Scientific Advisory Board @ IPARCOS

Bootstrapping Quantum Gravity

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IPARCOS

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Introduction: I joined IPARCOS in the early 2023 as a Ramon y Cajal fellow @ UCM, and I work on the project "quantum fields, gravity and strings" using

BOOTSTRAP METHODS → CFT BOOTSTRAP

BOOTSTRAP METHODS → AMPLITUDE BOOTSTRAP

This is a relatively novel line of research interdisciplinary and non perturbative, and I will take some minutes to contextualize and motivates it's applications to gravity and string theory.

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The greater CONTEXT

https://teorica.fis.ucm.es/bootstrap2024/index.html

Simons Collaboration on

The Nonperturbative Bootstrap

https://bootstrapcollaboration.com

The annual meeting of the collaboration will be this year

BOOTSTRAP - 2024 Madrid

This is a three weeks workshop which brings together leading scientists from all countries and it is unique in its format

Stony Brook University

SIMONS FOUNDATION

UNIVERSIDAD COMPLUTENSE MADRID

IPARCOS

A look at the 2023 activities

invited to join

UC SANTA BARBARA
Kavli Institute for
Theoretical Physics

Gravity from algebra: modern field theory methods for holography

Coordinators: Ofer Aharony, Agnese Bissi, Leonardo Rastelli, and Alexander Zhiboedov

I co-organized BOOTSTRAP 2023

June 26 – July 14, 2023

at Principia Institute, São Paulo, Brazil

ICTP SAIFR
International Centre for Theoretical Physics
South American Institute for Fundamental Research

This june 2024 I will take part in the Trinity college summer program

SCIENTIFIC CONTEXT & MOTIVATIONS

Outstanding problems in theoretical physics

1. strong coupling in QFTs
   eg. we know quarks and gluons are the constituents of nuclear matter but how?

   TASK: understand confinement
   low energy spectrum of QCD

2. what is the theory of Quantum Gravity?
   eg. we know that GR describes the motion of masses but what is a quanta of spacetime?

   2.1 GR is not renormalizable

   2.2 BH information paradox

   TASK: find a solution, eg a mathematical framework to resolve these issues

In this talk: look at some aspect of QG within String theory

Now, String theory was originally proposed to solve the problem of strong coupling but it was understood later that it works better as a theory of quantum gravity. the Theory of QG that we are going to look at originates from the AdS/CFT correspondence. These Theories of gravity are realistic enough to answer fundamental questions about quantum mechanics in GR

Type IIB superstring theory on $AdS_5 \times S^5$ $\longleftrightarrow$ $N=4$ super Yang Mills theory, maximally susy

string scale "α'"

string coupling "g_s"

$$\mathcal{L} = -\frac{1}{4}\mathrm{Tr}(F^2) + \frac{1}{2}(\partial_\mu \Phi^i)^2 + \text{fermions} + g_{YM}^2 \text{ interactions}$$

$SU(N)$ matrices

What does it mean that string theory works better as a theory of QG

In string theory there is a well defined limit to particle theories which is what we know

$$\mathcal{L} = \frac{1}{(\alpha')^4} \int dx \sqrt{g} \left(R + F_{(5)}^2 + \dots + \dots \right)$$

R → gravity

$F_{(5)}$ → five-form

$AdS_5 \times S^5$ is a solution

we look for a regime of parameters where the string theory is classical

Then the question: from the low-energy pov how renormalization is going to work?

Pass the question to the CFT

Now, what do we do in physics when we want to understand a problem of particles?

we make an experiment where most of the times we make things collide against each other (eg. LHC, LEC, ...)

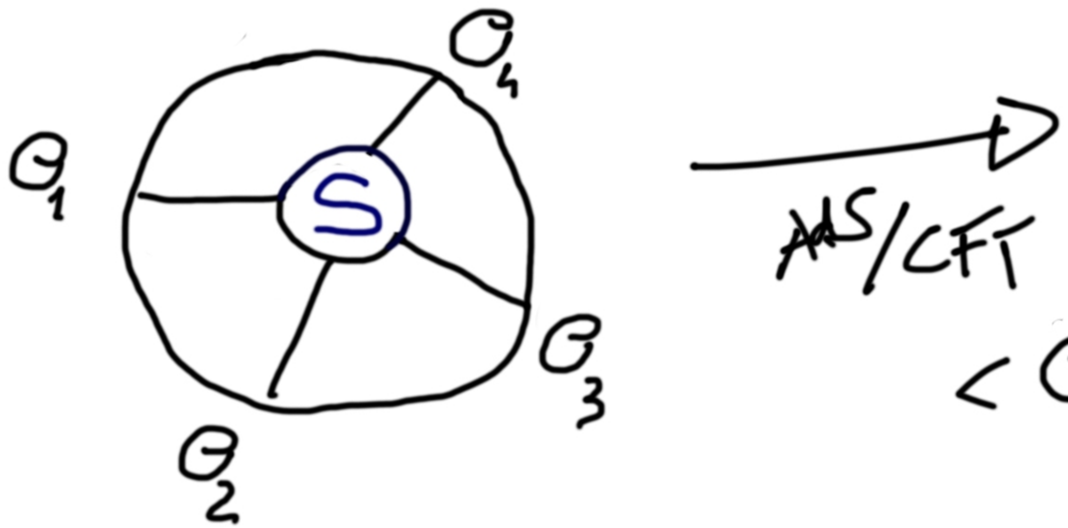
For QG in AdS we will do the same
we will compute a gravitational scattering amplitude by starting from the classical regime

More precisely the geometry of AdS is such that there is a boundary where we can think of preparing our particle state

$\alpha' \cdot |\text{curvature}| \ll 1$

$g_{YM}^2 N = \lambda \gg 1$

$g_{YM}^2 = g_s \ll 1$



TASK: compute CFT correlators

$$\langle \mathcal{O}_1(x_1) \ldots \mathcal{O}_4(x_4) \rangle$$

Now $N \gg 1$ therefore $S(s,t;\lambda,N) = \text{Tree-level} + \frac{\text{1-loop}}{N^2} + \dots$

the first order in the large N expansion is actually doable with traditional methods, diagrams, in some cases, and moreover there are no divergences at tree-level. But what about one-loop? All gravity fields of Type IIB sugra run in the loop! infinitely many Kaluza Klein modes on S^5. In addition, loop diagrams in 5d now are divergent

This is a situation where traditional methods do not help nevertheless we will succeed by using the:

BOOTSTRAP APPROACH

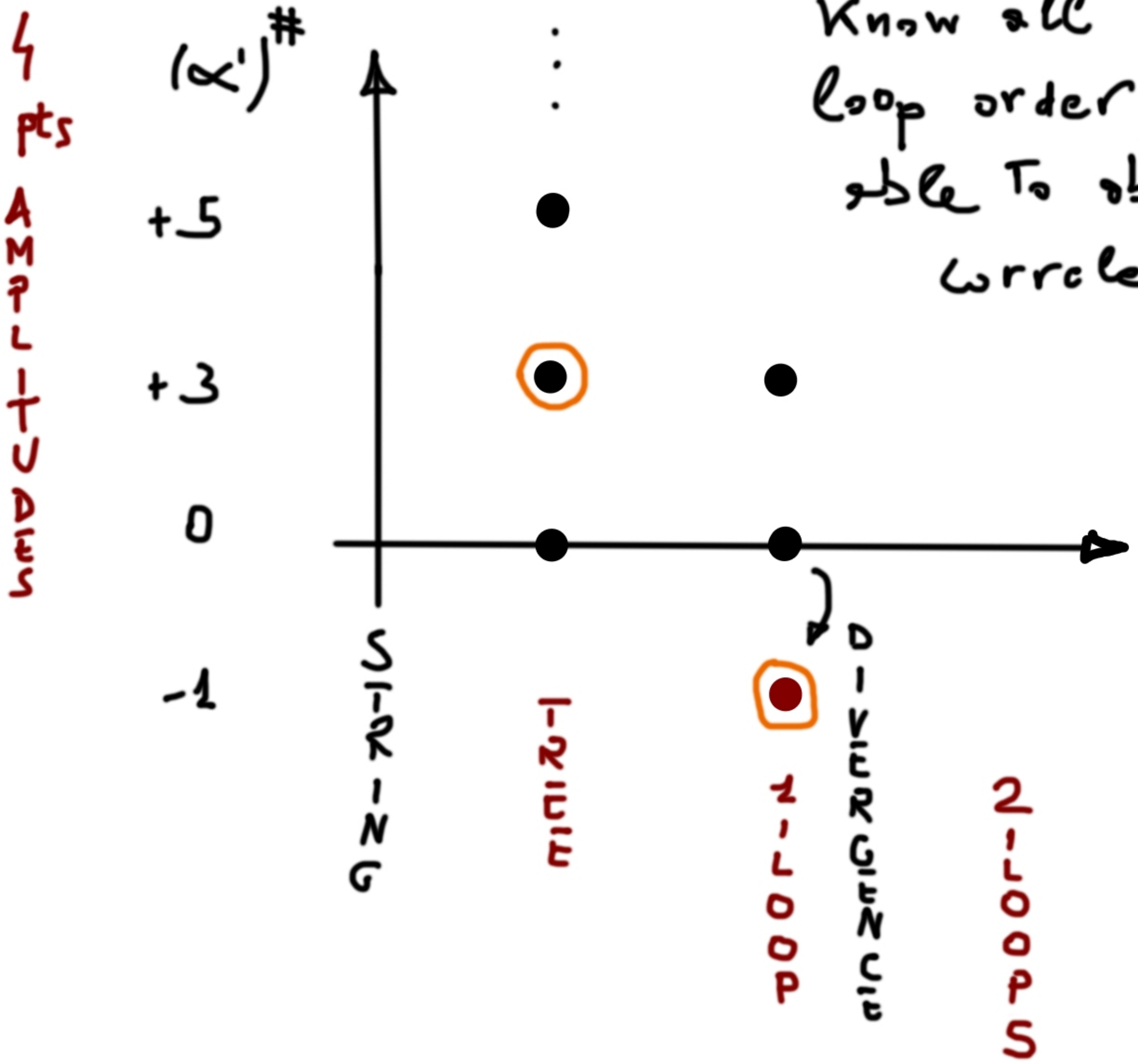
① optimize knowledge about the Theory
e.g. symmetries
spectral data

② understand the analytic prop. of the observables

③ use datapoint to fix the result as much as possible where are we now?

unprecedent result: we know all tree level anomalous dimensions; we know all max-log discontinuity for any loop order; the bootstrap has been able to obtain the complete 1-loop correlators up to an ambiguity

$$\sim \frac{c_{-1}}{\alpha'} + c_0$$



and the value of c_{-1} and c_0 is also known from the CFT! The simplest correlator is known up to 2-loops

results from Aprile, Drummond, Heslop, et al.

where do we go from now :

BOOTSTRAP for higher pts amplitudes
always FUN: the CFT guarantees a finite result but the latter has to be phrased in a gravity language to make progress

BOOTSTRAP for geometry-changing operators
these are maximally heavy operator insertion that deform $AdS_5 \times S^5$

[Aprile - Myers - Vieira 2023]

BOOTSTRAP for other strongely coupled theories like the conformal window of QCD_4.

BOOTSTRAP and ARTIFICIAL INTELLIGENCE

much more ...

Call: HORIZON-MSCA-2023-SE-01

with I.Scimemi, and the hadronic/QCD group

Thank you