European Cooperation in the field of Scientific and Technical Research - COST -

Brussels, 22 November 2013

COST 074/13

MEMORANDUM OF UNDERSTANDING

Subject :	Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action MP1305: Flowing matter

Delegations will find attached the Memorandum of Understanding for COST Action MP1305 as approved by the COST Committee of Senior Officials (CSO) at its 188th meeting on 14 November 2013.

MEMORANDUM OF UNDERSTANDING
For the implementation of a European Concerted Research Action designated as

COST Action MP1305
FLOWING MATTER

The Parties to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 4114/13 "COST Action Management" and document COST 4112/13 "Rules for Participation in and Implementation of COST Activities" , or in any new document amending or replacing them, the contents of which the Parties are fully aware of.

2. The main objective of the Action is to support the scientific research for the development of a unified picture of flowing matter.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 52 million in 2013 prices.

4. The Memorandum of Understanding will take effect on being accepted by at least five Parties.

5. The Memorandum of Understanding will remain in force for a period of 4 years, calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of section *2. Changes to a COST Action* in the document COST 4114/13.

A. ABSTRACT AND KEYWORDS

Flowing matter lies at the crossroads between industrial processes, fundamental physics, engineering and Earth Sciences. Depending on the microscopic interactions, an assembly of molecules or of mesoscopic particles can flow like a simple Newtonian fluid, deform elastically like a solid or behave in a complex manner. When the internal constituents are active, as for biological entities, one generally observes complex large-scale collective motions. The phenomenology is further complicated by the invariable tendency of fluids to display chaos at the large scales or when stirred strong enough. A fundamental understanding of flowing matter is still missing impeding scientific progress, effective control on industrial processes, as well as accurate predictions of natural phenomena. Flowing matter frequently presents a tight coupling between small-scale structures and large-scale flow urging for a unifying approach. The Action will coordinate existing research efforts into a synergetic plan of collaborations and exchanges to develop an innovative multi-scale approach able to encompass the traditional micro-, meso-, and macro-scales descriptions. Breakthroughs in the understanding of flowing matter will impact on fundamental key scientific issues, such as the glass, the elasto-plastic and the jamming transitions, as well as industrial applications including health, energy, cosmetics, detergents, food, paints, inks, oil and gas.
Keywords: Fluid dynamics, soft condensed matter, active matter, transport phenomena, complex rheology.

B. BACKGROUND

B.1 General Background

Real current problems/scientific issues: The understanding of the behavior of blood, probably the most obvious example of a **complex fluid**, can have important implication for cardiovascular diseases, currently responsible for nearly half of the deaths in the EU. The way blood flows and transports chemicals or drugs is strongly affected by the high-volume fraction (between 35 to 50% under physiological conditions) of erythrocytes (red blood cells). This corpuscular nature of blood is responsible for its extremely diverse large-scale behavior, from a simple Newtonian fluid (e.g. in large arteries), to complex rheology (e.g. shear thinning and thixotropic behavior), to chaotic motion. Furthermore, large-scale flow influences the stresses exerted by the plasma on individual erythrocytes and thus can strongly influence haemolysis (the deleterious liberation of hemoglobin after erythrocytes are damaged). Other paradigmatic examples of complex fluids, such as emulsions, wet granular matter and foams, are interesting for industrial applications but fundamentally difficult to describe because of their intermediate fluid/solid behaviour. Despite the common wisdom of matter being liquid or solid, complex fluids can indeed display mixed behavior. At rest they can behave like elastic solids, but they are able to flow like a liquid under sufficient applied stress. This paradoxical behaviour is intimately connected to the jamming transition (or glass transition) exhibited by these systems above a threshold concentration (or below the glass temperature for the glass transition). **Active matter** is composed by constituents that can swim or move autonomously. An important example includes phytoplankton, a crucial actor in the carbon dioxide cycle, responsible for about 50% of the earth's photosynthetic activity. Phytoplankton species can move by swimming or by controlling their density. The understanding of the behaviour of these out-of-equilibrium systems will allow to engineer artificial active matter capable to perform specific tasks, e.g. for biomedical applications. Janus particles coated with platinum that can move because of catalytic reactions are already a reality studied since several years. Often suspensions and active entities are transported not in simple flows but rather in **complex flows**. It is thus important to further deepen the current level of understanding on the statistical properties of complex flows, such as chaotic and turbulent flows, and on the way these flows transport heat and mass. Furthermore it is important for applications to develop models that reliably and efficiently can describe the influence of complex flows on the dynamics of complex fluids and active matter. In many practically important applications this coupling may be a two-way coupling with the internal flow constituents, either passive or active, influencing the flow itself.

Wide relevance and benefits: The industrial, biomedical and environmental applications involving complex fluids, active matter and complex flows are of fundamental relevance for Europe and its society. Applications include health monitoring and individual’s safety, drug production and delivery, development and functioning of advanced medical devices, environmental control and safety, carbon dioxide sequestration and conversion, clean and efficient combustion, rheology of porous materials, biofuel production as well as cosmetics, detergents, food, paints and inks, oil and gas or glass production. The scientific community working on flowing matter is highly fragmented. It includes at least three broad communities of scientists focusing on complex fluids, active matter and complex flows. The present sharp specialization of expertise clashes with the intrinsically multi-scale nature of complex fluids where large-scale rheology and small-scale structure are invariably tightly coupled. In order to achieve progress there is now a strong urge to unify the description at the different scales: this Action will foster this process by leveraging and coordinating national and international research efforts.

B.2 Current state of knowledge

Complex fluids – Complex fluids can be sub-divided into several broad groups. *Granular materials, glasses and dense suspensions of solid particles* contain solid particles that may interact strongly and abruptly stop flowing at the jamming transition. Recent studies focused on: clarification and quantification of the role of particle shape and polydispersity on particle packing and jamming transitions; search for general theoretical models, based on clear physical background, able to account for the different types of interactions and to cover a wide range of them; clarification of the origin, controlling factors, and phenomenological description of the shear banding phenomenon, still poorly understood and of important practical consequences. *Soft particle dispersions* (microgels, emulsions, foams, vesicles, biological cells) are made of deformable objects and, therefore, one should account for additional effects, such as the role of interfacial tension or visco-elastic properties of the particle material. In recent years several aspects were addressed: the role of particle deformability for the conditions of close packing and jamming; classification of the basic regimes of flow in these systems (e.g., diluted vs. concentrated; low vs. high Capillary number etc.); clarification of the scaling laws and the key factors which describe the system behaviour in these regimes; role of the dynamic material properties, such as interfacial rheology and bending elasticity of the interfaces, visco-elastic properties of the particle material, etc. *Polymer solutions, molecular aggregates and hydrogels* consist of molecular aggregates or large polymeric molecules. In recent years the theoretical approaches to describe flows in these systems were further elaborated and extensively verified with various new experimental and computational methods. Thus the relation between the microstructure and the macroscopic flow behavior was clarified to explain the various flows regimes, in terms of the aggregate structure, interactions, orientation and restructuring under the action of the hydrodynamic forces, etc. It has also been demonstrated that these fluids exhibit flow instabilities and chaotic motion even in the absence of inertia. It is now understood that those are caused by the interactions between the flow and the microstructure of the fluid.

Active matter - Active matter is composed by constituents that have the ability to convert energy into motion. As a result, the energy sources that keep these systems intrinsically out of equilibrium emerge from the small scales. This peculiarity imparts these systems with unique properties, distinct from many other out-of-equilibrium fluids. In the past 5 years, important developments in the field of colloid physics have made it possible to create active, self-propelled, colloidal particles. Simultaneously, major advances have started to be made in the physics of bacteria: micron-sized single-celled organisms with the ability to swim, as well as to self-replicate. These developments have the potential to open the door to the creation of a wealth of new soft materials, formed by active components, or of mixtures of active and passive components. The capabilities of bacteria to self-propel, perform biochemical functions, reproduce, and to adhere to other bacteria, enrich their interaction with synthetic soft matter components (colloids, polymers, emulsion droplets, etc.), and are in turn modulated by those interactions. As a result, the combination of both components gives rise to a new class of biologically functional gels and emulsions with applications in food, industrial biotechnology, and other sectors (e.g. such as microcapsules containing drugs that seek out targets within the body or motile gels that carry dental repair agents into tooth cavities ...). On larger scales, animal groups, like bird flocks or insect swarms, provide stunning examples of what is called self-organized collective behaviour.

Complex flows - Flows of Newtonian fluids at large scales or high velocity are invariably complex as they develop chaotic and turbulent motions. This is the case for flows in the oceans and in the atmosphere, as well as in many industrial processes. Under such conditions only a statistical description is possible. Despite the many efforts, the definition of analytical models capable to reliably model general turbulent flows is still a major challenge. This is at odds with the fact that the equations of motion for a viscous fluid are known, and still stand without modification, since more than 150 years. However, in many practical circumstances one needs to deal with the transport of entities, like passive particles or active swimmers, in dilute or even dense regimes. Under these conditions often only phenomenological equations are available to describe the dynamics of the particles. In recent years major progress has been made, also thanks to a previous COST Action (MP0806 on "Particles in turbulence"), but mostly limited to the case of passive and dilute conditions (thus in the one-way coupling approximation). While this previous knowledge is fundamental for future activities, here the focus will be primarily on the dynamics of complex fluids and active matter, thus involving the rather unexplored dense regime.

Current state of the art and relevant research within the EU and innovation: Many of the scientific topics at the core of the present Action have been supported within the EU, also through previous COST Actions. The Action will innovate at several levels: It will contribute to considerably advance the state-of-the-art within the broad areas of complex fluids, active matter and complex flows. It will foster the birth of a novel supra-disciplinary field of research on "Flowing matter", overarching small-scale molecular and structural properties, small- and large-scale flow physics, and large-scale rheology. It will stimulate the exchange of knowledge and techniques between academic and private sectors under a unified and broad framework.

B.3 Reasons for the Action

Need for an experts network, added value and benefits: Because of the ubiquitous presence of fluids, the understanding of their behavior has an immediate and enormous impact on many scientific communities, as well as on a wider number of industrial processes. The field however is extremely fragmented. The present COST Action will stimulate the interaction between these different communities, will foster collaboration between academia and the private sector and will support the development of a unified view on flowing matter. The Action will target to both European economical and societal needs as well as to its scientific and technological advance.

Research objectives, means and application. Impact and outcomes of the Action: the Action will support the scientific advance in three of the most active and challenging research areas in flowing matter. The action will foster the birth of a novel supra-disciplinary research field on flowing matter and it will contribute to the development of innovative numerical, experimental and analysis tools. Most of the scientific challenges faced by the Action have close connections with the multi-scale nature of the problems. The Action will thus innovate methods and approaches to multi-scale problems that may have a wider impact on science. The Action will stimulate the transfer of know-how, will foster multi-disciplinary and multi-sectorial collaborations and education of ESRs, thus casting solid roots on the topic in the longer period.

B.4 Complementarity with other research programmes

Many of the individual scientific topics relevant to the Action are the research subjects of EU and national projects. The COST Action will leverage and create synergies with several of these existing research projects. The research activities of Action participants are funded through ERC grants; FP7 EU-wide networks; EU Initial Training Networks; EU Infrastructure project and a multitude of national grants. Other COST Actions have also contributed to preparatory research in the field and others will contribute providing synergies in the coming years. There are however no systematic activities specifically aimed at integrating research at a broader level.

C. OBJECTIVES AND BENEFITS

C.1 Aim

The main objective of the Action is to support the scientific research for the development of a unified picture of flowing matter.

C.2 Objectives

Secondary objectives of the COST Action are:

- to support the fundamental research in complex fluids, active matter and complex flows;
- to stimulate the development of novel multi-scale methods and models;
- to disseminate the results towards other communities;
- to foster the multidisciplinary / multisectorial training of ESRs;
- to promote ESRs commitment towards outreach activities.

The concrete deliverables of the Action will be:

- state-of-the-art research covering a broad scientific ambit;
- scientific publications in high impact journals;
- multi-scale analytical and numerical models for flows in complex geometries of relevance for industries;
- a centralized database of resources open to the full scientific community (including experimental and numerical data, numerical codes, manuals, scientific articles and presentations);
- an online collection of seminars and web-based dissemination material;
- final activity report including self-evaluation;
- annual prizes for ESRs: two annual prizes for outstanding ESRs research and outreach activities.

C.3 How networking within the Action will yield the objectives?

The objectives of the Action will be achieved by the following means:

- bringing together the communities of scientists working on complex fluids, active matter and complex flows;

- bringing together scientists with expertise on experimental, numerical and modelling techniques;
- bringing together scientists in academia and in industry;
- inviting experts from other fields and organizing events in parallel at conferences in other domains;
- employing the COST instruments to maximize the exchange between scientists;
- fostering ESRs multidisciplinary and multisectorial career paths by announcing openings at groups and possibilities for stages at industries within the Action.

C.4 Potential impact of the Action

Because of the ubiquitous presence of fluids, the understanding of their behavior has a direct and enormous impact on many other scientific communities, as well as on a wide number of industrial processes. The scientific and technological problems at the core of the present Action are indeed so challenging and important that both academia and industry are currently devoting enormous efforts to their study. The field however is extremely fragmented. The present Action will stimulate the interaction between these different communities and will foster collaboration between academia and the private sector.

Potential impact includes: Advancement in the understanding and control of key complex fluid flow phenomena. Development of generic models able to provide a unified description across the different scales. Development of innovative paradigms, of new experimental techniques and approaches, of new computational algorithms and codes. Development of efficient and accurate application oriented models. Synergy and integration amongst EU and nationally funded research efforts. The most ambitious impact of the Action will be the development of a unified theoretical or phenomenological picture of flowing matter.

C.5 Target groups/end users

The target groups of the Action include:

- the academic sectors involved in the Action activity, that will directly benefit from the collaboration and exchange of expertise;

- the industrial partners involved in the Action, that will have direct access to an extensive network of experts and will be able to directly transfer the new knowledge and technologies developed within the Action to their R&D. Furthermore they will have the chance to get in contact and to hire young researchers with specific expertise in the field;
- the ESRs will have the possibility to access a wide network with complementary expertise. This will foster the development of a new generation of researchers with a multi-disciplinary and multi-sectorial career path;
- the broader scientific community will have access to the database of knowledge where scientific material like publications, presentations and lecture notes will be made available together with raw data;
- the society will have the possibility to learn about the research activities, the scientific challenges, the technological innovations and in general the implication of flowing matter research for the society, in the context of the dissemination activities promoted by the Action.

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

The Action focuses on the following scientific areas: **complex fluids**, **active matter** and **complex flows**.

Task 1) In **complex fluids** the small-scale structure and/or interactions can produce remarkable non-linear rheology at the large scales. Complex fluids can even display a solid like behavior as in the case of yield stress materials. The aim is to tackle the complex multi-scale problem where small and large-scales interact in a strongly non-linear way. The scientific focus of this task will be first on the understanding of the phenomenology of these processes. This will involve the study of colloids, polymers, emulsions, foams, surfactant solutions, powders, liquid crystals, droplets, interface dynamics, glassy systems, dense suspensions and similar materials. Physical phenomena that will be investigated include the glass/jamming transition, the flow of jammed/amorphous matter, the microscopic and macroscopic physics of yielding materials, the origin of the yielding behavior, including the role of non-local effects and the formation of macroscopically large shear-bands. The complexity of the particle-particle interaction coupled with hydrodynamic interactions makes it difficult to tackle the behaviour of dense suspensions. In rheology, the jamming transition at zero temperature appears as the emergence of finite yield stress at the critical packing fraction in the zero shear rate limit, and it has been revealed that the relevant variables such as stress components and velocity fluctuations show critical behaviour around the transition point. When the packing fraction is above the jamming transition, particles form temporal contact networks with inhomogeneous distribution of forces, resulting in characteristic heterogeneous dynamics. An important point will consist in understanding how universal this phenomenology is to which extent much system specific and dependent on small-scale details.

Task 2) From small-scale bacteria to large-scale groups (e.g. insect swarms or bird flocks) **active matter** provides stunning examples of self-organized collective behaviour. Active matter collective patterns may result either from the hydrodynamically mediated interaction (e.g. bacteria) or by the sole interaction between individuals in the group (e.g. bird flocks). On one side active matter thus has to be contrasted with the behaviour of passive matter with similar physical properties (e.g. shape, density, size) within the same flow field. On the other side there is a strong analogy with systems of interacting units, e.g. particles or spins, in condensed matter physics, where emergent collective phenomena, such as ordering and phase transitions, have been investigated in depth. Collective animal behaviour has fostered an intense interdisciplinary effort in the last ten years. Animals are described as active “self-propelled” particles where one studies the statistical properties and the ordering transition in fluids of such particles. Hydrodynamic theories have also been developed that theoretically predict the large scale, long time behaviour of self-propelled liquids. All these models and theories gave rise to a whole area of research where active matter, both living and inanimate (e.g. granular), is treated within a unified framework. Recent efforts led to considerable progress in the field of artificial active matter. Engineered particles were created where the fore and aft symmetry was broken either by partial coating or by asymmetric shape. These particles are capable to self-propel thanks to different phenomena such as catalysis, electrophoresis or thermophoresis. Besides the intrinsic fundamental knowledge that these systems provide, they enable the development of functionalized microfluidic devices.

Task 3) Fluids can flow across wide range of scales and at the larger scales or for higher velocities their motion invariably becomes chaotic or turbulent. Under such conditions a large number of length- and time-scales are involved in the dynamics, making the analytical or numerical modelling of **complex flows** a challenging task. An improved understanding of chaotic and turbulent flows is however necessary due to its ubiquity in natural and industrial applications. Emulsions like mayonnaise are often produced in large industrial vessels where turbulent flows are present. Active swimming zoo- and phyto-plankton organisms live in an ecological system characterized by turbulent currents. The task here will be to advance the current level of understanding of chaotic and turbulent flows in different geometries, to understand the dynamics, the tumbling rate and preferential migration of particles with complex non-symmetrical shapes (of relevance for active matter) and even in the limit of high densities. Attention will be given to the case of complex fluids and to the coupling between large-scale transport and the small-scale internal fluid structures. Innovative numerical, experimental and analytical techniques will have to be developed in order to be able to merge the phenomenology of chaotic and turbulent transport with the research topics of task 1) and 2).

D.2 Scientific work plan methods and means

The work plan will be organized both thematically, per task, and methodologically, per Working Group (WG). The WGs will group similar methodologies and will focus on all three scientific tasks. WGs interact at joint WG meetings and conferences and will overlap as many Action members will participate in multiple WGs.

Task 1: Will focus on the fundamental understanding of the origin of the yielding behaviour, including the role of non-local effects and the formation of macroscopically large inhomogeneity such as shear-bands. This includes the development of computational methods for yielding materials that will directly help technological application and scientific discovery. Will address the discontinuous shear thickening behavior of dense suspensions, where the jamming transition plays a role. Interestingly, suspensions can show shear thinning, continuous shear thickening, or discontinuous shear thickening, and the mechanisms behind this vastly different behavior is not yet clear. The macroscopic behavior of these non-Newtonian fluids is not necessarily well studied either. For example the macroscopic oscillation of the discontinuous shear thickening fluid was experimentally observed only recently. **Granular materials, glasses and dense suspensions of solid particles**: clarifying the role of interparticle interactions (along with the other factors studied so far) for the jamming transitions and for the shear-banding phenomenon. Of special interest are the depletion interactions, and the strong interaction created by bridging polymers and capillary bridges. Various model systems with well-defined characteristics should be developed to address these difficult issues properly. **Soft particle dispersions**: the theoretical description of the interplay between hydrodynamic and capillary phenomena, especially at high capillary numbers is still an open question which requires further development of the numerical methods to explain the experimental results. The role of interfacial rheological properties, especially for highly visco-elastic non-linear interfaces is currently of high interest. **Polymer solutions, molecular aggregates, hydrogels**: For these systems, the key question is how, on the basis of accumulated knowledge, to design molecular structures (size, branching, distribution of charges and specific functional groups, hydrophilic-lipophilic balance) with desired aggregation and flow behaviour. For all types of complex fluids, key scientific questions include: how do complex fluids behave in complex flow regimes, such as turbulent flow, elongational flow, etc. Until now the focus has been mostly on simpler flow regimes, which are easier to study experimentally and to model theoretically. How do the complex systems behave upon drying and significant change of solvent properties (polarity, ionic strength, pH, etc,) that create very strong mechanical stresses and induce phase changes? These processes are very important in the context of creating new structured materials and coatings with new functionality. How could one apply physico-chemical approaches (appropriate surfactants, polymers, counterions and combinations of those) to control the properties of the dispersed particles, their interactions and, thereby, the overall flowing behavior?

Task 2: In active matter flows the fundamental scientific questions are mostly connected to the development of statistical physics models for matter out of equilibrium. **Motility**: characterize the fundamental mechanisms that give rise to motility and identify generic aspects of individual and collective motion and those that are specific of the different classes of active materials. The nature and origin of synchronization or the role of confinement will be addressed. The role of the coupling to food or chemicals, and the role of chemo taxis and quorum sensing in the nature of motility will also be addressed. There is a need to clarify the connection between motility of synthetic micro-robots and microorganisms. **Active self-assembly**: The emerging structures and patterns that active matter gives rise to is a key aspect. The community is interested in understanding the basic principles that characterize the generation of clusters, or how activity affects underlying phase transitions. More challenging, the identification of processes that control the formation and stabilization of new structures will open new venues to use active matter to produce new types of materials. Identifying model systems for active matter is also a key issue to allow this field to develop fast. **Active flows**: The constituents of active matter deliver energy at small scales. As a result, the fluid flow, that suspensions of active micron-size particles or microorganisms give rise to, are qualitatively different from their passive counterparts when driven by external fields. There is a need to better understand the features of such flows and the origin of the turbulent and highly disordered nature of the flows they give rise to. **Control of active matter**: the basic principles addressed in the previous items will open the possibility to control active matter and structures under different flow conditions and in different geometries. The use of microorganisms in microfluidic devices, or under strong confinement, proved fruitful to develop new means to control, tune, and position matter at small scales.

Task 3: Complex flows are characterized by velocity fluctuations with complex spatial and temporal correlations. Classical examples of complex flows are turbulent flows, where, particularly at large Reynolds numbers, non-trivial correlations develop over an extremely broad range of length- and time-scales, making the development of efficient and accurate numerical or analytical models a daunting task. Other examples of complex flows include the broader class of chaotic flows, as well as elastic and bacterial turbulence. The latter two types of flows are peculiar in that they are forced at the microscopic scale by, respectively, the internal structure of the complex fluids, or by the active swimming of bacteria. From these examples it is clear there exists tight connection, key to many applications, between complex fluids, active matter and complex flows. Under this task a number of outstanding fundamental key issues related to complex flows will be investigated by a concerted combination of experimental, numerical and analytical approaches. With respect to past studies the focus will be on those aspects of the phenomenology and of the modelling more relevant to or emerging from complex fluids and active matter flows. Issues that will be investigated are the statistical properties of flows in different chaotic and/or turbulent regimes, as well as on the study of the transport of entities, with complex, e.g. non-spherical, or even deformable shapes. In the case of particle-laden flows at high volume fractions, the research activity will naturally overlap with those on complex fluids establishing a bridge between small-scale structure and large-scale rheology.

Method and means to achieve the objectives:

WG1 - Experimental techniques: Techniques for the precise control of dense suspensions of rigid or deformable particles; novel experiments with colloids as well as with living matter; improvement of tracking methods to obtain accurate individual trajectory data, also at high densities and during collective motion; large-scale rheology experiments, also in combination with micro-scale observations (e.g. by means of confocal microscopy); micro-scale experiments using microfluidics to impart controlled rheometric flow; improvement of existing experimental methods, such as X-ray tomography, neutron scattering and reflectivity, interfacial rheology, streak photography, particle image velocimetry (PIV) and micro-PIV, particle tracking velocimetry (PTV), NMRI (to access 3d flow information in dense suspensions).

WG2 - Numerical techniques: Small and large scale flows in simple and complex flow geometries will be investigated by various numerical approaches that effectively bridge the very large range of length and time scales. Descriptions at different coarse-grained levels will be obtained with approaches like molecular dynamics, spectral methods, finite element, finite volume, Lattice

Boltzmann methods, or multiparticle collision dynamics. These techniques, and hybrid approaches based on them, will also allow studying suspensions of passive and active particles with different shapes. In particular these methods will allow correlating the small-scale order with the large-scale rheological properties; atomistic, continuum, as well as innovative mesoscopic methods will be employed to study the complex rheology of yield stress fluids such as nano-emulsions and foams; particle models and coarse-grained theories, including all relevant variables and conservation laws, will be employed to describe the large-scale behaviour in living active matter.

WG3 - Analytical techniques: Analytical methods will be employed for the definition of models. In complex multi-scale flow problems one of the goals is to parameterize the influence of the small-scales on the macroscopic ones in an efficient and accurate way; statistical observables will be employed to characterize the small-scale properties of particles in active and passive suspensions. Study of the correlation between particles and local flowing properties; analytical techniques will be employed to rationalize experimental findings as well as to develop numerical models; comparative analysis between different collective phenomena, passive particles vs. active species of animal groups or molecular colonies, can help to characterize and define collective behaviour in complex fluids and in biological systems.

WG4 - Applications, dissemination and outreach: This WG will make contact with stakeholders, either academic or commercial, contributing to the problem definition, to the exchange of expertise, to the acquisition of new techniques and know-how; dissemination and outreach activities will contribute to reinforce the visibility of the Action research with benefits in terms of possibility to recruit ESRs; the Action website will contribute to exchange information amongst members with an important impact on the possibility to find collaboration and missing expertise; foster the transfer of the produced knowledge to real applications in pharmaceutical, food, personal care, chemical, oil and other industries.

E. ORGANISATION

E.1 Coordination and organisation

The Chair, the vice-Chair and the Managing Committee (MC) are responsible for the management of the Action. A Steering Committee (SC) is delegated by the MC for the day-by-day running of the Action and is composed by the Chair, the vice-Chair, the WG coordinators, the STSM manager, the Ombudswoman and the dissemination and outreach manager. The Ombudswoman will promote gender balance within the Action. The Chair will promote the integration of ESRs within the Action. Both will report to the MC. The STSM coordinator will handle all actions related to STSMs, from their advertisement, to the proposal to the SC for approval. The dissemination and outreach manager will be in charge of monitoring all dissemination and outreach activities, including the Action website, and will report to the MC.

The Action has the following milestones that repeats every year: **Action events**: annual MC meetings, WG meetings, STSMs, training schools, annual scientific conference; **Action website**: will be setup at the beginning of the Action and will be constantly update. It will have both technical dissemination sections, dedicated to Action participants and to the scientific community, as well as an outreach section, targeting at the broader society and high-school students. All Action participants will be able to write articles and share data and information on the website. The Action website will also inform on the progress of the Action, as well as on past and forthcoming events; **Annual progress and achievements report** (year 1 to 3).

The Action does not finance research, funded by national and international institutions, but will coordinate research efforts between different groups with different expertise and tools. The coordination will take advantage of all available COST instruments. The Action will setup a web-of-knowledge including a database of raw data and a platform for the organization of regular web-based seminars. The web will ease scientific exchange: disseminating on-going research and keeping an internal update on the current activities at different labs.

E.2 Working Groups

The Action is organized via a combined vertical and horizontal structures, respectively focusing on the methods (Working Groups) and on the scientific topics (tasks). The technical goal of the working groups will be to ameliorate, validate and extend the usability of tools and techniques. Working groups will also play a key role in initiating multidisciplinary collaborations by stimulating scientists to focus on the methods. **WG1: Experimental techniques.** Experiments have always been and still are the primary method for scientific discovery. Experimental tools and techniques are developed or deployed having in mind the system at study, its physical properties, the length- and the time-scales of the studied phenomenon. This WG will innovate experimental techniques with the goal of developing methods capable to observe at the same time the small- and large-scale in flows. The WG will also look into methods developed and employed in related disciplines that may be employed to study flowing matter. Challenges include the possibility to measure large 3d volumes at high frequencies, to observe in a non-destructive way bioactive flows, to measure inside non-optically transparent fluids. **WG2: Numerical techniques**. Will be in charge of innovating and benchmarking multi-scale numerical tools. The numerical tools will be particularly aimed at incorporating the broad expertise on micro- and macro-scale modelling present in the Action. The focus will be both on the effect of the small structures, on the large-scale flow, as well as the influence of large-scale flow on the small-scale dynamics. Numerical methods will be validated against each other, as well as against specific benchmark experiments. To this end a close collaboration with WG1 is envisioned. **WG3: Analytical techniques**. Here the ultimate goal is to develop the missing theory of flowing matter. The WG will focus on few key flows capable of displaying paradigmatic phenomenology. Phenomenological models will be discussed, developed and compared with simulations and experiments. Will work in close connection with both WG1 and WG2. **WG4: Applications, dissemination and outreach**. Scientists representative of other scientific communities as well as of industry will be invited to participate in this WG. The WG coordinates and implements dissemination and outreach activities and does play a key role for the impact of the Action. It will be in charge for the Action website with scientific material and presentations, announcement of career opportunities for ESRs, availability of courses at participant's institutions on technical or soft skills, directory with contact information of all Action participants. It will organize the annual research and outreach prizes for ESRs.

E.3 Liaison and interaction with other research programmes

The Action will actively seek collaboration with related Actions (MP1106, CM1101, FP1005 and MP1205) and it will build synergies with running EU projects such as FP6 Ideas (several Action participants are recipients of individual ERC grants), collaborative, as well as infrastructure projects (e.g. EuHIT), national projects (e.g. DFG-Priority Programme "Microswimmers – From Single Particle Motion to Collective Behaviour" SPP 1726, ANR Motimo, IIT SEED project ART_SWARM). The Action will closely collaborate with consortia such as SoftComp (aiming to establish a knowledge base for an intelligent design of functional and nanoscale soft matter composites), the European Society of Rheology, the European Mechanics Society and the ICTR (International Collaboration for Turbulence Research).

E.4 Gender balance and involvement of early-stage researchers

The Ombudswoman will monitor and provide feedback to the MC on all gender balance related issues relative to the activities planned by the Action, joining of new members, participants to meetings and STSMs. The Action will take concrete steps to support early-stage researchers e.g. by annually reserving a target fraction of its budget to ESRs. The Action will also stimulate involvement of ESRs by establishing two annual prizes, for the most outstanding research and outreach activities.

F. TIMETABLE

The duration of the Action is 4 years. Milestones (M) and deliverables (D) are indicated.

Year	WG1	WG2	WG3	WG4	M/D
Year 1	Kick-off meeting & set up of Working Groups				**M**
	WG meetings				
	Dissemination and outreach (lead by WG4)				
	Training school, STSMs				
	Annual workshop (including MC and WGs meetings)				
	Annual ESR research and outreach prizes				**D**
	Progress and achievements report				**M**
Year 2	WG meetings				**M**
	Dissemination and outreach (lead by WG4)				
	Training school, STSMs				
	Annual workshop (including MC and WGs meetings)				
	Annual ESR research and outreach prizes				**D**
	Progress and achievements report				**M**
Year 3	WG meetings				**M**
	Dissemination and outreach (lead by WG4)				
	Training school, STSMs				
	Annual workshop (including MC and WGs meetings)				
	Annual ESR research and outreach prizes				**D**

	Progress and achievements report	**M**
Year 4	WG meetings	**M**
	Dissemination and outreach (lead by WG4)	
	Training school, STSMs	
	Final conference (including MC and review meeting)	
	Annual ESR research and outreach prizes	**D**
	Other Action deliverables (see section C.2)	**D**
	Final report including self-evaluation	**D**

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: BE, BG, DE, DK, ES, FR, IE, IS, IT, NL, PT, SI, UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at 52 Million € for the total duration of the Action. This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

H. DISSEMINATION PLAN

H.1 Who?

The Action will deploy a vast program of dissemination and outreach activities. The respective lists of target groups will be specifically defined by the MC and regularly updated. Target groups for dissemination activities will include:

1. Researchers in the scientific fields related to the Action;
2. Researchers in scientific fields close to the topics of the action that may find the research activities conducted within the Action of interested for their work;
3. Industries and researchers at industries;
4. Universities and research Institutions working in topics related to the Action;
5. Other European projects and networks (COST Actions, Horizon 2020, …);

6. Research agencies and funding bodies at national and international level.

Outreach activities are meant to inform the general public about the science and the implications for society and industry of the research activities conducted within the Action. Target groups include:

1. Media: journals, digital media and TV;
2. Early Stage Researchers;
3. General public;
4. Students at high schools.

H.2 What?

The dissemination and outreach plans are aimed at maximizing the transfer of knowledge within and outside of the Action, targeting at different audiences (outreach activities will specifically address the broader society). Methods that the Action will employ may include:

1. Publication in scientific journals;
2. Scientific conferences organized by the Action where external researchers will be invited;
3. Organization of Action events on a side of other events like conferences or workshops;
4. Training schools for ESRs entering in the field;
5. Posting of documents on public and private section of the Action's website;
6. Sharing of raw data;
7. Leaflets and posters to display at participants' institutions
8. Annual reports on the Action's progress and achievements;
9. ESRs annual prizes for research and outreach activities.

Examples of outreach activities:

1. Articles in university magazines;
2. Media, local newspapers, TV;
3. Laboratory tours during open-days;
4. Science cafes, exhibitions at museums, public lectures;
5. Presence of the Action on electronic outreach channel like social media;
6. Lectures and events at high schools.

H.3 How?

Dissemination and outreach are key to the Action's goals and for this reason WG4 is directly responsible for the organization, promotion, coordination and monitoring of dissemination and outreach activities. WG4 will assign the annual scientific and outreach prizes for ESRs, thus stimulating the involvement of ESRs in outreach activities.

The Action will promote the publication of scientific papers not only in top peer-review journals but also on online open-access platforms (preprint servers, Action website). All Action instruments like Scientific Conferences, WG meetings, and training schools will directly contribute to the scientific dissemination. All these events will be open to the broader scientific community.

The Action website will play a vital role in dissemination and outreach addressing Action's members, the broader scientific community as well as the general public.

The website will contain:

1. Description of the scientific scope and objectives of the Action;
2. Information on how to join the Action, the WGs and how to apply for STSMs;
3. Updated information on all forthcoming and past events organized by the Action;
4. Collection of scientific presentations given at past Action events (e.g. SC, WG meeting and training schools);
5. List of all Action members with full contact information, field of expertise, years since PhD, participation in WGs and eventual involvement in the Action management;
6. List of recent publication from each Action participant;
7. Dissemination and outreach material such as posters and leaflets;
8. Media releases;
9. Information on how to apply for ESRs science and outreach prizes;
10. Dedicated page on awarded ESRs with respective motivations;
11. List of forthcoming and past outreach events;
12. Announcement of career opportunities and openings within the Action groups;
13. Availability of technical and soft skill training courses at participating institutions.