Scientific report 2018

Title: Approaching complex networks for time series analysis
Postdoc: José Luis Herrera diestra
Supervisor: Nathan Jacob Berkovits
Fapesp: 2016/01343-7 and 2017/00344-2

José Luis Herrera

Scientific report (2018)
Dr. Jose Luis Herrera D.
Postdoctoral researcher

During the calendar year 2018, I have had the opportunity to attend to two conferences, publish and submit research papers, as well as establish new collaborations, along with the ones I was already working on.

As part of my postdoctoral responsibilities, my research is focused in several applications of Network Science and Time series analysis to study propagation, containment and surveillance of diseases; intermittent spatiotemporal intervention on dynamical systems; detection of dynamical transitions in Electroencephalographic signals, characterization of speeches, as well as evaluation in individual and team performance in sports (particularly soccer) using complex networks approaches.

Below you can find a list of the activities and publications for this year 2018.

Invited oral presentation:

"Spatio-temporal intermittent interventions in social and dynamical systems". Dynamics Days Latin America and the Caribbean. 26 - 30 of November 2018. Punta del Este - Uruguay.

"Dynamical and topological characterization of the symbolic networks of disease outbreaks". International school and conference on Network Science - NetSci 2018. June 11 - 15, 2018. Paris - France.

"Analyzing disease outbreaks by means of symbolic networks". 15h Experimental Chaos and Complexity Conference. June 4 - 7, 2018. Madrid - Spain.

Articles published and submitted:

Damping and clustering into crowded environment of catalytic chemical oscillators.
Carlos Echeverria, **Jose L. Herrera**, Kay Tucci, Orlando Alvarez, Miguel Morales.
Accepted (August 2018) Physica A.

Using network science to analyze football passing networks: dynamics, space, time and the multilayer nature of the game.
J. M. Buldú, J. Busquets, J. H. Martínez, **J. L. Herrera-Diestra**, I. Echegoyen, J. Galeano, J. Luque.
Frontiers in Psychology 9, 1900 (2018).

Detection of time reversibility in time series by ordinal patterns analysis.
J. H. Martínez, **J.L. Herrera** and M. Chavez.
Accepted in Chaos: An interdisciplinary Journal of Nonlinear Science. (October 2018).

Local risk perception enhances epidemic control.
J.L. Herrera, Lauren Ancel Meyers.
Submitted to Journal of the Royal Society Interface (October 2018).

Scientific Report

Bootstrap não-perturbativa e a matriz S

Posdoc: Andrea Leonardo Guerrieri
Supervisor: Nathan Berkovits
Fapesp process: 2017/02303-1
Period: 01/06/2017 to 30/11/2018

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 The S-matrix bootstrap program

During the period that goes from the 01/06/2017 to the 30/11/2018 I mainly spent my efforts developing the new S-matrix bootstrap approach [1, 2, 3].

Despite the undeniable success in the CFT case, the bootstrap approach was first proposed to compute the S-matrix of the strong interaction particles in the 60's. However, that program has been almost abandoned after that the Quantum Field Theory framework proved to be the most efficient tool to compute perturbative scattering amplitudes. Later on, the Lattice QCD approach allowed access also to non-perturbative phenomena.

Triggered by the success obtained in the context of Conformal Field Theories, we propose to revisit the $\pi - \pi$ scattering using purely S-matrix techniques.

2.1 Bootstrapping QCD [4]

Pions are approximate Goldstone bosons due to the spontaneous and explicit chiral symmetry breaking. In this first paper I assumed only the presence of the *up* and *down* quark and to be degenerate in mass ($N_f = 2$); the electro-weak interaction is neglected in order to treat pions as stable particles (this approach is largely justified phenomenologically).

I generalized the setup in [3] in order to describe external particles charged under some $O(N)$ global group ($N = 3$ for pions) and I imposed some chiral zeros conditions in order to input the spontaneous symmetric breaking pattern that Goldstone bosons parametrize.

I discovered that the intricate multi-dimensional space of scattering lengths, effective ranges, chiral zeros and resonances draws a rich geography: there are exclusion "lakes", allowed "peninsulas" and kinks. QCD lies in a remarkable position in this space being at a kink on the boundary of the allowed low-energy parameter space.

3 Other research interests

3.1 Matching the Bootstrap and the ϵ-expansion [5, 6]

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 [7] 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.

3.2 Bootstrapping massless amplitudes via soft-theorems [8, 9]

As we have extensively shown in [8], 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 [9] and check it with explicit computations. In fact, soft behaviors of S-matrix for massless theories reflect the underlying symmetry prtiple 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.

4 Organization of events

I am one of the organizer of the S-matrix Bootstrap Workshop 2019 to be held in Sao Paulo the next September.

It is the third workshop focused on S-matrix related topics. Its main purpose is to gather experts on several different research fields related to the S-matrix and trigger their discussion. The topics covered will go from String S-matrix, to QCD phenomenology. We have managed to invite top researchers in all the fields.

5 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 Non-perturbative Bootstrap Annual Meeting (workshop).
- December 13, 2017, "String Cosmology and related topics" (mini-workshop and talk), University of Rome Tor Vergata. Title: "Generalized Wilson-Fisher Critical Points from the Conformal OPE".
- December 18-20, 2017, "6-th Rome joint Workshop: Weird theoretical ideas", Laboratori Nazionali di Frascati (workshop).
- December 21, 2017, La Sapienza University of Rome (invited talk). Title: "Bounding the space of S-matrices: Rebooting the Bootstrap".
- March 22, 2018, ICTP Sao Paulo (talk). Title: "Reboot(strap): towards QCD S-matrix".
- May 20-26, 2018, S-matrix Bootstrap Workshop 2018, Sao Miguel island, Azores (workshop).
- July 7-22, 2018, "Bootstrap 2018", Caltech (school, workshop and invited talk). Title: "The Pion Lake".
- 23 October, 15 November, 2018, Perimeter Institute (visit and invited talk). Title: "Bootstrapping QCD: The Pion Lake and Peninsula".
- November 8-9, 2018, Simons Collaboration on the Non-perturbative Bootstrap Annual Meeting (workshop).
- November 13, Purdue University (invited talk). Title: "Bootstrapping QCD: the Lake, the Peninsula and the Kink".

6 Publications

- A. L. Guerrieri, J. Penedones and P. Vieira, "Bootstrapping QCD: the Lake, the Peninsula and the Kink," arXiv:1810.12849 [hep-th].

7 Citations

The paper I submitted on the arXiv and that I'm going to publish soon is going to have a large impact on the Community according to feedback received during the talks I recently did on the same subject. It still has no citations, but my expectation is that their number will become important in upcoming years.

8 Works to appear soon

- Bootstrapping massless QCD with J. Penedones and P. Vieira.
- Bootstrapping flux tubes with A. Hebbar, J. Penedones and P. Vieira.
- A novel approach to fit scattering amplitudes with J. Penedones and P. Vieira.

9 Progress

As mentioned in the research statement, during the entire year 2017/2018 I put my efforts in developing the S-matrix Bootstrap for QCD. To achieve that goal I needed to develop a plethora of different skills: analytic, numerical, physical and informatics.

I studied in detail the analytic structure of the S-matrix, that in 3+1 dimensions it is an analytic functions of 2 variables which has, at very least, square root branch points corresponding to the minimal energy for particle to scatter. In order to study resonances I had to understand the structure of the second Riemann-sheet and their consequences on the physical sheet.

An analytic solution to the QCD bootstrap equation seems way beyond our current mathematical skills. For this reason, I decided to tackle this problem numerically. The bootstrap problem is recast into a Semidefinite Optimization Program that I efficiently solved using one of the best algorithms available, SDPB [10].

Moreover, to zoom in on QCD and Pion physics in particular, I studied the experimental literature and the various low energy effective field theory descriptions as the Chiral Perturbation Theory. In particular, the success of my approach heavily relies on the knowledge of the effective field theories.

To put in practice all the idea I used two different clusters for one entire year: one at the EPFL in Lausanne, the other at the Perimeter Institute. Future developments will rely even more heavily on cluster force.

10 Justification for a renewal of the fellowship

The framework described in the previous section calls for further developments. I will list some of them, starting from the projects I am already working on: their development and completion constitutes the main reason why I need an extension of my postdoc fellowship.

1. "Massless QCD". A problem that arise in bootstrapping $\pi - \pi$ amplitudes is the separation of scales between their masses and the typical QCD mass scale. A way to overcome this problem and make the analysis of the S-matrix easier is to consider massless pions. I already managed to generalize the analytic setup I used in the previous work to the massless case and the numerical analysis is going to start.

2. "Flux Tube theories". An interesting $1 + 1$-dimensional model for scattering of massless Goldstone bosons is the scattering of flux tube excitations on the QCD

string. I already started to get numerical results and I hope to make progress rapidly.

3. "Fitting experimental data". An exciting consequence of this S-matrix approach is that it furnish and analytic Ansatz for the full amplitude. I am using semi-definite programming to perform constrained fit on experimental data with this analytic Ansatz. Combining data-compression techniques I hope also to develop a faster and still reliable fit procedure.

4. "Towards precision and accuracy". A straightforward follow up of my paper is to push numerics and try to see how many particles in the QCD spectrum I can extract from its S-matrix. Unfortunately, this is not straightforward because of several physical and numerical challenges. To overcome the numerical ones I am going to be one of the first researchers in the Bootstrap community to use the parallel version of SDPB: SDPB Elementhal.

5. "Effective world-line for Heavy Quarks". I will mention this fun side-project that does not belong to my main research topics, but I hope it will in the future. The idea is that there exist different effective field theory descriptions to heavy quarks as HQET, NRQCD, pNRQCD and so on that seem to work in different regimes. I am proposing a new framework, the hopefully will be flexible enough to incorporate some features of the various effective field theories. Moreover, since EFT's has been crucial in developing the S-matrix bootstrap for QCD, I hope to get insights to bootstrap also Heavy-Quarks.

6. "Hamiltonian Truncation for AdS_2". I am proposing to use the hamiltonian truncation on AdS_2 in order to access to non-perturbative RG-flows on curved space-times and study, eventually, exotic critical points that can arise.

11 Schedule

Many of the projects described in the last section has already been started or already reached an advanced point. I plan to complete all of them for the end of the extension.

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Scientific Report

Title: Quantum measurement simulability and applications to Bell nonlocality
Postdoc: Leonardo Guerini
Supervisor: Nathan Jacob Berkovitz
Period: 01/Apr/2018 - 30/Nov/2018
Fapesp 2016/01343-7 and 2018/04208-9

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

Research report

Leonardo Guerini

November 2018

1 Introduction

Entanglement, measurement incompatibility, and intrinsic randomness lie among the most remarkable and counter-intuitive features of quantum theory. While research on entanglement is well-established and lie at the core of quantum advantages over classical resources, measurement incompatibility also offers a rich collection of properties to be investigated, and quantum-generated randomness only recently started to be studied. The typical context to investigate these concepts is the Bell scenario, a causal structure that conveys bipartite experiments. The approximation between quantum theory and causality in the last few years allowed for a deeper understanding of this scenario and opened new horizons.

In the following, we briefly describe the projects finished in 2018 or still in progress, addressing these fundamental aspects of quantum theory and applications.

2 Research projects

2.1 Uniqueness of the joint measurement [1]

Joint measurability refers to the property of a set of measurements to be implemented as a single one, the so-called joint measurement. In this work we address the problem of characterising the compatible tuples of measurements that admit a unique joint measurement. We derive a uniqueness criterion based on perturbation techniques and apply it to show that extremal points of the set of compatible tuples admit a unique joint measurement, while all tuples that admit a unique joint measurement lie in the boundary of such a set. We also provide counter-examples showing that none of these properties are both necessary and sufficient, thus completely describing the relation between joint measurement uniqueness and the structure of the compatible set. As a by-product of our investigations, we characterise the extremal and boundary points of the set of general tuples of measurements and of the subset of compatible tuples.

2.2 Joint measurability meets Birkhoff-von Neumann's theorem [2]

Quantum measurements can be interpreted as a generalisation of probability vectors, in which non-negative real numbers are replaced by positive semi-definite operators. We extrapolate this analogy to define a generalisation of doubly stochastic matrices that we call doubly normalised tensors (DNTs), and formulate a corresponding version of Birkhoff-von Neumann's theorem, which states that permutations are the extremal points of the set of doubly stochastic matrices. We prove that joint measurability arises as a mathematical feature of DNTs in this context, needed to establish a characterisation similar to Birkhoff-von Neumann's. Conversely, we also show that DNTs emerge naturally from a particular instance of a joint measurability problem, remarking its relevance in general operator theory.

2.3 Experimental device-independent certification of randomness generation in the instrumental scenario [4]

The instrumental scenario is a causal structure similar to the one used in a Bell experiment, in which the two parties communicate so that Alice's output becomes Bob's input. It was recently proved the existence of a gap between classical and quantum resources in this context, represented by the violation of an instrumental inequality [3]. In this project we investigate the advantages of the instrumental scenario for randomness generation. Besides the ease of implementation, the instrumental scenario enables the usage of only one input random seed for the generator, therefore requiring less initial randomness. We adopt a photonic platform to implement an instrumental process, equipped with active feed-forward of information, and realize a device-independent randomness certification and generation protocol, which enabled us to extract 192398 certified random bits, with a ratio between the extracted and the raw collected bits up to 0.53. This work provides a proof-of-principle of the validity of the instrumental process as platform for information processing tasks, constituting a valid alternative to Bell-like scenarios.

2.4 Remote quantum sampling [5]

We introduce the problem of remote quantum sampling (RQS): Alice is given a quantum state and Bob is given a quantum measurement, and their goal is to sample from the probability distribution generated by the performance of such measurement on such state. The question we pose is what resources they must share in order to implement this task remotely, depending on properties of the given state and measurements. While being a simple quantum-informational task, we show that this problem captures two of the most distinguishing features of quantum theory in the same framework: joint measurability and quantum teleportation. If the parties share only classical communication from Alice to Bob, RQS can be implemented if and only if the measurements are jointly measurable. If they also share maximal entanglement, then a succesfull RQS for tomographically complete sets of measurements is equivalent to teleporting the input-state. We also study the intermediate case, where the parties share non-maximal entanglement, and use computational techniques to investigate the entanglement cost of RQS.

3 Conferences and seminars

- Modern topics in quantum information, Jul 30 - Aug 17, International Institute of Physics - UFRN, Natal, Brazil. Contributed talk.
- Congresso Nacional de Matemática Aplicada e Computacional, Sep 17-21, IMECC - Unicamp, Campinas, Brazil. Invited talk.
- Research seminar, Sep 25, ICTP-SAIFR, São Paulo, Brazil.
- SpinOffQubit, Sep 27-28, IFUSP, São Paulo, Brazil. Invited talk.

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Scientific Report 2018

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: 1/Dec/2017 - 30/Nov/2018

ICTP
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INTERNATIONAL CENTER FOR THEORETICAL PHYSICS
SOUTH AMERICAN INSTITUTE FOR FUNDAMENTAL RESEARCH

Bithika Jain.

Nathan Berkovits

Introduction

My research interests are focused on deepening our understanding of the nature of fundamental particles and their interactions via electroweak forces. Standard model (SM) is the mathematical framework which encapsulates our current understanding of these elementary particles and fields. The last particle predicted by SM - the Higgs boson, was recently discovered. However, much remains to be understood about the dynamics of Higgs mechanism. Solutions aimed at explaining the origin and nature of Higgs often require new physics. The top-down solutions predict new physics possibly accessible at TeV scale energies, while bottom up perspective helps scrutinize available experimental data and suggest new search strategies. The lack of experimental evidence for new physics begs for a rigorous investigation strategies and theoretical input. I have used both analytical and computational techniques to investigate various new physics scenarios and the particles they predict with the aim of understanding universe in time scales of few nanoseconds till ~10 seconds after Big bang.

Dark matter phenomenology

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 [1]

Effective Potential and the Precision of Higgs Self Couplings

Determining the structure of Higgs potential is also important to understand the features of EW phase transition, whose properties can have significant implications for cosmology. Inflation predicts that the early universe was baryon-symmetric. However, one extra quark per 10 billion quark-antiquark pairs was created. This tiny excess is responsible for baryonic matter in the current universe. A dynamical mechanism for baryon asymmetry generation is needed. A strong first order phase transition (SFOPT) could provide a viable scenario to realize baryogenesis at the EW scale. Such a transition proceeds when the bubbles of the broken phase nucleate within the surrounding plasma in the symmetric phase. These bubbles expand, collide and coalesce until broken phase remains. Particles scatter with the bubble walls to generate Charge (C) and Charge-Parity(CP) asymmetries. These asymmetries help produce more baryons than antibaryons as laws of physics can change when particle is interchanged with its antiparticle while its spatial coordinates are inverted. Some of the net baryon charge created outside the bubble wall enters the broken phase. The higgs mass of 125 GeV does not allow SM electroweak phase transition to be first order and the CP violation induced is not large enough to generate baryon asymmetry. An essential feature of all viable realizations of electroweak baryogenesis (EWBG) is new physics. BSM physics needs to be coupled to SM with moderate strength and must be abundant in thermal plasma during the electroweak phase transition. This implies that new particles of masses around electroweak scale and with direct couplings to SM should exist. These should be discoverable at the collider and precision experiments like LHC. I examined the validity of the so-called Parwani method with Arnold-Espinosa method in computing the Higgs effective potential and investigated the precision of the Higgs couplings required for verifying the strong first order phase transition in Higgs Portal models and effective field theories [2].

Cosmological Phase Transition in extra dimension

I worked on a 5D model where dynamical generation of electroweak potential occurs and suppressed cosmological constant exists. We focussed on cosmology of this setup, with detailed numerical analysis to explore the parameter space which allows for successful strong phase transition detectable at the future gravitational wave detector [3]

Vacuum Stability in Holographic Models

There exists the problem of ElectroWeak (EW) vacuum in the SM. The true vacuum is at $\phi \sim 10^{11}$ GeV, much deeper than the EW one. When compared with the Hubble expansion of the universe the EW vacuum turns out to be metastable. In SUSY the SM Higgs quartic, $\lambda \propto g^2 + g'^2$. The gauge couplings never get negative values. This is how the stability problem is resolved. How does the Warped Extra dimensions solve the stability problem? We are also currently working on vacuum stability in Randall Sundrum Models by looking at the running of the higgs quartic. [4] We recently computed the effective potential for the Higgs using tadpole method as part of this project. Our next step is to identify running of the higgs quartic.

Conference and Seminars

1. 25th International Conference on Supersymmetry and the Unification of Fundamental Interactions (SUSY17) and the Pre-SUSY school, Tata Institute of Fundamental Research, Mumbai, India
2. Seminars at Department of Theoretical Physics, T.I.F.R, Mumbai, India and Department of Physics, I.I.T Powai, Mumbai, India
3. Cosmological probes of BSM - from the Big Bang to the LHC, Centro de Ciencias de Benasque Pedro Pascual Benasque, Spain
4. Seminars at Centre For High Energy Physics, Indian Institute of Science, Bangalore, India and Department of Physics, IISER, Pune, India

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SCIENTIFIC REPORT 2018

Title	Matéria Escura nas Galáxias
Postdoc	Ekaterina Karukes
Supervisor	Nathan Jacob Berkovits
Fapesp process	2016/26288-9
Period	01/Feb/2017 - 30/Nov/2018

INTERNATIONAL CENTER FOR THEORETICAL PHYSICS
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Research Report 2018

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.

Dark matter content and its distribution in the Milky Way galaxy

The Milky Way (MW) system also represents a challenge for the ΛCDM theory. In particular, there is a long-standing tension between the number of detected satellite galaxies around the MW and the predictions of the pure dark matter structure formation simulations within the standard ΛCDM theory, known as the "missing satellite problem" [6]. Nonetheless, in the last few years there is a growing evidence that by involving baryonic physics in the hydrodynamical simulations we are able to finally solve the problem [7]. In light of that, one of the key parameter that enters in the solution of the "missing satellite problem" is the total MW mass. Therefore, it is important to have a robust determination of that. Furthermore, understanding the distribution of DM in the MW is important in order to properly interpret direct and indirect DM searches (see e.g. [8]), and to probe more exotic DM models (see e.g. [9]).

Typically the direct way to estimate the mass distribution of the MW, or any other galaxies, is to measure the kinematics of different dynamical tracers such as stars, gas, globular clusters, and satellite galaxies. Then the derived rotation curve can be used to mass model the Galaxy, i.e. fitting the multicomponent model to it (see e.g. [10]). Furthermore, before mass modelling one usually needs to assume a parametric form for the DM distribution (however see [11]). The latter along with the uncertain measurements of the baryonic content of the MW and the uncertain measurement of the galactic parameters makes the estimation of the MW DM content to be uncertain.

The goal of this work is to use recent MW kinematical measurements in order to reconstruct the DM density profile of the MW assuming a gNFW profile [12] and by means of the rotation curve (RC) mass modelling. We use a Markov Chain Monte Carlo approach in order to perform the three parameter gNFW model fitting. We further validate the accuracy of the result on a suite of mock RC where we a priori know the parameters of the underlying gNFW DM density profile. We show that the local DM density ρ_0 values are recovered with a very good accuracy (within uncertainties < 20 %). We also find degeneracy between the scale radius r_s and the inner dark matter density slope γ. Besides, we demonstrate an important dependence of the quality of the gNFW parameters reconstruction on the underlying baryonic morphology. This is an ongoing work that I am doing together with people from ICTP-SAIFR/IFT UNESP and some other collaborators from Imperial College London (United Kingdom).

Indirect dark matter searches

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;
- beyond the sphere of ~ 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. We further calculated constraints for the combined analysis of the 7 most promising dIrr galaxies of our sample. During the period of my postdoc I have published one paper and one proceedings about indirect detection of dwarf irregular galaxies together with my collaborators from SISSA (Italy) and people from HAWC collaboration [13, 14].

Additionally, since November 2017, I am a member of the CTA collaboration, where I participate in the DM group. In particular, we are working on characterization of the Large Magellanic Cloud at TeV energies. This is an ongoing work.

Publications in 2018

- *Searching for TeV DM evidence from Dwarf Irregular Galaxies with the HAWC Observatory*, S. Hernandez Cadena, R. Alfaro, A. Sandoval, A. Belmont, V. Gammaldi, E.V. Karukes, P. Salucci for the HAWC Collaboration, 2018, PoS ICRC2017 (2018) 897, [14]
- *Theoretical predictions for dark matter detection in dwarf irregular galaxies with gamma rays*, V. Gammaldi, E.V. Karukes, P. Salucci, 2018, Phys. Rev. D 98, 083008, [13]

Talks at conferences, workshops and seminars in 2018

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

- May 2018, Workshop: Tensions in the LCDM paradigm, MTP, Mainz (Germany), Determination of the DM density profile of the MW (and how much to trust it);
- November 2018, Workshop: II South American Dark Matter Workshop, ICTP-SAIFR, São Paulo (Brazil), Milky Way dark matter density profile and its reconstruction.

Scientific visits in 2018

- May June 2018, Deutsches Elektronen-Synchrotron (DESY) (Zeuthen, Germany)

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[14] HAWC collaboration, S. H. Cadena, R. Alfaro, A. Sandoval, E. Belmont, H. Leon, V. Gammaldi et al., *Searching for TeV DM evidence from Dwarf Irregular Galaxies with the HAWC Observatory*, *PoS* **ICRC2017** (2018) 897, [1708.04642].

Scientific Report 2018

Title	Angular Power Spectrum and Angular Bispectrum of Large Scale Structure
PostDoc	Antonino troja
Supervisor	Nathan Jacob Berkovits
FAPESP process	2017/05549-1
Period	01/Nov/2017 - 31/Oct/2018

International Center For Theoretical Physics
South American Institute for Fundamental Research

Research Report 2018

Antonino Troja

Research in 2018

Academic activities

In 2018 I worked on several projects:

- The evaluation of angular power spectrum for Large Scale Structure (LSS) with the aim of analyze the Baryonic Acoustic Oscilation (BAO) feature, in collaboration with Rogerio Rosenfeld (ICTP-SAIFR/IFT), Felipe Oliveira (IFT), Hugo Camacho (USP). We were able to submit a paper about this work (see the Paper section for details);
- Covariance matrix estimation and measurements, both within the framework of the Dark Energy Survey (DES) and the Large Synoptic Survey Telescope (LSST);
- The analysis of angular bispectrum for the LSS, building a strong tool in order to provide predictions and measuring it on different N-body simulations, in collaboration with Emiliano Sefusatti (INAF Trieste) and Martin Crocce (ICE Barcelona);
- Cylindrical harmonic analysis on public Vipers data with the goal of develop a new tool in cosmological statistics that enjoys the properties of the Bessel functions. Vipers data are the best framework in order to develop this tool, in collaboration with Gigi Guzzo (UNIMI).

Activities within institute

During 2018 I organized and run:

- AC/JC Journal Club, in collaboration with Fabio Iocco and Ekaterina Karukes, at IFT;
- Weekly meeting group, within the cosmology group here at IFT.

Scientific visits

15-20/01/2018 - Visiting ICTP at Trieste, Italy;
05-11/11/2017 - Visiting LIneA at Observatorio de Rio de Janeiro.

Conferences, workshops and meeting attended

4-8/12/17 - LSST DESC 2017 Fall/Winter Sprint Week, Argonne National Laboratory, Lemont, IL;
18-20/04/18 - SCLSS, Oxford, UK;
16-20/07/18 - DES Y3KP Workshop, CMU Pittsburgh, PA;
20-22/07/18 - LSST DC2 Fest, CMU Pittsburgh, PA;
23-27/07/18 - LSST DESC meeting, CMU Pittsburgh, PA;
15-18/10/2018 - DES Michigan Workshop, Michigan University, Ann Arbor, MI.
LSST DESC Sprint Week - Argonne, IL

Papers

Camacho H. et al, 2018, arXiv:1807.10163