ERC Consolidator Grant 2015

Particle dynamics in the flow of complex suspensions

PaDyFlow

Cover Page:

- Name of the Principal Investigator (PI): Anke Lindner
- Name of the PI's host institution for the project: CNRS, Paris (France)
- Proposal duration in months: 60 months

Particle laden flows are ubiquitous in nature and industrial applications. Particle trajectories determine transport in porous media or biomedical conducts and effective suspension properties dictate flow behavior in food processing or biofluid flow. For a better control it is necessary to know how to predict these processes from the involved particle and flow properties. However, current theory is not able to capture the complexity of the applications and experiments have been carried out on too diverse systems for a unifying picture to emerge. A systematic experimental approach is now needed to improve the present understanding.

In this experimental project, we will use novel microfabrication and characterization methods to obtain a set of complex anisotropic microscopic particles (complemented by selected bioparticles) with tunable properties, covering size, shape, deformability and activity. The transport of these particles isolated or in small concentrations will be studied in chosen microfluidic model flows of simple fluids or polymer solutions. The many degrees of freedom of this problem will be addressed by systematically combining different relevant particle and flow properties. The macroscopic properties of dilute suspensions are particularly interesting from a fundamental point of view as they are a direct consequence of the individual particle flow interaction and will be measured using original microfluidic rheometers of outstanding resolution.

This project will lead to a comprehensive understanding of fluid structure interactions at low Reynolds number. Our findings will constitute the basis for novel numerical approaches based on experimentally validated hypotheses. Using our knowledge, local flow sensors, targeted delivery and novel microfluidic filtration or separation devices can be designed. Combining particles of chosen properties and selected suspending fluids allows the fabrication of suspensions with unprecedented tailored properties.

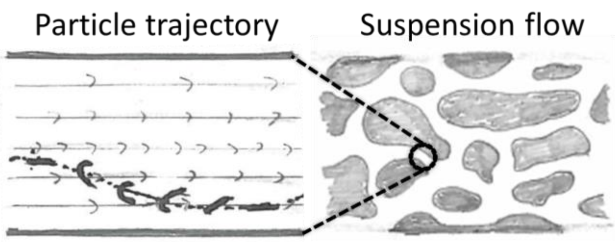
Section a: ***Extended Synopsis of the scientific proposal (max. 5 pages)***

Context

Particle laden flows are ubiquitous in nature, biology and industrial applications. The understanding of the ***transport of microscopic particles*** by a suspending fluid is necessary in situation as different as transport of red blood cells, traffic inside cells, design of novel micro-separation or -filtration devices, targeted delivery or biofilm formation. The ***macroscopic properties of suspensions*** dictate their behavior in applications as food processing, biofluid flow or biomedical applications. For a better control it is necessary to be able to predict the particle dynamics at the microscopic level as well as the macroscopic properties from ***particle properties and flow geometries***.

Industrial processes or biological applications are characterized by ***their complexity***. First of all, particles are often of complex shape and deformability or can even be self-propelled microorganisms. Then, the flow geometries involved are multiple, ranging from confined microflow geometries to extruders or porous filters. In these geometries, different flow types are observed, interaction with boundaries can become important and the ratio of a typical particle size to a typical flow scale can strongly vary. In a number of situations the suspending fluid is not a simple fluid but can be non-Newtonian by itself. Interactions of particles with the specific flows are thus not easy to understand or predict and transport of individual particles as well as suspension properties ***resist comprehension***.

State of the art



In all these cases, microscopic objects are transported through a given flow geometry. Most of these flows take place at low Reynolds number where inertia can be neglected and all stresses are linear in flow velocity (Guazzelli2012). This apparently simple situation becomes complex as soon as more complex particles (not spherical and rigid), with additional degrees of freedom are considered. These objects interact with the local flow that can orient or deform them and is in response modified itself. This is what is called a classical fluid structure interaction problem and is inherently non-linear. This interaction can lead to complex particle trajectories and cross stream migration. Trajectories are further modified by hydrodynamic interactions with other particles in their dilute suspensions and with bounding walls. The stresses exerted by the microscopic particles on the flow dictate the macroscopic flow properties of their suspensions, noticeable even at very small particle concentrations. The non-Newtonian character of their suspensions thus directly results from the microscopic particle flow interactions.

From a ***theoretical point of view a lot of progress has been made*** on the understanding of the transport of complex particles in viscous flows, addressing either the role of shape, flexibility or activity separately. Some theories predict the ***emergence of novel macroscopic properties*** of complex suspensions relying on modeling of the microscopic particle organization. Up to date, ***no common picture exists*** when ***several of these properties have to be considered simultaneously or when collective effects have to be taken into account***. This is mainly due to the fact that the many degrees of freedom of this multi-scale problem hinder numerical investigations and comprehensive theoretical modeling. The field ***crucially lacks experimental investigations, due to the absence of well controlled model*** systems. Furthermore, ***the weak non-Newtonian properties of dilute suspensions are often found outside the resolution of conventional rheometers*** and could so far not be precisely measured.

The dynamics of the transport of single rigid spherical or elongated particles at low Reynolds number are our days well understood (Guazzeli2012) and have been modeled using a Stokes flow approach and for example slender body theory (Cox1970). These findings are confirmed by experimental results.

When elongated particles have more complex shapes (like curved or chiral particles) or become deformable, no global picture exists. Sophisticated theoretical and numerical approaches, often based on slender body theory have addressed the question of the dynamics of rigid non-axisymmetric (Wang2012) or chiral particles (Marcos2009) under flow. Combining slender body theory with Euler's elastica, models have been developed to determine particle deformation and buckling instabilities of deformable fibers in viscous flows (Lindner2015). For these particles complex dynamics, coupling rotational (Jeffery1922) and translational dynamics, have been predicted, leading to complex trajectories (Young2007), including stable trajectories or fixed equilibrium positions in wall bound flows (Slowicka2013). No theoretical approach has so far addressed particles of complex shape and deformability at the same time. Most of the experimental investigations use biological objects (Kantsler2012, Harasim2013,Marcos2009) that are inherently complex, making it difficult to isolate given properties to be compared to the existing theories.

Active particles, as microswimmers, have recently attracted a lot of interest but are still relatively scarcely studied under flow. Most theories model micro-swimmers as a force dipole to describe the flow perturbation created in the far field (Lauga2008, Saintillan2013) and some theories also take a simple elongated particle shape into account (Saintillan2013,Zöttl2013). Experiments with bacteria have revealed complex phenomena as upstream swimming (Hill2007), rheotaxis (Marcos2012) or stable oscillatory trajectories (Rusconi2014). Real bacteria, typically formed by a head and flagella, are complex objects and the role of shape and possibly deformability cannot be separated from the role of activity in the observed dynamics making a direct link to existing theories difficult. The long range flow perturbations created by the micro-swimmers have another important consequence. Hydrodynamic particle-particle interactions have to be taken into account even in dilute suspensions, where particle volume fractions stay far below one. Only rare theories have considered such dynamics under flow (Ryan2011, Pahlavan2011) and this phenomenon still lacks experimental validation.

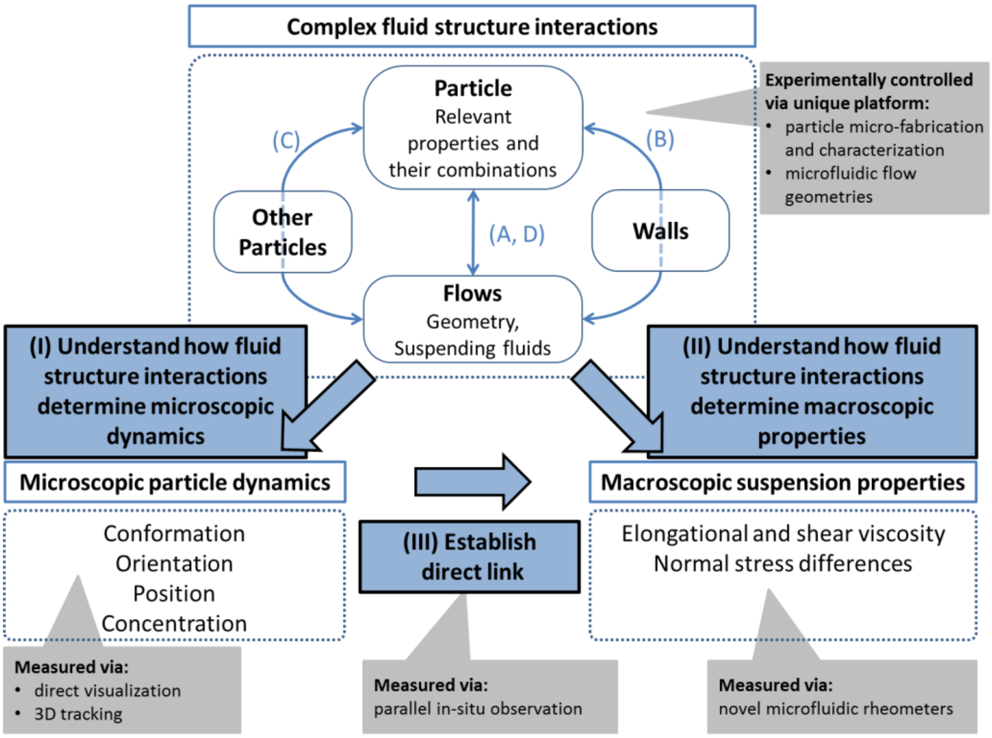


Figure 1. <u>*Concept of PaDyFlow:*</u> *Fluid-structure interactions determine particle dynamics as well as macroscopic suspension properties. The objectives are given in blue and the experimental methodology is indicated in grey.*

The stresses exerted by particles on the flow are determined by the specific fluid-structure interactions and result in complex macroscopic suspension properties. The study of these properties, in the limit of dilute suspensions, is particularly interesting from a fundamental point of view, as the microscopic conformation of individual particles can be directly linked to the macroscopic suspension properties. This direct link is masked in more concentrated suspensions, where new types of interactions, like particle contacts, aggregation or excluded volume effects, lead to other phenomenologies (Guazzelli2012), outside the scope of this project. Some recent theories have made intriguing predictions for dilute suspensions of complex particles. Normal stresses have been predicted to occur in very dilute sheared suspensions of flexible fibers as a direct consequence of the shear-induced fiber bucking (Becker2001). A decrease of the shear viscosity of active suspensions below the viscosity of the suspending fluid has been predicted (Saintillan2013) resulting from the mean particle orientation and a specific sign of the force dipole. It is experimentally challenging to measure macroscopic properties of very dilute suspensions, as the weak non Newtonian properties expected are typically outside the resolution of conventional rheometers. Using a microfluidic rheometer we have only recently succeeded to measure the viscosity of a dilute suspension of bacteria as a function of shear rate (Gachelin2013) but other non-Newtonian properties or different types of complex suspensions remain largely unaddressed from an experimental point of view. Nearly nothing is known on the macroscopic properties, when the suspending fluid is a non-Newtonian fluid, like a polymer solution, and thus nonlinear in itself. In this case an additional scale is added to the problem and potentially leading to novel macroscopic properties.

Objectives

The scope of this experimental project is to (I) understand how the ***interaction between a microscopic particle and a flow*** determines the ***particle conformation, orientation and position*** during ***particle transport***. Systematic understanding will be gained investigating the most relevant particle properties isolated and in combination of increasing complexity. In contrast to simulations, in experimental systems several degrees of freedom can be easily investigated as long as well controlled experimental model systems are used. The complex particles will be subject to representative model flows, of simple fluids and polymer solutions. PaDyFlow will also quantify the modification of the microscopic particle dynamics due to hydrodynamic interactions with bounding walls as well as hydrodynamic particle-particle interactions in dilute suspensions. The macroscopic properties of suspensions of small concentrations of these complex particles will be determined with the goal to (II) ***understand how particle and flow interactions determine the effective fluid properties***. PaDyFlow will then for the first time establish a (III) ***direct experimental link between the microscopic structure of complex particles under flow and the macroscopic properties of their dilute suspensions.***

Methodology

Recent progress in microfabrication methods now permits the ***fabrication of microscopic particles of well-defined complex properties*** and ***microfluidic flow devices*** are now commonly used to tune ***flow properties*** at low Reynolds number. It is thus now possible to obtain well controlled experimental model systems to overcome the enduring lack of experimental investigations. ***Recent microscopic rheometers*** developed by us and other groups allow for the first time to measure non-Newtonian properties of even very dilute suspensions and allow for a simultaneous direct observation of microscopic particles. ***Now is thus the right moment for an experimental project on the particle dynamics in the flow of complex suspensions***.

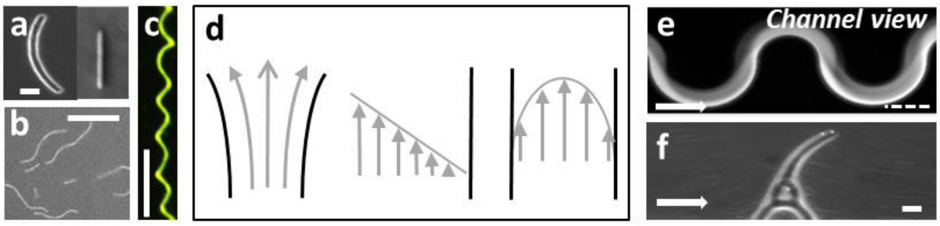


Figure 2. <u>Particles:</u> *(a) Complex shapes fabricated by UV projection lithography directly inside a microfluidic channel.* (Lindner2014) *(b) Suspension of fluctuating actin filaments. (c) Micro-helix formed by elastocapillary deformation of nano-ribbons* (Pham2015). <u>*Flows*</u>*: (d) Elongational, simple shear and Poiseuille flows.* <u>*Characterization methods*</u>*: (e) Serpentine microchannel used as a microrheometer,* (Zilz2013). *(f) Microfluidic beam bending experiment to measure the Young's modulus of micro-fabricated particles in situ. For a more controlled geometry see* (Duprat2015). *Scale bars 10 microns (except in (e) 100 microns).*

Using these novel techniques, we have over the last years built a unique experimental platform (Lindner 2014) in my group (Fig.2). This micro-fabrication and flow platform combines control over particle properties with controlled flow geometries and microfluidic rheometers. Micro-fabricated ***particles*** are complemented by selected biopolymers and bacteria. We have in this way access to different shapes (straight and curved fibers, helices) and mechanical properties (Duprat2015). Bacteria will represent active particles. The particle size typically ranges between 1-100 microns, determining whether thermal fluctuations or rotational diffusion (translational diffusion can be neglected in most cases) have to be taken into account. Controlled ***flows*** are obtained using microfluidic channels of different flow geometries and polymer solutions are used as non-Newtonian suspending fluids. Microfluidic channels are transparent and allow for a ***direct observation*** of the (fluorescently labelled) particles inside the channel through a microscope using a recently developed real time 3D tracking algorithm. The ***particle conformation, orientation and position*** can thus be obtained at each instant. ***The macroscopic non-Newtonian properties*** of the suspensions made by these particles will be accessed using original microfluidic rheometers of superior resolution adapted (Gachelin2013) or developed (Zilz2013) to this purpose in my group.

To respond to objective (I) ***"Understand how fluid-structure interactions determine microscopic particle dynamics"*** of PaDyFlow different types of fluid-structure interactions will be analyzed and then combined:

<u>A. Isolated particles interacting with flows of simple fluids</u>

We will systematically increase the complexity of the particle properties addressed, focusing on elongated particles. First the deformation of different particles will be investigated in simple elongational/compressive flows. Then the combined role of particle shape and deformability will be addressed in simple shear flows where rotational and translational properties can be coupled. The resulting (stable) trajectories in wall bound

Poiseuille flows will be investigated. In all cases Brownian and non-Brownian particles will be considered. Finally active particles (naturally of complex shape and deformability) will be studied. This will lead to a unifying picture of fluid structure interactions of (non)-axisymmetric, (non)-chiral, (un)-deformable and/or (non)-Brownian elongated objects with model flows. These results are the basis for the following tasks, adding further interactions with walls, other particles or complex fluids, in relevant situations.

B. Specific interactions with bounding walls

Wall interactions become important when particle trajectories bring particles towards bounding walls and will already be partially treated in A. Specific interactions, as rotation of elongated and flexible objects close to walls and transport of micro-swimmers along walls will be addressed here.

C. Particles interacting with other particles in their dilute suspension

Particle-particle interactions will be investigated in view of the measurements of suspension properties for homogeneous suspensions of fibers and active swimmers as a function of their (moderate) particle concentration in D. Mixtures between different particle types will lead to new types of interactions, as for example the capture of micro-swimmers by passive beads.

D. Interaction with non-Newtonian fluids

Modifications of fluid structure interactions due to non-Newtonian properties of the suspending fluid will be particularly noticeable when fluid elasticity and particle elasticity compete, as for example for flexible fibers transported in solutions of flexible polymers. The multiscale nature of this problem will be specifically addressed by decreasing for example the diameter of a microscopic fiber down to a typical polymer size. Strong local shear rates in the gap between particles and walls might lead to a modification of wall interactions for example in shear thinning fluids.

To respond to objective (II) of PaDyFlow ***"Understand how fluid-structure interactions determine macroscopic suspension properties"*** rheological measurements of suspension properties (shear viscosity, extensional viscosity and normal stress differences) will be performed, for different dilute suspensions, in particular of flexible fibers or spirals and microswimmers.

To respond to objective (III) of PaDyFlow ***"Establish a direct link between microscopic structure and macroscopic properties"*** particles will be visualized in parallel to the rheological measurements, reinforcing the link already established by relating objective (I) and (II).

Outcome

PaDyFlow will ***bridge the gap*** between the ***complexity encountered in applications*** and the ***only partial understanding*** provided by existing ***theory and modeling, treating only selected particle properties in specific flows.*** Using well controlled experimental model systems, we will gain a ***comprehensive picture of fluid-structure interactions at low Reynolds number, in situations with a large number of degrees of freedom and multiple scales***. We will deliver the necessary information to ***define the appropriate hypothesis*** at the basis of new ***numerical simulations and theories,*** having significant impact on their development. By directly linking the observed microstructure to the measured macroscopic flow properties of complex suspensions we address an important ***fundamental challenge*** of soft matter physics.

The understanding of the transport of complex particles paves the way to the design of ***new microfluidic devices***. Efficient microfluidic filtration and separation devices can rely on the design of new flow geometries, particles with specific properties can be used as local flow sensors or in targeted delivery applications. By combining selected microscopic particles with chosen suspending fluids ***allows for the fabrication of suspensions with novel tailored properties.***

Feasibility of the project and qualification of the PI

Using the flow and fabrication platform I have already published ***first important results***. The measurement of the non-Newtonian viscosity of an active suspension of micro swimmers using a microfluidic rheometer has been published in Phys. Rev. Lett. (Gachelin2013). The successful development of a novel microfluidic rheometer to measure normal stress differences (Zilz2013) and of an in-situ mechanical characterization method of hydrogels (Duprat2015) have both been published in Lab On Chip. Additionally, I have obtained a number of promising ***preliminary results*** (Fig.3),

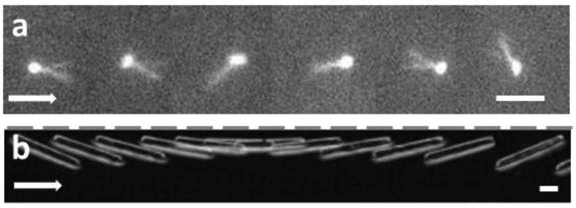


Figure 3. <u>Preliminary results:</u> *(a)"Active" Jeffery orbit of an E-Coli bacteria under shear flow. The body of the bacteria is kept in the center of the picture using our 3D tracking algorithm also registering the particle trajectory (b) Interaction of a rigid fiber in a confined channel with a side-wall.*

including for example the observation of an “active” Jeffery orbit or the complex interaction of a rigid fiber with a channel wall. The relevance and potential of this versatile platform has been ***recognized by the scientific community*** as proven for example by an invitation to a semi-plenary lecture at one of the most important meetings of the Fluid Dynamics community, the Annual Meeting of the American Society of Physics, Division of Fluid Dynamics (2800 attendees) in 2013 where I presented on the “Flow of complex suspensions”. Now is the right moment to fully exploit the large potential of our experimental model system.

The knowledge gained from my broad research activities in fields as (micro)-hydrodynamics, micro-fabrication techniques, fluid-structure interactions, complex fluid flow and rheology will be essential to the conceptual approach of PaDyFlow. I have always closely collaborated with modeling groups, allowing a smooth transfer of the experimental results into this community. The book chapter on “Elastic fibers in Flows” I have recently written (Lindner2015) or the invitation to guest edit a Special Issue on “Microfluidic Rheology” in Biomicrofluidics reflect the international recognition of this expertise. The combination of my conceptual and experimental expertise acquired during the last years brings me in a unique position to properly address the fundamental questions of this proposal.

Team and collaborations

4 PhD students (3 years each) and 3 PostDocs (2-3 years each, 8 years in total) will be hired during the project. They will each work with a specific type of particles and thus a specific experimental method. Close interaction and time overlap between the different PhD and PostDoc students will allow building a global understanding in the group. I have in the past already supervised a large number of students and I am confident to be able to successfully work with a growing research group. The team will be supported by a number of local collaborators on a daily basis: Olivia du Roure (actin filaments), Eric Clement (bacteria) and Thierry Darnige (particle tracking).

I have a strong network of well-established international collaborations with ***modelling groups*** with common publications directly comparing our experimental results to numerical simulations. Mike Shelley, New York University [Quennouz2015, Lindner2015] and Howard Stone, Princeton University [(Wexler2013)] in the USA. In Europe, these collaborators include several ERC grant awardees as Manuel Alves, Univ. Porto “Elastic-Turbulence” [Zilz2012, Zilz2013, Poole2013] and “SIMCOMICS” of François Gallaire, EPFL, Lausanne [Nagel2015]. The recent ERC project “TRITOS”, by Luca Brandt, approaches suspension flow from a different angle compared to PaDyFlow and deals with the flow of dense suspensions at high Reynolds numbers, mainly numerically. We have agreed to collaborate at a later stage of PaDyFlow extending some of our experiments studying channel flows of finite-size complex particles (not available in the rare experiments planned in TRITOS) to higher Reynolds numbers to be compared to their simulation results. I also collaborate with Al Crosby, Amherst University, USA on ***fabrication of complex particles*** [Pham2015].

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Section b: Curriculum Vitae (max. 2 pages)

Personal information

Family name, First name: Lindner, Anke

Researcher unique identifier(s): Research ID: F-3305-2010, google scholar profile Anke Lindner

Date of birth: 12/09/1971

Nationality: German

URL for web site: http://www.pmmh.espci.fr/~lindner/

Education

2010	Habilitation, UPMC, Paris "*Flow induced phenomena in structured fluids"*
1998-2000	Doctorate in Physics of Fluids at the "Ecole Normale Supérieure of Paris" *"Saffman-Taylor instability in complex fluids"* supervised by J. Meunier and D. Bonn
1996-1997	Master theses at the Theoretical Physics department of the University of Bayreuth, Germany *"Pattern formation in liquid crystals* supervised by L. Kramer

Current position

Since 2013	Professor, University Paris Diderot, Paris, France Research at the laboratory PMMH (Physique et Mécanique des Milieux Hétérogènes) of the ESPCI (Ecole Supérieure de Physique et Chimie de la Ville de Paris), Paris, France

Previous positions

2002-2013	Assistant Professor Université Pierre et Marie Curie, Paris, France
2001- 2002	Post-Doctorate at the PPMD, ESPCI, France *"Debonding of soft adhesives"* with C. Creton
2000- 2001	Consultant, McKinsey & Comp., international management consulting, Zurich, Switzerland

Fellowships and awards

2014	Invited Professor, Univ. Massachusetts, Amherst, USA (2 months)

Research activities

My research topics can best be summarized as "flow of complex fluids" and cover a broad range of topics from rheology of granular or active suspensions, to adhesion of soft viscoelastic materials and more recently fluid structure interactions, microfluidics and elastic flow instabilities. My fundamental experimental work has always attracted the interest of industrial partners.

Supervision of graduate students and postdoctoral fellows

I have supervised 9 PhD students (1 ongoing), 3 exchange PhD students from US and Europe (1 ongoing), 9 PostDocs (2 ongoing) and numerous Master students. My former students now work as assistant professors at the University of Lyon (O. Ramos), Univ. Pierre et Marie Curie Paris (E. Wandersamn), or Univ. Düsseldorf (J. Nase) or in industrial R&D at Total (H. Berthet), France, Arcema France (F. Tanguy), or the Norwegian Geotechnical Institute, Oslo (O. Johnsen).

Teaching activities

Since 2003 I have been an assistant professor and then a full professor at the two main universities with a physics department in Paris, with a yearly teaching load of 192h. I am very committed to teaching and in particular:

- I have built from scratch a new lab course on complex fluids and microfluidics with six different experiments at the Master's level.
- I have a special interest in developing the link between the University and Industry and have built a course with the aim to promote the professional career of students of the University.
- I also founded a training course on rheology for industrials that has opened every year since 2009 and has attracted engineers from the research and development departments from food industry, cosmetics,

pharmaceutics and building materials. Recently I have developed a new course on debonding mechanisms as part of a training course on adhesion (12 participants from industry in 2012).
- I teach Master courses on “Rheology of complex fluids” since 2005 and “Particulate suspensions” since 2014

Recently I have been invited to give lectures at international summer schools:
- “Interaction of microscopic structures and organisms with fluid flows” Mai 2015, Udine, Italy, 6h lecture on “Flow of complex suspensions”
- “Biofluids”, Marrakesh, September 2014, 2h lecture on “Active suspensions”

Organisation of scientific meetings (most relevant)

Feb. 2017	*Technical Chair* of the Annual Meeting of the American Society of Rheology, Tampa, USA
July 2015	*Session Chair* “Non-Newtonian fluid flows” Bifurcations and Instabilities in Fluid Dynamics (BIFD meeting), Paris France
April 2014	*Session Chair* “Microfluidic and Microrheology”, Europeen Rheology conference (AERC), Karlsruhe, Germany
Dec. 2013	*Scientific organizing committee*, International colloquium “Flow, fracture and interfaces in heterogeneous soft materials” Material Science Chair Michelin, ESPCI, Paris, France
Sept. 2011	*Mini-symposium chair* “Complex flows in microfluidic geometries.” Dynamics Days Oldenburg, Germany
Sept. 2011	*Session Chair*, "Soft adhesives" Annual Meeting of the American Adhesion Society, Savannah, USA

Institutional responsibilities

2010-2013 Head of the Master’s degree program “Complex Systems” in the Physics Department of the University Pierre et Marie Curie.

Comissions of trust

- *Referee* (more than 80 papers reviewed) for Phys. Rev. Lett, J. Fluid Mech., Micro and Nanofluidics, Rheologica Acta, JNNFM, Soft Matter, Physics of Fluids, Granular Materials, Journal of Adhesion
- *PhD committees* member of 12 PhD committees in France and Europe (external referee Spain, 2nd opponent Norway, cotutelle Germany)
- *Steering committees:* steering committee “French Adhesion Society”, “Chair Michelin-ESPCI”, member of the evaluation panel “DFG (German science foundation) Schwerpunkt “Particles in contact”, referee of the ANR (French Science Foundation), selection committee PhD award German Rheological Society.

Membership of scientific societies

Since 2014 Member of the COST action MP1305 Flowing Matter

Previous projects and industrial contracts (most relevant)

- St Gobain, Paris, France “*Stability of liquid curtains of paint*”, 2012-2014
- Michelin, Clermont-Ferrand, “*Contact of soft adhesives on rough surfaces”*, 2012-2014
- Schlumberger, Clamart, France “*Flow of fiber suspensions*”, 2008-2011
- European project “MODIFY” “Multi-scale modeling of interfacial phenomena in acrylic adhesives undergoing deformation”, Responsible for one of the experimental WPs, 2009-2012

Major collaborations

To complement my experimental activities, I have developed strong collaborations, acknowledged by common publications, with theoreticians on an international level. Ongoing collaborations: Mike Shelley, Courant Institute, New York, USA (interfacial instabilities, active suspensions, fluid-structure interactions); Howard Stone, Princeton University, USA (fluid-structure interactions in confined flows); Manuel Alves, Porto, Portugal and Rob Poole, University of Liverpool, UK (elastic flow instabilities). I also collaborate with Al Crosby, Amherst University, USA (fabrication techniques, adhesion). I have a network of close local collaborators at the ESPCI: Olivia du Roure (fluid-structure interactions), Eric Clement (suspensions) and Costantino Creton (adhesion).

Career breaks

10/2005-09/2006 Pregnancy and maternity leave (twins)

Appendix: All on-going and submitted grants and funding of the PI (Funding ID)

Mandatory information (does not count towards page limits)

On-going Grants

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*[1]
Adhesion at small time scales	Industrial partner (Michelin)	180.000	2014-2016	Principal investigator	none
Flow of protein solutions in injection processes	Industrial partner (Sanofi)	300.000	2015-2018	Principal investigator	none

Grant applications

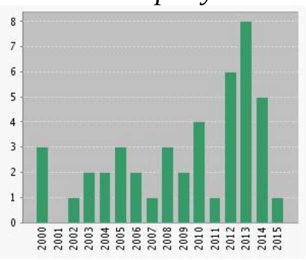
Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*[2]
Flow of complex suspensions	University Sorbonne Paris Cité	300.000	2015-2018	Coordinator	Whereas the scope of this project is partially similar with the current ERC application, the focus is different. This research project deals with ***dense suspensions and interfacial flows*** in collaboration with a group in Saarbrücken specialized in Capillary Break Up Rheology.

[1] Describe clearly any scientific overlap between your ERC application and the current research grant or on-going grant application.

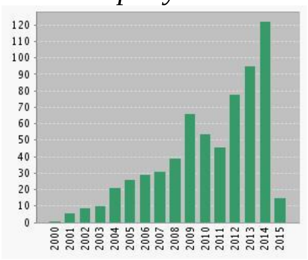
Section c: Early achievements track-record (max. 2 pages)

Citation metrics (44 publications in total)

Publications per year



Citations per year



From web of Science, 02/03/2015

Author of 43 papers (+1 in print) with a total of 648 citations (570 without self-citation), 457 citing papers, average citation number of 15 and an h-index of 15. 5 papers with more than 50 citations. 5 Physical Review Letters, 4 Journal of Fluid Mechanics (+1 in print) and 2 Lab on Chip. Four invited papers (Rheo. Acta, Granular Matter, Soft Matter, Phys. Fluids). Data from Web of Science.

I have supervised students since the end of my Post-Doc and they are first author on the corresponding publications, as is common practice in physics. The importance of my contribution (also with respect to other senior scientists) is shown by my role as last and/or corresponding author (indicated by *). From my 44 publications, I am first author of 10 publications, last author of 15 publications and corresponding author of 16 publications. From the 34 publications where I am not first author, in 28 cases the first author is a student supervised by myself.

In the following is a list of 10 recent publications, most relevant to the current proposal. They reflect my broad research topics and numerous international collaborations. I have started my career working on adhesion and granular suspensions. My recent publication list shows, that I have successfully established new research topics as fluid structure interactions, active suspensions, microfluidics and elastic flow instabilities.

Selected publications

Fluid structure interactions

- N. Quennouz, M. Shelley, O. du Roure, **A. Lindner,** *Transport and buckling dynamics of an elastic fiber in a viscous cellular flow*, (in press) J. Fluid Mech. (2015) [Combined experimental and numerical study on fiber transport]
- C. Duprat, H. Berthet, J. S. Wexler, O. du Roure and **A. Lindner**, *Microfluidic in situ mechanical testing of photopolymerized gels*, Lab on Chip, (2015),15, 244-252 [Design of a microfluidic in situ-testing method]
- **A. Lindner***, *Flow of complex suspensions*, Phys. Fluids 26 101307 (2014) [Invited paper, most cited paper Phys. Fluids, December 2014]
- H. Berthet, M. Fermigier and **A. Lindner***, *Single fiber transport in a confined micro-channel* Phys. Fluids 25, 103601 (2013) [Proof of concept of use of microfabrication method to study fiber transport]

Elastic flow instabilities

- J. Zilz, R.J. Poole, M. Alves, C. Wagner, C. Schäfer and **A. Lindner***, Serpentine channels: micro – rheometers for fluid relaxation times, Lab on Chip, 2014, 14 (2), 351 – 358 [First publication in a Journal dedicated to microfluidics, development of a novel rheometer.]
- J. Zilz, R. J. Poole, M. A. Alves, D. Bartolo, B. Levache and **A. Lindner*** *Geometric scaling of purely-elastic flow instabilities* J. Fluid Mech. 712 203-218 (2012) [Combined experimental, numerical and theoretical study on elastic flow instablities]

Active suspensions

- J. Gachelin, G. Miño, H. Berthet**, A. Lindner***, A. Rousselet and E. Clément *Non-Newtonian viscosity of E-coli suspensions*, Phy. Rev. Lett. 110, 268103 (2013) [First measurement of the rheological properties of an active suspension using a microfluidic rheometer, Phys. Rev. Lett., Editors choice, 15 citations in 1,5 years]

Adhesion

- D. Martina, C. Creton, P. Damman, M. Jeusette and **A. Lindner*** *Adhesion of soft viscoelastic adhesives on periodic rough surfaces* Soft Matter**, 8(19), 5350 – 5357 (2012)** [Use of micro-patterned surfaces to test adhesion. My first study using microfabrication processes.]
- J. Nase, **A. Lindner*** and C. Creton *Pattern formation during deformation of a confined viscoelastic layer: From a viscous liquid to a soft elastic solid* Phys. Rev. Lett. 101, 074503, (2008) [Representative publication on my work on adhesion mechanisms, Highlighted in Physic Today, 50 citations]

Granular suspensions

- C. Bonnoit, T. Bertrand, E. Clement and **A. Lindner*** *Accelerated drop detachment in dense granular suspensions* Phys. Fluids 24, 043304 (2012) [Flow of granular suspensions in complex surface driven flows]
- C. Bonnoit, J. Lanuza, **A. Lindner** and E. Clement" *A diverging mesoscopic length scale controls the rheology of dense suspensions"* Phys. Rev. Lett. 105, 108302 (2010) [Use of an original macroscopic rheometer to access properties of dense granular suspensions]

Book chapter

A.Lindner and M. Shelley, *Elastic fibers in flows* in "Fluid-Structure Interactions in Low-Reynolds-Number Flows" (2015) edited by C. Duprat and H. Stone, Royal Society of Chemistry, in press

Guest editor

Invited guest editor for "Biomicrofluidics" in 2015 to edit an issue on "Microfluidic rheology".

Invited conferences (16 in total)

I have been invited to conferences covering all the topics of my research activities (granular suspensions, adhesion, fluid structure interactions and elastic flow instabilities) on fundamental research conferences as well as important industrial meetings. This proves my acceptation in the different communities. My invited conferences include a semi-plenary lecture at one of the most important meetings of the Fluid Dynamics community, the Annual Meeting of the American Society of Physics, Division of Fluid Dynamics (2800 attendees) in 2013.

- Workshop "*Small meets Large: connecting microfluidics with marine ecology",* Okinawa, Japan, March 2015
- Meeting of the German Physical Society, March 2015, Focus Session, "*Disordered systems/glasses"*, Berlin
- CECAM workshop *"Flow and clogging in bottlenecks: simulations and experiments",* Saragossa, Spain, September, 2014
- ISPAC, "*International Symposium on Polymer Analysis and Characterization*," Les Diablerettes, Switzerland, June, 2014
- FINAT-Linking the label community, Technical Seminar, (*Yearly meeting of the European Adhesion Industry*), Barcelona, Mars, 2014
- Aspen, Winter Conferences "*Active Fluids: Bridging Complex Fluids and Biofluids"*, January, 2014
- DFD (Annual meeting of the APS Division of Fluid Dynamics) Pittsburg, USA, Semi-Plenary Lecture, November, 2013 *"Flow of complex suspensions"*
- Pressure Sensitive Tape Council Summit (*Yearly meeting of the American Adhesion Industry*), New Orleans, USA, Mai 2013
- Gordon conference "*Macromolecular Materials*", Ventura, USA, January, 2013
- Gordon conference "*Granular Matter*", Charlotte, USA, July, 2012
- IUTAM workshop, "*Mobile particulate systems*", Bangalore, India, January 2012
- Meeting of the German Physical Society, Focus session, "*Dense granular flows*" Dresden, Germany, March 2011
- Workshop at the Lorentz Center "*Flow instabilities and turbulence in viscoelastic fluids",* Leiden, Holland, July 2010
- FANAS 2010 Conference in Saarbrücken, Germany, October 2010
- *Gecko Workshop*, INM, Saarbrücken, Germany, July 2010
- Workshop *"Jamming and rheology"* Cargèse, France, April 2010

Seminars and oral presentations at conferences

I am invited to give around 5 seminars in international research institutions (MIT, Max Planck Göttingen, Weizman Institute etc…) per year and I give around 5 oral presentations at international conferences per year.