COSLAB 2001 Meeting (7^{th} – 10^{th} July)

Scientific Content

The abstracts (attached as Appendix C) give the details of the individual contributions.

The 31 talks (Gandra's talk was cancelled) were distributed through twelve sessions, usually of three talks each. Wherever possible, these sessions were themed. Naturally, there were sessions devoted to specific experimental fields, such as helium-3 or superconductors, and others to cosmological topics, for example the cosmic microwave background (the LAB and the COS of the programme title). However, the bulk of the contributions developed ways in which the one informed the other, either explicitly, or implicitly. Examples included vortex or cosmic string formation in low-temperature or cosmological phase transitions and new types of sonic and optical analogues of black holes. The shorter talks were punctuated with longer review talks (Volovik, Zurek, Krusius) that developed themes at length or provided overviews.

The programme was very full, but allowed for discussion after each talk. It was scheduled with long lunch and tea breaks to allow time for informal discussions. Most participants also found time to continue such discussions once the daily sessions were over.

Programme and Participants

The final programme for the Workshop is attached as Appendix A. Appendix B contains the list of participants. The abstracts are listed in Appendix C.

There were 59 participants in all, comprising 23 senior faculty members, 12 junior faculty, 15 postdoctoral researchers and 9 research students. They came from 15 different countries. The geographical distribution was as follows:

Belgium	1	Netherlands	5
Finland	2	Poland	1
France	6	Portugal	2
Germany	2	Slovenia	2
Greece	2	Spain	3
Israel	2	United Kingdom	25
Italy	2	USA	3
Japan	1	Total	59

Assessment of the Results

Not surprisingly, many of the speakers had been involved in the earlier ESF Network on *Topological Defects: Non-Equilibrium Field Theory in Particle Physics, Condensed Matter and Cosmology*. What was particularly exciting was the involvement of new people whose work was directly relevant to the Programme. At least 40% of the participants had not previously attended a Network meeting. Among these were new groups from the Universities of Amsterdam (Netherlands), Bar-Ilan (Israel), Lisbon (Portugal), Maribor (Slovenia), St Andrew's (United Kingdom), and Tours (France), all of whom contributed

talks. This interest may well lead to additional support for the Programme from countries not yet represented.

The talks at the meeting provided a very wide coverage of the relevant fields. One of its outcomes was to identify several themes for possible future small specialist workshops. One that seems particularly timely is *Black Hole Event Horizons in the Laboratory*, a topic that has aroused great interest in the community. A small workshop on this theme may be organized in 2002, probably at Tours (in addition to our major event for that year, the Summer School to be held in Cracow). Other topics that may be considered for later meetings included *Tests of the Kibble-Zurek Scenario* (possibly to be held in 2003), *Topological Defects in Cosmology* and *Point Defects.*

Comments on the meeting from the participants were almost universally positive. It may certainly be judged a success, particularly in terms of establishing communication between different disciplines.

R.J. Rivers T.W.B. Kibble
London, 5 September 2001

Appendix A: Programme

Saturday, 7 July

14.00	Tom Kibble and Ray Rivers	Welcome
14.10	Svenje Mehlert	The ESF
14.30	Grisha Volovik	Vacuum in Quantum Liquids and in High Energy Physics and Cosmology
15.30	*Tea*	
16.15	Luis Garay	Sonic black holes in Bose-Einstein condensates
16.45	Ulf Leonhardt	Optical black holes with halted light
17.15	Feodor Kusmartsev	New class of phase transitions driven by single-vortex excitations in confined geometries
17.45	*Reception*	
19.00	Committee Meeting	

Sunday, 8 July

09.00	Yuriy Bunkov	Cosmology in ^{3}He
09.30	Eddy Collin	Properties of ^{3}He inside Aerogel
10.00	Samo Kralj	Quench dynamics in nematic liquid crystals
10.30	*Coffee*	
11.00	Mitja Slavinec	Surface Induced Smectic-A Edge Dislocations
11.30	Arttu Rajantie	Defect formation in U(1) gauge field theories
12.00	Tom Kibble	Defect energy as an order parameter in gauge theories
12.30	*Lunch*	
14.00	Fernando Lombardo	Decoherence and defects
14.30	Ray Rivers	Condensed matter analogues of QED
15.00	Nuno Antunes	Global monopoles in and out-of-equilibrium
15.30	*Tea*	
16.15	Anne-Christine Davis	Supersymmetric Semilocal Strings
16.45	Leandros Perivolaropoulos	Q rings
17.15	*Close*	

Monday, 9 July

09.00	Renaud Parentani	Trans-Planckian dispersion relations and scale-invariance of inflationary perturbations
09.30	Mairi Sakellariadou	Are cosmic strings really ruled out by the most recent BOOMERanG and MAXIMA data?
10.00	Levon Pogosian	CMB bispectrum from cosmic strings
10.30	*Coffee*	
11.00	Tanmay Vachaspati	Topology from fermions
11.30	Nathan Lepora	Towards a Dual Description of the Standard Model

12.00	Jeroen Vink	Simulating Quantum Fields after a Quench
12.30	*Lunch*	
14.00	Tom Girard and Maria Ribeiro Gomes	Induced Phase Transitions in Planar Superconductors
14.30	Boris Shapiro	Recovery of Superconductivity in Quenched Mesoscopic Domain
15.00	Hagen Kleinert	Momentum space instabilities and the negative-eta regime in superconductors
15.30	*Tea*	
16.15	Mark Hindmarsh	Vortex formation in superconductors
16.45	Wojciech Zurek	Open problems in the dynamics of symmetry breaking
17.45	*Close*	

Tuesday, 10 July

09.00	Petr Jizba	World according to Renyi: Thermodynamics of fractal systems
09.30	Jean-Paul Maneval	Nanosecond time-resolved dynamics of superconducting films
10.00	John H Miller Jr	Quantum Nucleation of Topological Defects in Condensed Matter Systems
10.30	*Coffee*	
11.15	Victor Moshchalkov	Symmetry-Induced Vortex Patterns in Nanostructured Superconductors
11.45	Matti Krusius	Quantized vortex lines or sheets — what is formed in dynamic drives?
12.45	*Close*	

Appendix B: Workshop Participants

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Appendix C: Abstracts

ANTUNES, Nuno Dias
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Global monopoles in and out-of-equilibrium

I will present analytical and numerical results from recent studies of thermal properties of point-like defects in global field theories in two and three dimensions. The role of the defects in the critical behaviour of the field systems is described and the two cases are contrasted. I will also look at the behaviour of the defects in an out-of-equilibrium, temperature quenched system.

BUNKOV, Yuriy
CRTBT-CNRS, Grenoble
Cosmology in ^{3}He

The new experiment is now in course.

COLLIN, Eddy
CRTBT-CNRS, Grenoble
Properties of ^{3}He inside Aerogel

We present the last NMR measurements of the Grenoble ULT Group on superfluid ^{3}He contained inside Aerogel, and Aerogel covered by ^{4}He films. We propose that some of the properties of the superfluid could be explained by vortices trapped by the Aerogel network.

DAVIS, Anne
DAMTP, Cambridge
Supersymmetric Semilocal Strings

Cosmic string solutions are found in a theory with an N=2 supersymmetry. The theory has an SU(2) global and U(1) local symmetry, resulting in the strings solutions being semi-local. The associated fermion zero modes are found and the resulting cosmological implications discussed.

GANDRA, Pedro
Imperial College, London
Non-linear noise and phase transitions

The time-dependent Landau–Ginzburg theory has proved an excellent description for toy-models for the Kibble–Zurek mechanism of defect formation. However, linear (additive) noise is unrealistic in the context of quantum field theories, for which such models are expected to provide qualitative realisations. We attempt to improve this situation by including non-linear (multiplicative) noise in our study of these models.

GARAY, Luis
IMAFF, CSIC, Madrid
Sonic black holes in Bose–Einstein condensates

The sonic analogue of a gravitational black hole in dilute-gas Bose–Einstein condensates is investigated. It is shown that there exist both dynamically stable and unstable configurations which, in the hydrodynamic limit, exhibit a behaviour analogous to that of gravitational black holes. The dynamical instabilities involve creation of quasiparticle pairs in positive and

negative energy states. These features are displayed in two qualitatively different one-dimensional models, namely, a long, thin condensate with an outcoupler laser beam providing an atom sink, and a tight ring-shaped condensate. The creation of a stable sonic black hole can be simulated by solving the Gross–Pitaevskii equation numerically for a condensate subject to a trapping potential which is adiabatically deformed. A sonic black hole could in this way be created experimentally with state-of-the-art or planned technology.

GIRARD, Tom and GOMES, Maria Ribeiro
Centro de Fisica Nuclear, Universidade de Lisboa
Induced Phase Transitions in Planar Superconductors

Nucleation of the normal and superconductive phases of planar type I (first order transitions) superconductors under variation of external magnetic field or temperature occurs in multiquantum bundles with the formation of an intermediate phase not unlike the Abrikosov phase in type II (second order materials). We describe the phase nucleation processes at low temperatures of several materials of both types with coherence lengths from 40–400 nm, using a real time detection technique which is sensitive to flux motion. Under irradiation we observe the creation of flux which appears dynamically unrelated to the regular nucleation processes, and discuss its relevance to the "explosive nucleation" mechanisms of Shapiro et al.

HINDMARSH, Mark
University of Sussex, Brighton
Vortex formation in superconductors

The results of experiments by Carmi and collaborators searching for vortices formed at quenches in superconductors are mixed: one reports a positive result, the other negative, claiming a sensitivity a thousand times larger than the theoretical prediction. I review the theories of vortex formation, re-examine the experiments, and suggest refinements for the future.

JIZBA, Petr
University of Tsukuba, Japan
World according to Renyi: Thermodynamics of fractal systems

I discuss a basic thermodynamics properties of system with multi-fractal structure. This is possible by extending the notion of the usual Gibbs–Shannon entropy into more general framework — Renyi's parameter with the Hausdorff fractal dimension and hence derive how the first thermodynamics law and corresponding Maxwell relations must be modified to accommodate systems with varied Hausdorff dimensions. With the help of Renyi's entropy we find a physical setting for the Tsallis–Havrda–Charvat entropy. Finally, some further speculations on relevance of out approach to the Hagedorn phase transitions in hadronic physics and (cosmic) string theory are discussed.

KIBBLE, Tom
Imperial College, London
Defect energy as an order parameter in gauge theories

Phase transitions and crossovers in gauge theories may sometimes be distinguished by considering the energies of topological defects as order parameters. To study this idea, we have developed a non-perturbative formalism for measuring defect free energies (monopole mass or vortex tension), initially in three-dimensional lattice SU(2)+adjoint Higgs models. I shall present results for the monopole mass in the Georgi–Glashow model, and discuss more general models briefly.

KLEINERT, Hagen
Free University of Berlin
Momentum space instabilities and the negative-h regime in superconductors

I study the momentum space instabilities of the Ginzberg–Landau model in the ordered phase at zero external field. As a consequence of the thermal fluctuations of the magnetic field, the value $\kappa = 1/\sqrt{2}$ of the Ginzberg parameter κ separates a uniform regime from a regime with string spatially modulated fluctuations, caused by a minimum of gradient energy at nonzero momentum. The boundary between these two regimes is shown to correspond to a tricritical Lifshitz point. The modulated fluctuations are shown to produce a negative anomalous dimension $\eta \approx -0.2$, in excellent agreement with recent Monte Carlo simulations and earlier theoretical estimates.

KRALJ, Samo
Faculty of Education, Maribor, Slovenia
Quench dynamics in nematic liquid crystals

It is already well known that some basic facts of the coarsening dynamics of the Higgs field after the Big Bang can be studied in adequate condensed matter systems. For this purpose nematic liquid crystals (LC) are particularly adequate. In our contribution we present the influence of quench time, confining cavity size and geometry on the kinetics after the temperature driven isotropic-nematic phase quench. The semimicroscopic model based on Brownian molecular dynamics is used.

KRUSIUS, Matti
Low Temperature Laboratory, Helsinki University of Technology
Quantized vortex lines or sheets — what is formed in dynamic drives?

Quantized vorticity is created in macroscopic quantum systems as a response to an external field: in superfluids under rotation and in superconductors in magnetic field. In isotropic quantum systems the vorticity is supported only in the form of linear structures of the order-parameter field, as vortex lines. In anisotropic systems, such as the A phase of superfluid Helium-3, the vorticity may also be included in a domain-wall-like sheet. Such a combined structure is known as the vortex sheet. What is the rule which selects between the two competing topologies, in which quantized vorticity may appear in ^{3}He-A? This question has only recently been answered. Whether lines or sheets are formed, depends on how the external field, in this case rotation, is applied. If the external field varies sufficiently rapidly and strongly, then sheets adapt to changes in the external field faster than lines, are formed first, and thereby displace lines. Many of the features which make this phenomenon possible in ^{3}He-A, are also present in unconventional *p*-wave superconductors. It is possible that this could be a generic property of quantum systems with intrinsic anisotropy of the order parameter.

KUSMARTSEV, Feodor
Loughborough University
New class of phase transitions driven by single-vortex excitations in confined geometries

We present the first experimental evidence and demonstrate theoretically that in a system with confined geometry a new class of phase transitions, associated with the spontaneous generation of single vortices and single anti-vortices may arise. We also show experimentally and theoretically that this phenomenon arises both in mesoscopic system in thin films with

sizes from the submicron to the submillimetre. We establish an universal expression for the critical temperature of the new phase transition, which is universal and depends weakly on the system geometry. The obtained theoretical expression for the critical temperature is in excellent agreement with our experimental data.

LEONHARDT, Ulf
University of St Andrews
Optical black holes with halted light

In recent experiments the group velocity of light has been reduced to zero in alkali vapours and Bose-Einstein condensates. I demonstrate how to generate a genuine horizon using this technique.

LEPORA, Nathan
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Towards a Dual Description of the Standard Model

Will discuss some recent developments relating to a duality between SU(5) monopoles/dyons and the elementary particles. The talk is intended to be pedagogical in nature.

LOMBARDO, Fernando
Imperial College, London
Classical behaviour after a phase transition

In this talk we analyze the onset of classical behaviour after a second order phase transition and the relevance of the decoherence time in the defect formation.

MANEVAL, Jean-Paul
Ecole Normale Supérieure, Paris
Nanosecond time-resolved dynamics of superconducting films

We introduce a different method for sampling the zero-resistance states quenched from a normal bubble in a superconducting film. One knows that, in a narrow strip driven by an over-critical current step, the voltage only appears after a finite delay time T_d. We propose this delay as a test of the vorticity. Technically, this amounts to launching a bridge into the localized hot-spot regime (normal zone of micrometer extension) by means of a current pulse or of a laser pulse. Cooling of such films as epitaxial YBCO-on-MgO, or niobium-on-sapphire, requires only a few nanoseconds at low T. Later, a test pulse is applied to measure $T_d(Dt)$, where Dt is the interval between excitation and the test pulse. One observes the shortening of T_d at Dt = 100 ns, long after quenching into the R = 0 regime. However, the effect disappears at longer intervals, which sets a limit on the lifetime of topological defects. While the present approach does not allow to capture the details of the vorticity, it takes advantage of the short quenching and observation times, and is sensitive on the overall vorticity, rather than on the resulting magnetic flux. In addition, it provides a ground for experimentation of the time-dependent Ginzburg–Landau equation in its Kramer & Watts-Tobin (1978) form.

MILLER, John H Jr
University of Houston, Texas
Quantum Nucleation of Topological Defects in Condensed Matter Systems

The decay of the false vacuum, and related macroscopic quantum phenomena, have been of broad scientific interest for over two decades. Topological defects in condensed matter

systems, which can nucleate via quantum tunneling, include vortex rings in superconductors and superfluids, dislocation pairs in Wigner crystals and vortex lattices, and charge (or flux) soliton-antisoliton pairs in density waves (or Josephson junctions).* This talk will provide an overview of theory and experiment, with emphasis on solitons, and will conclude with possible future avenues of research in this far-reaching problem. * J. H. Miller, Jr., et al., Phys. Rev. Lett. 84, 1555 (2000).

MOSHCHALKOV, Victor
Kath. Univ. Leuven
Symmetry-Induced Vortex Patterns in Nanostructured Superconductors

Flux confinement phenomena have been studied in individual superconducting nano-plaquettes and their clusters and huge arrays (films with nanoengineered periodic pinning arrays (PPA)). In individual nanoplaquettes of the different form (loops, discs, triangles and squares) the superconducting critical temperature $T_c(H)$ was measured resistively and also calculated from the linearized Ginzburg-Landau equations. Novel symmetry consistent vortex patterns have been identified for triangles and squares, where antivortices can be spontaneously formed to keep the imposed symmetry (Nature 408, 833 (2000)). The invasive role of the contacts is discussed, together with the data on the non-local Little–Parks effect. In clusters of nanoplaquettes (double and triple loops, 2x2 antidot cluster, etc) the possibilities of the spontaneous change of connectivity are investigated. In films with the PPA pronounced peaks at integer and rational fields have been revealed in magnetization and transport measurements. The peaks are attributed to certain stable vortex configurations, related to the symmetry of the artificial pinning arrays. These configurations can be directly visualised by using different vortex imaging techniques.

PARENTANI, Renaud
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Trans-Planckian dispersion relations and scale-invariance of inflationary perturbations

We question the insensitivity of the predictions of inflationary models with respect to modifications of Planck energy physics. The modification we consider consists in replacing the usual dispersion relation by nonlinear ones. This way of addressing the problem has recently received attention and contradictory results were found. Our main result is to show that the adiabaticity of the mode propagation and the separation of two scales of interest, the Planck scale and the cosmological horizon scale, are sufficient conditions for the predictions to be unchanged. We then show that all models but two satisfy the first condition when the second is met. Therefore the introduction of a nonlinear dispersion is unlikely to have any discernible effects on the power spectrum of cosmological perturbations. [astro-ph/0101451]

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NCSR Demokritos, Athens
Q Rings

We show the existence of new stable ring-like localized scalar field configurations whose stability is due to a combination of topological and nontopological charges. In that sense these defects may be called semitopological. These rings are Noether charged and also carry Noether current (they are superconducting). They are local minima of the energy in scalar field theories with an unbroken U(1) global symmetry. We obtain numerical solutions of the field configuration corresponding to large rings and derive virial theorems demonstrating their stability. We also derive the minimum energy field configurations in 3D and simulate the evolution of a finite size Q ring on a three dimensional lattice thus generalizing our demonstration of stability.

POGOSIAN, Levon
Imperial College, London
CMB bispectrum from cosmic strings

We introduce a new method for computing the CMB bispectrum from active sources and apply it to a model network of cosmic string.

RAJANTIE, Arttu
DAMTP, Cambridge
Defect formation in U(1) gauge field theories

When a phase transition associated with a spontaneous symmetry breakdown takes place in a finite time, topological defects are typically formed. I review the theoretical picture of this phenomenon in Abelian gauge field theories and show how it differs from models with global symmetries. I also present theoretical predictions for the number density and the spatial distribution of defects produced in the phase transition and results of numerical simulations in which these predictions were tested.

RIVERS, Ray
Imperial College, London
How classical defects really form in Quantum Transitions

Defects are classical entities that can only appear after decoherence of the quantum order parameter fields. We indicate how this happens.

SAKELLARIADOU, Mairi
University of Athens
Are cosmic strings really ruled out by the most recent BOOMERanG and MAXIMA data?

The recently released analysis of the BOOMERanG data was taken as ruling out mixed perturbations models. We compare the predictions of a simple mixed perturbations model with the last BOOMERanG, MAXIMA and DASI data. We find that if strings contribute 18%, our predictions are consistent with the data (χ^2 per degree of freedom is of order unity). Our result put constraints on the particle physics models which predict the formation of cosmic strings at the end of an inflationary era.

SHAPIRO, Boris
Bar-Ilan University, Ramat Gan, Israel
Recovery of Superconductivity in Quenched Mesoscopic Domain

The relaxation dynamics of a quenched normal spot in a type-II superconductor is considered analytically and numerically. Different regimes of superconducting nucleation depending on temperature diffusion constant lead to various Abrikosov vortex structures. In particular, a ring-like vortex structure and regular growth of the Abrikosov lattice are possible scenarios.

SLAVINEC, Mitja
Faculty of Education, Maribor, Slovenia
Surface Induced Smectic-A Edge Dislocations

Using a Landau–de Gennes approach, we model the formation of an edge dislocation in a smectic-A cell. The driving force is the mismatch between the layer thickness in a bulk

smectic-A liquid crystal and that imposed by confining plates. The core structure of the dislocation is calculated taking into account spatial variations of the smectic translational order parameter. We numerically determine the critical condition for the surface-driven formation and depinning of the dislocation.

VACHASPATI, Tanmay
Case Western Reserve University, Cleveland, Ohio
Space of kink solutions in SU(N)xZ_2

We find (N+1)/2 distinct classes ("generations") of kink solutions in an SU(N)x Z_2 field theory. The classes are labeled by an integer q. The members of one class of kinks will be globally stable while those of the other classes may be locally stable or unstable. The kink solutions in the q^{th} class have a continuous degeneracy given by the manifold $\Sigma_q=H/K_q$ where H is the unbroken symmetry group and K_q is the group under which the kink solution remains invariant. The space Σ_q is found to contain incontractable two spheres for some values of q, indicating the possible existence of certain incontractable spherical structures in three dimensions. We explicitly construct the three classes of kinks in an SU(5) model with quartic potential and discuss the extension of these ideas to magnetic monopole solutions in the model.

VINK, Jeroen C.
University of Amsterdam
Simulating Quantum Fields after a Quench

We investigate (quantum) field dynamics after a quench in 1+1-dimensional scalar field theory. Before the quench the system is taken to be in its vacuum state. After the quench, the vacuum fluctuations augmented by the spinodal instability, develop into kink-like inhomogeneities. We discuss a new approach to supply the vacuum quantum fluctuations as initial conditions for subsequent classical field dynamics and compare it with the scheme used until now. Furthermore we use the recently developed Hartree ensemble method to simulate the quantum field dynamics after the quench.

VOLOVIK, Grigoriy
Low Temperature Laboratory, Helsinki University of Technology
Vacuum in Quantum Liquids and in High Energy Physics and Cosmology

In a modern viewpoint the relativistic quantum field theory is the emergent phenomenon arising in the low energy corner of the physical fermionic vacuum — the medium, whose nature remains unknown. The same phenomenon occurs in the quantum liquids: In the extreme limit of low energy, the condensed matter system of special universality class acquires all the symmetries, which we know today in high energy physics: Lorentz invariance, gauge invariance, general covariance, etc. The chiral fermions as well as gauge bosons and gravity field arise as fermionic and bosonic collective modes of the system. The conceptual similarity between this class of quantum liquid and the quantum vacuum of Standard Model, which is based on the common topology in momentum space, allows us to simulate in quantum liquids many phenomena related to the quantum vacuum. In particular, experimental verifications of the Adler–Bell–Jackiw equation for axial anomaly; of the Kibble–Zurek mechanism of defect formation; of the theory of electroweak baryoproduction and magnetogenesis have been performed in ultra-low temperature laboratories in Grenoble, Helsinki, Manchester and Lancaster. The inhomogeneous states of the quantum liquid induce nontrivial effective metrics of the space, where the free quasiparticles move along geodesics. This allows us to simulate the nontrivial gravitational field exhibiting the event horizon and ergoregion, and thus to study such phenomena as Hawking radiation and Bekenstein entropy of the black holes. Quantum liquids also suggest possible solution of the cosmological

constant problem: why the vacuum energy is by 120 orders of magnitude smaller than the estimation from the relativistic quantum field theory. The almost complete cancellation of the cosmological constant does not require any fine tuning and comes from the fundamental "trans-Planckian" physics of quantum liquids. The remaining vacuum energy is generated by the perturbations of quantum vacuum caused by matter (quasiparticles), curvature, and other possible sources, such as smooth component — the quintessence. This provides the possible solution of another cosmological constant problem: why the present cosmological constant is on the order of the present matter density of the Universe.

ZUREK, Wojciech
Los Alamos National Laboratory
Open problems in the dynamics of symmetry breaking

I shall discuss dynamics of symmetry breaking, focusing on the problems that offer the possibility of extending applicability of the ideas originating in the cosmological setting such as Kibble mechanism to other physical situations. This theme will also serve as a background for an overview of the meeting.