1 Proposal Description: DYGLAGEMEM

1.1 Research Topic

Understanding the physical properties of glassy materials has become a major research subject. These materials are often characterized by an extremely slow approach to equilibrium (metastability); furthermore, many observable quantities display a remarkable dependence on the history of the sample (memory). These systems can therefore be trapped in many different slightly off-equilibrium states and slowly move from one state to another.

It is now known that quite different systems, from ordinary glass to colloids, exhibit similar behaviors; they are commonly referred to as *glassy* systems. Understanding the (microscopic) origin of the (macroscopic) behavior is one of the most challenging topics of equilibrium and non-equilibrium statistical mechanics.

One of the most intriguing phenomena is aging, i.e., the dependence of some observables on the age of the system, and more generally the existence of memory, oblivion and rejuvenation effects. These are spectacular phenomena that merit full characterization and a deep experimental and theoretical understanding.

In the last year there has been a growing feeling that the structural glass problem may unfold itself in a most exciting manner. Whilst most of the early hopes of considering the freezing as a *conventional* phase transition were evaporating, another intriguing possibility arose: the transition may be driven by a diverging dynamical length scale. The evidence for this comes primarily from numerical simulations, but now experimental findings are being reported that support this proposal. Such ideas have spurred the community to renew its efforts to understand what is, after all, one of the great outstanding puzzles of condensed matter physics.

Besides these fundamental aspects, but closely tied to them, are other important aspects that have lead to this remarkable focus and interest in the field. It has become apparent that many materials, such as soft amorphous systems, formerly considered to be incomprehensible, may well be describable as new types of glasses. It is surprising, but now highly likely, that many systems of colloidal particles, gels, precipitates, and other amorphous materials may well be glasses in the formal sense. Given the importance of such materials in areas ranging from functional biomaterials to pre-ceramic materials and protein gelation, the scientific community finds considerable promise in systematizing this field. We shall call this outstanding area of condensed matter physics *soft matter glasses*. A deep change in thinking is occurring in this field, as we begin to have the methods to pose rational scientific questions concerning what formerly were considered to be hopelessly complex materials.

There is therefore the possibility that structural glasses may be categorized and understood at a fundamental level. Thus on the one hand we see that many interesting systems are being discovered to be glasses, albeit at new and much lower energy scales than had hitherto been considered. At the same time, the meaning of the glass transition itself is finding deeper resonances with fundamental physics, rather than with material science. It is thus a most opportune time to join forces to exploit that understanding across the range of what were previously thought to be dispersed and unconnected areas.

1.2 Project Objectives

The presence of very slow dynamics in glasses (structural glasses, spin glasses and soft matter glasses) implies that the experimental systems are not usually at full thermal equilibrium: this fact is at the origin of experimentally observed aging and memory effects. We face the task of studying systems which are near, but definitively not at, equilibrium. This is a serious complication, because the statistical mechanics of non-equilibrium systems is much less developed than the statistical mechanics of equilibrium systems. However, it gives us an excellent opportunity

to develop off-equilibrium statistical mechanics in a favorable setting. Some of the systems are microscopically very simple and they are very close to equilibrium: they can be studied experimentally with very high accuracy. Moreover, in many cases one can construct soluble mean field theory models which display a very rich structure and behavior. The same mechanism is responsible for the glassy behavior in these different systems; this suggests that there is some universality and that much more complex systems should display this same phenomenology.

Glassy systems have been studied in the past using rather different approaches (e.g., the mode coupling theory, the inherent structure approach and the replica theory). The time is ripe for a synthesis of these approaches; them we must confront it with the wide body of experimental knowledge currently gathered about the static and dynamic behavior of glassy systems. Naturally, these advances should also stimulate new experiments and thus further checks of the theory.

Our aim is not only to study general principles: we want to find concrete applications of the theory. For each particular case we must develop the appropriate technical tools, from which we will make concrete predictions that can be tested in numerical simulations and in real experiments when possible. We have different objectives that are linked to the different nature and phenomenology of the systems we study (spin glasses, strong and fragile structural glasses and soft matter glasses). However the main goals of our research that are common throughout are as follows.

- Recent theoretical, numerical and preliminary experimental work have shown that in the aging regime there is an effective temperature that controls the off-equilibrium dynamics of the system: this temperature is greater than the usual temperature. Our aim is to extend the present day theory in order to make more precise and universal theoretical predictions for the dependence of the effective temperature on the various parameters of the system. Simultaneously we will measure this effective temperature in experiments and we will compare it to the detailed theory we have developed. These measurements are very delicate as one has to measure thermal fluctuations (that are very small) in the aging regime which is not stationary.

  If theory and experiment are in good agreement, this will be a very important breakthrough; it will be the experimental proof of the correctness of the theoretical approach that has been consistently developed in the last twenty years both for glasses and structural glasses. An experimental failure of the theoretical prediction would imply a profound revision and may be a dismissal of some current theoretical ideas. Independently from the success of the theory, a detailed comparison of theory with the experimental data for the effective temperature will be a crucial step in our understanding of glassy materials.

- Recently it has been experimentally proved that aging spin glasses display remarkable and unexpected memory effects. At present a detailed theory of these memory effects does not exist but we are confident that we have in our hands the instruments that are needed to construct it.

  A more precise phenomenological characterization of these memory effects is also needed:

  - We want to study the dependence of the memory effects on different parameters (e.g. the time scale of the experiment).
  - Most memory effects have been seen after a temperature change. The study of memory effects after changes of the magnetic field will give complementary information.
  - We will also look for memory effects in others materials than spin glasses.

  These new experimental data will be crucial in order to distinguish among different the theoretical proposals and will allow detailed tests of the theory.

A microscopically based, phenomenologically correct theory of these memory effects would be a major progress.

- The spectacular divergence of the viscosity for fragile glasses near the glass transition (experimentally one measures an increase of 18 orders of magnitude) is a well known phenomenon. Nearly one century ago, it was parameterized by the Vogel Fulcher law where the viscosity is proportional to $\exp(A/(T-T_K)$. There have been some qualitative explanations of this law but they have never reached a full quantitative status. Using recent progress in glass theory, we plan to attack and solve this problem. If we are successful, one of the oldest open problems in the field will be elucidated.

- Different theoretical approaches have been used in the past: e.g., replica theory, the mode coupling theory and the inherent structure approach. All these approaches capture different properties of the phase transition for glassy systems. Our aim is to unify these different approaches in a coherent picture in order to use them in a synergetic way. To this end, it will be crucial to obtain precise predictions and to compare these with the results of numerical simulations.

- We want to push as far as possible the interpretation of many phenomena in colloidal systems, gels, precipitates and other soft amorphous systems in the framework of the theory of glasses. If this tentative approach is successful, we will understand a wide range of complex phenomenology in diverse materials using a unifying and general theory.

- Finally the extension of this approach to quantum glasses is a fascinating and open subject. Very interesting quantum phenomena happen in the milli-Kelvin region in glasses. These phenomena are not well understood. The interpretation of the quantum anomalies in the unified framework for glasses would be extremely important:

  - Quantum effects probe the properties of glasses in some special regions of configuration space: they are particularly sensitive to some *local* properties. The possibility of quantitative predictions would be a serious test of the theory.
  - In some situations quantum effects cannot be considered as small perturbations to classical physics: new quantum collective phenomena may exist also in glasses. Their identification, phenomenological characterization and theoretical interpretation is a great theoretical challenge.

2 Scientific Originality

The last two decades have seen major developments from the point of view of statistical physics in our understanding and analysis of a wide range of complex systems characterized by fundamental units in competition. Spin glasses and structural glasses are the best studied physical examples of materials with these properties. Colloidal particles, short polymers and other amorphous systems also show a similar glassy behavior.

There are many theories that have been developed to study these phenomena: the mode-coupling theory, the replica approach, the droplet and scaling models, the inherent structure approach, dynamical mean field theory, etc. Each of these different theories captures a part of the reality and it is adequate for describing the behavior of the system in a given situation, but they miss a fully comprehensive approach.

There is no doubt that many of the members of our network are very familiar with the state of art in the field: in the past many seminal contributions to these theories (and also systematic studies) came from members of our network. We have been very active in the

construction of these theories and in finding out their predictions for different systems. We have also introduced some theoretical models that are among the simplest that display a glass phase transition (these models have become rather popular). We have also been leaders in the field of large scale numerical simulations for spin glasses and structural glasses and we have made a strong effort to compare the numerical results with the theoretical predictions coming from different sources (e.g., replica theory, the droplet model, the mode coupling theory, the inherent structure approach).

An important point of originality of this project is to put together many different communities: those working on the analytic approach, the ones doing large scale simulations, and the experimentalists in the fields of spin glasses and structural glasses. This is presently important because till now the various threads have developed independently. The theories of structural glasses are just now beginning to benefit from the insights of spin glass physics and large numerical calculations. Our combined efforts are needed because two of the most challenging problems (i.e., a verification of the proposed fluctuation dissipation relations and the analysis of the memory effects) are very delicate. A large amount of experimental ingenuity and deep theoretical understanding is needed to reach a positive result. The analytical studies and the computer simulations will play a crucial role in making precise predictions and these will help in the planning of the experiments.

To this end we have to bridge the gap between a priori distinct systems, namely disordered magnets and structural glasses. The common aspects are the presence of very slow dynamics, aging effects, and the possibility of studying them in an unified theoretical approach.

The need to bridge the gap between different systems becomes particularly important in the case of the study of soft matter. If we consider the list of soft systems present in nature, the great majority of them are disordered and have rather large shear moduli in the long time limit. In fact, there has been much less focus on theoretical research in such systems. Certain specific aspects of gels and other soft glasses have been studied with some success, and understood in a limited way, and now we have in our hands the tools for trying to understand the structural and dynamical aspects of these systems in complete generality.

Recently there have been various indications that soft disordered materials can be described in terms of glass theory, but on an energy scale quite different to that of conventional glasses. This idea has considerable power since it may provide a route to understand a whole new class of soft materials. It is also intriguing from the point of view of glass theory itself, since with soft matter it is possible to tune more finely many important time scales, and therefore to look more carefully at phenomena that have been difficult to see thus far.

3 Research Method

The methodology will involve three complementary but linked approaches: theoretical analysis, computer simulation of models and experimentation on real matter systems. They will be combined symbiotically to guide research, understanding, conceptualization and technical development. Within the presently proposed network the experimental effort will be important in guiding and testing theoretical ideas, and inversely, the theoretical analysis will play a crucial role in the conception and in the planning of new experiments and in their interpretation.

- The study of model systems has played a crucial role in the understanding and development of statistical physics in general and of disordered, frustrated and/or non-equilibrium systems in particular. With this approach we extract potentially key ingredients and we test the consequences of these choices. In this way we will be able to recognize new systems and issues, and to make further predictions. This process has often required the development of new analytic and approximation techniques (as we have done in the past

in this field). In order to reach our aims we plan to use in a combined way the replica theory, the inherent structure picture and dynamical equations (which generalize the mode coupling equations in the off-equilibrium situation). In recent years it has become more and more clear that these three approaches are deeply related: one of our first tasks will be to understand how we can use the three approaches in a consistent and synergetic way. All possible efforts will be made to arrive at a combined qualitative and quantitative understanding of the energy landscape.

- Experimentation is of course the basis of physics - it stimulates, underlies and tests theoretical considerations. As we have explained in the previous sections we are going to conceive, plan and realize new experiments in close contact with the theory. Most of the nodes have very advanced laboratories with state of the art instrumentation in many different fields. Among the facilities available to the network are very well equipped laboratories for the study of magnetic properties at low temperatures, optical laboratories, rheometers and high pressure equipments to study glassy dynamics in model colloidal systems. Moreover in one laboratory we are able to make measurements in the milli-Kelvin region. We also have access to European and national facilities for synchrotron radiation and neutron scattering.

- Computer simulation is the third line of attack. Here model systems (both static and dynamic) will be simulated directly and appropriately designed probes will be used to measure them. This provides a significant complementary approach to both analysis and experimentation firstly by enabling controlled quasi-experiments to be performed on the same systems as the analysis without the extraneous influence of other effects in real materials, and secondly by allowing experiments and probes for which no presently realizable analogue is available. To perform these simulations we can follow different routes:

  - All the nodes have access to state-of-the-art supercomputers.
  - In some of the nodes (Rome, Badajoz) we have built Beowulf type clusters of workstations or personal computers and we plan to build new clusters in some of the other nodes. These clusters seem to be the most cost effective solutions for doing medium to large scale simulations. We plan the construction of a library of portable simulation programs that may run on parallel machines to be shared by the whole collaboration.
  - In Rome we can use full time an *APEmille* machine, a parallel supercomputer with theoretical maximum speed of 32 Gigaflops.
  - In the Badajoz node we will use a special purpose machine which simulates the behavior of two and three dimensional spin glasses at very high speed ($\approx 10^{10}$) spin flips per second.

The combination of these different approaches will be very valuable and will lead to advances not achievable without that synergy. Exchanges of researchers from one node to the other and small topical meetings are the ideal way to disseminate the expertise on different subjects from each node. A joint effort of translating our results in other people's formalism will be extremely useful and will be the first step toward the creation of an unified approach. The exchange among theorists and experimentalists will be extremely useful both in planning new experiments and in analyzing the data; it will also focus the theoretical research on those properties which can be measured in the laboratory.

4 Work Plan

All the nodes will pursue the general objective of a better understanding and quantification of glassy equilibrium and non-equilibrium behavior as described in the previous sections.

We plan to reach the following milestones. Although most of the nodes can give a contribution to a given objective, at present we believe that the most relevant contribution is likely to come from the nodes in parenthesis, among which there is already (or is in the process of being established) a collaboration based on complementary expertise. Of course we will do our best to use the competence of all the nodes in order to reach each given goal.

- We plan to have within two years very precise and reliable theoretical predictions for the behavior of the effective temperature in glassy systems (1,2,3,5,7). The first experiments concerning the effective temperature in a few materials will also be completed at that time (1,2,3). A systematic study of the effective temperature, together with the theoretical comparison and the realization of new experiments, will be achieved in four years (1,2,3,5,7).

- Planning and realizing new experiments on the memory effects in aging for spin glasses will be done in two years (1,2,3,4,8,9). We also believe that in two years we will have clarified the theoretical issues that are at the basis of this phenomenon (e.g., chaos in temperature) (1,3,4,5,7,8). In the last two years of this program we will look experimentally for other systems which display memory effects and we will use our improved theoretical understanding to produce a detailed theory of memory, oblivion and rejuvenation (1,2,3,4,5,6,7,8).

- In the first two years we will extract more quantitative predictions on the behavior of the viscosity as a function of the temperature within the framework of the mode coupling theory (1,2,4,5,6,9). We will use the information coming from the instantaneous normal modes (on which we plan to have strong advances in one year) and on the presence of an increasing dynamical correlation length near the mode coupling temperature (1,2,4,6,9). Simultaneously we shall compute the time needed to cross the energy barriers in some model theories (1,2,3,4,9). At the end of the first two years we will be ready to start the investigations on the temperature dependence of the viscosity in the lower temperature region, where the mode coupling theory cannot be applied; that will be completed in four years (1,2,4,6,9).

- During the first two years we are planning to study in detail the relations among replica theory (and other methods that can be used to compute the static properties) and the mode coupling theory (1,2,3,4,6,9). We are confident that a unified picture will emerge, where the properties of the instantaneous normal modes and of the saddle points will play a crucial role. A precise study of the static properties for structural glasses and spin glasses should be done in the first two years (1,2,3,4,7,8,9); large scale numerical simulation will play a crucial role in this task (1,2,3,4,7). A strong effort will be done to study existing models and to introduce new models for the glass transition on the lattice and this will also be done in the first two years (1,3). In the last two years we will put together all the information we have collected and try to construct an unique theory which encompasses all the advantages of the various theories which are available at the moment (1,2,3,4,5,6,7,9).

- In the first two years we will push for a more detailed phenomenological understanding of the interpretation of many phenomena in colloidal systems, gels, precipitates and other soft amorphous systems in the framework of the theory of glasses (1,2,4,5,6). The appropriate numerical simulations and new experiments will play a crucial role (1,2,4,5,6). In the last two years we shall apply our theoretical knowledge to understand this complex phenomenology of diverse materials under a unifying and general theory (1,2,4,5,6).

We hope in this way to make substantial progress in the study of a rather wide range of materials.

- The experimental clarification of the phenomenology of a quantum transition in the milli-Kelvin region for glasses should be done in the first two years. At the same time we should put together the new results from the classical theory of glasses with the phenomenological theories on quantum glasses (e.g. two levels theory) (1,3,4). Quantum simulations for glasses would be very useful (1,2,4,7). Finally in the last two years we will make an effort to interpret the quantum effect in the same theoretical framework that we have used for the classical case (1,2,3,4,6,9) and we will use this information to consolidate the theoretical framework.

Professional research effort on the network project			
Participant	Young researchers to be financed by the contract (person-months)	Researchers to be financed from other sources (person-months)	Researchers likely to contribute to the project (number of individuals)
1.	36	245	11
2.	24	72	4
3.	36	178	7
4.	36	420	22
5.	24	24	2
6.	24	81	4
7.	36	202	9
8.	24	36	3
9.	36	82	4
Totals	276	1340	66

5 Collective Expertise

Many of our nodes have been collaborating for a long time and they have similar expertises. Although not all the nodes have collaborated with all the other nodes, they form a strongly connected set of collaborating nodes: the proposed network is already a web a shared knowledge, as it will be clear from the following pages.

5.1 Rome

The group in Rome will study the dynamical and static properties of structural glasses and spin glasses, both theoretically and experimentally. We will consider many aspects which range from the probability distribution of the overlap in spin glasses to the eigenvalues of the instantaneous normal modes of a glass-forming liquid.

Most of our effort will be dedicated to the study of a very exciting idea which has been developed in the recent years: there is a natural definition of the temperature in off-equilibrium system that depends on the time scale of the observation. The theory predicts that the usual fluctuation-dissipation relations are no more valid in the *aging* regime and they are substituted by new generalized fluctuation relations as a function of this off-equilibrium temperature. These results are very interesting, because these new relations can be observed experimentally. We have been the first to study these relations in many disordered systems, spin glasses, disordered ferromagnets and structural glasses. The theoretical basis of these new relations and the deep connections with equilibrium thermodynamics have been elucidated in detail.

This effective temperature is a unifying concept in the study of spin glasses, structural glasses and soft matter glasses. Our aim will be to refine the theoretical analysis in order to have more clear cut predictions that will be compared with large scale numerical simulations. We plan also to understand some crucial issues as the relations of this approach with the mode coupling theory and the properties of the inherent structures.

A crucial step forward would be a systematic experimental study of this effective temperature (at the moment it has been clearly seen only in an experiment done by Ciliberto, in the Montpellier node of our network). In this respect we will collaborate with the two French nodes (for glasses and spin glasses respectively). We also plan to do this kind of experiment inside our node (an experiment on spin glasses is already in progress).

Moreover we plan to work with the British node on the analytic study of the low energy excitations, with the two French nodes and the Spanish node on numerical simulation of spin glasses and structural glasses, with the Amsterdam node on analytical studies, with the German and Irish nodes on the study of the mode-coupling theory, with the Orsay and Uppsala nodes on planning new kind of experiments on spin glasses.

Another part of the group has had active long term collaborations and exchanges of students for some time with Dublin and this, along with work of München has lead to the idea that soft amorphous systems may be describable in terms of glass theory. So far, colloidal particles with short ranged potential have been studied, and a new glass transition has been predicted, along with a new dynamical singular behavior. We propose to continue this work and to attempt to encompass more of the world of disordered soft materials (and particularly of polymer gels) into this motif. We will emphasize the glass transition paradigm as a mean to understand the viscoelastic and material properties of these systems.

Another part of the work involves the simulations in aging. We will attempt to further develop some of the recent work carried out with Dublin on the fundamental basis of MCT to accommodate aging phenomena.

Key scientific staff: Pisa SNS: Caracciolo (30%); **Roma:** Martin-Major (70%), Parisi (70%), Ruocco (50%), Sciortino (70%), Tartaglia (70%); **Insubria, Como:** Jug (30%); **Trento:** Fontana (30%), Maraner (30%), Viliani (30%).

Two publications: G. Parisi, *Off-Equilibrium Fluctuation-Dissipation Relation in Fragile Glasses*, Phys. Rev. Lett. **79** (1997) 3660; F. Sciortino, W. Kob and P. Tartaglia, *Inherent Structure Entropy of Supercooled Liquids*, Phys. Rev. Lett. **83** (1999) 3214.

5.2 Montpellier

The groups from the node in Montpellier have expertise in experiments, analytical calculations, as well as simulations of structural and spin glasses.

The group in Lyon is so far the only experimental group in the world who has directly measured how the fluctuation-dissipation theorem is violated for the dielectric properties of colloidal glasses in the glassy phase during aging. This was an important step in our understanding of such out of equilibrium systems since it demonstrates that the theoretical concepts that so far were tested only by means of computer simulations are testable and applicable also in real structural glasses.

In the future it is planned to continue the experimental studies on colloidal glasses to understand how the observed violation depends on the external parameters. Furthermore we want to investigate if the effective temperature is independent of the variables used to measure it. In parallel we are planning to study the fluctuation-dissipation relation using dielectric and mechanical measurements performed in different kinds of polymers. The results will be compared with those of similar experiments performed on spin glasses by the Orsay node. These measurements are extremely important in order to understand how the new theories and models

can be applied to different materials. This research program cannot be successfully performed without a strong interactions with the other nodes of the network. Specifically the Rome and the Manchester groups will be extremely useful for the interpretation of the experimental results in terms of the new models and for understanding how general these models are. The collaborations with the Spanish and the other French groups are also important in order to perform numerical simulations of these models.

The group in Toulouse has a lot of expertise on the static and dynamical properties of spin glasses that are "driven", i.e. tapped. These studies provide thus a link between spin glasses and "structural" glassy systems that are driven, like tapped granular materials or sheared super-cooled fluids. It is planned to further study frustrated spin systems under tapping-like dynamics in order to find links with the physics of granular media. Numerical studies of this type also provide an alternative way of exploring the geometry of meta-stable states. Natural collaborations arise with the Rome node, where the zero temperature dynamics and low lying states of spin glasses are actively studied. Collaborations with Manchester and the Spanish node would investigate the out of equilibrium aspects of driven systems.

The group in Montpellier has an extensive knowledge of the simulations of structural glasses (simple Lennard-Jones systems, network forming glasses such as SiO_2, polymeric systems) as well as Potts glasses. In the past we have investigated the static as well as dynamic properties of these systems, in the super-cooled phase (equilibrium) as well as in the glassy phase (non-equilibrium). In particular we have studied in great detail to what extent the mode-coupling theory of the glass transition is able to give a qualitative as well as quantitative description of the relaxation dynamics, how in the glassy phase the fluctuation dissipation theorem is violated, how the relevant excitations change during the aging dynamics, how an effective dynamical length scale can be defined and measured, and how the finite size scaling in mean field like models has to be done.

We plan to investigate how the low energy excitations of *finite* mean field like spin models changes as a function of the number of spins in order to see how the structure of the configuration space in finite systems is related to the one in the thermodynamic limit. We will strongly profit from collaborations with the group in Badajoz, Mainz, Orsay, and Rome. We plan to continue our studies of structural glasses and to try to identify in these systems a diverging length scale (in collaboration with the group in Rome). In addition we want to investigate to what extent mode-coupling theory is also able to give a "quantitatively" correct description of the dynamics of *strong* glass formers. To address these questions extensive discussions and collaborations with the groups in Dublin, Munich, and Rome will be absolutely necessary. Finally we want to investigate for the *strong* glass former SiO_2 how the fluctuation dissipation theorem is violated. For this we plan to collaborate and discuss with the groups in Amsterdam, Lyon, Manchester, and Rome.

Key scientific staff: **Lyon**: S. Ciliberto (50%); **Toulouse**: D. S. Dean (50%), **Montpellier**: W. Kob (50%).

Two publications: L. Bellon, S. Ciliberto and C. Laroche, *Violation of the Fluctuation-Dissipation Relation During the Formation of a Colloidal Glass*, Europhys. Lett., **53** (2001) 511; C. Brangian, W. Kob and K. Binder, *Finite-Size Scaling at the Dynamical Transition of the Mean-Field 10-State Potts Glass*, Europhys. Lett. **53** (2001) 756.

5.3 Orsay

The focus of this node is principally spin glasses. Our approach is three-fold: we deepen our numerical studies, we set up new experiments, and we develop phenomenological models to interpret the numerical and experimental results.

Recently we have spear-headed an approach where one determines the spin glass ground

state and then one considers effects of perturbations such as a magnetic field. More generally, it seems imperative to get the statistical properties of excitations above the ground state. To do this, first we shall extend our current methods which find low energy excitations. Second, we want to see how the energy changes when the magnetic field is increased; are level crossings chaotic or will more subtle scenarios arise? Along similar lines, we shall extend our work on the study of chaos in temperature using equilibrium simulations, in collaboration with the nodes in Spain and Italy.

From the experimental point of view, we have explored the non-equilibrium dynamics of spin glasses under different conditions. Our characterization of rejuvenation and memory effects in aging suggests that wall type dynamics dominate. New experiments are in preparation or in progress on systems having either Ising or Heisenberg spins, and in non-disordered but topologically frustrated systems. These should provide further probes of non-equilibrium phenomena such as aging, and further collaborations between the Saclay and the Uppsala nodes will be pursued. In addition, one of the crucial challenges to come is the measurement of magnetic fluctuations and putative departures from the fluctuation-dissipation relations; this will allow us to explore the different time regimes from non-equilibrium (aging regime) to equilibrium situations.

To model the results found in both the numerical and experimental studies, we will focus on position (real) space descriptions, considering energetic and geometric properties of spin clusters that are relevant for both the statics and the dynamics. To date, such a focus has been quite fertile: the consideration of sponge-like excitations and some topological properties of clusters has lead to cleaner observables and data analysis in numerous numerical studies. We plan to deepen previous work on free-energy excitations and apply this to simulations performed at the Rome and Badajoz nodes. Also, a particularly strong synergy will arise between the people at Orsay and at Saclay, from which we will reinterpret in this position space view old thermoremanent magnetization experiments. Similarly, using simulations, we will consider the relevance of sponge-like clusters and wall dynamics during aging. Finally, we will introduce a new class of out-of-equilibrium dynamics that should allow us to access significantly larger time scales; in this regime, we hope to tackle the issues surrounding the violations of the fluctuation-dissipation relation.

Key scientific staff: **Orsay**: O. Martin (70%) (permanent staff), F. Zuliani (70%); **Saclay**: A. Billoire (70%), J. Hammann (20%), M. Ocio (70%), E. Vincent (70%).

Two publications: Y. G. Joh, R. Orbach, G. G. Wood, J. Hammann and E. Vincent, *Extraction of the Spin Glass Correlation Length*, Phys. Rev. Lett. **82** (1999) 438; J. Houdayer and O. C. Martin, *Ising Spin Glasses in a Magnetic Field*, Phys. Rev. Lett. **82** (1999) 4934.

5.4 Saarbrücken

The German node combines groups which represent expertise and an established record of accomplishments in various aspects of the physics of glassy or complex systems, among them pioneering work utilizing mode coupling theory (MCT) to describe the dynamics of super-cooled liquids (Götze), introduction and development of dynamical mean-field theories for spin glasses (Zippelius, Horner) and cross-linked polymer melts, both equilibrium and off-equilibrium, development and prolific use of computational methods (Monte-Carlo, Molecular Dynamics, Quantum Monte-Carlo) for a wide range of glassy and other condensed matter systems (Binder, Rieger), and the design and performance of key experiments to study low energy tunneling excitations in glasses (Hunklinger).

Research within the net will include: **(i)** numerical studies of glassy dynamics (Mainz), and the glassy low-temperature phase (Göttingen, Mainz, Saarbrücken) concentrating on structure and organization of low lying states, **(ii)** detailed analytical and numerical tests of MCT for realistic liquids and extensions of MCT to mixtures, molecular liquids, colloids and polymeric

systems showing glassy behavior and to aging phenomena (München, Mainz), **(iii)** investigations of the crossover from short-time dynamics to aging in spin-glasses, aiming at solving the unsettled problem of uniquely fixing the large-time solution (Heidelberg), **(iv)** dielectric and ultrasound measurements in glasses at very low temperatures, and theoretical studies of two-level systems to clarify the nature of tunneling excitations, the role of interactions between them and the question of universality of glassy low-temperature physics (Heidelberg), **(v)** dielectric measurements under high pressure near the glass transition to clarify relaxation phenomena (Heidelberg), **(vi)** analytical and numerical studies of the viscoelastic behavior of random molecular networks, modeling gels as well as covalently bonded glasses (Göttingen), **(vii)** numerical investigation of model glasses with novel algorithms that can achieve equilibration deep in the glassy phase (Saarbrücken), **(viii)** phase transitions in classical and quantum spin glasses (Göttingen, Saarbrücken), Potts glasses (Mainz) and vortex glasses (Saarbrücken).

Envisaged contributions from the German node represent a broad spectrum of approaches to amorphous systems, with strengths on different aspects. MCT oriented theoretical and numerical work complements dynamical and replica approaches pursued at the German node as well as the British, two French and Italian nodes. The experimental and theoretical work on structural glasses concentrates on the very low temperature dynamics in the vicinity of the glass transition and will yield detailed information concerning properties of the lowest energy excitations at the microscopic level, allowing comparison with results of other analytical and numerical approaches to glassy physics used by the the Italian, the two French and Spanish nodes. Numerical work has a strong focus on structural glasses and realistic liquids. Recent and ongoing cooperations exist with the British, the two French, and Italian nodes on molecular MCT, numerical studies of aging in glasses and spin glasses, polymers, structure of network forming liquids, and quantum statistical physics for structural glasses.

Key scientific staff: Göttingen: A. Zippelius (25%), R. Kree (25%), A.Hartmann (50%), P. Müller (50%); **Heidelberg:** H. Horner (25%), S. Hunklinger (25%), C. Enss (50%), G. Kasper (50%), R. Kühn (50%); **Mainz:** K. Binder (25%), A. Latz (50%), J.Horbach (50%), W.Paul(50%); **München:** W. Götze (25%), M. Fuchs (50%), S.-H. Chong (50%), **Saarbrücken:** H. Rieger (25%), L. Santen (50%), J. D. Noh (50%), E. Carlon (50%), F. Hebert (50%).

Two publications: P. Strehlow, C. Enss and S. Hunklinger, *Evidence for a Second Order Phase Transition in Glasses at Very Low Temperatures — A Macroscopic Quantum State of Tunneling Systems*, Phys. Rev. Lett. **80** (1998) 5361; W. Götze, *Recent Tests of the Mode Coupling Theory for Glassy Dynamics*, J. Phys. C **11** (1999) A1.

5.5 Dublin

The Research Centre in Dublin has activities in a number of areas of soft condensed matter, colloidal glasses, and functional biomaterials. The main focus of the work is to understand soft glassy materials at a fundamental level, and then to harness that understanding. Various experimental model systems are of interest, including small polymeric spheres in dense colloidal suspensions. We seek to harness the understanding to engineer novel materials, that have specified mechanical and functional properties, and that may have unusual responsive and memory properties. It is currently believed that one unifying underlying theme for the formation and properties of such soft amorphous materials arises from the glass transition, interpreted in a new way.

So far, the theoretical work has been carried out in the framework of long term collaboration with Rome with additional collaborations with the German node. The long term collaboration has been very effective, with all of the main publications jointly between Dublin and Rome, and two Rome students have obtained their PhDs in Rome, and one Dublin student has begun work in Rome.

We have together tried to find new ways of thinking about dense colloidal systems and the soft amorphous materials that emerge at high volume fractions. We have so far mainly used Mode Coupling Theory of the glass transition, and have claimed that gelation at high volume fractions when driven by short ranged attractions is a new type of glass transition, and that the glasses thereby formed are what we have formerly known as gels, or amorphous soft materials. In broad terms we believe that in the dense gelling, aggregation or 'freezing' limit, there is a new paradigm emerging by which we can hope to understand the soft amorphous systems, their formation and mechanical properties. Clear and complete predictions can be made for slow dynamics, aging, rheology, and mechanical properties. The whole approach may be submitted to explicit experimental verification.

Based on this progress we are now ready to extend the work in three main directions. The first is to further extend domain of applicability of this paradigm. A tractable model that can be solved even at the mean field level will be developed, and studied in collaboration with Rome. This will provide us with complete predictions, with all of the mean field limitations, of the polymer gelation transition, seen through the perspective of a glass transition. However, there is considerable potential to enrich the existing successful relationships by interaction with the German node in this arena, since the proposed areas of research have resonances with each other.

The second area of research we propose to follow is the aging of colloidal systems. We have recently enlarged the MCT type formalism to accommodate aging. We are now ready to try to deepen our understanding of this problem.

Our third area of application involves extensions of work carried out recently with Rome to derive the MCT equations by a different route. There are two main problems in this arena where we expect new collaborations with Rome to be of help, as well as a much richer set of insights being developed from the whole network. These insights, as recent events connected to the p-spin model show, may be derived not just from structural glass work, but spin models also.

In particular, input from Amsterdam and Orsay should be of considerable interest to the development of corrections to the MCT-type limit mentioned above.

In summary, we plan at MCT-type level to further extend the glass paradigm to create an intellectual framework around the transition of soft amorphous systems and to harness the potential of the network to progress beyond MCT by correcting our recent dynamical equations.

Key scientific staff: Dawson (70 %).

Two publications: G. Foffi, E. Zaccarelli, F. Sciortino, P. Tartaglia and K. A. Dawson, *Kinetic Arrest Originating in Competition Between Attractive Interactions and Packing Force*, J. Stat. Phys. **100** (2000) 363; K. A. Dawson, G. Foffi, M. Fuchs, W. Gotze, F. Sciortino, M. Sperl, P. Tartaglia, Th. Voigtmann and E. Zaccarelli, *Higher Order Glass-Transition Singularities in Colloidal Systems with Attractive Interactions*, Phys. Rev. E **63** (2001) 11401.

5.6 Amsterdam

The theoretical group in Amsterdam will focus on the question whether there is universality in aging processes, that can be put in a thermodynamic framework. The central question is whether the variety of self-generated effective temperatures, that have been proposed in recent years, coincide within their error bars. In systems where this happens, one may say that the system behaves as a thermal system that lives at two temperatures, the one of the bath and this self-generated one. In such cases the aging dynamics satisfies the known laws of two-temperature thermodynamics, which is a severe constraint.

Most of the research will be devoted to study model systems which are simple enough to allow analytic solution of the dynamics. Though the physics of such models must necessarily be simple, the resulting dynamics can, in its long time regime, have quite acceptable characteristics.

Relations with other fields of physics, where a strong separation of time scales occurs, will be investigated. Results have been obtained already for black holes and quantum Brownian motion. Applications studied already by other groups in the network include granular materials. Collaborations are foreseen with e.g. the Rome node.

The experimental group in Amsterdam (Wegdam) will concentrate on colloidal glasses. As experimental techniques we will use light and X-ray scattering to measure the structure factor. With these techniques aging has been observed in a glass of colloidal plates (Laponite) in water at low volume fractions of the suspended particles. The particles are highly charged and interact via an anisotropic screened Coulomb potential. High density glasses of spherical particles have been observed as well. The particles are hard spheres. Other systems were inaccessible for experiment because any change of parameters lead to multiple scattering. With the development of new scattering techniques by our group the problem of multiple scattering can be avoided. We are now able to do experiments on colloidal systems where we introduce a short range potential: either by adding polymers or suspending the colloids in a binary liquid mixture. Thus we might observe the reentrant glass phase. The second path is to measure the dynamic structure factor when stress is applied to the colloidal glass. The aim is to provide experimental evidence for the mode coupling descriptions in these systems.

Key scientific staff: Nieuwenhuizen (70 %), Serral-Gracia (70 %), Wegdam (30 %).

Two publications: Th. M. Nieuwenhuizen, *Ehrenfest Relations at the Glass Transition: Solution to an Old Paradox*, Phys. Rev. Lett. **79** (1997) 1317; D. Bonn, H. Tanaka, G. H. Wegdam, H. Kellay and J. Meunier, *Aging of a Colloidal "Wigner" Glass*, Europhys. Lett. 45 (1999) 52.

5.7 Badajoz

The group in Spain (Badajoz-Madrid-Zaragoza) will study the static and dynamics properties of realistic spin glasses by means of analytical and numerical techniques.

In particular we are interested in studying the properties of the spin glass phase using statics as well on and off-equilibrium dynamics in order to distinguish between the different theoretical scenarios (e.g. droplet or continuous replica symmetry breaking).

Moreover, we will carry out numerical simulations in order to understand the behavior of spin glasses in presence of magnetic fields.

We also plan to carry out numerical simulations in order to mimic recent interesting memory experiments on spin glasses that has been done in two of the nodes of this proposal (Orsay and Uppsala nodes).

The Zaragoza group has developed a great skill in the construction of dedicated computers. In the last years this group has built several different parallel computers. In particular, the last one, SUE (a dedicated machine built only with programmable logic) has achieved a remarkable performance in simulating realistic spin glasses: it performs one spin flip in about one tenth of a nanosecond, notice that a real spin flips in about 1 picosecond.

The Badajoz and Madrid groups have mainly worked in the study of static and dynamics properties of disordered systems (diluted Ising systems, disordered Potts model, realistic spin glasses and diffusion in disordered and fractal media). For studying this systems they have used numerical simulations and analytical techniques, both of them based in the renormalization group.

We plan to work with the Rome and Orsay nodes on numerical and analytical approaches for realistic spin glasses and with the German one on numerical simulations in disordered systems.

Key scientific staff: S. Bravo (70 %), V. Garzó (70 %), J. J. Ruiz-Lorenzo (70 %), A. Santos (70 %,) L.A. Fernández (70 %), A. Muñoz Sudupe (70 %), J. L. Alonso (70 %), A. Cruz (70 %), A. Tarancón (70%).

Two publications: H. G. Ballesteros, L.A. Fernández, V. Martín-Mayor, A. Muñoz Sudupe, G. Parisi and J. J. Ruiz-Lorenzo, *Critical Exponents of the Three Dimensional Diluted Ising Model*, Phys. Rev. B **58** (1998) 2740; H. G. Ballesteros, A. Cruz, L.A. Fernández, V. Martín-Mayor, J. Pech, J. J. Ruiz-Lorenzo, A. Tarancón, P. Téllez, C. L. Ullod and C. Ungil, *Critical Behavior of the Three-Dimensional Ising Spin Glass*, Phys. Rev. B **62** (2000) 14237.

5.8 Uppsala

The Uppsala group will focus on experimental studies on model spin glasses especially devoted to two key problems for the understanding of the low temperature spin glass state. The first concerns the non-equilibrium nature of the spin glass phase as mirrored in aging, rejuvenation and memory phenomena observed at low temperatures, and the second concerns the equilibrium phase diagram in the H-T plane. The work will be coordinated with the experimental activities in Orsay and Rome, and integrated with the theoretical activities in the network.

1. The study of aging, memory and rejuvenation effects require experimental protocols that adequately accounts for the thermal and magnetic field history but still are simple enough to allow meaningful interpretations in terms of the intrinsic non-equilibrium state of the low temperature spin glass. Large efforts have been devoted to map aging and memory phenomena in different spin glasses, however, there remains many unresolved problems related to these intriguing phenomena. A close collaboration between theorists and experimentalists is required to make further progress in this subject, e.g. on how to design and perform experiments to derive experimental information on the new concept of effective temperature and its dependence of the age and the observation time.

2. Experimental indications on what the 3D spin glass equilibrium phase lines should look like is of importance to support and distinguish appropriate theoretical descriptions of the spin glass phase. Efforts to design experiments and interpret results from static and dynamic susceptibility data on different model spin glasses will be made that may resolve remaining questions and uncertainties as to this challenging subject.

The work on spin glasses will be complemented by studies of non-equilibrium phenomena on other systems that show glassy magnetic behavior such as strongly interacting magnetic nanoparticle systems and some high temperature super-conductors showing the Paramagnetic Meissner Effect.

Key scientific staff: Per Nordblad (50%), Peter Svedlindh (25%).

Two publications: K. Jonason, E. Vincent, J. Hammann, J.-P. Bouchaud and P. Nordblad, *Memory and Chaos Effects in Spin Glasses*, Phys. Rev. Lett. **81** (1998) 3243; M.S. Li, P. Nordblad and H. Kawamura, *Aging Effect in Ceramic Superconductors*, Phys. Rev. Lett. **86** (2001) 13339.

5.9 Manchester

The Manchester group will contribute to the advance in the research on glassy systems by focusing on two important topics, namely the thermodynamic properties of low temperature spin-glasses, with particular attention to the nature of the ordered phase, and the dynamic behavior of super-cooled glass-forming liquids, aiming to explain the origin of the glass transition and the nature of fragility. Both these fields of research are very much open and currently under intense investigation, not only within the proposed network, but also in numerous groups outside Europe.

1. The nature of the spin-glass ordered phase has been controversial for many years now, with the community split between advocates of the replica symmetry breaking (RSB) picture and the droplet picture. The issue can be settled as to which is correct from an examination of how the spins in the ground-state are re-orientated by various kinds of "probes". For example

a change of boundary conditions should cause a substantial re-orientation of the spins in the ground-state according to the RSB approach, but on the droplet picture the effects of boundary changes are local to the boundary region. We plan to continue our promising preliminary studies of this question in collaboration with the nodes in Rome and Orsay who are studying related approaches.

2. The most challenging problem in the physics of super-cooled liquids is to explain the origin of the glass transition: under cooling, a very steep increase of the relaxation time occurs in a surprisingly small temperature interval (often up to ten orders of magnitude in a few degrees). The main theoretical problem is that, although dramatic, this process is continuous, with no genuine divergence of any dynamical quantity. Thus, what is called the glass transition is actually just a rapid crossover and no obvious critical behavior can be associated with it.

In collaboration with the theoretical physics department in Goettingen, the Manchester group has recently developed a new and successful approach to the problem. The key idea is that the dynamic crossover corresponding to the glass transition is actually the manifestation of an underlying and more fundamental geometric transition. This geometric transition happens at the point where the properties of the *elastic* vibrations change qualitatively.

A newly started collaboration with the group in Rome will test the robustness of this approach, by performing both analytic calculations and numerical simulations in many different glassy systems. Furthermore, in future studies the key role of energy barriers must be thoroughly analyzed, in order to explain from a purely geometric point of view the origin of fragility. We are planning to do this from a numerical point of view in collaboration with the Rome node, and from an analytical point of view in collaboration with the German node.

Key scientific staff: Bray (50%), Cavagna (70%), Moore (50%).

Two publications: K. Broderix, K. K. Batthacharya, A. Cavagna, A. Zippelius and I. Giardina, *Energy Landscape of a Lennard-Jones Liquid: Statistics of the Stationary Points*, Phys. Rev. Lett. **85** (2000) 5360; A. Cavagna, *Fragile vs Strong Liquids: a Saddles Ruled Scenario*, Europhys. Lett. **53** (2001) 490.

6 Collaboration

An important strength of all elements of the network has been their ability to collaborate. Indeed, a review of the publications reveal that most of our achievements were reported in joint publications. There is a long tradition of cooperation, of spending periods at one another's laboratories, of running joint programs and of writing joint papers.

All of the collaborations have taken place within overlapping subsets of the current nodes. We now seek to extend our successful model beyond these boundaries and cross-fertilize our collaborations, but retain the successful elements of the subsets.

The teams will collaborate by a combination of joint and complementary studies, free exchange of information on both results and plans, and of mutual advising, building on many years of experience of such a mode of operation. This will be effectuated by exchanges of personnel between nodes for short and in some cases longer periods, by regular meetings, both smaller meetings of the people working on a given subject and larger meeting of the whole network (of one week), with an annual frequency, which will be used as an internal forum to exchange the results.

It should be noted that a significant fraction of the proposed principal personnel have already spent extended periods in one of the other nodes and several collaborations and very cordial and knowledgeable relationships pre-exist.

We shall encourage the exchange of graduate students and younger post-doctoral workers between the nodes, irrespective of the principal source of their funding, not only for their more

complete training but also as additional modes of communication and collaboration between the nodes. Again we have a significant track record in this regard.

Additionally we shall try to ensure that whenever feasible postdoctoral workers employed within the network spend part of their tenure at different nodes, for example one year in each of two nodes, each in a country different from that of their citizenship.

At a more technical level we plan the following actions:

- A very useful tool will be the construction of a library of simulation programs which may run on parallel machines which should be shared by the whole collaboration.

- One of the crucial issues is the identification of the properties of the energy excitations near and in the glassy phase. At this end we will set up a large data base of equilibrium (and near to equilibrium) configurations of different systems, in such a way that each member of the network can try his favored method of analysis and compare his results with those obtained by other members of the network. Since one of the great limitations of this field has been to simulate for long enough times, the possibility to share configurations and work on them together is important.

- We want to set up hardware and software for having seminars and colloquia organized in the network on line on the net (we plan to have a set of voice-transparencies on-line shows). A preliminary investigation has proved the technical realizability of such project at very low cost.

All the teams have a wide experience on the subject of this proposal. There will be no serious problem in integrating the less experienced teams into the network project. A non-negligible effort should be undertaken to spread among the network those theoretical and experimental techniques that are in the possession of only a few nodes: direct exchange of people, seminars on the net, topical meetings, workshops of the whole network, should be far enough to reach this aim. All other minor problems, if any, will be also solved in the meetings of the network or by direct exchange.

7 Organization and Management

The network will consist of nine nodes, several of which will involve the collective efforts of more than one institution in the same country. Formal coordination within and between nodes will be effectuated via communication between the coordinators of the nine nodes and the overall coordinator. These people will be responsible for organizing visits, meetings, the regular transmission of information about results and ideas, the preparation of reports and financial management.

It is fortunate that extensive and highly successful collaborations already exist in a more limited bilateral manner between most of the partners. The network therefore has a proven published record of managing its activities and coordinating meetings, and exchange of students. This network will now be enabled to enrich itself by interactions between all nodes.

This activity will be particularly important at the initial period of the network, in order to insure that all the needed technical information is well disseminated among the different nones in a such a way that the subsequent joint work will be facilitated.

Papers written will be submitted to a common data base accessible by all members. Additionally all nodes will be expected to provide regular information on progress which will be collected into bulletins to be posted electronically to members, again on a regular basis.

A World Wide Web site will be set up at which all relevant information about the network will be exposed. The site would contain information about:

- administration: members, addresses, vacancy advertising, etc.;
- scientific projects: research subjects at each node, research status, collaborations between nodes;
- scientific results: reports, preprints, papers etc.;
- an archive of on-line seminars, lectures, colloquia.

The proposed network coordinator has considerable experience also co-organizer of a number of workshops and conferences. He has been a member of the Scientific Council of many institutions, e.g the French National Council for Science, the Italian National Institute of Condensed Matter (INFM), the Human Frontier Organization Program, etcetera. At present he is the director of a newly established Centre for Research and Development of INFM (*Chimera*, a Center for Statistical Mechanics and Complexity), located in Rome.

8 Training Need

There are several reasons why training in the proposal area is of importance to the community.

There is a generic need to train our young scientists in the methodology of fundamental and challenging science, in the quantitative formulation and resolution of problems and the ability to recognize and extract the most important aspects of such problems and their wider implications.

A second generic need is to train them in the versatility which will be necessary for optimal progress, in the ability to move readily at will between pure theory (concepts, analysis, mathematics), simulations (hands-on-experience of computers large, small and special-purpose) and experiments (real experiments or fruitful dialogue with experimentalists): the intellectual and technical challenges that we face in the scientific research described in this proposal provide exceptional opportunities for training for quantitative problem formulation and solution.

Turning now to the more specialized aspects of this proposal we note that at its heart there are different elements. We certainly wish to substantially develop the understanding of the fundamental glass problem. But, for example, there are now hopes that colloidal science be implicated in this story in two ways; first as a source of models to further our understanding of glasses, and that glass paradigms seem to be able to explain whole new parts of soft matter disordered systems such as gels.

There is a clear need for experimentalists and theorists in this field to be trained in an integrated conceptual sense. Also there is enormous potential for the deepening of many areas of industrial application. Training in a network such as this offers the possibility for combined training in soft materials and glasses.

Various elements of the network have proven success in training in across a few nodes. It would take too long (and it would be boring) to report the list of all the collaborations we had in training. Just as a paradigmatic example let us consider the two nodes that are physically the most far away. A number of students from Rome are just finishing their Ph.D in Dublin and returning to Rome for positions there. Also, the first Irish students are now going to be trained in Rome in the methods of simulation for glassy systems. These students have gained experience in a wide variety of techniques and fields of application, and have proven very attractive as they pursue the next stage of their careers, and have contributed at the main international conferences and meetings.

9 Justification of the Appointment of Young Researchers

Young researchers to be financed by the contract				
Participant	Young pre-doctoral researchers to be financed by the contract (person-months)	Young postdoctoral researchers to be financed by the contract (person-months)	Total	Scientific specialties in which training will be provided
1.	0	36	36	P-07,P-10
2.	0	24	24	P-07,P-11
3.	0	36	36	P-07,P-10
4.	0	36	36	P-07,P-10,
5.	0	24	24	P-07,P-05
6.	0	24	24	P.07,P-05
7.	0	36	36	P-07,P-10
8.	0	24	24	P-07,P-10
9.	0	36	36	P-07,P-10
Totals	0	276	276	

Each node has a significant number of internationally recognized scientists and research supervisors, with well established educational facilities at the proposed post-doctoral level (and in most cases at pre-doctoral level too) and a full suite of research, computational, and library facilities at state-of-the-art level. We are well able to provide training at the highest international level.

Especially at the initial stage we plan to organize some short but intensive courses for young researchers we train, in order to give to them a common background. More technical and restricted courses will be done on the use of specialized instruments or analytic and/or numerical tools. Schools, collaboration workshops and topical meetings will also moments of collective training. The young researcher will also spend some time in other institutions of the network: we are convinced that this wide range of experience will be very useful to them.

Our past experience with other forms of funding has shown that we are able to attract the highest calibre of applicants for post-doctoral openings. The salary we offer are competitive and they are equal to those of a Marie-Curie fellowship.

We shall endeavor to make the best matches of nodes and candidates to further the highest level of productive training of Europe's potential scientists, with fair regard to national distribution and equality of opportunity (for example. between the sexes); our records of behavior testify to the past execution of this aim (e.g. the last ten PhD students of the coordinator are evenly distributed among the two sexes).

We shall advertise these opportunities widely and without prejudice, both electronically (via the Web pages we shall set up) and in the European scientific press. Vacancies will also be advertised on the CORDIS data-base, on the network's World Wide Web page, in the European scientific press and by notices and letters to educational institutions and to active scientists in the fields (we have the e-mail addresses of the most relevant European scientists in the field: this list contains a few hundred entries).

10 Training Program

Each node will train several post-doctoral researchers and doctoral students, but most of them will be funded from other sources. Each node will employ young post-doctoral workers from other EEC countries financed by the network with the number of man-months per node as

follows:
Nodes 1, 2, 3, 5, 7, 9: 36 man-months
Node 2, 5 ,6, 8: 24 man-months

All the students and post-doctoral workers will have strong elements of physics as their current specialty, although some may have a background in mathematics or electronics.

The young scientists will be trained in many fields, which include pure theory, large scale numerical simulations, real experiments and their theoretical interpretation. We will concentrate the training on fundamental physical aspects; however our contacts with the industry will be used to enlarge the scope of the training to possible industrial applications.

Training will be by personal instruction, experience in performing research tasks with feedback and regular discussion, by lectures and participation in seminars and conferences and by communication between nodes over the Internet.

We plan to organize two Summer Schools (using also additional sources of funding) and a few workshops during the period of the network.

All young researchers will be encouraged to spend time at other nodes in the network as well as their own and to interact with workers at other nodes. In certain cases, also to help the spread of some experimental technique, we will plan some fellowships in which will be jointly organized by two nodes.

11 Multidisciplinarity in the Training Program

Although the program is unified by the field of physics it brings together experimentalists and theoreticians which have worked in three different fields: structural glasses, spin glasses and soft condensed matter. The connection between these fields is a new phenomenon. We have attempted to keep a logical, manageable and tightly defined conceptual framework in this proposal, and the unifying theme of physics is therefore most important, rather than a large spread of languages. However, individual groups within the network have research or connections to materials science, functional materials, biomaterials, magnetic materials, colloid science, and physical chemistry. Via these relations we have been able to, and will continue to enhance the multidisciplinary of the enterprise.

Part of the theoretical work will be based on very large scale simulations of glassy systems. During the training program people will learn how to solve computer problems related to these large scale simulations (which are often done on parallel machines) and will become familiar with the state-of-art technical tools needed for analyzing the results. The acquired skills will be useful in any field (both in physics and in other sciences) where very large scale computations are needed.

12 Connections with Industry in the Training Program

At the present moment people in various nodes (e.g. in the German nodes and in Montpellier) have already existing contacts with glass industry and polymer industry (SCHOTT, COBELVER, BAYER, etc), i.e. industries for which the properties of glasses and other non-crystalline materials is of very high relevance (material properties in general, aging of these materials, surface properties, etc.). Therefore it is very likely that the knowledge acquired in the network, such as theoretical understanding, computational tools, etc., will ultimately also be of benefit for these types of industries. Furthermore the existing connections between certain members of the network and the research centers of the various companies will make very easy to organize stages for the young researchers in which they will learn in details which are the industrial needs and how these needs can be satisfied using their previous training.

We are in the process of making contacts with other industries working in related sectors. We have noted earlier that glasses are of great importance in many areas of industry. However, our main focus here is in the innovative aspects of the ideas that have been arising out of recent work. For example many features of soft amorphous materials, with novel memory and other functional aspects, are now expected to be understood by the paradigm of glasses. Such materials are useful in many applications: medical devices, implants, etcetera. We also plan organize training stages in these industries devoted to the study of soft materials.

13 Financial information

Financial information on the network project				
Participant	Personnel and mobility costs related to the appointment of young researchers (euro)	Costs linked to networking (euro)	Overheads (euro)	Totals (euro)
1.	137,268	50,000	66,626	258,894
2.	86,400	15,180	15,460	117,040
3.	129,600	20,820	19,640	170,060
4.	162,000	30,000	26,495	218,495
5.	101,400	15,000	11,640	128,040
6.	73,488	15,000	8.849	97,337
7.	120,312	31,600	14,522	166,434
8.	110,904	15,000	12,590	138,494
9.	112,608	20,000	18,761	151,369
Totals	1,033,980	217,600	194,583	1,446,163

The main expenses of the network (around 70%) are finalized to personnel cost of young researchers.

As we have already stated we have used the Reference Rates for Marie-Curie Fellows for determining the personnel cost of young researchers. Our past experience tells us that these salaries are competitive.

Some of the money of the coordinator's node in the category "Cost linked to networking" will be used for the organization of the meetings of the network.

In node 7 (Badajoz) 6600 Euro for a participant in less favored country (containing an ex-international post-doc Fellow, i.e. Ruiz-Lorenzo) will be used to buy some computer equipments (two large memory Linux PC) which is missing in Badajoz.

Overheads are on the average around 13% (with some fluctuations), with the exception of the node of the coordinator, where there are extra overheads related to the management of the whole network.