Pre-Proposal for a Workshop at KITP for Spring 2010

on

Strings at the LHC and in the early Universe

Coordinators:

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Abstract: In the next few years the *Large Hadron Collider* (LHC) at CERN will for the first time probe physics at energy scales more than an order of magnitude beyond that of the Standard Model. This experiment will explore an energy regime of particle physics where phenomena such as supersymmetry and Grand Unified Theories may become relevant. Certainly, the LHC should shed light on the mechanism of electroweak symmetry breaking and may discover the first fundamental scalar particle seen in nature. Currently, although we have a myriad of proposals for how physics behaves beyond the Standard Model, we have little theoretical guidance as to which of the many possibilities is realized in nature. String theory provides a theoretical arena in which different compactifications, or vacua, of the theory realize many of these different possibilities for beyond-the-standard-model physics. Indeed, many of the ideas currently used in so-called "model building" have their origins in string theory. Recent developments in string theory at the interface with particle phyiscs have led to an improved understanding of at least some part of the set of possibilities for observable physics which can be realized in string theory. The advent of the LHC provides a unique opportunity to make a concentrated attempt to relate observable phenomena to structures found in string vacua, and to find concrete ways in which string theory may have predictions or constraints for observable physics.

Recent work in the study of string vacua has also led to substantial progress in understanding how observable cosmology can be reproduced in string models. While recent experimental evidence favors primordial inflation, it has proven surprisingly challenging to construct large classes of string models with this property. Moreover, with the launching of the PLANCK satellite this year, it will hopefully be possible to measure gravity waves from the early universe. The measurement of the primordial tensor fluctuation offers an exciting prospect for testing or constraining string models based on cosmological observations.

The aim of the proposed workshop is to bring together world experts working at the interfaces of string theory, particle physics and cosmology. We would focus on the one hand on advancing techniques and new physics insights that string theory can bring to particle physics and cosmology, and on the other hand on what new data from the LHC and cosmological observations can say about the space of vacuum possibilities realized in string theory. Topics of interest would include recent advances in the non-perturbative study of string vacuum solutions, features of supersymmetry breaking scenarios and new developments in string cosmology. This workshop would be timed to maximize the possibility of concrete success in connecting string models to new observable particle physics and cosmology.

Time and budget: The ideal time for this long workshop would be spring 2010.

Scientific context and objectives

String theorists have been working for several decades now on understanding how four-dimensional physics, as described by the Standard Model of particle physics or other low-energy field theories, can arise from ten-dimensional string theory (or it's alter ego, eleven-dimensional M-theory). Many possibilities have been explored ranging from conventional compactifications on string scale compact internal manifolds to large extra dimensions with low string scales and warped compactification. All these classes of string "vacua" lead to different patterns of observed phenomena at the scale tested by the LHC. In recent years there has been an intensification of work on understanding more precisely the range of possible mechanisms available for constructing string vacua and the phenomenological consequences of these vacua. The prospect of new data in the next few years, either from the LHC or from cosmological data, which may give hints regarding supersymmetry breaking, the low-energy scalar content of the theory, or other features of physics beyond the standard model, sets the stage for possible dramatic progress in understanding how string theory may describe these features of TeV-scale physics.

This proposed workshop would be timed to coincide with a period of intense activity in the experimental particle physics community associated with the running of the LHC. Whether or not substantial new experimental results have been achieved at the time of the workshop, it should be an optimal time to make a serious attempt to make a connection between string vacua as we can best understand them and possible new physics at the LHC scale and beyond. We believe that the activity on the experimental side will focus much of the energy of the string community over the next few years on concrete aspects of model building, so that the string community working at the interface with particle physics will be "primed" at the time of the workshop for an intensive period of activity and attempts to connect to experimental particle physics, as well as ongoing cosmological experiment.

Although there was a string phenomenology workshop in Fall 2006, we believe that by Spring 2010, new developments in string theory at the interface with particle physics will have been significant; many new ideas will have entered the theoretical arena, and the focus of the string community will be on particle physics connections. Therefore, it will already be time for a new look at many of the questions addressed in the Fall 2006 workshop, as well as new questions which will arise in the coming years as the LHC goes into its full experimental research program.

It is worth mentioning some of the recent interesting progress in understanding string compactifications:

- In recent years our understanding of string compactifications leading to chiral theories in 4D, like heterotic strings on Calabi-Yau manifolds equipped with certain vector bundles has progressed.

- Another approach to chiral theories in 4D proceeds through D-brane constructions involving intersecting D6-branes in type IIA orientifolds or magnetized D9-branes in type I. Many such models have been constructed in recent years, including a formalism for deriving the low-energy effective action of these models. Study of nonperturbative string effects such as D-instantons has led to recent intense activities in the study of supersymmetry breaking effects and the generation of new charged sector couplings, which introduce a new hierarchy of scales to these theories.

- For a realistic string vacuum, massless scalars must be lifted from the theory by dynamically stabilizing the moduli present in most known string compactifications. In recent years mechanisms for stabilizing moduli, nonperturbatively in type IIB and at tree level in type IIA, have been explored. This has given rise to large classes of phenomenologically interesting string vacua. Recent work on these classes of vacua has focused on understanding nonperturbative effects and SUSY breaking phenomena in these models which would be important in connecting to physics potentially observable at the LHC. Another important thread of recent research on these models has involved understanding how inflation can be realized in models with stabilized moduli. It has proven remarkably difficult to achieve a "slow-roll" inflationary model in any controlled string vacuum, suggesting that cosmology may be an important arena in which to assess the viability of string vacua.

- In recent years, enormous new classes of string vacua have come under consideration. Applying T-duality and other string dualities to understood flux compactifications has led to new manifolds with so-called torsion, and other more exotic string compactification possibilities. Some of these spaces are geometric, though not Calabi-Yau, and have been recently studied by mathematicians as well as physicists. Other new compactification spaces, where the transition functions among different charts can include duality symmetries affecting the geometric structure of the space have been explored. These generalized compactifications are poorly understood so far but may be associated with enormous classes of genuine string models without a large radius limit.

All of the developments just listed have provided a deeper understanding of the structure of allowed string vacua. These recent developments have begun to probe important properties of the low-energy theory related to supersymmetry breaking and cosmology, which may be relevant to physics which will be seen in forthcoming experiments. In particular, the underlying mechanisms of supersymmetry breaking and mediation of supersymmetry breaking is a domain of intense research both in string and in field theory. This topic is especially timely and relevant in the context of the LHC experiments. One aspect, which may well be answered early in the LHC running, concerns the scale at which supersymmetry is broken for the ordinary particles, and whether their supersymmetric partners are already present at the TeV scale. If they are, then their pattern of masses will strongly constrain the possibilities for the underlying supersymmetry breaking and mediation mechanisms. Another issue is whether the particles and interactions observed at the TeV scale are just those of the standard model or its minimal supersymmetric extension, or whether there are extended Higgs, gauge, or matter sectors. The latter are suggested by many string compactifications, and would have important implications not only for LHC physics, but also for the possibilities for cold dark matter, neutrino mass generation, and whether the baryon asymmetry of the universe could have been created at the time of the electroweak phase transition. There is a tremendous need to improve the state of the art in supersymmetric model building concerning these and other issues, both from top-down and bottom-up perspectives, and in light of expected LHC discoveries and constraints.

The core of the plan for this program is to bring together people from the string community studying the phenomenology of string compactifications with others from the particle physics community focused on LHC-related phenomenology to critically assess the prospects for direct connections between string theory and phenomenological observations at the LHC, after about 1.5 years of running. In particular, we would like to focus on detailed studies of how the ideas motivated or derived from string theory have been tested or can be tested in the future, and how specific structures found in string vacua may relate to patterns of observed phenomena at the LHC.

A second related direction we would like to pursue at the workshop involves connections between string theory and cosmology. A realistic string compactification must not only connect with observable particle physics, but must also give rise to a realistic cosmology, including, we believe, primordial inflation. There may be correlations between the kinds of particle physics which can be realized in string vacuum models and the possibilities for cosmology. Upcoming astrophysical and cosmological experiments such as the PLANCK satellite mission, which will not only measure the fluctuations of the cosmic microwave background with new precision but also the primordial tensor modes— i.e. the gravity waves from the early universe— promise to provide an additional point of contact for understanding the cosmology of string vacua. For example, models proposed so far favor scenarios that predict that PLANCK should not detect any tensor modes. Therefore, a detection of tensor modes by PLANCK would create a challenge for string motivated inflationary models. PLANCK will also measure possible non-gaussianity in the microwave background. Some string models make predictions for observable non-gaussianity, so these observations will play another important role in constraining the space of string vacua. Since there is much overlap between the communities working on phenomenological aspects of string compactifications and those working on cosmological aspects thereof, and since these research programs are asking closely related questions, we believe it is natural to address both classes of questions in the same workshop.

In summary, we want to bring together in 2010 a group of people including the world's experts in string compactification and phenomenology, particle physicists involved in LHC physics, and inflationary cosmologists, to make a serious stab at connecting string theory to observable physics. We think the time and the questions will be right. Needless to say, many of the detailed issues being addressed currently, such as some of those mentioned above, may not be the precise points of focus for a workshop several years hence–in the next two years as the LHC comes online the theoretical landscape and questions of interest will probably change considerably, but it seems certain that whatever questions are of most interest, this will be a unique opportunity to try to for the first time make a concrete connection between string theory and nature.

3. Sample of expected participants

We have contacted the people below, who have expressed interest in attending the workshop for the periods of time stated (no time listed for key participants who responded expressing interest in attending but did not specify time availability). With the understanding that most of the mentioned colleagues have contributed to more than one of the specified topics and that these topics have considerable interrelations, we have grouped the names roughly according to research area as follows:

- **String model building:** Ignatios Antoniadis (CERN) [few weeks to a couple of months], Melanie Becker (Texas A&M), Dieter Lüst (Munich), Fernando Quevedo (DAMTP, Cambridge) [as long as possible], Elias Kiritsis (Ecole Polytechnique) [1-2 months], P. Nilles (Bonn) [a few weeks or more]

- **General string vacua** Shamit Kachru (Stanford) [one or more months], Joe Polchinski (KITP), Eva Silverstein (Stanford), Lenny Susskind (Stanford) [spring quarter]

- **String/LHC Phenomenology:**

  Michael Dine (UCSC) [a number of weeks], E. Dudas (Ecole Politechnique) [3 weeks], Lian-Tao Wang (Princeton) Kwoon Choi (Seoul U.) [a month or longer], G. Kane (Michigan U.) [a few weeks] Johnathan Feng (UC Irvine) [2 weeks], Joe Lykken () [3 weeks], Yasunori Nomura (Berkeley) [a month or two]

- **Inflationary cosmology:** Robert Brandenberger (Toronto U.) [longer term visit from April], Alan Guth (MIT), Renata Kallosh (Stanford), Andre Linde (Stanford)

- **String cosmology:** Sandip Trivedi (Tata) [at least a month] Liam McAllister (Cornell) [3 weeks]

The potential community of string theorists + phenomenologists + cosmologists potentially interested in this program is enormous, so we have tried to poll a representative sample in each area to get a sense of the level of interest in this program.

Virtually everyone we have heard from regarding this proposed workshop has been very enthusiastic about the proposed program and timing. Here are some extracts from the email we have received from the key participants mentioned above:

From: **Melanie Becker** ⟨mbecker@physics.tamu.edu⟩

Such a program is a great idea, I would love to attend.

From: **Robert Brandenberger** ⟨rhb@hep.physics.mcgill.ca⟩

Thanks for your invitation. I am very interested in participating. I would in fact be interested in a longer term visit (our winter semester ends at the beginning of April).

From: **Kiwoon Choi** ⟨kchoi@muon.kaist.ac.kr⟩

Thank you for informing your proposal for KITP program. I fully agree that your proposal is timely and will offer an exciting opportunity for us... As for the possibility of my participation, I will be very much interested in attending probably for a month (or even longer if I could have a sabbatical year at 2010 as I am currently planning).

From: **Michael Dine** ⟨dine@scipp.ucsc.edu⟩

While it is not possible for me to plan reliably quite this far in the future, I would certainly be interested in such a program and would be very likely to participate. I would probably participate as a commuter, coming three-four days a week for a number of weeks during the program.

From: **Emilian Dudas** ⟨dudas@cpht.polytechnique.fr⟩

It would be a great pleasure for me to participate to such a KITP workshop in 2010. I would be interested to participate for 3 weeks.

From: **Jonathan Feng** ⟨jlf@feng.ps.uci.edu⟩

I'd be happy to take part in this, but unfortunately, probably only for a 2 week visit (subject to the significant error from my prognosticating about 2010). I hope it goes through!

From: **Shamit Kachru** ⟨skachru@Stanford.EDU⟩

You can definitely include me as a potentially interested participant, if the stars aligned I would be happy to come for month(s) or more.

From: **Renata Kallosh** ⟨kallosh@stanford.edu⟩

Both Andrei Linde and I find the idea of this workshop and the timing very appropriate. Hopefully in 2010 we will have both LHC data and new cosmology data available... We would like to participate in the workshop. The actual time of participation may be limited due to our teaching obligations, we do not know yet our possibilities, otherwise such workshop would be most attractive to us.

From: **Kane, Gordon** ⟨gkane@umich.edu⟩

As you know, I very much share the goals you have described. I would be happy to participate in such a program if it went ahead. I would be constrained by teaching, but I would hope to come for a few weeks.

From: **Elias Kiritsis** ⟨kiritsis@cpht.polytechnique.fr⟩

I would be glad to participate in the the workshop, and I expect that I could be there for 1-2 months

From: **Dieter Luest** ⟨dieter.luest@lmu.de⟩

many thanks for your mail. This program sounds very exciting, and I definitely would like to participate. So please count on me.

From: **Joseph Lykken** ⟨jlykken@gmail.com⟩

I would certainly attend. Probably for 3 weeks.

From: **Liam McAllister** ⟨liam@lepp.cornell.edu⟩

This program sounds great to me. I doubt I'll be free for the entire semester, but something like three weeks of participation may be manageable. I hope the program indeed takes place.

From: **Hans-Peter** Nilles ⟨nilles@th.physik.uni-bonn.de⟩

thank you for the information. I find this suggestion an excellent idea and would like to support it…I am definitely interested in participating for the duration of a few weeks or so (and I might check even for an extended time, depending on my teaching obligations).

From: **Yasunori Nomura** ⟨YNomura@lbl.gov⟩

Thanks for the e-mail. I am interested in attending as long as I will be able to, presumably of order a month or two.

From: **Joe Polchinski** ⟨joep@kitp.ucsb.edu⟩

This sounds excellent, and I would of course enjoy participating.

From: **Fernando Quevedo** ⟨F.Quevedo@damtp.cam.ac.uk⟩

I think it is a great idea…I would try to participate as much as possible. At the moment I don't know what I would do that year since it is right after my sabbatical, but would be very interested to participate and stay as much as possible.

From: **Eva M Silverstein** ⟨evas@stanford.edu⟩

Thanks – it sounds very interesting and I'd be happy to be included as a likely participant

From: **Leonard Susskind** ⟨sonnysusskind@gmail.com⟩

It sounds like an excellent and timely idea. If the plan works out I hope to be able to participate for the entire spring quarter.

From: **Sandip Trivedi** ⟨trivedi.sp@gmail.com⟩

This is a great idea. It will be important to have a workshop in 2010, a year or so after the LHC has gotten going. I am very keen to attend and would like to come fo at least a month.

From: **Lian-Tao Wang** ⟨lianwang@Princeton.EDU⟩

Sounds like a very interesting workshop on exciting topics. I will make every effort to participate.