STARTPAGE

HUMAN RESOURCES AND MOBILITY (HRM)
ACTIVITIES

MARIE CURIE ACTIONS
Research Training Networks (RTNs)

PART B

“M a G I C”

(Mechanics and Geometry Interdisciplinary Collaboration)

CONTENTS

B1 SCIENTIFIC QUALITY OF PROPOSAL

B1.1 Research Topic

This interdisciplinary project takes advantage of a long-standing synergy between Geometry and Mechanics. At its heart is the development of the geometry of singularities of momentum maps in finite and infinite dimensional systems. The current state of the interaction of mathematics and applications shows that this mathematical development will provide a powerful new conceptual framework and language ensuring further progress in many topical applications in physics, chemistry and engineering which have reached a critical stage in their development. This synergy between traditionally applied areas and modern geometry is at the root of many recent developments covering an amazing range of topics, going all the way from differential topology and singularity theory to fluid mechanics and molecular spectra. In spite of (or because of) this success, there are many major open problems whose resolution is crucial for further progress. The project is based on three areas of mathematics and three areas of application:

Geometry	Mechanics
Poisson Geometry and Reduction	Nonlinear Control
Variational methods for symmetric systems	Molecules and Atoms (structure, spectra and dynamics)
Integrable and near-integrable systems	Fluids, complex fluids and turbulence

Modern developments, in particular the rapid progress in computer technology, have opened entirely new horizons and created problems of a completely new nature. Researchers have accumulated such an overwhelming amount of information that radically new theoretical concepts are required to complement the current—largely phenomenological—description. We propose to develop geometrical methods that address precisely this situation. Our new conceptual tools will provide the framework for the further rapid development of these fields, by aiding the qualitative analysis, classification, interpretation and modelling of data.

In the recent past, the participants in this RTN have initiated the development of such tools, already leading to exciting new insights and breakthroughs in some of the above applications. The combined unique expertise and experience of the proposed teams in relevant fields of mathematics, physics, chemistry and engineering (in particular nonlinear dynamics and geometry) guarantees successful management and execution of this training network.

Poisson geometry and reduction: Poisson geometry is our main mathematical method, organizing principle, the thread that runs through all of the proposed areas of application. The energy-momentum map has become an important theoretical object in modern symplectic geometry, and Poisson geometry and (singular) reduction is the main mathematical basis for the study of singularities of energy-momentum maps.

Variational methods for symmetric systems: Classical variational methods have been recently instrumental in finding new periodic solutions of the N-body problem, in studying symmetry reduction in Hamiltonian and Lagrangian systems, and are central in modern non-linear fluid dynamics.

Integrable and near-integrable dynamics: Our new results indicate that near-integrable classical dynamics inherits the geometry and singularities of the classical integrable systems. The semi-classical theory transfers these qualitative features to quantum systems. Especially interesting is the development of the appropriate geometric-dynamic tools for the understanding of the behaviour of the super (or non-Abelian) integrable systems and their perturbations.

Nonlinear control: Our geometric approach to nonlinear control addresses two topics: (optimal) control of systems defined on Lie groups, and the control of mechanical systems. Both involve symplectic and Poisson geometry; inherited from the underlying system as well as from the optimal feedback and the interaction with the controller system. Recently Poisson-like geometry has emerged as a natural tool for the analysis and control of systems with *non-holonomic* constraints - being prominent in robotic and biological applications-, with many fundamental issues waiting to be addressed.

Molecules and atoms: Detailed structure obtained from modern experiments require theoretical explanations based on sophisticated nonlinear mathematics: a local linear study is no longer adequate. There have been a number of notable recent successes in this direction, in particular the discovery of quantum monodromy in real molecules and atoms. However, many universal qualitative phenomena in quantum systems related to singularities of classical systems (such as the existence and behaviour of band structures) are still not entirely understood.

Nonlinear fluids Geometric techniques have already proved their power in fluid dynamics. For example, pure geometric arguments have introduced the averaged Euler and Navier-Stokes equations, various peakon equations and have proved crucial in understanding nonlinear hydrodynamic and plasma stability. Multiscale-multiphysics problems (such as geophysical models for weather and climate prediction, or the theory of liquid crystals) are at the stage of development where the geometric formulation can have a real impact on their theory and range of applicability. Thus the development of the analytic tools suggested above will influence the theoretical understanding of such systems, as well as enlarge their range of applicability.

In summary, the goal of this project is to study the Poisson geometry of the singularities which arise in the applications mentioned above, and use this as the basis of a new conceptual framework for their understanding.

B1.2 Project Objectives

This interdisciplinary project is divided into 3 close areas of mathematics and 3 distinct areas of application. The mathematical domains are (I) Poisson Geometry and Reduction, (II) Variational Methods in Symmetric Systems and (III) Integrable and Near-integrable Systems. While there are large regions of intersection between them, they are presented as distinct for administrative purposes, and each is overseen by a Coordinator (see B1.5). On the other hand, the three areas of application are naturally distinct: (A) Nonlinear Control, (B) Molecules and Atoms (structure, spectra and dynamics) and (C) Fluids, Complex fluids and Turbulence. Each of these three areas of application is also overseen by a coordinator (see §B1.5). Specific objectives and potential major breakthroughs are described at the end of this section.

I POISSON GEOMETRY AND REDUCTION

All three areas of application in this project use geometrical and topological techniques. The aim of this part is to develop further these techniques in response to demands from the applications. The first three projects, while not explicitly under an application heading, are universally applicable.

- I.1 Extend our understanding of the fundamental geometry of symplectic and Poisson group actions to include: singular reduction of cotangent bundles and Poisson and Dirac manifolds, reduction based on energy-momentum level sets (generalization of the Duistermaat-Heckmann results in this context and implementation of the Smale programme), geometric phases, optimal reduction, reduction of systems with non-proper symmetries, reductions by stages, and global invariants of Poisson systems with and without symmetry.
- I.2 Understand the generic structure and dynamics of Hamiltonian systems with nonholonomic constraints, particularly where the constraint arises from a nonintegrable distribution on the configuration manifold, both with and without symmetry. Applications to nonlinear control will be explored. Normal forms for general Poisson structures with and without constraints and with and without symmetry; application to the persistence, bifurcation and stability of relative equilibria (REs) and relative periodic orbits (RPOs).
- I.3 Investigate the geometry of constraints in Poisson and symplectic systems, and especially nonholonomic constraints. Extend known frameworks beyond affine and linear constraints to more general constraints and to accommodate additional symmetries and associated conservation laws; the ensuing reduction procedure. Dynamical features of these systems: existence of invariant measures, dynamic convexity, uniform and non-uniform hyperbolicity, stability and other ergodic properties. In-depth study of fundamental examples like the Routh sphere, thermostatted mechanical systems, or nonlinear electrical circuits.

Nonlinear Control

- I.4 Analysis and design of motion planning schemes for the control and stabilization of robotic locomotion systems with complex dynamics in structured environments.
- I.5 Optimal control on matrix Lie groups with applications to rigid body control. Poisson geometrical formulation of the problem. Numerical integration via Poisson integrators of the reduced dynamics. Integration via elliptic functions. Stability study of equilibria and search for periodic orbits. Geometric prequantization of the reduced dynamics.
- I.6 Geometry of switched Hamiltonian systems, in particular their symmetries and conservation laws. Analysis of the resulting dynamics. Typical application is to the dynamics of a walking robot.

Molecules and Atoms — structure, spectra and dynamics

- I.7 Analysis of the correspondence between the topological invariants of semi-quantum models of finite particle systems, reduction of classical Hamiltonian systems, Duistermaat-Heckman measure for classical problems, and the combinatorics of generating functions for the number of states for reduced quantum problems.

Fluids, Complex Fluids and Turbulence

- I.8 Analysis of relative equilibria of *complex fluids*, treated as geodesic flows on semi-direct products. Understanding the "coadjoint geometry" of model Euler-Poincaré systems, classifying their REs and calculating the stability and bifurcations.

II Variational methods for Symmetric systems

Variational principles (notably Hamilton's principle) lie at the foundations of mechanics and give Hamiltonian dynamical systems their particular flavour. They are used to derive equations of motion and to generate structure preserving approximations. They imply that trajectories such as (relative) equilibria and periodic orbits are critical points of appropriate function(al)s. Interactions between variational principles and symmetry are of particular interest.

II.1 Extend the variational characterization of Lagrangian periodic orbits as critical points of an action functional on loop space to the characterization of RPOs as critical points on relative loop spaces; in addition develop a variational theory for RPOs as critical points of reduced variational principles on loop spaces on quotients; compare the two theories. Develop methods for determining the topology and symmetry of (relative) loop spaces, and numerical techniques for finding minima of action functionals, and particularly minima with given symmetry and homotopy type. Extend these methods to relative heteroclinic trajectories (RHOs) of symmetric Hamiltonian systems and to relative periodic space-time patterns of Hamiltonian PDEs.

II.2 Develop the bifurcation theory of REs and RPOs of symmetric Hamiltonian systems, and numerical continuation methods for them. Study the persistence of REs and RPOs under forced symmetry breaking and the breaking of Hamiltonian structure (eg by the addition of dissipation). Develop mathematical description of generic symmetry breaking and Hamiltonian structure breaking behaviour.

Nonlinear Control

II.3 Optimal control and stability in constrained Hamiltonian systems. Study of the intrinsic sub-Riemannian geometry and calculus of variations for such non-holonomic systems. Applications to the stability study of equilibria, in terms of the Carnet-Carathéodory distance. Use these methods to better understand the relation between integrability and symmetry for non-holonomic systems.

II.4 Develop analysis and design methods for mechanical systems, including those with nonholonomic constraints. These techniques will utilize the geometric structure of these systems in the form of affine connections. The control problems of interest include controllability, trajectory planning, and optimal control.

Molecules and Atoms — structure, spectra and dynamics

II.5 Extend the recently developed 'choreography type' methods from gravitational N-body problems to molecular potentials. Prove the existence of choreographies and similar RPOs of molecular N-body problems, and develop numerical continuation methods techniques for finding and following such solutions. Compute the semiclassical 'signature' of the families of (relative) invariant tori that are organized by elliptic choreographies/RPOs and look for their occurrence in molecular spectra.

Fluids, Complex Fluids and Turbulence

II.6 Develop the theory and applications of reduced variational principles for symmetry reduced Lagrangian systems ('Euler-Poincaré Theory'), including infinite dimensional systems with (not necessarily free) actions of Lie groups and diffeomorphism groups. Use variational principles to systematically derive and analyse finite dimensional approximations to Hamiltonian PDFs and gauge theories, unifying and generalizing (eg to PCFs) such diverse models as point vortex solutions of Euler-Poincaré equations, peakon solutions of shallow-water equations, pseudo-rigid body models of rotating fluid masses and skyrmion models of atomic nuclei.

II.7 Develop methods for approximating Lagrangian systems by approximating their variational principles, eg by averaging, homogenization or discretization. Explore the interaction between these approaches and reduction methods in systems with symmetry. Obtain rigorous error estimates for the approximations. Apply reduced and approximate variational principles to obtain sound derivations, analyses and geometric formulations of several multiscale-multiphysics problems of current interest, including: geophysical models for weather and climate applications; perfect complex fluid models (PCFs) of liquid crystals and superfluid Helium-II that will explain the motion of defects, such as disclinations and vortices; new fundamental models for thermo-elastic materials.

II.8 Study covariant reduction for field theories, both in the Lagrangian and Hamiltonian pictures, with the goal to provide a general method that applies to any symmetries, not just the special classes already treated. Establish the relation of this reduction to multisymplectic reduction. Study the relation with covariance. Carry out explicit covariant reduction of particular physical relevant models, such as Yang-Mills theories, complex fluids, spin glasses, and relativity. Develop reduction for discrete multisymplectic systems and link it to numerical applications, having as model the very active field of geometric (and, in particular, symplectic) integrators.

III INTEGRABLE AND NEAR-INTEGRABLE SYSTEMS

Integrable Systems covers a vast area, particularly in Hamiltonian PDEs, but in this project we concentrate on geometric aspects and their applications.

III.1 Understand better the singularities arising in the torus fibrations associated to integrable systems, and resulting obstructions to triviality (hence to global action-angle coordinates), and effect on dynamics. Develop numerical methods for recognizing these singularities particularly in higher dimensions; study their transitions through bifurcations in integrable systems (quasi-periodic bifurcations); apply to Hamiltonian-Hopf bifurcation as it occurs in various ways in rigid body dynamics; understand their effect on semiclassical systems, and then on the quasi-classical spectra.

III.2 Study the long time dynamics of small perturbations of superintegrable hamiltonian systems, with special focus on the presence and the properties of “slow chaos” associated to resonances.

III.3 Develop tools for establishing long-term stability of REs where the non-compact group of symmetries prevents the usual energetic methods from applying. Establish Nekhoroshev stability of elliptic REs in models arising from applications.

Nonlinear Control

III.4 Investigate the origins of integrability for nonholonomically constrained systems. Study the geometry of the family of invariant tori and determine the differences with the Hamiltonian case. Understand the relation between integrability and symmetry for nonholonomic systems and perturbations of such systems. Investigate repercussions of this for control design where underlying dynamics is integrable in this nonholonomic sense.

Molecules and Atoms — structure, spectra and dynamics

III.5 Understand nonlinear dynamics of real molecules on the basis of the analysis of singularities of integrable approximations and related classical model systems. Uncover such singularities as “fractional monodromy”, “island monodromy” and compound singularities in real systems. In particular, describe the nonlinear dynamics of triatomic molecules with one large-amplitude degree of freedom (floppy molecules) using the “swing-spring” and “deformed spherical pendulum” models. This includes chemical reactions of the form HCN $\leftrightarrow$ CNH (reaction of isomerization).

III.6 Determine the relation of quantized integrable systems with singularities to molecular energy spectra. Analysis of correspondence between defects of periodic lattices, singularities of integrable systems and the density of molecular states as a function of the integrals of motion.

III.7 Investigate the dynamics and spectra of slow-fast coupled quantum dynamical systems, including the relationship between the (quantum) monodromy and the topological characterization of the spectral bands for such systems, and the bifurcations that can occur in these spectral bands.

III.8 Semiclassical analysis of time-dependent perturbations of integrable systems and time evolution of quantum systems; application to molecular and atomic control.

III.9 Use REs as organizing centres for resonances and transition states; global descriptions of energy-momentum level sets and decomposition by transition states. Applications to classical phase space transport and quantum density of states. Relevance of angular momentum dynamics in the (de)stabilization of van der Waals complexes in interstellar molecular clouds and in the high atmosphere.

Fluids, Complex Fluids and Turbulence

III.10 Birkhoff normal form has proved to be a powerful algorithmic method to deduce ‘modulation equations’ for finite dimensional systems. We will investigate its use in the context of fluid and plasma dynamics with the aim of getting a purely algorithmic method to deduce modulation equations valid with any prescribed precision. Concrete examples that will be studied are the Vlasov-Poisson system and the equations for the dynamics of the free surface of a perfect gravitating fluid.

Birkhoff normal form will be used also in connection with the so called ‘justification problem’ consisting in obtaining rigorous bounds on the error of the description. Furthermore we will study the possibility of using Birkhoff normal form in order to obtain long time existence of solutions for the considered models.

Major breakthroughs These are likely to include

- full description of singular reduction for cotangent bundle actions; understanding the meaning of integrable non-holonomic systems; ability to analyse non-linear non-holonomic Poisson constraints.
- the classification of choreography solutions in N-body problems; new variational methods for finding relative periodic orbits and relative homoclinic trajectories; and the extension of existing stability and bifurcation results to REs and RPOs with nontrivial isotropy subgroups in systems with non-compact symmetry groups;
- Understand slow-fast coupled quantum systems; gain insight into quantum evolution of systems with dynamical singularities, such as chemical reaction of isomerization; and understand the correspondence between singularities of integrable systems and corresponding quantum spectra.
- Complete understanding how torus bundles of different dimensions build up the global geometry when passing through bifurcation and of the computational aspects of obstructions against triviality of torus bundles. Understand the effects of the obstructions against triviality of the torus bundles at the level of operators and their spectra.
- New momentum maps for singular reduction for Hamiltonian equations in infinite dimensions, and an understanding of the role of thermal waves and reactive forces in the propagation of defects as singular solutions of continuum equations.
- New understanding of the mechanism by which averaging regularizes the mathematical description of turbulence.

Interdisciplinary projects

	Nonlinear Control	Molecules & Atoms	Fluids & Turbulence
Poisson geometry & reduction	I.4,5,6	I.7	I.8
Variational methods & symmetry	II.3,4	II.5	II.6,7,8
Integrable & near-integrable systems	III.4, III.9	III.5–9	III.10

It should be emphasized that while the other objectives are not explicitly interdisciplinary, they can be expected to have interdisciplinary outcomes, for the mathematical techniques in question underpin all the applications. Moreover, because of the common strands of mathematics running through the three areas of application, we expect that, in spite of the apparent distance between the three areas of application, the development of mathematical ideas and techniques for one area to be very quickly transferable to other areas.

B1.3 Scientific Originality

This section outlines the current state-of-the-art in each of the areas contributing to the project and explains how the project will advance it. It begins with a section on each of the areas of application, and continues with a description for a selection of the remaining individual Objectives.

A. Nonlinear control systems

The interdisciplinary discipline of systems and control theory deals with “open dynamical systems”, that is, dynamical systems which interact with their environment and whose dynamics can be changed by the interaction with a controller system. Usually such a controller system is given as a feedback law or as an open dynamical system itself. As a result systems and control theory is not only concerned with the description and analysis of dynamical behaviour, but also with *prescribing* dynamical behaviour by the addition of controllers.

Whereas traditionally control theory is mainly concerned with the regulation of systems around desired set-points, and thus often can rely on linear approximations around such set-points, linear thinking becomes inadequate if systems operate far from equilibria and if the nonlinearities in the dynamics cannot be neglected. Due to the ever increasing complexity of modern engineering systems and rising demands on their performance this is often the case. A typical example is the control of a 3D mechanical system, as encountered in mobile robots or the study of animal gait behaviour. During the last three decades geometric methods have become more and more important in nonlinear control theory, especially in the study of controllability, feedback linearization, decoupling control, optimal control, as well as stabilization. Secondly, there has been an increasing appreciation that, contrary to the linear case, no single theory can be developed covering ”all” nonlinear systems, and that instead the given geometrical properties of the nonlinear systems have to be taken into account and exploited for a proper controller design. As a result, an extensive control theory of mechanical systems has emerged during the last decade, both from a Lagrangian and a Hamiltonian side. This theory relies very much on notions and results developed in differential geometry and geometric mechanics, but at the same time it has given rise to new notions and problems which give a major impetus to the further development of geometric mechanics and dynamics. As an example the theory of stabilization and locomotion of mechanical systems with nonholonomic kinematic constraints and their symmetries can be mentioned, as well as the interconnection theory of port-Hamiltonian systems. The proposed network will offer a platform for such a collaboration by bringing together expertise from geometric dynamical systems and nonlinear systems and control theory. Important issues in this interdisciplinary collaboration involve the geometric theory of open Hamiltonian and Lagrangian systems and their control using concepts of energy shaping and symmetries, and the analysis and control of (quasi-) periodic orbits.

B. Molecules and Atoms — structure, spectra and dynamics

Modern experiments are now able to detect very detailed structure and complexity of these spectra which consist of many thousands of individual levels and reveal regularities and patterns that call for theoretical explanation. These spectral data can be very accurately reproduced by model phenomenological quantum Hamiltonians, but such models offer insufficient theoretical *explanation*.

Much more lies ahead. In the near future experiments will reach highly excited states of molecular systems with many degrees of freedom some which include large amplitude motions, where the number of individual states and the complexity and richness of the energy spectrum will increase by several orders of magnitude.

Furthermore, modern experimental technologies in the time domain make controlling and influencing these excited molecular and atomic systems reality. This calls for mathematical tools which not only classify and structure the large amount of concrete information but also describe complex quantum dynamics of coherent ensembles of great number of simultaneously excited states. Possible applications can become central in nanotechnology.

The only possibility to meet these demands can be met by studying qualitatively classical analogue systems, and in particular their singularities, and then applying the quantum-classical correspondence principle. There has been a number of notable recent successes in this direction, in particular the discovery of quantum monodromy in real molecules and atoms. However many universal qualitative phenomena in quantum systems related to singularities of classical systems (such as the existence and behaviour of band structures) are still not entirely understood.

C. Fluids, complex fluids and turbulence

This Theme takes advantage of the interdisciplinary unity of nonlinear science, which often implies that a breakthrough in one area will lead to breakthroughs in other areas. The Euler-Poincaré (EP) approach for continuum materials was pioneered in recent work by Holm, Marsden and Ratiu. This approach unifies the study of nonlinearity in fluid dynamics. For example, it unified the formulations of the known geophysical fluid dynamics models for ocean and atmosphere dynamics. The EP approach also informs the derivation and analysis of new fundamental models.

Recently, the mathematical unity of the EP approach has converged in two new formulations of physically different, but mathematically parallel theories of fluids. These new theories are Lagrangian-Averaged (LA) turbulence closure models, and perfect complex fluids (PCFs). This convergence provides the motivating vision for the scientific originality of this part of our proposal. The EP approach determines the dynamics in the same fundamental mathematical setting for both LA fluid flow (including LA turbulence closure models) and also the dynamics of PCFs (including, e.g., liquid crystals and quantum liquids). PCFs are "perfect," in the sense that their order parameters have no defects, or singularities. We propose to pursue this convergence along both of its parallel tracks for applications and further developments in mathematics.

Our research will take advantage of the dual perspectives: (i) the shared underlying EP geometrical properties of these theories, and (ii) their fundamental physical differences.

The shared geometrical properties of LA turbulence and complex fluids will provide a universal approach, while their physical differences will produce a diversity and contrast in interpretation of their solutions. We expect this contrast will enrich the dynamical interpretations of both theories. In addition, the shared underlying mathematics will provide parallel avenues for research, yielding multidisciplinary applications.

This rich interplay between mathematical investigations and physical applications in LA turbulence and complex fluids is the result of their shared EP framework. The EP framework shared by the dynamics of fluids, LA fluids and PCFs is couched as dynamics on Lie groups that have semidirect-product actions on vector spaces, and (for PCFs) actions also on coset spaces of broken internal symmetry groups. Physical properties carried by the fluid, such as its heat and mass, are defined in these vector spaces, and the order parameters for the internal degrees of freedom of PCFs are defined in these coset spaces. This convergence of mathematical properties of LA turbulence closures and complex fluid models in the EP framework reveals, and explains, such parallels for example as the shared nonlinear limiting equations for ideal (non-dissipative) evolution of both the LA Euler-alpha model and the second-grade model of rheological fluids.

Equilibria of gauge field theories are studied extensively using variational methods. Well known examples include sigma models (related to harmonic maps) and skyrmions. Remarkably little work has been done on the REs of these systems, and even less on RPOs. We will in particular consider how equilibria bifurcate as conserved quantities are 'turned on', and how RPOs bifurcate from REs as 'nonlinear normal modes'.

I Poisson Geometry and Reduction

The singular reduction of symmetric symplectic manifolds is a well established topic; nevertheless, a satisfactory implementation of this process for cotangent bundles has not yet been achieved, but is crucial for applications. Some global invariants for Poisson manifolds have been recently found and it is expected that their use in Poisson dynamics will yield fundamental results analogous to Arnold's Conjecture in the symplectic case.

Despite the numerous publications on the subject the level of understanding of nonholonomically constrained mechanical systems is far from satisfactory. Schemes allowing only the formulation of systems with linear and affine constraints have been so far developed in the Hamiltonian and Lagrangian sides. Even in those restricted situations our knowledge of the associated dynamics is limited to specific examples. The situation is even more dramatic when there are symmetries in the picture: not all symmetries lead to conserved quantities; the others lead to a "momentum equation" whose impact is not yet fully understood. Both from the theoretical and the applied point of view, a major problem is to move beyond the few well-studied examples and ask what kind of dynamics is generically possible in nonholonomically constrained systems, both as isolated systems and in the presence of external parameters. This question can be narrowed down near equilibria, periodic orbits and quasi-periodic tori, and is of importance in nonlinear control, where many systems have nonholonomic constraints.

II Variational methods for Symmetric systems

Although the variational theory for periodic orbits is very well developed, there is virtually no corresponding theory for *relative* periodic orbits (RPOs). Our aim is to provide *two* such theories. The first uses the standard action functional, but now defined on the space of *relative* loops in the full configuration space. The second uses reduced variational principles defined on the loop space of the quotient space of the configuration space. Reduced variational principles have been developed in recent work, but have never before been applied to RPOs. Numerical algorithms are needed to implement these variational methods in concrete examples.

The generic bifurcations of REs of symmetric Hamiltonian systems are only even partially understood in a few very special cases (eg Abelian momentum isotropy subgroups and free compact group actions). We are still a very long way from a complete theory for general proper Lie group actions. The theory for RPOs is even less well developed. There have been a number of recent numerical studies producing global bifurcation diagrams for REs and RPOs (eg for molecular and gravitational N-body systems) but current techniques are again restricted to special cases. The project proposed here aims to produce a general classification of such bifurcations and then an efficient suite of programmes to recognize them in specific applications.

Nonholonomic systems still have no satisfactory geometric formulation that would encompass the many needed applications, for example in robotics, control of aerial traffic, control of satellites, and biology (micro-swimmimg). This objective will shed light on the geometry and calculus of variations of such systems, from the fresh and highly dynamic point of view of geometric analysis and geometric measure theory in Carnot-Carathéodory (CC) spaces.

III Integrable and near-integrable systems

It has been known for some years that there are obstructions to having global action-angle coordinates in integrable systems, but the dynamical effects are less well-understood. A better understanding requires novel applications of singularity theory and KAM theory. These developments are of great importance to the applications in mechanics. We will be concerned with a number of examples along these lines, for example the rigid body undergoing Hamiltonian-Hopf bifurcation. In order to apply these geometric tools to concrete applications it's necessary to develop accurate numerical algorithms for computing these obstructions (monodromy and Chern classes, etc.) not only for the "pure geometric" case but for KAM-type perturbations in nearly integrable systems as well.

As is beginning to be understood, these obstructions are also important in quantum systems, and form the pivotal point in the Theme III-B.

Applications of Birkhoff normal form to PDEs have been up to now strongly limited by the quite poor understanding of the problem of small denominators in infinite dimensional systems. However, recent advances in the understanding of such small denominators allows one to give a precise meaning to the change of coordinate normalizing the system. We are now in a position to be able to extend this approach to the modulation equations for different applications such as the Vlasov-Poisson equation.

B1.4 Research Methods

This section describes the methods that will be used to achieve the project objectives in each of the contributing areas. The paragraphs are numbered according to the objectives to which they refer.

I Poisson Geometry and Reduction

I.1 The reduction procedures that are already known put together very sophisticated ideas coming from symplectic and Poisson geometry, from the theory of Lie group actions and from the theory of stratified spaces. Our main goal in the implementation of these ideas in the context of cotangent bundles is the obtention of a generalization of the so called embedding and fibration theorems. This point, together with our interest on geometric phases, will require the generalization to the singular context of well known tools coming form bundle theory. Concerning our search for global invariants, those that are already known for Poisson manifolds come from foliation theory. This branch of mathematics has also been very fruitful in determining the geometry of some conservation laws associated to canonical symmetries in Hamiltonian systems (optimal momentum map). Additionally, it has been recently shown that there is a clear interplay between these concepts and groupoid and algebroid theory and we plan to build on these methods to achieve the proposed objectives.

I.2 Techniques from singularity theory, bifurcation theory and KAM will be employed. The available normal forms for symmetric symplectic manifolds are built by adapting to this category the Slice Theorem which are ultimately based on the possibility of linearising such actions. We will use some very recent developments in the Poisson context in this direction.

I.3 The problem of constraints in mechanical systems has been tackled in the past with purely analytical methods (inspection of the associated differential equations) and in some restricted situations using geometric tools. For instance a distribution theoretical formulation of these systems opens the door to concepts like accessible sets, holonomy, and monodromy that provide valuable qualitative information about the associated dynamics. Additionally, in the presence of certain hypotheses on the nature of the constraints of a mechanical system one can fit these in geometric categories close to symplectic or Poisson manifolds. We plan to extend the degree of generality of these ideas as much as possible and to make them compatible with the existence of additional symmetries.

I.4 First, we plan to develop a kinematic expansion relating the generation of momentum and its effect on the motion of the system in terms of the shapes that the robot describes, using tools from geometric mechanics, geometric control theory, perturbation analysis, Lyapunov stability analysis and gait generation. Second, we will address the motion planning problem from an optimal control perspective, where we will take an energy viewpoint to identify the degrees of freedom which store the supplied energy using a port-controlled Hamiltonian approach.

I.5 We will use methods coming from differential and symplectic geometry, Hamiltonian mechanics and control theory.

I.6 The switched mechanical system will be modelled as an implicit Hamiltonian system with respect to a switching Dirac structure, whose Casimir functions will be investigated. Based on this analysis additional potential energy terms will be added to the actuated degrees of freedom, and the stability of the resulting controlled system will be investigated.

I.7 Simultaneous analysis of the same model problem corresponding to several resonant nonlinear oscillators from different complementary points of view. i) Purely classical study of dynamics on reduced (weighted projective) space, including topological analysis of corresponding partially integrable fibrations; ii) Purely quantum numerical study of complete quantum model; iii) Generating functions for the numbers of states and for the number of invariant functions, including algebraic description of the of the ring of invariants and Riemann-Roch theorem; iv) Algebraic geometry together with intersection theory to describe the fibre bundles arising in the semi-quantum model.

I.8 Characterize relative equilibria of EP complex fluids: - PCF motion as geodesic flows on semi-direct products - Coadjoint orbits of model systems on 1-dimensional domains - Classification, stability and bifurcations of relative equilibria (RE) of model systems. ”Slice reduction” at REs of EP equations (steady PCF flows).

II Variational methods for Symmetric systems

II.1 Cotangent bundle reduction and reconstruction methods from symplectic and differential geometry; Algebraic topology and equivariant Morse theory, equivariant dual action principles; Path following methods to obtain continuous deformations within given homotopy classes. Equivariant ”gluing” arguments to construct ”multibump” homoclinics.

II.2 Marle-Guillemin-Sternberg normal form, Lyapounov-Schmidt reduction, singular reduction, equivariant bifurcation methods, algebraic topology and use of M. Field's work on equivariant transversality.

II.3 We will use methods from metric analysis, symplectic geometry, Hamiltonian mechanics and control theory.

II.4 In the Lagrangian setting, the calculus of variations, and more specifically, Riemannian geometry, plays an integral part. The applicability of these tools in control theory is only beginning to be realized.

II.5 Since minimization principles are not applicable, it will be necessary to use methods for finding saddle-point RPOs, such as the Mountain Pass Lemma, and critical point counting methods such as category and Morse theories. The numerical methods would use as starting points (a) RPOs obtained as action minima of purely attractive systems, the repulsive core being introduced by homotopy; (b) nonlinear normal modes obtained by bifurcation/persistence from (relative) equilibria. When an RPO is found for an atomic or molecular system is should also be continued in energy and angular momentum. The stability and transverse vibrational frequencies of these solutions as functions of energy and angular momentum can also be computed at the same time.

II.6 Characterize finite-dimensional approximations to or invariant manifolds of solutions arising from EP PDEs: Pseudo-rigid bodies, arising from affine EP motion, and other EP motion on finite-dimensional groups; Measure-valued solutions arising from momentum maps for geodesic EP flows point vortices and vortex filaments for incompressible Euler and LA Euler-α equations momentum filaments and surfaces (vector peakons) for compressible, pressure-less LA Euler-α equations; Develop variational methods for REs and RPOs of gauge field theories, with a particular emphasis on skyrmions. Study the bifurcations of these REs and RPOs as the conserved quantities (spin and iso-spin for skyrmions) are varied.

II.7 Apply EP theory and other methods to obtain a sound geometric formulation of the equations for liquid crystals and superfluid Helium-II that will explain the motion of defects, such as disclinations and vortices. Apply the methods of Lagrangian averages (LA) in the derivation and analysis of mathematical models for a class of multiscale-multiphysics problems of modern interest, including :

- LA geophysical fluid dynamics (GFD) models (beyond quasi-geostrophy) for weather and climate applications, LA-GFD models provide average fluid descriptions that follow the motion of moisture and heat, while accounting for GFD balances between hydrostatic pressure gradient and Coriolis force

- Perfect complex fluids (PCFs), including liquid crystals, superfluid Helium-II and thermo-elastic materials. Breaking the symmetries of internal degrees of material freedom introduces order parameters, whose dynamical equations will be derived systematically by applying LA in the EP framework.

II.8 The key tools are the theory of Lie group actions on jet bundles taking into account the additional multisymplectic structure. Methods from the theory of Lie group actions as well as reduction theory will be employed.

III Integrable and near-integrable systems

III.1 The methods of a previous MASIE project concerning the geometry of KAM tori in nearly integrable Hamiltonian systems (Broer, Cushman and Fassò) will be further extended and applied to this setting. The study of concrete examples is essential, using both singularity and KAM theories, together with (algebraic) topology to describe and determine the global geometry of the torus bundles that are involved. Our focus will be on perturbations of the spherical pendulum and versions of the rigid body. The first step is to study these almost toric manifolds at the level of topology and classical mechanics, involving recent (independent) work by members of the F1 and NL1 teams. Bifurcation of these structures will be treated, globalizing the Hamiltonian Hopf bifurcation scenario. The semiclassical quantization will involve standard Bohr-Sommerfeld rules and powerful microlocal techniques, generalizing the semi-local study of focus-focus singularities by Vu Ngoc.

III.2 This research will use the methods of Hamiltonian perturbation theory, especially Nekhoroshev theory and recent results on adiabatic invariants mostly due to A. Neishtadt. This research has some contact points with project (II.1).

III.3 Extend the recent blow-up KAM stability method; use normal form theory to reduce to the Lie-Poisson spaces of the symmetry groups of interest.

III.4 We plan to use methods coming from differential and symplectic geometry, from Hamiltonian mechanics, from the theory of integrable systems, and from perturbation theory.

III.5 Qualitative theory of Hamiltonian dynamical systems, Hamiltonian stability analysis, bifurcation and singularity theory, normal form theory, reduction and singular reduction, fibre bundle theory, algebraic geometry, invariant theory, integrity and Groebner bases, generating functions, analysis of dynamical systems on algebraic varieties (reduced phase spaces) using symmetry and topology, Morse theory, homotopy theory, theory of three body systems, regularization, computer algebra, numerical methods of integration and continuation of periodic orbits, numerical methods in rotation number and cycle basis computation for torus bundles.

III.6 Modern semiclassical and geometric quantization theories, Duistermaat-Heckman theorem, theory of lattice defects, representation theory of lattice transformation groups. Quantum calculations of joint (energy-momentum) spectra.

III.7 Various topological and symmetry arguments, fibre bundle theory, characteristic classes, Atiyah-Singer theorem, combinatorial tools, generating functions. Quantum calculations of joint (energy-momentum) spectra.

III.8 2D and 3D wave packet propagation techniques and solving time dependent Schrödinger equation. Time-dependent semiclassical approximation. Coherent state theory.

III.9 using REs and relative TS as ways to simplify cross section and temperature dependant reaction rates calculations, various methods of finding, characterization, and continuation of this objects.

III.10 Spectral methods for the control of small denominators. Explicit construction of the Normal form in order to compare it to known modulation equations; study of the corresponding dynamics. Explicit construction of the normalizing transformation in order to study its properties and its use for the study of important physical systems.

B1.5 Work Plan

The project is divided into three *mathematical themes* (*viz.* Geometry, Variational methods and Integrable systems) and three *application themes* (*viz.* Nonlinear control, Molecules and Atoms and Fluids and Turbulence). Each of these 6 themes is overseen by a Coordinator (see bottom of this page). Furthermore, each theme-pair is divided into a number of *objectives* described in detail in Part B1.2 of this proposal. This subdivision is summarized below.

Summary of Objectives

Themes		Objective	Brief Description
		I.1	Geometry of symplectic and Poisson group actions
Poisson		I.2	Generic nonholonomic dynamics. Poisson normal forms. Geometry of constraints in Poisson systems
Geometry &			
		I.3	Geometry of constraints in Poisson systems
Reduction	*Control*	I.4	Motion planning for dynamic locomotion systems.
	Control	I.5	Optimal control on matrix groups.
	Control	I.6	Switching constraints and robot locomotion.
	Molecules	I.7	Topology, geometry, algebra and quantum problems
	Fluids	I.8	REs of complex fluids
Variational		II.1	Variational methods for RPOs. Numerical methods for finding minima of action functionals. Variational methods for RHTs
		II.2	Bifurcations and symmetry breaking.
methods &	*Control*	II.3	Optimal control and stability in constrained Hamiltonian systems
	Control	II.4	Lagrangian control of mechanical systems
Symmetry	*Molecules*	II.5	Choreography methods for molecular potentials
	Fluids	II.6	Reduced variational principles and EP theory. Finite dimensional fluid models.
	Fluids	II.7	Averaging, homogenization and discretization. Liquid crystal and superfluid Helium-II as EP systems
	Fluids	II.8	Reduction for field theories
Integrable and		III.1	Geometry of degenerations in torus fibrations. Joint spectra. Numerical computation of monodromy and Chern classes
		III.2	Perturbations of super-integrable systems
near-integrable		III.3	Long-term stability of REs
	Control	III.4	Nonholonomic integrable systems
systems	*Molecules*	III.5	Nonlinear dynamics of floppy molecules
	Molecules	III.6	Semiclassical methods for singular tori, defects of lattices
	Molecules	III.7	Dynamics and spectra of slow-fast coupled systems
	Molecules	III.8	Evolution of coherent states near singularities
	Molecules	III.9	Resonances and transition states
	Fluids	III.10	Normal forms in Fluid equations

The MaGIC Network is comprised of 15 teams following principally geographical criteria; 14 of the teams are from Europe and one from North America. In general a team consists of a number of individual scientists with different areas of expertise. The detailed composition of each team is described in B3. The teams which will work on each of the objectives are indicated in the next table. A letter ‘a’ indicates the team to which the *Objective Advisors* belong (see also Sections B3 and B4). The coordinators of the different themes are listed in the table further below.

	Teams														
Objective	UK1	CH	D	E	F1	F2	I1	I2	NL1	NL2	P	Ro	UK2	UK3	Ca
I.1	*	*	*	*	a				*	*	a	*	*		*
I.2	*	a		*	*				*	*	*		*		*
I.3			*	*	a		*		*	*	*			*	*
I.4	*			a			*			*		*			
I.5		*					*					a			*
I.6	*	*								*					
I.7	*					a									
I.8	*	*										*	a		
II.1	*		*		a			a	*				*		
II.2	*	*	*		*				a				a	*	*
II.3		*											*		*
II.4				*	*										*
II.5	*				*			*					*		
II.6	*	*		*	*						a		*	*	a
II.7		*	*		a								*	*	
II.8		*		a											
III.1			*			a			a						
III.2			*				a								
III.3							*								a
III.4		*		*	*		a		*	*					*
III.5	*					*		*	a						*
III.6						a			*						
III.7						a			*						
III.8						*			*						
III.9						a							*		
III.10		*						a						*	

It should perhaps be emphasized that many of these teams have been collaborating on a previous RTN (*MASIE: the geometry and dynamics of deformable bodies*). It can be observed in the table that these teams are collaborating on many more projects than the other teams. This is directly as a result of MASIE, and it is thus to be expected that as MaGIC progresses the new teams (E, I2, Ro, UK3) will become increasingly involved.

The 6 Theme Coordinators are from 6 different teams and 4 different countries:

	Theme	Coordinator
1.	Geometry & Reduction	T. Ratiu (CH)
2.	Variational methods	M. Roberts (UK2)
3.	Integrable Systems	H. Broer (NL1)
A.	Nonlinear Control	A. van der Schaft (NL2)
B.	Molecules and Atoms	D. Sadovskií (F2)
C.	Fluids & Turbulence	D. Holm (UK3)

Objective	MaGIC Network Project: Mid-Term Milestones
I.1	Complete description of singular reduction for cotangent actions
I.2	Resolution of the problem at the linear level: the symmetric Poisson version of the Witt-Artin decomposition.
I.3	Development of a mathematical framework capable of accommodating general constraints, symmetries, and conserved quantities.
I.4	Development of a kinematic expansion relating momentum generation and shape motion. Stability analysis of specific manoeuvres.
I.5	The understanding of the particular cases of low-dimensional Lie groups.
I.6	Modelling of a switched mechanical system as an implicit Hamiltonian system with respect to a switching Dirac structure, and the analysis of its symmetries and conservation laws.
I.7	Study of manifestations of singularities molecular examples with several resonances
I.8	Characterize PCF motion as geodesic flows on semi-direct products Classify REs for PCFs as constrained critical points of energy; obtain nonlinear stability criteria for these.
II.1	Establishment and comparison of the two variational approaches to existence of RPOs. Use topology of symmetric loop spaces to determine existence of and to classify choreographies. Development of numerical methods to respect homotopy class.
II.2	Bifurcations and path following techniques involving families of REs and RPOs for free actions Develop symmetric version of gluing arguments and multibump functions.
II.3	Description of forced symmetry breaking in model problems. Effect of breaking Hamiltonian structure on bifurcating families of REs
II.5	Understanding cases related to low-dimensional Lie groups, especially the interplay of symplectic and sub-Riemannian geometries. Establish the importance of CC distance estimates for stability of equilibria in these non-holonomic systems.
II.6	Formulate equations for liquid crystals and superfluid Helium-II with defects using EP theory Obtain stability and bifurcation results for REs of pseudo-rigid bodies, in the class of affine motions Characterize measure-valued solutions as arising from momentum maps in geodesic EP motion
II.7	Develop LA-GFD models that include rotation, buoyancy, compressibility and magnetic fields in turbulent flows Develop EP theory for imperfect CFs with frozen-in topological defects in their order parameters
II.8	To formulate a general theory extending the Euler-Poincaré equations for general symmetries.
III.1	The geometry transition through bifurcation in the integrable case. Computational tools in the integrable case Spectral effects of bundle obstructions in the integrable case
III.2	A first understanding of the existence of slow chaos
III.3	Examples showing how KAM theory can be used in this context. Precise formulation of Nekhoroshev stability results under “steep” conditions.
III.4	Understanding of integrability of some nonholonomic systems; some insight on relevant geometric structures.
III.5	Full description of triatomic molecules with diatomic rigid core and non-degenerate electronic state. Understanding the influence of the overall rotation of the system.
III.6	Relate singularities of integrable systems to manifestations in molecular spectra
III.7	Understand spectra of slow-fast coupled quantum systems
III.8	Wave-packet interpretation of the quantum analogue of the swing-spring model system.
III.9	Use REs as organizing centres for resonances and transition states
III.10	Computation of first terms of Birkhoff Normal form and of the corresponding transformation for some important problems, specifically the water wave problem in suitable regimes and the Vlasov-Poisson model.

Objective	MaGIC Network Project: Final Milestones
I.1	Block diagonalization techniques in stability studies, estimation and prediction of specific types of (relative) motions and qualitative dynamics.
I.2	Formulation of a Poisson Slice Theorem and of the subsequent reconstruction equations for equivariant Hamiltonian vector fields. Applications to equivariant Poisson dynamics.
I.3	Use of these tools in dynamics focusing on the qualitative behaviour of these systems, existence of solutions of interest in applications; (in)stability theorems.
I.4	Design of analytic motion planning strategies that accomplish both momentum generation and exact steering. Analysis of suboptimal gait patterns that solve the point to point reconfiguration problem.
I.5	Generalizations to Lie groups: SO(n), SE(n,R), SP(2n,R) and to other concrete Lie groups which appear in theoretical physics and engineering problems.
I.6	Control of the actuated degrees of freedom by mimicking additional potential energy terms, and the stability analysis of resulting gait patterns.
I.7	Systematic characterization of defects and of their organization in the joint energy-momentum spectra of molecular and atomic systems based topological and homotopic invariants
I.8	Coadjoint orbits of steady PCF systems on 1-dimensional domains
II.1	Applications of the variational approach for finding RPOs to concrete problems. Extend techniques to treat generalised (relative) choreographies. Adapt previously developed numerical methods for homotopy classes to preserve symmetry. Develop the “relative” analogue of multibump functions.
II.2	Bifurcations and path following techniques involving families of REs and RPOs for general actions.
II.3	General description of symmetry breaking effects.
II.5	Generalizations at least to matrix Lie groups, like SO(n), SE(n,R), Sp(2n,R), with applications.
II.6	Formulate equations for motion of defects *relative* to the fluid motion, characterize effects of this relative motion. Obtain stability and bifurcation results for REs of pseudo-rigid bodies, arising from EP affine motion Elliptic (in)stability of pseudo-rigid bodies and other affine solutions as exact nonlinear EP fluid motions. Characterize the Hamiltonian dynamics for the interactions of measure-valued EP solutions that arise as momentum maps (these are point vortices, vortex filaments, momentum filaments and surfaces).
II.7	Extend from isotropic Lagrangian statistics for LA-GFD to the more physically realistic setting of anisotropic, dynamic Lagrangian statistics Develop the EP theory for imperfect complex fluids whose topological defects, or singularities in their order parameters, may propagate *relative* to the fluid material. Explain the role of generalized two-cocycles in the Hamiltonian description of this relative motion of defects.
II.8	Development of a general multisymplectic reduction theory and link to existent examples of covariant Poisson brackets. The case of discrete systems will be considered next, based on this.
III.1	The transition in geometry through bifurcation in the nearly integrable case; Computational tools in the nearly-integrable case. Spectral effects of bundle obstructions in the nearly-integrable case
III.2	A detailed understanding of the properties of slow chaos, coupled to the investigation of its occurrence in real systems, e.g. from celestial mechanics
III.3	Full development of KAM technique for showing stability of REs with non-compact symmetry. Development of numerical methods for testing ”steepness” and application to the study of the stability of (relative) equilibria of selected Hamiltonian systems (Lagrangian points, Riemann ellipsoids, the levitron)
III.4	Geometric description of fibrations by invariant tori in non-holonomic systems
III.5	Monodromy of the degenerate electronic states of floppy molecules.
III.6	Relate defects in spectral lattice to information about density of states
III.7	Classify bifurcations in spectra of slow-fast coupled systems
III.8	Quantum dynamical manifestation of monodromy in molecular analogues of the swing-spring systems, such as CO_2 or $H\text{-}CX_3$. Investigation of wavepacket formation and detection in strong pulsed laser field. Possibility of molecular control.
III.9	Application of rotational transition state theory to phase space transport problems
III.10	Develop a general theory allowing to apply (and justify) the method of normal forms to quite general problems.

B2 TRAINING AND TRANSFER OF KNOWLEDGE ACTIVITIES

B2.1 Content and quality of the training programme

Training objectives

1. To introduce early-stage researchers to a range of mathematical concepts, problems and applications. To develop their expertise in a number of these fields and to train them to conduct research, to collaborate, and to communicate their results in both papers and oral presentations. To facilitate the career development of early-stage researchers.

2. To deepen and broaden the knowledge and skills of more experienced researchers (postdocs and established scientists) working in the areas of geometric mechanics, to make theoreticians aware of potential applications and to make applied scientists more aware of the new geometrical techniques. To train postdocs in project management, and to improve their communication skills, which is vital in interdisciplinary projects.

Network complementarity Expertise in the broad range of subjects from fundamental symplectic and Poisson geometry to its many applications (molecular spectra, fluid dynamics, nonlinear control) is spread thinly across Europe and the rest of the world. By conducting this programme at a European level we are able to expose students to a much broader multidisciplinary experience than would be possible at an institutional or national level, and put them into contact with a far greater number of potential academic employers. Furthermore, the areas of application would not be able to progress as fast without the breadth of expertise the network offers, and techniques developed for one application would be completely ignored by another.

Early stage & experienced researchers There is a need for 'knowledge transfer' and training programmes for both experienced researchers and early-stage researchers. Because of the interdisciplinary nature of the vast majority of the research in this network, it is necessary to have a significant proportion (over 30%) of experienced researchers in order to carry out successfully some of the projects. The projects suitable for early-stage researchers are concentrated in one area of expertise. This does not mean however, that they will not benefit from having joint supervision, and all early-stage and experienced researchers will have joint and complementary supervision.

On the other hand, the early-stage researchers will be exposed to the multidisciplinary nature of the network from the beginning, and while they will not be expected to become expert both in the geometrical techniques as well as the applications, their participation in training workshops and network conferences will ensure they are aware of the interesting problems and available techniques. This will encourage them to continue to perform good interdisciplinary research after they gain this early experience, and it will also place them in an enviable position in the subsequent employment market.

The early-stage researchers and experienced researchers employed by the network will be able, and encouraged, to attend training sessions or conferences outside the network whenever they feel it to be in line with their career development plans.

Schools A "Marie Curie Conferences and Training Courses" proposal is being prepared for the next round of applications, to run two summer schools on topics close to the themes of MaGIC. Although it is independent of MaGIC, it is linked to the current proposal as the Coordinator of that proposal is Ortega (Coordinator of Team 5). Moreover Montaldi, the MaGIC network coordinator, is one of the proposed organizers of the Conferences and Training Courses. Consequently, these schools and conferences will be beneficial for the early-stage and experience researchers to be employed by the MaGIC network.

It is also likely that short courses on the research topics of MaGIC will be presented at MaGIC conferences. These will be aimed at all young researchers working on these topics, not only the ERs and ESRs employed by the network.

Supervision, secondment etc The primary training mechanism for both early-stage and experienced researchers will be day-to-day interaction with supervisors while working on their projects. All the early stage and experienced researchers to be financed by the EC contract will also have co-supervisors from different teams with complementary expertise. They will spend a substantial amount of time working with their co-supervisors and also visit other network members who are working on the project or have relevant expertise. Supervisors and co-supervisors for each project are given in the 'team-by-team' accounts below.

Training workshops These are an important ingredient in the training of both early-stage and experienced researchers (see B3.2). Here they will meet in small groups and present the state of their project to key scientists in the fields related to their project. These small workshops will give them presentational skills, further input into their project and close contacts with each other and with the key scientists in the network.

Gender aspects It is to be noted that four of the European team coordinators are female (Martinez (E), Terracini (I2), Sousa Dias (P) and Derks (UK2)), and several of the Objective Advisors are also female, as are several of the joint supervisors. These female key scientists will provide role models for both the male and female researchers employed by the network. A mentoring scheme will be set up for all researchers employed by the network and all researchers will be encouraged to take part in it. Several of the female scientists in the network are willing to act as mentors to both male and female researchers in the network.

NETWORK RESEARCH TRAINING: a team-by-team description
In this section, an ER is an *Experienced Researcher*, while an ESR is an *Early Stage Researcher*.

Team 1 (UK1) The UK1 team will employ 2 ERs for 2 years each, and both will be based at UMIST. The first ER will work on forced symmetry breaking problems (Objective (II.2)), and will be cosupervised by Ortega (F1), and will benefit from collaboration with Roberts (UK2). The other ER will work on finite dimensional models arising from Euler-Poincaré systems such as perfect complex fluids (Objective (II.6), part of Theme II-C). She/he will be cosupervised by Ratiu (CH) with assistance from Holm (UK3), and Wulff (UK2). It is expected that the first ER will bring an expertise in the methods of Singularity Theory to the network, necessary for developing the techniques for analysing symmetry breaking bifurcations, and the second ER will bring knowledge of fluid mechanics and Hamiltonian PDEs. The Mathematics department at UMIST has a strong group in both the pure and applied aspects of Dynamical systems, which will enhance the training experience of the ERs.

In addition to their research they will gain valuable management experience by assisting the Network Coordinator by running the network website and producing a bimonthly e-newsletter keeping all participants abreast of network publications and activities, and in coordinating the Training Workshops (see above and B3.2). Since a degree of maturity is needed in order to be able to run the network on a day-to-day basis, this is a another reason it is felt that ERs are necessary.

Team 2 (CH) An ER will be employed for 2 years to work under the supervision of Ratiu on the derivation and analysis of complex fluid theory using the Euler-Poincaré framework (Objective (II.7)). Holm (UK3) will be cosupervisor, and the ER will also benefit from collaboration with Dullin (UK1). It is essential that the ER come to the project with an expert knowledge of fluid dynamics, especially complex fluids, in order to be able to develop and apply the geometric techniques related to the Euler-Poincaré framework. The ER should be able to move freely between the EPFL and Imperial College and (s)he and the two joint supervisors will schedule regular meetings.

Team 3 (D) An ER will be employed at the Technical University of Munich for two years to work on the dynamics and control of nonlinear electrical circuits (Objective (I.3)). The ER will be supervised by Scheurle. The overall goal of this research project will be the development of a unified approach to the modelling, analysis, simulation and control of electrical circuit systems using ideas and techniques of Geometric Mechanics as well as Dynamical Systems theory. In particular, the Birkhoffian concept of Geometric Mechanics will be employed. As part of this work, dissipative effects, for instance due to resistors within a circuit, and various circuit topologies not covered by existing theories will be investigated. Perturbation techniques are applied to study small dissipative effects and to design possible control strategies. The ER will interact with Ratiu (CH) who will act as a co-supervisor, and benefit from cooperation with Derks (UK2). The project requires a broad background in a number of topics, so that it is necessary to have a full time ER working on it. It would be particularly helpful, if the ER brought a knowledge of electrical circuits and/or control theory to the network.

Team 4 (E) This team will employ 2 ESRs for 3 years each. One will work under the supervision of Marco Castrillón Lopez on the multisymplectic formulation of complex fluids and spin glasses, part of Objective (II.8), and will be co-supervised by Ratiu (CH), and benefit from interaction with Holm (UK3). The other will work under the supervision of Jorge Cortes and Sonia Martinez on objective (I.4), and specifically on the stability and control of mechanical systems and the design of efficient motion planning algorithms to solve point-to-point reconfiguration and stabilization problems. He/she will be cosupervised by van der Schaft (NL2) and take advantage of the graduate courses and expertise offered by the Dutch Institute of Systems and Control.

Team 5 (F1) An ESR will work for three years under the supervision of Ortega on the reduction of nonholonomically constrained Poisson dynamical systems with symmetry, part of Objective (I.3). His/her work will be co-supervised by Cushman (NL1). The main goal of this research project will be the formulation of an adequate mathematical framework for these systems by using recently developed tools based on singular foliation theory. At some stages of this project the help and expertise of Marle (F1), Ratiu (CH), Śniatycki (Ca) and van der Schaft (NL2) is likely to be required. Techniques from normal form theory adapted to this problem will be required. At that point the input of Zung (F1) will be extremely valuable.

Team 6 (F2) The F2 team will employ an ESR, based in Dunkerque and working with Zhilinskii and Sadovskii on qualitative aspects of model quantum systems showing presence of fractional monodromy in the case of two and three dimensional vibrational problems with resonances (Theme III-B). It is supposed that the ESR will apply analytical and geometrical methods, in particular invariant theory, to study classical mechanical aspects and also perform numerical quantum calculations to study the manifestation of monodromy in quantum problems. This ESR will be cosupervised by Cushman (NL1) and Nekhoroshev (I2), specialists in mathematical aspects of monodromy.

Team 7 (I1) An ER will be employed at the University of Padua to work on integrable nonholonomic systems together with other sub-projects from Themes I and III. The ER will be supervised by Fassò. In Padua, the ER will be part of an active research group on Hamiltonian and dynamical systems, perturbation theory and geometric mechanics. Additional training will be provided by the interaction with members of other teams, which will be required and stimulated, especially with Cushman (NL1) and with Bates (Ca), who will act as co-supervisor. The project is an innovative one, in an area which requires a deep knowledge in diverse areas such as, Hamiltonian systems, nonholonomic systems, and differential, symplectic and Poisson geometry. While an ESR could be trained in some of these areas, it is difficult that he could arrive to master the whole subject. The project requires the expertise and the maturity of a young researcher who has already received his/her PhD training in at least some aspects of the areas involved.

Team 8 (I2) An Experienced Researcher will be employed at the University of Milano Bicocca for 2 years to work on the periodic and quasiperiodic problem of many interacting particles and their effects on the dynamics (Objectives (II.I) and (II.5)). The researcher will be supervised by Terracini, and will benefit from the local presence of specialists of Dynamical Systems Theory such us Bambusi, Giorgilli, Nekhoroshev. The ER is supposed to bring to the Milano node expertise on bifurcation theory, theory of normal modes, or other geometrical, topological and variational methods to the aim of developing a combined research project joining a variety of different techniques of nonlinear dynamical systems; (s)he will find possible applications to systems of n-body type (including molecular systems) and FPU chains. Concerning the first application, the ER will benefit from the joint supervision of Chenciner (F1), while for both the first and the second (s)he will have the opportunity of regularly interacting with both the UK1 (Montaldi, Sbano) and the UK2 (Roberts, Wulff) teams.

Team 9 (NL1) The NL1 team will employ both an ESR for 3 years and an ER for 2 years. The ESR will be employed by the team host (Univ Utrecht) but based in Gröningen working with Broer on the global geometry of KAM tori for nearly integrable Hamiltonian systems (Objective (III.1)). Concretely, (s)he will study numerically small nonintegrable Hamiltonian perturbations of the spherical pendulum to understand what happens to the KAM tori as the perturbation grows. This project will be cosupervised by Cushman (NL1), Fassò (I1) and Hanßmann (D).

The ER, based in Utrecht, will work on fractional and deformation monodromy, singularities of integrable systems, and their relation to molecular spectra (Objective (III.5) and generally Theme III-B). This project will be cosupervised by Sadovskii and Zhilinskii (F2). It is important in this project to employ an ER because of its interdisciplinary nature. It is expected that the person bring in expertise on molecular spectra.

Team 10 (NL2) The NL2 team will employ an ESR for 3 years, to work under the supervision of van der Schaft on the applications of switched hamiltonian systems and Dirac structures to the locomotion of robots (Objective (I.6)). The ESR will be cosupervised by Montaldi (UK1) and will also benefit from interactions with Ratiu (CH) and Cortes and Martinez (E).

Team 11 (P) An ESR (early-stage researcher) will work for 3 years on reconstruction of reduced Hamiltonian systems, under the supervision of Fernandes. The ESR will work on applying global invariants recently introduced in Poisson geometry (monodromy, holonomy, characteristic classes, etc.) to develop tools for a systematic understanding of the reconstruction of reduced Hamiltonian systems on Poisson manifolds (Objective (I.1)). Applications to the study of qualitative behaviour of solutions of concrete mechanical systems, will also be considered. The ESR will regularly interact with Ortega (F1) and Ratiu (CH), who will act as co-supervisors; (s)he will also visit Weinstein (Ca).

Team 13 (UK2) This team will employ two ESRs each for 3 years. One will work on bifurcations of REs and RPOs, numerical computation of these bifurcations and applications to molecular dynamics and celestial mechanics (Objective (II.2)). On the theoretical side the aim is to extend existing persistence theories for free group actions to the case of finite isotropy. On the numerical side the emphasis will be on detecting and exploiting discrete spatial and spatio-temporal symmetries of RPOs. The supervisors will be Roberts and Wulff, the cosupervisor will be Vanderbauwhede (NL1), and there will be interaction with Montaldi (UK1), Patrick (Ca), Ortega (F1), Ratiu (CH) and Lamb (UK3).

The other ESR will use ideas from variational and geometric methods, such as energy-momentum and energy-Casimir methods and geometric Evans-type methods (Objective (II.2)). These will be applied to prove shadowing or dissipation induced instability in Hamiltonian systems with a non-Hamiltonian perturbation, which preserves the symmetry group. The ESR will be supervised by Derks, and will benefit from cosupervision by Ratiu (CH).

Team 14 (UK3) The UK3 team will employ an ESR for 3 years, to work on homoclinic bifurcation in symmetric Hamiltonian systems (Objective (II.2)). The aim is the study of existence and bifurcations of heteroclinic cycles and homoclinic orbits in Hamiltonian systems with symmetry, ie reversible equivariant Hamiltonian systems, and the dynamics in the neighbourhood of such connecting orbits. The student, who will be supervised by Lamb, and co-supervised by Vanderbauwhede (NL1), will be expected to adapt Lin's method to Hamiltonian systems along the lines of "constrained Lyapounov-Schmidt" type analytical reduction techniques (Lin), and study low codimension homoclinic bifurcation in Hamiltonian systems with symmetry, among other things.

Industrial connections Scientists in the MaGIC network do not have any significant connections with industrial and commercial enterprises and it is not currently envisaged that any will develop during the 4 year programme. However future links are not ruled out and will be pursued if opportunities arise.

B2.2 Impact of the training and/or transfer of knowledge programme

Need for the network training Modern geometric techniques are being developed that are capable of solving new and old problems, and the training in this network will equip the next generation of researchers to research into both the fundamental geometry as well as the applications. The MaGIC network is expected to consist of around 60 European 'key scientists', 17 early-stage or experienced researchers financed by the EC contract and a further 25–30 pre- and postdoctoral researchers who are being supervised by network members and are working on projects close to the aims of the network. These researchers are divided between a large number of European Institutions (about 30 in this proposal) scattered across Europe, as well as working in different disciplines. (These figures are based on the team profiles in B3.1). The network will provide a powerful impetus towards greater cohesion in the field and greater interaction between the groups and disciplines and will lead to many more collaborations and the creation of a new and exciting focus of research in Europe. As has already been demonstrated in the RTN 'MASIE' (of which MaGIC is a development), success will attract other researchers from nearby fields and together with the number of young researchers trained by the network this will ensure its rapid growth in the years to come.

Transfer of knowledge This project is strongly interdisciplinary, dealing with fundamental questions in geometry, problems in fluid dynamics, in molecular spectra and in modelling and control of robotic locomotion. As such there is a considerable need for collaborative projects to be underpinned by the employment of an ESR or an ER. We have judged that in a number of the projects the need for interdisciplinary exchange is considerable, and for those we require experienced researchers. In all cases, the network fellows will have a local supervisor at their host institution, and a cosupervisor at a different team in the network. They will also have the opportunity of spending periods of up to a few months with their cosupervisors, or indeed with other members of the network who are interested in the same problem, or who are experts in techniques demanded by the project.

Impact of project Many of the scientists involved in this network are international leaders in the field(s), who will therefore ensure that the research carried out by the network is of the highest standard. This will have a knock-on effect on research in neighbouring fields ensuring that this too is of the highest quality. The truism that good science attracts good scientists, implies that the MaGIC network will attract research scientists (a) to work in this research area, and (b) to work in this geographical area (Europe).

Future careers The early-stage and experienced researchers who participate in this network will receive a uniquely interdisciplinary training which will incorporate introductions to a broad range of mathematical and physical ideas and techniques and exposure to a variety of different areas of applications, as well as more intensive training in a smaller number of techniques and applications. They will also have the opportunity to work for extended periods with several leading scientists from different institutes and to meet and present their work to many others at summer schools, conferences and workshops. This will inevitably broaden their range of academic contacts and substantially improve their job prospects within the academic sector. The variety of skills that they will develop working on the project, including computational, project management and communication, and the wide range of applications they will be exposed to, will also be valuable to those seeking jobs outside academia. Researchers employed by the network will be encouraged to take part in personal career development activities. Many national research councils run courses for PhD students and most institutes have staff development courses suitable for Postdocs. The mentoring scheme will stimulate researchers to evaluate their personal career development needs at regular intervals and act on the evaluation.

B2.3 Planned recruitment of early-stage and experienced researchers

Overall total of ESRs and ERs The network is proposing to provide 528 person-months of research training in the form of network fellowships. This figure can be broken down into 360 person-months (68%) of ESRs, and 168 person-months (32%) of ERs. It is envisaged that the ESRs will be appointed for periods of 36 months, and the ERs for periods of 24 months. If researchers leave before the end of their contract (eg to take a permanent position), then shorter term appointments will be made.

Breakdown of overall total The number of network fellows in each team whose employment will be financed by the proposed EC contract is given in the table below. In addition, the table shows the anticipated research effort that each team will devote to MaGIC projects. The figures (d) and (e) are based on the lists of 'key scientific staff' given in the team profiles. In addition to the key scientific staff and young researchers financed by the contract there will be over 30 other students and postdocs supervised by network members and working on projects close to those described in this proposal. See B3.1 for the number in each team. These students and postdocs are not included in the table.

Advertising for vacancies Vacancies for network fellows will be advertised throughout the European Union and beyond in the usual ways: through the media, websites (including the Cordis website for vacancies), email, newsletters, in accordance with the regulations in place at the host institution. It is anticipated that some of the current young researchers from the FP5 network MASIE will apply for ER positions in MaGIC. It is also expected that some ESRs will come from being students at the institutions of participating teams. However their applications will be considered in competition with those from outside the network. Finally, it is also expected that both ER and ESR applications will be generated by the Marie Curie Conferences and Training Courses proposal being prepared by Ortega (F1). Furthermore, every effort will be made to attract good young scientists from new member states to provide them with the experience of Universities with established high-quality research activities.

Equal opportunities Female applicants for the MaGIC fellowships will be strongly encouraged, and special care will be taken to ensure that time off research for childcare is taken into account in both the advertisements and appointments process. The option of making part-time appointments will be considered whenever appropriate and possible. The use of parental leave schemes will be encouraged whenever appropriate.

		Early stage and experienced researchers to be financed by the contract			Other professional research effort on the network project	
Network Team		Early stage researchers financed by the project (person-months) (a)	Experienced researchers financed by the project (person-months) (b)	Total (a+b) (c)	Researchers likely to contribute (number of individuals) (d)	Researchers likely to contribute (person-months) (e)
1	UK1	0	48	48	5	72
2	CH	0	24	24	3	38
3	D	0	24	24	4	43
4	E	72	0	72	7	96
5	F1	36	0	36	6	57
6	F2	36	0	36	6	102
7	I1	0	24	24	5	106
8	I2	0	24	24	7	130
9	NL1	36	24	60	3	26
10	NL2	36	0	36	3	22
11	P	36	0	36	6	70
12	Ro	0	0	0	3	41
13	UK2	72	0	72	6	60
14	UK3	36	0	36	4	35
15	Ca	0	0	0	7	82
Totals		360	168	528	75	980

B3 QUALITY/CAPACITY OF THE NETWORK PARTNERSHIP

The network consists of 15 teams of various sizes, of which fourteen are European and one is from North America. Many of the individuals have collaborated in the past (see table on p. 38)

B3.1 Collective expertise of the network teams

General Overview This project will bring together mathematicians and physicists with a wide range of expertise. This is essential to ensure that the new and highly sophisticated theoretical techniques that will be developed are applied immediately to practical physical problems of current interest, and conversely that the theoretical developments are driven by clearly-identified problems from these areas. The key fields of expertise that will be represented are:

Geometric structures: Symplectic, Poisson, differential geometry, reduction and other symmetry techniques.

Hamiltonian mechanics: application of geometric techniques, integrable systems, bifurcation theory and (equivariant) singularity theory, non-holonomic systems.

Nonlinear Control: geometric techniques in nonlinear control, optimal control on Lie groups, robot locomotion.

Non-Hamiltonian symmetric dynamics: stability and bifurcations of REs/RPOs, existence and local dynamics of heteroclinic cycles, symmetric chaos, dynamical systems techniques.

Variational methods: Constrained critical points, local and global minimization, saddle-point methods, Palais-Smale conditions.

Hamiltonian PDEs: fluid dynamics, Lagrangian and Hamiltonian approaches, averaging models, turbulence, field theories.

Semiclassical quantization: classical-quantum correspondences, EBK, singular EBK and trace formula techniques, tunnelling, applications.

Atoms and molecules: spectra, theoretical models, classical simulation, quantum computations, comparison with experimental data.

Near-integrable systems: KAM and other perturbation theories, monodromy and other topological features.

The fields of expertise that are contributed by each team are summarized in the table below and described in more detail in the individual team profiles later in this section.

Expertise Contributed by Each Team

	UK1	CH	D	E	F1	F2	I1	I2	NL1	NL2	P	Ro	UK2	UK3	Ca
Geometric structures	*	*		*	*	*	*		*	*	*	*	*		*
Hamiltonian mechanics	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Nonlinear Control		*	*	*						*		*	*	*	*
Symmetric dynamics	*	*	*		*			*	*				*	*	
Variational methods	*	*	*		*			*	*						*
Hamiltonian PDEs	*	*	*	*				*			*	*		*	
Semiclassical quant.	*					*	*	*							*
Atoms and molecules	*					*							*		*
Near-integrable systems		*	*		*		*				*				

TEAM 1: UK1

The UK1 Team brings together mathematicians and physicists from a number of universities in the UK with expertise in the stability and bifurcation theories of symmetric Hamiltonian and non-Hamiltonian systems, in KAM theory and in semi-classical methods and their applications to atoms and molecules. The team will be administered from UMIST.

Key scientific staff and expertise

Dr. J.A. Montaldi (Mathematics, UMIST — 40%; team coordinator and network coordinator) Began his research in applications of singularity theory to differential geometry, and has been working on bifurcations in symmetric Hamiltonian systems for the past 15 years, firstly on existence and stability of nonlinear normal modes and more recently on persistence and bifurcations of relative equilibria and relative periodic orbits. He has applied these techniques to finding rotational states of molecules and to relative equilibria of systems of point vortices.

Dr. S. Creagh (Theoretical Mechanics, Nottingham — 35%) Previously worked on semiclassical approximations for systems with symmetry, generalising Gutzwiller's formula for the density of states to such systems and to systems with broken symmetry. Recent work has been directed at developing methods for calculating tunnelling rates in classically non-integrable systems using complex classical dynamics and these methods are now being used to investigate the calculation of chemical reaction rates from complexified dynamics near the transition state.

Dr. H.R. Dullin (Mathematical Sciences, Loughborough — 35%) Research interests focus on dynamical systems with special emphasis on integrable systems in classical mechanics. Recent work includes the analysis of Hamiltonian and quantum monodromy in a variety of systems including simple molecules and certain geodesic flows.

Dr. L. Sbano (Mathematics, Warwick — 35%) Works on variational techniques for finding periodic and relative periodic orbits in classical systems with symmetry.

Dr. G. Tanner (Theoretical Mechanics, Nottingham — 5%) Research interests focus on semiclassical quantisation of classically non-integrable dynamics with special emphasis on atomic systems. Recent work includes the study of the dynamics near the triple collision in three-body Coulomb problems as well as spectral statistics and quantum graphs.

Other postdoctoral research fellows: 1.

Other postgraduate students: 1.

Linkages between teams Montaldi is currently collaborating with Ortega (F1), Roberts (UK2) and Tokieda (Ca) and has recently collaborated with Ratiu (CH). Dullin is collaborating with Holm (UK3), Hanßmann (D), and has joint publications with Holm and Fassò (I1). Sbano is collaborating with Roberts (UK2).

Role in network Montaldi is the network coordinator. UK1 will play major roles in all work on stability and bifurcations of REs and RPOs, in symmetry breaking bifurcations, and in the dynamics of finite dimensional fluid models. It will also contribute to Theme III "Integrable and near-integrable systems".

Two recent publications

- J. Montaldi and T. Tokieda, Openness of momentum maps and persistence of extremal relative equilibria. *Topology* **42** (2003), 833-844.
- H.R. Dullin, G. Gottwald and D.D. Holm, On asymptotically equivalent shallow water wave equations (2003), *Fluid Dyn. Res.* to appear.

TEAM 2: CH

The CH team is based at the Swiss Federal Institute of Technology in Lausanne. Its expertise lies mainly in geometric methods in classical mechanics and their applications to stability theory and bifurcations in the presence of symmetry, symplectic and Poisson geometry, symmetric bifurcation theory, fluid mechanics, geometric aspects of the structure of complex fluids, and infinite dimensional differential geometry and its relation to Banach algebras.. These methods have been successfully applied by the team members to both finite and infinite dimensional systems.

Key scientific staff and Expertise

Prof. T.S. Ratiu (Bernoulli centre, EPFL — 40%; team coordinator) Has worked on geometric methods in Hamiltonian systems, stability methods for REs and RPOs, dissipation induced instability, integrable systems, reduction theory, Hamiltonian bifurcation theory, applications to models in continuum mechanics and plasma physics and geometric PDE methods in fluid dynamics. His current interests in Hamiltonian dynamics include: the link between Hamiltonian bifurcation theory with symmetry and singular reduction, its implications for the stability of REs and RPOs and estimates of their numbers near stable equilibria; the study of an averaged ideal incompressible homogeneous fluid model (the α-Euler model); questions surrounding the phenomenon of non-Abelian integrability.

Dr. M. Buliga (Bernoulli centre, EPFL — 20%) works in elasticity theory, brittle fracture mechanics, calculus of variations, sub-Riemannian geometry, global analysis, numerical analysis. He is interested in the connection between symplectic geometry and sub-Riemannian geometry.

Dr. G. Loeper (Bernoulli centre, EPFL, from March 2004 — 20%) Works in Hamiltonian PDEs. Currently in Toronto, but takes up a position at the EPFL next year.

Other postgraduate students: 4.

Linkages between teams Ratiu has collaborated with many people in the network, including Ortega (F1), Montaldi (UK1), Derks (UK2), Holm (UK3), Fassò (I1), Weinstein (Ca). He was also PhD supervisor of Ortega.

Role in network Ratiu plays a central role in the network. He is the coordinator of Theme I "Poisson Geometry and Reduction", sits on the scientific committees of the annual conferences and makes important contributions to the strategic planning of the network. He will be cosupervisor of an ER to be employed by Team 1, and an ESR both with Team 10 and Team 4.

Two recent publications

- Chossat, P., Ortega, J.-P., and Ratiu, T.S., Hamiltonian Hopf bifurcation with symmetry, *Arch. Rat. Mech. Anal.*, **163** (2002), 1–33.
- Derks, G. and Ratiu, T.S., Unstable manifolds of relative equilibria in Hamiltonian systems with dissipation, *Nonlinearity*, **15** (2002), 531–549.

TEAM 3: D

The D team is formed by mathematicians from the Rheinisch-Westfälische Technische Hochschule of Aachen (RWTH) and from the Technical University of Munich (TUM). It will be administrated by TUM.

Key Scientific Staff and Expertise

Prof. J. Scheurle (TUM — 20%; team coordinator): Is the head of the chair of Dynamical Systems and Analytical Mechanics at TUM. He has worked on KAM theory for reversible systems, reduction of mechanical systems with symmetries (together with Prof. J.E. Marsden and Prof. T.S. Ratiu), hydromechanical instability and bifurcations, detecting chaos in mechanical systems, and control of mechanical systems.

Dr. H.-P. Kruse (TUM — 30%): Is a member of the nonlinear dynamics group at TUM. He studied various kinds of Hamiltonian structures of model equations for mechanical systems, in particular Poisson and Euler-Poincaré structures. He has also analysed the bifurcation and stability of REs and RPOs for rigid body as well as liquid bridge motions, and derived generalized Camassa-Holm equations.

Dr. H. Hanßmann (RTWH — 20%): Has been working on particular three degree of freedom Hamiltonian systems, such as the rigid body or isotropic harmonic oscillators and, motivated by these examples, on bifurcations of invariant tori in Hamiltonian systems. Current research interests include bifurcations in singular(ly reduced) Poisson spaces and singular reduction in specific examples of Hamiltonian systems with more than three degrees of freedom.

Dr. B. Sommer (RWTH — 20%): Has been working on singular bifurcations in the Hénon-Heiles family and KAM-theoretic strategies for perturbations of superintegrable Hamiltonian systems.

Other Postdoctoral research fellows: 3

Other postgraduate students: 4

Linkages between teams Scheurle and Kruse had long term collaborative projects with Ratiu (CH). Hanßmann was a PhD student of Broer (NL1) with whom he has joint past and current research work on quasi-periodic bifurcations. At the moment he is also working with Dullin (UK1) on singular reduction.

Role in the network The D team will significantly contribute to the geometry of constrained and controlled systems objectives, in particular to the geometry/topology of reduced spaces objective (I.1); also to the development of variational methods for REs and RPOs objective (II.1), the description of generic bifurcations in symmetric Hamiltonian systems objective and their behaviour under forced symmetry breaking (II.2), the bifurcation scenarios leading to non-trivial distributions of KAM-tori (III.1). Finally it will provide support for complex fluids and other Euler-Poincaré type systems (II.7).

Two recent publications

- H. Hanßmann and J.C. van der Meer, On the Hamiltonian Hopf bifurcations in the 3D Hénon-Heiles family, *J. Dynamics Diff. Eq.* **14** (2002), 675–695.
- J.E. Marsden, T.S. Ratiu, and J. Scheurle, Reduction theory and the Lagrange-Routh equations, *J. Math. Phys.* **41** (2002), 3379–3429

TEAM 4: E

The E team will be administered from the Consejo Superior de Investigaciones Científicas (CSIC) in Madrid.

Key Scientific Staff and Expertise

Dr. S. Martinez (CSIC, Madrid — 25%; team coordinator) Currently a Fulbright Scholar at the Coordinated Science Laboratory of the University of Illinois at Urbana-Champaign, she will soon be taking up a position at CSIC in Madrid. She works in mathematical control theory, and has dealt with the controllability analysis, optimal control and motion planning of underactuated mechanical systems using differential-geometric techniques. Her current research interests include the study of low-complexity representations of mechanical systems and distributed control for the coordination of multiple-vehicle systems.

Dr. M. Castrillón López (Geometry and Topology, UCM Madrid — 35%) has worked on several aspects of Variational Calculus of Field Theories. He is interested in the geometrical models of the classical Field Theories and the results concerning their gauge symmetries and constraints. In particular he is now working on the covariant formulation of Lagrangian reduction, a new area promising many interesting applications to complex field systems.

Dr. J. Cortes (Mathematics, Univ. Carlos III, Madrid — 25%) (Currently visitor at UIUC, USA) works on mathematical control theory and geometric integration, with a special emphasis on Lagrangian and Hamiltonian systems and the role of symmetry principles. His research pursues the development of differential-geometric and numerical tools that lead to improved dexterity, efficiency and autonomy in robotic mobility and manipulation. Application areas include robotic manipulators and mobile platforms, vehicles in space, earth, air, and sea, and mechanisms that move making use of nonholonomic constraints and impacts. His current research focuses on motion coordination algorithms for groups of autonomous vehicles, cooperative control and distributed algorithms.

Prof. P.L. Garcia (Mathematics, University of Salamanca — 35%). His main interest for the last 35 years has been the geometric structure of the calculus of variations and classical field theory. Firstly, Cartan and multisymplectic formalisms for classical fields and its applications to Gauge theories. Next, the generalization of this theory to higher order variational calculus. More recently, constrained variational calculus and its relation to Lagrangian reduction, with applications to Euler-Poincaré equations, gravitating relativistic dissipative fluids and H-minimal Lagrangian submanifolds of Kähler manifolds. With some contributions to geometric quantization, he has also worked on the theory of differential invariants of G-structures.

Prof. A. Ibort (Dept. of Mathematics, Univ. Carlos III, Madrid — 20%) has been working for more than twenty years on geometrical mechanics and symplectic geometry. More recently he has started to work on geometrical control, mainly on singular control theory combining topological, geometrical and analytic ideas to describe the properties of singular arcs. An important part of his activity on differential geometry is currently focused in using approximately holomorphic techniques to explore the topology of symplectic, contact and Poisson manifolds.

Prof. M. de León (Mathematics, CSIC, Madrid — 25%) has been an active researcher in Differential Geometry and Mechanics for more that 25 years. He is author of about 225 papers in journals and proceedings of conferences and three monographs of research. His current fields of interests include nonholonomic mechanics, reduction, geometric integrators, optimal control theory, Lie algebroids, multisymplectic field theory and elasticity.

Dr. C. Rodrigo (Mathematics, University of Salamanca — 35%) has worked in the Cartan formalism of constrained higher order variational problems, with special emphasis in the obtaining of Stress-energy-momentum tensors for natural bundles from the multi-momentum map. Recently, his interest has been focused on Lagrangian reduction problems, the problem of Lagrange on fibred manifolds, and its applications to non-holonomic and vakonomic mechanics.

Two recent publications

- M. Castrillón López, T. Ratiu, Reduction in principal bundles: Covariant Lagrange-Poincaré equations, *Comm. Math. Phys.* **236** (2003), 223–250.
- J. Cortes, S. Martinez, J.P. Ostrowski, and H. Zhang: Simple mechanical control systems with constraints and symmetry. *SIAM J. Control and Optimization* **41** (2002) 851–874.

Linkages between teams Collaborations already exist between Castrillón López and Ratiu (CH), and between Cortes and Lewis (Ca) and van der Schaft (NL2). It is clear that other collaborations will result from this network (eg, Cortes and Montaldi (UK1)).

Role in the network Castrillón López will be Objective Advisor for (II.8), and Cortes for (I.4).

TEAM 5: F1

The F1 Team is composed of a number of scientist working in several French universities and research institutions with a strong background on variational methods, Hamiltonian systems, symplectic and Poisson geometry, nonlinear PDEs for fluids and plasmas, and numerical methods. The team will be administered from the Department of Mathematics of the University of Franche-Comté in Besançon.

Key Scientific Staff and Expertise

Dr. J.-P. Ortega (Mathematics, Besançon — 50%; team coordinator): Has worked on the bifurcation theory and dynamics of symmetric Hamiltonian systems theory focusing on geometric approaches to the stability and bifurcations of relative equilibria and relative periodic orbits. He is particularly interested in the geometry of the conservation laws associated to the symmetries of Hamiltonian systems (momentum maps theory) and in applying the techniques that he has developed to controlled and constrained systems.

Prof. Y. Brenier (Mathematics, Laboratoire Dieudonné, Nice — 20%): He is an expert on the application of nonlinear PDE techniques to fluids and plasmas as well as in related numerical methods, and infinite dimensional geometry (groups of diffeomorphisms and polymorphisms). He was an invited speaker at the last International Congress of Mathematicians.

Dr. A. Chenciner (Mathematics and Astronomy, Bureau des Longitudes, Observatoire de Paris — 5%): Extensive work on variational techniques applied to n–body motion and celestial mechanics. He recently found, together with R. Montgomery, a new exact solution of the 3–body problem. He was an invited speaker at the last International Congress of Mathematicians.

Prof. C.-M. Marle (Mathematics, Paris VI — 40%): He is an expert on symplectic geometry, Hamiltonian systems, Poisson geometry, and mechanical systems, in particular subjected to non-holonomic constraints. He is currently interested in the applications of Lie groupoid and algebroid techniques in the characterization of the symmetries to Hamiltonian systems.

Prof. E. Séré (Mathematics, Paris-Dauphine — 10%): Works extensively on variational methods with applications to Hamiltonian systems and mathematical physics.

Prof. N. Tien Zung (Mathematics, Toulouse — 15%): Is an expert on dynamical systems and on symplectic and Poisson geometry.

Other Postdoctoral Research Fellows: 2

Other Postgraduate Students: 6

Linkages between teams Ortega is a former doctoral student of Ratiu (CH) and has been involved in several projects with Montaldi (UK1), Roberts, Wulff (UK2), Birtea (Ro), Cushman (NL1), and the members of the F1 node. He shares with Montaldi the supervision of two postgraduate students at the INLN (Nice). Brenier interacts regularly with Holm (UK3) and Ratiu (CH). The work of Marle has greatly influenced many of the topics in Theme 1 as well as the scientific work of, for instance, Montaldi (UK1), Ortega (F1), Ratiu (CH), Roberts, and Wulff (UK2). Chenciner has close contacts with Terracini and colleagues (I2).

Role in the network Ortega, the F1 node coordinator, is involved in the organisation of a series of events (2 conferences and 2 summer courses) which will take place during the next four years and aimed at enhancing the scientific activity proposed in the framework of the MaGIC project and paying special attention to the training of young researchers. Applications for the funding of these activities is being prepared in the context of the SCF Marie Curie Actions and to the French CNRS and Ministry of Foreign Affairs.

The F1 Team will play major roles in Themes I and II, and contribute to Theme III. Ortega will be Advisor on objectives (I.1) and (I.3), Séré on objective (II.1) and Brenier on objective (II.7).

Two recent publications

- Y. Brenier Derivation of the Euler equations from a caricature of Coulomb interaction. *Comm. Math. Phys.*, **212** (2000), 93–104.
- J.-P. Ortega and T. S. Ratiu *Momentum Maps and Hamiltonian Reduction*. *To appear* in Progress in Mathematics. Birkhäuser (2003).

TEAM 6: F2

Team consists mainly of physicists working on molecular systems from the point of view of dynamical system theory with tight contact between approaches based on classical and quantum mechanics. The team will be administrated from the Université du Littoral, Dunkerque and includes participants from Dunkerque and Université Joseph Fourier, Grenoble.

Key Scientific Staff and Expertise

Prof. B. Zhilinskii (Université du Littoral — 50%; team coordinator) has worked on qualitative theory of highly excited quantum systems using quantum classical correspondence. Has expertise in group theoretical method, including invariant theory, topological methods, dynamical system theory, applied to the analysis of concrete molecular systems.

Dr. F. Faure (Université Joseph Fourier — 40%) Has worked on topological methods in solid state physics, including quantum Hall effect. Expert in physical applications of topological invariants and characteristic classes. Has made recent successful applications of topological methods to molecular finite particle systems.

Dr. M. Joyeaux (Université Joseph Fourier — 20%). Expert in large scale theoretical chemistry calculations of molecular vibrational states.

Dr. D. Sadovskii (Université du Littoral — 50%) Has worked on modern classical mechanical methods (singular reduction, normalization, etc) with application to molecular problems. Major expertise in assignment and interpretation of complex molecular spectra. Expert in analytical and numerical calculations on computers.

Dr. S. Vu Ngoc (Université Joseph Fourier — 30%) Specialist in mathematical semi-classical methods, and major expertise in quantum monodromy analysis. Realises mathematical support of models developed on physically intuitive ideas.

Dr. L. Wiesenfeld (Université Joseph Fourier — 20%) Has experience in molecular dynamics and elementary chemical reactions. Uses both classical and quantum approaches in molecular dynamics.

Other postgraduate students 1

Linkage between teams Sadovskii and Zhilinskii have a long standing collaboration with Cushman (NL1) mainly on different aspects of classical monodromy. Collaboration with N. Nekhoroshev (I2) started during a long term stay of Nekhoroshev in Dunkerque and namely this collaboration is responsible for the new theme - fractional monodromy - included as a major point in the project. Collaboration between Faure and Zhilinskii created another important subject - topological invariant and molecular spectra - also included as another subject in the project.

Role in the network Sadovskii is the coordinator of Theme B "Molecules and Atoms: structure, spectra and dynamics". This Theme will play the essential and coordinating role in the application and testing of mathematical models on concrete physical examples and in formulating physically reasonable qualitative models to be formulated in rigourous mathematical language. Members of team work in some sense as translators from physical to mathematical language. Zhilinskii and will Advisor for Objective (I.7), Faure for Objective (III.7), Vu Ngoc for (III.6) and (III.1), Wiesenfeld for (III.9).

Two recent publications

- N. Nekhoroshev, D. Sadovskii, B. Zhilinskii Fractional monodromy of resonant quantum oscillators. C. R. Acad. Sci. Paris, Ser. I 335 (2002) 985-988.
- F. Faure, B. Zhilinskii. Topologically coupled energy bands in molecules. Phys. Lett. A 302 (2002) 242-252.

TEAM 7: I1

Key Scientific Staff and Expertise

Prof. Francesco Fassò (Mathematics, University of Padua — 50%) is a specialist in Hamiltonian perturbation theory (KAM and Nekhoroshev theory and applications), with interests and expertise in integrable Hamiltonian systems and non-holonomic systems.

Prof. Giancarlo Benettin (Mathematics, University of Padua — 40%) is an expert on Hamiltonian dynamics, KAM theory and dynamical systems.

Dr. Mauro Favretti (Mathematics, University of Padua — 50%) has expertise and interests on nonholonomic mechanical systems and control theory.

Prof. Mauro Spera (Mathematics, University of Padua — 30%) has research interests include geometric methods in quantum mechanics, vortex theory and link invariants, and loop space extensions of the index theory.

Prof. Gaetano Zampieri (University of Turin — 50%) has expertise on stability questions for ordinary differential equations, integrability problems for Hamiltonian systems, and the dynamics of nonholonomic systems.

Other Postdoctoral Research Fellows: 1

Other Postgraduate Students: 1

Linkages between teams Fassò has been in contact for several years with members of the CH, I2, NL1 and UK1 teams and more recently of the Ca team and has joint publications with Ratiu (CH), Broer and Cushman (NL1) and Dullin (UK1). Benettin had a long lasting collaboration and many joint publications with Giorgilli (I2) and is still in constant contact with members of the I2 team. Zampieri currently collaborates with Oliva (P).

Role in network Fassò will be Objective Advisor for (III.4) on integrable nonholonomic systems and Benettin will Advise on (III.2) on perturbations of superintegrable Hamiltonian systems. The I1 team will contribute to several project objectives in themes I, II, III, and B.

Two recent publications

- F. Fassò and A. Giacobbe, Geometric structure of "broadly integrable" Hamiltonian systems, *J. Geom. Phys.* **44** (2002), 156–170.
- G. Zampieri Dynamic convexity for natural thermostatted systems. *J. Diff. Eq.* **191** (2003), 55–66..

TEAM 8: I2

The Milano Team brings together scientists from different Mathematical Departments of the Milano area and will be based at the University of Milano Bicocca. Its collective expertise covers various fields of interest in the study of Dynamical Systems: variational and topological methods, group theory and equivariant Morse Theory, perturbation and KAM theory, singularity theory and self—similarity, differential geometry, Lie theory of differential equations, symmetry reduction methods.

Key Scientific Staff and Expertise

Prof. Susanna Terracini (Università di Milano–Bicocca — 50%; team coordinator) Principal scientific interests: variational methods in celestial mechanics, the n-body problem and lattices of interacting particles. Dynamical systems and nonlinear analysis. Reaction–diffusion systems of nonlinear PDEs. Pattern formation and free boundaries of segregated states.

Dr. Gianni Arioli (Politecnico di Milano — 50%) Research interests: Variational, topological and numerical methods for the study of differential equations. Current specific topics of research include: the 3-body problem in Celestial Mechanics, the Fermi-Pasta-Ulam model, classes of reaction diffusion equations, computer assisted proofs for the existence of bifurcations.

Prof. Dario Bambusi (Università di Milano — 30%) Principal scientific results: Some extensions of Nekhoroshev's Hamiltonian perturbation theory to PDEs. Extension of Birkhoff normal form to some PDEs. A simple approach to existence of periodic solutions in PDEs. Semiclassical normal form.

Dr. Davide L. Ferrario (Politecnico di Milano — 50%) Research interests focus on equivariant and computational topology, algebraic topology, degree and fixed point theory, symmetries in the N-body problem. Recent works include the study of periodic orbits for the N-body problem and algebraic topology of singular spaces.

Prof. Antonio Giorgilli (Università di Milano–Bicocca — 30%) Research interests: dynamical systems, in particular Hamiltonian near to integrable systems; KAM and Nekhoroshev theory with applications to physically interesting systems, e.g., the solar system and its main and minor bodies, models of FPU type, Statistical mechanics.

Dr. Paola Morando (Politecnico di Torino — 10%) Mathematical physics, analytical mechanics, constrained systems, group theory, Nambu theory.

Prof. Nikolai Nekhoroshev (Visiting 3 years at Università di Milano — 50%) Hamiltonian perturbation theory, geometry of Hamiltonian systems, geometry of integrable systems.

Other postdoctoral Research Fellows: 2

Other Postgraduate Students: 2

Linkages between teams Terracini has a strong scientific link with Chenciner (F1), whose PhD student Venturelli spent his final year in Milano, working with Terracini. Furthermore, Terracini has common research interest with Roberts and Wulff (UK2), and Montaldi and Sbano (UK1) on trajectories of the N-body problem that minimize the action and also on periodic and other distinguished orbits of FPU type chains. Scientific interchanges are very likely with Séré (F1) focusing on the existence of connecting orbits. Bambusi plans to collaborate with T. Bridges (UK2), Zhilinski and San Vu Ngoc (F2), and Holm (UK3) and Ratiu (CH). Moreover we mention possible connections of the researches of Terracini with Sousa Diaz (P), on variational problems, and of Morando with Ratiu (CH) and Ortega (F1) on generalized Lagrangian Systems.

Role in the network Terracini is the team coordinator and will be mainly involved in Theme II, Bambusi will be mainly involved in Theme III. The main strength of the Milano team consists in the breadth of its expertise in different aspects of Dynamical Systems, both from the theoretical and the applicative points of view. The Milano team will mainly contribute to the objectives related to the search of POs and RPOs in systems of many interacting particles (Theme II). Another relevant contribution will be given to the objectives related to Perturbation Theory. The Milano team will also contribute to the development of reduction methods in symmetric Dynamical Systems. Terracini and Ferrario will be Objective Advisors for (II.1), and Bambusi for (III.10).

Two recent publications

- D. L. Ferrario and S. Terracini, On the existence of collisionless equivariant minimizers for the classical n-body problem, preprint (2003) (55 pp.) `http://www.arxiv.org/abs/math-ph/0302022`.
- D. Bambusi, On the existence of coBirkhoff normal form for some nonlinear PDEs, *Commun. Math. Phys.* **243** (2003), 253–285.

TEAM 9: NL1

The NL1 team consists of 3 mathematicians with expertise in symmetries in Hamiltonian systems, singular reduction, KAM theory, classical and quantum monodromy and nonholonomically constrained systems. It will be administered from Utrecht.

Dr. R.H. Cushman (Mathematics, University of Utrecht — 25%; team coordinator) has great experience in many concrete examples in classical mechanics, and has recently been specialising in monodromy, singular reduction, singular toral fibrations and normal forms.

Prof. H. Broer (Mathematics, University of Groningen — 20%) works in dynamical systems, both conservative and non-conservative; in particular his interests lie in KAM theory, singularity and bifurcation theory, normal form theory.

Dr. A. Vanderbauwhede (Mathematics, University of Gent — 10%) works on relative equilibria (both Hamiltonian and dissipative), families of periodic solutions and their bifurcations. Has recently been working on numerical methods for following these types of trajectory.

Linkages between teams Cushman has worked with Sadovskii and Zhilinskii (F1) on quantum monodromy and the geometry of integrable systems, and has published papers with Roberts (UK2) and Vu Ngoc (F1).

Role in network Broer is the coordinator of Theme III “Integrable and near-integrable systems”, and van der Schaft of Theme A “Nonlinear Control”. Cushman will assist Team 5 (F1) in achieving objectives (III.5) and (III.6). He will also assist Broer with his investigations into the global geometry of KAM tori, and will be Objective Advisor for (III.1) and (III.5). Vanderbauwhede will assist other teams in achieving objective (II.1), will cosupervise the ESR in Team 13 (UK3), and will be Advisor for objective (II.2).

Two recent publications

- H.W. Broer and R.H. Cushman, Geometry of KAM tori for nearly integrable Hamiltonian systems. (preprint, University of Groningen, Nov. 2002).
- H.R. Dullin, A. Giacobbe, and R. Cushman, Monodromy in the resonant swing spring, (preprint, University of Loughborough, Dec. 2002).

TEAM 10: NL2

The NL2 team consists of 3 mathematical engineers with expertise in the geometric theory of nonlinear control. It is administered from the University of Twente, and based in the Faculty of Electrical Engineering, Mathematics and Computer Science.

Prof. A. van der Schaft (Mathematical Systems and Control Theory, University of Twente — 15%; team leader) has been working for more than twenty years within the area of nonlinear systems and control theory, with special emphasis on the geometric modelling and control of mechanical and electro-mechanical systems and the theory of dissipative and complementarity systems. In particular, he has been extensively working on the geometric theory of Hamiltonian control systems, for purposes of analysis, control and simulation of complex physical systems.

Dr. G. Blankenstein (Mechanical Engineering, KULeuven — 20%) has developed the theory of symmetries and reduction for implicit port-controlled Hamiltonian systems in his thesis. These results were extended to a theory for singular reduction during a postdoctoral visit at EPFL, in collaboration with Ratiu (CH). He has also worked on the passivity based control of underactuated mechanical systems. Recently, he has extended the framework of Dirac structures to include energy dissipative elements, with applications to modelling and control of electrical circuits. Finally, he has studied the symmetries of interconnected systems, with intended applications to robotic locomotion and control.

Prof. S. Stramigioli (Electrical Engineering, University of Twente — 10%) works in multi-body kinematics and dynamics, Port-Hamiltonian systems and Differential Geometric Control Theory, together with robotic applications such as telemanipulation and walking machines. He is coordinator of the R&D FP5 Network *GeoPlex* on Geometric Network Modelling and Control of Complex Physical Systems and will provide an important link between the networks.

Linkages between teams This team is bringing new expertise to the network which is expected to lead to new collaborations. There has already been collaboration between Blankenstein and Ratiu (CH), and between Van der Schaft and Cortes (E). The proposed ESR at this node will be cosupervised by the network coordinator Montaldi (UK1).

Role in network Van der Schaft is the Coordinator of Theme A “Nonlinear Control”, and the team brings to the network an important new expertise in geometric nonlinear control theory.

Two recent publications

- A.J. van der Schaft and B.M. Maschke, Hamiltonian formulation of distributed-parameter systems with boundary energy flow, *Journal of Geometry and Physics* **42** (2002), 166–194.
- G. Blankenstein and T.S. Ratiu, Singular reduction of implicit Hamiltonian systems. To appear in *Reports on Mathematical Physics*. Available at `http://www.arxiv.org/math.DS/0303022`

TEAM 11: P

The P team is based at the Istituto Superior Técnico (IST) in Lisbon, and is formed by researchers with expertise in the areas of symplectic and Poisson geometries, dynamical systems, geometric mechanics and symmetric Hamiltonian systems. All members belong to the Mathematics Department of IST except Kobayashi who belongs to the Mechanical Engineering Department of IST.

Key scientific staff and expertise

Dr. M.E.R. Sousa Dias (Mathematics, IST — 30%; team coordinator) has worked in singular reduction for symplectic manifolds, finite dimensional models for fluids as the pseudo-rigid bodies. Her current interests are singular reduction for cotangent bundles, stability and bifurcations of REs of Lie-Poisson type systems and applications to models arising from fluids.

Prof. R. Loja Fernandes (Mathematics, IST — 25%) has worked in Poisson geometry, integrable Hamiltonian dynamical systems, and deformation quantization. His current research focuses on global aspects of Poisson geometry, including Poisson topology and symplectic groupoids, and he is interested in applications to the reconstruction of reduced Hamiltonian dynamical systems.

Dr. L. Godinho (Mathematics, IST — 30%) has worked in the geometric description of symplectic reduced spaces for toric actions. Her current research focus on Hamiltonian torus actions and equivariant cohomology.

Dr. M. Kobayashi (Mechanical Engineering, IST — 25%) has worked with constrained mechanical systems, including linear and non-linear constraints and the d’Alembert-Chetaev and vakonomic formalisms. His recent interests include the Birkhoff approach to mechanics and dynamical aspects of mechanical systems.

Dr. J. Natario (Mathematics, IST — 25%) has worked in contact geometry aspects of General Relativity. His current research interests include perturbations of integrable systems with applications to rigid body dynamics and celestial mechanics.

Prof. W.M. Oliva (IST — 10%) has an extensive body of work in the area of dynamical systems either in finite and infinite dimensions. Recent interests include non-holonomic mechanical systems with linear, or affine or non-linear constraints, following the D’Alembert point of view and the Birkhoff approach to classical mechanics.

Other Postdoctoral Research Fellows: 2

Other Postgraduate students: 2

Linkages between teams Sousa Dias has joint publications with Roberts (UK2). Fernandes has contacts with Ratiu (CH) and Ortega (F1) although no joint publications have been produced yet. Kobayashi and Oliva have contacts with members of other teams, although no joint work has materialized.

Role in network The P team will contribute significantly to the geometry of constrained systems in Theme I, applications to celestial mechanics in Theme II and to the study of finite dimensional models arising from Hamiltonian PDEs in Theme III. Fernandes will be Objective Advisor for (I.1) on global Poisson geometry, Sousa Dias will be Advisor for (II.6).

Two recent publications

- M. E. Sousa Dias, Pseudo-rigid bodies: a geometric Lagrangian approach, *Acta Applicandae Mathematicae* **70**, (2002), 209–230.
- R. L. Fernandes, Connections in Poisson Geometry I: Holonomy and Invariants, *J. Differential Geom.* **54** (2000), 2, 303–365.

TEAM 12: Ro

This team is based at the Mathematics department of the West University of Timisoara (UVT), and has expertise in Geometric Mechanics, especially in control theory and in the geometry of Hamiltonian PDEs.

Key scientific staff and expertise

Prof. Dr. M. Puta (UVT — 30%; team coordinator): Has worked in geometrical mechanics, geometric quantization and optimal control on matrix Lie groups. Current interests include stability problems in rigid body dynamics with controls and in the charged top dynamics, numerical integration via Lie-Trotter integrator and Kahan integrator, as well as their geometrical quantization.

Dr. C. Vizman (UVT — 25%): Used Arnold's method for the study of partial differential equations as geodesic equations on (extensions of) diffeomorphism groups with right invariant metrics. Current interest include infinite dimensional symplectic manifolds: coadjoint orbits in (extensions of) groups of diffeomorphisms, such as the non-linear Grassmannians.

P. Birtea (UVT — 30%): Has worked in singular reduction on tangent and cotangent bundles, and in control theory.

Linkages between teams Puta has had several long term collaborative projects with Ratiu (CH) in areas ranging from rigid body dynamics to laser-matter dynamics. Birtea has collaborated with Ratiu (CH) and Ortega (F1).

Role in network The group at UVT will organize at least one focused workshop on the geometric problems in control theory. Puta will be Objective Advisor for (I.5) on control theory on matrix groups.

Two recent publications

- P. Birtea, M. Puta, T.S. Ratiu, R. Tudoran; A short proof of chaos in an atmospheric system, *Phys. Lett.* A **300**, No. 2-3, 189-191 (2002).
- M. Puta, R. Tudoran; Controllability, stability and the n-dimensional Toda lattice, *Bull. Sci. Math.* **126** No. 3, 241-247 (2002).

TEAM 13: UK2

The UK2 team consists of mathematicians from the University of Surrey (UniS) and the University of Southampton. The team offers strong expertise in stability and bifurcation theories in dynamical systems; variational methods in symmetric systems; geometrical methods in mechanical systems, especially ones with symmetries; semi-classical methods and their applications to atoms and molecules. Within the University of Surrey, the team is embedded in the research group on nonlinear dynamics, an internationally recognized research group and one of the largest groups on this topic in the UK. The University of Surrey is also a Marie Curie Institution for *Doctoral Training in Theoretical and Applied Nonlinear Systems* (Nonlinear@Surrey). Under this scheme, approximately 14 PhD students from the rest of Europe will be able to visit Surrey for periods of (typically) 4–5 months. The team will be administered from the University of Surrey.

Key Scientific Staff and Expertise

Dr. G. Derks (Mathematics, UniS — 20%; team coordinator): Works on the effects of perturbations on families of relative equilibria in Hamiltonian systems with symmetries; infinite-dimensional Poisson systems; stability and instability of solitary waves and front solutions; the multi-symplectic Evans function; applications of symplectic geometry to classical mechanical systems; and applications to fluids and optics. She is currently supervising 1 PhD student and 1 Postdoctoral Researcher and has previously supervised 1 Postdoctoral Researcher.

Dr. D.R.J. Chillingworth (Mathematics, Southampton — 30%): Works in dynamical systems and bifurcation theory with particular emphasis on symmetry-breaking. Recent results include a general formalism for forced symmetry-breaking from continuous (e.g.rotational) symmetry, and bifurcation analysis of bulk and patterned states of liquid crystals.

Prof. I. Melbourne (Mathematics, UniS — 10%): Works in dynamical systems, bifurcation theory, symmetry breaking and ergodic theory. Current interests include local bifurcations from equilibria in spatially-extended systems and from periodic solutions with spatiotemporal symmetry, and statistical properties of dynamical systems. Recently became interested in the detection of chaos in deterministic systems. He is currently supervising 2 PhD students and has supervised 7 Postdoctoral Fellows.

Prof. R.M. Roberts (Mathematics, UniS — 20%): Expert on geometric mechanics and its applications: symplectic geometry of group actions, reduction, normal forms, stability and bifurcations of REs and RPOs. Current interests include coupling between rigid and flexible dynamical modes in molecules and other systems. He has supervised 5 PhD students and 7 Postdoctoral Fellow and is currently supervising 2 PhD students.

Dr. I. Roulstone (Joint Centre for Mesoscale Meteorology, Meteorology Office, UK — 25%) has spent the majority of his career working in numerical weather prediction, treating the subject as a problem of mathematical physics. His research interests include applied differential geometry and analysis; Hamiltonian mechanics; control theory; geometric integration, and the application of these subjects to meteorology. During the last four years he has led a research group based at Reading University, which has enabled him to establish important collaborative projects with individuals and groups within the academic community and the Met Office, through national and international networks.

Dr. C. Wulff (Mathematics, UniS — 20%): Works on dynamical systems methods for PDEs, equivariant bifurcation theory; stability and persistence of REs and RPOs for Hamiltonian ODEs, with emphasis on noncompact symmetry groups. Recently she also got interested in numerical aspects. She is currently supervising 1 Diploma Student and has supervised 1 Diploma Student.

Other Postdoctoral Research Fellows: 2

Other Postgraduate Students: 2

Linkages between teams Roberts is the coordinator of a proposal for an FP6 Marie Curie RTN (AstroDyn) (see B8), and will act as a link between the two networks. Derks has joint publications with Ratiu (CH). Melbourne is currently working with Lamb (UK3) on Birkhoff normal form theory near REs and RPOs, and with Montaldi (UK1) on spatiotemporal aspects associated with Lyapunov centres near REs in Hamiltonian systems with symmetry and time-reversing symmetry. Melbourne and Wulff have joint publications with Lamb (UK3) on bifurcations from RPOs in non-Hamiltonian systems. Roberts has had several long term collaborative projects with Montaldi (UK1) in areas ranging from symplectic geometry to REs of molecules. He also supervised the PhD studies of Sousa Dias (P) and continues to work with her on 'Riemann's Theorem' and affine rigid bodies. Roberts and Lamb (UK3) are currently collaborating on the classification and stability of equivariant linear systems with time-reversing symmetries. Roberts and Wulff have joint publications with Patrick (Ca).

Role in network Roberts will be the coordinator for Theme 2: "Variational methods in symmetric systems"; he is also Coordinator of the proposed Marie Curie RTN *Astronet*, and will provide an important link between the two. Wulff is Advisor for Objective (I.8) and Derks for Objective (II.2).

Two recent publications

- G. Derks and T. Ratiu. Unstable manifolds of relative equilibria in Hamiltonian systems with dissipation. *Nonlinearity* **15** (2002), 531–549.
- R.M. Roberts, C. Wulff and J.S.W. Lamb. Hamiltonian systems near relative equilibria. *J. Differential Equations* **179** (2002), 562–604.

TEAM 14: UK3

All four scientists in this team are based in the Mathematics Department of Imperial College of Science, Technology and Medicine, London.

Dr. J.S.W. Lamb (Imperial — 25%; team coordinator): Is working on bifurcation theory for reversible equivariant Hamiltonian dynamical systems, in particular local bifurcations or REs and RPOs. Bifurcations of — and dynamics near — connecting (homoclinic/heteroclinic) orbits in reversible equivariant (Hamiltonian) systems are also being studied.

Prof. Darryl D. Holm (Imperial — 33%) works in nonlinear dynamics — ranging from solitons to chaos and turbulence. He specializes in using geometrical mechanics for the derivation and analysis of new equations that model the multiscale physics of pulse propagation in nonlinear optics and fluid dynamics. His earlier work in nonlinear optics provided the first evaluation of the quantum-classical crossover time in chaotic laser-cavity dynamics. He also invented and patented a new pulse shaping method based on iterated mappings for long-distance high-speed telecommunications in optical fibers.

Holm recently used geometrical mechanics in deriving and analysing new equations for coherent nonlinear pulses (solitons) propagating in shallow water. In fluid dynamics Holm is applying various methods from nonlinear dynamics in predicting the mean effects of subgrid scales and turbulence on the resolvable scales of fluid motion in weather forecasting, global ocean circulation and climate change. His recent work applied the technique of Lagrangian averaging in the framework of geometrical mechanics to develop new closure equations called ”alpha models” for the numerical simulation of turbulence. Lately, he is working with Ratiu (CH) in applying geometrical mechanics to derive new equations for the nonlinear dynamics of complex fluids such as liquid crystals.

Prof. S. Reich (Imperial — 5%): Is working on symplectic integration methods for Hamiltonian systems with application to molecular dynamics and geophysical fluid dynamics; development of structure preserving discretizations; backward error analysis and long time behaviour of numerical methods; large time-step methods for systems with multiple time scales.

Dr. J-L. Thiffeault (Imperial — 10%): Is working on dynamical system methods for studying mixing in fluids. These include both Lagrangian approaches, where the fluid trajectories are treated as a Hamiltonian system, and Eulerian approaches, where global eigenfunctions are sought.

Linkages between teams Holm has a long-standing collaboration with Ratiu (CH), and more recently with Dullin (UK1). Lamb is currently collaborating with Roberts and Wulff (UK2) and on a different project with Melbourne (UK2).

Role in network Holm is the coordinator of Theme C “Fluids, complex fluids and turbulence”. Reich will act as a link between this network and the Marie Curie RTN, CoRGI (Collaborative Research in Geometric Integration). Lamb will be Objective Advisor for (I.2) on dynamical features of Poisson and symplectic systems.

Two recent publications

- H.R. Dullin, G. Gottwald and D.D. Holm, On asymptotically equivalent shallow water wave equations (2003), *Fluid Dyn. Res* to appear.
- R.M. Roberts, C. Wulff and J.S.W. Lamb, Hamiltonian systems near relative equilibria. *J. Differential Equations* **179** (2002), 562–604.

TEAM 15: Ca

Team Canada brings together mathematicians from a number of Canadian universities with expertise in the geometric structure of mechanical systems, and the stability and bifurcation theories of symmetric Hamiltonian and non-Hamiltonian systems. The team will be administered from the University of Calgary.

Prof. J.Z. Śniatycki (Mathematics, University of Calgary — 40%; team coordinator) Began his research in quantum mechanics and quantum field theory, and has been working on geometric structure in classical and quantum mechanics and field theory for the past 35 years, firstly on geometric quantization in quantum mechanics, next on geometry and analysis of Yang-Mills theory, and more recently on the structure of dynamical systems with symmetries. He has applied formulated distributional Hamiltonian approach to dynamics and reduction of symmetries of non-holonomically constrained systems. He is currently collaborating with Cushman (NL1).

Dr. L Bates (Mathematics and Statistics, Calgary — 10%). Started research in global analysis and classical mechanics. Has mainly been working on nonholonomic systems for the last ten years, first on symmetry reduction and then on the relation between symmetries and gauge-like conservation laws. More recently he has been interested in problems concerning the blow up of symplectic charts. He has also been working on problems in the global geometry of classical integrable systems, particularly those with Hamiltonian monodromy. Currently he is collaborating with Śniatycki (Canada) and Cushman (NL1), and supervising a PhD student.

Prof. A. Lewis (Mathematics and Statistics, Queen’s University — 40%) Works in the areas of overlap between Geometric Mechanics and Geometric Control Theory. Interests in control theory include problems of controllability and optimal control theory. In mechanics, interests include differential geometric modelling, especially for nonholonomic systems. Did two-year postdoc at University of Warwick with Roberts (UK3). He is supervising three Ph.D. students and one M.Sc. student.

Prof. R. Littlejohn (Physics, Berkeley — 20%) is Professor of Physics at the University of California, Berkeley. His recent research interests have involved the application of geometrical methods and especially short-wavelength asymptotics and semiclassical mechanics to problems in atomic, molecular, nuclear, optical and plasma physics. Littlejohn currently has one graduate student and one postdoc.

Prof. G.W. Patrick (Mathematics and Statistics, University of Saskatchewan — 30%) Began his research in Geometric Mechanics and has been working on the stability of, persistence of, and the dynamics near relative equilibria. Has collaborated with Roberts and Wulff (UK3) on persistence and stability of RE in the case of noncompact groups. He has also worked on and extensively used structure preserving integration algorithms. He applied this work to coupled rigid bodies, underwater vehicles, and systems of point vortices. He is supervising one Ph.D. student.

Dr. T. Tokieda (Mathematics, CUNY, New York, USA — 25%) Began his research working on symplectic topology and capacity. He now works principally on Geometric Mechanics, and in particular on point vortices and on non-holonomic systems. Tokieda is currently collaborating with Montaldi (UK1).

Prof. A. Weinstein (Mathematics, Berkeley — 15%) Works in symplectic geometry and its generalizations (Poisson geometry and Dirac structures), with applications to hamiltonian systems with symmetry and constraints and to semiclassical approximations. Current interests include groupoids and twisted Poisson and Dirac structures, with applications to discrete and nonholonomic mechanics. He is currently supervising 4 PhD students and 2 postdocs. (Over the past 10 years, 14 PhD students and 14 postdocs.) Weinstein has recently been awarded an honorary doctorate by the University of Utrecht, host of Team 8.

Linkages between teams Bates and Śniatycki has had several long term collaborative projects with Cushman (NL1) in areas ranging from symplectic geometry through Hamiltonian mechanics to non-holonomic constraints. Patrick has collaborated with Roberts on persistence and with Roberts and Wulff concerning stability of relative equilibria in the case of noncompact groups, (UK2). Tokieda is collaborating with Montaldi (UK1). Weinstein is beginning to spend a significant amount of time in Europe, principally France, and more collaborations are expected to result.

Littlejohn is a leading international figure working on N-body quantum problem. He participates with Sadovskii and Zhilinskii (F2) on studies of intramolecular topological effects from a slightly different semi-classical point of view. He will collaborate further on manifestations of monodromy and topological invariants in three-body molecular systems and advise fellows in the F2 and NL1 teams who will work in this direction. Weinstein is the leading international figure working in Poisson geometry, and its relation to groupoids and algebroids. He will advise the coordinator and researchers of Theme 1, and particularly the ESR to be employed in Portugal.

Role in network Bates and Śniatycki will play major roles in the study of reduction of symmetries and mechanics on singular spaces, objectives (I.1) and (I.2), and the study of the geometry of nonlinear control, objectives (I.5) and (I.6). Patrick will play a major role in study of geometry of integrable and partially integrable systems, Objective (III.1), and he will be Advisor for objectives (III.3) on stability of equilibria and (II.6) on skyrmions. Littlejohn and Weinstein will have key advisory roles as described above. Littlejohn particularly will collaborate with and advise researchers in the F2 team. Weinstein will advise principally about Poisson Geometry and in general on Theme 1.

Two recent publications

- G.W. Patrick, Stability by KAM confinement of certain wild, nongeneric relative equilibria of underwater vehicles with coincident centers of mass and buoyancy. *SIADS* **2** (2003), 36–52.
- R. Cushman and J. Śniatycki, Nonholonomic reduction for free and proper actions, *Reg. Chaotic Dyn.*, **7** (2002) 61–72.

B3.2 Intensity and quality of networking

Collaboration and interaction between the teams will be achieved by the mechanisms described below together with the **Joint Supervision of Network Fellows** and MaGIC participation in the proposed Summer Schools described in §B8. All workshops, conferences and summer schools will be open to all interested participants, and special efforts will be devoted to attracting a wide range of postgraduate students from across Europe to these events.

Research Visits

Team members will regularly visit members of other teams to work together on specific sub-projects. It is anticipated that the average length of a visit will be around 1 week, but longer visits may also be possible. Typically the team members who are contributing most of their research time to this project may be expected to make several such visits a year and to act as host for several more. Project members working on the same sub-projects will also be able to meet at the events described below, and between research visits, workshops, conferences etc they will communicate by e-mail. Most of the funding for the research visits will come from the EC contract, but where possible this will be supplemented from other sources.

Focused Workshops

A programme of small, sharply focused workshops will be organized. Each of these will be dedicated to a few specific objectives and their main aim will be to review recent progress on those objectives and to exchange ideas about how to proceed. Typically each workshop may bring together 10–20 people, not all of whom may be project members. An excellent example of such meetings is provided by a series that Warwick has hosted over the past 3 years on the dynamics and spectra of molecules. Regular participants have included members of the proposed F2, NL1, UK1 and UK2 teams and the meetings provided the stimulation that led to their recent work on quantum monodromy. It is anticipated that approximately 5 of these meetings will be held per year of the project, lasting on average 2–3 days. The participation of project members will be funded mainly by the EC contract.

Conferences

A major international MaGIC Conference will be organized in each year of the project. Participants at the conferences are expected to include almost all MaGIC researchers and a large number of other scientists working in the same and related fields from throughout the world. Additional funding for these conferences may be sought from the EC Marie Curie Conferences Programme and from other national and international sources.

Training workshops

These will be small meetings each involving three or four of the Network Fellows, who will present their work to a small number of established scientists from the network principally to invite comments and suggestions. It will also have the effect of providing training in presentation skills and of encouraging a sense of scientific community amongst the Fellows. Each Fellow would attend about two of these workshops each year. Other PhD students and postdocs working in the participating teams would also be encouraged to attend.

While many individual scientists in the MaGIC network are still relatively young, it should be pointed out that each team contains at least one experienced researcher. Full integration of all teams into the project will be achieved by encouraging them to host workshops and other events, by distributing coordinating roles among all the teams and by joint supervision of ESRs and ERs by members of different teams.

The one team from a candidate country (Team 10 from Romania) will gain experience by hosting a workshop on Geometry and Control in Timisoara. They will also benefit from the wide range of potential collaborations.

A number of new collaborations are expected to develop from the network, not only with Timisoara (mentioned above), but between many pairs of teams. Some of the ERs and ESRs have joint supervisors who have not previously collaborated.

B3.3 Relevance of partnership composition

Existing links A number of bilateral links already exist between individual members of the teams, or have existed in the past. These are summarized in the following table and described in more detail in the team profiles.

Existing Bilateral Links Between Teams

	UK1	CH	D	E	F1	F2	I1	I2	NL1	NL2	P	Ro	UK2	UK3	Ca
UK1	-		c		c	c	c		c				c	c	c
CH	p	-	c	c	c		c					c			
D		p	-						c				c		
E		p		-					c	c					
F1	p	p			-				c		c	c			c
F2						-		c	c				c		c
I1	p	p					-				c				
I2						p	p	-							
NL1			p	p	p	p	p		-						c
NL2		p		p						-					
P											-				
R		p			p							-			
UK2	p	p	p					p	p		p		-		c
UK3	p	p												-	
Ca	p	p		p					p				p		-

below diagonal: p = joint publication

above diagonal: c = current research collaboration

New links The cosupervision of the network fellows and the frequent network workshops and conferences will promote new bilateral links. Indeed, many of the links above began under the RTN "MASIE" and MaGIC would provide the same impetus (as well as maintaining the existing links).

Extra-European team The non-European team based in Canada (with participants in the USA) consists of leaders in the field. There are already considerable bilateral links with the team, and the Network would enable the ERs and ESRs to take advantage of those links.

The network is not asking for any direct funding for the North American team. Any costs, either for sending our network fellows or key scientists for a short visit, or inviting the North American scientists to network meetings, would be borne by the European teams or from other funding.

B4 MANAGEMENT AND FEASIBILITY

B4.1 Proposed management and organizational structure

Management structure of the network The network will be managed through a system of coordinators:

- The *Network Coordinator* will have overall responsibility for the administration and scientific and training programmes of the network. He will be assisted by the Theme coordinators and the Team Coordinators for questions of scientific and organizational strategy. On a day to day basis he will be assisted by the experienced researcher employed as part of this project.
- Each team will have a *Team Coordinator* who will be responsible for the administration of that team and for overseeing the training of any early-stage and experienced researchers employed by his/her team. This will include control of the team's budget (according to his/her university's procedures) and the collection and submission to the network coordinator of administrative data for interim and final reports.
- Each of the six scientific *Themes* of the project will have a *Theme Coordinator* who will be responsible for preparing an annual plan for that section and an annual report on what has been achieved. For this (s)he will liaise closely with *Objective Advisors* who will take responsibility for many of the scientific objectives.

These coordinator positions are distributed widely among network researchers.

- The Network Coordinator is to be Montaldi (UMIST: UK1).
- The Theme Coordinators for the six themes are respectively, Ratiu (CH), Roberts (UK2), Broer (NL1), van der Schaft (NL2), Sadovskii (F2), and Holm (UK3).
- Objective Advisors are named in the team profiles in B3. There is at least one Objective Advisor in each team.
- The Team Coordinators are listed in the individual team profiles (B3.1), and their management experience summarized in B4.2 below.

Communication Network communication will take place at a number of different levels.

- Network conferences and workshops (at which there will be organizational meetings);
- Research visits and secondments;
- MaGIC website, and monthly e-newsletter (see below).

The EC experienced researchers employed at the network coordinator's institution (UMIST) will assist in maintaining a centralized communication network by collecting and redistributing abstracts and publication lists, running the network website and publishing a monthly e-newsletter. Other researchers financed by the EC contract will be expected to take over at least part of the coordination of the objective on which they are working.

Financial management The finances will be overseen by the coordinator, with the assistance of UVL (UMIST Ventures Limited). Each Team Coordinator will have responsibility for his/her team's finances. The sharing of the resources between the teams will be allocated according to decisions taken at organizational meetings. A tentative allocation is given in the table in B7.

All funds will be distributed to each team from the start. The proportion allocated to each team may vary over the 4 years and will be subject to review at annual meetings, and transfers between teams may be made.

The management costs will be used entirely for the auditing required by EC regulations.

Dissemination of the results The results of the project will be disseminated primarily by publication in leading international journals and by presentations at network meetings and at major international conferences. The network will ensure that it is represented at all the regular major mathematical meetings that cover the topics of the network research. Where possible the network will organize mini-symposia and similar events at these meetings. Reports and preprints will also be made available via the MaGIC website.

Intellectual property issues It is not expected that questions of intellectual property rights will emerge, and all the research financed by the Network will be published in the open scientific literature. However if any of the ideas and concepts that originate from the Network programme this Network prove to have commercial interest then necessary advice will be sought from the industrial development officers of the teams in the Network, and from the FP6 IPR Helpdesk.

B4.2 Management know-how and experience of network coordinator

The proposed Network Coordinator is Dr. J.A. Montaldi (Reader in Mathematics, UMIST, Manchester), a member of the UK1 team. UMIST has a great deal of experience managing national and international grants, through UMIST Ventures Ltd. (UVL). From October 2004 UMIST will merge with the University of Manchester, to form a single world class university; it is expected to be the largest university in the UK.

Montaldi himself has supervised or cosupervised 2 PhD students who have completed successfully, and is currently cosupervising 2 others (one in the ambit of the European Research Training Network MASIE). He has also cosupervised several postdoctoral research fellows.

In the fifth framework programme for High Level Scientific Conferences, he submitted a successful proposal to run two highly successful Euro Summer Schools (MASESS), and was principal organizer for both. In addition during the past 3 years, he has been on the scientific committees of three international conferences and one other summer school, and been invited to speak at several international conferences.

Montaldi has also obtained and managed a British Council grant for cooperation between the Universities of Nice and Warwick. He also co-organized the year-long *Warwick Symposium in Singularity Theory and its Applications*, held in 1989–90, involving a grant of around 50,000 pounds, and was on the scientific advisory board of the *Warwick Symposium in Geometric Mechanics and Symmetry* held in 2001–02.

B4.3 Management know-how and experience of other network teams

Team 2: CH

Ratiu is the coordinator of Theme I: “Poisson Geometry and Reduction”. He has organized several big international conferences, has managed research programs at mathematical research institutes in different countries, and is the director of the Bernoulli Centre (a new mathematical research institute based at the EPFL). The centre has experience hosting conferences and workshops. Ratiu’s experience will be drawn upon by his being on the scientific committees of the MaGIC Conferences, and indeed will be hosting one in Autumn 2004 on Geometry and Mechanics.

Team 3: D

Scheurle currently serves as the dean of the Faculty of Mathematics at TUM. He is coordinating the ”Continuum Mechanics and Hamiltonian PDE” section in the EU-funded RTN ”MASIE”, while Kruse is coordinating the ”Rods and Shells” project objective in that network. Also, Scheurle has regularly organized Oberwolfach conferences on all sorts of topics from Geometric Mechanics, as well as other international conferences and workshops about topics from this area. In particular, he organized a very successful workshop on ”Bifurcation theory and its Applications” within the EC-funded science network in Hamburg, in 1994.

Team 4: E

De León is Director of the Department of Mathematics of the CSIC in Madrid, and currently is the Coordinator for Mathematics in the Spanish Agency of Evaluation (Ministry of Science and Technology) and the Chairman of the International Congress of Mathematicians Madrid 2006.

Team 5: F1

Ortega is the coordinator of a Marie Curie proposal for Conferences and Training Courses (see §B8). It is expected that the Training Courses will encourage young scientists to apply for ESRs or ERs with the Network.

Team 6: F2

Sadovskii is currently the coordinator of Section 3 in the RTN “MASIE”, and is coordinator of Theme B in MaGIC. He has experience organizing workshops and conferences. He and Zhilinskii organized a recent MASIE workshop in Athens. Vu Ngoc is coordinator of a French interdisciplinary group (*ACI jeunes chercheurs*) of mathematicians, physicists and chemists, supported by the CNRS.

Team 7: I1

Fassò is presently the Team coordinator of the Padua Team of the FP5 RTN project *MASIE: Mechanics and symmetry in Europe*. Benettin has been the coordinator of the Padua-Milan Team of the EU Human Capital and Mobility project *Stability and Universality in Classical Mechanics*. Zampieri has organized several workshops at the University of Turin.

Team 8: I2

Terracini, Coordinator of this team, has experience leading the Milan Research Unit in the national network "Variational Methods and Nonlinear Differential Equations" funded by the Italian government. Last year the Milan local unit received a grant of 45000Eu. In addition, Terracini was the principal organizer of the "Thematic Programme on Nonlinear Analysis and Differential Equations" held at the University of Milano Bicocca in 2002 and funded by INdAM (with 50000Eu). The Thematic Programme included 14 short courses, held by internationally well known mathematicians and featured more than 30 invited talks. Bambusi, Galgani and Giorgilli also have a wide experience both in the administration of scientific grants and in organizing international courses and meetings.

Terracini has successfully supervised 5 PhD students, co-advised 3, and is presently supervising one PhD thesis on the equivariant periodic orbits for the n-body problem. She leads a research team presently including one PhD student, 2 Postdocs and 6 senior researchers.

The Mathematical Department of the University of Milano Bicocca will supply secretarial and administrative support to the Milano Node. Visiting members of the Network will be hosted at the University Hotel and can make use of all the facilities of the Mathematics Department. MaGIC ERs and ESRs will be integrated in all the activities of the Department.

Team 9: NL1

Broer has organized several international mathematics conferences in Groningen, and been on the scientific committees of several others. He is the Coordinator of Theme 3 "Integrable and near-integrable systems". Recently, Cushman organized (with Sniatycki and Bates (Ca)) a workshop in Banff.

Team 10: NL2

Both Van der Schaft and Stramigioli have been on organizing and scientific committees of numerous international conferences.

Team 11: P

The Portugal team has experience in the coordination of research projects, organization of national and international conferences and in the maintenance websites. Specifically, Fernandes was the coordinator of the research project "Métodos Geométricos e Topológicos em Sistemas Dinâmicos Hamiltonianos e Teoria Ergódica", and he has organized two international conferences in Lisbon, Godinho organized a Summer Mini-course in Lisbon, and Sousa Dias (with Roberts (UK2)) organized the international conference "Geometry, Symmetry and Mechanics, I", in Lisbon in 2001. Sousa Dias has also been responsible for the web maintenance of the publications archive of the RTN MASIE.

The IST is a major research centre, and hosts numerous conferences each year. They have a strong infrastructure for organizing such events, and MaGIC will benefit from that by holding a conference there.

Team 13: UK2

Roberts is coordinator of Theme 2 "Variational methods for symmetric systems". He is also coordinator of the proposed Marie Curie RTN "AstroNet", and will provide an important link between the two complementary networks. He is currently coordinator of the RTN "MASIE", and has organized several international conferences and workshops.

Team 14: UK3

The team coordinator is Lamb, who has experience organizing a number of workshops and conferences. Holm has been on numerous scientific and organizing committees for international conferences.

Team 15: Ca

J. Śniatycki has been Associate Director (Calgary) of the Pacific Institute of Mathematical Sciences, and will shortly be the Chairman of Division of Applied Mathematics of the Department on Mathematics and Statistics, University of Calgary. He has co-organized the Workshop on geometric quantization, Banff (1980) and with Bates and Cushman (NL1) organized the Workshop on nonholonomic constraints in dynamics, Calgary (1997). Patrick was until recently Head of Mathematics Department, University of Saskatchewan, Saskatoon.

Littlejohn has experience in organizing conferences (eg, on semiclassical mechanics, Los Alamos, 1989) and is currently an organizer of the semester-long program on semiclassical mechanics at MSRI (Mathematical Sciences Research Institute in Berkeley). Weinstein was the Director of the Center for Pure and Applied Mathematics, UC Berkeley, from 1989 to 1995. He also has considerable experience organizing conferences, including Groupoidfest 1997 and 2000 in Berkeley. Co-organizer since 1989 of the Northern California Symplectic Geometry Seminar, and is on the Organizing Committee for several conferences including Poisson 2000 (Luminy), 2002 (Lisbon), 2004 (Luxembourg).

B5 RELEVANCE TO THE OBJECTIVES OF THE NETWORK

Benefits to project from European scale As was pointed out in B2.2, the MaGIC network consists of around 60 European 'key scientists'. That these researchers are divided between about 30 Institutions scattered across Europe, shows the fragmented nature of this field of research. It is this fragmentation of the field together with its interdisciplinary nature that makes cooperation on a European scale essential. Moreover, few of the specializations of the project are represented in any one country, so the very interdisciplinary nature of the project requires a European scale.

For the interdisciplinary training of the experienced researchers and the interdisciplinary experience of the early-stage researchers to be possible it is imperative that the training is run on a pan-European scale. Furthermore, in order to develop and maintain long-term research collaborations, it is important that the next generation of scientist have contact with other researchers in the same and complementary fields, and at an institutional or even national level this can be impossible to achieve.

Need of project at Community level Recent developments in the geometric study of mechanical systems with symmetries have amply demonstrated that this is an exciting area of mathematics which combines the use of sophisticated geometrical and symmetry ideas from pure mathematics with techniques from applied mathematics, dynamical systems theory and physics, and with new geometrically based numerical methods. Moreover, apart from their intrinsic interest and beauty, these ideas and techniques are beginning to prove extremely fruitful in applications to real physical problems from areas as diverse as atomic and molecular spectroscopy, liquid crystals and geophysical fluid dynamics, and nonlinear control. However the great variety and diversity of the disciplines and techniques which are contributing to this area mean that it is frequently difficult for researchers with different scientific backgrounds to communicate with each other and for young researchers to enter the field.

A European Research Training Network can do much to address this problem. Currently there is no single institution, or even country, in Europe that has the resources and expertise to provide research training in all the geometrical, symmetry and numerical techniques that are used, and simultaneously to introduce young researchers to a range of applications. As the list of participants in B3.1 shows, expertise is concentrated in small groups scattered throughout the EU. To continue the bilateral links between teams that were initiated under the MASIE Research Training Network (FP5), and indeed to establish new links, a critical mass must be reached, and this can only be achieved at European level. The proposed Network will provide a framework for this.

One area of interdisciplinary research that is currently emerging within Europe is the application of geometry and symmetry methods to the analysis of atomic and molecular spectra. Recent work has demonstrated that new mathematical techniques are likely to prove highly successful in helping us to understand some of the structures seen in spectra, and conversely that interesting and difficult mathematical questions are raised by the analysis of spectra. The network will greatly facilitate and expand work in this area and also promote similar interdisciplinary collaborations in other areas. Similar statements can be made about applications to geophysical fluid dynamics, to models of liquid crystals and to nonlinear control theory, all of which are at a critical stage in their development and need the input from these geometric techniques.

Much of the activity in the last 20 or so years in geometrical mechanics has been focused in North America, but the recent move from there to Europe by a number of mathematicians working in this area meant that at the inception of the MASIE network we had an unprecedented opportunity to develop the subject on this side of the Atlantic much more rapidly and in a bigger way than would previously have been possible. By any standards, MASIE has been extremely successful, and it is important to develop these collaborations further.

The MaGIC Network will be a key element in this development and will help continue to spread the benefits across the whole of the EU. At the same time it will contribute substantially to the process of integrating this area of research with areas that are already strong in Europe, including equivariant dynamical systems theory and the application of mathematical methods to the qualitative study of atomic and molecular spectra, and to geophysical fluid dynamics and other applications.

B6 ADDED VALUE TO THE COMMUNITY

European added value The interdisciplinary nature of the MaGIC project provides a synergy between fundamental geometry—traditionally thought of as pure mathematics—and applied sciences such as molecular and atomic spectroscopy, geophysical fluid dynamics and control theory. This interdisciplinary synergy requires combining complementary national skills, which would not be possible without the MaGIC project. The high level and international visibility of the researchers participating in the MaGIC Network ensure that the quality of research and training provided will themselves promote excellence.

At the heart of this interdisciplinary effort lies the collaboration between mathematicians, physicists and chemists. Overcoming the language barriers is extremely important for the collaborations to exist and is one of the successes of the MASIE project, and will continue with MaGIC.

Attractiveness of Europe The MASIE network, precursor of MaGIC, was very successful in raising the visibility of European research in the field of Geometric Mechanics. It has led to a significant number of short-term and longer term visits by scientists from North America, Asia and Eastern Europe either to conferences or as postdoctoral researchers at one of the participating teams. Most recently, one of the foremost experts in Geometric Fluid Mechanics (D.D. Holm, now at Imperial College, London (UK3) and coordinator of Theme C) moved to Europe to take up a full-time position, and this was in no small part due to the new pan-European level of research collaboration. MaGICwill allow us to build on the progress made in the past three or four years.

Researcher's career prospects The training provided by the MaGIC Network will equip the early-stage and experienced researchers with a very sought after combination of skills. The interdisciplinary research training will create a sense of flexibility and a breadth that will stand any researcher in good stead in future research careers. This research experience, the management experience from contributing to running the network, and the presentational skills honed in the Training Workshops (see B2.1 and B3.2) will be valuable both in academic and industrial research.

Gender balance It is to be noted that 4 of the 12 European team coordinators are female (Martinez (E), Terracini (I2), Sousa Dias (P) and Derks (UK2)), as are several of the joint supervisors. These female key scientists will provide role models for both the male and female researchers employed by the network. A mentoring scheme will be set up for all researchers employed by the network and all researchers will be encouraged to take part in it. Several of the female scientists in the network are willing to act as mentors to both male and female researchers in the network. We will also ensure that 'time-off' research during periods of childcare is taken into account when assessing the eligibility of applicants, by making part-time appointments whenever appropriate. We will also encourage more women from outside the Network to participate in Network workshops and projects.

Personal circumstances relating to mobility We will endeavour to help as far as possible *all* applicants who may appear to have been disadvantaged in their research careers by personal circumstances which, for example, have constrained their mobility. Allowances similar to those discussed in the previous paragraph will be implemented as appropriate. Appointees will be offered language courses if they have a poor command of the language of the country they will be working in.

Integration of researchers from Candidate Countries The Network includes a team from one Candidate Country, Romania. The small team of researchers in the field at West University of Timisoara (UVT) will be encouraged to attend network conferences and workshops, and to pay research visits to other research teams in the network. One of their areas of expertise—optimal control on Lie groups—is new to most members of the network, but melds with the main aims of the network, and we can expect new collaborations in this field. Conversely, increasing the contact between the Romanian team and others will inevitable result in further integration of the former into the projects of this network where they are not explicitly involved at the outset. Consequently the network will provide the opportunity for initiating and sustaining collaboration between the UVT group and other groups in established EU member states.

The team coordinators and others involved in the recruitment of ERs and ESRs will encourage high quality young scientists from Candidate and Associated States to apply for the network positions. This will feed back into those countries by giving successful candidates both the experience of working in high-quality research environments and by forging collaborations with others that will ensure that the high quality of research is maintained after their return.

Furthermore, the organizers of Network Conferences will also ensure that the conferences are advertised in Candidate Countries or Associate States.

B7 INDICATIVE FINANCIAL INFORMATION

The table below shows approximately how the planned expenses for activities not related to the appointment of early-stage and experienced researchers will be allocated to the teams. Blanks indicate zeros. The sharing of columns (A) and (B) between the teams is based on the number of person-months indicated in the table in B2.3, together with the number of Themes or Objectives the individuals are collaborating in.

Note that the extra-European team requires no direct financing—all funding for example for sending RTN fellows to North America or for inviting researchers from those teams to network meetings, will be found from local budgets.

Indicative financial information on the network project (Excluding expenses related to recruitment of network fellows)					
Network Team		Contribution to the research/training transfer of knowledge expenses (Euro)		Management activities (including audit certification) (Euro)	Other types of expenses / specific conditions (Euro)
		(A)	(B)	(C)	(D)
1	UK1	56,386	8,000	15,000	2,000
2	CH	40,000	5,000	15,000	
3	D	35,000	5,000	15,000	
4	E	45,000	6,000	15,000	
5	F1	50,000	6,500	15,000	
6	F2	50,000	6,500	15,000	
7	I1	50,000	6,500	15,000	
8	I2	50,000	5,000	15,000	
9	NL1	40,000	5,000	15,000	
10	NL2	40,000	4,000	15,000	
11	P	45,000	5,000	15,000	
12	Ro	35,000	3,000	15,000	
13	UK2	40,000	6,000	15,000	
14	UK3	38,000	5,000	15,000	
15	Ca	0	0	0	
Totals		614,386	76,500	210,000	2,000

Other types of expenses The coordinator of the network requests a computer and printer for use by the UK1 team for running the day-to-day business of the network (as described in B4.1). The estimated cost of the equipment is 2000 Euros.

Swiss contribution It should be noted that if the agreement with Switzerland has not yet entered into force when the contract is signed, the financing of Team 2 will be underwritten by the Swiss Government. The total direct cost to the EC would therefore decrease from 3,484,822 to 3,223,487 Euros.

B8 PREVIOUS PROPOSALS AND CONTRACTS

Previous network The scientific programme proposed herein is a development of a Research Training Network funded under the FP5 Improving Human Potential programme:

(a) Acronym: MASIE

(b) Contract no: HPRN-CT-2000-00113

(c) Contract period: June 2000 - May 2004

Other sources of support Two of the teams are also participating in other current applications for Marie Curie RTNs:

- Team 11 (U. of Surrey) is participating in AstroNet, coordinated by M. Roberts (Surrey), and
- Team 12 (Imperial College, London) is participating in CoRGI (Collaborative Research in Geometric Integration), coordinated by B. Leimkuhler (U. of Leicester).

There is no overlap between the scientific programmes of MaGIC and of either of the two networks above. However, the programmes are complementary, and cooperation would be mutually beneficial, and it is envisaged that joint workshops may be held.

At the next possibility, J.P. Ortega (F1) will submit a Marie Curie Conferences and Training Courses proposal on the same subject as MaGIC. If it is funded, it will provide training for young scientists some of whom may become ESRs or ERs in MaGIC.

Previous proposal This proposal is based on a proposal for a similar network submitted in April 2003, acronym ENDGAME.

B9 OTHER ISSUES

There are no ethical or safety issues associated with the subject of this proposal.

A.

Does the research presented in this proposal raise sensitive ethical questions related to:	YES	NO
Human Beings		X
Human biological samples		X
Personal data (whether identified by name or not)		X
Genetic information		X
Animals		X

B. The proposers confirm that the research presented in this proposal does not involve any of the following:

- Research activity aimed at human cloning for reproductive purposes,
- Research activity intended to modify the genetic heritage of human beings which could make such changes heritable,
- Research activity intended to create human embryos solely for the purpose of research or for the purpose of stem cell procurement, including by means of somatic cell nuclear transfer
- Research involving the use of human embryos or embryonic stem cells with the exception of banked or isolated human embryonic stem cells in culture.

ENDPAGE

HUMAN RESOURCES AND MOBILITY (HRM)
ACTIVITIES

MARIE CURIE ACTIONS
Research Training Networks (RTNs)

PART B

"M a G I C"