

New Trends in the Mathematical and Physical Aspects of Magnetism

16-20 June 2025, Strasbourg

	Monday 16 June	Tuesday 17 June	Wednesday 18 June	Thursday 19 June	Friday 20 June
9:00-10:30		Mini course M. Ruggeri	Mini course M. Ruggeri	Mini course R. Hertel	Mini course R. Hertel
10:30-10:50		Coffee break			
10:50-11:50		C. Jourdana	B. Barton-Singer	P. Gravejat	D. Spirn
11:50-12:50		D. Cobb	R. Roussel	E. Gussetti	
12:50-15:00	Lunch				
15:00-16:00	L. Desplat	L. Bronsard		B. Deng	
16:00-16:30	Coffee break			Posters session	
16:30-17:30	D. Stantejsky	C. Melcher			
19:30-21:30		Dinner			

Mini courses:

Riccardo Hertel (IPCMS, Université de Strasbourg) **Nanomagnetism in Three Dimensions: Tools, Textures, and Dynamics** (*Thursday 19 June, 9:00 and Friday 20 June, 9:00*)

Simulating magnetic textures and their dynamics is a cornerstone of modern magnetism research. While micromagnetic methods are well-established, the rise of three-dimensional nanomagnetic systems introduces new complexities that demand advanced tools. Finite-element simulations are uniquely suited to capture geometric and topological effects inherent in 3D nanostructures. In this mini-lecture, I will present recent research that leverages finite-element micromagnetics to explore the structure and dynamics of complex 3D magnetic textures. Particular focus will be given to frequency-domain methods for efficiently modeling high-frequency oscillatory dynamics in these systems.

Michele Ruggeri (University of Bologna) **Structure-preserving numerical methods in micromagnetics** (*Tuesday 17 June, 9:00 and Wednesday 18 June, 9:00*)

A numerical method for approximating solutions to partial differential equations (PDEs) is called structure-preserving if it is designed to ensure that certain properties or features of the continuous

model (e.g., constraints on solutions, conserved quantities, etc.) are retained, in a certain sense, at the discrete level.

In this mini-course, we give an overview of structure-preserving numerical methods to approximate the PDEs arising in micromagnetics, the continuum theory of (ferro)magnetic materials. We discuss mathematically sound numerical schemes and their analysis, emphasizing how the discretizations in space (for which we will use the finite element method) and in time should be designed in order to guarantee that the approximate solutions have the features of the continuous problem (such as the unit-length constraint on the magnetization or the dissipative energy law characterizing its dynamics).

Talks:

Bruno Barton-Singer (IACM FORTH) **Explicit static and dynamical solutions in chiral magnets without Heisenberg interaction** (*Wednesday 18 June, 10h50*)

In the study of chiral magnets through the continuum model with Heisenberg, Dzyaloshinskii-Moriya and potential terms, some explicit energy minimizers are known at specially tuned couplings. Trivially, when DMI and potential vanish, we have solutions from the $O(3)$ sigma model, and less trivially a certain balance of DMI, Zeeman interaction and easy-plane anisotropy leads to a related moduli space of explicit minimizers. Although specialised, these explicit minimizers can be a starting point for further investigation of the chiral magnet at more physically realistic ranges of couplings.

In this talk I discuss a third case of vanishing Heisenberg interaction, with the potential any axisymmetric one, where we not only find infinite-dimensional spaces of static solutions but also infinite-dimensional spaces of dynamic solutions (to the conservative Landau-Lifshitz equation), including breathing and collapsing skyrmions (arxiv:2412.20336). I will review the derivation of these solutions through analogy to fluid dynamics, explore the phase diagram of solutions for different axisymmetric potentials, and discuss the potential of these solutions to help us find periodic solutions and singularity formation away from this limit.

Lia Bronsard (Université McMaster) **Boundary defects in Liquid Crystal** (*Tuesday 17 June, 15h00*)

We study the effect of "weak" and "strong" boundary conditions on the location and type of defects observed in a Landau de Gennes thin-film model for liquid crystals. We study both the minimizers of the associated Ginzburg-Landau energy as well as the Gamma limit when the correlation length tends to zero. A-priori estimates in case splay and bend moduli are included in the energy will also be presented. Finally, results in the case of the 3D Landau-de Gennes model with a magnetic field will be presented. These represent joint works with S. Alama, A. Colinet, D. Louizos, D. Stantejsky and L. van Brussel.

Dimitri Cobb (Universität Bonn) **Magnetic Relaxation: Effective Dynamics and Blowup in a Simple(r) Model** (*Tuesday 17 June, 11h50*)

This talk is concerned with describing the dynamics of a dilute plasma which has a very low electrical resistance $\mu = \varepsilon$ and a comparatively large viscosity, e.g. the Solar corona, Solar wind, or some

laboratory plasmas. In this situation, has been conjectured by physicists Woltjer (1958) and Taylor (1974-1986) that the fluid undergoes a two stage dynamic.

In a first stage, on a time scale $t \sim \log(\frac{1}{\varepsilon})$, the large viscosity drives the plasma to a force-free state, where the Laplace force acting on the fluid is small $j \times b = O(\varepsilon)$. In a second stage of evolution, on a time scale $t \sim \frac{1}{\varepsilon}$, the resistivity drives the evolution.

This conjecture has proven very very difficult to verify, by theoretical, numerical or even experimental arguments. By working on a 1D magneto-Stokes model, we will show rigorously that a two stage process does indeed take place in that setting. Moreover, we derive effective equations for the dynamics of the resistivity driven stage, and prove that the solutions of these equations may blowup in finite time.

This is joint work with Daniel Sánchez-Simón del Pino and Juan J. L. Velázquez (Universität Bonn).

Bin Deng (Institut de Mathématiques de Toulouse) **The conformal limit for bimerons in easy-plane chiral magnets** (Thursday 19 June, 15h00)

We study minimizers $m : \mathbb{R}^2 \rightarrow S^2$ of the energy functional

$$E_\sigma(m) = \int_{\mathbb{R}^2} \left(\frac{1}{2} |\nabla m|^2 + \sigma^2 m \cdot \nabla \times m + \sigma^2 m_3^2 \right) dx ,$$

for $0 < \sigma \ll 1$, with prescribed topological degree

$$Q(m) = \frac{1}{4\pi} \int_{\mathbb{R}^2} m \cdot \partial_1 m \times \partial_2 m \, dx = \pm 1 .$$

This model arises in thin ferromagnetic films with Dzyaloshinskii-Moriya interaction and easy-plane anisotropy, where these minimizers represent *bimeron* configurations. We prove their existence, and describe them precisely as perturbations of specific Möbius maps: we establish in particular that they are localized at scale of order $1/|\ln \sigma^2|$. This is a joint work with Radu Ignat and Xavier Lamy.

Louise Desplat (CNRS/SPINTEC) **Entropic effects and solitons in thermally activated magnetic transitions** (Monday 16 June, 15h00)

We investigate the mechanisms that govern the thermal stability of two technologically relevant systems: magnetic skyrmions, envisioned as information carriers in novel spintronics devices, and nanopillars, as used in magnetic tunnel junctions (MTJs) for data storage, and currently envisaged as stochastic p-bits for unconventional computing schemes. To do so, we combine the Kramers framework and a path sampling scheme in atomistic simulations.

In skyrmions, we find that their internal modes of deformation lead to a stabilizing entropic contribution to the Arrhenius prefactor. On the other hand, in nanopillars, the domain-wall mediated magnetization reversal yields a large, destabilizing entropic contribution to the prefactor, which scales like an exponential of the activation energy. Our simulations show good agreement with experimental measurements carried out on 50 nm diameter perpendicular MTJs, with mean dwell times down to the nanosecond. We explain this observation with very low Arrhenius prefactors in the femtosecond range.

In both cases, we challenge the common assumption of a constant, 1 ns attempt time in these systems, and underline the importance of the activation entropy in transitions involving solitonic textures.

Philippe Gravejat (CY Cergy Paris Université) **Solitonic vortices for the Gross-Pitaevskii equation in a strip** (*Thursday 19 June, 10h50*)

The talk deals with the Gross-Pitaevskii equation in a two-dimensional strip. This equation has explicit travelling wave solutions on the line that are called dark solitons and that remain travelling wave solutions on the strip. A natural question is to ask to what extent it is possible to construct true two-dimensional travelling waves in the strip.

A first answer will be given by a minimization procedure under constraint, but only when the width of the strip is large enough. Next a perturbative approach will provide a rigorous construction of two-dimensional stationary solutions with a fixed number of vortices, that are called solitonic vortices and were first described by numerical simulations and physical experiments in the context of the Bose-Einstein condensation.

This is joint work with André de Laire (University of Lille) and Didier Smets (Sorbonne University) on the one hand, and with Amandine Aftalion (CNRS and University Paris Saclay) and Étienne Sandier (Paris-East Créteil University) on the other hand.

Emanuela Gussetti (Universität Bielefeld) **On the long time behaviour of a stochastic Landau-Lifschitz-Gilbert equation in one dimension and applications to the Schrödinger map equation.** (*Thursday 19 June, 11h50*)

In this talk I will present a result concerning the existence of an ergodic invariant measure in $H^1(D, \mathbb{R}^3) \cap L^2(D, \mathbb{S}^2)$ for the stochastic Landau-Lifschitz-Gilbert equation (sLLGe) on a one dimensional interval, with null Neumann boundary conditions. The conclusion is achieved by employing the classical Krylov-Bogoliubov theorem and using techniques from rough path theory. We use the stationary solutions to the sLLGe to establish the existence of statistical stationary solutions to the Schrödinger map equation and to the Binormal curvature flow, by means of the fluctuation-dissipation method.

The talk is based on <https://arxiv.org/abs/2208.02136> and on <https://arxiv.org/abs/2501.16499>.

Clément Jourdana (Université Grenoble Alpes) **Numerical schemes for a Maxwell - complex matter coupling** (*Tuesday 17 June, 10h50*)

We are interested in the numerical study of laser-matter interaction for quantum microstructures inserted inside a dispersive material. The objective is to describe the collective behavior that can result in such quantum materials. For that, we want to have access to the time evolution of the matrix density of the quantum objects as well as that of the classical electromagnetic field. It leads to a coupling of Maxwell equations with Bloch equations and Debye/Lorentz models. We will see there are many theoretically equivalent ways to write the system depending on the variables involved but some formulations are more appropriate for efficient computations. We will consider a Finite Difference -

Time Domain (FD-TD) discretization with appropriate staggered grids in space and time. Exploring different strategies, we will identify those which preserve physical properties of interest at the discrete level while decoupling the equations.

This is a joint work with Brigitte Bidegaray-Fesquet.

Christof Melcher (RWTH Aachen University) **Skyrmions and emergent spin orbit coupling in a spherical magnet** (*Tuesday 17 June, 16h30*)

We discuss solitonic field configurations on a spherical magnet. Exploiting the Hamiltonian structure and concepts of angular momentum, we present a new family of localized solutions to the Landau-Lifshitz equation that are topologically distinct from the ground state and break rotational symmetry. The approach illustrates emergent spin-orbit coupling arising from the loss of individual rotational invariance in spin and coordinate space---a common feature of condensed matter systems with topological phases.

Robin Roussel (Institut de Mathématiques de Jussieu-Paris Rive Gauche) **Shape optimization approach for magnetic confinement** (*Wednesday 18 June, 11h50*)

In this talk, I will introduce a shape optimization approach for magnetic confinement in stellarator type fusion reactors. I will begin by explaining some basic notions of magnetic confinement for fusion in order to introduce stellarators and exhibit key differences with the better known tokamak design. Afterward, I will introduce the key notion of harmonic fields and explain how this object allows us to consider magnetic confinement in stellarators using a shape optimization approach. In the rest of the talk, I will focus on two applications of this approach. First, I will introduce the shape optimization problem for the helicity of harmonic fields and present a numerical scheme to compute and optimize this quantity. Finally, I will explain how this shape optimization approach allows us to study Poincaré maps of harmonic fields with respect to the domain geometry.

Daniel Spirn (University of Minnesota) **Frame fields coupled to applied magnetic fields** (*Friday 20 June, 10h50*)

Frame fields are locally-defined configurations on S^2 that are invariant with respect to a rotation group (for example, the cubic or tetrahedral group), and they are useful in describing nematic liquid crystals or ordered material with nonstandard symmetries. For example, tetrahedral frame fields can be used to describe certain phases in bent-core nematic liquid crystals. In this talk I will discuss methods for generating these fields using higher order tensors and harmonic map relaxations with specific nonlinear penalty functions. In particular the relaxation procedure reliably generates frame fields on arbitrary Lipschitz domains, except on co-dimension 2 sets. I will also describe how to couple such problems to applied magnetic fields. This is a joint work with Dmitry Golovaty, Matthias Kurzke, and Alberto Montero.

Dominik Stantejsky (IECL/Université de Lorraine) **Asymptotic shape of isolated magnetic domains** (*Monday 16 June, 16h30*)

In this talk, I will present a result on the asymptotic energy-minimizing shape of an isolated magnetized domain Ω in both two- and three-dimensional settings. The energy consists of two terms: the first penalizes the interfacial area of the domain, while the second represents the energy of the corresponding magnetostatic field. Here, the magnetostatic potential h_Ω is determined by $\Delta h_\Omega = \partial_1 \chi_\Omega$, corresponding to uniform magnetization within the domain. In the macroscopic regime $|\Omega| \rightarrow \infty$, we derive compactness and Γ -limit which is formulated in terms of the cross-sectional area of the anisotropically rescaled configuration. I will then explain how to find the solutions for the limit problems. This talk is based on a joint work with Hans Knüpfer.

Posters:

- **Jordan Berthoumieu** (CY Cergy Paris Université) **Orbital stability of a chain of dark solitons for general nonintegrable Schrödinger equations with non-zero condition at infinity**
- **Dean Louizos** (University of Minnesota) **Asymptotics for Minimizers of Landau-de Gennes with a Magnetic Field and Tangential Anchoring**
- **Abdelmajid Moustajab** (Institut de Mathématiques de Toulouse) **Domain walls in a Ginzburg-Landau type model for curl-free vector fields**
- **Hywel Normington** (University of Strathclyde) **A decoupled, convergent and fully linear algorithm for the Landau–Lifshitz–Gilbert equation with magnetoelastic effects**
- **Soré Soumaila** (Sorbonne Université) **Numerical study and decomposition of magnetic nanowire networks**
- **Lauriane Turelier** (IRMA, Université de Strasbourg) **Ferromagnetism and domain walls in nanowires**

Lunches and dinner:

- Lunches will be taken at the Restaurant Administratif Agricas (Entry from Cité administrative Gaujot, 14 Rue du Maréchal Juin, 67000 Strasbourg).
- The conference dinner is scheduled for Tuesday evening from 7:30 pm at the “Caveau du Gurtlerhof” in front of the cathedral (13 Place de la Cathédrale)