Il Colle di Galileo

Supergravity: What Is Next?

Organizers: Eric Bergshoeff (Groningen U.), Anna Ceresole (INFN Torino), Gianguido Dall'Agata (Padova U.), Sergio Ferrara (CERN), Renata Kallosh (Stanford U.), Henning Samtleben (Lyon U. & ENS), Antoine Van Proeyen (KU Leuven)

Supergravity is the latest development of the gravity theory established centuries ago by G. Galilei and I. Newton. The workshop 'Supergravity: What Is Next?' at the GGI in September and October 2016 reviewed the status of the field and considered many new developments and applications. It was also an occasion for a celebration of the theory that was discovered exactly 40 years before and is still at the center of much work in theoretical physics. Two of the fathers of supergravity were present at this workshop, Dan Freedman and Sergio Ferrara: both have recently written reviews [1, 2] on developments in supergravity from the early days to recent research and perspectives for the future.

Supergravity has been the tool to discover many ground-breaking ideas of superstring theory. There is a constant interplay between string ideas and supergravity calculations. Supergravity has appeared in many string conferences, but a workshop specifically devoted to supergravity developments had not been held for many years. The participants at this workshop had many common interests and enjoyed these weeks devoted to supergravity, which is for many of them a theory that is beautiful, intriguing and entertaining.

The workshop was attended by a large number of participants (99) in spite of its coinciding with the teaching period in most institutes in Europe. We review some of the work that was done in this workshop, referring to some of the publications that resulted from these discussions and collaborations.

1. Cosmology and supergravity

For over 15 years we have known that our Universe is accelerating. Recent observational possibilities have stimulated investigation of early-universe cosmology. String theory claims to be the fundamental theory for gravity, and should thus provide a theoretical framework to describe it. Novel cosmological scenarios have been developed that are inspired by string theory. In practice string theories can be investigated in the form of supergravity theories. These are often string theory-inspired supergravity theories (though not all supergravity theories are presently related to a string theory). During the workshop, α-attractor models for

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inflationary cosmology in N = 1 supergravity were studied by S. Ferrara and R. Kallosh. S. Ketov and M. Scalisi collaborated on other realizations of cosmological inflation in N = 1 supergravity.

Supersymmetry leads naturally to a negative cosmological constant, but new developments allow us to describe models with a positive cosmological constant and spontaneously broken supersymmetry. Recently, interesting methods have been developed using constrained superfields. This has led to a publication involving G. Dall'Agata, F. Farakos and M. Porrati, which was further discussed by R. Kallosh and A. Van Proeyen.

2. Compactifications of supergravity / string theories:

Though basic superstring theories are formulated in high dimensions, many interesting phenomena are only visible when the number of spacetime dimensions are reduced by compactification mechanisms. In this workshop various compactifications were studied. In particular, so-called flux compactifications were studied in a collaboration between A. Guarino, M. Trigiante and H. Samtleben, while P-fluxes were specifically discussed by F. Riccioni. There were also several discussions (G. Dibitetto, F. Riccioni) on tadpole cancelations and moduli stabilisation in string compactifications with fluxes. Finally, T. Van Riet considered brane-flux annihilation.

We further had some very illuminating discussions with A. Tomasiello, F. Riccioni on issues related to orientifolds.

Dyonic gaugings of four-dimensional supergravity typically exhibit a richer vacuum structure compared to their purely electric counterparts, but their higher-dimensional origin often remains more mysterious. G. Inverso, H. Samtleben, M. Trigiante considered the IIB origin of the dynamic gauged supergravities discovered 5 years ago by means of particular sphere and hyperboloid compactifications.

G. Inverso and D. Waldram worked on the relation between generalised geometry and consistent truncations. F. Pezzella and D. Waldram worked on the formulation of generalised geometric versions of string sigma models.

3. Symmetries

Supergravity theories have the remarkable property that many symmetries appear in the theories despite the fact that these were not required in the original constructions. They seem to miraculously appear in the final theory that was constructed only with a requirement of local supersymmetry. B. Julia considered symmetries with exceptional groups in the Lie classification.

H. Samtleben discussed applications of exceptional field theories to generalized IIB supergravity.

F. Riccioni considered other possible developments, and in particular how to write so-called exotic duality relations for the RR fields in the framework of 'double field theory'.

4. Structure of supergravity

Supergravity theories have a very intriguing structure. In this workshop the discussion between participants led to uncovering many unexpected properties of the actions. A new covariant formulation was found (D. Freedman, D. Roest and A. Van Proeyen) for N = 1 supergravity with Kähler couplings in the matter section. In view of recent applications of supergravity in cosmology, an early result of mass relations in supergravity theories was generalized such that it is applicable to backgrounds with curved spacetime (de Sitter or anti-de Sitter). The supercurrent and Einstein equations in the superconformal formulation were considered by S. Ferrara and A. Van Proeyen.

A review of the structure of N = 2 supergravity theories in D = 4, 5, 6 has been prepared by E. Lauria, A. Van Proeyen. The publication is expected in the following months.

Much attention was devoted to supergravity in 3 dimensions with discussions such as those between N. Deger, J. Rosseel and H. Samtleben. They considered several such theories with extra gauge groups. A new model for N = 4 topologically massive supergravity was established by S. Kuzenko and J. Novak. The exceptional groups are also important here, and M. Duff and S. Ferrara considered D = 3 unification of curious supergravities.

A. Ceresole has had the chance to discuss with many experts (B. Julia, B. de Wit, A. Van Proeyen, R. D'Auria, M. Porrati) the issue of off shell supergravity theories, revisiting the old problem of finding the minimal set of auxiliary fields in extended supergravities. Today, this problem arises in the context of supersymmetric localization techniques and in the computation of black hole entropies. Another topic of interest, examined by A. Gnecchi and building on recent work by S. Ferrara and A. Van Proeyen, was the derivation of mass formulae for gravitini when extended supersymmetry is broken in curved spacetimes.

5. Superparticles

Discussions at the GGI revealed that there were problems with the paper of A. Arvanitakis and P. Townsend on superparticles in AdS space. They were able to correct these with the help of fellow participant M. Cederwall.

6. Quantum supergravity

The quantum theory of supergravity remains one of the big mysteries of the field. After the enthusiasm in the first years, supergravity theories did not lead directly to finite quantum gravity theories. This has been improved by the embedding of supergravity in string theory, which is believed to be a consistent quantum theory of gravity. However, in the last 10 years surprising cancelations of would-be divergences have shocked and puzzled many researchers, such that the final word on this issue will have to be put off until future investigations.

In the workshop, quantization with non-linear supersymmetry was considered by R. Kallosh and A. Karlsson and more discussions took place with D. Murli. The background field method for non-linear theories was discussed. There was a very long and detailed discussion session on these subjects, led by R. Kallosh and with contributions by Z. Bern, E. Bergshoeff, A. Ceresole, G. Dall'Agata, S. Ferrara, A. Karlsson, A. Van Proeyen and T. Wrase.

Research on actions and counterterms with higher derivatives is also related to this subject. In particular, supergravity invariants in six dimensions were constructed by D. Butter, G. Tartaglino-Mazzucchelli and J. Novak.

I. Bandos developed a new approach to calculations of superamplitudes of D = 11 supergravity (SUGRA) and D = 10 supersymmetric Yang-Mills theories (SYM). Superamplitudes, which are superfield generalizations of the amplitudes, can be considered as multiparticle counterparts of so-called on-shell superfields. He obtained on-shell superfields describing linearized 11D SUGRA (and 10D SYM) by covariant quantization of a spinor formulation of 11D (and 10D) superparticle mechanics. The superamplitude formalism generalizing this on-shell superfield description was developed.

Discussions between I. Bandos and E. Sokatchev also brought up the idea of an alternative formalism. This involves the explicit SO(D − 2) invariance for complex structure, which helps to make an on-shell superfield and amplitude formalism more similar to its well-developed D = 4 counterparts. The formalism is now under further development. D. Sorokin also participated in this discussion during the workshop.

7. Non-relativistic supergravity

For many years supergravity was only discussed in the context of relativistic theories. However, it turns out that the structure of gravity theories that are non-relativistic also offer many interesting prospects. This study has become important in the context of AdS/CFT. Condensed matter models built on effective field theory coupled to Newton-Cartan background fields have been used. This has led to the introduction of Newton-Cartan geometry with torsion. The same torsion occurs in recent studies of Lifshitz holography. Non-relativistic gravity theories are also used for localization techniques to exactly calculate non-perturbative properties of (non-relativistic) supersymmetric field theories such as the partition function and the expectation value of Wilson lines. Ultra-relativistic versions of gravity, known as Carroll gravity, have been studied as well (J. Gomis, E. Bergshoeff). Furthermore, investigation of taking a new non-relativistic limit of (super-)strings has led to a so-called Galilean (super-)string (J. Gomis, P. Townsend). It is amusing to see that after so many years Galilei still puts his stamp on this kind of research in which Galilean symmetries and their central extensions play such an important role.

8. Black holes and branes

Supergravity also has solutions like black holes, cosmic strings, domain walls, etc.. The study of these solutions within supergravity leads to a better understanding of these objects and their entropy. In particular, B. Vercnocke has worked on black holes and their thermodynamics, and N. Deger has worked on intersections of S-branes in supergravity theories. The method for generalizing 'Brane wrapping rules', discovered in previous years, to include all the branes in string theory, has been elaborated (E. Bergshoeff, F. Riccioni, O. Hohm).

9. AdS/CFT

The duality between conformal field theories and AdS supergravity is on the latter side based on solutions of the supergravity field equations. D. Freedman and K. Pilch considered the extension of bulk supersymmetry to the AdS4 boundary, to solve a puzzle in the N = 8 superconformal theory.

Supergravity also profits from developments in conformal field theory. The full uplift of the GPPZ holographic renormalization group flow to IIB supergravity has been obtained, using exceptional field theory techniques. This solved a problem that had not been clarified for more than 15 years. This project was started by M. Petrini, H. Samtleben and K. Skenderis.

Collaboration initiated between M. Trigiante and T. Van Riet aims to find and classify the lightlike geodesics on certain Wick rotations of AdS moduli-spaces in gauged supergravity (which have only recently been classified). The physical relevance of this mathematical problem concerns the AdS/CFT correspondence. By means of this correspondence, one can derive that the lightlike geodesics on the conformal manifold of a Euclidean CFT (endowed with a pseudo Riemannian Zamolodchikov metric) are in one-to-one correspondence with the instantons of the CFT. This can most easily be seen via supergravity. Discussions at the GGI led to the idea for the paper in which Euclidean wormhole solutions in Type IIB string theory are compactified to AdS5.

Y. Lozano has worked on the CFT interpretation of the transformation of non-Abelian T- duality in AdS5 × S5 backgrounds. When this duality acts on the internal space, the CFT interpretation is made in terms of linear N = 2 quivers. It remains an open issue what this interpretation is when it acts on the AdS5 part of the geometry. Together with S. Penati and D. Sorokin, Y. Lozano also started a new project that refers to the extension of fermionic T-duality to the non-Abelian set-up. It is an interesting new possibility to construct self-dual AdS backgrounds as well as new solutions.

M. Graña and D. Waldram obtained an understanding of marginal deformations of N = 1 D = 4 superconformal field theories using generalised geometric descriptions of the dual gravity solution.

10. Conclusion

Holding such an intensive workshop on supergravity turned out to be very useful. During these months, participants found both a stimulating environment and colleagues who could contribute to fruitful discussions for their research. This has led to progress in the understanding of these interesting theories and in their applications. Supergravity researchers found a wonderful setting in this Galilean environment.

The presence of three Simons Fellow--Dan Freedman, Massimo Porrati and Paul Townsend--for extended periods was extremely beneficial in fostering a lively scientific atmosphere at the GGI throughout the program. The administrative staff provided immensely valuable assistance and was helpful in smoothing out every logistic aspect, including making possible the realization of a commemorative mug for the participants to take home as a nice memory of the 40th anniversary of Supergravity.

References

[1] D. Z. Freedman, Lecture for the Fortieth Anniversary of Supergravity, arXiv:1702.02203 [hep-th]

[2] S. Ferrara and A. Sagnotti, Supergravity at 40: Reflections and Perspectives, 2017. arXiv:1702.00743 [hep-th].