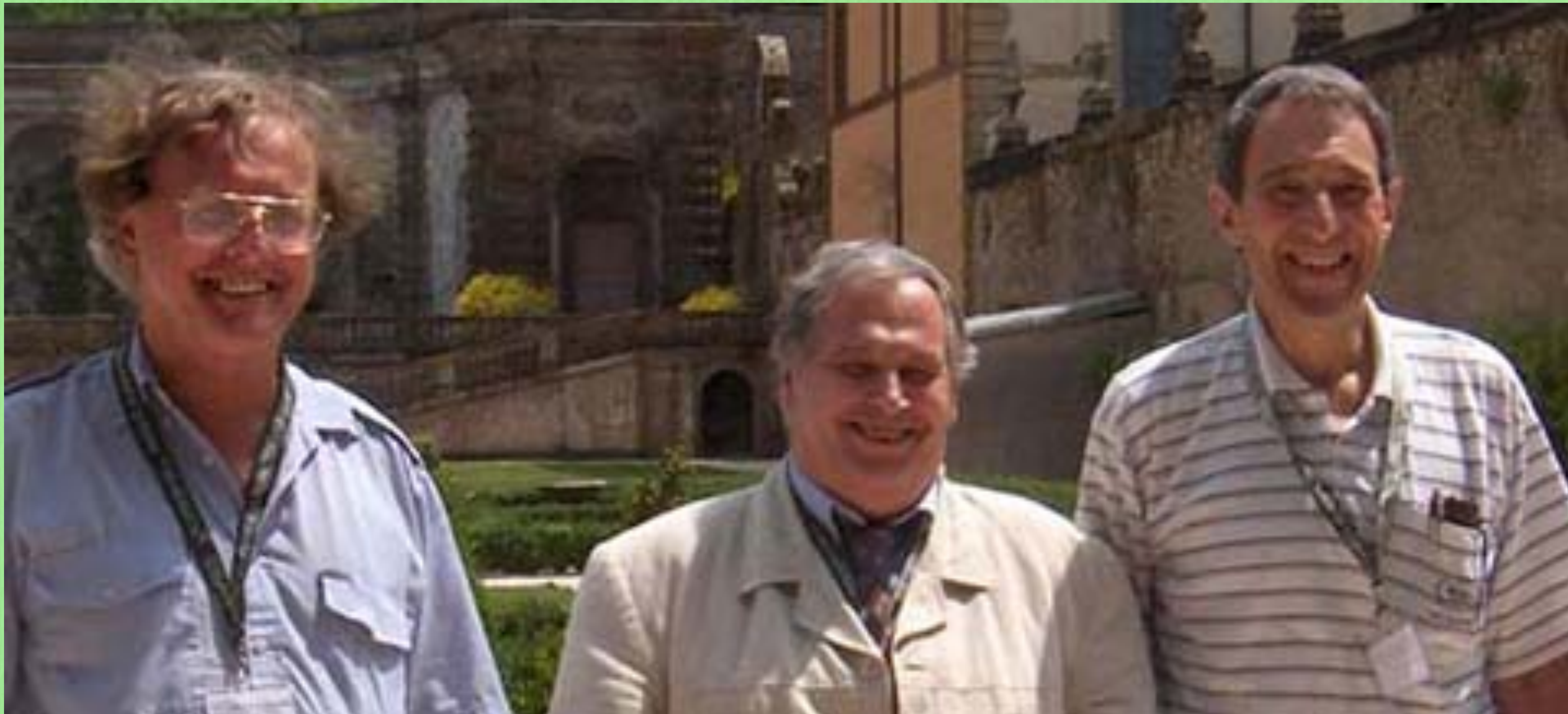

CELEBRATING SUPERGRAVITY AT 40

24 JUNE 2016 CERN

OPEN PROBLEMS AND OUTLOOK

BERNARD DE WIT NIKHEF AMSTERDAM UTRECHT UNIVERSITY

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ESPECIALLY ABOUT THE FUTURE !

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ESPECIALLY ABOUT THE FUTURE !

Supergravity was enormously succesfull from the very beginning. It soon attracted a large number of talented researchers and the field developed quickly.
I will start with a short overview of its accomplishments during the first eight years.

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coupling of fermions to gravity; fermionic gauge fields
tetrad fields (vielbeine)
torsion and other geometrical features
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Superspace, superfields, supergraphs

(off-shell) counterterms
superspace geometry
N=4 Yang-Mills vanishing three-loop beta function
one-loop supergravity corrections, etc.

Extended supergravities

classification based on massless N-extended supermultiplets
the spin-2 barrier: N can be at most equal to 8
beyond N=4 there exist no matter supermultiplets
(some of these conclusions may perhaps be evaded for infinite field configurations)
non-compact symmetry groups
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anti-de Sitter groundstates

Kaluza-Klein supergravity

consistent truncations; possible uplifts to higher dimensions (recurrent theme)
residual supersymmetry in lower dimensions
dimensional reduction and its modification

Matter couplings

by iteration ('Noether method')

in many cases this is still the only method available

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the issue of auxiliary fields

different off-shell formulations

compensating multiplets (also in superspace)

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Conformal supergravity

interesting in its own right

backbone of the superconformal multiplet calculus

Quantization issues

quartic ghost terms

related to a lack of off-shell closure of the gauge algebra

in an off-shell theory the quartic ghost terms are induced when
integrating out the auxiliary fields

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Higher-D barrier

supergravity is not possible beyond 11 dimensions

construction of D=11 supergravity

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I will sketch some selected developments after 1984 that were based on supergravity in the modified perspective.

Sugergravity is the 'low-energy' action of string theory

- Therefore supergravity and string theory share the same DUALITY symmetries. These are
electric-magnetic dualities (S-duality: strong/weak coupling) and
T-duality (momentum/winding).

These dualities are reflected in the various supergravity Lagrangians that have been derived.
Note: for supergravity integer-valued duality groups are not automatic

From the string amplitudes one can extract an effective action that describes the same S-matrix elements. This has originally been done for graviton-graviton scattering.
To do this for supergravity is more complicated, because these actions will contain higher-derivative couplings. Many results have been obtained using various techniques and have been very useful.

- Sometimes unexpected phenomena are discovered in supergravity without any obvious explanation, whose underlying origin can be understood in the context of string theory. One of them concerns the so-called c-map according to which certain 3D N=2 supergravity systems can be uplifted to 4D in two inequivalent ways.

In string theory this can be explained by noting that 10D string theory compacitfied on a circle has two different inequivalent decompactification limits corresponding to either the momentum modes or the winding modes becoming massless. Upon a (supersymmetric) compactification on a CY manifold times a circle one thus recovers the IIA and IIB decompactification lin the uplift to four dimensions!

This is therefore a manifestation of ‘string-string duality’ in supergravity.

- The supermembrane was constructed in superspace, which is only consistent in an 11D supergravity background. It was proven that the spectrum of the supermembrane was continuous, which was at first seen an unwelcome surprise. Until later when it was realized that the continuous spectrum could be interpreted in the context of D0-particles.

  The supermembrane preceded the so-called Dirichlet branes. There have been many studies of world-volume brane actions.

  It was quite unclear fore some time how 11D supergravity could have any relation with string theory.
  Eventually it was understood how 11D supergravity has an interpretation in string theory as the strong-coupling limit of IIA string theory. The arguments leading to this conclusion were based in part on Kaluza-Klein theoretical ideas.

☀ The perspective of effective actions became especially prominent in maling the major advances to N=2 supersymmetric gauge theories based on exploiting both supersymmetry (holomorphicity) and electric-magnetic duality.

Because of these developments the issue of the possible finiteness of supergravity became less urgent and almost disappeared! Until it reappeared much later when explicit higher-loop calculations were being performed.........).

Further information on supersymmetric gauge theories was obtained from brane constructions, geometric engineering and the like, and most recently by localization (in curved spaces).

AdS/CFT integrability and the gauge-string correspondence has opened a window where exact additional results can be derived for superconformal gauge theories. It is not possible to do justice to this topic in the context of this talk and it is also somewhat removed from supergravity. But it should be included here as an example of how the overlap between string theory/supergravity (IIB strings moving in an $\mathrm{AdS}_5 \times S^5$ background), and other features such as integrability can lead to amazing results.

- General gaugings can be studied by making use of a so-called embedding tensor, which defines the embedding of the gauge group into the maximal rigid symmetry group of the supergravity. The approach is based on the fact that the embedding tensor must belong to a specific representation of the rigid symmetry group, subject to two group-theoretical constraints. This necessarily leads to a hierarchy of p-form fields.

For the maximal supergravities the representations of the various p-forms turn out coincide with the representations one finds in M(atrix)-Theory compactified on a torus.

The bosonic interactions that involve the p-form fields of the tensor hierarchy (group-theoretically encoded in the embedding tensor) follow from the invariance under the generalized tensor gauge transformations without relying on supersymmetry!

One of the surprises discovered in this approach concerns the existence of a continuous degeneracy of SO(8) gaugings of N=8 supergravity which cannot be uplifted to 11 dimensions, at least not to the known supergravity!

The fact that the interactions of the p-form fields do not just follow from supersymmetry, but are derivable from the p-form gauge transformations, is an essential element in the recently proposed framework of exceptional geometry: a supergravity theory with extra coordinates belonging to a representation of the U-duality group. These extra coordinates are (partially) suppressed by a covariant section constraint (inspired by double field theory).

All these developments have a considerable impact on the issue of consistent truncations/uplifts. This starting points of this approach is quite different to that of generalized geometry. In practical applications they seem to be complementary.

- Another topic concerns charged black holes in supergravity and string theory of the Reissner-Nordström type. When the charges become (uniformly) large (so that one is in the thermodynamic limit) then the result for the entropy as calculated in string theory (à la Boltzmann) is expected to match the Bekenstein-Hawking entropy of supergravity. This has been confirmed in many cases. It is fair to say that this represents practically the only situation where black-hole thermodynamics can be studied (and explained) on the basis of the microscopic (string and brane) states.

  There have been a number cases of BPS black holes where the relation between the microstate degeneracies and the macroscopic results from supergravity are in exact agreement. On the field theory side it requires the introduction of higher-derivative couplings and on the string side one has modular forms.

  One has also made use of localization techniques to capture the non-perturbative contributions.

OUTLOOK

As indicated there is a rich variety of topics and research questions ahead. Some of them may be quite difficult or perhaps close to impossible, but when one considers matters from a historic perspective there is no reason to pessimism.

Admittedly, the question about the relation with the physical world remains an issue. Perhaps ‘Nature knows of our efforts’ but it is not yet possible to inform us about it for whatever reason. After all, we have no solid arguments indicating why and at which energy scale supersymmetry should manifest itself. I do think we have strong theoretical arguments that that supersymmetry should eventually show up, but unfortunately that is not of direct practical use.

On the other hand, we live in a world where we can observe the collision processes of black holes, where colliders produce data with unprecedented energies and luminosities. Where new observational tools are constantly invented. Where Nature itself shows us that, indeed, there are still very important and interesting questions that are worth pursuing!

As a community we therefore have a duty to connect our beautiful theoretical ideas to the world of experiments. Some of us are working on these questions but unfortunately there is no unique scenario as yet. The desired experimental signals could come form particle colliders or from elsewhere in the cosmos. Which makes it even more interesting!

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Congratulations to Supergravity and many happy returns!