***SPHYNX*, CEA Orme des Merisiers, Service de Physique de l'Etat Condensé**
http://iramis.cea.fr/spec/SPHYNX/
LIONS, CEA Saclay, Nanosciences et Innovation pour les Matériaux, la Biomédecine et l'Énergie
http://iramis.cea.fr/nimbe/lions/

INTERNSHIP POSITION

INFLUENCE OF CHEMICAL COMPOSITION ON THE MECHANICAL PROPERTIES OF 3D PRINTED MATERIALS

Reducing the density of materials is a promising route to reduce our energy footprint. One solution is to replace massive materials with lattice materials formed by carefully arranged micro-beams. Among them, random architectural structures inspired by bone structure have the best assets with isotropic mechanical response and unprecedented performance in terms of elastic modulus to density ratio while meeting the challenges of the circular economy. These metamaterials are manufactured by 3D printing and, of all the manufacturing technologies available, printing by UV polymerisation of organic liquid resin is the most promising.

These resins can be loaded with nanoparticles to modulate the properties of the resulting metamaterials and enhance their mechanical strength. In this context, a variety of resins has been generated, but the mechanical performance of the printed material has not yet been evaluated. In addition, many printing parameters are also known to affect the final properties. Thus, the characterization of the mechanical properties of these resins is necessary to control the performance of these new materials

The objective of the internship is to evaluate by Dynamic Mechanical Analysis (DMA) the viscoelastic properties such as Young's modulus, shear modulus, compressional and shear viscosity, and glass transition temperature of the new resins formulated in the laboratory. The aim is to establish the link between the formulation and the mechanical properties. The internship will be divided into two parts: 1) the study of mechanical properties as a function of different formulations; 2) the study of mechanical properties as a function of different printing parameters.

This internship project is experimental and will be carried out at the *Service de Physique de l'Etat Condensé* (SPEC) of the CEA Saclay of the University of Paris-Saclay, located at the Orme des Merisiers centre, 91191 Gif sur Yvette, France, in collaboration with the *Nanosciences and Innovation for Materials, Biomedicine and Energy* (NIMBE) laboratory of the CEA Saclay and the *Pôle Universitaire Leonard de Vinci* (France), and will involve researchers of different expertise. The successful candidate will have to integrate into this consortium and interact with the whole. In return, he/she will benefit from a highly multidisciplinary framework: additive manufacturing, physics, chemistry and mechanics of polymers, and mechanics of continuous media and experimental mechanics. A strong taste for experimentation and manipulation is also required.

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PROPOSITION DE STAGE 2022/2023

TURBULENT FLOWS BEYOND THE KOLMOGOROV BARRIER THROUGH SMALL SCALE 4D-PTV MEASUREMENTS

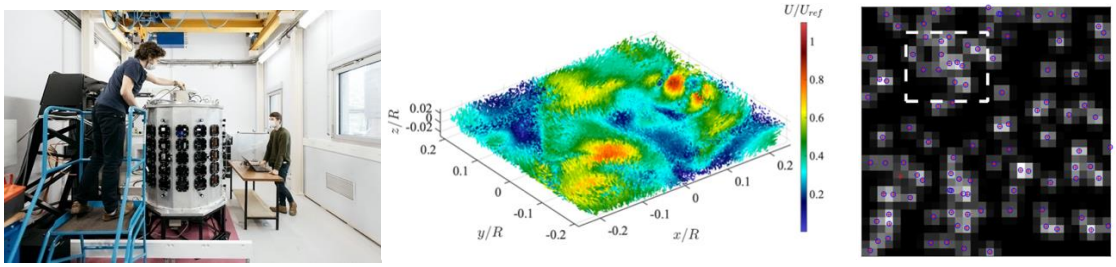

Figure 1: (Left): The Giant Von Karman facility. (Middle) : 4D-PTV measurements : particle trajectories, color coded by their velocities, measured at the center of a Von Karman flow. (Right) : Identification of particles in highly dense image

Viscous flows are ubiquitous in nature and impact many areas of physics, engineering sciences, astrophysics, geophysics, or aeronautics. If you stir strongly enough a viscous flow, it becomes turbulent and displays vortices of various sizes. Typical sizes and organization of such structures can be described by a power-law energy spectrum characteristic of a scale-to-scale energy transfer, by which all the energy injected at large scale is transferred and dissipated at small scale. The typical scale for energy dissipation is called the Kolmogorov scale η and marks the transition between the power law behavior and a steep exponential decay in the wavenumber range. Therefore, scales smaller than η contain a negligible fraction of the kinetic energy. Because of that, it is often thought that scales below η are irrelevant and that "nothing interesting is happening below". Recent theoretical and experimental advances [Dubrulle 2019] however suggest that many interesting phenomena do happen below η and this may impact the validity of Navier-Stokes equations (NSE).

Indeed, below η, energy fluxes can still happen and could create a non-viscous dissipation totally independent of the fluid viscosity. This would constitute dissipative singularities which existence could be the origin of the well-known dissipative anomaly in turbulent flows. Following theoretical work of [Betchov 1957] and confirmed by numerical simulations [Eyink 2022], thermal noise from the molecular agitation of the fluid could compete with macroscopic motions at scales below η. More generally, we may think that the whole structure of small-scale turbulence is affected by thermal fluctuations that may impact or impede the development of quasi-singularities.

In the BANG project, we explore the validity of the NSE as a fluid model by studying the phenomena occurring below the Kolmogorov scale, using multi-scale tools and advanced visualization techniques, *ie* 4D Particle Tracking Velocimetry (4D-PTV), in a dedicated large turbulent experiment called Giant Von Karman (GVK) built at CEA (see Figure 1). To access small scales, we plan to carry out several 4D-PTV measurement campaigns in GVK, using high particle densities as well as unconventional optical conditions with telecentric lenses allowing for a magnification of 2 tested at LMFL. Under such optical conditions, the most difficult step 4D-PTV algorithms must face resides in the image particle detection.

This internship's aim is to develop and assess particle detection methods in order to increase the spatial resolution. The intern will build on the different algorithms and tools developed at ONERA then process and analyze the experimental image data from GVK. At first, he/she will be in charge of creating a preliminary benchmark scenario and datasets that mimics the main features of the experimental setup. This scenario will be the basis for preliminary tuning of the processing tools before the intern handles experimental data processing and analysis from the GVK facility.

The internship is the first step toward a full PHD position devoted to the discovery of sub-Kolmogorov phenomena. (financement ANR-BANG)

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PROPOSITION DE STAGE 2023

CONTRIBUTION OF IMAGE ANALYSIS TO THE STUDY OF STRESS CORROSION BEHAVIOUR OF GLASS

Glass is a widely used material because of its many advantages: transparency, hardness, low thermal expansion, high melting point temperature, relative chemical inertia, etc. However, it has one major weakness: its fragility. Relatively moderate stresses can cause it to break suddenly, without any warning. Glass is also sensitive to the phenomenon of stress corrosion cracking : under the influence of certain environmental conditions (relative humidity, temperature, etc.). In this case, apparently harmless stresses (much lower than those leading to its sudden breakage) can lead to crack propagation at low rate, as observed in the slow cracking of car windscreens.

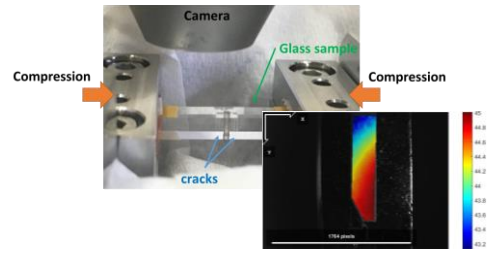

Figure 1 : detail of experimental set-up of stress corrosion cracking and first image of DIC obtained in silica glass

Recently, a methodology based on image correlation (DIC : Digital Image Correlation, see as example https://en.wikipedia.org/wiki/Digital_image_correlation_and_tracking) has been developed to acquire various quantities necessary (stress intensity factor, precise position of the crack tip, etc.) to identify the laws of fracture. It consists of speckling (i.e. depositing a pattern of randomly dispersed "spots") on the surface of a sample and studying by image analysis the displacement of these "spots" when the sample is mechanically stressed. This method has been developed for relatively soft materials (acrylics) and the transition to hard material such as glass is not easy. A change of scale is necessary (pattern with smaller "spots"). Techniques (deposition, etching, image acquisition…) have be tested by SPHYNX members and are fruitful.

The objective of this internship is to optimize and qualify the methodology based on DIC and recently developed in SPHYNX. In this context, the candidate will acquire stress corrosion cracking data for different glass composition: from pure silica to ternary glass (SiO_2-B_2O_3-Na_2O). He/She will be in charge of the different steps: speckling preparation in the SPEC clean room, implementation of mechanical tests on a dedicated experimental set-up and image analysis. The results will be compared to the ones already obtained in the laboratory or/and the published ones.

This internship will take place in the SPHYNX lab located in the *Condensed State Physics Service* which is a joint CEA / CNRS unit (UMR 3680 CEA-CNRS). Researchers study condensed matter physics, from the most fundamental physics to industrial applications. The candidate will have the opportunity to use and learn first-hand advanced methods for characterising materials and their surfaces, from the macroscopic to the nanometric scale. The approaches will be based on experimental platforms and theoretical tools developed in-house. The candidate will have the opportunity to manipulate theoretical and experimental tools used in the field of materials science, mechanics and statistical physics.

No further thesis work planned

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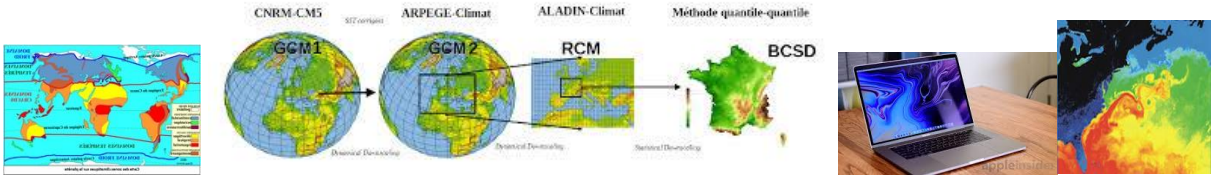
PROPOSITION DE STAGE/THESE 2022/2023

SOBER SIMULATIONS OF CLIMATE BIFURCATIONS



Greenhouse gases produced by human activity influence the Earth's climate, producing elevation of mean temperature, localized extreme events, and even bifurcations. Such bifurcations have been observed in laboratory experiments or simple models of climate. Reproducing them and studying them with classical simulation is both a challenge, and a problem in itself: indeed, the climate system is multi-component, and implies a pharaonic range of scales: for example, the simulation of the atmosphere (one of the components of the climate) requires in principle the consideration of all scales between that of hurricanes (100 km) and those at which energy is dissipated (0.1 mm), or a range of scales of 10^{11}. This range of scale is inaccessible to the largest computers currently in existence, which have neither enough memory nor enough CPU to handle such a large number of degrees of freedom.
On the other hand, even if it were possible, the corresponding simulation would be a energy sink: to simulate climate at a resolution 10km for 100 years takes 6 years of real time, and consumes as much electric energy as 50 french families during that time.

We are just facing a paradoxical situation where simulating the effects of climate change participates to climate change.

The solution to be able to perform sober simulations is to decimate~~s~~ degres of freedom, and simulate just those that are relevant to our purpose. How to achieve this is however a theoretical challenge, and no viable solution has been proposed so far.

In this project, we propose a new approach, which combines two new theoretical tools: the first one, called information geometry, is a new technique that allows to caracterize non-equilibrium transitions; the second one, called log-lattices, allows to perform sober numeical simulation by considering the whole range of scales, but by reducing the number of scales taken into account as we go down in size. The corresponding model is without adjustable parameters, and can be simulated on a laptop.

The main purpose of this project is then to study some simple bifurcations that can occur in the climate system, by applying it to a simplified representation of the atmosphere or the ocean. Most of the work will involve simulations in Python on a small computer.

The core of this project is numerical and statistical, but theoretical developments on turbulence theory via multi-fractal formalism and wavelet transforms can be carried out. This project will be supervised by B. Dubrulle (CNRS). The internship subject requires a solid background as a physicist, particularly in non-linear physics, as well as a strong taste for numerics. It may lead to a PhD on a related topic, in co-tutella with E-J. Kim (Coventry University).

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PROPOSITION DE STAGE 2022/2023

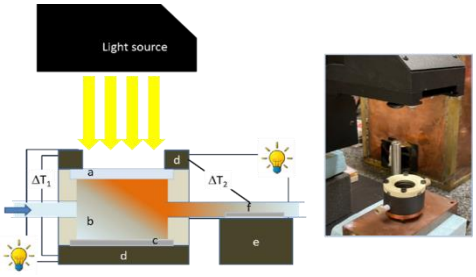
THERMOELECTRIC ENERGY CONVERSION IN COMPLEX FLUIDS (INTERNSHIP 1/2)

1. COGENERATION OF HEAT AND ELECTRICITY USING NANOFLUIDS

Thermoelectricity, a materials' capability to convert heat in to electric energy has been known to exist in liquids for many decades. Unlike in solids, this conversion process liquids take several forms including the ***thermogalvanic*** reactions between the redox ions and the electrodes, the ***thermodiffusion*** of charged species and the temperature dependent formation of electrical double layer at the electrodes. The observed values of Seebeck coefficient (Se = -$\Delta V/\Delta T$, the ratio between the induced voltage (ΔV) and the applied temperature difference (ΔT)) are generally above 1 mV/K, an order of magnitude higher than those found in the solid counterpart.

At SPHYNX, we have two on-going research projects to understand and exploit the heat-to-electricity conversion mechanisms in such complex fluids. (**Please consult Internship 2/2 for the second proposition**)

1) Co-generation of heat & electricity using *nanofluids* (liquid suspensions of nanometer-sized additives) via hybrid solar-thermal collectors. In this project, we combine the Sun-light absorption and the thermo-electrodiffusion of nano-additives to simultaneously produce heat and electricity from the solar radiation[1]. A prototype device has been built (see figure) by our partner laboratory (National Optical Institute, INO, Firenze, Italy) and currently being tested at SPHYNX. For the nanofluids, we use maghemite (iron oxide, collaboration with Sorbonne U) nanoparticles in aqueous media known for their long-term stability, moderately elevated heat absorption capacity and improved thermoelectric efficiency[2,3]. The internship has for its short-term goal to benchmark the prototype feasibility by determining the extractable magnitude of heat generation, thermal gradient and the power-output as a function of the irradiation power and nanoparticle concentration. Upon its successful completion, the internship will be converted into a PhD thesis research project investigating the underlying laws of physics behind the solar radiation absorption (heat) and the thermoelectric potential and power generation and other associated phenomena in various types of nanofluids, as well as the development of larger and more evolved devices identifying the impact of cell geometry (including that of thermal insulator), fluid-flow patterns, etc.. (The candidate must apply for PhD scholarship).



Hybrid solar-thermoelectric cell developed via INO/SPHYNX collaboration

Our long-term goal is to deepen the understanding of the bespoke compound thermoelectric phenomena in liquid media, and to demonstrate the application potential of complex thermoelectric liquids based on affordable, abundant and safe materials for thermal energy harvesting as an energy efficiency tool.

The ideal candidate will have strong background in Physics (thermodynamics) with some theoretical/practical notion of Chemistry (CPGE in MP/PC/BCPST or Undergraduate double-major in Physics & Chemistry, and Energy/Electrochemistry/Chemistry courses in Master 1&2). **No numerical skills are necessary for these positions, however, basic data analysis skills are required. Hands on experience in the laboratory environment (glovebox handling, electronic hardware manipulation, etc.) is a plus.**

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REFERENCES:

[1] Z. Liu *et al.*, "Enhancement of solar energy collection with magnetic nanofluids," *Therm. Sci. & Eng. Prog.*, **8**, 130 (2018).
[2] E. Sani, *et al.*, "Multifunctional Magnetic Nanocolloids for Hybrid Solar-Thermoelectric Energy Harvesting," Nanomaterials, 11(4), 1031; https://doi.org/10.3390/nano11041031 (2021).
[3] T. Salez *et al.*, "Magnetic enhancement of Seebeck coefficient in ferrofluids," *Nanoscale Adv.*, **1**, 2979 (2019).

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PROPOSITION DE STAGE 2022/2023

THERMOELECTRIC ENERGY CONVERSION IN COMPLEX FLUIDS (INTERNSHIP 2/2)
THERMOGALVANIC ENERGY CONVERSION IMPROVEMENT IN IONIC LIQUIDS VIA BY REDOX SOLVATION AND COORDINATION CHEMISTRY

Thermoelectricity, a materials' capability to convert heat in to electric energy has been known to exist in liquids for many decades. Unlike in solids, this conversion process liquids take several forms including the ***thermogalvanic*** reactions between the redox ions and the electrodes, the ***thermodiffusion*** of charged species and the temperature dependent formation of electrical double layer at the electrodes. The observed values of Seebeck coefficient ($Se = -\Delta V/\Delta T$, the ratio between the induced voltage (ΔV) and the applied temperature difference (ΔT)) are generally above 1 mV/K, an order of magnitude higher than those found in the solid counterpart.

At SPHYNX, we have two on-going research projects to understand and exploit the heat-to-electricity conversion mechanisms in such complex fluids. (**Please consult Internship 1/2 for the other proposition**)

2) Thermogalvanic energy conversion improvement in ionic liquids via by redox solvation and coordination chemistry. Room temperature ionic liquids (RTILs) are molten salts that are liquid below 100 °C and up to 200 – 400°C. Compared to classical liquids, they exhibit many favorable features such as high boiling points, low vapour pressure, high ionic conductivity and low thermal conductivity accompanied by higher Se values. The latter is believed to stem from a complex and strong ionic environment in the solvation/complexation layer surrounding the redox species unique to ionic liquids[1,2]. A clear understanding and the precise control of the speciation of metal ions and their impact on the structural entropy change of the solvation layer is a key to the rational design of future TEC liquids. The proposed internship is experimental, exploring first the relationship between the ionic constituents of the liquid (various RTILs and RTIL/solvent mixtures) the thermogalvanic effect of commercially available redox salts via Seebeck coefficient (voltage), impedance and power measurements. In the subsequent PhD period (funding available), the study will be extended to tackle the coordination chemistry of transition metal redox ions made with commonly available metals (Fe, Cu, etc), involving), involving metal complexation studies, electrolysis, and spectral & electrochemical characterization methodologies (collaboration with IJCLab, UPSaclay).

Our long-term goal is to deepen the understanding of the bespoke compound thermoelectric phenomena in liquid media, and to demonstrate the application potential of complex thermoelectric liquids based on affordable, abundant and safe materials for thermal energy harvesting as an energy efficiency tool.

The ideal candidate will have strong background in Physics (thermodynamics) with some theoretical/practical notion of Chemistry (CPGE in MP/PC/BCPST or Undergraduate double-major in Physics & Chemistry and Energy/Electrochemistry/Chemistry courses in Master 1&2). **No numerical skills are necessary for these positions, however, basic data analysis skills are required. Hands on experience in the laboratory environment (glovebox handling, electronic hardware manipulation, etc.) is a plus.**

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REFERENCES:

[1] T. Salez "Effets thermoélectriques dans des liquides complexes: liquides ioniques et ferrofluides" Thèse de Doctorat, PSL Research University (2018)
[2] M. Beaughon « Thermoélectricité dans les solvants, liquides ioniques et ferrofluides » thèse de doctorat, l'université Paris-Saclay (2022)

Many-body physics of topological defects in active materials

Nom des responsables du stage ou thèse: Ananyo Maitra and Cesare Nardini
(Theoretical & numerical internship, possibly leading to a Ph.D.)

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Lieu du stage: Saclay/Paris
Stage uniquement : NON
Thèse uniquement: NON
Stage pouvant déboucher sur une thèse : OUI
Financement proposé : OUI (stage)

In a nutshell: Understanding the many-body physics of topological defects in active materials with a combination of analytical and numerical techniques; exploring their relevance for collective phenomena in active and living systems.
Expected skills: Basic statistical mechanics methods and willingness to perform both analytical and numerical work. Some experience on field theories and/or soft matter is a plus but is not necessary. Interest in continuing for a PhD.

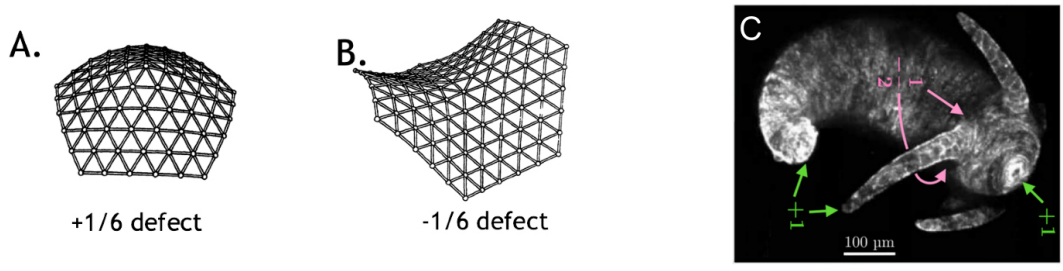

Figure 1: (Bottom) *(A,B) Disclination defects (here nodes with either five or seven neighbours) induce a curvature in the underlying material and, due to active forces, interact non-reciprocally [4]. (C) Clustering of topological defects in Hydra embriogenesis [5] cannot be explained with equilibrium theories. The main goal of this project is to theoretically describe the many-body physics of defects in active materials.*

Many space-time features of biological and active materials, from morphogenesis to the structure of dense assemblies of self-propelled colloids, are caused and controlled by topological defects [2]. The properties of these defects, though, present several puzzles: in equilibrium systems, topological defects behave quite similarly to electric charges: they can neither be created nor destroyed and defects of the same charge repel while opposite charges attract. Yet, many of the observed structures of living and active materials require defects of the same charge to cluster together. How is this possible? How do the interactions between active defects differ from their passive counterparts? Are defect-driven phase transitions changed by activity, and what are the properties of defect-ordered structures? These are the overarching questions that this theoretical project will seek to answer.

The internship will focus on investigating the two-body interactions of defects in a minimal model of active matter using analytical and numerical techniques. The starting point will be field theories that have been developed in the last 20 years to describe active matter [1]. We will explicitly calculate two-defect interactions in active nematics and then in other ordered phases such as hexatics, generalising methods developed for passive systems [3]. The obtained stochastic dynamics for defects will be integrated numerically to predict the defect-ordered phases that may arise. The project is suitable for being continued as a PhD.

[1] M.C. Marchetti et al, Rev. Mod. Phys. **85**, 1143 (2013); [2] S. Shankar et al., Nat. Rev. Phys. **4**.6 (2022); [3] G. F. Mazenko, Phys. Rev. Lett. **78**, 401 (1997); [4] H. S. Seung et al. Phys. Rev. A **38**, 1005 (1988); [5] L.A. Hoffmann, et al., Science advances 8.15 (2022); [6] L.M. Pismen, Phys. Rev. E **88** (2013).

PROPOSITION DE SUJET DE STAGE DE M2 ET/OU DE THESE

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Code d'identification CNRS : UMR 3680
Nom du ou des responsables du stage ou thèse: Cesare Nardini
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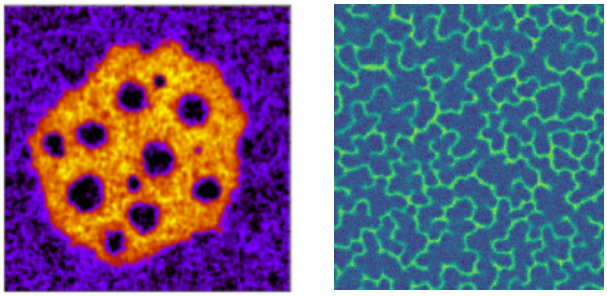
Lieu du stage: Saclay/Paris
Stage uniquement : NON Thèse uniquement: NON
Stage pouvant déboucher sur une thèse : OUI
Financement proposé : OUI (stage) si oui, type de financement : OK pour stage

Controlling phase separation in active systems

Expected skills: Knowledge of basic statistical physics; interest in using both analytical and numerical techniques; knowledge of field theories and soft matter is considered as a plus but is not mandatory. Interest in continuing the project for PhD after the internship.

Examples of active systems, formed of units that are able to extract energy from the environment and dissipate it to self-propel, are found everywhere in nature: flocks of birds, animal swarms, suspensions of bacteria or tissues are all biological active systems. Recently, scientists have built synthetic active systems using catalytic colloidal particles or micro-robots; active matter is a class of soft materials capable of new forms of self-organization. Furthermore, active systems have theoretically fascinating properties, a fact that drove a very intense research activity lately. Future applications may encompass the engineering self-assembling materials using active units, considered as a defining agenda in the community.
Large assemblies of active units display collective phenomena that are absent in equilibrium. One of the most ubiquitous is phase separation, where even repulsive but active particles phase separate into dense and dilute phases. In some cases, this resemble to liquid-vapor phase separation of standard fluids. Due to broken time-reversibility, however, active systems often shows very different features from liquid-vapor phase separation, and currents in the steady state: the dense regions can support a population of mesoscopic vapor bubbles (bubbly phase separation, resembling to a boiling liquid), or the vapor-liquid interface can be unstable, giving rise to active foam states. Even basic properties of phase separated system such as interfacial tensions are qualitatively impacted by activity.



Non-equilibrium types of phase separation arising in active systems due to negative surface tensions. Shown is the density field (bright colors denote dense regions). Bubbly phase separation (Left) and an active foam state (Right). One of the main goals of this project is to control such phases in particle-based models.

The main open theoretical question is how to control these novel states of matter in terms of microscopically tunable parameters. The main goal of this internship is to start filling this gap. We will employ both analytical (coarse-graining techniques, stochastic calculus, field theoretical analysis) and numerical techniques (direct numerical simulations of particle systems and field theories). The project is well suited to be continued during a PhD (subject to funding). On the long-term, this work will provide a guide for experimentalists to design novel self-assembling materials using active units.

References:

E. Thjung, C. Nardini, M.E. Cates, PRX, **8**, 031080, 2018; J. Tailleur, M.E. Cates, Ann. Rev. Cond. Mat., **6**, 219, 2015; G. Gommper et al., Journal of Physics: Condensed Matter **20**, 193001, 2020; G. Fausti et al., PRL **127**, 068001, 2021.

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INTERNSHIP/THESIS PROPOSAL

STRESS CORROSION BEHAVIOUR OF MESOSTRUCTURED GLASS BY PHASE SEPARATION

Glass is a widely used material due to its many advantagious properties: transparency, hardness, low thermal expansion, high melting point temperature, relative chemical inertia, etc. However, it has one major weakness: its fragility. Relatively moderate stresses can cause it to break suddenly and without any warning. Glass is also sensitive to stress corrosion cracking: sub-crtical cracking aided by environmental conditions (relative humidity, temperature, etc.). In this case, apparently harmless stresses (much lower than those leading to its sudden breakage) can lead to crack propagation at low rates, as observed in the slow cracking of car windscreens. This stress corrosion cracking (SCC) also depends on the intrinsic parameters of the glass: chemical composition, microstructure, etc.

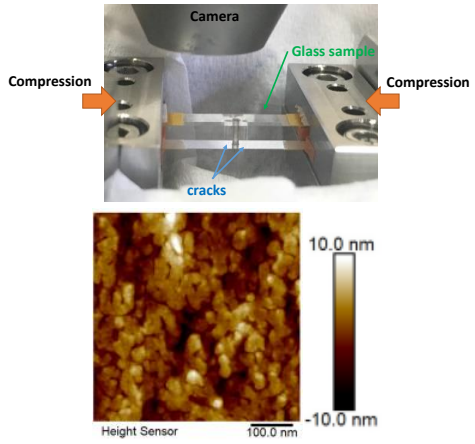

Figure 1 : Experimental set-up of stress corrosion cracking (top) and (bottom) AFM image of the fracture surface of a phase separated glass sample.

The phenomenon of phase separation in glasses leads to a meso-structured material which can improve mechanical properties such as crush resistance[1]. It is also at the origin of glass-ceramics, consisting of microcrystals dispersed in a glass matrix, developed to take advantage of the benefits of both components: ceramics and glasses. They are used, for example in optical thermometry applications, kitchen utensils, dental materials, etc. However, the stress corrosion behaviour of this type of material is still poorly understood.

The objective of this internship is to examine stress corrosion cracking in several different glassy ceramics. Samples will concern as fabricated samples and their phased separated counterparts which will be achieved by varying annealing protocols. The candidate will make use of an existing SCC experimental set-up (Figure 1 top). The rate of crack propagation and its variation with applied stress will be measured for each samples to obtain the characteristic stress corrosion resistance curves. Additionally, the candidate will have the opportunity to use a state-of-the-art Atomic Force Microscope (AFM) to characterize *post-mort*em fracture surfaces. These studies will aid in characterising the size of phase separation and will feed different statistical tools (stochastic modelling, fractal analysis).

This internship will take place in the SPHYNX lab located in the *Condensed State Physics Service* which is a joint CEA / CNRS unit (UMR 3680 CEA-CNRS). Researchers study condensed matter physics, from the most fundamental physics to industrial applications. The candidate will have the opportunity to use and learn first-hand advanced methods for characterising materials and their surfaces, from the macroscopic to the nanometric scale. The approaches will be based on experimental platforms and theoretical tools developed in-house. The candidate will have the opportunity to manipulate theoretical and experimental tools used in the field of materials science, mechanics and statistical physics. Finally, the very fundamental and applied character of this research will allow the candidate to find opportunities in the academic world (thesis) and in industry.

This intership may lead to a thesis (funding to be determined)

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