Overview of ST&FI

String Theory & Fundamental Interactions

Lorenzo Bianchi

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The big picture

Open problems in theoretical physics

- Consistent theory of quantum gravity.
- Non-perturbative regime of quantum field theories.

The idea

String theory as a unifying framework to address different aspects of supersymmetric quantum field theories, conformal field theories and quantum gravity with innovative techniques.

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Main research lines in Torino

- Conformal field theories and holography
- Non-perturbative aspect of $\mathcal{N} = 2$ supersymmetric field theories
- String theory in singular backgrounds
- String Field Theory

People

Staff members

- Lorenzo Bianchi (Unito)
- Marco Billò (Unito)
- Marialuisa Frau (Unito), National coordinator
- Alberto Lerda (UPO)
- Igor Pesando (Unito), Local Coordinator
- Carlo Giovanni Maccaferri (Unito)
- Marco Meineri (Unito)

Postdocs

- Just arrived: Ekaterina Sysoeva (PRIN)
- Just left: Alessandro Pini (INFN)

PhD students

- Elia de Sabbata (Unito)
- Biswas Dripto (Unito)
- Thekla Lepper (Unito)
- Andrea Mattiello (Unito)
- Alberto Ruffino (Unito)
- Paolo Vallarino (Unito)

Ongoing projects

- PRIN contract 2020KR4KN2 "String Theory as a bridge between Gauge Theories and Quantum Gravity" (local coord. M. Frau)

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- Strong coupling in QFT is hard to study but crucial (e.g. QCD in the infra-red: confinement, . . .)

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- One typically needs to
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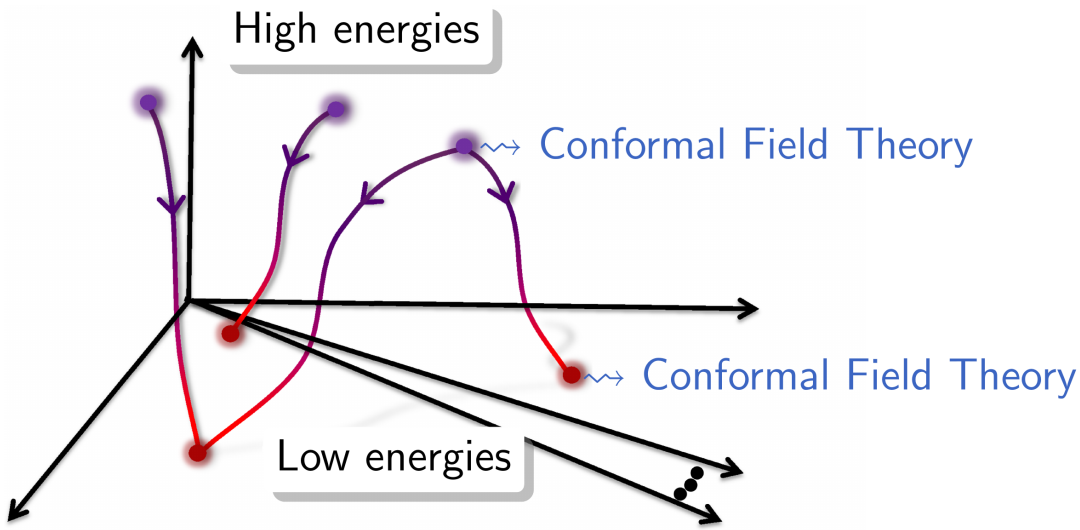
  - Include all the non-trivial classical solutions (instantons, ...)
- A possible strategy: learn by studying highly symmetric theories and observables, so that the dynamics is very constrained (but not trivial!)
  - Supersymmetry
  - Conformal symmetry

Part I

Conformal field theories and holography

Conformal field theories

- Scale invariance.
- Special (fixed) points in the space of QFTs.
- Critical points of second order phase transitions.



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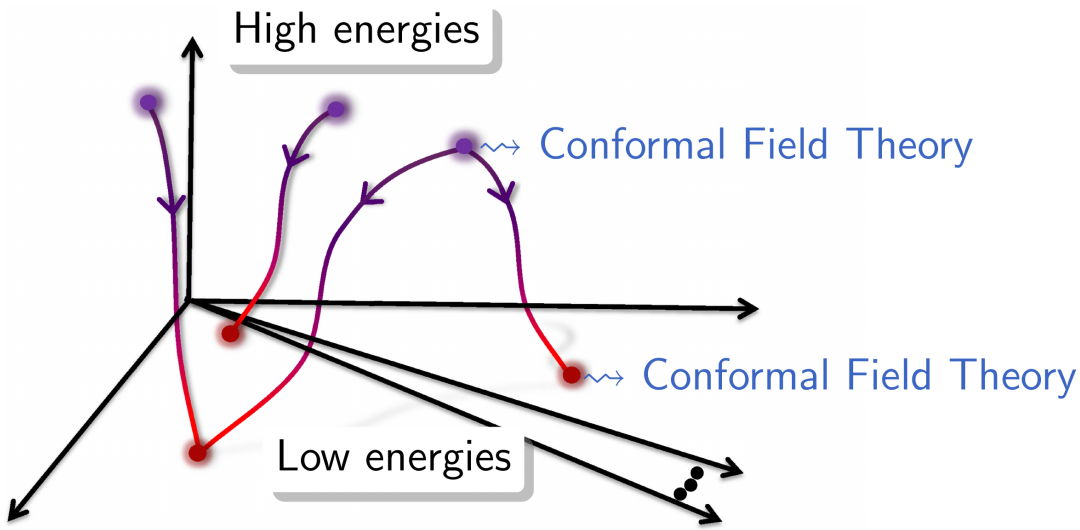

Example

Wilson-Fisher fixed point for the O(N) statistical model. Many applications: Ising, Superfluid Helium, ...

Conformal bootstrap

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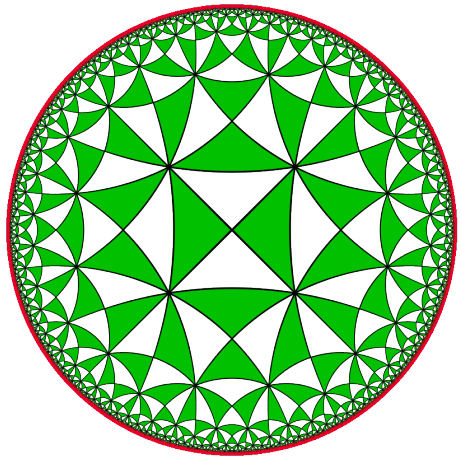
The defect bootstrap in St&FI

- Focus on extended excitations.
- Interesting examples: Wilson lines, boundaries, twist operators,...
- Explore and constrain the space of defects in the O(N) critical model. [L.Bianchi, D. Bonomi, E. De Sabbata: SciPost Phys. 15 (2023) 055, JHEP 04 (2023) 069]

See also Marco's talk tomorrow...

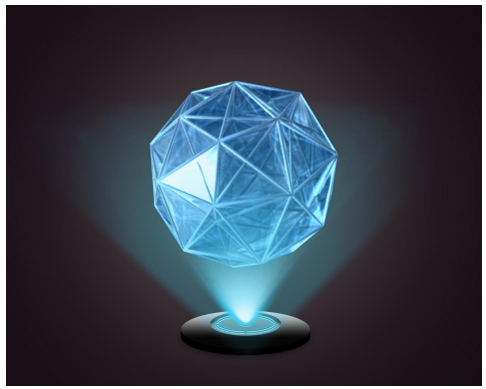
Holography



AdS/CFT

String (gravity) in Anti de Sitter $\longleftrightarrow$ Conformal field theories

- Strong/weak duality
- Weak coupling computations in gravity to get information on the strongly coupled regime of CFTs
- Non-perturbative computations in CFTs to explore the quantum structure of gravity in AdS
- Get insight into important problems, e.g. black hole information paradox.[L.Bianchi, S. De Angelis, M. Meineri: SciPost Phys. 14 (2023) 148]



Part II

Non-perturbative aspects of $\mathcal{N} = 2$ supersymmetric field theories

Some aspects of $\mathcal{N} = 2$ SYM theories

- Very interesting case: $\mathcal{N} = 2$ susy gauge theories in $d = 4$
- Localization (Pestun):
  - Action exact w.r.t. to a BRST charge Q constructed out of susy generators.
  - For certain observables the path integral (defined on S^4) localizes to the fixed points of Q i.e. to a matrix model
  - In $\mathcal{N} = 4$ SYM the matrix model is gaussian, for generic $\mathcal{N} = 2$ it has (infinite) interaction terms
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  - Also (conformal) defects such as BPS Wilson loops localize
- Some conformal cases (massless, zero β-function) admit an holographic dual of the $\mathrm{AdS}_5 \times \mathcal{M}$ type
- Can often be engineered by $6d$ or $10d$ string constructions involving D-branes: deep insights and ideas

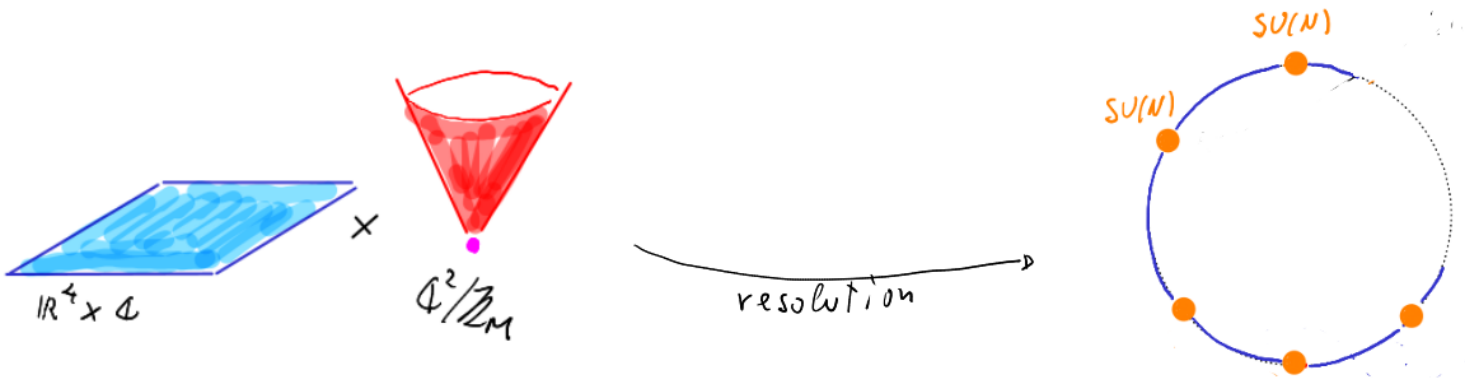
Our approach: some highlights

- We introduced the "full Lie Algebra approach" for the localization matrix model in the large-N limit.
  - Allows to push perturbative expansions to very high orders (> 100 loops...) $\rightarrow$ resummation into exact functions of the coupling $\rightarrow$ strong coupling behaviour
  - Explicit checks of the AdS/CFT correspondence in non maximally supersymmetric settings
  - Applied to local observables and Wilson loop defects
- We exploited various insights from the string embedding of particular theories (e.g., quiver gauge theories)

An example

D3-branes on an orbifold

$\mathcal{N} = 2$ quiver conformal SYM



- Near-horizon: type II string theory on $\mathrm{AdS}_5 \times S^5/\mathbb{Z}_M$
- Compute structure constants using Witten diagrams

- Organize chiral operators into twisted and untwisted
- Use localization to compute their CFT structure constants
- Push to strong coupling

Match!

[M. Billò, M. Frau, A. Lerda, A. Pini, P. Vallarino, PRL 129 (2022) 3, 3; JHEP 10 (2022) 020]

Part III

String theory in singular backgrounds

String and Gravity

- Open strings interact as gauge bosons
- Closed strings interact as gravitons
- Gravity automatically emerges even if one starts from gauge theory

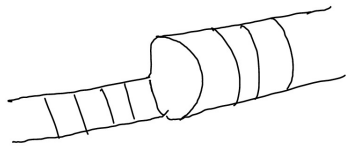


Figure: An open string metamorphing into a close string.

- What has string theory to say on the two classes of GR singularities?

String and GR singularities

- The first class of singularities is spacelike singularities, i.e. singularities at fixed time, i.e. "Big Bangs"
  Can string give any clue on how to go trough a "Big Bang"?
- The second class of singularities is timelike singularities, i.e. singularities fixed in space, i.e. "Black Holes"
  Can string give any signature on GW?

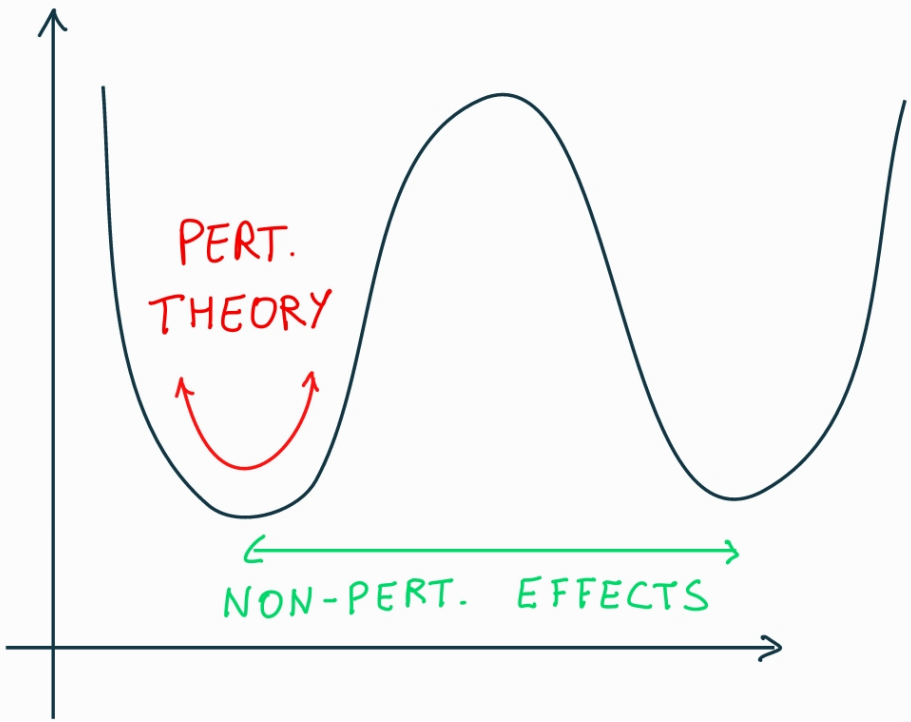
Part IV

String field theory

String Field Theory: Idea

- Strings and D-branes: high-UV d.o.f. with their own quantum dynamics.
- Is it possible to build a Quantum Field Theory of these extended objects?
- Strings dynamics well understood in first quantization (perturbative S-matrix)
- But perturbative amplitudes are not the full story. Can we describe the various string theory backgrounds as different vacua of the same theory?

String field theory is designed for this.



String Field Theory: Main achievements

- Particle field theory: a standard quantum field theory
- String field theory: a QFT for infinite massive higher spin fields in interactions with the graviton and gauge bosons.

D-branes: CLASSICAL SOLUTIONS of String field theory. Same as instantons in Yang-Mills and/or black-holes in GR.

Some milestones (1999-today):

1. The tachyon vacuum/D-brane decay (A. Sen 1999, M. Schnabl 2005)
2. All (bosonic) D-branes solutions (T. Erler, C. Maccaferri 2014-2019)
3. Non-perturbative D-Instanton contributions from the SFT path integral (explicit check of S-duality!) (A. Sen 2020)

String Field Theory: Current research in ST&FI

Long term goal

Understand Open/Closed duality and Holography from String Field Theory!

Start from a MASTER theory (open-closed SFT) and integrate out open or closed strings to get dual equivalent theories.

- D-branes deformations from closed strings: (C. Maccaferri, J. Vosmera): JHEP 10 (2022) 173
- Reformulation of open-closed SFT: (C. Maccaferri, A. Ruffino, J. Vosmera): JHEP 08 (2023) 145
- Open-Closed SFT in the large N limit and geometric transitions (C. Maccaferri, A. Ruffino, J. Vosmera): JHEP 09 (2023) 119

String Field Theory is a useful non-perturbative approach to String Theory, in the framework of standard Quantum Field Theory.

For more details: See the short review "String Field Theory"
By C. Maccaferri ArXiv 2308.00875 (Oxford Research Enciclopedia, in press)