Annex I

PART A: CONTRACT DETAILS AND OBJECTIVES

1: Full Title: The Origin of Our Universe:
Seeking Links Between Fundamental Physics and Cosmology

Short Title: UniverseNet

2: Proposal Number: 035863-2

Contract Number: MRTN-CT-2006-035863

3: Duration of the project: 48 Months

4: Contractors and Place(s) of Implementing the Project

The Co-ordinator and other Contractors listed below shall be collectively responsible for execution of work defined in this Annex:

The Co-ordinator

1. The Chancellor, Masters and Scholars of the University of Oxford [UOXF.DR] established in United Kingdom

Other Contractors

2. Lancaster University [ULANC], established in United Kingdom;
3. King's College London [KCL], established in United Kingdom;
4. Institut de Física d'Altes Energies Barcelona [IFAE], established in Spain;
5. Rheinische Friedrich-Wilhelms-Universität Bonn [UniBonn], established in Germany;
6. Ludwig-Maximilians-Universität München [LMU], established in Germany;
7. Nordisk Institut for Teoretisk Fysik Copenhagen [NORDITA], established in Denmark;
8. European Organisation for Nuclear Research Geneva [CERN], established in Switzerland;
9. Helsingin yliopisto [UH.HIP], established in Finland;
10. University of Ioannina [U.IOANNINA], established in Greece;
11. Istituto Nazionale di Fisica Nucleare Padova [INFN], established in Italy;
12. Universite Paris 7 Denis Diderot [UP7DD], established in France;
13. Centre National de la Recherche Scientifique Annecy [CNRS], established in France;
14. Uniwersytet Warszawski [UW], established in Poland;
15. Seoul National University [SNU], established in Korea.

The Co-ordinator and other Contractors are referred to jointly as "the Consortium".

The “Laboratoire AstroParticule et Cosmologie (APC)” which is carrying out part of the work is a Joint Research Unit (UMR 7164) formed by the Université Paris 7, the Observatoire de Paris, the Commisariat à l’Energie Atomique and the Centre National de la Recherche Scientifique.

The “Laboratoire d’Annecy-le-Vieux de Physique Théorique (LAPTH)” which is carrying out part of the work is a Joint Research Unit (UMR 5108) formed by the Centre National de la Recherche Scientifique and the Université de Savoie-Chambéry.

5: Project Overview

This Network brings together the key theoretical physics groups in 10 EU states, as well as in a third country (Korea), interested in the fundamental physics which shaped our Universe. It builds on existing collaborations amongst the participating institutions which are active across the whole spectrum of research in particle cosmology and astroparticle physics, from phenomenological issues concerning cosmic matter and radiation, dark matter and dark energy, to fundamental questions about the nature of space-time and of the Big Bang itself.

The interface between particle physics and cosmology has become very exciting in recent years, largely due to the establishment of ‘standard models’ in both fields which satisfactorily describe all known phenomena but whose very success, paradoxically, establishes them as intrinsically incomplete pictures of physical reality. The standard Big Bang cosmology, based on the familiar physics of electromagnetism, weak interactions and nuclear reactions, reconstructs our history back to the beginning of the nucleosynthesis era, when the universe was 10^{-2} s old. The Standard Model (SM) of particle physics, brilliantly confirmed by all accelerator experiments to date, allows us to extrapolate back further to $\sim 10^{2}$ GeV or $\sim 10^{-12}$ s, when the unified electroweak (EW) symmetry was spontaneously broken and all known particles received their masses through the Higgs mechanism. To go beyond this point requires an extension of the model; indeed its very success *requires* new physics beyond the Standard Model (BSM).

The most promising approach towards addressing the ‘naturalness’ problems of the SM, in particular the Higgs mass hierarchy problem, introduces (‘softly broken’) supersymmetry (SUSY) between fermions and bosons in the Minimal Supersymmetric Standard Model (MSSM). Precision measurements of radiative corrections support this possibility and show that it enables ‘grand unification’ of the gauge interactions (GUT) at the very high energy of 10^{16} GeV. Whether this is indeed the route that Nature has chosen will be definitively decided at the forthcoming LHC accelerator which should have sufficient energy to create the superpartners of known particles. When supersymmetry is broken locally, like any other gauge symmetry, an intimate connection with gravity emerges. This is supergravity (SUGRA), the effective field theory below the Planck scale. However unification of gravity with the other interactions seems to require viewing fundamental ‘particles’ as, instead, excitations of extended objects in the framework of (super)string theory. The identification of ‘dualities’ between different string theories indicates the existence of an even more fundamental underlying structure – M-theory. Another important development has been the recognition that the additional dimensions whose existence is required by such theories, may become accessible at relatively low energies. The weakness of gravity can then be understood if it alone propagates in these new dimensions (which may be large, or even infinite), while the gauge interactions are confined to a 3+1-dimensional 'brane'. This has triggered an explosion of interest in modified theories of gravity, at both very small and very large spatial scales where it has never been tested experimentally.

Turning to cosmology, the empirically successful Friedmann-Robertson-Walker (FRW) model describing an adiabatically expanding, homogeneous and isotropic universe also requires extreme fine tuning of the initial conditions. The problem essentially consists of explaining why the universe is as old (>3 x 10^{17} s) or as large (>10^{28} cm) as it is today, relative to the Planck time (5 x 10^{-44} s) or the Planck length (2 x 10^{-33} cm), which are the appropriate physical scales of quantum gravity. A definitive resolution of this may have to await progress in string/M-theory, but an attractive solution is that there was a period of non-adiabatic accelerated expansion or 'inflation', perhaps associated with a phase transition in the vacuum state, which reduced the spatial curvature of the universe to zero. This naturally generates a nearly scale-invariant spectrum of scalar density fluctuations which can seed the growth of the observed large-scale structure (LSS) of galaxies, and leaves a characteristic imprint in the angular anisotropy of the cosmic microwave background (CMB). Recent observations by e.g. the WMAP satellite and galaxy surveys such as 2dFGRS and SDSS have provided compelling support for this picture.

Another fundamental problem of the standard cosmology is that the observed abundance of baryonic matter is ~10^9 times greater than the relic abundance expected from a state of thermal equilibrium, while no antimatter is observed, thus requiring a primordial asymmetry. To generate this dynamically requires new physics to violate baryon number (*B*) and charge-parity (*CP*) at high temperatures, in an out-of-equilibrium situation to ensure time asymmetry. Alternatively, a primordial lepton number may be converted to a baryon number through non-perturbative SM processes at high temperatures; the former may be linked to the recent discovery of neutrino oscillations which suggests lepton number violation at high energies. Moreover, baryons are a minor constituent of the universe, since all large structures appear to be dominated by dark matter, the major part of which is required to be non-baryonic. The most likely possibility is that dark matter consists of relic exotic particles arising in BSM physics; if so then there may be indirect signatures of their decays and annihilations in the high energy cosmic radiation incident on the Earth. Recent deep observations of the Hubble expansion using Type Ia supernovae indicate that there is an even bigger component of unclustered 'dark energy' which has *negative* pressure like a cosmological constant, causing the Hubble expansion to accelerate. All astronomical data now seem to be consistent with a 'concordance model' which has 72% dark energy, 23% dark matter and 4% baryons, with structure formation seeded by adiabatic, nearly scale-invariant gaussian density fluctuations of fractional amplitude ~10^{-5}.

Notwithstanding such impressive progress on the observational front, it is clear that we have yet to secure a *physical* understanding of why the universe is as it is. This requires concerted effort on the underlying BSM physics which offers mechanisms for inflation and baryogenesis, as well as particle candidates for the dark matter and possibly even scalar fields which can behave as dark energy. Perhaps the real solution to the conundrum posed by dark matter and dark energy lies instead in modifying Einsteinian gravity on scales where it has never before been tested. Certainly the biggest challenge is to resolve the cosmological constant problem of field theory as well as the initial singularity problem of general relativity, which can perhaps be addressed only in a consistent quantum theory of gravity. We wish to emphasize that this is a technically very demanding and *interdisciplinary* research field, and among the most exciting frontier areas of fundamental physics today.

5.1 Overall Objectives

Given the ambitious scale of the problem being tackled, namely explaining the microphysical origin of our universe, it would be inappropriate to have fixed goals. Nevertheless a structured approach is essential, accordingly it is intended to conduct a coordinated programme of research and training on the following six key topics at the interface of physics and cosmology.

i) The origin of baryons: Baryons are the only form of matter in the universe the existence of which is certain. The conditions for generation of a baryon asymmetry were thought to be achievable only at the GUT scale but the realisation that non-perturbative SM effects can violate *B* has opened up the possibility that this may have happened at the EW scale. In fact this does not work (too little *CP*-violation and too weak a phase transition) in the SM but might be possible in the MSSM if the scalar top and the lowest mass chargino are sufficiently light – this possibility can be tested at future colliders. Another possibility for low temperature baryogenesis is the Affleck-Dine mechanism in which squarks/slepton fields acquire large vacuum expectation values along a 'flat direction' of the scalar potential of e.g. the MSSM during the inflationary era. This leads to the formation of a condensate the decay of which can create baryon number. The condensate can fragment into non-topological solitons known as 'Q-balls' which may also constitute dark matter. Another intriguing possibility, motivated by the recent discovery of neutrino oscillations, is that the baryon asymmetry is generated by the non-perturbative EW processing of a primordial lepton asymmetry created through the out-of-equilibrium decays of massive right-handed Majorana neutrinos. These are usually invoked to provide masses to the left-handed neutrinos through the 'see-saw' mechanism. The possibility of baryon creation directly from inflaton decay is also interesting in view of the restrictive limits on the reheating temperature after inflation from considerations of gravitino production.

ii) The origin of dark matter: All structures in the universe bound by gravity, from individual dwarf, spiral and elliptical galaxies, to clusters and superclusters, appear to be dominated by unseen matter. A variety of astronomical studies – galactic dynamics, gravitational lensing, formation of structure, X-ray studies of clusters, CMB anisotropies, etc. – have established a good case that most of the dark matter is 'cold' i.e. consists of slowly moving non-relativistic particles which are non-interacting. However several observations on galactic scales suggest that the situation may be more complicated. It has even been proposed that dark matter may be an illusion due to modification of Newtonian dynamics (MOND) at very low accelerations. Establishing the identity of the dark matter or alternatively demonstrating that MOND is physically and cosmologically viable, is among the key challenges in cosmology. A natural candidate for dark matter is a new particle arising in new BSM physics which is cosmologically stable through carrying a new conserved charge. The best-studied such particle is the neutralino, which is usually the lightest SUSY particle and stable by virtue of a new exact symmetry – *R*-parity. Detailed studies have been done of the relic abundance of neutralino dark matter in the MSSM as well as in other more constrained models such as mSUGRA. Taking into account important constraints from particle physics experiments, the allowed parameter space satisfying the 'WMAP bound' on the relic density is rather limited. Other SUSY candidates have also been considered such as the axino and gravitino, as well as superheavy string-scale relics ('cryptons'). Alternatively the dark matter particles may be excitations in an ultralight scalar field such as the axion. Direct searches for interactions of dark matter particles with laboratory detectors, as well as indirect searches for their annihilation products (such as neutrinos and γ–rays) need to be guided by considerations of their possible microscopic properties, as well as observational developments in our understanding of the distribution of dark matter.

iii) <u>The origin of cosmic radiation</u>: The origin of cosmic rays has remained a mystery since they were first discovered nearly a century ago. Mechanisms have been proposed for their acceleration to high energies in astrophysical sources such as supernova remnants, but we still lack a definitive signature of their origin through observation of the γ-rays or neutrinos that should be produced in the same sources. Moreover although the spectrum continues beyond 10^{11} GeV, sources in the Galaxy cannot accelerate particles beyond ~10^{9} GeV – apart from the physical limitations for plausible sources, gross anisotropies should then be seen since the Galactic magnetic field is too weak to randomise the directions of such particles. In fact the observed arrival directions are *isotropic* indicating that the sources at such high energies are very distant and therefore very energetic, perhaps γ-ray bursts. In that case the interactions of the cosmic rays, if these are protons, with the CMB should result in a cutoff in the spectrum at ~5 x 10^{10} GeV. Presently there are contradictory observations concerning this and new definitive data from the Pierre Auger Observatory is eagerly awaited. If the spectrum is found to extend beyond this energy, it would suggest that the sources are in fact local but not astrophysical – perhaps superheavy relic particles decaying or annihilating in the Galactic halo. Alternatively there may be something wrong with our understanding of cosmic ray propagation e.g. violation of Special Relativity at very high energies. Conversely if the cutoff is in fact established, then we would in effect have an energy-calibrated cosmic proton beam – detailed study of the 'air showers' generated by their interactions in the atmosphere would enable new physics to be probed up to 10^{6} GeV (c.m.s) – well beyond the reach of any terrestrial accelerator. Moreover high energy neutrinos should also be detectable from the extragalactic cosmic ray sources with forthcoming neutrino telescopes such as IceCube, opening up a new astronomy as well as providing a unique laboratory for astronomically-long baseline studies of neutrino oscillations, sensitive to a variety of new physics including quantum gravity. Auger too can detect ultrahigh energy neutrinos as quasi-horizontal and Earth-skimming showers and is sensitive to possible enhancements of their interaction cross-section due to new physics such as new dimensions at the TeV scale.

<u>The origin of cosmic structure</u>: The density fluctuations responsible for the generation of structure in the Universe have been investigated in exquisite detail by WMAP and 2dF/SDSS and these findings must be confronted with inflationary models based on present ideas about BSM physics. In some models the sector of the theory responsible for inflation is described by global SUSY, while in others stringy fields and SUGRA play an essential role. Within the latter class, models based on string theory in the context of large extra dimensions have received a lot of attention. Different models of inflation give, in general, different predictions for the scale-dependence of the primordial density fluctuations which can be confronted with the precision cosmological data. The data also indicate possible features in the fluctuation spectrum which may be a signature of high energy processes such as phase transitions in 'flat direction' fields occurring during inflation. It is likely that we will soon see the emergence of a preferred paradigm of inflation which is an intrinsic part of the broad picture of physics beyond the SM, which alone among the simple possibilities fits the data. There are also attractive alternative possibilities such as the 'curvaton' mechanism for generating scale-invariant fluctuations; the curvaton field can easily be incorporated into a low-energy field theory which is testable at colliders. The liberation of inflation models from the need to generate structure from the inflaton also alters completely the analysis of the 'landscape' of vacuua predicted by string theory.

v) The origin of dark energy: The combination of recent cosmological observations which indicate that the expansion rate is accelerating (as seen in the Hubble diagram of SN Ia), that the Universe is flat (as deduced from the CMB), and that dark matter cannot provide the critical density, has led to the amazing conclusion that the Universe is dominated by a uniformly distributed form of (dark) energy which behaves as Einstein’s cosmological constant. We can also envisage a dynamical dark energy in the form of an ultralight scalar field which is slowly evolving down its potential to some asymptotic minimum which may be at zero – this has been named ‘quintessence’. However the energy density of dark matter and dark energy today are comparable which creates a severe fine-tuning problem since in general they would have varied differently during the last 14 billion or so years of cosmological evolution. Some quintessence models with exponential scalar potentials can ‘track’ the energy density of dark matter, however fine-tuning is necessary to obtain the negative pressure required to drive accelerating expansion. New possibilities emerge if the quintessence field can interact with dark matter. There may be violations of the equivalence principle due to the new long range force, and even time variations of coupling constants if quintessence is identified with ‘moduli’ of string/M theory. It is also possible that we are being misled and that the dark energy is mimicked by a modification of general relativity on very large scales (e.g. though the opening up of a new spatial dimension), or because the underlying FRW cosmological model is an oversimplified description of the real inhomogeneous Universe. It is essential in this regard to formulate new observational tests which can discriminate between these possibilities.

vi) The origin of space-time: Space-time may well turn out to be a *derived* concept in a theory of quantum gravity such as string/M theory and its emergence from such a fundamental theory is of prime importance for cosmology. Even though we are far from the final formulation of string/M theory, there is great interest in its implications for the early Universe. In string theory, there are membranes of various dimensions – D-branes – which live in the 10-dim ‘bulk’ space-time, and much attention has been paid to the idea that our Universe in fact resides on a 4-dim D-brane. This has motivated study of higher-dimensional string theory geometries that may avoid the initial singularity, possibly forming a link with pre-Big Bang cosmology. Given the observational successes of the inflationary paradigm, it is natural to inquire whether inflationary potentials compatible with observation can arise from attractive forces between D-branes. A recent development has been the discovery that the key parameters of the theory, such as the size and shape of extra dimensions (‘moduli’) can be fixed by background ‘fluxes’ leading to the emergence of a so-called ‘landscape’ with a very large number of possible vacuum states. The cosmological implications of this need to be explored particularly since CMB experiments such as the forthcoming Planck satellite will achieve levels of precision where they may be able to directly test string-theoretical scenarios. A parallel development is the ‘holographic’ interpretation of space – describing the physics in a bulk space-time in terms of a different theory living on a *lower* dimensional surface. By analogy with a previous holographic relationship known as AdS/CFT, it is possible that the dual holographic theory would turn out to be non-gravitational. This dual description can potentially be used to give a radically new perspective on traditional cosmological problems such as the mechanism for inflation.

5.2 Overall Approach and Methodology

As the Network’s name suggests, its activities have a common thread, namely the birth and early evolution of our Universe as indicated by models of the fundamental interactions. The nature of the subject inherently demands interaction between different disciplines – field theory at both zero and finite temperature, string/M-theory and its novel phenomenology which is just beginning to be explored, relativistic astrophysics and cosmology, relativistic perturbation theory, etc. The majority of the participants have been trained in particle physics and relativity and have gained the necessary knowledge of astrophysical phenomenology through their research experience. Their methodological approach towards research is essentially problem-led insofar as the necessary technical tools are acquired and used as and when necessary. All the participants are very experienced in this regard and have regular programmes of seminars and workshops which are essential to stimulate the exchange of ideas and to foster collaborations. Moreover many of them are based in large universities which have many other related activities, providing further support for interdisciplinary work. It is in general difficult to bridge areas as different in their history and methodology as astronomy and particle theory, but the participants have had considerable success in doing so, as their research record testifies.

With reference to specific techniques for the solution of problems, the participants have both developed and use state-of-the-art methods as necessary, for example non-perturbative methods in field theories at high temperature, computer simulations on the lattice, new mathematical techniques in string/M-theory etc. Although this is primarily a Network of theorists, several of them are also participating in experiments (e.g. Planck, Pierre Auger Observatory, IceCube) or act as consultants to large experimental collaborations (e.g. at the LHC). Moreover some take part in planning activities such as ApPEC (Astroparticle Physics European Coordination) and ASTRONET (ERAnet for astrophysics/cosmology). Thus the experimental and observational developments of direct relevance to the research goals will be kept under scrutiny and new data – whether from satellites, underground facilities, telescopes or colliders – will be responded to immediately both in order to test existing theoretical models as well as to formulate new ones.

The Network is interdisciplinary, bringing together the two ‘big sciences’ – astronomy and particle physics – which have rather different teaching methodologies. This will be kept in mind in devising a coherent training programme. In the annual schools in particular, novel pedagogical methods will be used where possible to communicate effectively the physical concepts underlying modern particle physics to researchers with an astronomy background who have no training in field theory and, conversely, ‘master classes’ in astrophysics/cosmology will be devised for those with a particle physics background to update them on modern developments.

PART B: IMPLEMENTATION

1. Description of the joint Research/Training Project

Research

The anticipated collaborative activities are listed below under the overall objectives. The expected participation by the various Partners in the specific projects is given (with the lead group highlighted) and the key goals are listed in *approximate* order of priority. Many of the above problems are *interrelated* hence in a fast-moving field such as this, it would be premature to be more specific at this stage. This is about the level of detail that it would be appropriate to specify, say to a prospective pre-doctoral student – to attempt to be more explicit would be counter-productive since this will not allow new developments (both observational and theoretical) to be taken into account in order to redefine the physics goals as and when necessary.

a) The origin of baryons in particular as mediated by sphalerons during the supersymmetric electroweak phase transition, through L-violating operators (leptogenesis) and through the decay of flat direction scalar fields in supersymmetric theories (Affleck-Dine mechanism) or inflaton decay, and through novel mechanisms in higher dimensional theories;

Electroweak baryogenesis in supersymmetric models (Partners **4**, 9, 11)

Affleck-Dine baryogenesis in supergravity (Partners 1, 2, 5, 7, **9**)

Leptogenesis tied to models of neutrino mass/mixing (Partners **1**, 2, 4, 7, 8, 10, 11, 13, 14)

Possibilities for baryogenesis in brane-world cosmologies (Partners 1, 5, **7**, 11)

Key goals:

(a) to refine collider tests for models of baryogenesis at the SUSY electroweak phase transition;

(b) to examine whether leptogenesis is achievable in phenomenologically acceptable models of neutrino masses and mixings, subject to constraints on the reheating temperature;

c) to study the possibility of low temperature baryogenesis by 'flat directions' or through direct inflaton decay, and the possible relation to the dark matter problem.

b) The origin of dark matter specifically cold dark matter candidates in supersymmetric models such as neutralinos, axinos and Kaluza-Klein states, superheavy dark matter candidates such as cryptons appearing in string/M-theory, ultralight axions, the contribution of known neutrinos to hot dark matter and possible candidates for warm dark matter, as well as investigation of methods for their direct and indirect detection:

Relic abundance of neutralinos, subject to experimental constraints on SUSY parameter space, and the phenomenology of their detection (Partners 1, 2, 4, **5**, 8, 10, 11, 12, 13)

Alternative dark matter candidates in SUSY and Kaluza-Klein models (Partners 1, 2, 5, 7, 8, 9, 10, 11, 13, **15**)

Axions and other pseudo-scalars (Partners 2, **4**, 5, 11, 14, 15)

Warm and hot dark matter candidates (Partners 1, 2, 7, 11, **13**)

Key goals:

(a) to relate experimental results, both from accelerator searches as well as from non-accelerator experiments searching for dark matter signals, to the SUSY parameter space, in order to constrain neutralino dark matter;

(b) to establish whether there are other viable BSM particle candidates for dark matter;

(c) to determine whether dark matter is indeed entirely cold and non-interacting;

(d) to test if MOND is cosmologically acceptable from considerations of structure formation.

c) The origin of cosmic radiation with particular focus on γ-ray and neutrino signals and on the recently observed ultra high energy cosmic rays beyond the GZK cutoff which must be due to new physics beyond the Standard Model or exotic astrophysics:

Constraining acceleration mechanisms in possible astrophysical sources with γ-ray and ν observations (Partners 1, 11, **12**, 13)

Probing quantum decoherence, *CPT* violation etc by studying neutrino oscillations over cosmological baselines (Partners 1, **3**)

The spectrum, and anisotropy of high energy cosmic rays and neutrinos expected from 'top down' and 'bottom up' sources allowing for propagation effects (Partners **1**, 5, 11, 12)

Key goals:

a) to understand the astrophysical aspects (acceleration mechanisms, propagation through magnetic fields and radiation backgrounds, etc.) of cosmic rays sufficiently well so as to be able to establish whether new physics is necessary to explain the observed spectrum;

(b) to improve models of ultra high energy cosmic ray interactions using data from forthcoming forward physics experiments at colliders;

(c) to devise probes of new physics through the flavour content of cosmic high energy neutrinos;

(d) to test models of new physics which predict altered cross-sections for ultrahigh energy neutrino interactions (e.g. through mini black-hole formation in TeV scale quantum gravity).

d) The origin of cosmic structure arising from primordial fluctuations generated during an inflationary era, whether arising in the effective supergravity field theory as derived from string/M-theory, as well as in novel contexts of genuinely stringy solutions to the fundamental cosmological problems. The emphasis will be on constraining theoretical models by using the recent precision data on CMB anisotropy (WMAP) and the large-scale structure of galaxies (2dF, SDSS) which are still consistent with a gaussian, adiabatic, scale-invariant spectrum of scalar density perturbations, but also show interesting features (lack of power on large scales, possible spectral 'glitches') that might turn out to be specific probes of the physics of the inflationary era. It is also essential to pursue alternatives for the origin of the primordial fluctuations, as in the 'curvaton' model which predicts (correlated) isocurvature fluctuations and is easily linked to BSM physics. The possible effect of 'trans-Planckian' physics on inflationary fluctuations needs to be investigated, as also possible effects arising during the reheating epoch.

Models of inflation and their confrontation with observational CMB and LSS data (Partners **1**, 3, 6, 7, 8, 10, 11, 12, 14, 15)

The generation of primordial fluctuations through the 'curvaton' mechanism (Partners **2**, 9, 10, 12)

Cosmological perturbation theory in higher-dimensional models (Partners 1, 2, 10, 13, **14**)

Possible effects of 'trans-Planckian' physics and reheating (Partners 3, 5, **7**, 11, 15)

Key goals:

(a) to further develop inflationary models in both supergravity and string/M-theory;

(b) to use high precision observational data to constrain them and establish whether there is a preferred solution to the problems associated with SUSY breaking by the large vacuum energy during inflation;

(c) to study the implications of possible large dimensions for inflation;

(d) to establish whether parametric resonance and other collective phenomena can occur during reheating in realistic models, subject to the gravitino production bound;

(e) to study alternative mechanisms such as the curvaton for structure formation.

e) The origin of dark energy, the key question being whether this is a cosmological constant or a time-varying vacuum energy of a scalar field ('quintessence') or perhaps arising due to modifications of Einsteinian gravity at large distances/small curvature, or even "faked" by effects such as the backreaction of cosmological perturbations or bulk viscosity of a non-ideal gas which contributes to dark matter

Resolution of the cosmological constant problem in higher dimensions (Partners 2, **5**, 14, 15)

Phenomenological models for quintessence based in particle theory (Partners 2, 4, 6, 9, 11, **12**, 14, 15)

Possible modifications of gravity leading to cosmic acceleration (Partners 1, 3, 8, **11**, 12)

Development of non-standard cosmologies with no dark energy which may be consistent with the observational data (Partners 1, 8, 10, **14**)

Key goals:

(a) to investigate the phenomenological constraints on the interactions of the quintessence scalar field with ordinary matter,

(b) to study the problems related to the presence of new long-range interactions (for instance, violation of the equivalence principle) associated with an ultralight scalar,

(c) to investigate possible variations in time of the coupling constants due to identification of the scalar of quintessence with moduli of the underlying superstring/M theory,

(d) to establish whether cosmological observations really require dark energy in the context of inhomogeneous world models.

(e) to determine if there is a connection between the origin of dark energy and of dark matter

f) The origin of space-time focusing on the class of string/M-theory models for which the many free parameters (or moduli) can be fixed and the origin of inflation in such models, as well as the formulation of a holographic description of cosmology by development from well-understood holographic descriptions of certain static spacetimes by considering accelerated observers who possess space-time horizons.

Pre-Big Bang Cosmology (Partners 1, 3, **8**, 10, 15)

The cosmology of dilatons and string moduli (Partners 1, 2, 3, **5**, 6, 9, 10, 11, 14, 15)

Non-perturbative potential from gaugino condensation (Partners 1, 5, 12, **14**, 15)

Black holes and cosmology (Partners 1, 2, 3, 5, **6**, 10, 15)

Higher-dimensional brane-cosmology and AdS/CFT (Partners 1, 2, 5, 8, **10**, 14, 15)

Holograpic interpretations of space-time (Partners 1, 2, 5, 8, **15**)

Key goals:

(a) to develop an understanding of whether D-brane evolution through a non-trivial higher-dimensional space can provide a non-singular description of our cosmological evolution;

(b) to develop a holographic interpretation of cosmology, understanding how gravitational effects play a role in the alternative theory;

(c) to study cosmology in versions of string and M-theory with fixed moduli fields, understanding whether this can lead to a four-dimensional universe at low energies;

(d) to apply the new insights gained from the above work to long-standing problems in cosmology, such as the origin of inflation and the nature of the emergence of our four-dimensional space-time from an earlier, entirely string-theoretic epoch.

Training and Transfer of Knowledge (ToK)

Person-months of Early Stage Researchers (ESR) and Experienced Researchers (ER)

The Network as a whole undertakes to provide a minimum of 552 person-months of Early Stage and Experienced Researchers whose appointment will be financed by the contract. Quantitative progress on this, with reference to the table contained in Part C and in conformance with relevant contractual provisions, will be regularly monitored at the consortium level.

The complementarity of the Partners in terms of both technical expertise and the different work environments they offer are intended to provide a stimulating experience for both graduate students and post-docs.

All vacancies will be published on the internet (both on the home page of the Network and on the CORDIS website) as well as on various physics bulletin boards and information services. Colleagues working in this field world-wide will be alerted so they can encourage their researchers to apply for these positions. In appointing researchers, applicants will be sought from all over the world (keeping in mind the 30% rule for those from third countries).

The main emphasis in training researchers will be to provide the necessary technical background in *both* particle physics and cosmology. The ERs would usually have a strong background in particle physics so their training will focus on astrophysics/cosmology and advanced topics e.g. string/M-theory. The ESRs will be exposed to a comprehensive graduate programme which covers both areas. The training commitments have been distributed among the various Partners keeping this in mind. The annual schools will be an essential tool for providing a pedagogic introduction to problems at the research frontier, for both ESRs and ERs. Many senior participants are regularly called upon to lecture at such schools and several of them have written influential reviews in this field (see e.g. *http://www.slac.stanford.edu/spires/reviews*). The Partners have organised many such schools in the past and a flavour of the balance achieved between pedagogical lectures given by senior scientists and seminar-style contributions from the recruited researchers may be gathered from e.g. the programme of the last Aegean School they organised (*http://www.physics.ntua.gr/cosmo05*).

Whereas training for ERs is usually conducted in English throughout Europe, this is not the case for ESRs since lecture courses etc. are often given in the national languages. Specifically the Partners in Greece cannot accept pre-docs since their graduate programs are conducted partly in Greek and so it would be difficult for them to attract suitable pre-doc applicants from elsewhere. However the Partners in Finland, France, Germany, Italy, Spain and, particularly the UK, receive applications from prospective ESRs based in other countries so can train both pre- and post-docs. The Partner in Poland will for the *first time* host an ESR – it is intended to fill this position taking advantage of their strong links with the Partners in Germany. The Partner at CERN will also host short visits by students registered to do a PhD in one of the other Partner institutions. All Partners who will accept researchers intend to set up a joint web-based 'pool' of qualified applicants, so that fluctuations which are foreseen in the number of applicants to individual Partners can be smoothed out whenever possible by exchanging suitably qualified applicants.

The training given will have two key components:

(i) **Individual training** through:

- First, the standard academic programme of each Partner (lecture courses, research seminars, discussion groups, journal clubs, etc.);
- Exchange visits and secondments between the Partners – this will depend on the specific topics that the researchers are engaged on investigating;
- Collaborative research with senior staff of the host Partners – whenever possible they will endeavour to catalyse collaborations between recruited researchers belonging to different Partners with the intention of stimulating their mobility and career prospects.

(ii) **Common training** through:

- Participation in advanced schools, in particular those organised by the Network but also including other well-known international schools (Cargese, Erice, Les Houches, etc.);
- Participation in the Network meetings, where recruited researchers will have priority in being given opportunities to make presentations;
- Short visits to CERN which conducts an Academic Training Programme and offers many opportunities to form collaborations and gain exposure in the international community.

The proposed schedule is as follows:

1st Year**: First Network School + Full Network Meeting**, with lectures by both Network participants and invited outside experts, as well as seminars by recruited researchers and reports from the Scientists-in-charge (foreseen within 1 year of Start Date – proposed host Partner 10).

2nd Year**: Second Network School + Full Network Meeting + Mid-Term Review**, as above, along with the participation of Commission's Representative (foreseen within 2 years of Start Date – proposed host Partner 2).

3rd Year: **Third Network School + Full Network Meeting,** as above (foreseen within 3 years of Start Date – proposed host Partner 11).

4th Year: **Fourth Network School + Full Network Meeting**, as above. At this final meeting the achievements of the network will be reviewed, with the focus on future implications, both for the research area and for continuing collaborative activities of the Participants (foreseen within 4 years of Start Date – proposed host Partner 4).

With regard to a Career Development Plan for both ESRs and ERs, it is intended that this would be formulated by the recruited researcher concerned together with his/her research supervisor, in consultation with the respective Scientist-in-Charge. This will be supervised by the 'Mentor' assigned by the Co-ordinator to the researcher concerned. This is in order to take into account that circumstances are different for different people, depending on the country they are working in, their particular area of research, and their personal perspectives on their future. Every measure will be taken to promote mobility between the Partners.

Concerning gender issues in the employment of researchers, all Partners are legally committed to promoting equal opportunities for men and women and several of them make special efforts to attract female students already at the undergraduate level. All Partners will pool their experience regarding methods that have proven to be effective in attracting female researchers at both the pre-doc and post-doc levels; the advice of female scientists of the Network will be actively sought by the Co-ordinator in this regard.

The breakdown among the different Teams, along with the research effort of the Network supported by other funding, is shown in the Table below. In estimating the minimum research effort, only permanent staff members have been counted and the participants have been weighted by the fraction of their time they will devote to the Network, keeping in mind their other existing commitments. In practice the post-doctoral researchers supported by non-network funds will make an additional substantial contribution. There is an approximate proportionality between the research effort of the Teams and their commitment to training of researchers.

Several Partners have 'Extended Teams' in their respective countries in order to overcome fragmentation by involving active researchers from other institutions, while maintaining a compact management structure. These associated groups will not benefit from direct network funding (in particular from overheads) and the researchers recruited by the Network will always be appointed by the formal Contractors in the Consortium. The Extended Teams will nevertheless contribute significantly to the overall research effort as can be seen in the Table below. Their members will attend Network meetings and other specialist workshops and conferences, as well as engage in relevant ToK activities, supported by the respective Partner.

Partner Number	*Partner Description*	*ESRs (person-months)*	*ERs (person-months)*	*Other research effort (person-months)*
1	**University of Oxford**	36	24	149
2	**Lancaster University**	-	24	134
	Extended Team: University of Durham	-	-	60
	Extended Team: University of Liverpool	-	-	24
3	**King's College London**	36	-	115
4	**Institut de Fisica d'Altes Energies, Barcelona**	36	24	192
	Extended Team: Instituto de Fisica Teórica, Madrid	-	-	43
	Extended Team: Universidad Autonoma de Madrid	-	-	91
5	**Rheinische Friedrich-Wilhems Universität Bonn**	18	24	84
6	**Ludwig-Maximilians Universität München**	18	-	72
7	**Nordic Institute for Theoretical Physics, Copenhagen**	-	12	62
	Extended Team: Niels Bohr Institute, Copenhagen	-	-	86
	Extended Team: University of Aarhus	-	-	48
8	**European Organisation for Nuclear Research, Geneva**	24		86
9	**University of Helsinki**	24	24	158
10	**University of Ioannina**	-	48	132
	Extended Team: National Technical University Athens		-	48
	Extended Team: N.R.C. Demokritos, Athens	-	-	12
	Extended Team: University of Athens			24
	Extended Team: University of Patras	-	-	24
	Extended Team: University of Thessaloniki	-	-	48
11	**Instituto Niazionale di Fisica Nucleare, Padova**	36	24	130
	Extended Team: INFN Ferrara	-	-	82
	Extended Team: INFN Lecce	-	-	34
	Extended Team: INFN Pisa	-	-	62
	Extended Team: INFN Trieste	-	-	79

	Extended Team: Laboratario Nazionale del Gran Sasso			144
	Extended Team: ICTP Trieste	-	-	58
12	**APC, Universite Paris VII**		24	168
13	**Laboratoire d'Annecy-Le-Vieux de Physique**	36		86
	Extended Team: Institut de Physique Nucléaire de Lyon	-	-	38
14	**Uniwersytet Warszawski**	36	24	202
15	**Seoul National University**	-	-	79
	Extended Team: University of Seoul	-	-	10
	Extended Team: Chonbuk National University			14
	Extended Team: Hanyang University	-	-	91
	Extended Team: Inje University	-	-	36
	Extended Team: Pohang University	-	-	10
	Extended Team: KAIST, Daejeon	-	-	72
Total		300	252	3089

This Network being devoted to fundamental science has no direct connection with industry. However it should be noted that researchers who have been trained in this area acquire many transferable skills (in particular mathematical modelling of complex problems) which are highly sought after by industry. They also acquire valuable communication skills through writing research papers and presenting their work at seminars and at national and international conferences. The ERs will be given the opportunity to acquire useful academic skills through participation in both undergraduate and graduate teaching, supervision and evaluation of undergraduate research projects, and organising seminars, workshops and conferences.

Being based in universities, both ESRs and ERs will also have ample opportunity to widen their academic horizons and engage with broader aspects of their work and its relation to society. Thus all the desirable complementary skills (management, communication, ethics etc) will be imparted to the recruited researchers in an appropriate manner during the scientific activity they will carry out. They will benefit from the contacts they will make in the course of their training, not only in Europe, but also through attending international schools and conferences in the rest of the world.

2. Management

The Consortium will be administered by a ‘Steering Committee’ consisting of all the Scientists-in-Charge representing the Partners and chaired by the Co-ordinator with the assistance of the ‘Network Administrator’. This committee will be responsible for all strategic decisions concerning general scientific issues, recruitment and training of researchers, dissemination of results and public outreach activities as well as financial matters. For specific tasks such as the organisation of the annual school it will devolve responsibility to a ‘Meetings Committee’ which will be chaired by the Scientist-in-Charge of the Partner who will host the event, as well as others who will be co-opted for the occasion (the Co-ordinator will serve *ex-officio*). In addition it will appoint ‘Science Conveners’ for each of the main research Tasks. It is felt that this “light touch” management is best suited to ensure efficient functioning of the Network, and the key to efficient communication and dissemination of information is to make use of the world-wide-web. The Network’s webpage will provide links to all the Partners (including ‘Extended Teams’), list all the Participants (Staff, post-docs and graduate students), advertise the ESR and ER positions available and provide all publications and annual reports of the Network in electronic form, as well as links to relevant sites such as professional newsgroups, e-archives, journals, conference and job listings. It will have a section with password-restricted access for the Scientists-in-Charge where all confidential documents, in particular correspondence with the Commission, will be made available for download.

The ‘Steering Committee’ will conduct its business through regular email contact and phone or video conferences which will be scheduled by the Chair when appropriate. Each Scientist-in-Charge will be responsible for reporting on the activities of their respective node, specifically on the general progress of any researcher(s) recruited (both training and career development), joint publications with other Participants, secondments and short visits to other Partners, participation in workshops and conferences and any other relevant matters (e.g. visits by distinguished researchers, outreach activities etc). He/she will be responsible for submitting an annual report on behalf of the partner, to be incorporated into the report for the whole Network by the Co-ordinator which will be presented at the annual Network meeting. For Partners who have ‘Extended Teams’, the Scientist-in-Charge will be helped in these tasks by one senior scientist from each of the participating research groups, who may be invited in consultation with the Chair to participate in meetings of the Committee when necessary. Moreover each Scientist-in-Charge must authorise a Deputy at the same institution to act in their absence and appoint a local Administrator who will be responsible for liasing with the Network Administrator.

The ‘Meetings Committee’ will always include at least one ESR and ER who will be invited to contribute suggestions regarding the academic programme and take specific responsibilities for the practical organisation which will provide valuable professional experience as well as enhancing their visibility. Thus the training programme will be able to engage constructively with the perceived needs of the recruited researchers themselves. The annual schools will also provide the opportunity to invite the participation of both senior and young researchers from outside the Network and indeed outside Europe as well, in order to reach out to and engage the wider scientific community. Such links would of course be of great value in broadening the career prospects of the Network’s recruited researchers. They will be given priority in being able to give short presentations on their work during the annual Network meeting which will be interlaced with the school (e.g. pedagogical lectures in the morning and specialist seminars in the afternoon). When appropriate such events will be held in collaboration with a sister network which has overlapping interests, e.g. “Quest for Unification” (MRTN-CT-2004-503369) and “ForcesUniverse” (MRTN-CT-2004-05104).

The selection of the researchers will be left to the individual Partners each of whom have legally well-defined and transparent procedures in place for recruitment with due attention to equal opportunities and gender issues. All advertisements must make it clear that these are Network appointments and governed by a common code of conduct and selection criteria. Each Partner will be required to list (on the restricted access webpage) all applications received for both ESRs and ERs along with their shortlist and final choice. This will enable all the Partners to efficiently monitor the availability of good applicants and facilitate each other in making the best appointments possible. This would be particularly useful for the selection of ESRs since Partners can direct suitably qualified applicants (e.g. from among their own graduating students) to each other, thus both ensuring mobility and helping to establish new collaborative links.

To ensure the welfare of the researchers appointed by the Network, each one of them will have a 'Mentor' assigned to them by the Co-ordinator whose function will be to provide an independent assessment to the Steering Committee of the research and training opportunities made available to them by the host Participant. The researchers will thus have an independent source of help and advice available apart from their local research supervisor and this would be particularly helpful if any problems arise. (Such mentoring has proved very successful in the Oxford Collegiate system.) The recruited researchers will also be encouraged to communicate among themselves through a dedicated forum on the Network webpage in order to share common experiences and pass on helpful tips to each other.

The full Network will meet once a year during the annual training school. At such meetings, the Scientists-in-Charge will report on the work being carried out, specifically the appointment of researchers, specific training activities undertaken such as schools and workshops, and scientific publications. Participation in outreach activities such as Open Days, talks at schools, programmes for continuing education or widening access to universities etc will also be reported.

This will be supplemented by reports from the appointed Science Conveners on the state-of-the-art concerning specific Tasks in order to stimulate discussion and obtain criticism and feedback concerning the Network's activities. This is particularly important in a fast-moving field where research priorities may have to change in response to new experimental or observational findings. (The most crucial such meeting would be during the mid-term review when the external Assessor appointed by the Commission will scrutinise the overall activity of the Network and may suggest possible modifications.) The most important component of the meeting would however be the talks given by recruited researchers on their activities which are expected to trigger the formation of new collaborations and stimulate mobility between the Partners.

With regard to financial aspects of the management, an important issue is how to smooth over the delays often involved in receiving funds from the Commission. Researchers need to be hired on an annual cycle starting in the autumn and the open positions need to be advertised by the beginning of that year. Large institutions usually have sufficient funds to enable the Partners based there to keep to the recruitment plan even when there are delays in obtaining the periodic payments, however Partners at smaller Universities, particularly in Less-Favoured Regions often face severe difficulties under such circumstances. Hence a detailed spending plan will be drawn up and reviewed annually by the Steering Committee to ensure that the contracted training activities proceed on schedule. Similarly with regard to the ToK activities, participation of Network members at conferences, secondments, short visits, schools and workshops etc will be planned out as far as possible in advance in order to anticipate spending patterns. Provision has been made for the employment of a part-time Network Administrator to assist the Co-ordinator, and also for the Partners to engage professionals to obtain audit certificates every two years.

The results of the research carried out will be submitted for publication in international refereed journals and presented at national and international meetings. As mentioned younger members of the Network will be specifically encouraged to present results at Network meetings and the senior participants will also facilitate their participation in external workshops and conferences. Many of the senior Participants are regularly invited to be organisers and rapporteur speakers at international meetings, so the activities of the Network will be widely discussed and influence the direction of research in this field well beyond the Network itself. All publications will be made available through the Network's webpage and downloads provided for talks given by the Participants and other pedagogical material e.g. lecture notes. Finally, given the interest of the general public in the subject, an 'outreach' programme will be developed with the focus on participation by the recruited researchers and the female Participants in an effort to both widen access and provide a broader cultural context for the cutting-edge science that will be done.

In summary, the organisation and management framework is well adapted to the size of the Network which was determined by the need to involve as many of the key researchers in Europe as possible and, in particular, include colleagues based in both Less-Favoured Regions who would benefit especially from such collaboration, as well as major national and international organizations who would provide valuable exposure and enhanced training opportunities to the recruited researchers. The Participant in a third country will bring an international dimension to both the research and training, at zero cost to the Commission.

3. Indicators of Progress and Success

3.1 Quantitative indicators of progress and success to be used to monitor the project

3.1.1 Research Activities

In reporting on progress with the implementation of its research plan the Network will provide information and data on the following:

- organisation of or participation in and presentations to external specialist workshops and conferences (number; dates, places, title of event)
- specialist exchange among Network Partners (number, nature, when, where, who)
- individual and joint publications, directly related to the work undertaken within the contract (number, references)
- development of new scientific collaborations (number, references)
- scientific awards and prizes obtained from the work directly related to the contract (number, details)
- interest expressed in the Networks' dedicated Website (number of hits)
- visits of Senior Researchers from inside and/or outside the Network (number, name, place and time of visit)
- contacts with relevant academic users groups (number, name)

3.1.2 <u>Training / Transfer of Knowledge (ToK) Activities</u>

In reporting on progress with the implementation of its training and ToK Plan the Network will provide information and data on the following:

- the rate of recruitment of ESR and ER for each participant and for the Network as a whole (ratio person-months filled/offered)
- the nature and justification for adjustments, if any, to the original overall number of person-months of ESR and ER as well as to the breakdown of this overall number among the participants (see table contained in Part C)
- the time and duration of each individual appointment.
- the number, names and level of involvement of senior researchers directly associated with the tutoring/supervision of the recruited ESR or ER, at each participant
- the number of ESR that are expected to present their PhD thesis and when
- the number and place of the short visits and secondments undertaken by each individual ESR or ER either within or outside of the Network
- number of visits of the ESR and ER to their home scientific community
- attendance at Network meetings by the ESR and ER (number, names, place, date)
- participation in and presentations to workshops and conferences by ESR and ER (number, names, place, date)
- organisation of training events (e.g. schools, training workshop/seminar, hands-on training session on specialised instrument/techniques) at individual participant sites (number, attendees' names, place, date)
- organisation of Network-wide training events (number, attendees' names, place, date)
- participation in training events organised outside the Network (number, attendees' names, place, date)
- number, place, purpose of any meeting (e.g. workshop) organised by the ESR or ER themselves

3.2 <u>Qualitative indicators of progress and success to be used to monitor the project</u>

3.2.1 <u>Research Activities</u>

In reporting on progress with the implementation of its research plan the Network will provide information and data on the following:

- general progress with research activities programmed at individual, participant team and Network level
- highlights on particularly innovative developments (novel concepts, approaches, methods)
- citation index for individual and joint publications directly related to the work undertaken within the contract
- expected scientific breakthroughs
- overall progress and possible problems encountered with individual work packages and/or Network-wide research activities
- nature and justification for adjustments, if any, to the original research work plan

- progress on cross interaction among disciplines represented within the Network
- access to/use of state-of-the-art infrastructure and facilities
- highlights on wider societal and/or ethical components of the project, such as public outreach activities
- highlights on the scientific community recognition of the Network research contribution (awards, invitation to conferences, …)

3.2.2 **Training/Transfer of Knowledge Activities**

In reporting on progress with the implementation of its training plan and ToK the Network will provide information and data on the following:

- general progress with training and ToK activities programmed at individual, participant team and Network level (type of guidance, supervision, coaching or mentoring in place to support ESR and ER)
- highlights on the development of particularly innovative approaches to training and ToK (e.g. specific training packages of Network-wide relevance)
- highlights on the exploitation of the "complementarities" between Network participants with respect to training and ToK
- nature and justification for adjustments, if any, to the original training/ToK (e.g. opportunities for new collaborations regarding training activities)
- career development plans as elaborated by the ESR and ER involved in the project
- career development opportunities/prospects for ESR and ER involved in the project
- achievements regarding the acquisition of complementary skills such as communication, language skills, computer skills, project management, ethics, team building, etc.
- achievements regarding the training/ToK on specialised instruments/equipment
- level of satisfaction of the trainees (e.g. as expressed in response to questionnaires)

3.2.3 **Management**

In reporting on progress with its management the Network will provide information and data on the following:

- effectiveness of the "internal" communication and decision making between the co-ordinator, team leaders, supervisors, down to the ESR and ER, including feedback processes
- effectiveness of the communication between the Network and the Commission Services (frequency, efficiency, timely feedback), particularly regarding the conformance with contractual provisions and the implementation of contingency plans where needed
- Network self-assessment through benchmarking activities (exchange of best practices among participants and/or development of *ad hoc* performance indicators regarding cost management, staff selection, measurement of research/training/ToK outputs, recruited researchers' involvement, etc.)
- overall quality and efficiency of the "external" communication strategy of the Network (CORDIS; personal, team and Network web sites updates; newsletters; etc.)
- effectiveness of the recruitment strategy of the Network in terms of equal opportunities (including gender balance) and open competition at international level