Scientific Report 2017

Title	**Analysis of Time series using a Network Science approach**
Postdoc	**José Luis Herrera Diestra**
Supervisor	**Nathan Jacob Berkovits**
Fapesp process	**2017/00344-2**
Period	**01/06/2017 - 15/11/2017**

ICTP SAIFR

INTERNATIONAL CENTER FOR THEORETICAL PHYSICS
SOUTH AMERICAN INSTITUTE FOR FUNDAMENTAL RESEARCH

Research report
(June - November 2017)

José Luis Herrera Diestra

Introduction

Since its introduction in 1998, Network Science has proven to have a broad set of applications. Among the disciplines where Network Science has been successfully applied we can find Medicine, Psychology, Biology, Sociology, Economics, among others. Recently, the extensive toolkit of Network Science has been extended to the study of Time Series. The idea of mapping time series into graphs is actively developed at present via different approaches (correlations[1,2], visibility[3,4], recurrence analysis[5], transition probabilities[6], etc). The work that is described below involves different applications of Networks Science and Time Series individually as well as a combination of them. We study and characterize evolution of diseases, interaction of students in a given university, strategies of surveillance and immunization in populations.

Research June - November 2017

In the following, is a summary of the research and activities which I have been performing from June until November of 2017.

Surveillance on temporal networks [7]

To help health policymakers gain response time to mitigate infectious disease threats, it is essential to have an efficient epidemic surveillance. One common method of disease surveillance is to carefully select nodes (sentinels, or sensors) in the network to report outbreaks. One would like to choose sentinels so that they discover the outbreak as early as possible. The optimal choice of sentinels depends on the network structure. Studies have addressed this problem for static networks, however, we explore designing surveillance systems for early detection on temporal networks. This study is based on the idea that vaccination strategies (well studied in temporal networks) can serve as a method to identify sentinels. To assess the ability to detect epidemic outbreaks early, we calculate the time difference (lead time) between the surveillance set and whole population in reaching 1% prevalence. We find that the optimal selection of sentinels depends on both the network's temporal structures and the infection probability of the disease.

Immunization strategies in social complex networks [8]

As infectious disease outbreaks emerge, public health agencies often enact vaccination and social distancing measures to slow transmission. Their success depends on not only strategies and resources, but also public adherence. Individual willingness to take precautions may be influenced by global factors, such as news media, or local factors, such as infected family members or friends. Here, we compare three modes of epidemiological decision-making in the midst of a growing outbreak. Individuals decide whether to adopt a recommended intervention based on overall disease prevalence, the proportion of social contacts infected, or the number of social contacts infected. While all strategies can substantially mitigate transmission, vaccinating (or self isolating) based on the number of infected acquaintances is expected to achieve the greatest herd immunity and number of infections averted.

Persistent events in diseases [9].
We analyse time series of diseases from different countries symbolic time series analysis. The symbolic approach involves the transformation of a time series into a sequence of symbols by using an appropriated codification rule; this symbolization reduces the sensitivity to observational noise. In this project, we characterize time series of various disease in different countries by combining symbolic ordinal analysis and network representation. Specifically, a time series is transformed in a sequence of symbols (ordinal patterns) that is used to construct a directed and weighted graph where the different symbols that appear constitute the network nodes. We characterize these time series in the Permutation entropy - Complexity plane and via new measures of In/Out entropy in a node, which measures its role in the network (attenuation or amplification of entropy).

Causality networks of diseases [10]
Identifying causal networks is important for effective policy and management recommendations on climate, epidemiology, financial regulation, etc. Using the Convergent cross-mapping method for detecting causality in nonlinear dynamics [11], we study and characterize: 1) causality effects between environmental factor on Dengue and Malaria cases in Venezuela and Colombia at state level; 2) the possible spatiotemporal causal effects between Venezuelan and Colombian states in the number of cases of vector-borne diseases, particularly Dengue and Malaria.

Conferences seminars and collaborations.

- Collaboration visit. Prof. Desiderio Vazquez. Pontificia Universidad Católica del Perú, Lima - Perú. June 2017.
- Collaboration visit. Grupo de Caos y Sistemas Complejos. Universidad de Los Andes, Mérida - Venezuela. July 2017.
- Presentation of two oral contributions at 1st Latin American Conference on Complex Networks. 25-29 September 2017. Puebla - Mexico

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Scientific Report 2017

Title	The S-matrix Bootstrap
PostDoc	Andrea Leonardo Guerrieri
Supervisor	Nathan Jacob Berkovits
FAPESP process	2017/02303-1
Period	01/Jun/2017 - 30/Oct/2017

ICTP SAIFR

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Research Report 2017

Andrea L. Guerrieri

13/11/2017

1 Introduction

Strongly coupled field theories challenge theoretical physicists since the very early investigations of quantum field theories. Among all the mathematical tools developed to understand the physics of such strongly coupled systems, Monte Carlo methods have shown to be the most effective in the case of non-supersymmetric theories, which happen to be, until now, the only relevant for experimental physics. However, in the last ten years several groups scattered around the world and now gathered into the new Bootstrap Collaboration have shown that Bootstrap related techniques can compete and in some cases surpass computationally Monte Carlo methods and draw a map of the space of conformal filed theories leading to a new comprehension of non-perturbative phenomena. The main idea of the Bootstrap is to define physical observables and compute them uniquely using internal consistency conditions. Its practical incarnation in the case of Conformal Field Theories (CFTs) in dimension greater than two allowed to compute, among all the results, the critical exponents at the vapor-water critical point with unprecedented precision.

2 Research in the period from 01/06 to 30/10 2017

The researches I'm doing and the ones I completed in the 2017 represent various applications of Bootstrap ideas in condensed matter and particle physics.

2.1 Matching the Bootstrap and the perturbative ϵ-expansion [1, 2]

The "unreasonable" effectiveness of the CFT Bootstrap in computing the critical exponents of several CFTs like the Wilson-Fisher critical point, $O(N)$ models, $\mathcal{N} = 4$ SYM, SCFTs in three and four dimensions calls for an analytic explanation. Starting from the seminal paper by Rychkov and Tan [3] we show that in the perturbative regime (ϵ-expansion) conformal invariance alone is enough to determine the leading order properties of the critical points. In particular, we study the possible smooth deformations of Generalized Free Field Theories by exploiting the singularity structure of the conformal blocks dictated by the null states. In this way we derive, at the first non-trivial order in the ϵ-expansion the anomalous dimensions of an infinite class of scalar local operators, without using the equations of motion. In the case where other computational methods apply, the results agree.

2.2 Bootstrapping massless amplitudes via soft-theorems [4, 5]

As we have extensively shown in [4], soft theorems for Nambu-Goldstone bosons impose a number of consistency conditions on the structure of the tree-level massless scattering amplitudes that are sufficient to determine them, once one fixes a small number of low energy constants. It is therefore natural to ask whether this happens at loop level [5] and check it with explicit computations. In fact, soft behaviors of S-matrix for massless theories reflect the underlying symmetry principle that enforces its masslessness. As an expansion in soft momenta, sub-leading soft theorems can arise either due to (I) unique structure of the fundamental vertex or (II) presence of enhanced broken-symmetries. While the former is expected to be modified by infrared or ultraviolet divergences, the latter should remain exact to all orders in perturbation theory. Using current algebra, we clarify such distinction for spontaneously broken (super) Poincarè and (super) conformal symmetry. We compute the UV divergences of DBI, conformal DBI, and A-V theory to verify the exactness of type (II) soft theorems, while type (I) are shown to be broken and the soft-modifying higher-dimensional operators are identified. As further evidence for the exactness of type (II) soft theorems, we consider the α' expansion of both super and bosonic open strings amplitudes, and verify the validity of the translation symmetry breaking soft-theorems up to $\mathcal{O}(\alpha'^6)$. Thus the massless S-matrix of string theory "knows" about the presence of D-branes.

2.3 The S-matrix bootstrap: Adler's zero and chiral symmetry breaking [6]

Despite the undeniable success in the CFT case, the bootstrap approach was first proposed in the context of the S-matrix for massive theories more than 60 years ago. The S-matrix Bootstrap program in its original form has been almost abandoned after that quantum field theory became the main tool to compute scattering amplitudes. However, triggered by the successes obtained in CFTs and by the recent revival started in [7], we propose to revisit the pion-pion scattering and generalize the results in [7] to the case in which the external particles have also a global flavor symmetry and to impose and study the effect of the Adler's zero constraint due to the spontaneous breaking of the chiral symmetry. Another important feature of QCD scattering amplitudes is the presence of resonances: unstable particle that show up in the scattering amplitude as poles in the second Riemann-sheet and their introduction is object of our current investigations. In this way we would be able to put constraints on the space of the possible non-perturbative S-matrices with the long-term expectation to draw a map of all the consistent interactions among massive particles.

3 Conferences and Seminars

- May 15 - June 16, 2017, Bootstrap 2017 (school and workshop), ICTP-SAIFR, Sao Paulo.
- October 2017, EPFL Lausanne (invited talk and visit).
- November 9-10, 2017, Simons Collaboration on the Nonperturbative Bootstrap Annual Meeting.

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Scientific Report 2017

Title: Beyond Standard Model Physics under the ground and in the sky
Postdoc: Bithika Jain
Supervisor: Nathan Jacob Berkovits
Fapesp: 2016/01343-7 and 2017/05770-0
Period: 01/Sep/2017-30/Nov/2017

Bithika Jain

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Research Report 2017

Bithika Jain

Introduction

Cosmology and particle physics are in an exciting data-rich era, with several collider and astronomical searches underway. The precise measurements of the Standard Model (SM) parameters along-with stronger bounds on unseen new physics from LHC, Dark Matter (DM) experiments beg rigorous investigation strategies and theoretical input. The goal of my research is to focus on deepening our understanding of physics Beyond the Standard Model (BSM). 014

Research in 2017

Dark matter phenomenology

LHC Dark Matter Signals from Vector Resonances and Top Partners[1]

Competitive bounds from collider searches, direct detection and indirect detection have made the DM puzzle enticing.Extensions of the Standard Model which address the hierarchy problem and dark matter (DM) often contain top partners and additional resonances at the TeV scale. We explored the phenomenology of a simplified effective model with a vector resonance Z' , a fermionic vector-like coloured partner of the top quark T' as well as a scalar DM candidate ϕ and provide publicly available implementations in CalcHEP and MadGraph. We studied the $pp \to Z' \to T'\overline{T'} \to t\bar{t}\varphi\varphi$ process at the LHC and found that it plays an important role in addition to the $T'\overline{T'}$ production via strong interactions. It turns out that the presence of the Z' can provide a dominant contribution to the $t\bar{t}$+MET signature without conflicting with existing bounds from Z 0 searches in di-jet and di-lepton final states. We also found that through this process, the LHC is already probing DM masses up to about 900 GeV and top partner masses up to about 1.5 TeV, thus exceeding the current bounds from QCD production alone almost by a factor of two for both particles

Higgs potential

On the Validity of the Effective Potential and the Precision of Higgs Self Couplings [2]

The global picture of the Higgs potential in the bottom-up approach is still unknown. A large deviation as big as O(1) fluctuations of the Higgs self couplings is still a viable option for the New Physics. An interesting New Physics scenario that can be linked to a large Higgs self coupling is the baryogenesis based on the strong first order phase transition. We revisited the strong first order phase transition in two classes of Beyond the Standard Models, namely the Higgs portal with the singlet scalar under the Standard Model gauge group with the Z2 symmetry and the effective field theory approach with higher-dimensional operators. We investigated a few important issues in the validity of the effective potential, caused by the breakdown of the high-temperature approximation, and in the criteria for the strong first order phase transition. We illustrated that these issues can lead to O(1) uncertainties in the precision of the Higgs self couplings, which are relevant when discussing sensitivity limits of different future colliders. We showed that the correlation between the Higgs trilinear coupling and the quartic coupling will be useful for differentiating various underlying New Physics scenarios and discuss its prospect for the future colliders.

We are now further exploring the issue of baryon number violation criteria by calculating the spharelon energy in the SM+ Singlet scenario. [4]

For twin higgs setups we are estimating the higgs self couplings and understanding their sensitivity in future colliders. [5]

Holographic Models

A Perturbative RS I Cosmological Phase Transition [3]

We identify a class of Randall-Sundrum type models with a successful first order cosmological phase transition during which a 5D dual of approximate conformal symmetry is spontaneously broken. Our focus is on soft-wall models that naturally realize a light radion/dilaton and suppressed dynamical contribution to the cosmological constant. We discuss phenomenology of the phase transition after developing a theoretical and numerical analysis of these models both at zero and finite temperature. We demonstrate a model with a TeV-Planck hierarchy and with a successful cosmological phase transition where the UV value of the curvature corresponds, via AdS/CFT, to an N of 20, where 5D gravity is expected to be firmly in the perturbative regime.

We are also currently working on vacuum stability in Randall Sundrum Models by looking at the running of the higgs quartic. [6]

Conference and Seminars

I have presented my work at the following workshop:-
Nov, 2017- LHC CHAPTER II: THE RUN FOR NEW PHYSICS - IIP, Natal, Brazil

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[4] B. Jain, M. Son, Sphaleron and Criteria for Baryon Number Violation, article in preparation.
[5] B. Jain, K. Mohan, D. Sengupta, Higgs couplings in Twin Higgs Models, article in preparation.
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SCIENTIFIC REPORT 2017

Title	Matéria Escura nas Galáxias
Postdoc	Ekaterina Karukes
Supervisor	Nathan Jacob Berkovits
Fapesp process	2016/26288-9
Period	01/Feb/2017 - 31/Jan/2019

Ekarukes

Nath Berkovits

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Research Report 2017

Ekaterina Karukes

Introduction

Today we know that only 15.5% of the total matter in the Universe is in form of ordinary baryonic matter. While the other 84.5% is provided by dark matter (DM), which is detectable only through its gravitational influence on luminous matter. Theoretically it is believed that DM is build up from massive, weakly and gravitationally interacting particles. In this widely accepted (Λ)CDM scenario, the virialized structures are described accordingly the well known NFW profile. The (Λ)CDM model describes the large-scale structure of the Universe well. However, on the galactic and sub-galactic scales it seems to have several problems. One way to investigate the properties of the DM is to use kinematical observations of galactic RCs.

On the other side, although, as mentioned above DM is detectable only through its gravitational influence on luminous matter, there are many well-motivated particle DM candidates that are predicted to annihilate or decay in Standard Model (SM) particles and to produce secondary cosmic rays, such as gamma rays, that might potentially be observed. There are several good astrophysical targets for looking for this kind of signal, that are Galaxy clusters, dwarf spheroidal (dSph) galaxies and the Galactic Center.

Research in 2017

Since the starting date of my postdoc (February 2017) I have been working on the following projects.

The universal rotation curve of dwarf disc galaxies [1]

Dwarf galaxies are interesting systems for many reasons. First of all, they are close enough to study their dynamical properties. Second of all, they are most common type of galaxies in the Universe and in the (Λ)CDM scenario they may be related to the building blocks of more massive galaxies.

The core-cusp problem[1] is the best documented in dwarf rotationally supported galaxies due the fact that their baryonic fraction is low (they are believed to be DM dominated at any radii) and their kinematics is rather simple. Additionally, to dwarf rotationally supported galaxies, dwarf spheroidals also play an important role in different DM studies, however these systems are dispersion-dominated, that makes their kinematics more complicated.

In our work we studied the kinematics of a sample of dwarf rotationally supported galaxies (or how we called them dwarf disk galaxies), which are members of Local Volume, with an average optical velocity $< V_{\rm opt} >=35$ km/s. This was done in order to extend the relationships between the global luminous properties of normal spiral galaxies and its dark matter properties down to dwarf disk galaxies in the context of URC. The results of this study are extremely interesting, because they can greatly improve our knowledges about the standard model of galaxy formation and evolution. At the same time, it could also help us to have a better understanding of the nature of DM itself.

Prospects for dark matter detection in the extended halos of dwarf irregular galaxies with gamma rays [2]

Usually as the prime targets for indirect DM searches are considered to be dwarf spheroidal galaxies. This is because they are thought to be DM dominated objects and the contamination from intrinsic astrophysical sources is negligible in them. Besides dwarf galaxies, the Galactic Center region is also a good target for the DM searches, both because of its proximity and its predicted large DM concentration.

Whereas in our work we propose to investigate dwarf irregular galaxies as new targets for indirect searches of DM with gamma-ray telescopes. Main motivations for that are

- the kinematics and therefore the DM content of these galaxies are very well defined;

[1] One of the problems in the standard (Λ)CDM scenario.

- beyond the sphere of $\sim$ 4 Mpc the number of rotationally supported dwarf irregular galaxies starts to dominate on pressure-supported objects or dwarf spheroidal galaxies.

We were able to put prospective constraints on the particle DM mass and annihilation cross section that were obtained by the analysis of a sample of 36 dwarf irregular galaxies.

Determination of the dark matter density parameters of the Milky Way [3]

The goal of this work is to constrain the dark matter distribution in the Milky Way. In order to do so we combine the observations of the circular velocity of different tracers in the inner part of the Milky Way ($\sim$ 2.5-$\sim$ 20 kpc) with that of the outer part. The latter is obtained from a spherical Jeans analysis using the measured velocities of the Milky Way halo stars. Then, based on these observations, we develop a code that simulates a set of the mock data (rotation curves) in order to investigate the DM parameters of the generalised NFW profile. In other words we test the precision of the recovered DM parameters of the Milky Way that are obtained by means of the kinematical measurements. The results of this study will be useful for both the galaxy formation theories as well as for the indirect DM searches.

Talks at conferences, workshops and seminars

I have presented my work at the following conferences, workshops and seminars

- May 2017, South American Dark Matter Workshop, ICTP-SAIFR, São Paulo (Brazil), Dark matter distribution in dwarf disk galaxies
- May 2017, University of Campinas (UNICAMP), São Paulo (Brazil), The nature of Dark Matter from properties of galaxies (invited seminar)
- October 2017,Workshop: Amsterdam-Paris-Stockholm, 7th Meeting, Kasteel Woerden (The Netherlands), Prospects for dark matter detection in dwarf irregular galaxies

Scientific visits

- July 2017, Fermilab (USA)

References

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[2] V. Gammaldi, E. V. Karukes and P. Salucci, *Prospects for dark matter detection in the extended halos of dwarf irregular galaxies with gamma rays*, [1706.01843].

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Scientific Report 2017

Title	Integrabilidade em teorias de gauge
Postdoc	Ryo Suzuki
Supervisor	Nathan Jacob Berkovits
Fapesp process	2016/25619-1
Period	01/Feb/2017 - 30/Sep/2017

Ryo Suzuki
Nathan Berkovits

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This scientific report summarizes my activity at ICTP-SAIFR from February 1st to September 30th in 2017.

1 Research

Duality is an important prediction of string theory. One of the most studied examples of the string dualities is the AdS/CFT correspondence. In particular, the one between $\mathcal{N}=4$ Super Yang Mills (SYM) theory in four dimensions and superstring on $\mathrm{AdS}_5 \times \mathrm{S}^5$ in the planar limit attracts sharp attention because both $\mathcal{N}=4$ SYM and $\mathrm{AdS}_5 \times \mathrm{S}^5$ superstring theories are believed to be integrable. By making full use of integrability, and various quantities have been computed at any values of the 't Hooft coupling λ.

In this project, I reconsider the statistical property of $\mathcal{N}=4$ SYM, namely the free energy. From the large N_c behavior of the free energy, one can tell whether the vacuum of the theory is in the confined or deconfined phase. In between the vacuum undergoes the so-called Hagedorn transition, where the free energy apparently diverges. The Hagedorn transition of a large N_c gauge theory resembles the high temperature property of string theory.

1.1 Grand partition function of $\mathcal{N}=4$ SYM

The grand partition function of $\mathcal{N}=4$ SYM on $\mathbb{R} \times \mathrm{S}^3$ is defined as

$$\mathcal{Z}(\beta, \vec{\omega}) = \mathrm{tr}\, \left(e^{-\beta \mathfrak{D} + \sum_i \omega_i J_i} \right), \qquad \mathfrak{D} = \mathfrak{D}_0 + \lambda \mathfrak{D}_2 + \dots, \qquad \lambda = \frac{N_c\, g_{\mathrm{YM}}^2}{16\pi^2} \tag{1}$$

where β is the inverse temperature, $\mathfrak{D}$ the dilatation operator, $\omega_i\ J_i$ the R-charges We take the trace over all gauge-invariant local operators in the $SU(2)$ sector, made out of complex scalars $\{W, Z\}$. The grand partition function (1) has the weak coupling expansion

$$\mathcal{Z}(\beta, x, y) = Z_0(x,y) - 2\beta\lambda\, Z_2(x,y) + O(\lambda^2), \qquad (x,y) = \left(e^{-\beta+\omega_W}, e^{-\beta+\omega_Z} \right). \tag{2}$$

The first term $Z_0(x,y)$ has been known for any finite N_c and for any chemical potentials. The second term $Z_2(x,y)$ has been known only for the case $x=y$ and at large N_c, due to technical difficulty coming from Pólya enumeration theorem.

By using the technique of permutation groups, I obtained $Z_2(x,y)$ to any orders of $1/N_c$ expansion. The result is given by the plethystic exponential of the singe-trace grand partition function, as

$$\frac{Z_2(x,y)}{N_c} = 2 \prod_{h=1}^{\infty} \frac{1}{1-x^h-y^h} \sum_{k=1}^{\infty} \left(\sum_{d=1}^{\infty} \mathrm{Tot}(d) \frac{x^{kd} y^{kd}}{1-x^{kd}-y^{kd}} - \sum_{L=2}^{\infty} \sum_{m=1}^{L-1} x^{km} y^{k(L-m)}\, \delta(\gcd(m,L),1) \right),$$

where Tot is Euler's totient function, and gcd is the greatest common divisor. The first few terms read

$$\frac{Z_2(x,y)}{N_c} = 6x^2y^2 + \left(10x^3y^2 + 10x^2y^3\right) + \left(26x^4y^2 + 36x^3y^3 + 26x^2y^4\right)$$
$$+ \left(44x^5y^2 + 84x^4y^3 + 84x^3y^4 + 44x^2y^5\right) + \left(84x^6y^2 + 176x^5y^3 + 254x^4y^4 + 176x^3y^5 + 84x^2y^6\right)$$
$$+ \left(134x^7y^2 + 348x^6y^3 + 548x^5y^4 + 548x^4y^5 + 348x^3y^6 + 134x^2y^7\right) + \dots \quad (3)$$

The term $6x^2y^2$ is responsible for the one-loop dimensions of the $SU(2)$ Konishi descendant, which is $3N_c\, g_{\rm YM}^2/(4\pi^2)$. By comparing this result with the recent prediction of integrability (the Q-system in XXX spin chain), one finds perfect agreement.

Since the above results are simple, one can immediately extract the location of singularity to compute the Hagedorn temperature $T_H(\lambda)$. At weak coupling, the Hagedorn temperature for general chemical potentials in the $SU(2)$ sector is given by

$$T_H(\lambda) = \begin{cases} \dfrac{1}{\log(e^{\omega_1}+e^{\omega_2})} \left[1 + \dfrac{4\lambda e^{\omega_1+\omega_2}}{(e^{\omega_1}+e^{\omega_2})^2}\right] & (e^{\omega_1} > 0 \ \text{ and } \ e^{\omega_2} > 0, \ e^{\omega_1}+e^{\omega_2} \geq 1)\,, \\ \dfrac{2}{\log(e^{2\omega_1}+e^{2\omega_2})} \left[1 + \dfrac{4\lambda e^{2\omega_1+2\omega_2}}{(e^{2\omega_1}+e^{2\omega_2})^2}\right] & (e^{\omega_1} < 0 \ \text{ or } \ e^{\omega_2} < 0, \ e^{2\omega_1}+e^{2\omega_2} \geq 1)\,, \end{cases} \quad (4)$$

which generalizes all the known results in the literature. One can also find that the Hagedorn temperature changes discontinuously in the space of complex chemical potentials.

1.2 Lecture note on superstring

I have summarized a series of lectures about superstring theories, which Prof. Berkovits at ICTP-SAIFR in 2016. The lecture note together with `Mathematica` files may appear on arXiv.

The lecture note consists of four sections:

1. Ramond-Neveu-Schwarz (RNS) formalism

In RNS formalism, the worldsheet super(conformal) symmetry is realized explicitly. The prescriptions for computing scattering amplitudes are clear. However, due to the problem of the zero-modes of bosonic ghosts, general computation can be tedious.

2. Green-Schwarz (GS) formalism

In GS formalism, the target-space supersymmetry is manifest. Extra spinor degrees of freedom are removed by imposing the so-called κ-symmetry. The GS formalism can be generalized straightforwardly to general curved backgrounds, like $\mathrm{AdS}_5 \times \mathrm{S}^5$. However, due to non-standard kinetic terms of fermions, one has to choose light-cone type gauge-fixing, which makes it hard to compute general scattering amplitudes.

3. Pure-Spinor (PS) formalism

In the original version of PS formalism, the target-space supersymmetry is manifest. Extra degrees of freedom are cancelled by pure-spinors and the BRST charge. In light-cone gauge, GS and PS formalisms are classically equivalent. The vertex operators can be constructed in analogy with superparticle action in 10 dimensions.

4. Untwisted PS formalism

It is known that worldsheet superconformal symmetry can be made manifest if one adds more variables to the minimal PS formalism. The untwisting PS formalism was introduced in the lecture, and its relation to the RNS formalism is explained.

2 Publication

[1] R. Suzuki, "Refined Counting of Necklaces in One-loop $\mathcal{N} = 4$ SYM," JHEP **1706** (2017) 055, [arXiv:1703.05798 [hep-th]].

3 Seminars and conferences

Below is the list of seminars and conferences I participated in 2017:

- Poster presentation at *Integrability in Gauge and String Theory 2017*; Ecole normale supérieure, Paris, France, July 2017. https://www.phys.ens.fr/̃igst17/
- Talk at ICTP-SAIFR; São Paulo, Brazil, June 2017.
- Poster presentation at *Progress in Quantum Field Theory and String Theory II*; Osaka City University; Osaka, Japan, March 2017.
https://sites.google.com/site/progresinqftandstringtheory/

SCIENTIFIC REPORT 2017

TITLE	ANGULAR BISPECTRUM OF LARGE SCALE STRUCTURE
POSTDOC	ANTONINO TROJA
SUPERVISOR	NATHAN JACOB BERKOVITS
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Research Report 2017

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Introduction

Observations of the Cosmic Microwave Background (CMB) and Large Scale Structure (LSS) of the Universe allow us to better understand the physics that drives the evolution of the primordial perturbation all the way to the large-scale distribution of galaxies we see today, leaving, however, important open problems. The latest Planck results [1] show that the Universe is composed only for the $\approx 4\%$ of the total energy density by ordinary baryonic matter. The remaining 96% is unknown, composed by non-baryonic matter (the so-called dark matter $\approx 26\%$) and the mysterious dark energy ($\approx 70\%$).
It is impossible to directly observe dark matter, since it interacts only gravitationally. However, it is possible to relate the distribution of the visible matter (galaxies) with the distribution of the total matter content by writing

$$\delta_m \approx b_1 \delta_g + \frac{1}{2} b_2 \delta_g^2,$$

where δ_m is the total matter density distribution, δ_g is the galaxy density distribution, b_1 and b_2 are the linear and quadratic bias parameters respectively. This relation is local and it is satisfied by the galaxy distribution only on average, since there is a significant scatter among different regions of the Universe.
Since the galaxy distribution is the only observable in photometric surveys, we need to know as precisely as possible the relation between dark matter and galaxies. To this end, it is crucial to understand the statistical properties of the galaxy distribution. It is possible to describe the galaxy distribution as a non-Gaussian 3-dimensional field, in which non-Gaussianity arises from the highly non-linear clustering process, which introduces non-linear coupling between different scales.

1 Research in 2017

Since the beginning of the Post-Doc, I worked on the following project.

Matter Bispectrum

At first order, the galaxy distribution is analyzed by taking its power spectrum, i.e. the Fourier transform of the 2-point correlation function, which parametrizes the excess probability of finding two galaxies at a certain distance. Unfortunately, the amplitude of the power spectrum (parametrized by the amplitude of dark matter fluctuations at $8h^{-1}$Mpc, σ_8) is degenerate with the bias parameters, leading to weak constraints. For this reason, the bispectrum is now one of the main tools in constraining cosmological parameters. The bispectrum is the Fourier counterpart of 3-points correlation function, which parametrizes the excess probability of finding three galaxies in a given triangular configuration. The dependence of the cosmological parameters on a particular triangular configuration (equilateral,

isosceles, squeezed, etc...) allows to constrain different parameters by taking different bispectrum configuration, thus removing the degeneracy.
My idea was to analyze the photometric distribution of the galaxies, in order to constrain its *angular spectrum* and *bispectrum* [1, 2]. We can indeed treat the photometric galaxy distribution as a spherical field, allowing us to use angular statistics. Due to its power in removing degeneracy, in view of present and forthcoming photometric surveys like DES and LSST, the angular bispectrum is likely to become one of the main tools in the analysis of photometric of datasets.
I derived an estimator for both angular power spectrum and bispectrum. The application of my estimators to real datasets will provide new constraints to cosmological parameters. In view of this, the DES survey represents the best framework in which introduce the estimators, in order to get stronger and statistical more reliable cosmological constraints comparing to the currently planned more traditional approach [4, **?**].

References

[1] Planck Collaboration, 2016, A&A, 594, A13

[2] Planck Collaboration, 2016, A&A, 594, A17

[3] Troja, A., Sefusatti, E., Crocce, M., 2017, *in prep.*

[4] Troja, A., Rosenfeld, R., 2017, *in prep.*