Out of Equilibrium Statistical Physics (20h)

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This lecture addresses a wide range of intrinsically out of equilibrium systems, introducing their experimental realizations, and the theoretical and numerical methods to understand them. These systems encompass all imaginable temporal and spatial scales ranging from the microscopic (phase separation of semiconducting impurities in a glass..) to the cosmological scales (aggregation of galaxy clusters)!

1 Introduction (∼5 hours)

1.1 Physical examples: introductiong to scale invariance

- Non conserved systems: magnetic systems (Ising, XY (liquid crystals...), soap froth (Potts), magnetic bubbles...).
- Conserved systems : binary mixing, Langmuir films,...
- Aggregation phenomena (polystyrene bids at the surface of water, galaxies,...); monodispersity and polydispersity; introduction to reaction-diffusion systems like $A+A \to 0$, $A + A \to A$, $A + B \to 0$.
- Dynamical phase transitions (DP, PC; link to reaction-diffusion systems).
- Other examples of out equilibrium systems: interface dynamics, turbulence, road traffic, finance, game theory (dynamics of poker tournament...), epidemiology, forest fires, river models...
- In all these examples, the notion of scale invariance is illustrated visually (experimental pictures and data) and quantitatively (through the introduction of spatiotemporal correlation functions).

1.2 General introduction to the dynamics

- Master equation, detailed balance condition,...
- Monte Carlo algorithms

2 Non conserved systems: the Ising model (∼6 hours)

The out of equilibrium dynamics of the Ising model and its experimental application are extensively studied as a paradigm of non conserved systems.

2.1 Glauber dynamics in $d = 1$ (master equation, correlation functions,...)

2.2 Glauber dynamics in $d > 1$: mean field theory

2.3 Model A (T=0)

- Equivalence to the Ising model
- Approximate solution: large N, OJK, larde d methods...

3 Conserved systems (∼3 hours)

This section is devoted to the study of conserved systems, and in particular to phase separation.

3.1 Lifschitz-Slyosov theory

3.2 Spin exchange dynamics in the Ising model

3.3 Brief introduction to Model B (T=0)

4 Reaction-Aggregation-Diffusion models (∼6 hours)

This section introduces the basic tools to study reaction-diffusion systems and their application to a very wide range of domains (epidemy/opinion spreading, road traffic, aggregation...)

4.1 Models in $d = 1$

- $A + A \to A$: exact solution in $d = 1$ and mean field theory; river model.
- $A + A \to 0$: exact solution in $d = 1$ and mean field theory; link with the Glauber dynamics of the Ising model.
- $A + B \to 0$.
- Dynamical phase transitions ; the exemple of directed percolation (mean field theory).

4.2 Schmoluchowski equation

- Mean field equation and effective aggregation kernel
- Kernel classification: monodispersity and polydispersity.

Examples of experimental systems treated in this lecture

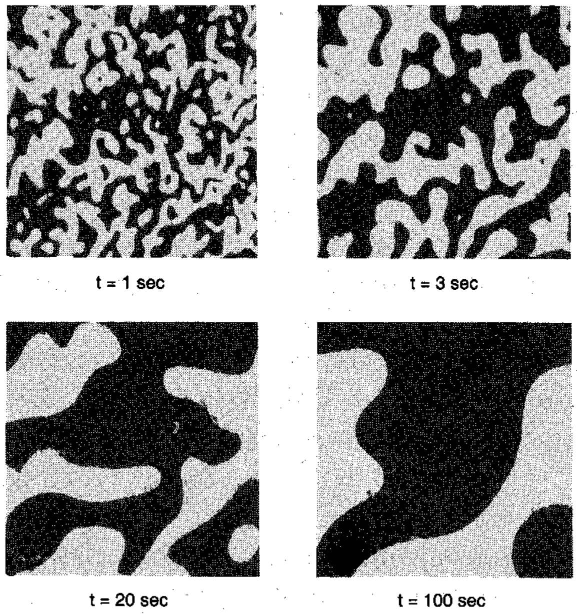

Figure 1: *4 snapshots of a thin nematic liquid crystal quenched in an electric field (Yurke, Mason et al.), leading to a dynamics in the universality class of the* $d = 2$ *Ising model. The domains grow on a scale* $L(t) \sim t^{1/2}$.

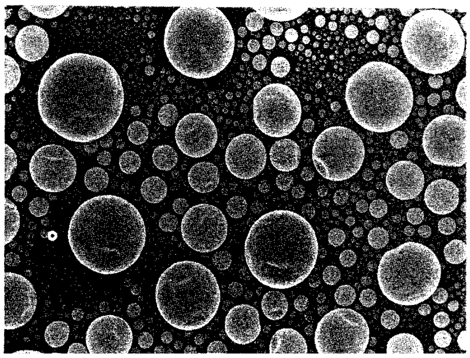

Figure 2: *Electronic microscopy picture of the condensation of iron droplets (from Family et Meakin, 1988). The polydispersity of the droplet sizes is clearly apparent and can be understood within Schmoluchowski's mean field approach.*

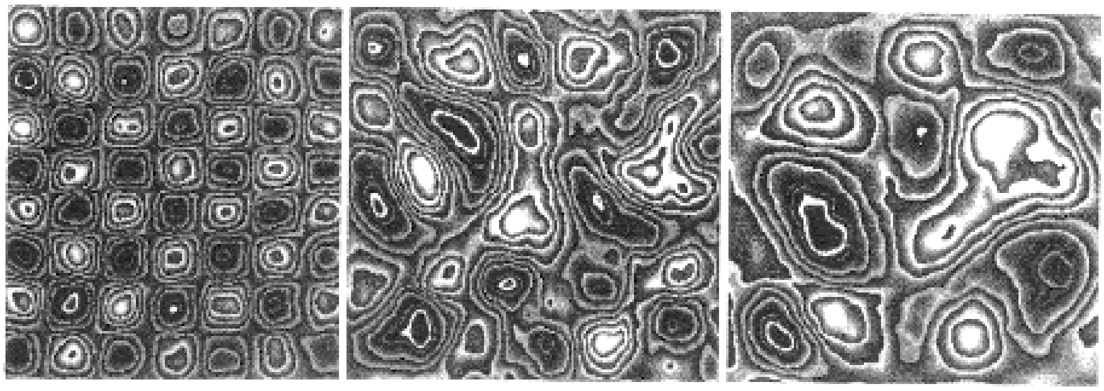

Figure 3: *Decaying turbulence of a thin laye of water (Tabeling et al.).*

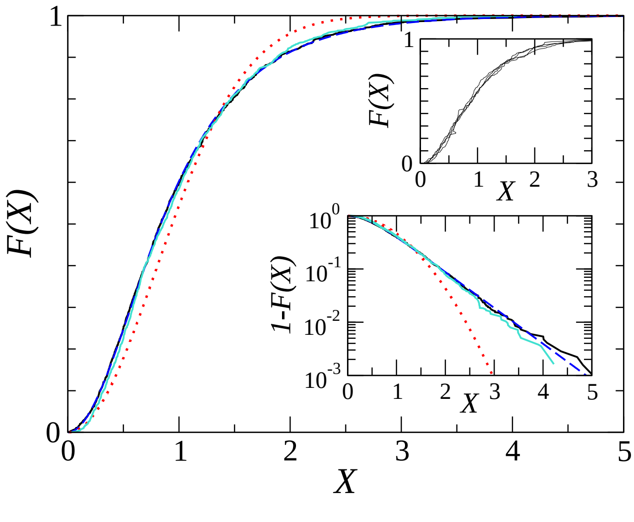

Figure 4: *At any moment of a poker tournament (not too close to its beginning, when all players start with the same amount of chips), we plot the time-independent fraction $F(X)$ of players who have less chips than a given player having X times the average fortune (stack). Comparison between actual data (World Poker Tour & Internet tournaments) and a theoretical model using standard tools of out of equilibrium statistical physics.*