PhD Opportunity

Design of functional properties in random many-particle materials by means of cooperative electromagnetic scattering

General information.

- **Research lab:** CEMHTI – CNRS, Orléans, France.
- **Supervisors:** Cédric Blanchard, Olivier Rozenbaum.
- **Contract:** 36 months (full-time).
- **Salary:** 2135€/month.
- **Starting:** Sept.-Nov. 2024 (possibility of realizing a remunerated Master Internship before).

Summary. This thesis will allow the candidate to acquire expertise in the numerical modeling of electromagnetic waves in inhomogeneous materials. It aims to understand how textural parameters – e.g., size, shape or constitution of the inhomogeneities – can be used to control and manipulate light/matter interactions in complex media. Based on the comprehension of the mechanisms at play, the PhD student will work on the conception of new materials useful to the energy transition, in particular daytime radiative cooling and thermophotovoltaics.

The candidate. He/she will have a good undergraduate degree in a relevant subject (physics, mathematics/physics) with a solid background in electromagnetism, optics and/or mathematics, and must have completed a Master's degree before the beginning of the thesis.

Context and originality. Prompted by the versatility of the optical properties offered by inhomogeneous media, laboratories and companies are showing a growing interest in technologies based on composite materials. In Fig. 1 for instance, a material made up of randomly distributed particles can be observed. Naturally, its electromagnetic response is driven by a variety of parameters such as the arrangement of the particles, their size distributions, their shape, their volume fraction, their constitution, etc. The resulting texture can be geometrically complex and, therefore, its thermo-optical properties difficult to calculate. Because of this complexity, it is usual to model the interactions that occur in inhomogeneous materials by making hypotheses (e.g., independent scattering, effective medium, geometrical optics, etc.) which often turn out to be questionable. These approximations limit the comprehension of the mechanisms involved in light/matter interactions, and thus prevent the design of materials relevant to the development of new energy transition technologies.

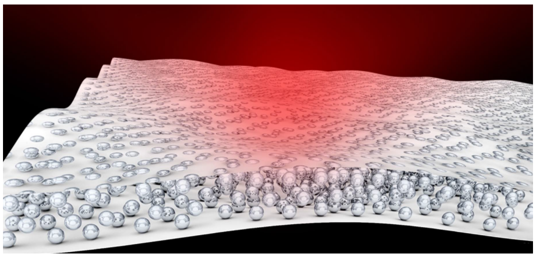
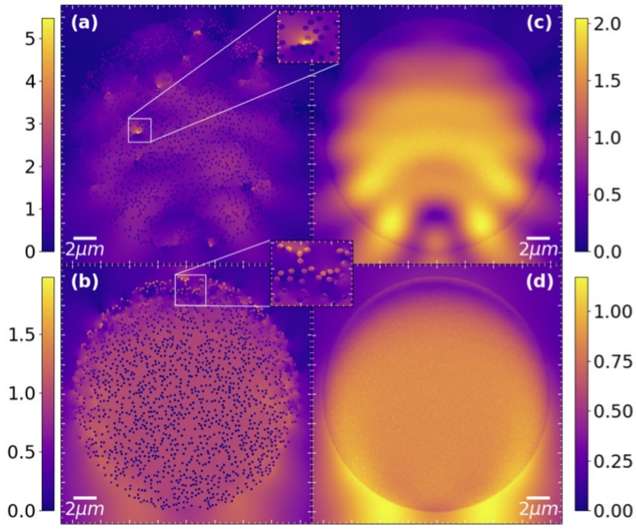


Figure 1: Schematic of randomly distributed microsphere inclusions for radiative cooling application. From *Y. Zhai et al. Sciences (355) 2017.*

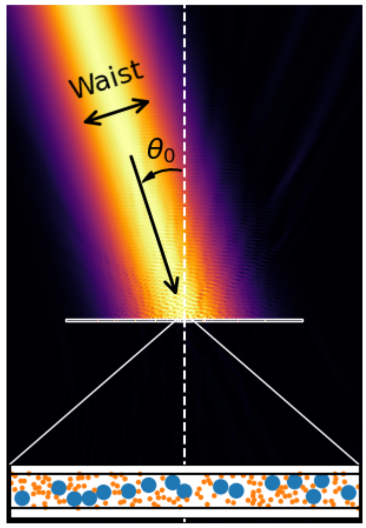
> The originality of this thesis lies in the full-wave simulations of many-particle systems with essentially no approximation. The goals are to define the role of the textural parameters on the electromagnetic response and identify the degree to which these parameters may be used as a way of control to implement competitive functional properties.

Objectives and realizations. We will concentrate our interest in random particulate media, such as that showed in Fig. 1. The different compositions will be treated by numerically solving

Maxwell equations. To do so, the PhD student will benefit from in-house numerical codes, which are based on the multipolar expansion of the electromagnetic fields – see Fig. 2 for examples of simulated structures.



(a) Magnetic field in disordered structures: (a,b) individual configurations, (c,d) mean values. From *T. Guerra, [...], C. Blanchard. Part. Part. Syst. Char. (39) 2022.*



(b) Perfect absorption of a beam incident on a particulate material. From *T. Guerra, [...],C. Blanchard. Phys. Rev. B, 107, L220202, 2023.*

Figure 2: Examples performed with our in-house numerical tools.

The thesis will be split into two axes, (i) the exploration of the mechanisms linking textural disorder and propagation of waves in inhomogeneous materials, and (ii) the exploration of new concepts for the design of materials with valuable functional properties. The two axes will differ in their exploration approaches, the first having a theoretical character with the numerical simulation of idealized materials. The second will be more applicative, as the focus will be put on real structures.

➫ Axis (i) is concerned with theoretical configurations where resonant interactions between the particles are artificially enhanced by considering complex frequencies. The mathematical poles of the scattering matrix (relating the incident and scattered radiations) in the complex plane will be investigated, providing substantial insight into the degree to which cooperative effects can govern or dominate the materials response.

➫ In Axis (ii), the objective is to numerically engineer new compounds able to reproduce a targeted functionality – e.g., an absorption/emission peak, typically in the near infrared for thermophotovoltaic applications. We will take advantage of investigations we recently realized showing the possibility of achieving near perfect absorption with nanoparticle suspensions (see Fig. 2(b)).

Facilities and equipment. The CEMHTI lab offers excellent facilities for numerical simulation; including three computing servers having 512GB, 1.5TB, and 4.5TB of RAM.

How to apply? If your scientific interests match this description and you want to make an impact in the theory of light/matter interaction and optical properties design, please send the following documents to cedric.blanchard@cnrs-orleans.fr:

(i) A curriculum Vitae. (ii) A cover letter. (iii) A letter of recommendation, from a professor for example. (iv) Academic marks.