

ICTP Instituto Sul-Americano para Pesquisa  
Fundamental: um Centro Regional para Física  
Teórica

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## **3. Summary of the Project's main goals**

Fundamental research in theoretical physics has historically led to developments in all areas of science. In addition to producing technological applications coming from a better understanding of the physical laws of the universe, fundamental research in theoretical physics has led to new methods of problem-solving which has revolutionized areas of mathematics, biology, computer science, economics, and other areas of study.

Throughout the world, the importance of this research has led to the creation of theoretical physics institutes which focus on research, on the training of graduate students and postdocs, and on the organization of schools and workshops. Although these theoretical physics institutes have different structures and many are connected with public universities, they are all disconnected from undergraduate physics departments and have independent hiring policies and academic responsibilities from the rest of the university. Because of this autonomy, these theoretical physics institutes are able to attract the best researchers to their faculty. And because of the prestigious faculty and the organization of schools and workshops, these institutes are able to attract highly qualified graduate students and postdocs. As a result, the academic and research programs at these autonomous theoretical physics institutes increase the international impact of their host universities.

To fulfill the need for such a theoretical physics institute in South America, the ICTP South American Institute for Fundamental Research (ICTP-SAIFR) was created in 2011 in Sao Paulo as a collaboration between the Sao Paulo Research Funding Agency (FAPESP), the International Centre for Theoretical Physics (ICTP-Trieste) - a category 1 institute of UNESCO, the Sao Paulo State University (UNESP), and the Instituto de Física Teórica (IFT-UNESP) in whose building it is located. The ICTP-SAIFR in South America was the first regional center of ICTP created outside of Trieste, and because of its success, the ICTP-Trieste has now created regional centers in the continents of Central America (Mexico), Africa (Ruanda), and Asia (China).

In this UNESP-ICTP-FAPESP collaboration, the role of UNESP is to provide the infrastructure of the IFT-UNESP building including an auditorium, a computer lab, and first floor office space, as well as provide the salaries of their two secretaries, one accountant, one computer technician, and up to five tenured research professors. The role of ICTP-Trieste is to provide organizational support to the secretaries, and financial support for visitors from other South American countries. And the role of FAPESP is to provide financial support for visitors, postdocs, and Young Investigators, and for the organization of schools and workshops.

In its brief existence, the ICTP-SAIFR has already established itself as the premier institute for theoretical physics in South America. Its international schools and workshops for graduate students and researchers are selected from online proposals every year by the ICTP Scientific Council and attract the top students and lecturers from all over the world to São Paulo. Since the creation of ICTP-SAIFR, the graduate physics department of IFT-UNESP has been awarded the highest rating from the national agency CAPES despite its relatively small size. And with the help of a world-class scientific council and international search committee, ICTP-SAIFR has been able to reverse the brain drain and attract the top candidates to its faculty and postdoctoral positions. Its faculty currently include **Director Nathan Berkovits**, winner of the [2009 TWAS Physics Prize](#) for his research in string theory and the [2021 John Wheatley Award](#) for ICTP-SAIFR's role in South America, **Vice-Director Rogério Rosenfeld**, member of the Dark Energy Survey collaboration and president of the Brazilian Physical Society from 2019-2021, **Pedro Vieira**, joint professor at Perimeter Institute and winner of the [2018 Sackler Physics Prize](#) and [2020 New Horizons in Physics Prize](#) for his research in quantum field theory, **Riccardo Sturani**, member of the LIGO-Virgo collaboration which was recently awarded the Nobel Prize for the detection of gravitational waves, and **Ricardo Martinez-Garcia**, winner of a Serrapilheira grant for his research in mathematical ecology, coauthor of the [December 2020 cover of Science](#), and elected in 2020 as an affiliated member to the Brazilian Academy of Science. Pedro Vieira is originally from Portugal and spends 6 months per year at IFT-UNESP with a [FAPESP São Paulo Excellence Chair](#), and Riccardo Sturani and Ricardo Martinez-Garcia came to Brazil from Italy and Spain as FAPESP Young Investigator Fellows and began their permanent positions at IFT-UNESP in February 2022 as soon as the Covid-19 hiring restrictions were relaxed.

Simons-FAPESP "tenure-track" professors and FAPESP postdocs with temporary positions at ICTP-SAIFR are annually selected through an online application process involving hundreds of applicants. For the postdoctoral positions, a final short list of candidates are interviewed by the ICTP-SAIFR faculty and associated researchers in the research area of the candidates. And for the Simons-FAPESP group leader positions, the final short list of candidates are invited to present seminars and are interviewed by members of the ICTP-SAIFR Scientific Council and International Search Committee consisting of distinguished professors including Nobel Prize winners. These ICTP-SAIFR fellowships have attracted many outstanding researchers to return or to immigrate to Brazil, reversing the brain drain. In 2023, two new Simons-FAPESP "tenure-track" professors will be selected in the areas of theoretical physics and biological physics.

The main role of a theoretical physics institute is to foster the interchange of information between visiting and local researchers, and the ICTP-SAIFR has an active visiting program with over 150 visitors per year spending between one week and two months at the institute. There are weekly seminars and journal clubs in various subareas of theoretical physics, and the complete list of visitors and research seminars can be found on the ICTP-SAIFR webpage [www.ictp-saifr.org](http://www.ictp-saifr.org). Research seminars are frequently recorded and made available online using equipment installed with the guidance of the Perimeter Institute and ICTP Trieste audiovisual departments.

In addition to the research conducted by its members and visitors, the ICTP-SAIFR regularly organizes schools, mini-courses, workshops and programs for doctoral students and researchers in all areas related to theoretical physics. The success of these activities has allowed the IFT-UNESP masters and doctoral programs to attract the top students in theoretical physics from all of South America, and to receive the top ranking of Brazilian graduate physics programs since 2011. Over the next years, the ICTP-SAIFR intends to build on these recent accomplishments and continue to improve its research and organizational activities and consolidate its status as the premier theoretical physics institute in South America.

## 4. Accomplishments in the period

During the period from December 1, 2021 - November 30, 2022, ICTP-SAIFR concluded its thematic grant 2016/01343-7 from 2016-2022 and a new FAPESP thematic grant 2021/14335-0 starting on December 1, 2022 was approved. Highlights during the 6 years of 2016/01343-7 are all described in the ICTP-SAIFR bimonthly [scientific bulletins](#) and include [Science](#) and [Physical Review Letters](#) cover articles among its over 1000 publications, and awards from international organizations such as the Breakthrough Prize Foundation and the American Physical Society for ICTP-SAIFR [research](#), [training](#) and [outreach](#).

Perhaps the main highlight of this most recent period was the hiring in February 2022 of ICTP-SAIFR researchers Riccardo Sturani and Ricardo Martinez-Garcia as permanent IFT-UNESP professors. Both of these researchers came to ICTP-SAIFR as Fapesp Young Investigators, with Riccardo Sturani coming from Italy as a researcher in gravitational waves and Ricardo Martinez-Garcia coming from Spain as a researcher in complex systems and biodiversity. Riccardo Sturani is a member of the LIGO-Virgo collaboration since 2007 which was awarded the 2017 Nobel Prize for the detection of gravitational waves, and is coordinator of a new FAPESP thematic grant on LIGO which began on November 1. Ricardo Martinez-Garcia is a coauthor of the [December 2020 cover of Science](#), winner of a Serrapilheira grant for young researchers, and is an affiliated member of the Brazilian Academy of Science. The ability of ICTP-SAIFR to attract these top-level researchers to Brazil is proof that the center is accomplishing its goal of reversing the brain drain.

A second main highlight was the return to in-person activities after the pandemic. During the pandemic period of April 2020 - February 2022, ICTP-SAIFR organized over 150 online activities including online PhD schools and workshops for over 4000 online participants, as well as online lectures and minicourses and workshops for high-school students and teachers and the general public. In March 2022 after the relaxation of restrictions, ICTP-SAIFR finally returned to in-person activities with the organization of dozens of schools and workshops for graduate students and researchers.

The most ambitious school was the 5-month [Serrapilheira/ICTP-SAIFR Training Program in Quantitative Biology and Ecology](#) from July 4 - December 2, 2022 which was organized in partnership with the private non-profit Serrapilheira Institute. A new association "Instituto Amigos do SAIFR" was established in 2021 to facilitate the application of private funds for ICTP-SAIFR activities, and the IFT-UNESP computer laboratory was reformed to allow online transmission of this activity. This Serrapilheira/ICTP-SAIFR Training Program included daily lectures on various topics in quantitative biology and ecology by 41 international researchers, which were presented to a group of 31 graduate students from Latin America selected from

hundreds of applications. In addition to the daily lectures, the Training Program also included weekly [research seminars](#) by the invited professors, as well as [informal meetings](#) with senior researchers in Brazil to develop collaborations.

Selection of the graduate students in the Training Program was based on online interviews, as well as grades and recommendation letters. The students were required to have a basic knowledge of calculus and be fluent in English, but were not required to have previous experience with biology. The goal of this Training Program is to build an interdisciplinary group of researchers in Brazil who can use the quantitative methods of physics and mathematics to solve problems in biology and ecology. The first edition of this Training Program was held online in July 2021, and the third edition will be held in January-February 2023.

Another school organized in 2022 by ICTP-SAIFR together with the Mainz Institute for Theoretical Physics was the [Joint ICTP-SAIFR/MITP Summer School on Particle Physics beyond the Standard Model](#). This two-week school from September 12-23 consisted of 6 minicourses on advanced topics presented by international lecturers to 63 PhD students, including 18 PhD students from Europe financed by Mainz.

This international particle physics school was combined with a [Program on New Directions in Particle Physics](#) from September 5-23 in which 13 senior researchers from Europe and the USA were invited to spend 3 weeks in São Paulo to develop collaborations with Brazilian researchers. The Program featured daily informal seminars and discussion sessions, and the first week of the Program was organized at the site of the old IFT building near the financial section of São Paulo. This site is conveniently located next to the hotel of the visitors, and contains new installations which can be used for future ICTP-SAIFR activities.

Other PhD schools organized by ICTP-SAIFR in 2022 included a [School on Disordered Elastic Systems](#) from October 3-14, a [School on Applications of Non-Linear Systems to Socio-Economic Complexity](#) from October 17-22, and a [School on Quantum Computation](#) from November 14-25. The two-week School on Quantum Computation received over 200 applications, and several future activities on quantum computation are planned in 2023-2024. In collaboration with NCC-UNESP, ICTP-SAIFR also organized a 10-week online [São Paulo Codata-RDA School on Research Data Science](#) from May 9 - July 15 in which participants received training material and live online sessions for improving their data skills.

In addition to these PhD schools, ICTP-SAIFR organized several in-person workshops for researchers in 2022 including a [Workshop on Representation Theory and Applications](#) for mathematical physicists from April 25-29, a [Workshop on New Horizons in Quantum Correlated Materials](#) for condensed matter physicists from August 15-19, a [Workshop on Classical Gravity and its Applications](#) for general relativists from August 29-31, a [Workshop on Electromagnetic Effects in Strongly Interacting Matter](#) for nuclear physicists from October 25-28, and a [Workshop on the Nature of Dark Matter](#) for astrophysicists from November 2-4.

One of the goals of ICTP-SAIFR is to stimulate collaborations between research groups at different institutions in São Paulo, and from November 9-11, ICTP-SAIFR organized a 3-day workshop [Condensed Matter Theory in the Metropolis](#) with invited talks by 33 local researchers in the area of condensed matter physics. This workshop was extremely successful, and in 2023, ICTP-SAIFR plans to organize similar workshops for local researchers in the areas of field theory/particle physics, cosmology/astrophysics, complex systems/biology, and quantum matter/quantum information.

To motivate students to enter the field of physics, ICTP-SAIFR has instituted several

prizes for young researchers. One such prize is the SAIFR-Perimeter Fellowship in which 3 or 4 top undergraduate students from Latin America are invited to a joint Master's program in which they spend one year at a São Paulo institution and one year at the world-famous [Perimeter Scholars International](#) program at Perimeter Institute in Waterloo, Canada. The students are selected through two 3-hour exams given at the end of a one-week school [Journeys into Theoretical Physics](#) including lecturers from Perimeter Institute and São Paulo universities. In 2022, the fifth edition of this school was organized from August 1-7, and the 3 selected students will begin the joint Master's program in March 2023 at IFT-UNESP and IAG-USP.

Another prize is the [ICTP-SAIFR Prize in Classical Gravity and Applications](#) which is granted annually to the best PhD thesis from Latin America in the area of classical gravity and its applications. Candidates for this prize are nominated by their thesis advisor, and an international panel selects the winner and honorable mentions. The winners are invited to give a talk on their research at the annual [ICTP-SAIFR Workshop on Classical Gravity and Applications](#) which was held in 2022 from August 29-31 with talks by the winners of the 2021 and 2022 prizes.

In addition to these research and training activities for graduate students and researchers, ICTP-SAIFR expanded in 2022 its online and in-person outreach activities which attract thousands of participants from all over Brazil and Latin America. These ICTP-SAIFR outreach activities were recently highlighted in the [December edition of the American Physical Society monthly newsletter](#).

For high-school teachers, ICTP-SAIFR completed the [translation](#) of all 18 volumes of the Perimeter pedagogical material into Portuguese and Spanish with support from the American Physical Society and Perimeter Institute, and organized weekly online workshops in [Spanish](#) and [Portuguese](#) showing hundreds of high-school teachers how to use this material in their classroom. In January, an [online workshop on gravitational waves](#) was organized for high-school teachers in Spanish and Portuguese including a virtual tour of LIGO. And in June and October, [in-person workshops](#) were organized for high-school teachers including participants from 7 different countries in Latin America.

For high-school students, ICTP-SAIFR's successful series of [Saturday morning minicourses](#) returned from its online version to in-person lectures with minicourses on astrophysics (Roberto Costa IAG-USP, March-April), electromagnetism (Pedro Vieira, May-June), statistical mechanics (Luana Pedroza UFABC, June-July), quantum mechanics (Alexandre Reily Rocha, August), cosmology (Rogerio Rosenfeld, September-October) and particle physics (Ricardo Matheus, October-November). In addition, high-school teachers Lucas David and Felipe Santos presented [weekly online classes](#) to students on advanced topics in mathematics and physics, and Clewton Fonseca organized [minicourses](#) to prepare middle term and high school students for participation in the physics Olympics. A [one-week online school](#) was organized in January with the Univ. of Porto in which high-school students worked on research projects supervised by doctoral students, and a [one-week](#) in-person school on quantum information and python programming was organized for high-school students in July. And in October, ICTP-SAIFR organized in CEU Butantã a new activity ["Physics Games"](#) for middle-school students in which a scientific presentation was followed by a question-answer competition for the students.

For the general public, ICTP-SAIFR continued its online presentations on Thursday evenings entitled ["Física em Casa"](#) and organized five online presentations of [Sci-SAIFR book club](#) where physicists discussed science concepts behind their favorite books. ICTP-SAIFR also developed a [Youtube library of interviews](#) of physicists, [multimedia presentations](#) on complex systems in Brazil, [podcasts](#) on different areas of theoretical physics, and short informative [Instagram videos](#) on modern physics

topics which attract thousands of viewers.

The 185 research publications during this period in the areas of high-energy physics and complex systems are described below in section (a), and the various schools and workshops are described in section (c). During this period, ICTP-SAIFR organized international schools on data science (May 9 – July 15), quantitative biology and ecology (July 4 – December 2), particle physics (September 12-23), disordered elastic systems (October 3-14), nonlinear systems to socio-economic complexity (October 17-22) and quantum computation (November 14-25), international workshops on mathematical physics (April 25-29), quantum correlated materials (Aug. 15-19), classical gravity and applications (Aug. 29-31), electromagnetic interactions in strongly interacting matter (Oct. 25-28), dark matter (Nov. 2-4) and theoretical condensed matter (Nov. 9-11), a program on particle physics (Sept. 5-23) and minicourses on quantum field theory (July 12-21) and cosmology (Oct. 18-27).

The activities of ICTP-SAIFR in 2022 will be described below in more detail including:

- (a) research related to publications;
- (b) research related to visitors;
- (c) organization of schools, workshops, minicourses, outreach activities, meetings and seminars.

## a. Research related to publications

The research conducted at ICTP-SAIFR during this period included various subareas of theoretical physics related to high-energy physics and complex systems. The publications involved research performed by principal and associated researchers, postdoctoral fellows, and visitors of ICTP-SAIFR. Various ICTP-SAIFR researchers are also members of international experimental collaborations such as the CMS detector at the LHC, the LIGO, and the Dark Energy Survey collaborations. In this period, ICTP-SAIFR researchers had a total of 185 publications and several of them will be described below.

### **a1. High Energy Physics**

#### a.1.1. String theory

String theory is at present the only known consistent theory of quantum gravity which, in addition to gravitons, contains both spin-one gluons and higher-spin massive states. The hybrid version of superstring field theory was used in [22] to compute the coupling of gluons to higher-spin 3/2 states, and was used in [23] to compute stringy corrections to D=4 super-Yang-Mills instanton solutions.

In addition to string field theory methods, one can also use sigma model methods to describe superstring backgrounds. In [65], the geometrical properties of sigma models in general backgrounds were discussed using the BV formalism. And in [151], deformations of non-integrable backgrounds were described using sigma model methods.

Using the AdS-CFT correspondence, the expectation of Wilson lines in supersymmetric gauge theory can be related to string theory partition functions in



AdS backgrounds. Wilson lines in  $D=3$   $N=4$  supersymmetric Chern-Simons theory were studied in [178], and deformations of half-BPS circular Wilson loops in  $D=4$  supersymmetric Yang-Mills theory were studied in [179].

Integrability of both the gauge theory and string theory plays an important role in this correspondence, and can be used to simplify computations. In [180] and [181], integrability was combined with geometrical aspects of string theory involving the division of the worldsheet into hexagon and null polygons to simplify the computation of perturbative and non-perturbative  $N=4$   $d=4$  super-Yang-Mills scattering amplitudes. Integrability methods were also used in [182] to relate Wilson line expectation values of  $N=4$   $d=4$  super-Yang-Mills with OPE coefficients of states with large spin. And in [68], integrable spin chain models in  $D=3$  were related through the correspondence with the Penrose limit of a supergravity solution.

Field theories which are conformally invariant contain special properties which allow their description as “celestial amplitudes” in lower dimensions. In [69], the infrared divergences of celestial amplitude expressions of  $D=4$  gluon scattering were compared with the celestial graviton scattering amplitudes coming from flat-space holography. And in [67], the most general conformally invariant and duality invariant version of electromagnetism was studied and related to a generalization of Born-Infeld theory.

### a.1.2. Particle and Astroparticle Physics

The Standard Model (SM) of Particle Physics has been tested to great precision and searches for phenomena proposed by models beyond the SM were conducted at the Large Hadron Collider (LHC). Also, the overwhelming astrophysical evidence for the existence of dark matter points to the incompleteness of the SM. ICTP-SAIFR researchers have been actively working on these important issues.

Results from the CMS collaboration at the LHC were reported in [70-128]. As highlights we can list the contributions that were published in Physical Review Letters: the search for double Higgs production in the 4 b-quark final state [74]; the first evidence for the production of the  $X(3872)$  particle, possibly a tetraquark state, in relativistic heavy ion collisions [78]; the first search for exclusive diphoton production at high mass with tagged protons [79]; the measurement of the inclusive differential Higgs boson production cross section in the tau-lepton pair channel [89]; the first observation of a charged charmed B-meson in heavy-ion collisions [96]; the test of charm-quark dynamics via multiparticle correlations in Pb-Pb Collisions [98]; the search for flavor-changing neutral current interactions of the top-quark and Higgs boson in final states with two photons [102]; and the search for resonances decaying to three W-bosons [118].

On the theoretical side, several studies were conducted involving aspects of physics beyond the SM. [137] and [140] studied models with two Higgs doublets that can have dark matter candidates, [138] and [139] analyzed consequences of the so-called 3-3-1 models and [141] explored the possibility of a right-handed neutrino to be the dark matter. The effective field theory approach to physics beyond SM was explored in the context of the LHC run II results in [32] and [33]. The production of axions, a dark matter candidate, in mergers of neutron stars was the subject of [34].

In the theory of low-energy strong interactions, the three-body bound state problem was studied in arbitrary dimensions with zero-range interactions in [39], whereas entanglement effects in momentum space from an effective action was the subject of [40].

2022 was the 10th anniversary of the crowning of the Standard Model with the detection of the Higgs boson at CERN and an outreach article was written in [156].

### a.1.3. Cosmology and Gravity

ICTP-SAIFR researchers are taking part in international collaborations to explore the cosmos, such as the Dark Energy Survey (DES), the Rubin Observatory's Legacy Survey of Space and Time (LSST), the Javalambre Physics of the Accelerated Universe Survey (J-PAS) and the related S-PLUS and MiniJ-PAS surveys, the Laser Interferometer Gravitational-wave Observatory (LIGO), KAGRA and Virgo Collaborations.

The DES finished data-taking in 2019 covering 5000 square degrees of the sky and has recently published several analyses using data from the first three years of observations - the so-called DES-Y3. The results are reported in [41-60] and [157-160]. Validation of the data analysis on simulations, robustness tests on calibrations and on model uncertainties were assessed in [41-43]. These tests were essential to the main results of DES-Y3, presented in [44] with the most precise determination of cosmological parameters from a photometric galaxy survey. The ICTP-SAIFR group has been working especially on the harmonic space analysis of the correlation functions - the angular power spectra - results were published for cosmic shear in DES-Y1 [50] and in DES-Y3 [156]. The detection of baryon acoustic oscillations (BAO) combining both real and harmonic space was reported in [49]. Several results from the 1 square degree MiniJ-PAS Survey with 60 optical bands were published [3-8]. Results from the third observing run of the LIGO-Virgo, with some of them also involving the newcomer KAGRA detector in Japan, were published in [164-176]. In particular, a search for subsolar-mass binaries was published in Physical Review Letters [170].

On the more theoretical side, Fisher matrix forecasts were made for the angular power spectrum of multi-tracer galaxy surveys [1] and for cross-spectra [2], whereas machine learning techniques were used for improving covariance matrices [9] and for mimicking the halo-galaxy connection [10]. Also, the effective field theory of large-scale structure was applied to multi-tracer in [11]. Dynamics of binary systems of compact objects obtained at fourth order in post-Minkowski and in post-Newtonian approximations in the effective theory approach [129] were used to study the effects of gravitational radiation with spin [130] and the large-eccentricity expansion [131]. The impact of standard sirens in gravitational wave events forecasted for the Einstein Telescope for cosmography were studied in [162], whereas the use of dark sirens to measure the Hubble constant was projected in [163]. A nice review article on Fundamental Gravity and Gravitational Waves was published in [161]. [183-184] study the consequences of beyond the standard cosmological models, with an interacting dark energy component.

### a.1.4. Astrophysics

The science that can be pursued with the ASTRI mini-array for detection of high-energy gamma rays, a precursor of the Cherenkov Telescope Array (CTA) was explored in [28,29,30]. Numerical simulations of the great eruption of  $\eta$  Carinae star was the subject of [26] and the diffusion of large-scale magnetic fields was studied using MHD simulations in [27].

The use of a deep learning model to temporally evolve the dynamics of gas accreting onto a black hole was investigated in [69].

## a.2. Complex Systems

### a.2.1 Mathematical Biology

The employment of mathematical modeling has been crucial for the understanding of biological systems at all levels from microbes to humans. During the last year, mathematical modeling of the covid-19 virus and vaccination methods in Brazil was especially important. In [37-38], different time periods for vaccination in Brazil were compared. In [35], the effect of contact interactions between neighbors in different types of households in Brazil was studied. And in [36], the impact of school reopenings on the spread of the pandemic was predicted.

Mathematical modeling also plays an important role in preserving biodiversity in the Brazilian ecosystem. Using mathematical models, the effect of wildfires on animal species in the Pantanal was studied in [133], the climatic distribution of trees in the Atlantic forest was studied in [134], the interaction of insects and plants was studied in [135], and the consequences of habitat loss on bird communities was studied in [136]. Habitat loss and the consequent fragmentation of feeding grounds changes predator-prey interactions, and [61] discussed models to predict how this affects biodiversity. In [62-63], models were constructed to explain vegetation patterns in different environments, and [64] discussed spatial patterns in a more general context including microbial colonies.

Biodiversity depends on a delicate balance between extinction and the creation of new species. [18] studied this balance in a two-island system, [19] used a specific Derida-Higgs model to study speciation, and [21] studied this balance for mitochondrial and nuclear genomes.

### a.2.2. Non-linear systems

The study of non-linear systems has applications in various areas of physics and an important question is how to synchronize coupled systems. One model involving coupled oscillators was developed by Kuramoto, and in [20], this Kuramoto model was generalized to include frustration and the complete phase diagram was derived. In [25], another synchronization model of oscillators developed by Ossler was analyzed and shown by numerical simulations to be an effective model of synchronization. And a third model of synchronization involving mobile "agents" connected to fixed oscillators was investigated in [24].

Another important application of non-linear systems is to study non-perturbative solitons and condensates. In [12-13], the collisions of solitons in Bose-Einstein

condensates were studied using beyond-mean-field interactions. And in [14-17], the properties of super-solid phases of solitons in Bose-Einstein condensates were studied including a detailed description of their crystalline and multi-ring structures

### a.2.3. Condensed matter theory

With the experimental discovery of materials which display high-temperature superconductivity, an important problem in condensed matter theory is to understand the physics behind this remarkable property. In [145-149], several aspects of superconductivity were studied including its non-unitary nature, its sensitivity to impurities, its discrete symmetries, and the local interactions and effects of strain of the high-temperature superconducting material Sr<sub>2</sub>RuO<sub>4</sub>.

Another material with remarkable properties discovered recently is graphene. Although graphene is composed entirely of carbon atoms like graphite and diamond, its structure involves two-dimensional sheets which display completely different behavior from the one-dimensional structures of graphite or the three-dimensional structures of diamond. As discussed in [144] and in the Nature article of [150], twisting the relative angle of the two-dimensional graphene sheets produces behavior similar to that of heavy fermion materials such as uranium. In [154], quantum field theory tools such as anomaly analysis were used to explain the properties of these two-dimensional materials.

Another important problem in condensed matter theory is to describe the dynamics and transport behavior of electrons in materials. In [153] and [155], the electron transport behavior of materials used in the harvesting of solar energy was discussed. And in [154], the transport properties of carbon nanostructures such as graphene were described in aqueous solvents.

## b. Research related to visitors

Between December 2021-2022, the ICTP-SAIFR hosted 6 long-term visitors who stayed more than two weeks. The research developed during their visit is described below:

### **Jesus Maurício Encina Riveros** – Univ. Mayor de San Andrés (Jan. 1-Nov. 30)

From January to November 2022, I worked in a multidisciplinary research project supervised by Prof. Ricardo Martínez-García titled "A stochastic model for a competition of two kinds of microbial species with public-good production regulated by quorum sensing" where we established a competition model of two kind of microbial species in which one of them is a producer of public-good and the other is a non-producer (a cheater). We were aimed to computationally model this competitive dynamics through a stochastic approach. We have established the mechanisms of interactions of both kinds of individuals based on stochastic models such as The Majority Vote Model (MV), Contact Process models (CP), Death-Birth processes (DB) and game theory besides some biological aspects of microbial species. We regarded a conservative system, so that the number of individuals in the system remains constant at each time step and interactions were performed on square lattices. The main objectives of this project were: first, to find out how producers overcome cheating when the production of public-good is controlled by quorum-sensing in a well-mixed system, and second, how quorum-sensing controls the invasion of cheaters for specific spatial configurations of the system in both one and two dimensions. We approached this dynamics of competition both numerically through Monte Carlo simulations and analytically through a master equation for the density of producers under Simple Mean-field approximation. Results are still being collected and a paper is expected to be published.

### **Tiago Mendes Santos** – MPI for the Physics of Complex Systems (May 30 – June

11)

During my visit to ICTP-SAIIR, I presented a seminar entitled "Many-body physics through the lens of Machine Learning", where I discussed some topics in my current research related to the applications of concepts and techniques of Machine Learning in problems related to strongly correlated systems. I also had interesting discussions with local researchers about the topics presented in my seminar.

### **Andrea Leonardo Guerrieri – Tel Aviv University (May 8 – June 12)**

The research performed during my visit to ICTP-SAIIR focused on the non-perturbative S-matrix Bootstrap. Two are the subjects I have developed. The first is related to String and M-theory. I have studied the numerical bounds on the first correction to the Einstein-Hilbert action in dimensions 9, 10, and 11. The results have been obtained using new numerical algorithms designed during my visit. In the upcoming publication, we will compare these numerical results with the precise theoretical predictions from String and M-theory. The second is related to extending the bootstrap including the effect of multi-particle processes. This is an important open problem in particle physics, and one of the hardest. For simplicity, we study multi-particle processes in the context of 1+1 dimensional EFTs related to the QCD flux-tube dynamics. During my visit, I performed preliminary perturbative computations that helped to set up the problem concretely. We will include the multi-particle constraints and study their effect on the existing bootstrap bounds.

### **Eugenio Megias – Granada University (Aug. 29 – Sept. 10)**

During my visit to the ICTP-SAIIR I have focused on two topics: 1) the study of physics beyond the Standard Model of particles, through the use of models with extra dimensions, as well as their holographic interpretation through AdS/CFT correspondence, and 2) the study of the hydrodynamics of relativistic fluids. The objectives that I have been achieved are: 1. Study of the coupling of Gravity in continuum effective field theories (EFT). Within a continuum sector in the presence of gravity, we explain that and EFT with a free continuum cannot consistently couple to standard gravity. At finite temperature, we find a contribution on the Friedmann equation induced by the horizon in the bulk, and explore brane cosmology in dilaton-gravity backgrounds. On this topic I have a joint collaboration with the following professors: Prof. Mariano Quirós (IFAE, Barcelona), Prof. Rogério Rosenfeld and Dr. Sylvain Fichet (ICTP- SAIIR, São Paulo, Brazil). 2. I have studied the application of the equilibrium partition function formalism for the computation of the transport coefficients of relativistic fluids induced by quantum anomalies, at first and second order in the hydrodynamic expansion. We provide results for theories with Abelian and non-Abelian chiral fermions, and discuss some features of the corresponding constitutive relations.

### **Luiz C. L. Botelho – UFF (Oct. 3-26)**

We have evaluated the behavior of the ratio of Laplace Beltrami operators functional determinants under re scaling of the background metric by constant factors, a technical result used to produce insights on the topological behavior of the Bosonic Polyakov's string giration radius when evaluated on the covariant path integral framework. We have made also progress on the evaluation of the gyration radius now associated to the Fermionic Polyakov's String by analyzing the behavior under the metric re-scaling by an over all constant factor of the associated fermionic determinants which appears in Polyakov's Fermionic String path integral (see for instance: Statistical field theory, vol2 CItzykson & J-M Drouffe-Cambridge monographs on mathematical physics chap1991 chapter 9 - 9.3.2 &9.3.3 ). We also have done calculations in the path integral framework of some models for the quark antiquark wave function connected by a flux tube of a phenomenological confinant abelian Gluonic field (those calculations including quark spin degrees of freedom through a fermionic Wilson Loop) with a confining fourth order gluon propagator.

### **Pierre Ronceray - Turing Centre for Living Systems (CENTURI) & Aix Marseille Université (Oct. 1-18)**

Scientific discussions with Profs. Ricardo Martinez Garcia and Danilo Liarte. Advising discussions with a Masters student (Benjamin Garcia De Figueiredo). Three talks: ICTP-SAIIR colloquium, informal lecture, journal club at the Serrapilheira school. Writing of a proposal for a school in 2024 with Ricardo Martinez Garcia.

## **c. Organization of activities**

Between December 2021 – November 2022, the ICTP-SAIIR organized seven São Paulo International Schools for Theoretical Physics, two minicourses, seven workshops, one program and weekly outreach events, seminars, colloquia and journal clubs. The complete list of 2022 activities is on the webpage <https://www.ictp-saifr.org/2022-activities/> , the list of weekly seminars, colloquia

and journal clubs is on the webpage <https://www.ictp-saifr.org/2022-research-seminars-and-activities/> . Activities of December 2021 are described on “Past research seminars and activities” at <https://www.ictp-saifr.org/other-years-research-seminars-and-activities/>. Most of the activities were recorded and the videos are available online on the associated webpages.

## c1. São Paulo International Schools

The six São Paulo International Schools were on the subjects of data science (May 9 – July 15), quantitative biology and ecology (July 4 – December 2), particle physics (September 12-23), disordered elastic systems (October 3-14), nonlinear systems to socio-economic complexity (October 17-22) and quantum computation (November 14-25). The schools were for mostly master’s and PhD students, and those students not from São Paulo were housed in a hotel in shared rooms. The students were asked to anonymously evaluate the schools, and the links to view their evaluations are:

<http://bit.ly/survey-qbio2022-week4-5>

<http://bit.ly/survey-bsmp2022>

<http://bit.ly/survey-des2022>

<http://bit.ly/survey-school-on-applications-of-nonlinear-systems-to-socio-economic-complexity/>

<http://bit.ly/survey-qc2022>

All lectures of the schools were filmed and the videos are available online on the school webpage.

### c1A. São Paulo CODATA-RDA School of Research Data Science (May 9 – July 15)

The online São Paulo CODATA-RDA School of Research Data Science (May 9 – July 15) is described on the webpage <https://www.ictp-saifr.org/codata-rda22/> and involved 11 lecturers and 50 participants. This online school focused on analyzing large amounts of data and included lectures on the principles and practice of Open Science, research data management and curation, research computing infrastructures, large scale analysis, statistics, and modeling techniques. This school took place simultaneously with the [CODATA-RDA School of Research Data Science – South Africa](#) and many of the materials and live sessions were jointly organized.

Lecturers:

- **Bianca Peterson** (HART: Hypertension in Africa Research Team, NWU)
- **Lesego Makafola** (University of Pretoria)
- **Louise Bezuidenhout** (Data Archiving and Networked Services (DANS))
- **Marcela Alfaro-Cordoba** (University of California)
- **Martie van Deventer** (Dept. of Information Science, University of Pretoria)
- **Menno van Zanen** (SADiLaR, North-West University)
- **Raphael Cobe** (NCC, Sao Paulo State University)
- **Renier van Heerden** (South African Research and Education network – SANReN)
- **Sara El-Jadid** (Queens University, Belfast)
- **Siphethile Gncumana** (Council for Scientific and Industrial Research (CSIR))
- **Terence van Zyl** (Institute for Intelligent Systems, University of Johannesburg)

### c1B. Serrapilheira/ICTP-SAIFR Training Program in Quantitative Biology and Ecology (July 4 -Dec. 2)

The Serrapilheira/ICTP-SAIFR Training Program in Quantitative Biology and

Ecology (July 4 – Dec. 2) is described on the webpage <https://www.ictp-saifr.org/qbioprogram/>. The program trained young Brazilian and other Latin American scientists for world-class research on biology and ecology using the quantitative methods of mathematics, physics, and computer science.

The training program was highly selective and involved students at the beginning of their graduate studies who have already developed quantitative skills and are interested in applying these skills in solving cutting-edge problems in biology and ecology. Lectures in all areas of biology and ecology were presented by international experts, and no previous knowledge of biology was required.

The program was divided into introductory and advanced modules. The introductory module of this training program took place at ICTP-SAIFR from July 4 – September 2 with the participation of 31 Latin-American students. Topics included fundamentals of quantitative biology and ecology, mathematical modeling in biology using deterministic and stochastic approaches, computational methods, statistical modeling, and hypothesis- and data-driven research.

The advanced module was held at ICTP-SAIFR from September 12 to December 2 with the same 31 participants. Topics included genetics, community ecology and biodiversity, biophysics, molecular and structural biology, microbial ecology, immunology.

In addition to attending lectures by internationally renowned researchers, students in the program worked in small groups on a research project.

#### Lecturers and Topics:

##### *Quantitative foundations of biological concepts*

- Joshua Weitz – *Georgia Institute of Technology, USA*
- Adriana Lucia Sanz Garcia – *Georgia Institute of Technology, USA*
- Jeremy Harris – *Georgia Institute of Technology, USA*
- Jacopo Marchi – *Georgia Institute of Technology, USA*

##### *Hypothesis-driven research*

- Glauco Machado – *University of São Paulo, Brazil*
- Ricard Alert-Zenón – *Max Planck Inst. for Complex Systems, Germany*

##### *Data-driven research*

- C. Daniela Robles-Espinoza – *Universidad Nacional Autónoma de México*
- Mariana Gómez-Schiavon – *Universidad Nacional Autónoma de México*

##### *Computational Methods*

- Sara Mortara – *Re. Green/U. of São Paulo*
- Andrea Sánchez-Tapia – *Rio de Janeiro Botanical Garden Research Institute, Brazil*
- Ricardo Cerri – *Federal University of São Carlos, Brazil*

##### *Conservation science and decision-making*

- Michael Bode – *Queensland University of Technology, Australia*
- Paul Armsworth – *University of Tennessee, USA*

##### *Mathematical modelling in biology*

- Ricardo Martínez-García – *ICTP-SAIFR, Brazil*
- Roberto Kraenkel – *Institute of Theoretical Physics at UNESP, Brazil*

##### *Genetics and epigenetics*

- Deborah Toiber – *Ben-Gurion University of the Negev, Israel*
- Sean H. Rice – *Texas Tech University, USA*

##### *Evolution*

- Thomas Flatt – *University of Fribourg, Switzerland*
- Hanna Kokko – *University of Zurich, Switzerland*

##### *Developmental biology*

- Moisés Mallo – *Instituto Gulbenkian de Ciência, Portugal*
- Ross Sozzani – *North Carolina State University, USA*

#### *Neurobiology*

- Joe Paton – *Champalimaud Foundation, Portugal*
- Mauro Copelli – *Federal University of Pernambuco, Brazil*

#### *Molecular and structural biology*

- José Onuchic – *Rice University, USA*
- Paul Whitford – *Northeastern University, USA*

#### *Systems biology*

- Jorge Carneiro – *Instituto Gulbenkian de Ciência, Portugal*

#### *Immunology*

- Daniel Mucida – *The Rockefeller University, USA*
- Carolina Lucas – *Yale University School of Medicine, USA*
- Carmen Molina-Paris – *Leeds University, UK*

#### *Biophysics*

- Vijay Balasubramanian – *University of Pennsylvania, USA*
- Curtis Callan – *Princeton University, USA*

#### *Community ecology and biodiversity*

- Paulo Guimarães – *University of São Paulo, Brazil*
- Miguel Lurgi – *Swansea University, UK*

#### *Climate change impact on biodiversity*

- Malin Pinsky – *Rutgers University, USA*
- Morgan Tingley – *University of California, Los Angeles, USA*

#### *Behavioral ecology*

- Iain Couzin – *Max Planck Institute of Animal Behaviour, Germany*

#### *Microbial ecology*

- Jacopo Grilli – *ICTP-Trieste, Italy*
- Martina dal Bello – *Massachusetts Institute of Technology, USA*

#### *Disease ecology and epidemiology*

- Cara Haney – *The University of British Columbia, Canada*
- Zayda Morales Moreira – *The University of British Columbia, Canada*
- Jessica Metcalf – *Princeton Univ., USA*

## c1C. Joint ICTP-SAIFR/MITP Summer School on Particle Physics beyond the Standard Model (Sept. 12-23)

The Joint ICTP-SAIFR/MITP Summer School on Particle Physics beyond the Standard Model (Sept. 12-23) is described on the website <https://www.ictp-saifr.org/bsmp2022/> and involved 6 lecturers and 57 participants. The school provided in-depth lectures in advanced topics in theoretical particle physics, covering important areas where recent progress has been made in the field.

### Lecturers and Topics:

#### 1st week

- **Csaba Csaki** (Cornell University, USA): *Naturalness-motivated BSM*
- **Jay M. Hubisz** (Syracuse U., USA): *Cosmology*
- **Yael Shadmi** (Israel Institute of Technology – Technion, Israel): *Tools at the Frontiers of BSM: amplitudes*

#### 2nd week

- **Tilman Plehn** (University of Heidelberg, Germany): *Tools at the Frontiers of BSM: future colliders and machine learning*
- **Raffaele Tito d’Agnolo** (IPhT-Saclay, France): *The light and feeble frontier: light DM, Feebly Interacting Particles, Axion-like Particles and other beasts*
- **Gilad Perez** (Weizmann Institute, Israel): *Frontiers in non-natural BSM*

## c1D. School on Disordered Elastic Systems (Oct. 3-14)



The School on Disordered Elastic Systems (Oct. 3-14) is described on the webpage <https://www.ictp-saifr.org/des2022/> and involved 7 lecturers, 2 speakers and 35 participants. The school covered well-tested and successful theoretical methods used to study disordered elastic systems (critically-coordinated lattices, scaling theories and calculations for jamming and glasses in infinite dimension), as well as more recent developments that have attracted a lot of attention in the past few years (mechanical metamaterials, machine learning and biopolymer fibrous networks).

#### Lecturers and Topics:

- **Corentin Coulais** (University of Amsterdam, Netherlands): *Mechanical Metamaterials*
- **Andrea J. Liu** (University of Pennsylvania, USA): Intersection of data science and soft/living disordered elastic systems
- **Tom C. Lubensky** (University of Pennsylvania, USA): *Elasticity and Topological Mechanics*
- **Fred C. Mackintosh** (Rice University, USA): Semiflexible polymer and fiber networks
- **Xiaoming Mao** (University of Michigan, USA):

*Lecture 1: Vibrational modes and rheology of generic mechanical networks*

*Lecture 2: General introduction to finite frequency topological mechanics I*

*Lecture 3: General introduction to finite frequency topological mechanics II*

*Lecture 4: Maxwell lattice topological mechanics and topological soft modes in disordered materials*

- **James P. Sethna** (Cornell University, USA): *Scaling functions in disordered elastic materials*
- **Pierfrancesco Urbani** (CNRS, France): *High Dimensional Models for Jamming*

#### Seminar Speakers:

- **Márcia Barbosa** (Federal University of Rio Grande do Sul, Brazil): Water: From Ice Age to Nanoscience
- **Edgar Zanutto** (Federal University of São Carlos, Brazil): New glass research center in Brazil

### c1E. School on Applications of Nonlinear Systems to Socio-Economic Complexity (Oct. 17-22)

The School on Applications of Nonlinear Systems to Socio-Economic Complexity (Oct. 17-22) is described on the webpage <https://www.ictp-saifr.org/school-on-applications-of-nonlinear-systems-to-socio-economic-complexity/> and involved 4 lecturers and 42 participants. The school aimed to provide an interdisciplinary training to PhD students interested in complex systems and its applications to social research. Lectures covered theoretical and computational aspects of complex systems and presented the current research trends in the field.

#### Lecturers and Topics:

- **Pablo Balenzuela** (Universidad de Buenos Aires, Argentina): *Multi-agent Models in Complex Networks*
- **Marcelo Kuperman** (Instituto Balseiro-Bariloche, Argentina): *Introduction to Evolutionary Game Theory*
- **Cristina Masoller** (Universidad Politécnica de Catalunya, Spain): *Time Series Analysis*
- **Viktoriya Semeshenko** (Universidad de Buenos Aires, Argentina): *Economic and Financial Networks: Models and Analysis*

### c1F. School on Quantum Computation (Nov. 14-25)

The School on Quantum Computation (Nov. 14-25) is described on the webpage <https://www.ictp-saifr.org/qc2022/> and involved 4 lecturers, 7 seminar speakers and 103 participants. The main purpose of the school was to provide short courses and lectures from the basics concepts to the state of the art on quantum computing: quantum algorithm efficiency, quantum complexity theory, quantum simulators, adiabatic quantum computing, quantum machine learning, and different architectures where quantum computing can be implemented, such as superconducting qubits, trapped ions, and photonics systems. The school also offered short courses about the use of quantum computing in the cloud.

### Minicourses:

- **Askery Canabarro** (UFAL, Campus Arapiraca, Brazil): *Quantum Finance*
- **Eduardo Duzzioni** (UFSC, Brazil): *Quantum algorithms: from basics to differential equations*
- **Thomas Monz** (University Innsbruck, Austria): *Trapped Ion Quantum Computers*
- **Francisco Rouxinol** (UNICAMP, Brazil): *Superconducting Qubits*

### Seminars:

- **Caslav Brukner** (University of Vienna and Institute for Quantum Optics and Quantum Information at Vienna ): *IFT-Colloquium: How does a quantum particle see the world?*
- **Rafael Chaves** (IPP/UFRN, Brazil): *Characterizing networks and phase transitions with classical and quantum machine learning*
- **Felipe F. Fanchini** (UNESP Bauru, Brazil): *Calibrating Question Answering Systems with Quantum Neural Networks*
- **Markus Hennrich** (Stockholm University, Stockholm, Sweden): *IFT-Colloquium – Trapped Rydberg ions*
- **Ivan de Oliveira** (CBPF, Brazil): *Nuclear Qubits*
- **Ana Predojevic** (Stockholm University, Sweden): *Quantum light: generation, characterization, and application*
- **Enrique Solano** (Chief Visionary Officer of Kipu Quantum, Germany and Founder of QUANVIA, Spain)

## c2. Workshops

ICTP-SAIFR organized workshops on the subjects of mathematical physics, quantum correlated materials, classical gravity and applications, particle physics, electromagnetic interactions in strongly interacting matter, dark matter and theoretical condensed matter. The purpose of these workshops was to discuss the status, recent progress and perspectives in each of the fields mentioned.

### c2A. Workshop on Representation Theory and Applications (April 25-29)

The workshop focused on recent advances in the representation theory of Lie algebras, their generalizations and applications. The webpage of the workshop is <https://www.ictp-saifr.org/wrta2022/> and speakers and topics included:

- **Drazen Adamovich** (U.Zagreb , Croatia): *On the representation theory of affine vertex algebras on conformal and collapsing levels*
- **Nicolás Andruskiewitsch** (U. Córdoba , Argentina): *On the double of the Jordan plane*
- **Tomoyuki Arakawa** (RIMS, Japan): *Weight representations of affine Kac-Moody algebras and small quantum groups*
- **Juan C. Arias** (IME-USP, Brazil): *Classical, Quantum and Categorical*
- **Luan Bezerra** (IME-USP, Brazil): *Partitions with parity and representations of quantum toroidal superalgebras*
- **Lucas Calixto** (UFMG , Brazil): *Representations of the Cartan type Lie superalgebra  $W^{(\infty)}$*
- **Agustín M. Cañadas** (Universidad Nacional de Colombia, Colombia): *Wargaming with Quadratic Forms and Brauer Configuration Algebras*
- **Jethro van Ekeren** (UFF , Brazil): *Chiral homology, Hodge theory and Poisson homology*
- **Pedro F. F. Espinosa** (Universidad Piloto de Colombia, Colombia): *Categorification of some integer sequences and Brauer configuration algebras*
- **Isaias D. M. Gaviria** (Universidad Nacional de Colombia, Colombia): *An Algorithm to Build the Auslander-Reiten Quiver of Some Equipped Posets*
- **Naoki Genra** (Kavli IPMU, Japan): *Coset constructions of  $W$ -superalgebras of type  $B$*
- **Reimundo Heluani** (IMPA, Brazil): *Double Poisson Vertex Algebras – and Courant-Dorfman Algebras*
- **Andoni A. de La Hera** (ICMAT, Spain): *Superconformal Vertex Algebras from Killing Spinors*
- **Iryna Kashuba** (IME-USP , Brazil): *Representations of Jordan algebras and superalgebras*
- **Libor Krizka** (Charles University, Czech Republic): *Admissible representations of simple affine vertex algebras*

- **Zhanna Kunetsova** (UFABC, Brazil): *Beyond the 10-fold way: 13 associative  $Z_2 \times Z_2$ -graded superdivision algebras*
- **Ashish Mishra** (U. Fed. Para, Brazil): *On quasi Steinberg characters of complex reflection groups*
- **Germán B.A. Monsalve** (UFAM, Brazil): *Faces of polyhedra associated with Relation modules*
- **Bely R. Morales** (IME-USP, Brazil): *Holomorphic integer graded vertex superalgebras*
- **Oscar A. H. Morales** (UFSCAR, Brazil): *Admissible tame representations of vertex algebras*
- **Adriano A. de Moura** (UNICAMP, Brazil): *Trees Are Real And Totally Ordered Graphs Are Prime*
- **Mikhail Neklyudov** (IME-USP, Brazil): *Ergodicity of infinite particle systems and applications*
- **Luis E. Ramirez** (UFABC, Brazil): *Relation modules and its subquotients*
- **Gordan Radobolja** (U.Split, Croatia): *Non-injective homomorphisms between certain Verma modules*
- **Henrique O. Rocha** (IME-USP, Brazil): *Representations of Map Superalgebras*
- **Francesco Toppan** (CBPF, Brazil):  *$Z_2 \times Z_2$ -graded Lie (super)algebras and detectable parastatistics*

## c2B. Workshop on New Horizons in Quantum Correlated Materials (Aug. 15-19)

In this workshop, junior researchers as well as prominent experimentalists and theoreticians discussed low dimensionality effects, frustrations, spin-orbit coupling, charge fluctuations, superconductivity, and disorder in strongly correlated systems. The webpage of the workshop is <https://www.ictp-saifr.org/qcm2022/> and speakers included:

### Talks:

- **Alix McCollam** (Radboud University, Netherlands): *Hyperfine interactions and antiferroquadrupolar order: their role in  $PrOs_4Sb_{12}$*
- **Andrés Santander-Syro** (Université Paris-Saclay, France): *Imaging the itinerant-to-localized transmutation of electrons across the metal-to-insulator transition in  $V_2O_3$*
- **Daniel Cabra** (Universidad Nacional de La Plata, Argentina): *Lattice assisted magneto-electric coupling*
- **Eduardo Miranda** (UNICAMP, Brazil): *Mott domain wall matter: a state with non-Fermi liquid behavior*
- **Eric Andrade** (USP-São Carlos, Brazil): *Disorder, low-energy excitations, and topology in the Kitaev spin-liquid*
- **Eva Pavarini** (Forschungszentrum Jülich GmbH, Germany): *Finding true Kugel-Khomskii systems*
- **Fernando Garcia** (USP-São Paulo, Brazil): *Spin excitations and electronic structure in the  $BaFe_2As_2$  family of materials*
- **Gustavo S. Lozano** (Universidad de Buenos Aires, Argentina): *Vortex-Vortex interactions in superconductors with nematic order*
- **Helena Bragança** (UnB, Brazil): *Finite-time quantum quench in the extended Hubbard model*
- **Karen Hallberg** (Centro Atómico Bariloche, Argentina): *Novel subbands in electronic spectral densities of correlated systems*
- **Leni Bascones** (Instituto de Ciencias de Materiales de Madrid, Spain): *Electronic correlations in the "normal" state of twisted bilayer graphene*
- **Luis Gregório Dias** (USP-São Paulo, Brazil): *Parafermionic zero modes in strongly correlated fermionic lattices.*
- **Marcelo Rozenberg** (Université Paris-Saclay, France): *Solid State Neuroscience*
- **Mariana Malard** (UnB, Brazil): *Vacancy-engineered interacting nodal-line semimetals*
- **Milan Radovic** (Paul Scherrer Institute, Switzerland): *Creating and Tuning Electronic states and Phases of  $NdNiO_3$*
- **Natanael de Carvalho Costa** (UFRJ, Brazil): *The role of electron-phonon interactions in quasi-2D compounds*
- **Ricardo Lobo** (École Supérieure de Physique et de Chimie Industrielle, France): *The optical response of the quantum material family  $BaCoS_2$ - $BaNiS_2$*
- **Ricardo Urbano** (UNICAMP): *Orbital anisotropy in Kondo lattice materials*
- **Rodrigo Pereira** (International Institute of Physics-UFRN, Brazil): *Spontaneous spin chirality versus magnetization in a zigzag chain*
- **Valentina Martelli** (USP-São Paulo, Brazil): *Exploring thermal transport in complex oxides*
- **Vanildo Silva de Carvalho** (Universidade Federal de Goiás, Brazil): *Emergence of superconductivity at the onset of nematic order*

- **Vivian França** (UNESP-Araraquara, Brazil): *Entanglement as a witness of metal-insulator transitions in 1D systems*

#### Short talks:

- **Cynthia Contreras Medrano** (Centro Brasileiro de Pesquisas Físicas, Brazil): *Study on the structural disorder and magnetic frustration in the QSL candidate  $Sr_2Cu(W_{0.5}Te_{0.5})O_6$  perovskite under doping with Fe and Sb atoms*
- **William Natori** (Institute Laue Langevin, France):  *$S=3/2$  Kitaev Spin Liquids*
- **Daniel Reyes** (Instituto Militar de Engenharia, Brazil): *Incommensurate charge density wave vector on multiband intermetallic systems exhibiting competing orders*

## c2C. Workshop on Classical Gravity and Applications (Aug. 29-31)

The aim of this workshop is to further stimulate activities in the Latin-American community in these rapidly evolving research areas related to classical gravity, to strengthen and spur new connections and collaborations, and to award the [2021 and 2022 ICTP-SAIFR Prizes for the best Latin-American thesis in Classical Gravity and Applications](#). The webpage of the workshop is <https://www.ictp-saifr.org/cga2022/> and speakers included:

#### Plenary talks:

- **Raul Abramo** (USP-São Paulo, Brazil): *Towards a complete statistical description of LSS on the light cone*
- **Thaisa Storchi Bergmann** (UFRGS-Porto Alegre, Brazil): *Black Holes: exotic but ubiquitous in the Universe*
- **Archisman Ghosh** (University of Ghent, Belgium): *Fundamental physics and cosmology from gravitational-wave observations*
- **Valerio Marra** (UFES – Vitória, Brazil): *ALTB N-body simulations: cosmology beyond homogeneity and isotropy*
- **Jessica Muir** (Perimeter Institute, Waterloo): *k-Nearest-Neighbor Statistics as a Probe of Modified Gravity*
- **José Dias do Nascimento Jr.** (UFRN, Brazil): *Hunting Exoplanets by Gravitational Microlensing*
- **Elena Sellentin** (Leiden University, the Netherlands): *Getting the huge Euclid data set into shape for non-standard cosmological theories*

#### IFT-Colloquium:

- **Luis Lehner** (Perimeter Institute, Waterloo, Canada): *Testing GR with black hole ringdown. Not as simple as it sounds*

#### Gravity Prize:

- **Marcos A. Argañaraz** (University of Cordoba, Argentina): *Double null coordinates and applications in Kerr spacetime*
- **Carlos Mauricio Correa** (University of Cordoba, Argentina): *Cosmic voids as cosmological laboratories*
- **Caroline Guandalin** (Queen Mary University of London, UK): *Extracting fundamental physics out of the large-scale structure of the Universe*
- **Iara Ota** (ICTP-Trieste/SISSA, Italy): *Black hole spectroscopy: prospects for testing the nature of black holes with gravitational wave observations*

#### Contributed talks:

- **Pedro Bessa** (UFES, Brazil): *Testing Gravitational Lensing in an expanding Universe*
- **João Cavedagne Lobato** (UFRJ, Brazil): *Generalizing the stochastic gravitational wave signal to Horndeski theories*
- **Eunice Monyenye Omwoyo** (Universidade Federal do Espírito Santo, Brazil): *Remarks on the black hole shadows in Kerr-de Sitter space times*
- **Josiel Mendonça Soares de Souza** (Universidade Federal do Rio Grande do Norte, Brazil): *Late Time Cosmology with Bright Standard Sirens*
- **Antonino Troja** (UniPD, Italy): *The Euclid mission NISP instrument: performances and data simulations*

## c2D. Workshop on Electromagnetic Effects in Strongly Interacting Matter (Oct. 25-28)

In this workshop, the role of electromagnetic interactions in the following topics: QCD phase diagram and the critical point, Experimental observations of the magnetic field in HIC, Lattice QCD in a magnetic field, Particle production in a magnetic background, Isobar collisions and the chiral magnetic effect, Topological transport phenomena in the QGP, Electron-ion collider, Lambda polarization, Magneto-hydrodynamics, AdS/CFT approaches for QCD, Neutron stars, Color superconductivity, Relativistic-like phenomena in condensed matter, etc. The webpage of the workshop is <https://www.ictp-saifr.org/eesm2022/> and speakers included:

### Invited Speakers:

- **Alejandro Ayala** (UNAM, Mexico): *Anisotropic photon emission from gluon fusion and splitting in peripheral heavy-ion collisions with a strong magnetic background*
- **Cesar A. Bernardes** (UFRGS, Brazil): *Searches for the chiral magnetic effect and strong electromagnetic fields in heavy ion collisions with the CMS detector at the LHC*
- **Fabio Braghin** (Universidade Federal de Goiás, Brazil): *Weak magnetic field corrections to low energy light vector and axial mesons couplings and mixings*
- **Daniel Brandenburg** (Brookhaven National Laboratory, USA): *Studying the electromagnetic fields of heavy-ion collisions with photon-mediated processes*
- **David Dudal** (KU Leuven, Belgium): *A possible half-integer Quantum Hall Effect: RQED bulk perspective and more*
- **Gergely Endrodi** (Bielefeld University, Germany): *QCD matter in strong magnetic and electric fields*
- **Ricardo R. S. Farias** (Universidade Federal de Santa Maria, Brazil): *Issues related to regularizing thermo and magnetic contributions within nonrenormalizable theories*
- **Eduardo Souza Fraga** (UFRJ, Brazil): *Strange magnetars admixed with fermionic dark matter*
- **Kenji Fukushima** (University of Tokyo, Japan): *Chiral anomaly and the interpretation with spacetime dependent electromagnetic fields*
- **Marcelo Loewe** (Pontificia Universidad Católica (PUC), Chile): *Electric and magnetic field effects, including temperature, on a scalar self interacting theory  $\lambda\phi^4$  theory*
- **Manuel Malheiro** (Instituto Tecnológico da Aeronáutica, Brazil): *Effects of Strong Electric and Magnetic Fields in Superdense Matter*
- **Enrique Munoz** (Pontificia Universidad Católica (PUC), Chile): *Fermion mass and width in QED in a magnetic field*
- **Alfredo Raya** (Universidad Michoacana de San Nicolás de Hidalgo (IFM-UMSNH), Mexico): *Aspects of Chiral Symmetry Breaking in RQED*
- **Luis Alberto H. Rosas** (Universidad Autónoma Metropolitana-Iztapalapa, Mexico): *Magnetic screening mass for neutral pions*
- **Norberto Scoccola** (Comisión Nacional de Energía Atómica, Argentina): *Mesons under strong magnetic field in the NJL model*
- **Igor Shovkovy** (Arizona State University, USA): *IFT-Colloquium: Electromagnetic probes of magnetized quark-gluon plasma*
- **Vladimir Skokov** (North Carolina State University, USA)
- **Cristian Villavicencio** (Universidad del Bío-Bío (UBB) – Chillán, Chile): *Finite Energy Sum Rules at finite magnetic fields: advances and perspectives*
- **Gang Wang** (University of California-Los Angeles, USA): *Search for the Chiral Magnetic Effect in Heavy-ion Collisions*

### Contributed Talks:

- **Alfonso Ballon-Bayona** (Universidade Federal do Rio de Janeiro, Brazil): *Magnetising the  $N = 4$  Super Yang-Mills plasma*
- **Duifje van Egmond** (CPHT, Ecole Polytechnique, France): *Signatures of the Yang-Mills deconfinement transition from the gluon two-point correlator*
- **Jorge Igor Jaber-Urquiza** (UNAM, Mexico): *Magnetic field effect on Higgs boson production rate through gluon fusion*
- **Kauan Marquez** (Universidade Federal de Santa Catarina, Brazil): *Exploring the effects of Delta Baryons in magnetars*
- **Tulio Eduardo Restrepo** (Universidade Federal do Rio de Janeiro, Brazil): *QCD pressure at finite temperature and high magnetic fields*

- **Ashik Ikbal Sheikh** (Kent State University, USA): *Probing electromagnetic field with charge dependence of directed flow in STAR experiment at RHIC*
- **William Rafael Tavares** (Universidade Federal de Santa Catarina, Brazil): *The magnetic field independent regularization applied to light meson masses: the neutral  $\rho$  meson case*
- **Dean Valois** (Bielefeld University, Germany): *Lattice QCD with an inhomogeneous magnetic background*

## c2E. SAIFR/Princípa Workshop on the Nature of Dark Matter (Nov. 2-4)

This workshop covered interdisciplinary aspects of the experimental searches for dark matter and outlined the viable models. The webpage of the workshop is <https://www.ictp-saifr.org/dm2022/> and speakers included:

### Plenary talks:

- **Carlos R. Argüelles** (La Plata National University & CONICET): *Dark matter in the Milky Way: from SgrA\* to the entire halo*
- **Kimberly Boddy** (University of Texas at Austin, USA): *Cosmological constraints on Dark Matter*
- **Enrico Bertuzzo** (USP, Brazil): *Inelastic dark states at the lifetime frontier*
- **Thomas Hambye** (Université Libre de Bruxelles, Belgium): *Domain of Thermal Dark Matter*
- **Manfred Lindner** (Max Planck Institute for Nuclear Physics – MPIK, Germany): *Direct Dark Matter Detection & New XENONnT Results*
- **Diego Restrepo** (University of Antioquia, Colombia): *Dirac dark matter, neutrino masses, and dark baryogenesis*
- **Josh Ruderman** (New York University, USA): *Light Dark Sectors*
- **Philip Tanedo** (UC Riverside, USA): *Dark matter in compact objects*
- **Andrea Tesi** (INFN, Italy): *Dark dark sectors*
- **Aion Viana** (IFSC-USP, Brazil): *Indirect dark matter searches with high-energy electromagnetic probes*
- **Liantao Wang** (University of Chicago, USA): *Conformal freeze in, asymmetric reheating, and dark photon*
- **Carlos Yaguna** (UPTC Tunja, Colombia): *Two-component dark matter from a  $Z_4$  symmetry*

### Contributed talks:

- **Pedro Bittar** (IFUSP, Brazil): *Asymmetric Dark Matter in the  $Z_2$  preserving Twin Higgs*
- **Álvaro Santos de Jesus** (II-P/UFRN, Brazil): *Search for Dark Sector by Repurposing the UVX Brazilian Synchrotron*
- **Jacinto Paulo Neto** (II-P/UFRN, Brazil): *Early matter domination and production of dark matter*
- **Peter Reimitz** (IFUSP, Brazil): *Light Vector Mediators and DM*
- **Michael Shamma** (TRIUMF, Canada): *Cogenesis and (Nearly) Degenerate Dark Sectors*
- **Dêivid Silva** (UFPB, Brazil): *Using dark matter to solve the  $H_0$  problem*
- **Yiming Zhong** (University of Chicago, USA): *Collapsed dark matter halo*
- **Gabriel Brandao de Gracia** (IFT-UNESP, Brazil): *ELKO SPINOR AS DARK MATTER? A theoretical framework for a future LAB detection*

## c2F. II ICTP-SAIFR Condensed Matter Theory in the Metropolis (Nov. 9-11)

The goal of this meeting was to promote collaborations and exchanges between groups working on both hard and soft condensed matter theory in the city of São Paulo and nearby scientific poles, such as Campinas and São Carlos. The webpage of the workshop is <https://www.ictp-saifr.org/cmtm2022/> and speakers included:

- **Eric Andrade** (USP São Carlos): *Kondo screening and random singlet formation in highly disordered systems*
- **Lucy Assali** (IFUSP): *On the nature of structural phase transitions in the Ruddlesden-Popper  $\text{CaO}(\text{CaMnO}_3)_n$  hybrid improper ferroelectric family*

- **Thiago Branquinho** (UFABC): *Revealing mechanisms of light harvesting and charge separation in molecular systems: challenges for time-dependent density functional theory*
- **Dario Bohamon** (Mackenzie): *Driven chiral response of twisted bilayer graphene devices*
- **Marília Caldas** (IFUSP): *Optical properties of organized packing of thenyl-furan oligomers TFFT: an initial view*
- **Kaline Rabelo Coutinho** (IFUSP)
- **Gustavo Dalpian** (UFABC): *Materials Informatics: current trends and a few examples*
- **Luis Gregório Dias** (IF-USP): *Majorana states in vortices: can you know it when you see it?*
- **Jose Carlos Egues** (USP São Carlos): *Cornering Majoranas*
- **Antônio Martins Figueiredo Neto** (IFUSP): *Influence of Magnetic Field on the Two-Photon Absorption and Hyper-Rayleigh Scattering of Manganese-Zinc Ferrite Nanoparticles*
- **Vivian França** (UNESP-Araraquara): *Quantum information tools and their ability to detect quantum phase transitions in condensed matter models*
- **Vera Bohomoletz Henriques** (IFUSP)
- **Jose Abel Hoyos** (USP São Carlos): *Dynamical Griffiths singularities*
- **Lidia Gomes** (UFPE): *Computationally Guided Control of Carriers in Semiconductors: Density Functional Theory allied to Phase-Boundary Mapping to Engineer Defects in Thermoelectrics*
- **Maurice de Koning** (IFGW-UNICAMP): *Plastic deformation of superionic water ices*
- **Gabriel Landi** (IFUSP): *Diverging current fluctuations in critical Kerr resonators*
- **Cedric Rocha Leão** (UFABC)
- **Eduardo Miranda** (UNICAMP): *The domain wall between a Mott insulator and a metal is an anomalous metal*
- **Caetano Rodrigues Miranda** (USP): *Molecular storytelling and materials design towards a sustainable world*
- **André Farias de Moura** (UFSCar): *Computer simulations of the selective photodegradation of viruses by chiral nanoparticles*
- **Eduardo Novais** (UFABC): *Impurities in the extended Hofstadter-Hubbard model*
- **João Nuno** (UFABC): *Constructing realistic low-energy effective models of materials*
- **Cristiano L. P. de Oliveira** (IFUSP): *Structure investigations of oriented systems at nanoscale*
- **Caio Otoni** (UFSCar): *Supramolecular assembly of nanostructured biomass*
- **Alberto Petri** (ISC-CNR, Italy): *Markov dynamics and entropy production in a Prandtl-Tomlinson model for friction*
- **José Pedro Rino** (UFSCar): *Molecular Dynamics simulation of supercooled ZnSe: Structural relaxation and Crystal nucleation*
- **Silvio Roberto Salinas** (IFUSP): *Elementary statistical models for the nematic transitions in liquid-crystalline systems*
- **Leandro Seixas** (Mackenzie): *Why Green Hydrogen Matters*
- **Juarez L. F. da Silva** (IQSC-USP)
- **Edison Z. da Silva** (UNICAMP): *Search for new electrified high temperature superconductors*
- **Guilherme Matos Sipahi** (USP São Carlos)
- **Silvia Titotto** (UFABC): *4D printing and biomimetics – key concepts and applications*
- **Pedro Venezuela** (UFF): *2D materials for photovoltaic energy harvesting*

### c3. Minicourses

The ICTP-SAIFR organized two minicourses in 2022, on particle physics and cosmology. The topics, lecturers and webpages for these minicourses are:

- 1) July 12-21 - Minicourse on Universality in the Epsilon-Expansion - Alessandro Codello (UdelaR – Montevideo, Uruguay)

This course was focused on the analysis of universality classes in conformal field theories of arbitrary dimension using a reformulation of the perturbative renormalization group

<https://www.ictp-saifr.org/epsilon2022/>

- 2) October 18-27 - Minicourse on the Entropy of Cosmological Perturbations - Antonio Enea Romano (Antioquia U., Colombia)

This workshop reviewed the notion of entropy perturbations in different gauges, and clarified some misconceptions about the relation between conservation laws

and adiabaticity, showing that it is possible to model the effects of entropy on comoving curvature perturbations by appropriately defining a momentum dependent effective sound speed (MESS).

<https://www.ictp-saifr.org/minicourse-on-the-entropy-of-cosmological-perturbations/>

#### c4. Program

In 2022 the Program on New Directions in Particle Physics (<https://www.ictp-saifr.org/ndfp2022/>, Sept 5 - 23) in an open format centered around discussions, with a small number of talks. Topics covered included BSM model-building, dark matter, dark sectors, axions, the cosmological constant, possible experimental signals at collider, non-collider and astrophysical experiments. Participants in the program include:

- **Daniele Barducci** (Rome U., Italy): *Quantum Cosmology with a distinct hint from Condensed Matter Physics*
- **Adriano Lana Cherchiglia** (UFABC, Brazil)
- **Sylvain Fichet** (ICTP-SAIJR, Brazil): *The Warped Dark Photon*
- **Christina Gao** (University of Illinois Urbana Champaign, Fermilab, USA): *Axion Wind Detection with the Homogeneous Precession Domain of Superfluid Helium 3*
- **Gero von Gersdorff** (PUC-Rio, Brazil)
- **Christophe Grojean** (DESY and Humboldt University, Germany): **IFT-UNESP Colloquium: The Higgs Fabrics: Once and Future**
- **Matheus Hostert** (Perimeter Institute, Canada): *Dark neutrino sectors in modern neutrino experiments*
- **Jay M. Hubisz** (Syracuse U., USA): *Quantum Computation as a tool for Particle Theory*
- **Seth Koren** (Enrico Fermi Institute, University of Chicago, USA): *Discrete Gauged Baryon Minus Lepton Number and the Cosmological Lithium Problem*
- **André Lessa** (UFABC)
- **Leonardo de Lima** (UTFPR-Toledo, Brazil): *Probing the top-Higgs sector with composite Higgs models at present and future hadron colliders*
- **Ricardo D'Elia Matheus** (IFT-UNESP): *Clustering techniques as a way to explore BSM models' parameter space*
- **Oleksii Matsedonskyi** (Weizmann, Israel): *Reassessing the Window for Electroweak Baryogenesis*
- **Peter Reimitz** (IFUSP, Brazil): *Light Vector Mediators in forward physics and indirect detection experiments*
- **Gabriele Rigo** (IPhT-Saclay, France): *Vacuum Stability Bounds on Higgs Coupling Deviations from New Fermions*
- **Marcos Cardoso Rodriguez** (UFRRJ, Brazil): *Neutrinos masses in MSSM with  $R$ -Parity Violation when the left-handed sneutrinos get non-zero vacuum expectation values*
- **Maximilian Ruhdorfer** (Cornell University, USA): *RG of GR from On-shell Amplitudes*
- **Yuri Shirman** (University of California-Irvine, USA): TBA
- **John Terning** (UC Davis, USA): **IFT-UNESP Colloquium: The Magnetic Monopole Ninety Years Later**
- **Thiago Tomei** (NCC UNESP, Brazil)
- **Joseph Tooby-Smith** (Cornell University, USA): *Electroweak flavour unification and anomaly free gauge groups*
- **Riccardo Sturani** (ICTP-SAIJR/IFT-UNESP)
- **Tomer Volansky** (Tel Aviv U., Israel): *Dark Matter*

#### c4. Outreach events

The ICTP-SAIJR organized 8 different types of online outreach activities in 2021 aiming at different audiences. The format, topics and webpages for these events are:



### 1) Física em Casa:

Physics at Home is an outreach program of ICTP-SAIFR introducing current topics in theoretical physics to the general public in an online format. The webpage for the program is <http://outreach.ictp-saifr.org/fisica-em-casa/>. Topics covered during these meetings included:

[31 de março – “O que as antipartículas podem contar sobre nossa existência” Leandro Salazar de Paula \(IF-UFRJ\)](#)

[28 de abril – “Molha ou não molha?” - Carolina Brito \(UFRGS\)](#)

[07 de dezembro – “O Prêmio Nobel de Física de 2022: Emaranhamento quântico” - Gabriela Barreto Lemos \(UFRJ\)](#)

### 2) Clube do Livro – Sci-SAIFR:

In this outreach program, a physicist uses a science fiction book to discuss with the audience the physics concepts behind it. Books discussed during 2022 meetings included: <http://outreach.ictp-saifr.org/clube-do-livro/>

[10 de novembro – Para explicar o mundo com Chee Sheng Fong \(UFABC\)](#)

[25 de agosto - A primavera silenciosa com Flávia Marquitti \(ICTP-SAIFR/UNICAMP\)](#)

[23 de junho - O debate na literatura sobre a teoria de cordas com Nathan Berkovits \(ICTP-SAIFR/IFT-UNESP\)](#)

[10 de março - O cerne da matéria – Rogério Rosenfeld \(ICTP-SAIFR/IFT-UNESP\)](#)

### 3) Doses of Physics

In this new outreach project of ICTP-SAIFR on Instagram, the journalist and TV news presenter Letícia Brito (TV UFG/ICTP-SAIFR) is producing a series of short weekly videos on physics for the general public (<http://outreach.ictp-saifr.org/doses-de-fisica/>). Topics covered in 2022 include observational cosmology, astrophysics, quantum information and quantum mechanics.

### 4) Podcast 30 minutes of Physics

In this outreach project, the science journalist Vittor Chiodi interviews researchers on Physics: <http://outreach.ictp-saifr.org/podcast-30-minutos-de-fisica/>. Topics covered in 2022 included particle physics, complex systems, climate change and astrophysics.

### 5) 5th IFT-Perimeter-SAIFR Journeys into Theoretical Physics (August 1-7)

The 5<sup>th</sup> edition of this school is described on the webpage <http://www.ictp-saifr.org/journeys> and involved 4 lecturers and 58 participants. The top students in this school were accepted to a joint master`s program where they will spend one year at Perimeter Institute (Waterloo) and one year at ICTP-SAIFR/IFT-UNESP. The students accepted to the joint program include Maitá Carvalho Micol (IAG-USP), Thiago Oliveira Ferreira (UFRGS) and Otavio D'Ambrosio Arounian Ramos Bittencourt (IFUSP).

Lecturers and Topics included:

- **Junwu Huang** (Perimeter Institute, Canada): *Dark Matter: Cosmos and Lab*
- **Riccardo Sturani** (ICTP-SAIFR/IFT-UNESP, Brazil): *Gravitational Wave Astronomy*
- **Pedro Vieira** (ICTP-SAIFR/IFT-UNESP, Brazil & Perimeter Institute, Canada): *S-Matrix Bootstrap*
- **Sung-Sik Lee** (McMaster University & Perimeter Institute, Canada): *Emergent phenomena in quantum matter*

### 5) Minicourses for High-School Students:

This program involves several minicourses on topics of modern physics to high-school students which were held online every Saturday morning. The webpage for the minicourses is <http://outreach.ictp-saifr.org/ensino-medio/minicurso/> and topics covered include:

1. As estrelas e a tabela periódica: você sabe de onde vêm os elementos químicos? – 26 de março a 09 de abril - Roberto Costa (IAG-USP)
2. Relatividade e eletromagnetismo – 7 a 04 de junho - Pedro Vieira (ICTP-SAI FR, IFT-UNESP & Perimeter Institute, Canadá)
3. Investigando o mundo quântico: de átomos a líquidos – 25 de junho a 09 de julho - Luana Pedroza (UFABC)
4. Mecânica quântica para todo mundo – 13 a 27 de agosto - Alexandre Reily Rocha (IFT-Unesp)
5. Física do universo: cosmologia – 24 de setembro a 15 de outubro - Rogério Rosenfeld (ICTP-SAI FR / IFT-Unesp)
6. Introdução à física de partículas – 22 de outubro a 12 de novembro - Ricardo Matheus (IFT-Unesp)

In addition, U. Porto and ICTP-SAI FR jointly organized the 2nd Summer School for Young Physicists. During this online school, 40 talented high school students were selected to develop research projects created and supervised by 10 graduate students. Participants also attended a minicourse on Statistical Mechanics by Ricardo Martínez García (ICTP-SAI FR/IFT-UNESP) and on Cosmology by Roberto da Costa (IAG-USP), and participated in roundtables on academic career choices. The website of this activity is <http://outreach.ictp-saifr.org/edv22/> and a third edition is planned for 2023 (<http://outreach.ictp-saifr.org/escolaverao/>)

Furthermore, ICTP-SAI FR organized a one-week winter school for 42 high school students. Topics included a minicourse on Quantum Computation by Prof. Gastão Krein (IFT-UNESP), a programming course on Python with Physics by IFT-UNESP PhD students, and lectures on vectors, complex numbers, probability and statistics by ICTP-SAI FR outreach coordinators Felipe Novaes (E.E. Dr. A. Brasiliense/ICTP-SAI FR) and Lucas David (ETEC Guaracy Silveira/ICTP-SAI FR) (<http://outreach.ictp-saifr.org/cursodeinverno/>).

In addition, Lucas David and Felipe Novaes, high-school teachers with FAPESP fellowships, complemented these minicourses with additional theoretical classes on mathematical tools used in physics. These classes were presented weekly online on Saturdays and Tuesdays, and links to the classes by Lucas David and Felipe Novaes are

<http://outreach.ictp-saifr.org/modulo-de-aulas-complementares-ift/>

<http://outreach.ictp-saifr.org/modulo-de-aulas-complementares-ufabc/>

Cleuton Fonseca, who is also a high-school teacher with FAPESP fellowship, teaches classes for high-school and middle-term students to prepare for the physics olympiad exams in Campinas: <http://outreach.ictp-saifr.org/programa-olimpiadas/>

## 6) Physics Games:

Physics Games is a new outreach program of ICTP-SAI FR introducing current topics in theoretical physics to students in middle school through entertaining games. In the first session of this program on Oct 6, Rogério Rosenfeld (ICTP-SAI FR/IFT-UNESP) presented a short seminar on cosmology followed by a game based on the seminar. This activity was held at CEU Butantã - Elizabeth Gaspar Tunala, an educational center in the west zone of São Paulo (<http://outreach.ictp-saifr.org/jogos-de-fisica/>).

## 7) Workshops for High-School Teachers

This program presents classroom methods for teaching modern physics concepts to high-school teachers using material developed by Perimeter Institute and translated and adapted by ICTP-SAIFR to Portuguese and Spanish. In 2022 ICTP-SAIFR organized several online and two onsite activities led by ICTP-SAIFR outreach coordinator Ana Luiza Sérgio and outreach assistant Karina Gonçalves.

The meetings were held on Saturdays, with the active participation of over 1000 high-school teachers from all over Latin America. Topics discussed at these online meetings in Portuguese in 2022 are described at <http://outreach.ictp-saifr.org/ensino-medio/professores/fisica-de-fronteira-para-a-sala-de-aula-online/> and in Spanish at <http://outreach.ictp-saifr.org/ensino-medio/professores/fisica-de-fronteira-para-a-sala-de-aula-online/espanol/>.

In addition, a 1-week online summer school in Portuguese and Spanish on Gravitational Waves was organized. The activities included minicourses based on Perimeter material translated into Portuguese and Spanish by ICTP-SAIFR, a virtual visit to the LIGO observatory, and an online discussion session with LIGO researchers Gabriela Gonzalez and Riccardo Sturani. <http://outreach.ictp-saifr.org/cursoveraoprofessores2022/>

The in-person activities held at IFT were:

04 de junho de 2022: São Paulo – Do micro ao macro  
22 e 23 de outubro de 2022: São Paulo – Prêmio Nobel

## c5. Weekly seminars, colloquia and journal clubs

In 2022, weekly seminars were regularly organized. There were 83 seminars and the complete list is on the webpage <https://www.ictp-saifr.org/2022-research-seminars-and-activities/>. There were also weekly journal club meetings in string theory, particle physics, cosmology and complex systems.

## c6. Annual meeting of Steering Committee and Scientific Council

On March 2, 2022, the ICTP-SAIFR scientific council met online to discuss the activities planned for 2023. And on October 3, 2022, the ICTP-SAIFR steering committee met online to discuss the future plans of the center. The council members are listed on the webpages <http://www.ictp-saifr.org/steering-committee/> and <http://www.ictp-saifr.org/scientific-council/>. The 2023 meeting of the steering committee and scientific council will be in-person on February 6-7, 2023.

# 5. Description of Institutional Support

The ICTP-SAIFR received support from both the Instituto de Física Teórica (IFT) and from the Universidade Estadual Paulista (UNESP). All professors and secretarial staff of the IFT have been extremely supportive of all ICTP-SAIFR activities.

The UNESP university is providing the salary for four ICTP-SAIFR secretaries including an executive secretary, an accountant, a computer systems manager and an executive manager. Since January 2021, the computer systems manager position has been vacant with the departure of Lucas Sanches to Germany. The hiring of his

replacement by UNESP has been delayed due to the pandemic.

## 6. Activity Plan for 2023

In 2023, with the approval of the new thematic grant, the ICTP-SAIFR will continue to expand its research, outreach and training activities in all areas related to theoretical physics. Confirmed scientific activities in 2023 which will be organized by ICTP-SAIFR include international schools and workshops on several topics (see list below). The list of 2023 activities planned up to now include the activities:

### **São Paulo International Schools on Theoretical Physics**

[Serrapilheira/ICTP-SAIFR Training Program in Quantitative Ecology](#)

January 9 – March 3, 2023

[School on Light and Cold Atoms](#)

March 6-17, 2023

[Latin-American School on CTA Science](#)

March 27-31, 2023

[School on Nonlinear Dynamics, Complex Networks, Information Theory, and Machine Learning in Neuroscience](#)

May 22-26, 2023

[School on Emergent Phenomena in Non-Equilibrium Quantum Many-Body Systems](#)

June 26 – July 8, 2023

SAIFR-Perimeter Journeys in Theoretical Physics

July 17-23, 2023

[School on Modern Amplitude Methods for Gauge and Gravity Theories](#)

July 24 – August 4, 2023

School on Quantum Chaos

August 21 – September 1, 2023

School on Mathematical Modelling and Governance

October 30 – November 3, 2023

School on Origin of Matter Domination in the Universe

November 20 – December 1, 2023

2nd School on Data Science and Machine Learning

December 4-8, 2023

Machine Learning Methods for Materials

December 11-15, 2023

### **Meetings/Programs/Workshops**

[Quantum Technologies for São Paulo, Brazil, and Latin America](#)

January 30 – February 10, 2023

2023 Meeting of Scientific Council and Steering Committee

February 6-7, 2023

[SAIFR-Principia Workshop on Low Dimensional Quantum Gases](#)

March 19-22, 2023

APS-SAIFR Satellite March Meeting

March 20-22, 2023

APS-SAIFR Satellite April Meeting

April 24-26, 2023

[Physics Opportunities at an Electron-Ion Collider 2023](#)

May 2-6, 2023

[Holography@25](#)

June 5-17, 2023

Workshop on Strong Electron Correlations in Quantum Materials: Inhomogeneities, Frustration, and Topology

June 19 – 24, 2023

Bootstrap 2023

June 26 – July 14, 2023

[Gravitational Waves meet Amplitudes in the Southern Hemisphere](#)

August 14 – September 1, 2023

Increasing Diversity and Inclusion in Science

November 13-15, 2023

Proposals to Boost STEM Participation in Underrepresented Groups

November 16-17, 2023

### Outreach

III Curso de Verão ICTP-SAIFR para Professores de Física de Ensino Médio

January, 2023

[III Escola de Verão ICTP-SAIFR para Jovens Físicos](#)

January 12-19, 2023

Minicursos para Estudantes de Ensino Médio

March-November, 2023

Física de Fronteira em Português

March – November, 2023

Física de Frontera en Español

March – November, 2023

Clube do Livro Sci-SAIFR

March – November, 2023

ICTP-SAIFR Módulos de Aulas

March – November, 2023

III Curso de Inverno ICTP-SAIFR para Jovens Físicos

July, 2023

## 7. Data management

The main data produced by ICTP-SAIFR activities are research articles, recorded videos and pdf files of lectures and seminars, and online material for the general public. The research articles are available online on public sites such as <http://xxx.arxiv.org> for preprints and on the journal sites for Open Access publications. The recorded videos and pdf files of lectures and seminars are all posted online on the ICTP-SAIFR websites of the activities and at <https://www.ictp-saifr.org/2022-research-seminars-and-activities/> and <https://www.ictp-saifr.org/other-years-research-seminars-and-activities/>. And the online material for the general public is available on the various webpages of the ICTP-SAIFR website <http://outreach.ictp-saifr.org/>

## 8. Use of Reserva Técnica Funds

Between December 2021- November 2022, the part of the reserva tecnica funds related to "Custos de Infraestrutura Direta do Projeto" was used for the following purposes:

- a) Design and fabrication and mailings of posters for announcements of Schools/Workshops activities: R\$ 12,075.55 (See SM-outra 003)
- b) Advertisement of postdoc positions in international magazines: R\$ 3,410.40
- c) Advertisement of activities using online mailing system (mailjet): R\$ 2,451.22 (See SM-outra 003)
- d) Service payment to technician and specialized companies for technical support in the transmission and recording of online events: R\$ 9,410.00 (see SM-outra 010)
- e) Use of Zoom platform for all ICTP-SAIFR online activities: R\$ 8,117.44 (see SM-outra 010)
- f) Reform of computer laboratory involving the installation of recording equipment and blackboard for online transmission of ICTP-SAIFR activities in the computer laboratory such as the Serrapilheira/ICTP-SAIFR Training Program: R\$ 49,190.68
- g) Purchase of 3 Dell laptops to be used for ICTP-SAIFR activities: R\$ 22,109.22
- h) Airfare and perdiem and registration fee for ICTP-SAIFR associated researcher Riccardo Sturani to present a talk with the title "Analytic waveform models" at the meeting Gravitational Waves beyond the Boxes II (April 4-8) at Perimeter Institute (Waterloo, Canada): R\$ 13,604.62
- i) Airfare for ICTP-SAIFR associated researcher Riccardo Sturani to present a talk with the title "Integration methods" at the meeting High-Precision Gravitational Waves (April 4-8) at KITP Santa Barbara (USA): R\$ 5,367.81
- j) Perdiem for ICTP-SAIFR associated researcher Riccardo Sturani to present a talk with the title "Measuring the Hubble constant with black sirens" at the meeting COSMO Rio 2022 (August 22-26) at the Rio de Janeiro Planetarium: R\$ 1,300.00
- k) Perdiem for ICTP-SAIFR associated researcher Vivian Dornellas to present a talk with the title "Public good dilemma for a microbial population under the flow" at the meeting CCS2022 (Oct. 17-21) at Palma de Mallorca (Spain): R\$ 3.000,00

And the part of the reserva tecnica funds related to "Benefícios Complementares" was used for the following purposes:

- a) Airfare for ICTP-SAIFR director Nathan Berkovits to Zurich (Switzerland) to present a talk with the title "Worldsheet approach and open-closed string duality" at the meeting Deciphering AdS-CFT Duality (April 10-15) at the SwissMAP research station in Les Diablerets: R\$ 9.591,25
- b) Airfare for ICTP-SAIFR director Nathan Berkovits to Rio de Janeiro to present two lectures with the title "String theory and quantum gravity" at the meeting XVIII Brazilian School of Cosmology and Gravitation (Sept. 12-16) at CBPF: R\$ 966,24
- c) Airfare for ICTP-SAIFR director Nathan Berkovits to Los Angeles (EUA) to present a talk with the title "D=5 Holomorphic Chern-Simons and the Pure Spinor Superstring" at the meeting HirosiFest (Oct. 27-28) at Caltech University: R\$ 8,300,53

- d) Perdiem and registration fee for ICTP-SAIFR vice-director Rogerio Rosenfeld to present a talk with the title "Rubin observatory 's LSST" at the meeting COSMO Rio 2022 (August 22-26) at the Rio de Janeiro Planetarium: R\$ 3,770,00
- e) Airfare and perdiem and registration fee for ICTP-SAIFR vice-director Rogerio Rosenfeld to present a talk with the title "Mitigating baryonic effects with a theoretical error covariance" at the meeting II Encontro Primavera da SBF (Sept. 26-29) at the IIP in Natal: R\$ 4,320.47
- f) Airfare and perdiem and registration fee for ICTP-SAIFR vice-director Rogerio Rosenfeld to present a talk with the title "Cosmology with state-of-the-art photometric galaxy surveys" at the meeting SILAFEA (Nov. 14-18) at Quito (Ecuador): R\$ 13,693.00

## 9a. Articles in refereed scientific journals

9a1. Articles by ICTP-SAIFR Associate Researchers – they are presented following the order of the Project Team (item 2d)

- [1] L. R. Abramo, J. V. D. Ferri, I. L. Tashiro, e A. Loureiro, "Fisher matrix for the angular power spectrum of multi-tracer galaxy surveys", *J. Cosmol. Astropart. Phys.*, vol. 2022, nº 08, p. 073, ago. 2022, doi: 10.1088/1475-7516/2022/08/073.
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- [3] R. M. G. Delgado *et al* including L.R. Abramo, "The miniJPAS survey - The role of group environment in quenching star formation", *A&A*, vol. 666, p. A84, out. 2022, doi: 10.1051/0004-6361/202244030.
- [4] J. E. Rodríguez-Martín *et al.* including L.R. Abramo, "The miniJPAS survey - Galaxy populations in the most massive cluster in miniJPAS: mJPC2470-1771", *A&A*, vol. 666, p. A160, out. 2022, doi: 10.1051/0004-6361/202243245.
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doi: 10.1093/mnras/stac1469.

- [11] T. Mergulhão, H. Rubira, R. Voivodic, and L. R. Abramo, "The effective field theory of large-scale structure and multi-tracer", *J. Cosmol. Astropart. Phys.*, vol. 2022, n° 04, p. 021, abr. 2022, doi: 10.1088/1475-7516/2022/04/021.
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## 9a2. Articles by ICTP-SAIFR Postdoctoral Associates

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## **10. First page of publications**

**See two annexed files for publications of professors and postdocs on ICTP-SAIFR research team.**

## **11. Scientific reports of postdocs and direct doctoral students**

**See annexed file for scientific reports of**

**Vivian Dornelas, Gabriel Andreguetto Maciel, Wilmar Alberto Cardona Castro, Pablo Souza de Castro Melo, Cassiano Antonio Daniel, Lucas Nogueira de Sá Martins, João Victor Silva Rebouças e Ulisses Marques Portugal.**

## **12. Scientific reports of EP, JC and TT**

**See annexed file for scientific reports of Lucas Campos, Felipe Novaes, Karina Gonçalves, Clewton da Fonseca, Vitor Chiodi, Artur Carmo, Guilherme Araújo**

## **13. Slides presented in workshops/conferences/meetings**

**See annexed presentations of ICTP-SAIFR researchers who used Reserva Tecnica funds**