A Geometric Approach to Quantum Gravity

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A Geometric Approach to Quantum Gravity

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Motivations of the project and background

Objective: Study of the geometrical structure of quantum gravity, in particular of extended supergravity theories as low-energy limit of superstring theory around non perturbative vacua.

Method: Application of dualities, such as electric magnetic duality and holography, as symmetries of extended supergravity.

Rationale:

- Dualities allow to access non perturbative sectors of the theory, e.g. strong/weak coupling duality;
- Extended supergravity means that there is more supersymmetry, which is more restrictive and hence more predictive;
- AdS/CFT and AdS/CMT can provide information about condensed matter systems (graphene/ Weyl semimetals)

⇒ Front-line research both in theoretical physics and in mathematics, as well as interplay with condensed matter physics.

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M2 branes with fluxes revisited

[With M. Trigiante, in preparation]

Some background

- The ungauged extended supergravities are characterized by a global (on-shell) symmetry group which, at the classical level, is a non-compact, real Lie group acting on the electric field strengths and their magnetic duals as a generalized electric-magnetic duality. In particular, exceptional Lie groups, such as G_2, F_4, E_6, E_7 and E_8 play a prominent role in this context.
- Quantum corrections generally break this group to a discrete subgroup, such as the group $PSL(2,Z_7)$ discussed later. This global symmetry group (or duality group) encodes the known string dualities: T-duality, S-duality and the more general U-duality.
- A gauged supergravity is constructed from an ungauged supergravity by promoting a suitable subgroup of the global symmetry group to gauge group.
- M2 branes are solutions of D=11 supergravity which are spatially extended objects possessing a D=2+1 world volume. Fluxes corresponding to gauge field strengths in the internal 8-dimensional space are parameters of the theory.

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Our results

We have considered M2 branes with fluxes in the framework of D=11 supergravity.

- By studying a self-duality condition in the D = 8= 4+4 internal space transverse to the brane, we have been able to find new solutions, even in the presence of non constant fluxes.
- In particular, we have constructed new solutions by starting from a couple of Arnold-Beltrami flux branes of [Fré, Grassi, Ravera, Trigiante, arXiv: 1511.06245[he p-th]], and from instantons.
- We have analyzed the supersymmetry properties of these M2 branes, by means of the Killing spinor equations, in analogy to [Duff, Evans, Khuri, Lu, Minasian,hep-th/9706124].
- In the framework of exceptional field theory, we have applied this technique to an $\mathcal{N}=1$ solution of 11-dim. supergravity including 7-dim. Englert fluxes [Englert, Phys.Lett. 119B, 339 (1982)] found by P. Fré [P. Fré, arXiv: 1601.02253], admitting a discrete non-Abelian symmetry PSL(2,Z_7).

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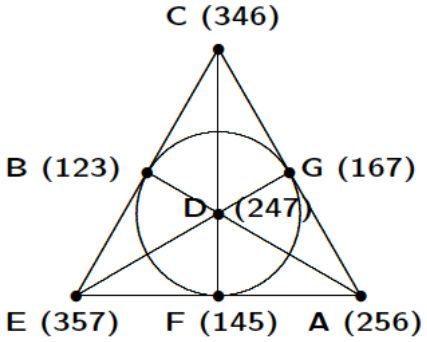
Our results and outlook

- We have been able to find the normal form of these solutions by Fré in terms of labels of the Fano plane, invariant under PSL(2,Z_7), describing the multiplication structure of octonions:



Fano plane

- This technique should allow a comparison with the non-associative non-geometric R flux background obtained by a chain of T-dualities from the twisted torus [M. Günaydin, D. Lüst, E. Malek, arXiv:1607.06474 [hep-th]], by explicitly acting with the Weyl reflections corresponding to the T-duality.
- It could provide an explicit example of the "mysterious duality" between M-theory and Del Pezzo surfaces conjectured in [A. Iqbal, A. Neitzke, C. Vafa, hep-th/0111068].

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Unconventional Supersymmetry at the boundary of AdS Supergravity

[With L. Andrianopoli, M. Trigiante, R. D'Auria, arXiv1801.08081, in press, JHEP]

Some background

The AdS/CFT duality [Maldacena, hep-th/9711200] has provided important insights into the properties of strongly coupled non-gravitational models from a classical supergravity theory in one dimension higher. In the supergravity limit, it implies a one-to-one correspondence between quantum operators in the boundary CFT and fields of the bulk supergravity, which act as sources for the operators of the CFT.

On the other hand, there is a close analogy between the properties of some condensed matter special systems, e.g. graphene, and relativity, because the equations of motion of the quasiparticles describing collective modes in graphene at the Dirac points have the same expression as the Dirac equation of relativistic free electrons.

⇒ Relativistic theories allow to explore the special properties of graphene with a 2-dimensional spatially curved surface [Cortijo, Vozmediano, condmat/0612623].

Viceversa, graphene has been proposed as a simple laboratory to check gravitational cosmic phenomena, like Hawking-Unruh radiation [Iorio, Lambiase, arXiv: 1108.2340 [cond-mat.mtrl-sci]], or wormholes.

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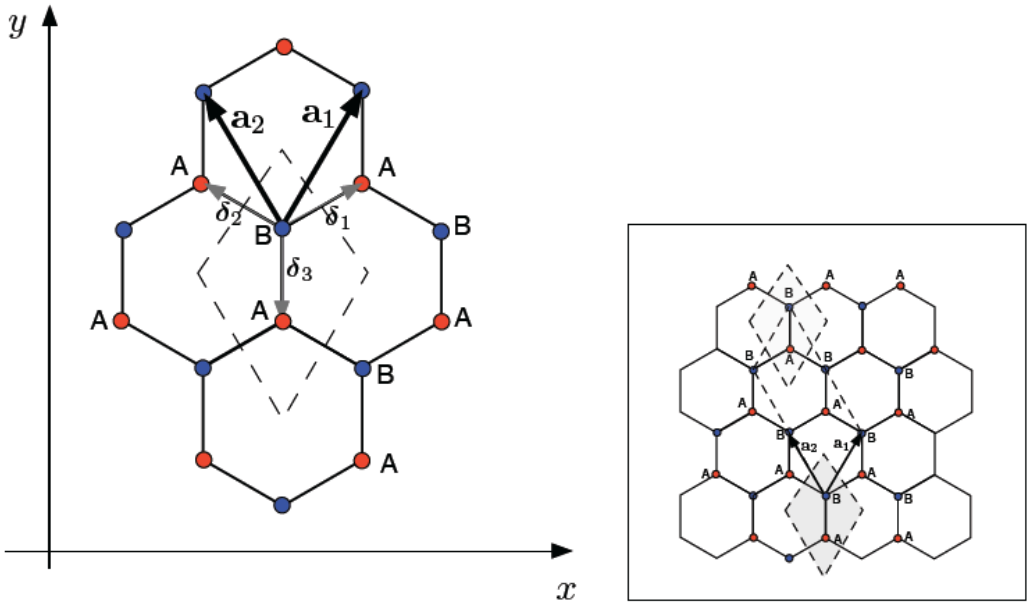
The graphene honeycomb lattice

Graphene is a two-dimensional layer of carbon atoms (one single layer of graphite).

The carbon atoms in graphene form a honeycomb lattice with a hexagonal structure.

It is a bipartite lattice composed by two triangular sublattices (sites A and sites B).

⇒ Belonging to site A or B defines a spin-like quantum number: Pseudospin



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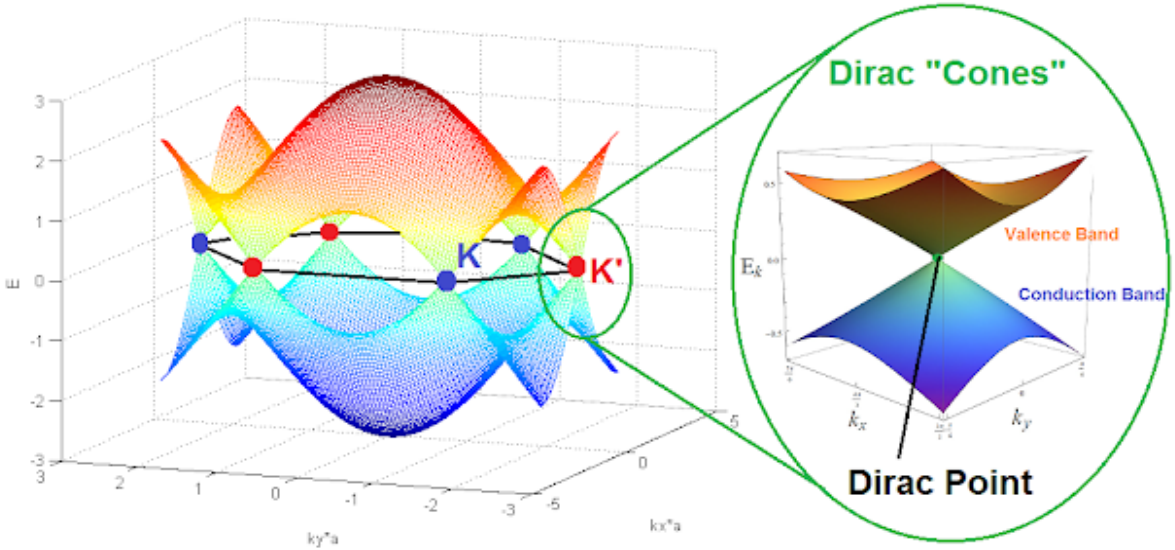
The graphene Dirac cone

Electron Band Structure of graphene



At the Dirac points:

Spectrum is

linear: $E_k = \pm \hbar\, c\, |k|$

helical: pseudospin

Electrons in graphene obey the same type of equations as relativistic Dirac massless particles with

$c \rightarrow v_F = 10^6$ m/s $= c/300$ Fermi velocity

⇒ "Analogue relativity": Possibility to observe relativistic effects in condensed matter!

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Our results

- In the spirit of the gauge-gravity correspondence, we have related pure D = 4 $\mathcal{N}$ = 2 AdS_4 supergravity with boundary as described in [Andrianopoli, D'Auria, arXiv:1405.2010 [hep-th]] to a D =2+1 Super-Chern-Simons theory developed in [Alvarez, Valenzuela, Zanelli, arXiv:1109.3944[hep-th]] (AVZ model) which was shown to describe the behavior of graphene near the Dirac points.
- The AVZ model displays $\mathcal{N}$ = 2 local supersymmetry in spite of the absence of gravitini. The only propagating field in the model is a spin ½ Dirac spinor with a possible mass term given in terms of the three-dimensional negative cosmological constant.
- For a specific choice of the D = 2+1 boundary (Neumann boundary conditions), corresponding to a local AdS_3 geometry placed at spatial infinity of the D = 3+1 supergravity theory, we have succeeded in reproducing the AVZ model.

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- Asymptotically AdS_4 solutions featuring the correct boundary geometry in the Fefferman-Graham parametrization comprise the ``ultraspinning limit'' [Caldarelli, Emparan, Rodriguez, arXiv:0806.1954 [hep-th]] of AdS_4-Kerr black hole. In general, we can consider an AdS_3 slicing of AdS_4 (black string) [Emparan, Horowitz, Myers, hep-th/9912135], with a BTZ black hole [Bañados, Teitelboim, Zanelli, hep-th/9204099] on the boundary.
- The supersymmetry parameter of the D = 2+1 theory is proportional to the propagating spinor field of the AVZ model. From the correspondence with D = 3+1 supergravity, we gain an interpretation of the propagating spinor field of the AVZ model in terms of the radial component of the D = 3+1 gravitino.
- This top-down approach to graphene is more preditictive than the more common bottom-up one, because it is constrained from the properties of the D=3+1 supergravity theory.

⇒ We are discussing with the condensed matter group at the Politecnico di Torino to see whether it is possible to check some predictions from supergravity on the physical properties of graphene, such as transmission coefficients or conductance.

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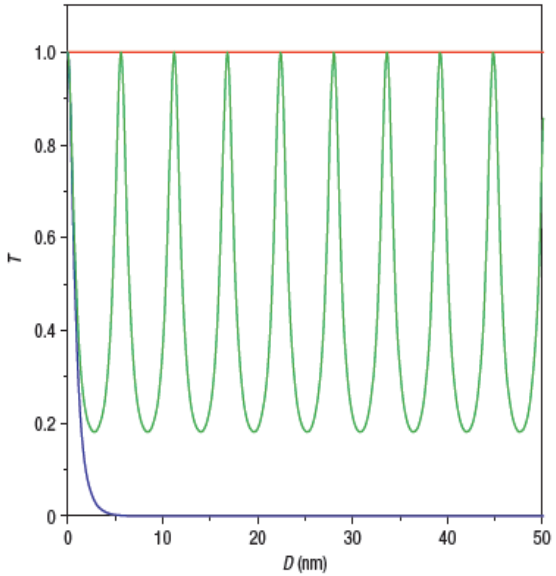
Outlook:

- Klein paradox: transmission of an electron across a barrier in graphene

[Katsnelson et al., Nature Phys. 2, 620 (2006); Calogeracos, Nature Phys. 2, 579 (2006);Shytov et al., Phys. Rev. Lett. 101, 156804 (2008)]

Transmission coefficient



Graphene: transparent

Bilayer graphene: on the supergravity side, could it correspond to wormholes between two disjoint 2+1 boundaries of 3+1 space-time?

Ordinary semiconductor: exponential decay

- Application to Weyl semimetals in D=3+1, which would be related to AdS_5 [Gomes, Helayel-Neto, 1711.03220]

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Workshops and Conferences

- Visits at Cern, Geneva, 30/01-11/02/2017, 22-27/08/17 and 14-17/02/18;
- Cost Network Meeting 'The String Theory Universe' (Chair S. Penati, U. Bicocca; vice-chair Y. Lozano, U. Oviedo, ES), U. Bicocca, 20-24/02/2017;
- Cost Network Meeting 'Quantum Structure of Spacetime' (Chair R. Szabo, U. Edinburgh, UK; vice-chair P. Aschieri, U. Piemonte Orientale), Bayrischzell, Germany, 21-25/04/2017;
- Visit at the Arnold Sommerfeld Center (Chair D. Lüst), Munich, Germany, 26-29/04/2017;
- Talk at the Workshop 'Stings and Supergravity in Piedmont', Università di Torino, 6 June 2017;
- Poster at the 54 International School of Subnuclear Physics, Centro Ettore Majorana, Erice (TP), 14-23/06/2017;
- Riemann International School on Mathematics of the Simons Foundation, 'Topological and Algebraic Advances in Quantum Field Theory', Università dell'Insubria, Varese, 31/07-04/08/2017;
- Talk at the 102 Congress of the Società Italiana di Fisica, Università di Trento, 11-15/09/2017;
- Workshop 'Holography and Supergravity 2018', Universidad Adolfo Ibáñez, Viña del Mar, Chile, 8-12/01/18

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Publications

1) L. Andrianopoli, BLC, M. Trigiante, R. D'Auria, `Unconventional Supersymmetry at the boundary of AdS Supergravity', arXiv1801.08081, in press, JHEP]
2) BLC, M. Trigiante, Multifield and non-Abelian generalizations of Born and Born-Infeld theories, JHEP 1610:160 (2016), arXiv:1609.07399]

In preparation:

3) BLC, M. Trigiante, `M2 branes with fluxes revisited'

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Links to other Projects and Collaborations

- Cost network "Quantum Structure of Spacetime" (Chair R. Szabo, U. Edinburgh, UK; vice-chair P. Aschieri, U. Piemonte Orientale)
- ERC Advanced Grant "Fundamental Aspects of Strings and Gravity" (P.I. D.Lüst, ASC Munich, Germany)
- Newly inaugurated Arnold-Regge Center for Algebra, Geometry and Theoretical Physics, Torino (Chair P. Fré; vice-chair A. Grassi)
- FONDECYT (National Fund for Scientific and Technological Research) program of the CONICYT (Comisión Nacional de Investigación Científica y Tecnológica) Chilean government funding agency with A. Anabalòn, (Universidad Adolfo Ibáñez, Viña del Mar), J. Zanelli (Centro de Estudios Científicos, Valdivia) and P. Salgado (U. Concecpión)
- Discussions with the group "Nanophysics and Quantum Systems" (F. Dolcini) at the Politecnico di Torino on graphene and Weyl semimetals