry, UvA, June, 2019
3. Tom Clement, *Simulation of multiplexing in immune cell receptors using eGFRD*, Masters thesis MSc Bioinformatics and Systems Biology, VU, November, 2019

### 2020

1. Lotte Slim, *Optimal Cellular Prediction and the Push-Pull Network*, Masters thesis MSc Physics, UvA, July, 2019.
2. Manuel Reinhardt, *Estimating the Mutual Information for Time-varying Signals for Cellular Signaling Networks*, Masters thesis MSc Physics, LMU Munich, July, 2019.

## 2021

1. Raimon Terricabreas, "Coordination of replication initiation and division processes in *E. coli*", master's thesis, Physics Masters, University of Utrecht, October, 2021.
2. Muriël Louman, "Modeling the stability of the cell cycles of *E. coli* bacteria", AMEP Lab project, VU-UvA Masters Physics and Astronomy, Amsterdam, July, 2020.
3. Karydas Theophanes, "Simulating a reactive-diffusion system with a reactive 2D plane on eGFRD", AMEP Lab project, VU-UvA Masters Physics and Astronomy, Amsterdam, August, 2021.

**2022** Geert Schulpen, *Predicting the future of complex signals, the information bottleneck applied to the generalized Langevin equation*, masters thesis University of Utrecht, November 2022

## Invited lectures at international conferences and meetings

### 2017

1. P. R. ten Wolde *Fundamental Limits on Cellular Information Transmission*, Advanced Lecture Course on Computational Systems Biology, Aussois, France, March 19-25, 2017
2. P. R. ten Wolde, *Combining Molecular Dynamics with Mesoscopic Green's Function Reaction Dynamics*, Workshop Scaling Cascades in Complex Systems, Berlin, Germany, March 27 – 29, 2017
3. P. R. ten Wolde, *Finite Size Effects in Cellular Information Transmission*, Workshop Exploiting Finite Size Effects in Simulations, Paris, France, April 18 – 21, 2017
4. P. R. ten Wolde, *Fundamental Limits to Cellular Information Transmission*, Workshop Dynamics, Thermodynamics, and Information Processing in Chemical Networks, Luxembourg, June 13 – 16, 2017
5. P. R. ten Wolde, *Cellular Information Transmission* (4 lectures), Summer School, Cargèse, France, June 26 – July 7, 2017
6. P. R. ten Wolde, *The Robust Ticking of a Circadian Clock*, EMBO Conference: Quantitative Principles in Biology, Heidelberg, Germany, November 2 – 4, 2017
7. Joris Paijmans, *Using thermodynamics to reveal the mechanisms behind the robust ticking, input compensation and entrainability of the cyanobacterial circadian clock*, Felix Naef, EPFL, Lausanne, March 2017
8. Joris Paijmans, *Discrete gene replication events drive coupling between the cell cycle and circadian clocks*, mini symposium on theoretical chronobiology, Marc Lefranc, Université de Lille, Lille, May 2017
9. Joris Paijmans, *Two intertwined circadian oscillator in the cyanobacterium *S. elongatus**, Royal Dutch Academy of Sciences (KNAW) Biophysics meeting, Amsterdam, June 2017
10. Joris Paijmans, *The remarkable robustness of the circadian clock*, Cyanobacteria Young Investigator Symposium, Heinrich Heine University, Düsseldorf, September 2017

### 2018

1. Y. Li, P.R. ten Wolde, *Shape Transformations of Vesicles induced by Swim Pressure*, APS March Meeting, Los Angeles, USA, March 5-9, 2018.
2. P. R. ten Wolde, *The robust ticking of a circadian clock in growing and dividing cells*, Winter Class Modelling Growth and Metabolism of Microorganisms, University of Utrecht, Utrecht, Feb. 18, 2018
3. P. R. ten Wolde, *Thermodynamics of Biochemical Copying*, Workshop Principles of Microbial Adaptation, Lorentz Center, Leiden, March 5 – 9, 2018
4. P. R. ten Wolde, *The robust ticking of a circadian clock*, David Chandler Linnett Memorial Symposium, Cambridge, April 13, 2018
5. P. R. ten Wolde, *Combining Molecular Dynamics with Mesoscopic Green's Function Reaction Dynamics*, Fourth Biological Diffusion and Brownian Dynamics Brainstorm Meeting, Heidelberg, April 16 – 18, 2018

6. P. R. ten Wolde, *Thermodynamics of biochemical copying*, Workshop Biological Ageing from the Perspective of Physics, Information Science, Genetics and Cell Biology, Jacobs University, Bremen, July 16 – 20, 2018
7. P. R. ten Wolde, *Cellular Information Transmission*, Workshop Biological Ageing from the Perspective of Physics, Information Science, Genetics and Cell Biology, Jacobs University, Bremen, July 16 – 20, 2018
8. P. R. ten Wolde, *Optimal Cellular Information Transmission*, Workshop Bits and Biology, Institute for Theoretical Sciences, New York, Sep 13, 2018
9. P. R. ten Wolde, *Optimal Cellular Information Transmission*, Simons Workshop on Nonequilibrium Physics in Biology, Stony Brook, Dec 03, 2018

## 2019

1. Pieter Rein ten Wolde, *Thermodynamics of Biochemical Copying*, IEEE International Symposium on Information Theory, Paris, July 9, 2019
2. Pieter Rein ten Wolde, *Optimal Cellular Information Transmission*, Workshop Dynamics, Randomness, and control in molecular and cellular networks, Boston, November 13, 2019
3. Yao Li, *Shape transformation of vesicles induced by swim pressure*, Beijing Institute of Technology, Beijing, China, October 14, 2019
4. Yao Li, *Shape transformation of vesicles induced by swim pressure*, Tianjin University, Tianjin, China, October 18, 2019
5. Yao Li, *Shape transformation of vesicles induced by swim pressure*, Tongji University, Shanghai, China, October 22, 2019
6. Yao Li, *Membrane dynamics in and far from equilibrium*, Gottingen, Germany, October 29, 2019

## 2020

1. P. R. ten Wolde, *“Optimal Cellular Sensing”*, Workshop, Advances in Theoretical and Experimental Methods for Analyzing Complex Regulatory Networks, Banff, February 16, 2020.
2. P. R. ten Wolde, *“Optimal Cellular Information Transmission”*, Solvay Workshop on “Physics of Living Systems: from Molecules to Whole Organisms”, Brussels, December 4, 2020.

## 2021

1. P. R. ten Wolde, *“The bacterial cell cycle: an adder or a sizer?”*, seminar in BPPB series, Pittsburgh, 29/10/2021.
2. P. R. ten Wolde, *“Optimal cellular information transmission”*, Annual Dutch Physics Meeting “The Magic of Physics”, Veldhoven, 20/01/2021.
3. M. Berger and P. R. ten Wolde, *“Is size all that matters? Cell cycle regulation in E. coli”*, virtual Physbio conference, Paris, 06/06/2021.

## 2022

1. P. R. ten Wolde, *“Robust Replication Initiation Cycles from Coupled Homeostatic Mechanisms”*, EMBL Course “Physical Biology of the Cell”, Heidelberg, April 25, 2022
2. P. R. ten Wolde, *“Robust Replication Initiation Cycles from Coupled Homeostatic Mechanisms”*, EMBL Course “Physical Biology of the Cell”, Workshop “Models of Noise Propagation in Bacterial Cells”, Utrecht, April 20, 2022
3. J. Poulton, *Optimal prediction in a noisy environment*, invited oral presentation at Mathematical Models in Biology: from Information Theory to Thermodynamics, 2022, Banff International Research Station.

## Academic Teaching 2017-2022

### 2017

1. Pieter Rein ten Wolde, VU – UvA Masters course “Soft Condensed Matter and Biophysics”, together with Peter Schall and Gijs Wuite.

### 2018

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### 2019

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### 2020

1. VU – UvA Masters course “Soft Condensed Matter and Biophysics”, together with Peter Schall and Gijs Wuite.
2. Mareike Berger, Teaching assistant for course at VU Soft condensed matter and Biological Physics, October 2020 - February 2021.

### 2021

1. Pieter Rein ten Wolde, VU – UvA Masters course “Soft Condensed Matter and Biophysics”, together with Peter Schall and Gijs Wuite, 10/2021 – 02/2022.
2. Mareike Berger, Teaching assistant for VU-UvA course “Soft condensed matter and Biological Physics”, 10/2021 – 02/2022.
3. Age Tjalma, Teaching assistant for VU-UvA course “Soft condensed matter and Biological Physics”, 10/2021 – 02/2022.
4. Manuel Reinhardt, Teaching assistant for VU-UvA course “Soft condensed matter and Biological Physics”, 10/2021 – 02/2022.

### 2022

1. Pieter Rein ten Wolde, VU – UvA Masters course “Soft Condensed Matter and Biophysics”, together with Peter Schall and Gijs Wuite, October 2022 - February 2023
2. Age Tjalma, Teaching assistant for VU-UvA course “Soft condensed matter and Biological Physics”, October 2022 - February 2023.
3. Manuel Reinhardt, Teaching assistant for VU-UvA course “Soft condensed matter and Biological Physics”, October 2022 - February 2023.
4. Daan Mulder, Teaching assistant for VU-UvA course “Soft condensed matter and Biological Physics”, October 2022 - February 2023.

## Selected awards & recognitions 2017-2022

### 2019

1. ERC Advanced Grant “Optimal Cellular Prediction” .

### 2020

1. Yao Li, Best presenter award, 4th Young Scientists' Forum on Theoretical Physics and Interdisciplinary Studies, Beijing, China, January 6-8, 2020

### 2021

1. Mareike Berger, “*Is size all that matters?*”, 2<sup>nd</sup> poster prize at Dutch Biophysics, 11/10/2021.

## **2022**

1. Jenny Poulton, Outstanding reviewer award 2022- IOP.

## **Valorization 2017-2022**

1. Freely available GFRD code to simulate reaction-diffusion systems at the particle level.  
( [www.GFRD.org](http://www.GFRD.org))
2. Software: Kinetic Monte-Carlo KaiC simulator (<https://sourceforge.net/projects/kmc-kaic/>) -  
Computer programme for simulating cyanobacterial clock system.