

Non-Equilibrium Statistical Physics

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Motivation

Equilibrium statistical physics

- Well-defined framework
- Fluctuation-response relations for dynamics
- Changes of scale / coarse-graining straightforward

$$Z = \text{Tr } e^{-\beta H} \rightarrow ?$$

Non-equilibrium statistical physics

- Many / most systems of interest **not** at equilibrium
- May take too long to equilibrate: transients matter, **aging**
- Or be **driven** from outside (biological systems), which breaks detailed balance (microscopic reversibility)
- Often no Hamiltonian, system defined purely by **dynamics** (e.g. agent-based models, network dynamics)
- Even this dynamical description may be **unknown**

Research questions

- What general **frameworks** for non-equilibrium are there?
- How do we **change scale** or focus on **subsystems**?
- What **structures** and **behaviours** can non-equilibrium dynamics produce?
- How do we analyse systems with many different **timescales**?
- Can we **learn** dynamical models from data?

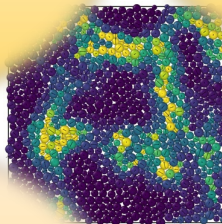
Techniques you can learn

- Path integrals (coherent states, Martin-Siggia-Rose)
- Trajectory thermodynamics, large deviation techniques
- Field-theoretic methods & simulations
- Cavity methods for networks
- Long-time scaling, stochastic simulation, molecular dynamics
- Random matrix theory

Areas for Bachelor projects

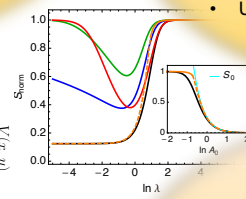
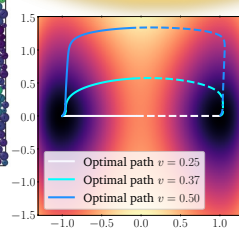
Active matter

- Dynamics of **dense active matter**: Long-range correlations? **Avalanches** of rearrangements? Active **doping**?
- **Non-reciprocal** interactions: Multiple instability length scales in field theory, travelling states, oscillator systems
- Rheology of active matter, **elastoplastic models**
- Active processes in dynamics of **polymer networks**



Dynamics with non-Gaussian noise

- Relevant in bacterial swimmer suspensions, granular gases, ...
- Exact solutions in low noise limit
- Time for crossing potential barrier?
- Is **non-Gaussian noise more efficient**?
- Effects of **activity**, e.g. self-propulsion? Dimensionality effects?

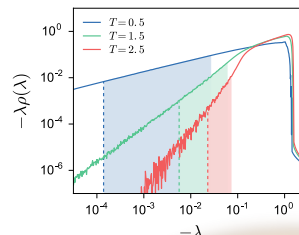
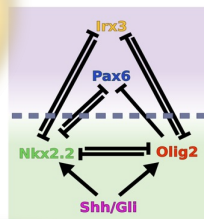


Path-based thermodynamics

- Study dynamical large deviations: trajectories with high current, activity
- Probe by biasing trajectory distribution: **thermodynamics of fluctuating paths**, dynamical phase transitions
- Interaction of driving (bias) and aging?
- Universality classes of aging?

Subnetworks & coarse graining

- Most biological networks too large for intuitive understanding: reduce to subnets
- Gives **memory functions**, can be nonlinear (for multiple fixed points)
- **Machine learning network topology** from memory effects (boundary structure)?
- Coarse-graining larger networks by "milestoning"?

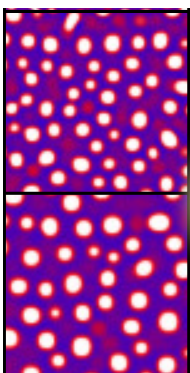


Dynamics on networks

- Simple picture of amorphous material: hopping on **network of metastable states**
- Non-eq dynamics: competition of energetic (barriers) & entropic (connectivity) effects
- Flexible model: energy-connectivity correlations (local minima, saddles), ...
- Analysis by **random matrix theory**, links to many-body localization, ...

Phase separation in complex mixtures

- Relevant in soft matter (colloids), biology (cytoplasm, lipid membranes)
- How do particle species redistribute between phases? Effect of crowding?
- Non-eq. **structures by slow kinetics**?
- Growth of **competing phases**?



Amorphous matter & rheology

- Amorphous materials (glass, sand, emulsions, biopolymers) **trapped in metastable states**
- Effects of disorder & heterogeneity on dynamics & mechanical behaviour (rheology)?
- Important also for **biophysics**, e.g. in **cytoskeletal rheology**

