

## PhD Fellowship — 3 years (doctoral contract)

### Thermal transport in magnetic particulate media: from the nanoscale to the macroscale

Project | CNRS 80|PRIME 2026 (MITI)

*We invite motivated candidates to join us in an ambitious CNRS-funded interdisciplinary project at the crossroads of theoretical nanomagnetism, condensed-matter physics, and thermal engineering. Build the first rigorous multi-scale theory of heat transport in magnetic nanocomposites, in close collaboration with state-of-the-art experimental groups.*

#### Supervision and partner institutions

- **H. Kachkachi** (PhD supervisor), Université de Perpignan Via Domitia (UPVD) / PROMES-CNRS (UPR8521)
- **R. Bastardis** and **F. Vernay**, UPVD / PROMES-CNRS
- **F. Tournus**, **V. Giordano**, and **S. Pailhes**, Institut Lumière Matière (ILM, UMR5306), Université de Lyon I

This is a theoretical PhD thesis. The candidate will be based at PROMES and will make regular scientific visits to ILM, where the experiments will be carried out.

#### Scientific context and motivation

In this project, we investigate heat transport in nanostructured particulate media, exemplified by assemblies of magnetic nanoparticles (MNPs) embedded in metallic or semiconductor matrices. This topic lies at the intersection of condensed-matter physics, nanomagnetism, and thermal engineering. Its control is of direct societal relevance. In **cancer hyperthermia**, MNPs excited by an alternating magnetic field act as localized heat sources whose spatial and temporal temperature profiles must be controlled with sub-degree precision. In **power electronics and microelectronics**, MNP-loaded composite matrices are used as thermal interface materials for heat dissipation in processors, power LEDs, and EV batteries. In **thermoelectrics**, dilute magnetic semiconductor nanocomposites are of particular interest because magnetic dopants interact indirectly through conduction electrons via the RKKY mechanism, which strongly influences charge transport and thermoelectric properties such as the Seebeck and Peltier coefficients. Recent work within the team has also focused on understanding how magnetic nanoparticles affect thermal conductivity. The overall objective is to optimize thermoelectric performance and improve heat-to-electricity conversion efficiency.

Despite this importance, a comprehensive theoretical framework is largely missing. Most of the existing models rely on effective-medium approaches (Maxwell-Garnett, Bruggeman) that average over the discrete nanostructure and thus fail to capture nanoscale “hot-spot” physics and transient dynamics. The present project addresses this gap through a bottom-up multi-scale theory validated experimentally on two model systems: **Co@Cu** (metallic matrix, electron-dominated transport, ideal for testing RKKY effects) and **Co@Ge** (semiconductor matrix, phonon-dominated transport, strong thermoelectric coupling).

#### Key scientific challenges and objectives

- **Multi-scale incoherence.** No robust analytical and numerical framework currently bridges microscopic particle parameters (anisotropy, volume, interactions) to macroscopic thermal conductivity without losing information on local gradients. The project will generalise our Green’s-function model for 1D chains to full 3D nanoparticle assemblies, yielding an analytical temperature field  $T(\mathbf{r}, t)$  driven by each particle’s dissipated power  $P_i(T)$ .
- **Long-range magnetic interactions.** In metallic and semiconductor matrices, long-range dipolar and oscillatory RKKY exchange interactions profoundly modify the collective magnetic state, the specific absorption rate (SAR), and hence the heat sources themselves—a feedback loop not captured by standard thermal models.
- **Kapitza interface resistance.** Spin-lattice energy transfer at the NP/matrix interface is limited by phonon impedance mismatch. The project will attempt to develop microscopic interface phonon models replacing phenomenological fitting parameters with physically grounded conductance values.

#### PhD work plan (36 months)

- **Year 1.** Literature review; familiarisation with spin-dynamics codes (LLG); extension of the Green’s-function heat model to 3D assemblies; implementation of anisotropic RKKY interactions in the stochastic LLG code; first visit to ILM to understand synthesis and measurement constraints.
- **Year 2.** Parameterisation of the multi-scale model with real structural and magnetic inputs; first quantitative comparison between predicted and measured thermal conductivity  $\kappa(H, T)$  via thermoreflectance.
- **Year 3.** Systematic numerical exploration of parameter space; construction of “thermal phase diagrams” mapping the blocking-transition signature in thermal transport; manuscript writing and publication of results.

## Methods/Tools

Statistical physics; theory of magnetism; analytical Green's-function formalism for heat transport in heterogeneous media; stochastic LLG equation; linear and nonlinear response theory (SAR and dynamic susceptibility); microscopic phonon interface modelling; numerical simulations (Python / C++).

## Required profile

We seek a strong background in condensed-matter theoretical physics (Master's degree or equivalent); solid analytical skills and demonstrable experience with numerical modelling (Python and/or C++); familiarity with statistical physics and/or magnetism; genuine interest in multiscale approaches and theory-experiment interplay.

## Position details

- **Duration:** 3 years (CNRS doctoral contract), starting **1st October 2026**.
- **Location:** PROMES-CNRS laboratory, Université de Perpignan Via Domitia, Perpignan, France; regular scientific missions to ILM, Université de Lyon I, Lyon, France.
- **Stipend:** Standard CNRS doctoral contract ( $\sim$  €2300 gross per month), in accordance with current French regulations.
- **Visa support:** For non-EU/EEA candidates, the laboratory will provide the official hosting agreement (convention d'accueil) required for the visa application.
- **Working language:** **English** (knowledge of French is not required but is an asset for daily life).

## Application

Please send the following documents as a **single PDF file** to Prof. H. Kachkachi at hamid.kachkachi@univ-perp.fr, with the subject line [NanoMagHeat PhD 2026] - **Surname, First name:**

- Detailed Curriculum Vitae (including list of any publications or reports)
- Motivation letter (max. 1 page), explaining your fit with the project
- Academic transcripts (Bachelor's and Master's, or equivalent, grades)
- Names and contact details of two referees willing to provide a recommendation

**Application deadline: 30 June 2026.** Early applications are strongly encouraged and will be reviewed on a rolling basis.

**N.B.: Only applications whose profile closely matches the required scientific skills will receive a full review.**

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