The Heritage of Supergravity

Personal Prelude and The Play

Sergio FERRARA
(CERN – LNF INFN)

FayetFest, December 8-9 2016
Ecole Normale Superieure, Paris

I happened to meet Pierre Fayet at a CNRS meeting in Marseille, in 1974, where one of the first Conferences covering the subject of Supersymmetry took place (I also met Raymond Stora on that occasion). In those days Pierre had just completed with his mentor Jean Iliopoulos the famous paper on the "Fayet-Ioliopoulos mechanism", which was the first consistent model with spontaneously broken Supersymmetry.

During the subsequent couple of years, when I was at the Ecole Normal Superieure as a CNRS visiting scientist, Pierre obtained several ground-breaking results, including a first version of the MSSM.

The model spelled out clearly the role of particle superpartners, R-symmetry and the need for two Higgs doublets. He also worked extensively on N=2 Supersymmetry, on the supersymmetric Higgs mechanism in super Yang-Mills theories, and studied the role of central charges. We published together a "Physics Reports" on Supersymmetry (received in 1976 – published in 1977). This work also addressed Supergravity, which was just at its beginning.

Supergravity will be the focus of the remainder of this talk, in view of its 40-th Anniversary that the Organizers decided to celebrate within this FayetFest.

PHYSICS REPORT (Section C of Physics Letters) 32, No. 5 (1977) 249–334. NORTH-HOLLAND PUBLISHING COMPANY

SUPERSYMMETRY

P. FAYET* and S. FERRARA**

Laboratoire de Physique Théorique de l'Ecole Normale Supérieure, 24 rue Lhomond, 75231 Paris Cedex 05, France

Received 2 July 1976

Contents:

1. Introduction 251
2. Supersymmetries and Graded Lie Algebras 253
2.1. Graded Lie Algebras 253
2.2. Supersymmetry algebra in four-dimensions 254
2.3. Supersymmetry with internal symmetries 257
2.4. Particle supermultiplets 259
2.5. All possible symmetries of the S-matrix 262
3. Superfields and Lagrangian models 263
3.1. Field representations and superfields 263
3.2. The supersymmetric spinor-scalar interaction (super-S^3 theory) 269
3.3. Supergraph techniques and renormalization 271
3.4. Supersymmetric gauge theories 274
3.5. Perturbation theory and renormalization of supersymmetric gauge theories 279
3.6. Asymptotic freedom and infrared convergence 281
4. Spontaneous symmetry breaking and conservation laws 283
4.1. Generalities about spontaneous symmetry breaking 283
4.2. Spontaneous breaking of internal symmetry 286
4.3. Spontaneous breaking of gauge invariance 289
4.4. Spontaneous supersymmetry breaking: the $U(1)$ method 293
4.5. What about fermion number? 294
4.6. Spontaneous supersymmetry breaking: a second method 297
4.7. A larger algebra 299
4.8. Beyond the tree approximation 300
5. Models of weak and electromagnetic interactions 302
5.1. Spontaneous breaking of SU (2) × U (1) gauge invariance 303
5.2. A semi-realistic model of weak and electromagnetic interactions 305
5.3. The problem of the neutrino as a Goldstone particle 310
5.4. How to include the muon sector? 312
6. Geometry of superspace, supergravity and strings 313
6.1. Gauge supersymmetries 313
6.2. Supergravity theory 318
6.3. Local Graded Lie Algebras in two-dimensions 319
6.4. Supersymmetric strings: the Neveu–Schwarz–Ramond and the Colour- U(1) models 322
Conventions and notations 327
References 327
Note added in proof 330

Abstract:

Supersymmetry transformations turn bosons into fermions and conversely. We discuss the algebraic aspects of the new structure, its role in relativistic quantum field theory and its possible applications to particle physics.

Single orders for this issue

PHYSICS REPORT (Section C of PHYSICS LETTERS) 32, No. 5 (1977) 249–334.

Copies of this issue may be obtained at the price given below. All orders should be sent directly to the Publisher. Orders must be accompanied by check.

Single issue price Dfl. 34.00, postage included.

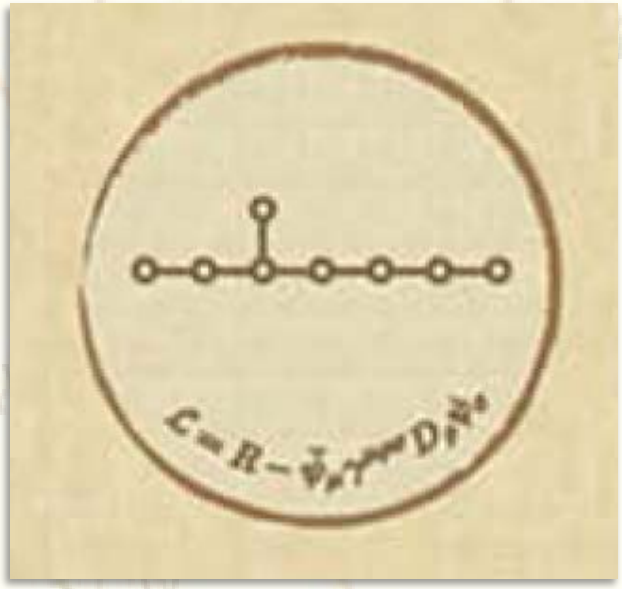
* Address after October 1977: California Institute of Technology, Pasadena, California 91125, U.S.A.
** On leave of absence from Laboratori Nazionali di Frascati, I.N.F.N., Frascati, Italy. Address after September 1977: Theory Division, CERN, 1211 Genève 23, Switzerland.

Supergravity as carved

on

the Iconic Wall

at the «Simons Center for Geometry and Physics», Stony Brook



Personal Prelude

Toward the birth of Supergravity

In the early 1970s I was a staff member at the Frascati National Laboratories of CNEN (then the National Nuclear Energy Agency), and with my colleagues *Aurelio Grillo* and *Giorgio Parisi* we were investigating, under the leadership of *Raoul Gatto* (later Professor at the University of Geneva) the consequences of the application of "Conformal Invariance" to Quantum Field Theory (QFT), stimulated by the ongoing Experiments at SLAC where an unexpected Bjorken Scaling was observed in inclusive electron-proton Cross sections, which was suggesting a larger space-time symmetry in processes dominated by short distance physics.

In parallel with *Alexander Polyakov*, at the time in the Soviet Union, we formulated in those days Conformal invariant Operator Product Expansions (OPE) and proposed the "Conformal Bootstrap" as a non-perturbative approach to QFT.

Conformal Invariance, OPEs and Conformal Bootstrap has become again a fashionable subject in recent times, because of the introduction of efficient new methods to solve the "Bootstrap Equations" *(Riccardo Rattazzi, Slava Rychkov et al.)*, and mostly because of their role in the AdS/CFT correspondence.

The latter, pioneered by *Juan Maldacena, Edward Witten, Steve Gubser, Igor Klebanov and Polyakov*, can be regarded, to some extent, as one of the great legacies of higher dimensional Supergravity. It can be used to gain information on strongly coupled gauge theories, and affords a variety of applications to Particle Physics, String Theory and Condensed Matter Physics.

In 1973 I was awarded a Fellowship at the CERN Theory Division, which was considered the most prestigious place where a young European physicist could go. Subsequent events revealed that going to Geneva was a truly timely choice, since when I started my Fellowship, in the fall of 1973, *Julius Wess* and *Bruno Zumino* had just formulated supergauge invariant (now called supersymmetric) QFT in four dimensions, and then found that milder divergences occur in these theories with respect to standard renormalizable QFT.

The original name was inherited from fermonic strings, where a local (conformal) fermionic symmetry on the world sheet was introduced by *André Neveu* and *John H. Schwarz*, *Pierre Ramond*, and *Jean-Loup Gervais* and *Benji Sakita*.

During my two-year period as a CERN Fellow I wrote four papers with *Zumino*, two of which also with *Wess* and *Jean Iliopoulos* (at the time a visiting scientist at CERN). With *Zumino* we formulated four dimensional Supersymmetric Yang Mills Theories (the new name for supergauges introduced by *Abdus Salam* and *John Strathdee*), thus opening the way to consider supersymmetric extensions of the Standard Model, the MSSM and alike.

The merging of supersymmetry with Yang-Mills gauge symmetry was a non-trivial step, and the potential link with the Standard Model was motivated by the so-called “Hierarchy Problem” and “Naturalness of Scales”, which in these new theories were alleviated thanks to so-called “Non-Renormalization Theorems”.

Many people contributed to these developments. Aside from the previously mentioned collaborators of *Zumino*, I can surely mention *Kelly Stelle*, *Peter West*, *Warren Siegel*, *Jim Gates*, *Marc Grisaru* and *Martin Rocek*.

In retrospect, the most influential of my joint papers with *Zumino*, written during my period as a Fellow, was the one on the *"Supercurrent multiplet"*, a multiplet which extended Noether's theorem to Supersymmetry and whose components include the Energy Momentum Tensor and a vector-spinor fermionic current, as well as a vector, a scalar and a pseudo scalar. The considerations that follow were among the starting points which led *Daniel Freedman*, *Peter van Nieuwenhuizen* and myself to formulate Supergravity in four dimensions as the supersymmetric extension of GR.

Since in theories with local (gauge) symmetries Noether currents couple, to first order, to gauge fields, the fact that the stress tensor couples to the metric tensor in GR indicated that the spinor current should have coupled to a spin-3/2 massless gauge field, of the type introduced by *William Rarita* and *Julian Schwinger* (RS) in 1941, and promptly used by *Shuichi Kusaka* as a hypothetical spin-3/2 neutrino.

The structure of the super-current multiplet indicated two facts that were later exploited, namely that a supersymmetric extension of GR should have involved only two particles of helicities (2,3/2), and that the field corresponding to the latter should have been a Rarita-Schwinger field, to be coupled to GR. This seemed in contrast with a superspace formulation of a Super Riemannian Geometry, which was originally pursued by *Pran Nath*, *Richard Arnowitt* and *Zumino*, where many ordinary fields with different spin were needed.

In the fall of 1975, even if I had offers from the US, following a suggestion of *Jacques Prentki*, at the time CERN-TH Division leader, I accepted a CNRS position at the Ecole Normale Superieure in Paris.

There I had the chance to meet *Daniel Freedman*, who was also trying to work out a consistent theory for spin 3/2 coupled to GR.

Peter van Nieuwenhuizen was then his colleague at Stony Brook. He was also collaborating with us, since he was investigating the quantum properties of fields of different spins coupled to GR, and the possibility of ultraviolet cancellations similar to those encountered in super-Yang-Mills theories.

In the spring of 1976 the breakthrough was achieved. Using the Noether procedure, Fierz rearrangements and Riemann tensor identities (and a computer at the Brookhaven National Laboratory), we proved that there is a unique Lagrangian, with only spin 2 and 3/2, and a unique set of supersymmetry transformation rules, which defines pure Supergravity in four dimensions, the supersymmetric extension of GR.

General Coordinate transformations, when combined with Supersymmetry, promoted the latter to a gauge symmetry as well, since spinors in curved space must necessarily depend on the space time point due to the local Lorentz symmetry.

The original supergravity: N=1, D=4

$$\mathcal{S} = \int d^4x\, e \left[-\frac{1}{2\,k^2}\, e^\mu_a\, e^\nu_b\, R_{\mu\nu}{}^{ab}(\omega) - \frac{i}{2}\, \overline{\psi}_\mu\, \gamma^{\mu\nu\rho}\, D_\nu(\omega)\, \psi_\rho \right]$$

$$\frac{\delta\,\mathcal{S}}{\delta\,\omega} = 0 \longrightarrow D_\mu\, e^a_\nu - D_\nu\, e^a_\mu = -\frac{i\,k^2}{2}\, \overline{\psi}_\mu\, \gamma^a\, \psi_\nu$$

$$\delta\, e^a_\mu = -\frac{i\,k}{2}\, \bar{\epsilon}\, \gamma^a\, \psi_\mu \qquad \delta\,\psi_\mu = \frac{1}{k}\, D_\mu\, \epsilon$$

NOTE

e, ψ and ω : one-forms valued in different local Lorentz representations.

Supergravity can be regarded as an Einstein-Cartan theory with a massless gravitino and «torsion»

The Play

The next forty years

The construction of Supergravity as the gauge theory of local supersymmetry prompted *Stanley Deser* and *Zumino* to formulate this theory as the Einstein-Cartan version of GR minimally coupled to a (spinor valued) one-form field, the RS gravitino (word coined by *Sidney Coleman*).

In their work, a quartic spin-3/2 coupling with gravitational strength, required in our formulation by local supersymmetry, originated as a Torsion contribution to the spin-connection when treated as an independent field. This extends the so-called first-order or Palatini formulation of GR.

A subsequent superspace formulation of Supergravity by *Wess* and *Zumino* in 1978, where an appropriate super torsion Constraint was introduced to reproduce the flat super geometry of the super-Poincare algebra, revealed that our second-order approach, rather than the Palatini-Einstein-Cartan formulation, is equivalent to the Wess-Zumino curved Superspace. In particular, it reproduces the so called "auxiliary fields", needed to have an off-shell formulation and thus a tensor calculus as in standard GR, introduced by *Peter van Nieuwhenuizen* and myself and *Stelle* and *West*.

In the months following the Spring of 1976 several important results were obtained, both during the Summer Institute organized by the Ecole Normale Superieure in Paris and during subsequent visits of some of us to Stony Brook and to CERN.

In particular , also in collaborations with *Eugene Cremmer*, *Joel Scherk*, *Bernard Julia*, *Ferdinando Gliozzi* and *Peter Breitenlohner*, the first matter couplings were obtained and, with *Peter van Nieuwnhuizen*, the first extended N=2 Supergravity formulated.

In a fundamental parallel work, *Gliozzi*, *David Olive* and *Scherk* discovered that the dual spinor model, after a GSO projection, becomes supersymmetric in space-time and not only on the string world-sheet. Moreover, they found that N=4 Supergravity Coupled to N=4 Yang-Mills is the low energy effective theory of the 10D dual spinor model. Meanwhile *Scherk*, *Lars Brink* and *Schwarz* classified super Yang-Mills theories in all dimensions.

In these milestones of Superstring Theory, Supergravity in diverse dimensions started to emerge as a low-energy limit.

The years 1977 and 1978 were the most performing for Supergravity because the discovery of off-shell formulations allowed to write general matter-coupled Lagrangians and to begin a systematic study of the SuperHiggs effect, the mass generation for the gravitino as a consequence of the spontaneous breaking of local Supersymmetry. This includes a joint work with Cremmer, Julia, Scherk, Girardello and van Nieuwenhuizen.

Moreover, the ultraviolet properties of Supergravity theories started to be investigated and pure supergravity was shown to be finite at one and two-loops. This is to be contrasted with the later, fundamental work of *Marc Goroff* and *Augusto Sagnotti*, where GR was shown to diverge at two loops. Three-loop counter terms in different forms of Supergravity were however exhibited by different authors, including *Renata Kallosh* and *Deser*, *Jason Kay* and *Stelle*.

In a pivotal step, in those years examples of all extended supergravities in four dimension were derived and the appearance of electric magnetic (*e.m*) duality symmetries was noticed, with duality groups that act in a non-linear way on the scalar fields of the theory.

The N=8 supergravity in 4D was constructed by *Cremmer* and *Julia*, and shown to possess a very large duality group, the exceptional group E7(7).

Gauged N=8 Supergravity in 4D was constructed by *Bernard de Wit* and *Hermann Nicolai*, and gauged Supergravity in diverse dimensions was studied by many people, including *Michael Duff*, *Murat Gunaydin*, *Chris Hull*, *Nicholas Warner*, *Paul Townsend*, *Leonardo Castellani*, *Riccardo D'Auria* and *Pietro Fré*.

E.m. dualities were later promoted to string U-dualities by *Hull* and *Townsend*.

Cremmer, *Julia* and *Scherk* constructed Supergravity in the highest possible number of dimensions, eleven, following a previous classification of Super-Poincare algebras by *Werner Nahm*.

This theory led *Witten* to formulate, in the Mid 1990s, the remarkable M-theory hypothesis, thus identifying an elusive theory in eleven space-time dimensions via the strong coupling limit of the Type-IIA Superstring. Through webs of dualities, this step allowed to unify the different form of 10D Superstrings, thus also connecting different types of extended objects, called generically branes, which emerge as solitonic solutions from higher dimensional Supergravity.

The largest supergravity: N=1, D=11

(Cremmer, Julia, Scherk, 1978)

$$\mathcal{S} = \int d^{11}x\, e \Big[-\frac{1}{4\,k^2}\, e_a^\mu\, e_b^\nu\, R_{\mu\nu}{}^{ab}(\omega) - \frac{i}{2}\,\overline{\psi}_\mu\,\gamma^{\mu\nu\rho}\,D_\nu\left(\frac{\omega+\hat{\omega}}{2}\right)\psi_\rho$$

$$-\frac{1}{48}\,F_{\mu\nu\rho\sigma}\,F^{\mu\nu\rho\sigma} + \frac{k}{192}\left(\overline{\psi}_\mu\,\Gamma^{\mu\nu\alpha\beta\gamma\delta}\,\psi_\nu + 12\,\overline{\psi}^\alpha\,\Gamma^{\gamma\delta}\,\psi^\beta\right)\left(F_{\alpha\beta\gamma\delta} + \widehat{F}_{\alpha\beta\gamma\delta}\right)$$

$$\frac{2\,k}{(144)^2}\,\epsilon^{\alpha_1\ldots\alpha_4\beta_1\ldots\beta_4\mu\nu\rho}\,F^{\alpha_1\ldots\alpha_4}\,F^{\beta_1\ldots\beta_4}\,A_{\mu\nu\rho}\Big]$$

$$\frac{\delta\,\mathcal{S}}{\delta\,\omega} = 0 \longrightarrow \omega\,, \qquad \widehat{\omega}_\mu^{ab} = \omega_\mu{}^{ab} + \frac{i\,k^2}{4}\,\overline{\psi}_\alpha\,\Gamma_{\mu ab}{}^{\alpha\beta}\,\psi_\beta$$

$$\widehat{F}_{\mu\nu\rho\sigma} = F_{\mu\nu\rho\sigma} - 3\,k\overline{\psi}_{[\mu}\,\Gamma_{\nu\rho}\,\psi_{\sigma]}$$

Can be regarded as General Relativity in D=11 coupled to a gravitino and a 3-form, sourced by 2- and 5-branes. It is regarded as the low-energy manifestation of M-theory, whose fundamental ingredients are not strings.

Duff had been the first, in the 1980s, to advocate the central role of generic extended objects in an overall picture.

D-branes in string theories first appeared in the classic works of *Massimo Bianchi*, *Gianfranco Pradisi* and *Sagnotti*, and of *Joe Polchinski*.

The advent of M theory marked the ***"second string revolution"***. The 1980s witnessed extensive investigations of Kaluza-Klein (KK) theories, largely aimed at classifying possible KK consistent reductions (spontaneous compactifications).

General Lagrangians including soft breaking terms of gravitational and/or gauge origin were derived by *Cremmer*, *Luciano Girardello*, *Antoine van Proeyen* and myself, and were applied to supersymmetric models of Particle Physics.

No-scale Supergravity, a theory with a naturally vanishing cosmological constant, was built by *Cremmer*, *Costas Kounnas Dimitri Nanopoulos* and myself, and was readily applied to Physics beyond the Standard Model with *John Ellis*. Twenty years later these models were linked to string vacua in flux compactifications by *Steve Giddings*, *Shamit Kachru* and *Polchinski*.

All these developments made it possible to derive parameter spaces of masses and couplings for supersymmetric extensions of the Standard Model, which can be explored in experimental searches for new physics, as was done at LEP experiments in the past and is currently done at the LHC collider.

Supersymmetric extensions of the Standard Model were introduced and widely investigated by *Pierre Fayet* and by *Savas Dimopoulos* and *Howard Georgi*, relying heavily the soft-breaking terms derived by *Girardello* and *Grisaru* and by *Riccardo Barbieri*, *Carlos Savoy* and myself, and by *Arnowitt, Ali Chamseddine* and *Nath*.

A new wave of activity in Supergravity was spurred when *Michel Green* and *Schwarz* ignited the ***"first string revolution"*** with the discovery of their cancellation mechanism (for gauge groups E8xE8 or/and SO(32)), making Heterotic and Type-I superstrings (which can only afford the latter option) and their point limit, 10D (1,0) supergravity, free of potential gauge anomalies and also of the gravitational anomalies previously studied by *Luis Alvarez-Gaumé* and *Witten*.

Super-Higgs→ soft-breaking terms

(Cremmer, SF, Girardello, Van Proeyen, 1983)

$$\mathcal{S} = \int d^4x\, e \left[-\frac{1}{2\,k^2} R + \partial_i \partial_{\bar{j}} \mathcal{G}\, D_\mu z^i\, D_\nu \bar{z}^{\bar{j}}\, g^{\mu\nu} \right.$$

$$\left. - V(z,\bar{z}) - \frac{1}{2}\, e^{\mathcal{G}/2}\, \bar{\psi}\mu\, \gamma^{\mu\nu}\, \psi_\nu + \ldots \right]$$

$$V = e^{\mathcal{G}} \left[\mathcal{G}_i\, \mathcal{G}_{\bar{\jmath}}\, \left(\mathcal{G}^{-1}\right)^{i\bar{\jmath}} - 3 \right]$$

$$\mathcal{G} = K + \log |W|^2 \qquad \mathcal{R}_{i\bar{\imath}} = -\partial_i \partial_{\bar{\imath}} \log \det \mathcal{G}_{k\bar{k}}$$

$$\frac{1}{2}\, \mathrm{Str}\, M^2 \Big|_{V_{z_i}=0} = e^{\mathcal{G}} \left[(N-1) + \mathcal{G}^i\, \mathcal{G}^{\bar{\jmath}}\, \mathcal{R}_{i\bar{\jmath}} \right]$$

In the limit $M_{Pl} \rightarrow \infty$ with a finite gravitino mass, these results imply the emergence of the soft breaking terms needed in SSM models.

(Barbieri, SF, Savoy, 1982; Chamseddine, Arnowitt, Nath, 1982; Hall, Lykken, Weinberg, 1983)

The anomaly cancellation mechanism placed restrictions on compactification manifolds, uncovering enticing connections between the supergravity analysis and Algebraic Geometry.

The Calabi-Yau compactifications investigated by *Philip Candelas*, *Gary Horowitz*, *Andrew Strominger* and *Witten* resulted in a paradigmatic example of N=2 supergravity analysis in terms of Special Geometry and Mirror Symmetry.

All this machinery of compactifications was thus reconsidered, taking into account restrictions coming from the Green-Schwarz mechanism. Important implications exist for compactifications to six dimensions preserving eight supercharges, where some anomaly canceling terms modify the low energy couplings of tensor multiplets to gauge fields.

In the 1990s, Supergravity evolved into a major tool for the study of Black Holes (BH), and in particular of their BPS properties, given their emergence as supersymmetric solitons in four-dimensional N-extended Supergravity.

An interesting interplay between charged black-holes and the moduli-space geometry of the underlying Supergravity emerged through the "Attractor Mechanism", a property noticed by *Kallosh*, *Strominger* and myself when we met at an Aspen Summer Institute, in Colorado, in 1995.

In N=2 Supergravity supersymmetric black holes enjoy a universal formula for their Bekenstein-Hawking Entropy, in terms of the (square modulus) of the central charge computed at its extremum in moduli space (see also work with *Gary Gibbons*).

The name attractors was coined since these solitons follow trajectories in the moduli space of scalar fields which, independently of the initial conditions, reach the same extremal point, which coincides with the value of field at the BH Horizon. This explains why the moduli dependent ADM mass is a continuous parameter while the entropy is quantized in terms of the BH charges.

These results were then extended to theories with N-extended supersymmetry and in higher dimensions in work including my collaborators and friends *Kallosh*, *Paolo Aschieri*, *Bianca Cerchiai*, *Laura Andrianopoli*, *Stefano Bellucci*, *Anna Ceresole*, *Chamseddine*, *Gianguido Dall'Agata, D'Auria*, *Fré*, *Murat Günaydin*, *Maria Lledo* , *Alessio Marrani*, *Mario Trigiante, Armen Yeranyan* and *Zumino*.

Partial supersymmetry breaking in N=2 supergravity was studied in collaboration with *Girardello* and *Massimo Porrati*, with inspiration from the work of *Ignatios Antoniadis*, *Hervé Partouche* and *Tom Taylor*, and a minimal model with flat potential was explored.

In 1997 Supergravity found itself again at center stage in the work of *Juan Maldacena*, amusingly entitled "The Large-N Limit of Superconformal Field Theories and Supergravity" where the famous AdS/CFT duality was formulated, which was soon followed by important additions by *Witten*, *Gubser*, *Klebanov* and *Polyakov*. This might be called the ***"third string revolution"***, and would have been impossible without a particular compactification of type IIB Supergravity on AdS5 x S5 derived in 1985 by *Hyiung-Jin Kim*, *Larry Romans* and *Peter van Nieuwenhuizen*.

This completes my personal recollection of many past years devoted to Supergravity. The recent years 2013-2016 witnessed a revival of spontaneous breaking of local Supersymmetry, boosted by applications to Cosmology, and in particular to the inflationary Universe with a de Sitter phase, with an eye to observational results of the Planck Mission.

A prominent role in this work was played by *Andrei Linde*, a proponent of Inflationary Cosmology, and indeed *Daniel Freedman* and I collaborated independently with *Kallosh* and *Linde*. I also collaborated with a number of colleagues, including *Antoniadis*, *Dall'Agata, Emilian Dudas*, *Alex Kehagias*, *Porrati*, *Sagnotti*, *Jesse Thaler, Van Proeyen*, *Timm Wrase* and *Fabio Zwirner*.

Supergravity has also found some applications in higher-spin field theories, via the AdS/CFT correspondence. Supersymmetric versions of OPEs and of the Conformal Bootstrap for N-extended superconformal field Theories are currently under investigation.

In the quantum domain N=8 Supergravity in four dimensions was proved to be ultraviolet finite at very high loop order, following the pioneering work of *Zvi Bern*, *Lance Dixon* and *David Kosower*. These properties seem to descend from some amazing relations with the rigid N=4 Yang-Mills theory, which possesses exceptional conformal and integrability properties. It is not yet excluded that N=8 Supergravity be a perturbatively finite theory of Quantum Gravity. In any case this search is going to teach us new lessons on the ultraviolet cancellations which can occur in theories including General Relativity.

Thank You