Eur Phys J C **33**, s01, s906–s907 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2003-03-1101-9

EPJ C direct
electronic only

String theory

A short overview

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Received: 28 October 2003 / Accepted: 7 November 2003 /
Published Online: 25 November 2003 –

Abstract. A short overview of 35 years of string theory is given.

1 The first string revolution

The first string revolution occurred 35 years ago. At that time we tried to find realizations of the S-matrix and it had been realized that the description of Regge poles and direct channel resonances are dual to each other. Then at the Vienna Conference of 1968 Gabriele Veneziano [1] proposed an amplitude for the scattering of 4 pions that satisfied this duality. This was the start of the 'Veneziano Model' or as it would be called later 'The Bosonic String Model'. The model had linear trajectories and Regge behaviour and it started a real revolution. Shortly thereafter the model was generalized to N-point amplitudes by Koba and Nielsen [2] and within two years it was realized to be amplitudes for the scattering of strings by Nambu, Nielsen and Susskind [3].

The next great breakthrough came in 1971 when Pierre Ramond [4] generalized the Dirac equation to strings. He had realized that the Veneziano Model was based on a string generalization of the Klein-Gordon equation. This led to fermionic strings. Shortly afterwards Neveu and Schwarz [5] generalized the Veneziano Model and got a new bosonic model. It was within two years realized that the two models were unified into one with both bosons and fermions and had massless spin-1/2, 1 and 2 particles and the critical dimension was 10 [6]. The latter particles could describe gravity but at that time the model was still regarded as a model for the strong interactions and the successes of QCD at the time made the interest for string theory fade away for almost all but for a few die-hards.

2 The second string revolution

In 1984 Green and Schwarz [7] showed that certain of the 10-dimensional string theories were indeed anomaly free and could describe a unified theory of gauge and gravity theory. One found five seemingly consistent theories known in perturbation theory and all seemingly perturbatively finite. This started the next revolution. There was an enormous activity and hope that we were close to finding the ultimate theory. Now, 19 years later and 35 years after Veneziano's paper it is appropriate to ask how far we have come and how much of the hopes of that time that have been realized. In this overview i follow to some extent the concluding talk by David Gross at Strings'03.

2.1 What is string theory?

The string theories were found as perturbation series and the most important fundamental question is what is the underlying principle. What is the generalization of the equivalence principle? Here we have seen no progress. We need a principle at the quantum gravity level and we cannot refer to classical ideas here. This is the challenge!

2.2 How many string theories are there?

In 1994-1995 the third string revolution accurred [8]. It was realized that all the five string theories together with an 11-dimensional model with supergravity as the low-energy limit are all dual to each other. This means that they are all just different perturbation series around different vacua of the same underlying theory. This created again an enormous activity. Although not strictly mathematically proven this fact was shown in many cases and led to new insight into the non-perturbative behaviour of string theory, since by duality such ones can be obtained by simple perturbation calculations in a dual theory. It also showed that the 11-dimensional model named 'M-theory' could be the underlying model we are looking for. It still lacks a proper description. All these investigations did heavily use the properties of branes [9], solitonic states in the theories.

A further dramatic insight came when Maldacena [10] showed another kind of dualiy between string theory and the maximally supersymmetric gauge theory in four dimensions. Is this model, properly understood, the ultimate model we look for?

2.3 What is string perturbation theory?

String perturbation theory is very different from field theory perturbation theory. One diagram could give the whole contribution to that order. This makes it easier to prove finiteness at a certain order. Finiteness is essentially proven [11] and the perturbation expansion has again come into the limelight with the dualities mentioned above.

2.4 How do we compute in string theory?

Here we have seen an enormous progress. Many different schemes have been developed, such as the use of matrix models [12], the heavy use of (BPS) branes, F-terms [13] and string field theory, especially the use of tachyon condensates [14]. Also the use of the dualities mentioned above give huge insights. However, lacking a fundamental formulation, we still do not have general methods to compute.

2.5 What is string phenomenolgy?

In the beginning there were some very promising progress. However, the more we have learnt the more freedom we seem to find and there is still no conclusive phenomenology.

2.6 What is string theory at very high energy?

What happens at the Planck scale and beyond? We do not know. There are signs of a phase transition [15], which is a very attractive scenario. Perhaps we cannot reach the initial singularity since we change the phase before we reach it. This is very much connected to the detailed understanding of the underlying theory which we still lack.

A very interesting aspect though is the computation of the entropy of certain black holes within string theory [16]. This shows that black holes can exist in a unitary theory.

String cosmology is a very interesting emerging subject. However, it is too early to know what we can expect here.

2.7 What is the correct string theory vacuum?

There has been no real progress here. Instead it has been realized that within our present knowledge there might be a huge number like 10^{1000} possible vacua. This fact has led some people to argue for the anthropic principle [17]. However, I think it is against all the spirit that we have put into the field and all the previous successes that we have seen, to believe in it. Only time will tell who is right here.

2.8 Does string theory have distinctive predictions?

If string theory or rather M-theory is the fundamental theory there should be distinctive predictions from it. So far it has shown the possibilty that some surprising results could be distinctive. One such feature is the possibility of large extra dimensions [18]. They are a logical possibility and there is activity to see if they can be found already at present accelerator energies.

3 Towards a new string revolution?

The progress has been quite substantial over the last 35 years but we still lack fundamental insight. We know a lot about many calculational techniques but we probably need still another revolution. When or if it will come only history will tell.

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