Research Plan for 2004

Theory Programme, Helsinki Institute of Physics

Programme Director: K. Enqvist

The present Theory Programme consists of five projects:

- Biological Physics
- Cosmology
- Particle Physics Phenomenology
- String Theory and Quantum Field Theory
- Ultarelativistic Heavy Ion Collisions

Because of financial reasons, no call for new projects will be issued in 2004.

1 Project: Biological Physics

Project leader: Ilpo Vattulainen

1.1 General Background

Our aim is to continue and further develop on-going activities in the field of biological physics and soft matter. The activities will be organized jointly by HIP and the Laboratory of Physics at the Helsinki University of Technology (HUT).

The present activitity started in January 2001, when the group leader returned to Finland. The HIP project in turn was initiated in January 2002, after which the activities have developed at a steady pace. Currently our group consists of the group leader and 3 post-doctoral scientists, 3 graduate students, and 4 undergraduate project workers. During the first 9 months of 2003, our group has submitted 10 manuscripts to refereed international journals.

The proposed research program for 2004 involves the application of a variety of theoretical and computer simulation methods to study the physical properties of biological and soft-matter systems. On the one hand, we focus on the development of coarse-graining methods and mesoscopic simulation techniques for multiscale modeling of biologically relevant soft matter systems. On the other hand, our objective is to apply them together with analytical tools to actual biological problems. A few specific examples of our research projects in 2004 are given below:

1.2 Research Plan

- Development of techniques for coarse-graining soft matter systems such as one- and many-component lipid bilayers. The coarse grained models obtained in this fashion will be studied through mesoscale simulation techniques that we develop as well. This comprehensive work is related to multiscale modeling in general and will be part of many (on-going and) future projects.

- Studies of biological cellular membrane systems. The research will include studies of various aspects of lipid membranes: cationic liposomes often used as vehicles of DNA and drugs into the cell; the diffusion mechanisms in lipid-cholesterol bilayers; lipid rafts (heterogeneous membranes with self-organized microdomains) that have been claimed to play an essential role for the function of membrane proteins; properties of small solutes such as antibiotics and alcohol molecules in membranes, and their influence on membrane structure.

- Properties of single biological molecules, molecular entities, and dilute colloids: the dynamics of micelles and liposomes; dielectrophoretic motion in colloids; structural properties of lipoproteins known as transporters of cholesterol; individual proteins in an aqueous and non-aqueous solvent; dendrimers.

Some of the above topics, and in particular in the context of lipid membrane systems, will be coupled to experimental activities when appropriate (work in progress).

Further activities include, e.g., the organization of summer schools, conferences, and workshops, teaching in the field of soft matter and biological physics, popularization of our research field, and networking especially within the European Research Area.

2 Cosmology

Project leader: K. Enqvist

2.1 General background

The development of particle cosmology has been boosted by the accurate measurement of the cosmic microwave background (CMB) temperature fluctuations by the WMAP satellite. This has generated much activity to determine the cosmological parameters from the data. In the Cosmology Project we have focused on isocurvature perturbations, and in particular correlated isocurvature perturbations. Such considerations also serve as a preparation for the science of the ESA Planck Surveyor Mission, which we participate in.

On a more theoretical front, there has been a number of attempts to incorporate string and brane inspired ideas into cosmology. These can be considered as alternatives to the standard inflationary Big Bang universe and as such provide an important backdrop for interpreting the future CMB data.

2.2 Research Plan

- The Project participates in the Planck Surveyor Mission LFI Consortium, where the Project Leader has a Co-Investigator status and is responsible for the coordination of the Finnish scientific participation in Planck. This activity is partially supported by the Academy of Finland/TEKES Antares space science programme and is a joint effort together with Department of Physical Sciences. We participate in the "From map to C_l" task force activities, developing algorithms for destriping the temperature maps; the team leader is doc. Hannu Kurki-Suonio (Phys. Dept.). Contact with the Data Processing Center in Trieste will be maintained by E. Sihvola.

- We plan to consider WMAP and other data and scan the space of cosmological parameters to extract limits on correlated isocurvature fluctuations. CMB polarization studies will also be conducted.

- We study the non-gaussianity of the perturbations in hybrid inflation models. We plan to consider reheating after inflation by taking into account the full backreaction of the produced thermal particles.
- Curvaton models, where density fluctuations do not originate in the inflaton sector, will also be actively studied. Particular attention will be given to MSSM flat directions as curvatons, also in the context of brane world scenarios. Inflationary models based on branes and strings will be studied.

We are part of the EU network "Supersymmetry in the Early Universe". We also belong to a Nordic network. We will collaborate with the McGill University (Canada), Tokyo University, Uppsala University, University of Milano, CNR Bologna, and with the HIP String Theory Project on issues related to extra dimensions. We also interact with the members of the Finnish Planck Consortium (the Observatory of the Helsinki University, Tuorla Observatory, and Metshovi Radio Observatory) on CMB-related matters. In 2004 Finn Ravndal (University of Oslo) continues as a NorFa visiting professor.

3 Particle physics phenomenology

Project leader: Katri Huitu

3.1 General background

The basic interactions of physics are under study in the project. The most pressing current problems in particle physics are the missing link of the Standard Model, namely the Higgs boson, the small, but nonvanishing mass of neutrino, and the origin of CP violation. For the last two new experimental data keep coming in from the neutrino experiments and B-factories, while the mechanism of the electroweak symmetry breaking will most probably be revealed only after the start of LHC. The research done in the project is closely connected with physics accessible at the colliders.

3.2 Research Plan

The research in the project is mostly done in the framework of supersymmetric models or higher dimensional scenarios, which both offer solutions to the hierarchy problem of the electroweak sector.

- A central problem in all supersymmetric models is the breaking mechanism of supersymmetry. The breaking can be parametrized with the so-called soft terms, which do not lead to problems in the scalar sector. These soft terms determine the particle spectrum and thus are of major phenomenological importance in the models. The work on the consequences of the different breaking methods is in progress.

- Supersymmetric models can have a number of new sources for CP violation. We have studied time dependent CP violation in the decay $B \to \phi K_S$, for which experimental results seem to hint that beyond the Standard Model physics is involved. The study will be expanded to other decay modes, and the effects of more refined treatment of hadronic matrix elements will be studied. The possibilities for spontaneous CP violation in connection with the R-parity breaking are being studied.

- The most crucial effects of extra dimensional models may be changes in the production and decay of the Higgs boson. This has been studied in the case of small extra dimensions and is being studied for large extra dimensions, where the effects are qualitatively different due to the large density of the Kaluza-Klein states.

- In addition to B-physics experiments, neutrino experiments have brought new information on particle properties. The implications of new neutrino data will be studied, especially in grand unified scenarios.

The group will continue to participate in a Nordic collaboration on the physics studies about LHC. With several other groups we have a common EU-network application on physics at LHC. We also participate in an EU-network "Probe on new physics". In addition, there are on-going collaborations with researchers from several universities and research centres.

4 String Theory and Quantum Field Theory

Project leader: Esko Keski-Vakkuri

4.1 General background

String theory derives from the particle physics tradition of trying to understand physics at ever smaller scales. However, coming back from the bottom has not proven to be so easy: the derivation of quantities like the mass of the electron or any of the Standard Model parameters from string theory is still up in the air. On the other hand, string theory has been more powerful as a theory including gravity. It has provided us the first microscopic derivations of the entropy of black holes, and given us concrete models of the conjectured holographic property of gravity. So it is natural to wonder if the problem of deriving concrete predictions from string theory could be met with more success in the context of cosmology. In the meantime, while "traditional" cosmological models have proven to be succesful in explaining the astrophysical data, it has become more of an accepted view that the models are essentially phenomenological with more fundamental physics hiding somewhere underneath. Thus it is no surprise that during the past couple of years there have been increasingly many conferences, workshops, and meetings including the words "string" and "cosmology" in their titles. But, for string theorists, it has also become increasingly clear that our knowledge of properties of string theory in time-dependent backgrounds is still at infancy.

4.2 Research Plan

- The easiest way to construct toy "cosmological" backgrounds in string theory is by identifying points on the known ones. Such Lorentzian orbifold constructions were studied intensively recently. It turned out that many such constructions yield regions with closed causal curves, so it also become apparent that little is known in regard to Hawking's famous chronology protection conjecture in string context. We studied one such class of backgrounds, also known as the embedding spaces of the elliptic de Sitter spaces, and found ways to deal with the closed causal curves that seem to crop up at the outset of the construction. We found new appropriate ways to define time in Lorentzian orbifold constructions, and to formulate quantum field theory in them. This investigation was not yet fully extended to interacting theories, so further studies are in the plans.

- Another, very interesting angle on time dependent phenomena in string theory comes from the study of decaying unstable brane configurations. This goes by many names, "rolling tachyons", "S-branes", and such. This is a fascinating area with many promising physics outcomes such as a new form of dark matter, new models for inflation, and a holographic model for de Sitter space. We are currently investigating string scattering from decaying branes. Preliminary results hint at a new duality between such backgrounds and classes of random matrix models. There are also interesting links to modern results on mathematical analysis. It seems that this is a truly rich area to explore and we plan to continue this investigation, in particular to understand the duality better. Another related topic is to investigate stacks of S-branes, with the idea that such stacks could give rise to meaningful cosmological backgrounds while providing microscopic string models for them. We have also planned to develop a Lorentzian counterpart of the so-called fractional D-branes, as S-branes trapped at singularities of Lorentzian orbifolds. Finally, we also plan to explore the tachyon dynamics -motivated cosmological brane world scenarios in collaboration with members of the Cosmology project.

- Another related topic, actually the first example of a holographic theory, is the relationship between matrix models and Liouville theory which provides a nontrivial example of two-dimensional quantum gravity. Recently a version of this system was shown to model rather accurately the classical features of de Sitter backgrounds and inflation, and quite surprisingly there were many parallels with the lessons learned from matrix models studies. Our target for this year is to further this understanding by considering the quantum mechanical version of the system and how the classical geometry is recovered. There is hope to clarify the recent statements about the implications of the finite entropy for de Sitter as well as the mechanisms of chaotical/eternal inflation.

- We are also starting a program of translating some recent useful techniques for calculating correlation functions in boundary conformal field theories, into a method to calculate scattering amplitudes from D-branes in curved geometries.

We plan to invite several visitors for 2004 (typically we have 10-20 visitors annually). Also we will have two long term visiting professors: prof. Ulf Lindström from Uppsala University will spend several months at HIP in 2004, and prof. Peter Presjnader from Comenius University will spend most of the first half of 2004 at HIP. As far as networks go, we are a member of the Nordic Project network in String Theory. Its main activity is biannual workshops specially geared towards educating graduate student

5 Ultrarelativistic Heavy Ion Collisions (URHIC)

Project leader: Kari J. Eskola

5.1 General background

Our research programme covers the description of URHIC from primary production of QCD quanta and formation of the QGP to final state observables measurable in the experiments at CERN and BNL. Our URHIC phenomenology studies apply perturbative QCD, Yang-Mills equations of motion and relativistic hydrodynamics. On the other hand, we explore the basic properties of the QGP both through effective models and through first-principles calculations using the latest computational techniques.

5.2 Research Plan

- We have successfully predicted the multiplicities and described the bulk of the hadron spectra in central Au+Au collisions at RHIC by taking the initial QGP densities from pQCD+saturation and describing the spacetime evolution of the system by hydrodynamics. Armed with the RHIC constraints, we will next predict the bulk hadron spectra in Pb+Pb at the LHC. Already started for the CERN Hard Probes Collaboration (HPC), studies of chemical equilibration of gluons and quarks will be carried on. Flow and its anisotropies in non-central collisions requiring recently developed azimuthally asymmetric hydro codes, will be explored further. On our list are also particle correlations (HBT). Work towards 1+3 dimensional hydro code is in progress.

- Once the bulk hadron spectra are under control, thermal production of electromagnetic probes of the QGP can be computed and predictions for RHIC and LHC can be presented; activity already started for the HPC in collaboration with Saclay and Annecy.

- Recently, primary gluon production from classical fields in the color-glass-condesate model was computed *correctly* for the first time by Lappi, making thus the phenomenology of the QGP initial state work much better. The next problem being addressed is the creation of (anti)quarks from these fields. Collaboration with Saclay.

- We continue the studies of parton distributions (PDFs) and hard QCD processes. In addition to global pQCD (DGLAP) fits of the nuclear PDFs, we study the nonlinear effects in the scale evolution. Consequences for gluon saturation will be considered. Extension to NLO is on our working list. Collaboration: Iowa State, CERN/TH, HPC.

- The observed suppression of large-p_T hadron spectra in central Au+Au at RHIC will be analyzed in detail on the basis of our previous pQCD+factorization study and in terms of energy losses of energetic partons in the QGP. Collaboration with CERN/TH.

- One significant project has been completed recently: the computation of the QCD free energy to order $g^6 \log(g)$. This has required extensive computations of 4-loop diagrams with symbolic computational methods. One will next proceed to the numerical lattice Monte Carlo computation of remaining non-perturbative effects.

The free energy computations, both for QCD and for electroweak theory, have also been extended to situations when a finite net baryon or lepton number density exists. Many significant problems remain and will be solved.

Active visitor program continues. We also organize the Strong&Electroweak Matter -meeting in Helsinki in June 2004.