

Supersymmetry and the Early Universe

Final Report

Network short title: The Early Universe

Contract Number: HPRN-CT-2000-00152

Commencement date of contract: 1 June 2000

Duration of contract (months): 48 + 4
(extension granted until 30 September 2004)

Home page:

<http://www-thphys.physics.ox.ac.uk/users/SubirSarkar/eunet.html>

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PART A - RESEARCH RESULTS

A.1 Scientific Highlights

The collaborative research activities between different network Teams are summarised below under the headings of the main objectives of the network, and all publications are listed (A.2). Additional publications by the **young researchers** supported by the network are also given (A.2.1), as well as joint publications with related EU networks (A.2.2).

(i) Inflation

Nilles and **Peloso** (Bonn) and **Sorbo** (Trieste & Paris) clarified the important question of gravitino production during preheating following the end of inflation, by doing the first explicit nonperturbative calculation in a model with broken supersymmetry [84, 85, 119, 120]. It was found that in models with gravity mediated supersymmetry breaking, the fermionic field which is mostly produced at preheating is the partner of the inflaton field, while the production of gravitinos is well below the bound set by nucleosynthesis arguments.

Jeannerot (Trieste) and Lazarides (Thessaloniki) constructed a supersymmetric hybrid inflation model based on the Pati-Salam gauge group $SU(4)_c \times SU(2)_L \times SU(2)_R$ which successfully avoids the overproduction of monopoles at the end of inflation, as well as achieving a low reheat temperature satisfying the thermal gravitino constraint [60, 61, 62].

Dimopoulos and Lyth (Lancaster) with Lazarides and **de Austri** (Thessaloniki) developed the ‘curvaton’ paradigm according to which the primordial density perturbation originates from the vacuum fluctuation during inflation of a scalar field different from the inflaton; this may allow non-slow-roll ‘thermal’ inflation to originate structure, yield non-gaussianity and also give a correlated baryon or neutrino isocurvature perturbation with predicted magnitude. They studied curvaton evolution before and after inflation, taking into account the supergravity corrections as well as thermal effects on the curvaton potential [26, 27]. **Postma** (Trieste) considered model-independent constraints on the curvaton in supersymmetric theories, finding that non-renormalizable operators, residual isocurvature perturbations, and thermal effects constrain this scenario severely [122] and in addition, the curvaton field may decay prematurely through resonance effects [125]; she also showed that the bound on the inflationary Hubble scale in the curvaton scenario may be evaded if the curvaton mass increases significantly in the post-inflationary epoch [124].

Enqvist and Kasuya (Helsinki), with Mazumdar (Trieste), discussed the fragmentation of the inflaton condensate and argued that it can give rise to quasi-stable solitons and slow reheating [39]. They studied chaotic inflation with a running mass and showed that the Universe could then be reheated slowly via surface evaporation of inflatonic lumps [40]. **Postma** (Trieste) presented a gauge invariant formalism for the evolution of density perturbations in the inhomogeneous reheating scenario [116] and also discussed the phenomenological constraints [123]. Enqvist (Helsinki) with Mazumdar and **Postma** (Trieste) considered the possibility of generating adiabatic density perturbations from spatial fluctuations in the inflaton decay rate, due to quantum fluctuations of light moduli fields coupling to the inflaton [43]. Enqvist (Helsinki) and Mazumdar (Trieste) [42] wrote an invited review on the cosmology of flat directions.

Cline (Geneva) with Crotty and Lesgourgues (Annecy) discussed whether the anomalously small CMB quadrupole moment measured recently by WMAP might suggest new physics [19]. Crotty and Lesgourgues (Annecy) with Garcia-Bellido (Madrid) obtained stringent bounds on the possible isocurvature contributions to the primordial fluctuations using recent cosmic microwave background and large scale structure data [22].

(ii) Dark matter

Sigl and Bertone (Paris) showed with Silk (Oxford) that the accretion of dark matter particles by the massive black hole present at the center of our Galaxy creates a region of very high density where the dark matter annihilation rate is considerably increased, thus facilitating

detection [4, 5, 6]. Bertone and Silk used the sound speed and the density profiles inferred from helioseismic data to constrain the effect of the accretion and annihilation of supersymmetric dark matter particles on the evolution of the Sun [75].

Coriano, Faraggi (Geneva & Oxford) and **Plümacher** (Oxford) discussed possible metastable matter states that arise from Wilson line breaking of GUT symmetries in semi-realistic heterotic string models as candidates for the decaying dark matter particles whose decays may create ultra-high energy cosmic rays [20]. Ferrer (Barcelona) and Evans and Sarkar (Oxford) calculated the expected anisotropy of such cosmic rays for various models of the dark halo and showed that it would be detectable by the forthcoming Pierre Auger Observatory [44].

Roszkowski (Geneva & Lancaster) proposed, with Kim (Lancaster), the possibility that relic axinos constitute the dark matter [21]. They also continued, with Nihei (Lancaster) and **Ruiz de Austri** (Lancaster & Thessaloniki), a programme of accurately calculating the relic density of neutralino dark matter subject to all laboratory bounds [70, 81, 82, 83, 87]. Roszkowski (Lancaster) and **Ruiz De Austri** (Thessaloniki) studied the coannihilation of neutralinos with sleptons for both the MSSM and the CMSSM [83] and explored the implications for the dark matter abundance of imposing $SO(10)$ boundary conditions on softly broken MSSM [25]. Lazarides (Thessaloniki) with **Pallis** (Trieste) found that the CMSSM with $\mu < 0$, supplemented by a Yukawa quasi-unification condition (which allows an acceptable b mass) is not viable, since the cosmological upper bound on the lightest sparticle relic abundance is incompatible with the data on the branching ratio of the decay $b \rightarrow s + \gamma$ [53].

Hansen and Silk (Oxford) and Lesgourgues (Annecy) showed that a sterile keV mass neutrino is an excellent candidate for warm dark matter [58].

(iii) Cosmological phase transitions

Laine (Geneva) and Rummukainen (Helsinki) made a detailed study of non-perturbative aspects of the electroweak phase transition in two-doublet models [72] and calculated the pressure of the plasma above the QCD deconfinement phase transition to order $g^6 \ln(1/g)$ [65].

Tkachev (Geneva) and Garcia-Bellido (Madrid) studied the dynamics of symmetry breaking and tachyonic preheating in inflationary models [49].

Peloso (Bonn) and **Sorbo** (Paris) showed that excessive production of gravitational relics may occur from strings generated at the phase transition which ends hybrid inflation [86]. Jeannerot (Trieste) and Rocher (Paris) found that cosmic string formation is inevitable within supersymmetric grand unified theories, assuming standard hybrid inflation and considering all models that have successful baryogenesis [63].

(iv) Baryogenesis

Enqvist (Helsinki), Mazumdar and Perez-Lorenzana (Trieste) presented a model for Affleck-Dine type baryogenesis in theories with large extra dimensions [1].

Jeannerot (Trieste) and Lazarides (Thessaloniki) showed that in their SUSY GUT inflationary model, adequate baryogenesis via primordial leptogenesis occurs consistently with the Solar and atmospheric neutrino oscillation data [60]. Giudice and collaborators studied thermal effects in leptogenesis [150]. Dent, Lazarides and **Ruiz de Austri** (Thessaloniki) studied a non-thermal leptogenesis scenario in which the inflaton decays directly into light particles [102]. **Rodejohann** (Trieste) analysed the consequences for leptogenesis in see-saw models with hierarchical mass matrices [129] and also considered the contribution of novel diagrams contributing to the decay asymmetry in type II models [130]. Boubekour (Lancaster), Hambye (Oxford) and Senjanović (Trieste) demonstrated the possibility of leptogenesis at low scales using soft supersymmetry breaking terms [10]. Buchmüller, **Di Bari** (Barcelona) and Plümacher (Geneva) obtained an upper bound on the neutrino mass from leptogenesis [14, 15] and presented an analytical description of thermal leptogenesis [16].

(v) **String/M-theory cosmology**

Forste, Lavignac and Nilles (Bonn), and Lalak (Bonn & Warsaw) presented sum rules that have to be fulfilled by the bulk and brane tensions in order to obtain consistent solutions to the cosmological constant problem, and gave a critical evaluation of the mechanism of self-tuning [149]. Lalak, with Falkowski and Pokorski (Warsaw) presented a five dimensional gauged supergravity which admits the Randall-Sundrum solution as a BPS vacuum with vanishing energy [45], and discussed how to obtain four-dimensional supergravities from five-dimensional brane worlds [46]. Groot Nibbelink, Nilles and Meissner (Bonn), and Olechowski (Warsaw) discussed the localization of bulk fields in theories with extra dimensions, an observation particularly important for a realization of the cosmological aspects of the brane world scenario [55, 80]. Meissner and Nilles (Bonn), with Olechowski (Warsaw) studied the details of supersymmetry breakdown in theories with extra dimensions [79]. Instabilities of bulk fields in higher dimensional cosmology were identified and studied by Groot Nibbelink (Bonn) and Nilles (Bonn) with Olechowski (Warsaw) [56]. Nilles, Papazoglou and **Tasinato** (Bonn) studied brane-world models which try to realise the self-tuning mechanism of the cosmological constant [121]. **Tasinato** (Bonn) and collaborators studied the properties of new examples of codimension-2 brane world models [88, 110] and constructed models that smoothly connect from a contracting to an expanding universe [98]; they also presented new time dependent solutions for low energy string systems that are free of cosmological singularities [132]. **Bucci** (Warsaw) and collaborators demonstrated the possibility of stabilization of the scalar sector, including the radion, in the gauge model with one universal extra dimension [92].

Ellis (Geneva) and Mavromatos (London) studied the effects of quantum gravity induced space-time foam on particle interactions and the consequences for ultra-high energy cosmic ray propagation [30, 31]. They proposed supersymmetric models of space-time foam which can account for the observed dark energy [38]. These models can violate the equivalence principle [37] and evade the constraints imposed by observations of high energy synchrotron radiation from the Crab Nebula [36, 35].

Leontaris (Ioannina) and Mavromatos (London) constructed a metric that describes the distortion of space-time surrounding a D(irichlet)-brane (solitonic) defect after being struck by another D-brane [73]. By viewing our four-dimensional universe as such a struck brane, the appearance of a band of massive Kaluza-Klein excitations for the bulk graviton was noted. Mavromatos (London) and Rizos (Ioannina) considered the $\mathcal{O}(\alpha')$ string effective action, with Gauss-Bonnet curvature-squared and fourth-order dilaton-derivative terms [77, 78]. They showed that a non-factorizable metric of the Randall-Sundrum type, with four-dimensional conformal factor $e^{-2k|z|}$, can be a solution of the pertinent equations of motion. Rizos (Ioannina), with Faraggi and Nooij (Oxford) classified the $\mathcal{Z}_2 \times \mathcal{Z}_2$ orbifold with symmetric shifts on six dimensional compactified internal manifolds and presented a class of three generation $SO(10)$ models [153]. Kanti (Geneva), with Tamvakis and **Olasagasti** (Ioannina) studied further the possibility of obtaining localized black hole solutions in Randall-Sundrum brane world models [67].

Kortals-Altes (Marseille) and Laine (Geneva) studied the fate of discrete symmetries when gauge degrees of freedom are located on a topological defects (as in the case of branes) [71].

Kachelreiss (Geneva) and **Plümacher** (Oxford) found that the enhancement of the neutrino scattering cross-section (through exchange of Kaluza-Klein gravitons) in TeV-scale quantum gravity models is inadequate to enable cosmic neutrinos to be the primaries for ultra-high energy cosmic rays [64].

Binetruy (Orsay) and Silk (Oxford) studied the constraints imposed by the CMB and gravitational lensing on brane models where gravity at very large distances is five-dimensional [7].

Abel (Orsay) and Kogan (Oxford) examined the cosmological effects of the Hagedorn phase in brane-world models and found that even in the absence of a cosmological constant, winding modes cause a negative 'pressure' that can drive brane inflation [133].

Pokorski (Warsaw) and Quiros (Madrid) collaborated on studying brane effects on extra

dimensional scenarios [17].

Nicolis and Rattazzi [118] proved the stability of the Dvali-Gabadadze-Porrati model by the method of the boundary effective action. Quirós (Madrid) and collaborators studied the issue of radion stabilization within five-dimensional supersymmetric theories compactified on the orbifold S^1/Z_2 [156] and the propagation of fermions in the bulk [157].

(vi) **Cosmological constraints**

Enqvist (Helsinki) and Mazumdar (Trieste) studied in detail the astrophysical constraints on heavy stable relic particles which arise in supergravity models [2].

Brax (Geneva) and Martin and Riazuelo (Paris) collaborated on the constraints on quintessence models from the CMB [12, 13].

Mavromatos (London) and Ellis (Geneva) continued their study of phenomenological constraints on models of non-critical string induced space-time foam in quantum gravity, the most interesting of which arise due to possible non-trivial optical properties of matter propagating in such backgrounds [32, 34].

Hansen (Oxford), Petcov (Trieste) and collaborators [28] showed that the experimentally observed large neutrino mixing ensures that effective flavor equilibrium is established between all active neutrino species well before the big-bang nucleosynthesis, so that a large neutrino chemical potential is no longer allowed.

A.2 Joint Publications and Patents

These are in *alphabetical* order rather than in “order of importance” as specified in the guidelines since one cannot judge so soon the relative importance of publications in a frontier research area. The number of citations on the SPIRES database (<http://www.slac.stanford.edu/spires/>) has been given as some measure of their impact on the academic community. Enclosed are copies of 5 representative papers ([15, 65, 70, 77, 84]) which reflect the range of our activities

- [1] R. Allahverdi, K. Enqvist (Helsinki), A. Mazumdar (Trieste) and A. Perez-Lorenzana (Trieste), “Baryogenesis in theories with large extra spatial dimensions,” Nucl. Phys. B **618** (2001) 277 [arXiv:hep-ph/0108225].* (29 citations)
- [2] R. Allahverdi, K. Enqvist (Helsinki) and A. Mazumdar (Trieste), “Possible astrophysical signatures of heavy stable neutral relics in supergravity models,” Phys. Rev. D **65** (2002) 103519 [arXiv:hep-ph/0111299].* (14 citations)
- [3] B. A. Bassett, **M. Peloso** (Bonn), L. Sorbo (Trieste) and S. Tsujikawa, “Fermion production from preheating-amplified metric perturbations,” Nucl. Phys. **B622** (2002) 393 [arXiv:hep-ph/0109176].* (7 citations)
- [4] G. Bertone (Paris), G. Sigl (Paris) and J. Silk (Oxford), “Annihilations from the galactic centre,” Proc. 3rd International Workshop On The Identification Of Dark Matter (2000) p.311 [arXiv:astro-ph/0011553]. (3 citations)
- [5] G. Bertone (Paris), G. Sigl (Paris) and J. Silk (Oxford), “Astrophysical limits on massive dark matter,” Mon. Not. Roy. Astron. Soc. **326** (2001) 799 [arXiv:astro-ph/0101134]. (19 citations)
- [6] G. Bertone (Paris), G. Sigl (Paris) and J. Silk (Oxford), “Annihilation Radiation from a Dark Matter Spike at the Galactic Centre,” Mon. Not. Roy. Astron. Soc. **337** (2002) 98 [arXiv:astro-ph/0203488]. (22 citations)
- [7] P. Binetruy (Orsay) and J. Silk (Oxford), “Probing large-distance higher-dimensional gravity with cosmic microwave background measurements,” Phys. Rev. Lett. **87** (2001) 031102 [arXiv:astro-ph/0007452]. (21 citations)

- [8] P. Binetruy (Orsay), R. Schaeffer, J. Silk (Oxford) and F. David, “The Primordial Universe: Proc. 71st Les Houches Summer School On Physics” (Springer-Verlag, 2000).
- [9] L. Boubekour (Trieste), S. Davidson, **M. Peloso** (Bonn) and **L. Sorbo** (Paris), “Leptogenesis and rescattering in supersymmetric models,” *Phys. Rev. D* **67** (2003) 043515 [arXiv:hep-ph/0209256].* (9 citations)
- [10] L. Boubekour (Lancaster), T. Hambye (Oxford) and G. Senjanovic (Trieste), “Low-scale leptogenesis and soft supersymmetry breaking,” *Phys. Rev. Lett.* **93**, 111601 (2004) [arXiv:hep-ph/0404038].* (8 citations)
- [11] P. Brax (Geneva) and J. Martin (Paris), “High energy physics and quintessence”, Proc. 35th Recontres de Moriond (2000) [arXiv:astro-ph/0005449]. (1 citation)
- [12] P. Brax (Geneva), J. Martin (Paris) and A. Riazuelo, “Exhaustive study of cosmic microwave background anisotropies in quintessential scenarios,” *Phys. Rev. D* **62** (2000) 103505 [arXiv:astro-ph/0005428]. (70 citations)
- [13] P. Brax (Geneva), J. Martin (Paris) and A. Riazuelo, “Quintessence model building,” Proc. 6th Workshop on Nonperturbative Quantum Chromodynamics, Paris (2002) [arXiv:hep-th/0109207]. (2 citations)
- [14] W. Buchmuller, **P. Di Bari** (Barcelona) and M. Plumacher (Geneva), “A bound on neutrino masses from baryogenesis,” *Phys. Lett. B* **547** (2002) 128 [arXiv:hep-ph/0209301].* (44 citations)
- [15] W. Buchmuller, **P. Di Bari** (Barcelona) and M. Plumacher (Geneva), “The neutrino mass window for baryogenesis,” *Nucl. Phys. B* **665** (2003) 445 [arXiv:hep-ph/0302092].* (75 citations)
- [16] W. Buchmüller, **P. Di Bari** (Barcelona) and M. Plümacher (Geneva), “Leptogenesis for pedestrians,” [arXiv:hep-ph/0401240].* (37 citations)
- [17] M. Carena, A. Delgado, J. Lykken, S. Pokorski (Warsaw), M. Quiros (Madrid) and C. E. Wagner, “Brane effects on extra dimensional scenarios: A tale of two gravitons,” *Nucl. Phys. B* **609** (2001) 499 [arXiv:hep-ph/0102172].* (28 citations)
- [18] J. A. Casas (Madrid) and A. Ibarra (Oxford), “Massive neutrinos and lepton-flavour violating processes,” arXiv:hep-ph/0109161. (4 citations)
- [19] J. M. Cline (Geneva), P. Crotty (Annecy) and J. Lesgourgues (Annecy), “Does the small CMB quadrupole moment suggest new physics?,” *JCAP* **0309**, 010 (2003) [arXiv:astro-ph/0304558]. (40 citations)
- [20] C. Coriano, A. E. Faraggi (Oxford & Geneva) and **M. Plümacher** (Oxford) “Stable superstring relics and ultrahigh energy cosmic rays,” *Nucl. Phys. B* **614** (2001) 233 [arXiv:hep-ph/0107053].* (34 citations)
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- [24] T. Damour, I. I. Kogan (Oxford) and **A. Papazoglou** (Bonn), “Spherically symmetric spacetimes in massive gravity,” *Phys. Rev. D* **67** (2003) 064009 [arXiv:hep-th/0212155].* (16 citations)
- [25] R. Dermisek, S. Raby, L. Roszkowski (Lancaster) and **Roberto Ruiz De Austri** (Thessaloniki), “Dark matter and $b(s) \rightarrow \mu^+ + \mu^-$ with minimal $SO(10)$ soft susy breaking,” *JHEP* **0304** (2003) 037. [arXiv:hep-ph/0304101].* (26 citations)
- [26] **K. Dimopoulos** (Lancaster), G. Lazarides (Thessaloniki), D. Lyth (Lancaster) and **R. Ruiz de Austri** (Thessaloniki), “The Peccei-Quinn field as curvaton,” *JHEP* **0305** (2003) 057 [arXiv:hep-ph/0303154].* (31 citations)
- [27] **K. Dimopoulos** (Lancaster), G. Lazarides (Thessaloniki), D. Lyth (Lancaster) and **R. Ruiz de Austri** (Thessaloniki), “Curvaton Dynamics,” *Phys. Rev. D* **68** (2003) 123515 [arXiv:hep-ph/0308015].* (29 citations)
- [28] A. D. Dolgov, S. H. Hansen (Oxford), S. Pastor, S. T. Petcov (Trieste), G. G. Raffelt and D. V. Semikoz, “Cosmological bounds on neutrino degeneracy improved by flavor oscillations,” *Nucl. Phys. B* **632** (2002) 363 [arXiv:hep-ph/0201287]. (103 citations)
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- [30] J. R. Ellis (Geneva), N. E. Mavromatos (London) and D. V. Nanopoulos, “How large are dissipative effects in noncritical Liouville string theory?,” *Phys. Rev. D* **63** (2001) 024024 [arXiv:gr-qc/0007044]. (16 citations)
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A.2.2 Joint Publications with other RTN Networks

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PART B - COMPARISON WITH THE PROJECT PROGRAMME

B.1 Research achievements

Research Objectives:

There has been intense activity in recent years seeking to extend the Standard Model of particle physics with the hope of obtaining an unified framework for all the fundamental forces including gravity. The most ambitious such scheme starts with the superstring/M-theory relevant at the Planck scale. Between this and the energy scales accessible in the laboratory lie several stages of spontaneous symmetry breaking including a compactification of space-time dimensions. Cosmological considerations have proved crucial in testing these ideas, for the early universe is the ultimate ‘laboratory’ sensitive to such phenomena. Moreover, the fundamental questions in cosmology relating to the observed homogeneity and isotropy of the universe and its matter content (both baryonic and dark), as well as the origin of the density perturbations which grew into the observed large-scale structure of galaxies, can only be addressed by such extensions of the Standard Model. These new physical ideas almost invariably invoke a new symmetry in Nature — supersymmetry — the search for which is a major goal for particle physics and cosmology.

The objective of this Network was to conduct a coordinated programme of research and training on six key topics at the particle physics/cosmology interface: **Inflation, Particle dark matter, Cosmological Phase Transitions, Baryogenesis, String/M-theory Cosmology, Cosmological Constraints.**

Research Method:

The activities of this Network had a common focus, namely the birth and early evolution of our universe as indicated by supersymmetric 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, general relativistic perturbation theory, etc. Our methodological approach towards research was problem-led insofar as the essential technical tools were acquired and used as and when required. With reference to specific techniques for the solution of problems, state-of-the-art methods were developed as necessary, for example non-perturbative methods in field theories at high temperatures [16, 150], large-scale computer simulations on the lattice [65], new mathematical techniques in string theory [46, 55], et cetera.

Breakdown of Tasks:

Schedule and Milestones:

The proposed schedule and the actual realization is given below:

1. **Meeting Of Team Leaders** to fix research tasks, collaborations, appointment of young researchers, education and outreach activities (*within 1 month of Start Date*) — this was held at CERN, Geneva, 28 Jun 2001, with the participation of 30 network members.
2. **First Network School + Full Network Meeting**, with lectures by both Network Scientists and invited outside experts, as well as seminars by young researchers and reports from the Team Leaders (*foreseen within 1 year of Start Date*) — this was also held at CERN, Geneva, 18-22 Apr 2001 and had about 70 participants.
3. **Second Network School + Full Network Meeting + Mid-Term Review**, as above, along with the participation of Commission Referees (*foreseen within 2 years of Start Date*) — this was held at Oxford, 26-29 Sep 2002 and attended by about 60 people.

4. **Third Network School + Full Network Meeting**, as above (*foreseen within 3 years of Start Date*) — this was held during Planck'03 at Madrid, 26-31 May with nearly 80 participants.
5. **Fourth Network School + Full Network Meeting**, as above. At this final meeting the achievements of the Network will be reviewed and discussed, with the focus on future implications, both for the research area and for continuing collaborative activities of Network Participants (*foreseen within 4 years of Start Date*) — this was held during Planck'04 at Bad Honnef near Bonn, 24-28 May with nearly 100 participants.

The expected milestones and the actual achievements are given below:

- (i) **Inflation:** Determine which class of supersymmetric inflationary models is consistent with LSS/CMB data and gravitino production (by Mid-term Review); Establish definitive tests for such models by PLANCK (by Project End) — Significant progress was made on the first goal, but the second proved more elusive. The 'curvaton' paradigm for generation of the primordial density perturbation was developed by network members.
- (ii) **Particle dark matter:** Calculate precise signatures of cosmic rays from unstable relic particles (by Mid-term Review); Establish definitive LHC signatures of neutralino dark matter (by Project End). — this was fully achieved and detailed predictions have been made taking into account the latest constraints on the dark matter abundance from WMAP.
- (iii) **Cosmological phase transitions:** Determine whether symmetry non-restoration is phenomenologically possible (by Mid-term Review); Establish whether the domain wall problem can be evaded in supersymmetric models (by Project End) — this was partly achieved . . . the conditions for the domain wall network to decay away due to 'bias' were given.
- (iv) **Baryogenesis:** Determine the viability (post LEP 2) of baryogenesis at the supersymmetric electroweak phase transition (by Mid-term Review); Delineate the link between neutrino masses and baryo/leptogenesis (by Project End) — this was fully achieved and indeed the work done by network members has contributed in a major way to establishing the viability of leptogenesis.
- (v) **String/M-theory cosmology:** Calculate precise signatures of pre-Big Bang cosmology (by Mid-term Review); Determine new mechanisms for solving the cosmological initial condition problems (by Project End) — here the primary goal changed dramatically with the emergence of the brane-world paradigm, however significant progress was made on several new fronts and strong links were established with sister networks such as "Superstring Theory" and "Quantum space-time".
- (vi) **Cosmological constraints:** Establish the cosmological viability of R-parity violation which can be experimentally probed (by Mid-term Review); Obtain firm bounds on new light particles from primordial nucleosynthesis (by Project End) — this was fully achieved and results by the network members are quoted in the standard 'Review of Particle Properties'.

Research Effort of the Participants:

Given below in tabular form is the number of person-months spent on network-related activities by both the young researchers supported by the network, and those supported from other sources. The latter numbers are necessarily approximate but give some indication of the concerted effort that was devoted to making the network activity a success.

Professional research effort on the Network project			
Participant	Young researchers financed by the contract (person – months) (a)	Researchers financed from other sources (person – months) (b)	Researchers who contributed to the project (number of individuals) (c)
1. UOXF.DR	48	156	9
2. DPUB	38	104	6
3. CERN	0	116	7
4. UHEL	24	120	6
5. U.IOANNINA	48	96	9
6. CSIC	47	200	8
7. LPT	48	168	9
8. SISSA	72	48	7
9. UW	24	88	9
Totals	336	1096	70

B.2 Overall organisation and management

Organisation, co-ordination and management of the network:

The Network consisted of teams based at 9 institutions in as many countries. Five of these were Extended Nodes i.e. they had associated Sub-Nodes at other institutions in their respective countries. These were: Team 1 (University of Oxford + University of Lancaster), Team 5 (University of Ioannina + University of Thessaloniki), Team 6 (CSIC Madrid + Universidad Autónoma de Madrid + Universidad Autónoma de Barcelona + Universidad de Granada), Team 7 (Université Paris Sud + Observatoire de Paris + ENSLAPP Annecy + Centre de Physique Theorique Marseilles) and Team 8 (SISSA Trieste + ICTP Trieste). Further the Oxford Team made King’s College, London a sub-contractor following the move there of a key member to take up a new position. A Network Steering Committee was set up consisting of the nine Team Leaders, chaired by the Coordinating Scientist. The Team Leaders of the Extended Nodes were individually responsible for their respective Sub-Nodes. Each Team Leader appointed a backup who was be responsible for Network related matters in their absence. Administrative decisions were taken by the Coordinating Scientist, in consultation with the other Team Leaders with whom he was in regular email and telephone contact.

Many members of the network had already been involved in EU networks and many more had collaborated on related activities in the past. For example, the Geneva, Madrid, Oxford, Paris, Thessaloniki and Trieste nodes were part of the ongoing TMR network ‘Beyond the Standard Model’ (ERBFMRX-CT96-0090). Researchers from many of the nodes were also part of the HCM ‘Theoretical Astroparticle’ (CHRX-CT93-0120, DG12 COMA) and ‘Flavour Dynamics’ (CHRX-CT93-0132) networks, while researchers from Lancaster and Thessaloniki were involved in the ‘Phase Transitions in the Early Universe’ network (ERB-CHRX-CT94-0423). Thus the institutions participating in the network already had a history of exchanges of students and post-doctoral researchers. Several of our senior members had also spent extended periods in the past at other institutes in the network, and in particular, many of us had met and collaborated at CERN. Thus the coordination of the network was quite straightforward.

One of our teams was based in Greece (Ioannina and Thessaloniki) and another in Poland (Warsaw). Our colleagues at these institutions are internationally recognised as the leading researchers in their respective geographical regions and moreover they had closely collaborated with other network members in the past (e.g. in the TMR network ‘*Beyond the Standard Model*’, ERBFMRX-CT96-0090 and the HCM network ‘*Flavour Dynamics*’, CHRX-CT93-0132). Thus no special provision was felt to be necessary for their special provision into the network. However

the need to promote their existing strengths further in view of their relative isolation was acknowledged inasmuch as the Warsaw team was invited to organise the PLANCK-02 conference (“Supersymmetry & Brane Worlds”, Kazimierz, 25-29 May 2002) which was sponsored jointly by this network and our sister network ‘*Physics Beyond the Present Energy Frontier*’ (HPRN-CT-2000-00148). This was an extremely well organised and highly successful meeting attended by nearly 100 participants, including many leading researchers from the USA, and boosted the already impressive reputation of the Warsaw group even further. Similarly the Greek team hosted the “Second Aegean Summer School of the Early Universe”, Syros, 22-30 Sep 2004 as part of the activities of the network. This too was very well organised and well attended and had several lecturers and many participants from the network teams.

Communication Strategy:

The results of the research carried out were published in international refereed journals and presented at national and international conferences. An outreach programme was also developed.

The central source for all information concerning the network was the WWW homepage (<http://www-thphys.physics.ox.ac.uk/users/SubirSarkar/eunet.html>) which listed all network members (with hyperlinks to their individual homepages where available, email addresses and individual publications on electronic databases), network meetings (with appropriate hyperlinks), the network’s annual reports et cetera. Links were also provided to related networks in the HCM programme. Most importantly, all network publications were made available electronically. A newsgroup-style ‘Discussion Forum’ was set up to enable all Network Participants, in particular their young members, to follow and contribute to ongoing debates in an open manner — however this did not prove successful! Nevertheless the webpage has received nearly 8000 ‘hits’ to date, testifying to its popularity.

Dissemination of the Network’s achievements:

Members of the network helped to organise and/or participated in many important international conferences (partial list for lack of space!):

- International Workshop on Strong and Electroweak Matter, Marseilles, 14-17 Jun 2000
- C. Korthals-Altes, Marseille (Chair)
- SUSY 2K, Geneva, 26 Jun-1 Jul 2000 (<http://wwwth.cern.ch/susy2k/susy2k.html>)
- P. Binetruy, Orsay (plenary speaker), P. Brax, CERN, S. Davidson, Oxford (speaker), J. Ellis, CERN (LOC), G. Giudice, CERN (LOC), R. Jeannerot, ICTP, M. Kachelriess, CERN (speaker), H.B. Kim, Lancaster (speaker), M. Laine, CERN (speaker), Z. Lalak, Warsaw (speaker), G. Leontaris, Ioannina, D. Lyth, Lancaster (speaker), J. March-Russell, CERN (LOC), A. Masiero, SISSA (plenary speaker), H-P. Nilles, Bonn (speaker), **M. Plümacher**, Oxford (speaker), S. Pokorski, Warsaw (speaker), M. Quirós, Madrid (plenary speaker), J. Rizo, Ioannina, L. Roszkowski, Lancaster (speaker), S. Sarkar, Oxford (speaker), G. Veneziano, CERN (organiser),
- Conference on Cosmology and Particle Physics, Verbier, 17-28 Jul 2000 (<http://mpej.unige.ch/kunze/capp2000/final/capp2000.html>)
- Invited speakers: J. Garcia-Bellido, Madrid, M. Kachelriess, CERN, M. Laine, CERN, J. March-Russell, CERN
- Thirty Years of SUSY, Minneapolis, 13-15 Oct 2000 (<http://www.tpi.umn.edu/susy30.html>)
- Invited Speakers: J. Ellis, CERN, A. Masiero, SISSA, H-P. Nilles, Bonn
- 36th Rencontres de Moriond on Electronic Correlations: From Meso-Physics to Nano-Physics, Les Arcs, 20-27 Jan 2001 (<http://www.lps.u-psud.fr/moriond01/>)
- J. Garcia-Bellido, Madrid (speaker)

- 37th Karpacz Winter School, 6-15 Feb 2001 (<http://www.ift.uni.wroc.pl/karp37/>)
- Z. Lalak, Warsaw (lecturer)
- Workshop: Supersymmetric Models & String Theory in Cosmology, Heidelberg, 4-7 Apr 2001 (http://www.thphys.uni-heidelberg.de/~weinstoc/ws_ssc.html)
- Speakers: S. Groot-Nibbelink, Bonn, R. Jeannerot, Trieste, A. Masiero, Trieste, H.P. Nilles, Bonn (co-organiser), M. Olechowski, Warsaw, **M. Peloso**, Bonn, **M. Plümacher**, Oxford, M. Quiros, Madrid, S. Sarkar, Oxford,
- Planck'01, La Londe les Maures, 1-16 May 2001 (<http://www.esf.org/>)
- R. Jeannerot, SISSA (speaker), D. Lyth, Lancaster (plenary speaker), Z. Lalak, Warsaw (plenary speaker), J. March-Russell, CERN (plenary speaker), A. Masiero, SISSA (plenary speaker), H-P. Nilles, Bonn (plenary speaker), S. Pokorski, Warsaw (plenary speaker), M. Quiros, Madrid (Vice-Chair & plenary speaker), G. Ross, Oxford (plenary speaker), G. Senjanovic, ICTP (plenary speaker), L. Sorbo, SISSA (speaker), K. Tamvakis, Ioannina (plenary speaker) G. Tasinato, SISSA (speaker),
- IPPP Workshop on Phenomenology of Beyond the Standard Model, Durham, 6-11 May 2001 (<http://www.ipp.dur.ac.uk/BSM/bsmindex.html>)
- Lecturers: P. Binetruy, Orsay, A. Masiero, SISSA, H-P. Nilles, Bonn, S. Pokorski, Warsaw, M. Quiros, Madrid, L. Roszkowski, Lancaster
- SUSY01: The 9th International Conference on Supersymmetry and Unification of Fundamental Interactions, Dubna, 11-17 Jun 2001 (<http://susy.dubna.ru/>)
- P. Binetruy, Orsay (IPC), J. Ellis (IAC), A. Falkowski, Warsaw (speaker), G. Giudice (IAC), Z. Lalak, Warsaw (plenary speaker), H-P. Nilles, Bonn (IPC & plenary speaker), M. Quiros, Madrid (plenary speaker), G. Ross, Oxford (IAC), G. Senjanovic, ICTP (plenary speaker),
- 13th Rencontres de Blois: Frontiers of the Universe, Chateau de Blois, 17-23 Jun 2001 (<http://wwwusr.obspm.fr/conf/blois2001.html>)
- Invited speakers: S. Sarkar, Oxford J. Silk, Oxford
- String Phenomenology and Searches Beyond the Standard Model, Brighton, 4-5 Jul 2001 (<http://www.pact.cpes.sussex.ac.uk/SummerFest/>)
- R. Toldrà, Oxford (speaker)
- International Europhysics Conference on High Energy Physics, Budapest, 12-18 Jul 2001 (<http://www.hep2001.elte.hu/>)
- Plenary speakers: P. Binetruy, Orsay, A. Hebecker, CERN, S. Sarkar, Oxford
- International Workshop on Neutrino Oscillations, Venice, 24-26 Jul 2001 (<http://axpd24.pd.infn.it/NO-VE/NO-VE.html>)
- Invited speakers: M. Fabbrichesi, SISSA, S. Petcov, SISSA
- M Theory Cosmology, Cambridge, 21-25 Aug 2001 (<http://www.damtp.cam.ac.uk/user/mt-cosmo/>)
- Invited speakers: P. Binetruy, Orsay, J. Garriga, Barcelona
- COSMO-01: International Workshop on Particle Physics and the Early Universe, Rovaniemi, 30 Aug-4 Sep 2001 (<http://www.physics.helsinki.fi/cosmo01/index.html>)
- S. Groot Nibbelink, Bonn (speaker) H-P. Nilles, Bonn (IAC & plenary speaker [120]), **M. Peloso**, Bonn (speaker [120]), S. Sarkar, Oxford (IAC & plenary speaker) L. Roszkowski, Lancaster (IAC & plenary speaker), R. Toldrà, Oxford (speaker)
- Summer Insitute on Elementary Particle Physics, Corfu, 30 Aug-20 Sep 2001 (<http://theory.physics.uoi.gr/corfu2001/>)
- Lecturers: N. Mavromatos, London, G. Ross, Oxford
- 4th meeting of the RTN network “Across the Present Energy Frontier: Probing the Origin of mass”, Corfu, 10-13 Sep 2001 (<http://theory.physics.uoi.gr/corfu2001/>)

- Speakers: L. Boubekur, SISSA, A. Faraggi, Oxford, D. Ghilencea, Bonn, S. Pascoli, SISSA, M. Piai, SISSA, G. Tasinato, SISSA.
- First Aegean School on Cosmology, Samos, 21-29 Sep 2001
 - N. Mavromatos, London (lecturer)
- DESY Theory Workshop on “Gravity and Particle Physics”, Hamburg, 9-12 Oct 2001 (<http://www.desy.de/desy-th/workshop.01/index.html>)
 - P. Binetruy, Orsay (lecturer) J. March-Russell, CERN (plenary speaker) H-P. Nilles, Bonn (plenary speaker) M. Piai, SISSA (speaker), J. Silk, Oxford (plenary speaker) G. Tasinato, SISSA (speaker).
- Workshop on Ultra High Energy Cosmic Rays, 3-7 Dec 2001 (<http://www.lapp.in2p3.fr/UHECR2001/>)
 - Speakers: F. Ferrer, Oxford, R. Jeannerot, SISSA, R. Toldrà, Oxford
- International Workshop on Neutrino Oscillations and their Origin, Tokyo, 5-8 Dec 2001
 - S. Petcov, SISSA (invited speaker).
- 30th Conference on High Energy Physics and Cosmology, Coral Gables, 12-16 Dec 2001 (<http://www.globalfoundationinc.org/>)
 - J. Vergados, Ioannina (speaker)
- IUCAA Meeting on the Interface of Gravitational and Quantum Realms, Pune, 17-21 Dec 2001
 - S. Sarkar, Oxford (plenary speaker)
- Cairo International Conference on High-Energy Physics, Cairo, 9-14 Jan 2002
 - J. Casas, Madrid (invited speaker [18]), R. Jeannerot, SISSA (invited speaker [61])
- 30th International Meeting on Fundamental Physics, Jaca (Spain), 28 Jan-1 Feb 2002 (<http://www.unizar.es/imfp2002/>)
 - Speakers: J. Garcia-Bellido, Madrid, E. Massó, Barcelona
- Dark 2002: 4th International Conference on Dark Matter in Astro and Particle Physics, Cape Town, 4-9 Feb 2002 (<http://dark2002.phy.uct.ac.za/>)
 - C. Boehm, Oxford (speaker), J. Ellis, CERN (plenary speaker) H-P. Nilles, Bonn (plenary speaker), L. Roszkowski, Lancaster (plenary speaker), J. Vergados, Ioannina (speaker)
- DM2002: 5th International Symposium on Sources and Detection of Dark Matter and Dark Energy in the Universe, Marina del Rey, 20-22 Feb 2002 (<http://www.physics.ucla.edu/hep/DarkMatter/dm2002.html>)
 - L. Roszkowski, Lancaster (invited speaker).
- Nordic Workshop on Astroparticle Physics and Cosmology, Copenhagen, 1-2 Mar 2002 (<http://www.nordita.dk/steen/nordic/nordic.html>)
 - S. Sarkar, Oxford (invited speaker)
- ESO-CERN-ESA Symp. on Astronomy, Cosmology and Fundamental Physics, 4-7 Mar 2002 (<http://www.eso.org/gen-fac/meetings/symp2002/>)
 - P. Binetruy, J. Ellis (plenary speaker)
- 37th Rencontres de Moriond: Electroweak Interactions and Unified theories, 9-16 Mar 2002 (<http://moriond.in2p3.fr/EW/2002/>)
 - Invited speakers: C. Boehm, Oxford, M. Quiros, Madrid, L. Roszkowski, Lancaster
- XIV Workshop on Beyond the Standard Model, Bad Honnef, 11-14 Mar 2002 (<http://www.physik.uni-halle.de/Fachgruppen/Theorie/qft/BadHonnef/BH02/>)
 - Speakers: H-P. Nilles, Bonn, S. Forste, Bonn, A. Hebecker, CERN, M. Olechowski, Bonn
- The Cosmological Model, Les Arcs, 16-23 Mar 2002 (<http://moriond.in2p3.fr/J02/>)
 - D. Langlois, Paris (IPC & plenary speaker), D. Lyth, Lancaster (plenary speaker) J. Silk, Oxford (plenary speaker)

- (Alternative) Dark Matter, Cosmic Structure and the Early Universe, Ringberg Castle, 8-12 Apr 2002 (<http://www.mpa-garching.mpg.de/banerjee/workshop/>)
- Invited speakers: C. Boehm, Oxford, **M. Plümacher**, Oxford, P. Ullio, SISSA
- Annual Meeting of the Hellenic Society for the Study of High Energy Physics, Patras, 25-27 Apr 2002 (<http://leandros.physics.upatras.gr/hep2002/>)
- Speakers: N. Mavromatos, London, J. Rizos, Ioannina, K. Tamvakis, Ioannina
- QCD and gauge theory dynamics in the RHIC era, Santa Barbara, 27 Apr-23 May 2002 (<http://www.kitp.ucsb.edu/activities/qcd02/?id=8>)
- C P Korthals Altes, Marseille (invited speaker)
- COSMO-02: International Workshop on Particle Physics and the Early Universe, Chicago, 18-21 Sep 2002 (<http://pancake.uchicago.edu/cosmo02>)
- IAC: D. Lyth & L. Roszkowski (Lancaster)
- Plenary Speakers: D. Lyth (Lancaster), M. Quiros (Madrid), L. Roszkowski (Lancaster), G. Sigl (Paris)
- Speakers: P. Crotty (Annecy), **P. Di Bari** (Barcelona), **K. Dimopoulos** (Lancaster), F. Ferrer (Oxford), S. Groot-Nibbelink (Bonn)
- International School on CP Violation, Baryogenesis and Neutrinos, Prerow, 15-21 Sep 2002 (<http://topas.physik2.uni-rostock.de/prerow2002/>)
- **M. Plümacher**, Oxford (Lecturer)
- International Workshop on Identification of Dark Matter, York, Sep 2002
- Plenary Speaker: P. Ullio (SISSA)
- “First International Workshop on Frontier Science,” 6–11 Oct 2002, Frascati
- Plenary speaker: J. García-Bellido (Madrid)
- “International Conference on Neutrinos and Implications for Physics Beyond the Standard Theory,” 11–13 Oct 2002, New York
- Invited speaker: S.T. Petcov (SISSA)
- International Workshop on Neutrinoless Double Beta Decay, Gran Sasso, 9–11 Nov 2002
- Speaker: S.T. Petcov (SISSA), **W. Rodejohann** (SISSA)
- International Workshop “The New Cosmology Confronts Observation,” Santa Barbara, Nov–Dec 2002
- Speaker: P. Ullio (SISSA)
- VIII Christmas Workshop on Particle Physics, Madrid, Dec 2002
- Organizing Committee (Madrid): A. Casas, J.R. Espinosa, J. García Bellido, J.M. Moreno and M. Quirós.
- Meeting on Astroparticle Physics with Gamma-Ray Telescopes, Padova, Jan 2003
- Invited Speaker: P. Ullio (SISSA)
- International Workshop on Neutrino Oscillations and their Origin, 9–16 Feb 2003, Kanazawa
- Invited Speaker: S.T. Petcov (SISSA)
- International Conference on Neutrinos: Data, Cosmology and the Planck Scale, 3–7 Mar 2003, Santa Barbara
- Invited Speaker: S.T. Petcov (SISSA)
- 10th International Workshop on Neutrino Telescopes, 11–14 Mar 2003, Venice
- Invited Speaker: S.T. Petcov (SISSA)
- Moriond Workshop on Electroweak Interactions, 12–22 Mar 2003, Les Arcs
- Speakers: **M. Postma** (ICTP), S. Profumo (SISSA) & C. Yaguna (SISSA)

- Electroweak Interactions and Unified Theories, Les Arcs, 15–22 Mar 2003
- Speaker: **M. Postma** (ICTP)
- “SUGRA 20: International Conference on 20 Years of SUGRA and search for SUSY and Unification,” Boston, 17–20 Mar 2003
- IAC: M. Quirós (Barcelona)
- Recent Developments in High Energy Physics and Cosmology, Athens, 17–20 Apr 2003
- Plenary Speakers: J. Ellis (CERN), N. Mavromatos (KCL), S. Sarkar (Oxford), I. Rizos (Ioannina), G. Leontaris (Ioannina)
- Workshop on Science with the New Generation of High Energy Gamma-ray Experiments: “Between Astrophysics and Astroparticle Physics,” May 2003, Perugia
- Invited Speaker: P. Ullio (SISSA)
- “Supersymmetry in the Desert: SUSY 2003”, Tucson, 5–10 June 2003
(<http://www.physics.arizona.edu/susy2003/>)
- Invited Speaker: M. Quirós (Madrid)
- First Yamada Symposium and International Conference on “Neutrinos, Dark Matter and Nuclear Physics”, Nara, 9–14 Jun 2003
- Invited Speaker: S.T. Petcov (Trieste - SISSA)
- Baryogenesis workshop, Ann Arbor, 9–27 Jun 2003
- Speaker: **P. Di Bari** (Barcelona), **W. Rodejohann** (Trieste - SISSA)
- Euresco Conference “What Comes Beyond the Standard Model?”, Portoroz, 12–17 Jul 2003
- Speakers: Martin Sloth (Helsinki), **M. Postma** (Trieste - ICTP)
- International Europhysics Conference on High Energy Physics, Aachen, 17–23 Jul 2003
- Speaker **W. Rodejohann** (Trieste - SISSA)
- SLAC Summer Institute On Particle Physics: “Cosmic Connection To Particle Physics”, Stanford, 28 Jul – 8 Aug 2003
(<http://www-conf.slac.stanford.edu/ssi/2003/>)
- Lecturer: J. Ellis (Geneva)
- “Second International Conference on String phenomenology,” Durham, 29 Jul – 4 Aug 2003
(<http://www.ippp.dur.ac.uk/SP03/>)
- Organising Committee: A. Faraggi (Oxford)
- Speakers: J. March-Russell (Oxford), H.P. Nilles (Bonn), P. Kanti (CERN), Z. Lalak (Warsaw), N. Mavromatos (London), M. Quiros (Madrid), J. Casas (Madrid), V. Di Clemente (Oxford), M. Borunda (Trieste)
- COSMO-03: International Workshop on Particle Physics and the Early Universe, Ambleside, 25–29 Aug 2003
(<http://www.ippp.dur.ac.uk/cosmo03/>)
- Speakers: H.P. Nilles (Bonn), K. Enqvist (Helsinki), **R. Sturani (Helsinki)**, Martin Sloth (Helsinki), A. Jokinen (Helsinki), J. Valiviita (Helsinki), F. Ferrer (Oxford), D. Langlois (Paris),
- “Conference On Thinking, Observing And Mining The Universe”, Sorrento, 22-27 Sep 2003
(<http://www.na.infn.it/congr/Thinking2003/>)
- Invited Speaker: E. Massó (Barcelona)
- “DESY Theory Workshop 2003: GUTS and Branes”, Hamburg, 23–26 Sep 2003
(<http://www.desy.de/desy-th/workshop2003/>)
- Invited Speaker: M. Quirós (Madrid)
- “Hierarchy Problems in Four and More Dimensions”, ICTP Trieste, 1-4 Oct 2003
(<http://agenda.ictp.trieste.it/agenda/current/fullAgenda.php?ida=a0386>)
- Invited Speaker: M. Quirós (Madrid)

- International Workshop on “Astroparticle & High-Energy Physics”, Valencia, 14–18 Oct 2003 (<http://nac15.ific.uv.es/conference/>)
- Invited Speakers: C. Boehm (Oxford), J. García-Bellido (Madrid), E. Massó (Barcelona), S. Sarkar (Oxford)
- 2nd International Workshop on Neutrino Oscillations, Venice, 5–8 Dec 2003
- Invited Speaker: S.T. Petcov (Trieste - SISSA)
- “Dark Matter and Dark Energy”, Bad Honnef, 8–11 Dec 2003 (<http://www.th.physik.uni-bonn.de/nilles/darkmatter/>)
-Organising Committee: H. P. Nilles (Bonn)
-Speakers: P. Binétruy (Orsay), K. Enqvist (Helsinki), D. Hooper (Oxford), **A. Papazoglou** (Bonn), M. Plümacher (Geneva), S. Sarkar (Oxford), **G. Tasinato** (Bonn)
- “IX Christmas Workshop on Particle Physics,” Madrid, 15–17 Dec 2003 (<http://gesalerico.ft.uam.es/workshop9/workshop03.html>)
- Organising Committee: A. Casas, J.R. Espinosa, J. García-Bellido, M.B. Gavela, J.M. Moreno and M. Quirós (Madrid)
-Invited speaker: J. Lesgourgues (Annecy)
- “The Third Generation as a Probe for New Physics: Experimental and Technological Approach”, IFAE/UAB Barcelona, 18–20 Dec 2003
- Invited Speaker: M. Quirós (Madrid)
- “From Fields to Strings: Circumnavigating Theoretical Physics. A Conference in Tribute to Ian Kogan,” Oxford, 8–10 Jan 2004 (<http://http://www-thphys.physics.ox.ac.uk/users/PeterAusting/Conference/>)
- Organisation: S. Sarkar
- Speakers: **A. Papazoglou** (Bonn), S. Randjbar-Daemi (Trieste - ICTP)
- IoP Meeting on Double Beta Decay, Brighton, 28 Jan 2004
- Speaker **W. Rodejohann** (Trieste - SISSA)
- International Workshop on Neutrino Oscillations and their Origin, Tokyo, 11–15 Feb 2004
- Invited Speaker: S.T. Petcov (Trieste - SISSA)
- “XXXII International Meeting on Fundamental Physics”, Alicante, 1–5 Mar 2004 (<http://ific.uv.es/imfp04/>)
- Invited Speaker: J. García-Bellido (Madrid)
- “XXXIXth Rencontres de Moriond: ElectroWeak Interactions and Unified Theories”, La Thuile, 21–28 Mar 2004 (<http://moriond.in2p3.fr/EW/2004/>)
- Invited Speakers: **P. Di Bari** (Barcelona), J.R. Espinosa (Madrid)
- “Contents and Structures of the Universe”, La Thuile, 28 Mar – 4 Apr 2004 (<http://moriond.in2p3.fr/J04/>)
- Invited Speaker: J. García-Bellido (Madrid), F. Ferrer (Oxford)
- String Phenomenology 2004, Ann Arbor, 1-6 Aug 2004
- Plenary Speakers: H.P. Nilles, Bonn; M. Quirós, Barcelona
- PASCOS '04, Boston, 11-22 Aug 2004
- Plenary Speakers: H.P. Nilles, Bonn; M. Quirós, Barcelona
- 5th Rencontres du Vietnam: Particle Physics and Astrophysics, Hanoi, 5-11 Aug 2004
- Invited Speakers: A. Broncano, A. Casas, J. R. Espinosa and J. M. Moreno (Madrid)
- Intern. Workshop on Particle Physics and the Early Universe, Toronto, 17-21 Sep 2004
- Convener: J. García-Bellido (Madrid), Plenary Speaker: H.P. Nilles (Bonn)

Given the interest of the general public in cosmological matters, an ‘outreach’ programme was developed. Network members have written commentaries on scientific developments for both professional publications such as CERN Courier and Physics World, as well as articles for popular magazines such as New Scientist. Key scientific findings of the Network have been publicised through such channels. Many Network members also gave non-technical talks to schools, teachers and the general public. Young researchers were particularly encouraged to engage in such activities in order to communicate their enthusiasm and the intellectual excitement of the subject to the broader audience whose support for fundamental research is essential in the long run. We list below a representative selection of such activities.

Commentaries in professional publications: P. Binetruy (Orsay) wrote a popular article titled “*How many dimensions to our universe?*” for Europhysics News 33 (2002) 54. J. Ellis (Geneva) wrote a number of articles for CERN Courier (e.g. “*Science knows no boundaries*”, Jan/Feb 2002) and Physics World (e.g. review of “*Facing Up: Science and its Cultural Adversaries*”, Apr 2002). N. Mavromatos (London) wrote a review article on “*Testing models for quantum gravity*” for CERN Courier (Sep 2002). S. Sarkar (Oxford) wrote a news report on “*Could the end be in sight for ultrahigh-energy cosmic rays?*” for Physics World (Sep 2002).

Talks to general audiences: **P. Bucci** (Warsaw) gave an overview of ‘Finite-temperature Field Theory’ for non-specialists, at the Warsaw University Science Worker’s House in the Summer Term 2002. **K. Dimopoulos** talked about ‘A Voyage in the Cosmos through Space and Time’ to the Hellenic Society of Lancaster University in Jan 2002. J. Ellis (Geneva) gave many popular talks, e.g. to physics teachers visiting CERN on ‘Matter, Antimatter and the Universe’ (Mar 2002). Z. Lalak (Warsaw) gave a popular lecture on brane worlds at the biannual meeting of the Polish Physical Society at Torun, September 2001. S. Sarkar (Oxford) gave several popular talks on ‘Seeing the edge of the universe’ and ‘The Road to Quantum Gravity’ (Georgia Tech Summer School, Worcester College, Oxford, Jul 2001, ‘Oxford Access Scheme’ Summer School, Aug 2001, Institute of Physics Schools Lecture, Shrewsbury School, Sep 2001, Institute of Physics ‘Young Physicist’s Conference’, Oxford, Nov 2001, Science Society, New College, Oxford, Nov 2001, Linacre College, Oxford, Feb 2002, St Edward’s School, Oxford, Mar 2002, Taunton School, May 2002).

Network meetings, schools, workshops etc:

The initial meeting Of Team Leaders to fix research tasks, collaborations, appointment of young researchers, education and outreach activities was held at Geneva (during the SUSY’01 conference at CERN) on 28 Jun 2001, with the participation of 30 network members. The First Network School/Meeting, with lectures by both Network Scientists and invited outside experts, as well as seminars by young researchers and reports from the Team Leaders was also held at CERN, Geneva, 18-22 Apr 2001 and attended by about 70 people. The programme consisted of topical lectures in the mornings and specialised seminars in the afternoons. The Second Network School/Meeting had a similar format and was held at Oxford, 26-29 Sep 2002 and attended by about 60 people; the mid-term review was held at the end of the meeting. The Third and Fourth Network School/Meeting were held during the PLANCK series of conferences as detailed below.

The following scientific meetings were organised under the aegis of the network:

- “International workshop on Physics and Astrophysics of Extra Dimensions”, College de France, Paris, 9 May-22 Jun 2001 (<http://www.iap.fr/users/sigl/extradim.html>)
- Organised by the Orsay and Paris nodes. The idea was to host a two-month long meeting in Paris where world experts could be present for periods of time ranging from one week to one month to discuss the most recent issues in the field. This attracted 180 participants. The first period was concluded by a three-day meeting (28 May-1 June) on “Ultra High Energy Cosmic Rays”, while the second period was concluded by a week (18-22 Jun) devoted to “Cosmology”.

- “Les Journées des Lacs Alpains de Cosmologie”
(http://www.lapp.in2p3.fr/~lesgourgues/frame_science2.html)
- ▷ 1st Journée (Université de Genève, 16 Jan 2001)
- ▷ 2nd Journée (LAPP, Annecy, 22 May 2001)
- ▷ 3rd Journée (CERN, 20 Nov 2001)
- ▷ 4th Journée (Université de Genève, 24 May 2002)

In order to reinforce the cohesion of network members at the Geneva and Annecy nodes, Annecy has been organising regular meetings (every four months) intended mainly for CERN, Annecy and University of Geneva cosmologists (with participation also from Lausanne and Grenoble).

The following international conferences were organised *jointly* with our sister network ‘Physics Across the Present Energy Frontier’ (HPRN-CT-2000-00148).

- “From the Planck Scale to the Electroweak Scale - Supersymmetry & Brane Worlds”, Kazimierz, Poland, 25-29 May 2002 (<http://www.fuw.edu.pl/~susy/Planck02.html>)
This attracted 100 participants from the two networks and from other institutions in Europe and USA. An important discussion theme was “Cosmology in brane worlds and the role of supersymmetry”. An informal meeting of the 20 network members present was also held, in order to plan the forthcoming mid-term review meeting.

- Speakers: P. Binetruy (Orsay), L. Boubekur (SISSA), **P. Bucci (Warsaw)**, P. Chankowski (Warsaw), E. Dudas (Orsay), A. Faraggi (Oxford), S. Forste (Bonn), **N. Irges (Madrid)**, K. Kowalska (Warsaw), Z. Lalak (Warsaw), D. Lyth (Lancaster), R. Matyszkiewicz (Warsaw), K. Meissner (Warsaw), H-P. Nilles (Bonn), M. Olechowski (Bonn), J. Pawelczyk (Warsaw), **M. Peloso (Bonn)**, S. Pokorski (Warsaw), A. Pomarol (Barcelona), L. Roszkowski (Lancaster), S. Sarkar (Oxford), K. Tamvakis (Ioannina), G. Tasinato (SISSA).

- 6th European Meeting “From the Planck Scale to the Weak Scale,” Madrid, 26–31 May 2003 [<http://makoki.iem.csic.es/~planck03/>]
This attracted about 80 participants from the 2 networks plus a similar number from other institutions in Europe and USA. As listed below, many network members, in particular young researchers, gave talks. The annual business meeting of the network was held on the last day of the conference.

- Organizing Committee (Madrid): A. Casas, J.R. Espinosa, J.M. Moreno and M. Quirós
- Speakers: P. Binétry (Orsay), L. Boubekur (SISSA), **P. Bucci (Warsaw)**, **P. Di Bari (Barcelona)**, **K. Dimopoulos (Lancaster)**, E. Dudas (Orsay), H. Dreiner (Bonn), A. Falkowski (Warsaw), A. Faraggi (Oxford), F. Ferrer (Oxford), A. Ibarra (CERN), Z. Lalak (Warsaw), D. Lyth (Lancaster), H.M. Lee (Bonn), H-P. Nilles (Bonn), A. Pomarol (Barcelona), **A. Papanozoglou (Bonn)**, S. Pokorski (Warsaw), A. Pomarol (Barcelona), **M. Postma (Trieste)**, G.G. Ross (Oxford/CERN), L. Roszkowski (Lancaster), S. Sarkar (Oxford), G. Senjanovic (Trieste), **L. Sorbo (Annecy)**, **R. Sturani (Helsinki)**, **G. Tasinato (Bonn)**.

- “From the Planck Scale to the Weak Scale,” Bad Honnef, 24–28 May 2004 (<http://www.th.physik.uni-bonn.de/nilles/planck04/index.html>)

This attracted about 100 participants from the 2 networks and from other institutions in Europe and USA. As listed below, many network members, in particular young researchers, gave talks. The annual business meeting of the network was held during the conference.

- Organizing Committee (Bonn): H.-P. Nilles, **G. Tasinato**

- Speakers: L. Boubekur (Lancaster), A. Casas (Madrid), T. Dent (Ioannina), H. Dreiner (Bonn), J. Espinosa (Madrid), A. Falkowski (Warsaw), A. Faraggi (Oxford), A. Ibarra (CERN), D. Lyth (Lancaster), J. Moreno (Madrid), **A. Nicolis (Madrid)**, M. Plümacher (Geneva), **M. Postma (Trieste - ICTP)**, M. Quiros (Madrid), G.G. Ross (Oxford/CERN), L. Roszkowski (Lancaster), **W. Rodejohann (SISSA)**, S. Sarkar (Oxford), **G. Tasinato (Bonn)**, M. Thormeier (Bonn), K. Turzyski (Warsaw), S. West (Oxford)

- The following international school was also organised by our network:
Second Aegean School on the Early Universe, Syros, 22–30 Sep 2003

(<http://www.physics.ntua.gr/cosmo03/>)

This attracted about 90 participants and the main lecturers included S. Sarkar (Oxford) and K. Tamavakis (Ioannina). Other network members gave short talks as listed below.

- Speakers: **K. Dimopoulos** (Lancaster), T. Dent (Thessaloniki), I. Rizos (Ioannina), G. Leontaris (Ioannina), **R. Ruiz de Austri** (Thessaloniki), **A. Papazoglou** (Bonn), F. Ferrer (Oxford), N. Mavromatos (London), G. Lazarides (Thessaloniki), L. Perivolaropoulos (Ioannina)

Networking activities:

H. Casini (Oxford) moved for the second year of his fellowship (supported by CONICET Argentina) to the Centre de Physique Theorique, Marseille, a node of the French Team. J. Lesgourgues (Annecy) moved to Geneva to become a CERN fellow in Oct 2001. I. Kogan (Oxford) spent his sabbatical year (2001–02) in Paris interacting closely with the members of the Orsay Team. J. Rizos (Ioannina) also took his sabbatical (2001–02) in Paris.

Konstantinos Pallis having obtained his PhD at Thessalonki moved to become a network fellow at SISSA in Feb 2002. **Lorenzo Sorbo** having obtained his PhD at SISSA moved to become a network fellow at Paris in Oct 2001. **Roberto Ruiz de Austri**, having obtained his PhD at Lancaster, moved to become a network fellow at Thessalonki in Oct 2001.

Michael Plümacher, having spent 2 years as a network fellow at Oxford moved to Geneva as a CERN fellow in Oct 2002. **Riccardo Sturani** moved to Helsinki from Oxford in Oct 2001 to become a network fellow.

Study visits:

K. Dimopoulos (Lancaster) → Thessaloniki (April-May 2002), **P. Di Bari** (Barcelona) → Madrid (Apr 2004), J.R. Espinosa (Madrid) → Geneva (Mar 2003), S. Forste (Bonn) → Warsaw (Feb 2001), C. Korthals Altes (Marseille) → Geneva (Autumn 2001, Spring 2002), G. Leontaris (Ioannina) → Geneva, Paris (Jul 2002), N. Mavromatos (London) → Geneva, Ioannina, Paris, J.M. Moreno (Madrid) → Geneva (Nov 2003, Feb 2004), **A. Nicolis** (Madrid) → Trieste (Apr 2003), Geneva (Jun, Nov 2003), H.P. Nilles (Bonn) → Geneva (Mar 2002), **I. Olasagasti** (Ioannina) → Geneva (Nov 2002), M. Olechowski (Bonn) → Warsaw (Feb 2002), **M. Peloso** (Bonn) → Geneva (Apr 2001) Oxford (Mar and Nov 2001), M. Quiros (Madrid) → Oxford (Jan 2002) → Geneva (Jul 2004), J. Rizos (Ioannina) → Geneva, London, Paris (several), **W. Rodejohann** (Trieste) → Hamburg (Jun 2003), S. Sarkar (Oxford) → Geneva (several), K. Tamvakis (Ioannina) → Oxford (Jan 2004), Geneva (Feb 2004).

J.D. Vergados (Ioannina) visited the USA during 10-16 Dec 2001 to collaborate with P. Nath (North Eastern University) and to speak at the “Coral Gables Conference on Elementary Particle & Astrophysics”, with the prior approval of the EC.

B.3 Training overview

All vacant positions for young researchers were advertised on the EC website (<http://improving.cordis.lu/rtn/>) as well as on the website of the host institution. In addition email alerts were sent to comprehensive lists of researchers in both Europe and the USA with a request to draw these vacancies to the attention of prospective applicants. (Posts were not advertised in magazines such as *Nature* due to the high cost of such advertisements.) Typically over ten applications were received from qualified candidates for each post advertised.

All the Teams have delivered (or even exceeded) the number of person-months of training specified in the Contract inspite of the difficulties in appointing young researchers in accordance with the schedule specified in the contract (which was insisted on by Brussels). Although the nominal start date of network activities was 1 June 2000, the advance payment was not

received from the EC until Nov that year so that it was not possible for most Teams to make appointments until Oct 2001, keeping in mind that post-doc appointments normally begin in the Autumn. Consequently there was an under-spend in the first year (1/6/00–31/5/01), resulting in a rather low first periodic payment. Several Teams who made appointments in Autumn 2001 (in particular Greece and Poland) faced financial difficulties, since their host institutions were unwilling to provide support in advance for the appointed young researchers. (We welcome the initiative by Brussels to avoid such situations by asking for projections of estimated spending along with the annual financial statements.)

Young Researchers Financed by the Contract						
Participant	Deliverable (in Person-Months)			Financed till 10/04 (in Person-Months)		
	Pre-doc	Post-doc	Total	Pre-doc	Post-doc	Total
1. UOXF.DR	0	48	48	0	48	48
2. DPUB	0	24	24	0	38	38
3. CERN	0	0	0	0	0	0
4. UHEL	0	24	24	0	24	24
5. U.IOANNINA	0	48	48	0	48	48
6. CSIC	0	48	48	0	(12)** + 47	(12)** + 47
7. LPT	0	48	48	0	48	48
8. SISSA	0	72	72	0	72	72
9. UW	0	24	24	0	24	24
Totals	0	336	336	0	351	351

** This refers to the appointment of Irges (Madrid) which was subsequently deemed invalid as he was aged over 35 at the time of appointment. We have not counted this in the totals.

The young researchers supported by the network had, in many cases obtained their PhDs at other nodes of the network (Pallis, Peloso, Sorbo, Ruiz de Austri), or at institutions which have close links with the network (Bucci, Davis, Di Bari, Dimopoulos, Irges, Nicolis, Plümacher, Sturani). Thus they were already familiar with the activities of the network and did not require any special measures for integration. All appointments were made in accordance with the rules and regulations of the host institutions, which usually specify that there must be no bias with regard to gender, religious beliefs etc. Three of the 14 young researchers appointed (Bucci, Olassagasti, Postma) were women — while this is far short of 50%, it perhaps represents the fraction of female researchers in this subject as a whole.

The training of the young researchers was largely left to the host nodes. As is common practice for young post-docs, they were free to pursue their research programme, often forming collaborations with other network members at the annual meetings and at other conferences and schools, as well as with non-network people at their host institutions. They were encouraged to represent the network at conferences and given priority for presenting their work at network meetings. Many of them were given the opportunity to undertake additional responsibilities such as graduate lecturing, supervision of research projects etc to develop their teaching skills. The programme at the annual schools reflected the multidisciplinary nature within the network, with lectures on both astrophysical and particle physics issues. This was particularly useful for young researchers and graduate students in the network, who have usually been trained in one or the other area. Several collaborations have been formed between astrophysicists and particle physicists in the network (e.g. [3, 140, 138]).

B.4 Industry connections

None

B.5 Recommendations

The questionnaire filled in by the Co-ordinator and Team Leaders will be sent separately.