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As the COVID-19 pandemic swept across the world in 2020, ICTP took swift action to protect its staff and visitors from the growing international health emergency. By early March, the institute had suspended all on-site activities and staff began teleworking. Courses for Postgraduate Diploma students became 100% virtual, with professors teaching online from their home offices or living rooms.

ICTP took additional steps to ensure that its scientific community could remain connected and overcome isolation as the world entered national lockdowns. It quickly embraced online, interactive platforms like Zoom to deliver its seminars and colloquia, providing expanded, interactive access to ICTP’s rich programme of lectures by staff scientists and invited speakers (all colloquia were recorded and can be watched on ICTP’s YouTube channel). While most of ICTP’s Scientific Calendar activities (conferences, schools and workshops) for 2020 were postponed or cancelled, some, like the Summer School on Superstring Theory and Related Topics, went online as well, offering livestreamed talks by the world’s top string theorists to some 149 registered participants from 32 countries plus thousands more who watched the proceedings online.

“The mission of a global institute like ICTP perhaps has an even greater relevance and urgency in this crisis, which could accentuate intellectual isolation in different parts of the world,” said ICTP Director Atish Dabholkar, adding, “Perhaps this adversity is also an opportunity to think of new ways to deliver on this mission. Using interactive technology is one way ICTP can help diminish the intellectual isolation many of us are experiencing during this coronavirus crisis.”
Researchers in ICTP’s Quantitative Life Sciences (QLS) section participated in a regional scientific task force to ensure the integrity of data being used in efforts to fight the spread of the coronavirus. Matteo Marsili, head of the QLS section, and his colleague Jacopo Grilli used models to simulate the consequences of policies aimed at reducing the number of infections. Their goal, and that of the task force, was to help policymakers find ways to intervene ahead of COVID-19 infections, to minimize the enormous social and economic disruption caused by outbreaks. “It’s important to give an informed view to policymakers, with a clear quantification of the uncertainties so that they understand what data are needed to monitor the situation,” says Grilli.

ICTP’s SciFabLab, a hub of do-it-yourself innovation, put their expertise to work in response to a scarcity of personal protection equipment for local civil protection workers on the frontlines of the COVID-19 pandemic. After consulting its Maker community as well as technical assistants from Trieste hospital, the Lab produced 90 re-useable facial shields.

In the face of enormous challenges with the COVID-19 pandemic, ICTP’s partner institutes in Brazil, China, Mexico and Rwanda have discovered ways to overcome the difficulties imposed by lockdowns and social distancing. But longer-term consequences loom: “As universities and institutes across the country go virtual, researchers are scrambling to protect their funding and their careers,” said Zhang Min, coordinator of the ICTP-Asia Pacific (ICTP-AP) in Beijing.

They arrived at ICTP in August 2019, eager to embark on a year of intense academic study. By spring 2020, ICTP’s Postgraduate Diploma students found themselves in lockdown as the COVID-19 pandemic took hold. Isolated from their classmates and professors, not to mention their families thousands of kilometres away, the students relied on perseverance and virtual learning to continue their studies. Read how ICTP helped the young scholars cope with the pandemic restrictions by minimizing interruptions to their learning.

ICTP is well known for its ability to bring scientists together, whether it is in a lecture hall, a corridor or at its beloved coffee bar. When the COVID pandemic made impromptu, encounters impossible, ICTP researcher Mehrdad Mirbabayi devised a virtual solution.
High Energy, Cosmology & Astroparticle Physics

Research Topics

Phenomenology of Particle Physics

The High Energy, Cosmology and Astroparticle Physics (HECAP) section has four broad research areas.

- Phenomenology of Particle Physics
- Cosmology
- ICTP Atlas Experimental Group at the CERN Large Hadron Collider
- String and Quantum Field Theories

In 2020 the group has been active in different aspects of particle phenomenology, including dark matter and the physics of axion particles, flavour and neutrino phenomenology, and developments of theoretical techniques applied to particle phenomenology.

Quantum Chromodynamics, Axion, and Dark Matter

The Quantum Chromodynamics (QCD) axion is among the particles that could better explain the observed abundance of dark matter in the Universe. If the associated U(1) symmetry is restored after inflation topological defects form in the early universe and decay producing cold axions.

Among such objects there are cosmic axionic strings. With the help of large-scale computer simulations, the group performed a study of the estimates of the amount of relic axions produced by such objects. Several new features of the evolution and decay of axion strings have been uncovered, including running spectral index and non-linearities in the emitted radiation. The final result is a lower bound on the axion mass, which is substantially larger than previous estimates, which did not include such effects. The bound may substantially affect the expectations of ongoing and future experimental searches and alter the implications of a hypothetical discovery of such particle.
Axion-Like Particles

Members of the group investigated the interchange between early universe cosmology and dark matter direct detection, in the context of axion models with naturally suppressed couplings to photons. The results are valid for any generic case of a photophobic axion. In the context of the cosmological relaxation mechanism, this study uses the electroweak scale as the link connecting the relaxion production at early times with the dark matter absorption rate in direct detection. In this particular scenario, the relaxion field constitutes all the observed dark matter relic density and its allowed mass range is fixed to a few keV by construction.

Lepton and Flavour Symmetries

A comprehensive review of models of lepton (and quark) flavour have been completed for the Review of Modern Physics, which has been accepted for publication. The review contains several original results concerning the classification of flavour models, in particular those based on non-linear symmetries and on symmetries non-commuting with the Poincaré or gauge group.

Another study worked out by members of the group focused on the possibility to account for the hierarchy of charged lepton masses and mixings in the context of simple modular invariant models. The hierarchy is determined by the small displacement of a complex modulus from a symmetric point, where the modular group is spontaneously broken to a non-trivial residual group. The construction is motivated by supersymmetric compactification, in the limit in which one modulus is lighter.

Neutrino Phenomenology

Another study carried out by the group focused on the coherence for neutrino oscillations during propagation in matter. The cases of constant density, adiabatically varying density, density jumps, and the castle wall (CW) density profile have been considered. The key new feature in matter is the existence of energy regions with enhanced coherence, and in particular, the existence of energies at which the coherence length becomes infinite. A physical interpretation of this phenomenon is given. In the case of constant density, there is unique infinite coherence energy which is close to the MSW resonance energy. For the CW profile, there are several such energies which are close to the parametric resonance energies. Propagation in the CW profile leads to effective spread of the wave packets in the configuration space due to the phenomenon of eigenstates splitting at the borders between layers. In the case of massless neutrinos (or negligible masses), the coherence persists continuously. The results are relevant for neutrinos propagating inside the collapsing stars. The analysis shows that the decoherence may not affect collective oscillations in the central parts of these stars.

One of the long-standing problems in neutrino physics is the low energy excess of events detected by the MiniBooNE experiment. Since an oscillation explanation of the excess is practically excluded, in recent years several non-oscillatory explanations of the MiniBooNE excess were proposed. In this connection, a systematic search for phenomenological non-oscillatory scenarios based on new physics was performed which can explain the excess.
The key elements of the scenarios are the production and the decay of new light (0keV-100MeV) particles (fermions or/and bosons). About 20 scenarios were identified with minimal possible number of new particles and interaction points. In practice, they are all reduced to few generic scenarios and in this way the effective theory of the MiniBooNE excess has been developed. The scenarios can be tested with near or close detectors in neutrino experiments such as T2K ND280, NOvA, MINERvA as well as in NOMAD and PS191. It turns out that practically all the scenarios are excluded or strongly disfavored by one or several experiments. The developed formalism can be used to search for new physics unrelated to MiniBooNE result.

New physics can emerge at low energy scales, involving very light and very weakly interacting new particles. These particles can mediate interactions between neutrinos and usual matter. For light mediators, neutrino refraction can have resonances at energies of existing experiments. Properties of the resonance refraction were studied in detail. This refraction can substantially modify neutrino oscillations in certain energy ranges. Possible manifestations of the resonance refraction were explored. In particular, it has been shown that resonance refraction on relic neutrinos cannot explain the MiniBooNE anomaly.

Applications of Formal Theoretical Physics Techniques to Particle Physics

Members of the group have studied the space of consistent, relativistic, and unitary effective field theories. In particular, they focused on a simplified setting: the forward limit of 4D amplitudes. The problem of mapping the space of UV EFTs has been related to the mathematical theory of moments. During the analysis, a novel class of Exotic EFTs has been identified. These EFTs are defined by violating causality constraints at tree-level, which are however consistent (and thus causal) when considering quantum corrections.

A second topic of research has focused on the study of the Hamiltonian Truncation technique, which provides estimates of the spectrum of a theory that converge from above to the exact values as the cut-off (intrinsic to the method) is removed. The estimates of the spectrum can thus be interpreted as rigorous upper bounds on the spectrum. This feature, however, is not entirely satisfying because it does not provide rigorous two-sided error bars on the values of the spectrum. A new study, started during the second half of 2020, is trying to overcome this fundamental problem by setting a “dual optimization” problem, that is, an optimisation problem whose extrema coincide with the Hamiltonian, but the convergence is achieved from below. The target is to achieve rigorous two-side bounds on the spectrum. This would be especially interesting in higher dimensional applications of Hamiltonian Truncation.

Another topic of research has focused on on-shell calculation techniques applied to the SM EFT. These allowed members of the group to compute, in a simple manner, anomalous dimensions of SM EFT operators with cutting edge precision, and to uncover and simplify the structure of the RG mixing among operators. Ongoing related work includes finding a slick way of computing the QCD beta function at very large orders, finding further
simplifications to boost the efficiency of the method, applications to future precision experiments like lepton flavour violating dipoles measurements and e<->mu transitions.

Applications of Artificial Intelligence to Particle Physics

Members of the group started exploring the possibility to use Artificial Intelligence techniques to study particle phenomenology. One idea is strongly influenced by the Anderson localization in one dimension and investigates if a neural network (NN) can be efficiently trained to find the 'correct' Langrangian for a given localization feature. In fact, this question is already in an input/output format which can be implemented using labels as in supervised learning. Two possibilities in this direction are:

↗ **Spectrum vs. Model:** The NN is trained via different spectra (input) and it must learn the corresponding model (output). In this case, the labels can be spectra from clockwork, Randall-Sundrum deconstructed, Anderson-like, etc.

↗ **Eigenvector vs. Model:** In this scenario, the NN looks for Lagrangians given the eigenvector localization pattern. This is especially useful in cases where the zero-mode exhibits a very particular localization compared to the other states, e.g., in the scalar clockwork model where the zero-mode is exactly massless and exponentially localized. A more ambitious direction is to consider unsupervised learning, a method from which one can in principle end up obtaining new Lagrangians.

Despite the success of Machine Learning (ML) in experimental physics, the flow of ideas from physics to ML has just started to be explored. The goal here is to use ML to re-discover physical symmetries and conserved quantities from a system without prior assumptions about the problem. An example is to consider SU(3) flavour rotation to rediscover the (approximate) symmetry underlying the baryon and meson multiplets. By training the NN with pairs of e.g., baryons on the same octet, one can examine which quantity is learned by the NN on the bottleneck layer (which has fewer neurons than the others). Besides the energy, possible invariant quantities are the Casimir operators.
Research

Cosmology

In 2020 the primary research activities of the Cosmology group were in the following directions:

Theoretical Studies of de Sitter space

The group published results in different directions. An important problem in inflationary cosmology is to understand the behaviour of light particles (in particular scalar particles); in the asymptotic limit of long time, one expects to find some sort of thermalization, and this phenomenon was studied for a scalar field with quartic self-interactions (Mirbabayi). Another outstanding open problem in cosmology is to show under which assumptions the Universe starts inflating. Following previous studies with only two spatial dimensions, a theorem was rigorously proven in the realistic case of three spatial dimensions, assuming initial conditions have a certain degree of symmetry (Creminelli). Another line of research was about the possibility of quantum tunnelling into a de Sitter space (Mirbabayi).

Beyond Perturbation Theory in Inflation

The study of primordial perturbations produced during inflation is usually limited to perturbation theory. Some interesting questions, for instance the calculation of the primordial black hole abundance, may not be amenable to this kind of approach. The group developed a new technique, based on the semiclassical expansion, that allows to perform calculations beyond perturbation theory.

Black Holes with Scalar Hair

Given the recent experimental interest in black holes, it is interesting to understand under which assumptions they are described by the solutions given in General Relativity. The possibility of "dressing" a black hole with a scalar profile (hair) was studied, understanding the hidden assumptions and possible exceptions of a quite general no-go theorem.
2018 saw the completion of Run II of the CERN LHC, which ended in December. Run II delivered an unprecedented 150 inverse femtobarns of proton collision data to the ATLAS experiment at a centre of mass energy of 13 TeV. Most of this data was collected in 2017 and 2018. Results from this huge data set have been the subject of data analysis since 2019.

PhD student Mohamed Faraj (Palestine) successfully completed his PhD and obtained a postdoctoral position within ATLAS. Jacopo Magro’s thesis was almost completed and will be finalised in early 2021. Baktash Amini (Afghanistan) successfully completed his Masters thesis and graduated and Sajad Nazari (Afghanistan) joined the group in a similar capacity. Leonid Serkin (Mexico) won an INFN fellowship and will remain with the group for two additional years.

The group continues to work on top quark and Higgs boson studies including searching for resonances in the top-antitop quark system and the search for processes involving multiple top and bottom quarks. These studies are based on the full run II datasets which are now available for the collaboration to analyse.

The group continues to contribute to various technical aspects of the ATLAS experiment such as the validation of Monte Carlo simulation samples, Monte Carlo production, and the development of new statistical tools.

The group organised several particle physics masterclasses for high school and university students as well as visits of school students to CERN, including a programme for students from China.

The presence of the ICTP ATLAS group continues to provide an added visibility of the ICTP at CERN which has helped catalyse other activities such as the African School in Fundamental Physics and particle physics masterclasses worldwide.
In 2020 the main research activities of the String Theory and Quantum Gravity section were in the following directions:

**Exact results in Supersymmetric Quantum Field Theories and String Theory**

The holomorphic anomaly equation for the Vafa-Witten partition function for twisted four-dimensional $N=4$ super Yang-Mills theory on CP2 and for the gauge group SO(3) was derived from the path integral of the effective theory on the Coulomb branch. It was shown that the holomorphic kernel of this equation, which receives contributions only from the instantons, is not modular but ‘mock modular’. The partition function has correct modular properties expected from S-duality only after including the anomalous non-holomorphic boundary contributions from anti-instantons. Using M-theory duality, this phenomenon was related to the holomorphic anomaly of the elliptic genus of a two-dimensional noncompact sigma model, which was computed independently in two dimensions. The anomaly both in four and in two dimensions was traced to a topological term in the effective action of six-dimensional $(2,0)$ theory on the tensor branch. Generalizations to other manifolds and other gauge groups were considered to show that mock modularity is generic and essential for exhibiting duality when the relevant field space is noncompact.

Supergroup analogues of 3-manifold invariants $Z$, also known as homological blocks, which were previously considered for ordinary compact semisimple Lie groups, were introduced, focusing on super-unitary groups, and working out the case of SU(2|1) in detail. Physically, these invariants are realized as the index of BPS states of a system of intersecting five-branes wrapping a 3-manifold in M-theory. The homological blocks are q-series with integer coefficients. An explicit algorithm to calculate these q-series for a class of plumbed 3-manifolds was provided and the quantum modularity and resurgence properties for some particular 3-manifolds were studied. Finally, a formula was conjectured, relating the $Z$ invariants and the quantum invariants constructed from a non-semisimple category of representation of the unrolled version of a quantum supergroup.

Many BPS partition functions depend on a choice of additional structure: fluxes, Spin or Spin-c structures, etc. In a context where the BPS generating series depends on a choice of Spin-c structure, it was shown how different limits with respect to the expansion variable $q$ and different ways of summing over Spin-c structures produce different invariants of homology cobordisms out of the BPS q-series.

Motivated by the search for rational points in moduli spaces of two-dimensional conformal field theories, it was investigated how points with enhanced symmetry algebras are distributed there. First, the bosonic sigma-model with $S1$ target space was studied in detail and hitherto unknown features were uncovered. It was found for instance that the vanishing of the twist gap, though true for the $S1$ example, does not automatically follow from enhanced symmetry points being dense in the moduli space. Then the supersymmetric sigma-model on $K3$ was explored by perturbing away from...
the torus orbifold locus. Though a
definite conclusion on the distribution
of enhanced symmetry points in the K3
moduli space was not reached, several
observations were made on how chiral
currents can emerge and disappear
under conformal perturbation theory.

String Phenomenology
Further evidence for the conjecture
that superstring/M-theory compact-
tified on compact Ricci flat manifolds
exhibit instabilities whenever the
metrics do not have special holono-
my was presented. Using worldsheet
conformal field theory instabilities
of Type II superstring theories on
compact, Ricci flat, spin 3-manifolds
including a worldsheet description of
their spin structures, were investigated.
It was shown that the instabilities are
signalled by the appearance of stringy
tachyons at small radius and a negative
(1-loop) vacuum energy density at large
radius.

Heterotic string compactifications
on Calabi-Yau manifolds admitting a
Strominger-Yau-Zaslow fibration were
studied. It was shown that upon reduc-
ing the system in the T3-directions, the
Hermitian Yang-Mills conditions can
then be reinterpreted as a complex flat
connection on R3 satisfying a certain
co-closure condition. A number of
abelian and non-abelian examples were
given and various properties of these
models, which are new local solutions
to the Hull-Strominger system on
T3xR3, were studied.

A recent theorem of Fosco-
lo-Haskins-Nordström which con-
structs complete G2-holonomy
orbifolds from circle bundles over
Calabi-Yau cones was used to construct
and investigate a large class of general-
isations of the M-theory flop transition.
It was found that in many cases a UV
perturbative gauge theory appears to
have an infrared dual described by a
smooth G2-holonomy background in
M-theory. Various physical checks of
this proposal were carried out affirm-
atively.

Quantum Gravity, Black
Holes and Holography
Limitations of locality in semiclassi-
cal gravity were studied by examining
what information for the bulk state
can be recovered by a set of observers
who live near the boundary of global
AdS, and are allowed to act only with
simple low-energy unitaries and make
measurements in a small interval of
time. The observers are not allowed
to leave the near-boundary region. A
physical protocol was described that
nevertheless allows these observers to
obtain detailed information about the
bulk state. This protocol uses the lead-
ing gravitational back-reaction of a bulk
excitation on the metric, and also relies
on the entanglement-structure of the
vacuum. For low-energy states, it was
shown how the near-boundary observ-
ers can use this protocol to completely
identify the bulk state.

Connections between the Wheeler
DeWitt approach for two-dimensional
quantum gravity and holography were
analysed, focusing mainly in the case of
Liouville theory coupled to c=1 matter,
with the motivation to understand
whether some form of averaging is
essential for the boundary theory. In
a spirit similar to the recent studies of
Jackiw-Teitelboim (JT)-gravity, it was
argued that macroscopic loop oper-
ators define the asymptotic region
on which the holographic boundary
dual resides. It was argued that Matrix
quantum mechanics and the associated double scaled fermionic field theory on
the contrary, is providing an explicit “unitary in superspace” description of the
complete dynamics of such two-dimensional universes with matter, including the
effects of topology change. It was proposed that if we associate a Hilbert space to
a single boundary dual, it seems that it cannot contain all the information present
in the non-perturbative bulk quantum gravity path integral and MQM.

Various other questions in quantum gravity were investigated, in connection
to the black hole S-matrix in certain toy models, aspects of bulk reconstruction in
AdS/CFT, the role of symmetries on null boundaries and thermodynamics of black
holes in higher derivative theories of gravity.

Three training activities were held in 2020, all virtually, one at ICTP and two out-
side ICTP; in South Africa and Brazil.

### Training Activities

**Summer School on Superstring Theory and Related Topics**

Organizers: Atish Dabholkar  
E. Gava  
V. Hubeny  
Z. Komargodski  
K.S. Narain  
Local Organizer: K. Papadodimas

**2nd Joint ICTP-SAIFR School on Particle Physics**

Organizers: E. Bertuzzo  
J. Elias Miró  
R. Rosenfeld  
ICTP Scientific Contact: G. Villadoro

**Strings 2020**

Organizers: F. Alday  
A. Bissi  
A. Castro  
R. de Mello Koch  
S. Minwalla  
M. Perry  
ICTP Scientific Contact: K. Papadodimas

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Table 1. Number of participants in training activities by gender and country development status.
Research

Funding

Italian Istituto Nazionale di Fisica Nucleare (INFN) has kindly aided in the funding of the "Summer School on Superstring Theory and Related Topics" as well as our Postdoc M. Celoria.

Staff and Long-Term Visitors

Research Scientist
Section Head:
Paolo Creminelli
Bobby Acharya
Atish Dabholkar
Joan Elias Miró
Mehrdad Mirbabayi
Kyriakos Papadodimas
Pavel Putrov
George Thompson
Giovanni Villadoro

Emeritus Scientists
Kumar S. Narain
Seifallah Randjbar-Daemi
Goran Senjanovic
Alexei Smirnov

Research Staff Associates
*Leopoldo Pando Zayas
*Ravi Sheth

Scientific Consultants
Francesco Benini
Edi Gava
Andrea Romaniano

Visiting Professor
Marina Cobal

Visiting Scientists
(2 months or more)
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Laure Gouba
Kaniba Mady Keita
Giancarlo Panizzo
Michele Pinamonti
Vladimir Tello
Kate Shaw
Mohammad Sheikh-Jabbari
Oscar Zapata Norena

Post-doctoral Fellows
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Marco Celoria
Francesca Ferrari
Nayara Fonseca
James Ingoldby
Oliver Janssen
Olga Papadoulaki
Arnab Rudra
Arturo R. Sanchez Pineda
Leonid Serkin
Jiahua Tian
Ida Zadeh

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Mohammed Imad Faraj
Alfredo Gonzalez Lezcano
Andrea Grigoletto
Giovanni Guerrieri
Mehmet Asim Gumus
Diksha Jain
Jacopo Magro
Marwan Najjar
Giovanni Tambalo
Vicharit Yingcharoenrat

STEP Fellows
Zainab Nazari
Research in the CMSP Section spans some of the most exciting areas of theoretical condensed matter physics, including the investigation of properties of nanostructures, the study of interacting many-body quantum systems, quantum information processing, computer simulations of fluids and solids with atomistic, molecular, and electronic structure methods, the design of new materials for renewable energy applications and synchrotron-radiation related physics. The CMSP Section has continued to play a pivotal role in two specific initiatives:

- Sustainable Energy.
- Trieste Institute for Theoretical Quantum Technologies (TQT Institute).

The Sustainable Energy initiative is focused on computational investigations of materials relevant for renewable energy applications. Quantum atomistic simulations are employed to understand the behaviour of materials and processes, such as photoabsorption and photocatalysis. The initiative encompasses in-house research activities, cooperation with the Centre’s students and visitors, as well as training activities. Examples for 2020 are a hands-on school on electronic excitations in Novel Materials (smr3421) and an on-line workshop on excited charge dynamics in semiconductors (smr3516).

Since its beginning in 2019, the TQT Institute has been continuing to operate through several different actions, with the aim to create a Quantum-Hub in Trieste to coordinate and promote research activities related to the emerging Quantum Technologies. In 2020 various activities in quantum information took place. Furthermore, TQT has started several partnerships with external Institutions in the areas of education and training. Among the activities organized, smr3426 in January and smr3474 in October were of particular interest.

The Sustainable Energy Initiative is fully integrated in the CMSP Section, while the Institute on Quantum Technology is a joint effort of three different Institutions, with the CMSP Section playing a leading role within ICTP.

Despite the huge difficulties that emerged in 2020 related to the pandemic crisis, all the CMSP staff and affiliated personnel made a considerable effort to keep the scientific atmosphere of the section alive. In addition to the more traditional activities (schools and conferences) that became virtual in 2020, several different online initiatives were launched to foster the exchange of
ideas, to stimulate collaborations and to keep the ICTP community united. This was of particular importance for regular visitors and associates, who could not come to ICTP in 2020, as well as for younger scientists and collaborators.

Thanks to the enthusiasm and commitment of the ICTP-CMSP community, 2020 was dense with (virtual) events, research activities and collaborations. Finally, the experience gained so far in managing virtual events will be likely employed in the post-pandemic period as well, in synergy with more conventional (in-presence) events.

The research at the CMSP Section builds on four main pillars:

- The physics of nanostructures.
- Quantum many-body systems.
- Atomistic, molecular, and electronic structure simulations.
- Materials for renewable energy applications.

Within this spectrum of interests, the investigations branch out in several different directions, which are summarized below.

**Heat and charge transport through nano-devices**

CMSP researchers currently study several of these systems with particular attention to the role of quantum coherence and local correlations, including transport through quantum dots and wires, hybrid structures, molecular transistors, topological superconductors, spintronic and nanoelectromechanical systems. Electron transport is also studied by combining many-body physics techniques with ab initio electronic structure and methods.

**Heat engines and thermodynamics at the nanoscale**

We are currently interested in understanding how thermal machines retain and/or modify their properties when they are scaled down to dimensions where quantum mechanical and fluctuation effects are dominant.

**Solid state quantum information processing**

Researchers at CMSP are looking into the properties (and protocols) of solid-state qubits, both in semiconducting and superconducting nano-devices.

**Physics of Nanofriction**

Current approaches in the ICTP-SISSA extended group proceed on three fronts. The first is addressing individual problems posed by experiments, mostly by means of classical non-equilibrium molecular dynamics. This area includes the superlubric sliding of clusters, nanotubes, and charge-density-wave systems. The second addresses the role of quantum mechanics in nanofriction, including the building of an ab initio approach to electronic friction, and quantum phenomena in the sliding of atomic ion chains. The third front, and the most ambitious, is building a bona fide theory of sliding friction, something quite promising which is just at the beginning.

**Nanostructures and nanostructured phases of graphene on metal surfaces**

We presently investigate by means of ab initio computations the formation and properties of nanostructured phases of graphene on metal surfaces and the physics governing the formation and growth of intercalated gas nano-
bubbles in graphene. This includes in particular rare-gas solidification in nanobubbles at ambient temperature and their growth/ripening with increasing annealing temperature.

**Disordered systems and Many-body localization**

One of the main assumptions of statistical mechanics is that when an isolated system evolves under its Hamiltonian dynamics, it will reach a state of equilibrium where a statistical description holds. Recently, this assumption has been challenged by a series of papers demonstrating that in disordered, interacting systems, equilibration is hindered by quantum effects. This phenomenon has been dubbed Many-Body Localization (MBL) and is the subject of intense research at CMSP.

**Many-body systems and quantum simulators**

We are actively working on this topic in a number of different directions: i) the ground state phase diagram of various strongly correlated systems; ii) the dynamics of many-body systems from the case of sudden perturbation to the (quasi-)adiabatic regime; iii) quantum control of many body systems; iv) the entanglement in complex quantum systems; v) dissipative many-body systems.

**Adiabatic Quantum Computation**

At CMSP we are actively working on how the adiabatic algorithm performs on classical optimization problems as well as in several other topics related to quantum annealing.

**Strongly Correlated Systems**

The goal of this research field is to understand the fundamental physics of Fermi-and non-Fermi liquids, non-conventional superconductivity of cuprates and iron pnictides, SYK models, the interplay between superconductivity and magnetism in strongly-correlated materials, the properties of spin chains and ladders, and exotic magnetism emerging in quantum liquids.

**Physics of Ultra-High Pressure Systems**

Understanding, explaining, predicting their evolution under pressure is an important physics challenge as well as a potential opportunity to create new metastable but useful materials. Recent themes include the formation of non-molecular CO$_2$ phases, the mixing behaviour of methane/water fluids at planetary conditions, the role of anharmonicity in LiH, the computational discovery of a new spin liquid phase in O$_2$, and new phenomena in high pressure frictional shear.

**Acid-Base Chemistry in Water and Interfaces**

A particular area of ongoing development is probing the properties of water as a 3D-network which will hopefully help discover its collective structural and dynamical signatures.
Hydrogen-Bond Networks in Biological Systems

An active area of ongoing research is using a combination of both ground- and excited state electronic structure calculations to understand the electronic and optical properties of these systems. Classical molecular dynamics combined with enhanced sampling methods such as umbrella sampling and metadynamics are used to explore the conformational landscape of these proteins.

Chemical Physics of Solvation

A combination of both computational simulations and statistical mechanical theory is used to examine how these solutes perturb the structural, dynamical, electronic and spectroscopic properties of water.

Multiferroic materials

Current research is strongly focusing on magnetoelectric multiferroics that are simultaneously ferromagnetic and ferroelectric, and in which an electric field can be used to modify their magnetic properties. Using first-principles density-functional calculations, we investigate the microscopic mechanisms generating magnetoelectric effects in multiferroic layered materials and interface systems, and explore ways to chemically and structurally tailor the magnetoelectric couplings for targeted electrically controlled magnetic properties.

Hydrogen from Sunlight: Water Splitting on Iron Oxide Surfaces

Using computer modelling, we are simulating how this reaction takes place on hematite surfaces. Many properties of this material make it very appealing as an anode in photo-electrochemical water splitting reactions, but major aspects of this process remain to be understood.

Dye Sensitized TiO₂ Surfaces

We are investigating the interactions of the dyes with the surfaces, with the electronic structure and with excited electronic states.

Titanium-based Photocatalysts for Water Splitting and CO₂ Reduction

We investigate by density functional theory why some titanium-based photocatalysts are more active than pure titania for these reactions. The systems considered are comprised of black hydrogenated titania, sodium titanate and copper clusters at titania surfaces.

Metal-Air Batteries

We work to understand the basic electrochemical reactions taking place in these batteries during formation and dissolution of oxides of lithium and sodium, as well as in the presence of electrocatalysts such as MnO₂. Computer simulations using density functional theory are our main tool.

Bio-Inspired Catalysts

We are investigating molecules, called phthalocyanines, which are related to heme molecules critical in blood.
In addition to the close collaborations with local scientific institutions such as SISSA, Elettra, and the University of Trieste, the research activities in the CMSP Section benefit of numerous collaborations worldwide that include: Princeton University, USA
University of Oxford, UK
Centre for Quantum Technologies, National University of Singapore
Ludwig-Maximilians-University (LMU) Munich, Germany
Ecole Normale Superieure (ENS), Paris, France
Université Paris Diderot, Paris, France
Aalto University, Helsinki, Finland
Max Planck Institute for the Physics of Complex Systems, Dresden, Germany
IQOQI Innsbruck, Austria
Max Planck Institute for Quantum Optics, Garching, Germany
Scuola Normale Superiore, Pisa, Italy
Departamento de Física, Universidad Nacional del Sur & IFISUR, Argentina.

The intense efforts of CMSP scientists are reflected by 100 publications in peer reviewed printed journals in 2020. In addition to these publications, there are numerous papers already accepted for publication or into the process of reviewing. Among the published papers, 17 were published in high impact journals such as PNAS, Phys. Rev. Lett., Phys. Rev. X, Nano Letters, JACS, J. Chem. Phys. Lett., JHEP, Science and Nature publishing groups.

The impact of CMSP section’s work can be seen by looking at the cumulative number of citations that (summed over) all the members and affiliated to the section have received in the last years. In 2020 the Section has received approximately 13000 citations, continuing the positive trend of the previous years (for instance, in 2019 the citations were approximately 12000).

The staff members and senior postdocs of CMSP supervised numerous Postdocs, PhD, Diploma and Master students, as well as long-term visiting students.

**Ph.D. Students Supervised or Co-Supervised**

**SISSA:**
Claudia Artiaco
Federico Balducci
Philip C. Cruz
Youness Diouane
Giuliano Giudici
Eduardo Gonzalez Lazo
Ali Khosravi
Adu Offei-Danso
Rajat Panda
Silvia Pappalardi
Tommaso Parolini
Nishan Ranabhat
Anam Sara
Yusuf Shaidu
Federica Surace
Xhek Turkeshi

**Scuola Normale Superiore, Pisa:**
Vittorio Vitale

**Camerino University:**
Bibek Bhandari
Paolo Erdman
Emanuele Costa

**Trieste University:**
Paola Delcompare Rodriguez

**Napoli University:**
Davide RATTACASO

**Other Long-Term Visitors**
Wenbin HE (CSRC Beijing)
Pengfei LIANG (CSRC Beijing)

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1. Source: Web of Science
Diploma or Master Students Supervised or Co-Supervised

ICTP Diploma Students 2019/2020 - Until August 2020
Amel Alhassan (Sudan)
Ezron Cabrera (Philippines)
Cornelio Cap Lopez (Guatemala)
Edward Donkor (Ghana), PhD student since fall 2020
Jesus Espinoza-Valverde (Costa Rica)
Poetry Tarabunga (Indonesia), PhD student since fall 2020
Anne Nadine Tewonou Djota (Cameroon)
Amar Thakuri (Nepal)
Mikheil Tsitsishvili (Georgia), PhD student since fall 2020

ICTP Diploma Students 2020/2021 - From September 2020
Julia Blandine Bassila (Congo)
Joshua Carlo Casapao (Philippines)
Maha Hsouna (Tunisia)
Pelluce Kabarokole (Uganda)
Lien Thi Le (Vietnam)
Valerius Evan Ligasetiawan (Indonesia)
Jonah Langson Nagura (Nigeria)
Rolando Gabriel Ramirez Camasca (Peru)
Puja Thapa (Nepal)

Master Students
Alex Pividori (Università degli studi di Trieste)

STEP Visiting Scientists and Students
Reyhaneh Khasseh (Iran)

The staff of CMSP taught the following courses at the ICTP Postgraduate Diploma Programme and at Master and PhD programs in other universities.

- Course on Simulation, SISSA
- Course on parallel Fast Fourier Transformations, ICTP-SISSA Master in High Performance Computations
- Course on Electronic Structure Theory: Quantum Chemical Methods, SISSA PhD programme in Condensed Matter Physics
- Advanced Statistical Mechanics, Diploma Programme
- Advanced Quantum Mechanics, Diploma Programme
- Theory of classical and quantum computation, SISSA PhD program
- Biological Physics, Diploma Programme
- Numerical Methods I, Diploma Programme
- Numerical Methods II, Diploma Programme
- Many-Body Phenomenology, Diploma Programme
- Electrons and Phonons in Solids, Diploma Programme
- Several courses of the 1st and 2nd year of the Master in Physics, ICTP-EAIFR, Kigali
CMSP scientists participated in the organisation of International Conferences both within and outside ICTP.

**School on Quantum Information Theory and Thermodynamics at the Nanoscale**

Organizers: Alexia Auffèves (Institut Néel-CNRS, Grenoble)  
Fabio Benatti (Università degli studi di Trieste)  
Abderrahim El Allatì (University Abdelmalek Essaâdi, Al Hoceima)  
Morad El Baz (University Mohammed V, Rabat)  
Yassine Hassouni (University Mohammed V, Rabat)  
Massimo Palma (Università degli Studi di Palermo)  
Mauro Paternostro (Queen's University, Belfast)

ICTP Scientific Contact: Antonello Scardicchio
Co-sponsors:
Université Abdelmalek Essaâdi  
Faculté des Sciences et Techniques, Al-Hoceima  
Faculté Pluridisciplinaire de Nador, Hassan II Academy of Science and Technology  
CNRST - Centre National pour la Recherche Scientifique et Technique  
Provincial Association for the Support of Proximity Activities

**Workshop on Quantum Information Theory and Thermodynamics at the Nanoscale**

Organizers: Alexia Auffèves (Institut Néel-CNRS, Grenoble)  
Fabio Benatti (Università degli studi di Trieste)  
Abderrahim El Allatì (University Abdelmalek Essaâdi, Al Hoceima)  
Morad El Baz (University Mohammed V, Rabat)  
Anass El Haddadi (University Abdelmalek Essaâdi, Al Hoceima)  
Yassine Hassouni (University Mohammed V, Rabat)  
Taoufik Mourabit (University Abdelmalek Essaâdi, Al Hoceima)  
Mauro Paternostro (Queen's University, Belfast)  
Yahya Tayalati (University Mohammed V, Rabat)  
El Hassane Zerouali (University Mohammed V, Rabat)

ICTP Scientific Contact: Antonello Scardicchio
Co-sponsors:
Université Abdelmalek Essaâdi  
Faculté des Sciences et Techniques, Al-Hoceima  
Ecole Nationale des Sciences Appliquées d'Al-Hoceima  
Faculté Pluridisciplinaire de Nador  
Hassan II Academy of Science and Technology  
CNRST - Centre National pour la Recherche Scientifique et Technique  
Provincial Association for the Support of Proximity Activities

**Emergent Hydrodynamics in Integrable Quantum Many-body Systems and Beyond**

Organizers: Bruno Bertini (University of Ljubljana)  
Benjamin Doyon (King's College London)  
Romain Vasseur (University of Massachusetts)

Local Organizer: Marcello Dalmonte
Co-sponsor:
Trieste Institute for the Theory of Quantum Technologies (TQT)
Joint QLS-CMSP Virtual Summer Retreat on Heat, Water, Noise, and Life

Organizer: Ali Rajabpour (IPM)
Local Organizers: Ali Hassanali Edgar Roldan

Frontiers of Nanomechanics
Organizers: Eva Weig (University of Konstanz, Germany)
Yaroslav Blanter (TU Delft, The Netherlands)
Florian Marquardt (Max Planck Institute for the Science of Light, Germany)
Local Organizer: Mikhail Kiselev

ICTP-SISSA-CECAM Workshop on Molecular Dynamics and its Applications to Biological Systems
Organizers: Giovanni Bussi (SISSA)
Alessandro Laio (SISSA)
Alessandra Magistrato (SISSA)
Christian Micheletti (SISSA)
Alex Rodriguez (ICTP)
Edgar Roldan (ICTP)
Angelo Rosa (SISSA)
Local Organizer: Ali Hassanali
Co-sponsors:
International School for Advanced Studies
Centre Européen de Calcul Atomique et Moléculaire

Conference on Quantum Annealing/Adiabatic Quantum Computation
Organizers: Wolfgang Lechner (IQOQI)
Hidetoshi Nishimori (Tokyo Institute of Technology)
Giuseppe E. Santoro (SISSA)
Local Organizer: Antonello Scardicchio
Co-sponsor:
Trieste Institute for the Theory of Quantum Technologies (TQT)

Virtual Winter School on Strongly Correlated Quantum Matter
Organizers: David Luitz (MPIPKS)
Markus Heyl (MPIPKS)
Mario Collura (SISSA)
Local Organizer: Marcello Dalmonte
Research

Seminars

Joint ICTP/SISSA Statistical Physics Seminar: How to Avoid ‘Heated’ Arguments Among your Spins
9 January 2020 at 11:30 held at SISSA
Speaker: Paola Cappellaro (MIT, USA)

Joint ICTP/SISSA Statistical Physics Seminar: Geometry of Bounded Critical Phenomena
16 January 2020 at 11:30 held at SISSA
Speaker: Giacomo GORI (IPT, Heidelberg University)

Joint ICTP/SISSA Statistical Physics Seminar: Emission of Correlated Jets from a Driven Matter-Wave Soliton
21 January 2020 at 15:00 held at SISSA
Speaker: Peter Jeglič (Jozef Stefan Institute, Ljubljana, Slovenia)

Joint ICTP/SISSA Statistical Physics Seminar: Cesium Matter-Wave Solitons
21 January 2020 at 11:30 held at SISSA
Speaker: Tadej Mežnaršič (Jozef Stefan Institute, Ljubljana, Slovenia)

News and Views: Computational Studies of the Liquid-liquid Transition in Supercooled Water: Old and New Numerical Results
23 January 2020 at 11:00 held at ICTP
Speaker: Francesco SCIORTINO (Univ. di Roma La Sapienza, Rome, Italy)

Joint ICTP/SISSA Statistical Physics Seminar: Quantum Quenches in Sine-Gordon Theory: Progress and Challenges
28 January 2020 at 11:00 held at SISSA
Speaker: Gábor TAKÁCS (Budapest University of Technology and Economics, Hungary)

News and Views: First Principles Theory of Flexoelectricity and Related Materials Properties
6 February 2020 at 11:30 held at ICTP
Speaker: Massimiliano STENGEL (Catalan Institution for Research and Advanced Studies ICREA, CSIS-ICMAB, Bellaterra, Spain)

Emergent Behavior in Quantum Dynamics of Many-Body Systems: Quantum Dynamical Phase Transitions and Intrinsic Irreversibility Observed through NMR Loschmidt Echoes and OTOCs
12 February 2020 at 11:00 held at ICTP
Speaker: Horacio M. PASTAWSKI (Inst. de Física Enrique Gaviola and Facultad Matematica, Astronomia, Fisica y Computacion, Universidad Nacional de Cordoba, Argentina)

31 March 2020 at 11:00
Speaker: Zeinab Ebrahimpour (ICTP Optics Lab., Trieste, Italy)

Virtual Joint ICTP/SISSA Statistical Physics Seminar: The Frustration of Being Odd: Boundary Conditions and Bulk, Local Order
31 March 2020 at 11:00
Speaker: Fabio Franchini (Ruder Boskovic Institute, Zagreb, Croatia)

Virtual Joint ICTP/SISSA Statistical Physics Seminar: Spectral Properties and Thermalization with Matrix Product Operators
7 April 2020 at 11:00
Speaker: Mari Carmen Banuls (Max Planck Institut fuer Quantenoptik, Germany)

Atomistic Simulation Webinar Series: Heat and Charge Transport in Water at Ice-Giant Conditions from ab initio MD Simulations
7 April 2020 at 11:00 held virtually
Speaker: Federico Grasselli (SISSA, Trieste)

Virtual Joint ICTP/SISSA Statistical Physics Seminar: Resurgence and Non-perturbative Physics: Applications in Condensed Matter
21 April 2020 at 11:00
Speaker: Marcos Mariño (Geneva University, Switzerland)

Atomistic Simulation Webinar Series: Network Analysis of Chemical Signal Propagation in Proteins
22 April 2020 at 11:00 held virtually on the Jitsi Platform Webinar
Speaker: Ivan Rivalta (Univ. di Bologna, Dipt. di Chimica Industriale ‘Toso Montanari’, Bologna)
Atomistic Simulation Webinar Series: Multi-technique Analysis of Extracellular Vesicles: Not only size matters
29 April 2020 at 11:00 held virtually
Speaker: Pietro Parisse (NanoInnovation Laboratory, Elettra, Trieste, Italy)

CMSP Joint Virtual MIPiPKS/ICTP Seminar
4 May 2020 at 14:00 held virtually
Speaker: Michael Knap (TU Munich) and Alessandro SILVA (SISSA Trieste)

Atomistic Simulation Webinar Series: The Multi-configuration Time Dependent Hartree (MCTDH) Approach and Applications in Gas Phase and Condensed Phase Chemistry
6 May 2020 at 11:00 held virtually
Speaker: Steve Ndengue (East African Institute for Fundamental Research (EAIFR), Kigali, Rwanda)

Joint ICTP/SISSA Condensed Matter: Quantum many-body scars, mixed phase spaces and non-universal thermalization
7 May 2020 at 11:30 held virtually
Speaker: Maksym Serbyn (IST, Austria)

Joint ICTP/SISSA Statistical Physics: Building a Path-integral Calculus: A Covariant Discretization Approach
12 May 2020 at 11:00 held virtually
Speaker: Vivien Lecomte (Laboratoire Interdisciplinaire de Physique, Université Grenoble-Alpes)

Atomistic Simulation Webinar Series: Nuclear Quantum Effects - Fast and Accurate
13 May 2020 at 11:00 held virtually
Speaker: Venkat Kapil (Laboratory of Computational Science and Modeling Ecole Polytechnique Fédérale de Lausanne)

Joint ICTP/SISSA Statistical Physics: Brownian Motion in a Non-equilibrium Bath: Theory and Experiment
19 May 2020 at 11:00 held virtually
Speaker: Matthias Krüger (Georg-August-Universität Göttingen)

Atomistic Simulation Webinar Series: A Study of the atomic and electronic structure of the antimonene/bismuth selenide interface: in search of proximity effects
20 May 2020 at 11:00 held virtually
Speaker: Roberto Flammini (Istituto di Struttura della Materia ISM-CNR, Roma)

Joint ICTP/SISSA Statistical Physics: On Solitons and Calogero-Moser-Sutherland Systems
26 May 2020 at 11:00 held virtually
Speaker: Edwin Langmann (Royal Institute of Technology, AlbaNova Center)

Atomistic Simulation Webinar Series: Order and disorder at bio-inorganic interfaces: the cases of ZnO binding peptides and FeOx(OH)y biomineralization
27 May 2020 at 11:00 held virtually
Speaker: Lucio Colombi Ciacchi (Conrad Naber Endowed Chair, Hybrid Materials Interfaces Group, Faculty of Production Engineering, University of Bremen, Germany)

Atomistic Simulation Webinar Series: On the nature of interactions between water/ionic liquid solutions and bio-molecules revealed by synchrotron-based UV Resonance Raman spectroscopy
3 June 2020 at 11:00 held virtually
Speaker: Barbara Rossi (Elettra Sincrotrone Trieste, Italy)

Joint ICTP/SISSA Statistical Physics: Quantum fields in curved space-times with atomic and optical systems: new directions from synthetic gauge fields and quantum emitters
9 June 2020 at 11:00 held virtually
Speaker: Iacopo Carusotto (INO-CNR BEC Center and Università di Trento)

Atomistic Simulation Webinar Series: Modeling Materials and Processes in Hybrid/Organic Photovoltaics: From Dye-sensitized to Perovskite Solar Cells
10 June 2020 at 11:00 held virtually (Virtual Atomistic Webinar)
Speaker: Filippo De Angelis (Dept. of Chemistry, Univ. of Perugia and Computational Lab. for Hybrid/Organic Photovoltaics CLHYO, CNR-SCITEC, Perugia, Italy)

News and Views: Topology, Molecular Simulation and Machine Learning as Routes to Exploring Structure and Phase Behavior in Molecular and Atomic Crystals
11 June 2020 at 15:00 held virtually
Speaker: Mark E. Tuckerman (NYU, Arts and Science, New York, U.S.A.)
Joint ICTP/SISSA Statistical Physics: Thermalization, Chaos and Holography  
16 June 2020 at 11:00 held virtually  
Speaker: Jan de Boer (Amsterdam University)

Atomistic Simulation Webinar Series: Molecular Simulations with Focus on Atmospheric Processes  
17 June 2020 at 11:00 held virtually (Virtual Atomistic Webinar)  
Speaker: Daniel Schlesinger (Dept. of Environmental Science (ACES) Atmospheric Science Unit & Bolin Centre for Climate Research, Stockholm University, Sweden)

HECAP-CMSP Joint Seminar: Boundary Conditions for Chiral Fermions  
17 June 2020 at 14:30 held virtually  
Speaker: David Tong (University of Cambridge)

Joint ICTP/SISSA Statistical Physics: Cold atoms inspired interacting systems: Beyond the ergodic paradigm  
23 June 2020 at 11:00 held virtually  
Speaker: Jakub Zakrzewski (Institute of Physics, Jagiellonian University, Krakow, Poland)

Atomistic Simulation Webinar Series: High-temperature Phase Evolution in Icy Planet Molecular Mixtures  
24 June 2020 at 11:00 held virtually (Virtual Atomistic Webinar)  
Speaker: Andreas Hermann (School of Physics & Astronomy, University of Edinburgh, U.K.)

Joint ICTP/SISSA Statistical Physics: Quantum Electronic Circuit Simulation of Quantum Field Theories  
30 June 2020 at 11:00 held virtually  
Speaker: Ananda Roy (Physik-Department, Technische Universitaet, Munich, Germany)

Joint ICTP/SISSA Statistical Physics: Signatures of Universality Out of Equilibrium  
14 July 2020 at 11:00 held virtually  
Speaker: Luca Tagliacozzo (ICCUB, Universitat de Barcelona, Spain)

News and Views: Will Aliens Drink Water?  
23 October 2020 at 11:00 held virtually  
Speaker: Ali Hassanali (ICTP, Trieste, Italy)

Joint ICTP/SISSA Statistical Physics: Spatio-temporal Control of Correlations via Inhomogeneous Dissipation  
4 November 2020 at 14:00 held virtually  
Speaker: Jamir MARINO (Johannes Gutenberg-Universität Institut für Physik, Mainz, Germany)

Joint ICTP/SISSA Statistical Physics: Entanglement Entropy of Energy Eigenstates Follows a Universal Scaling Function  
10 November 2020 at 11:00 held virtually  
Speaker: Thomas BARTHEL (Duke University, Quantum Information Science, Durham NC 277708, U.S.A.)

News and Views: Quantum optics toolbox for correlated electron systems  
12 November 2020 at 16:00 held virtually  
Speaker: Mohammad HAFEZI (University of Maryland, Departments of ECE and Physics)

Atomistic Simulation Webinar Series: Molecular insights on Poly(N-isopropylacrylamide) coil-to-globule transition induced by pressure  
13 November 2020 at 11:00 held virtually  
Speaker: Letizia TAVAGNACCO (CNR-ISC and Physics Department, Rome Sapienza University)

Joint ICTP/SISSA Statistical Physics: Universal Survival Probability for a d-dimensional run-and-tumble particle  
17 November 2020 at 11:00 held virtually  
Speaker: Satya N. MAJUMDAR (LPTMS, University of Paris-Sud, Orsay, France)

Joint ICTP/SISSA Statistical Physics: Detecting Fractional Chern Insulators in Few-boson Systems  
24 November 2020 at 11:00 held virtually  
Speaker: Cecile REPELLIN (LPMMC, CNRS, Grenoble, France)

Joint ICTP/SISSA Statistical Physics: Entanglement entropies and the modular bootstrap for $Z_3$ Riemann surfaces  
1 December 2020 at 11:00 held virtually  
Speaker: Jacopo Viti (IIP-UFRN, Natal, Brazil and INFN Florence, Italy)
News and Views: Amon based Quantum Machine Learning  
3 December 2020 at 14:00 held virtually  
Speaker: Anatole von Lilienfeld (Faculty of Physics, University of Vienna) 

Atomistic Simulation Webinar Series: Supporting Drug Discovery Projects: My Computational Research in Pharma  
9 December 2020 at 11:00 held virtually  
Speaker: Ferruccio Palazzesi (Aptuit, an Evotec Company, Verona, Italy) 

Joint ICTP/SISSA Statistical Physics: Boundary emptiness formation probabilities in the six-vertex model at $\Delta = - 1/2$  
10 December 2020 at 14:00 held virtually  
Speaker: Alexi Morin-Duchesne (Mathematical Physics, Univ. Catholique, Louvain-la-Neuve, Belgium) 

Joint ICTP/SISSA Statistical Physics: Counting statistics for non-interacting fermions in a d-dimensional potential  
15 December 2020 at 11:00 held virtually  
Speaker: Naftali R. Smith (Ecole Normale Superieure, Paris and LPTMS, Orsay, France) 

Atomistic Simulation Webinar Series: Liquid-liquid critical point in realistic models of water  
23 December 2020 at 15:00 held virtually  
Speaker: Gül H. Zerze (Chemical and Biological Engineering Princeton University, NJ 08544, U.S.A.) 

Online Workshop on Many-body Physics out of Equilibrium  
24 March 2020  

Virtual Workshop on Real-time Dynamics in Strongly Correlated Quantum Matter  
8-9 April 2020 with the Max Planck Institute for the Physics of Complex Systems 

Other Events

| smr  | least developed | developing | developed | least developed | developing | developed | least developed | developing | developed | totals | least developed | developing | developed | least developed | developing | developed | totals | least developed | developing | developed | least developed | developing | developed | totals | least developed | developing | developed | least developed | developing | developed | totals |
|------|----------------|------------|-----------|----------------|------------|-----------|----------------|------------|-----------|--------|----------------|------------|-----------|----------------|------------|-----------|--------|----------------|------------|-----------|--------|----------------|------------|-----------|--------|----------------|------------|-----------|--------|----------------|------------|-----------|--------|
| 3426 | 0              | 44         | 9         | 0              | 20         | 3         | 0              | 64         | 12        | 76     |                |            |           |                |            |           |        |                |            |           |        |                |            |           |        |
| 3500 | 0              | 38         | 20        | 0              | 16         | 1         | 0              | 54         | 21        | 75     |                |            |           |                |            |           |        |                |            |           |        |                |            |           |        |
| 3514 | 1              | 26         | 95        | 0              | 1          | 11        | 1              | 27         | 106       | 134    |                |            |           |                |            |           |        |                |            |           |        |                |            |           |        |
| 3550 | 2              | 23         | 8         | 1              | 17         | 1         | 3              | 40         | 9         | 52     |                |            |           |                |            |           |        |                |            |           |        |                |            |           |        |
| 3483 | 6              | 39         | 36        | 0              | 17         | 12        | 6              | 56         | 48        | 110    |                |            |           |                |            |           |        |                |            |           |        |                |            |           |        |
| 3474 | 12             | 45         | 61        | 1              | 14         | 10        | 13             | 59         | 71        | 143    |                |            |           |                |            |           |        |                |            |           |        |                |            |           |        |
| subtotals | 21      | 215        | 229       | 2              | 85         | 38        | 23             | 300        | 267       | 590    |                |            |           |                |            |           |        |                |            |           |        |                |            |           |        |
| totals     | 465     |            |           | 125            |            |           | 590            |            |           |        |                |            |           |                |            |           |        |                |            |           |        |                |            |           |        |

Table 2. Number of participants in training activities by gender and country development status.
Staff and Long-Term Visitors

*Virtual Collaborations

Research Staff Associate
Alexander Nersesyan

Boltzmann Fellows And Long-Term Visiting Fellow Scientists
Alejandro Rodriguez Garcia
Natasa Stojic

Scientific Collaborators
Giuseppe Mussardo
Mauro Sellitto
Alessandro Silva

Post-Doctoral Fellows
Adriano Angelone
Khatereh Azizi
Giuliano Chiriaco
Ricardo Franklin Mergarejo
Pierre Martin Fromholz
Sukanya Ghosh
Karen Hovhannisyan
Ana Laura Gramajo
Gonzalo Manzano Paule
Tiago Mendes Santos
Elham Moharramzadeh Goliaei
Uriel Nicolas Morzan
Victor Naden Robinson
Andrei Pavlov
Samare Rostami

Emeritus Scientists
Vladimir E. Kravtsov

Distinguished Staff Associate
*Boris Altshuler

Ph.D and Masters Students
Claudia Artiaco
Federico Balducci
Philip C. Cruz
Paola Delcompare Rodriguez
Youness Diouane
Edward Donkor
Giuliano Giudici
Eduardo Gonzalez Lazo
Ali Khosravi
Adu Ofrei-Danso
Rajat Panda
Silvia Pappalardi
Tomaso Parolini
Alex Pividori
Nishan Ranabhat
Anam Sara
Yusuf Shaidu
Federica Surace
Poetri Tarabunga
Mikheil Tsitsishvili
Xhek Turkeshi
Vittorio Vitale
Matteo Votto

Long-Term Visiting Scientists
Stefano Chesi
Wenbin He
Pengfei Liang
Elisabetta Paladino
Nawaz Qaisrani
Sayed Reza Safdari
Yingdan Wang

STEP Fellow
Reyhaneh Khasseh
Diploma Students

Diploma Students 2019/2020
Amel Alhassan
Ezron Cabrera
Cornelio Cap Lopez
Edward Donkor
Jesus Espinoza-Valverde
Poetry Tarabunga
Anne Nadine Tewonou Djota
Amar Thakuri
Mikheil Tsitishvili

Diploma Students 2020/2021
Julia Blandine Bassila
Joshua Carlo Casapao
Maha Hsouna
Pelluce Kabarokole
Lien Thi Le
Valerius Evan Ligasetiawan
Jonah Langson Nagura
Rolando Gabriel Ramirez Camasca
Puja Thapa

Regular Associates
*Alireza Akbari
Meher Kiran Ayulasomayajula
*Meher Ayulasomayajula
*Barnali Chakrabarti
Fernando Iemini De Rezende Aguaír
Arti Kashyap
Anokhi Jayaprakash
*Damiun Mei Duan
*Laleh Memarzadeh Esfahani
*Gebremedhn Hagoss Gabreyesus
*Seyed Akbar Jafari
*Meena D. Jeyapragasam
*Lucy Kiruri
*Brijesh Kumar
*Jorge Augusto Lasave
*Kavitha Louis
*Saptarshi Mandal
*Aikaterini Mandilara
*Aliezer Martinez Mesa
*Javier Antonio Montoya Martinez
*Ali Naji
*Thanh Thi Kim Nguyen
*Viet Huy Nguyen
*Carlos C. Pinilla Castellanos
*Taegeun Song
*Seyed Mehdi Vaez Allaei
*Ines Paula Villar

Simons Associates
*Liliana Del Carmen Arrachea Tor Jun-ior Alberto Res Riera
*Luis Eduardo F. Fao Torres
*Ali Ghorban Zadeh Moghaddam
*Yasir Iqbal
*Vahid Karimipour
*Arti Kashyap
*Fernando C. Lombardo
*Adel Mellit
*Juan Pablo Paz
*Ghosh Prasenjit
*Alexandre Rocha Reily
*Junior Alberto Torres Riera
*Etienne Wamba

Senior Associates
*Narayan Prasad Adhikari
*Reza Asgari
*Daniel Carlos Cabra
*Alain Moise Dikande
*Daniel Dominguez
*Amit Dutta
*Hala Elkhodzondar
*Karen Astrid Hallberg
*Yassine Hassouni
*Sumathi Rao
*Yuriy Rubo
*Pragya Shukla

Junior Associates
*Mohsen Amini Abchuyeh
*Salomao David Cumbula
*Abderrahim El Allati
*Kwang Hyok Jong
*Long Dinh Dang
*Ayman Khalil Farhat
*Jiasen Jin
*Ashwin Joy
*Yedilfana Setarge Mekonnen
*Darwin Barayang Putungan
*Pei Wang

Short Term Visitors
(Speakers who have given virtual semi-nars remotely are not listed below.)
Moulay-Badr Attaiaa
Tommaso Calarco
Horacio Pastawski
Neda Rafaelhosseini
Francesco Sciortino
Michael Sonner
Massimiliano Stengel
Carlo Vanoni
In addition to the ICTP support, the members of the section have attracted additional funding through:

- ERC Grants (MODAPHYFRIST and AGEnTh),
- EU Grants (SoFiA, PASQUANS),
- Google Quantum Award,
- Elettra,
- Italian Minister of Education (QUANTRA and FARE),
- HU Howard University,
- CINEAC and CSRC grants for computer time.

Furthermore, several grants and contributions were received by CMSP members to support smr activities and conferences.
Condensed Matter & Statistical Physics
Sustainable Energy

It is one of the key challenges of our times to provide cheap and abundant energy to society while respecting the need to curb emissions of greenhouse gases. One key element to address this challenge is the discovery of new materials which can facilitate the conversion and storage of energy.

The role of ICTP’s initiative on sustainable energy is to act as a facilitator for scientists from all over the world to collaborate on this important topic and to apply state-of-the-art scientific methodologies to energy-materials related problems.

This goal is achieved by organizing schools, workshops, and tutorials in this general area, by training young scientists and by providing scientific tools, such as software libraries.

The year 2020 was characterized by the coronavirus pandemic, which has precluded any possibility to hold most of our usual in-person activities. Instead, we focussed on online activities and reaching out via internet-based events. One important leg of these activities is the collaboration with ICTP’s partner institute in Rwanda, EAIFR, where considerable research in computational materials science is taking place.

Professional Staff
Ralph Gebauer
Nicola Seriani

Post-doctoral Fellows
Samare Rostami
Nandhakumar Velankanni
The research of the initiative on renewable energy is focused on computational materials science. In the following, we will give a short overview of some of the topics currently treated.

Given the ever-increasing atmospheric CO\(_2\) level, reducing CO\(_2\) emissions and capturing CO\(_2\) to convert it into other useful chemicals is an immediate need. Among different methods available for reducing CO\(_2\) to hydrocarbons, electrochemical methods are particularly attractive because they are easy to set up and suitable for medium-scale production. Several catalysts have been reported to carry out these reactions, of which Cu-based alloys are interesting due to high end-product selectivity. In this project we use DFT calculations to calculate energetics and kinetics of various catalytic reactions leading to CO\(_2\) reduction.

![Figure 1. Selective C1 product formation over C2 production during electrochemical CO\(_2\) reduction on a PdCu(110) surface.](image)

Via a neural-network potential through charge equilibration technique and investigating different properties of these materials from small clusters to large systems for interfaces.

Assigning effective atomic charges that properly reproduce the electrostatic fields of molecules is a crucial step in the construction of accurate interatomic potentials. In this work, we try to develop a new approach based on the idea of the charge equilibration process, to reproduce the evolution of atomic charge in presence of other atoms in different positions.

Hematite is a promising material to use as a photoanode in photoelectrochemical cells for solar water splitting, due to its long-term stability in alkaline solutions, its abundance, and its visible light absorption capabilities. Doping hematite with Ti can enhance the photoelectrochemical activity of this material. In a study on the photoelectrochemical behaviour of a planar thick Ti-doped hematite film under illumination, it was observed that some photogenerated holes are able to traverse at a long distance across the hematite film. Our purpose is to understand the process of this phenomenon by means of DFT calculations.

![Figure 2. Using neural networks to unravel the atomic structure in TiO\(_2\) – ZrO\(_2\) systems.](image)
Crystal structure prediction for Lithium-chloride via a neural network potential through the charge equilibration technique

In this study, through a structural search using the minima hopping method together with an artificial neural network potential, we find several novel lithium-chloride polymorphs.

Figure 3. Adsorption geometries of reaction intermediates for the Oxygen Evolution Reaction (OER) cycle on a pristine MoS$_2$ layer.

### Activities & Events

**Computational School on Electronic Excitations in Novel Materials Using the Yambo Code**

Organizers: Daniele Varsano (CNR-NANO)  
Maurizia Palumbo (University of Rome Tor Vergata)  
Alejandro Molina-Sánchez (IIINL)  
Conor David Hogan (CNR-ISM)  
Davide Sangalli (CNR-ISM)  
Ralph Gebauer (ICTP)

Local Organiser: Ivan Giroto  
Cosponsor: MAX EU Centre of Excellence, Psi-k

**Online Workshop on Excited Charge Dynamics in Semiconductors**

Workshop to discuss recent progress in the investigation of dynamics of excited charges in semiconductors. Topics include: electron transport, ultrafast dynamics, light-matter interactions, polaron formation and dynamics, exciton dynamics and dissociation, excited-state relaxation, time-dependent density functional theory, many-body perturbation theory.

Organizers: Ralph Gebauer  
Nicola Seriani

### Table 2. Number of participants in training activities by gender and country development status.

<table>
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Research

Activities

Electrostatic Control of Magnetic Transitions in Bilayer Chromium Triiodide

Electronic Properties of Rotational Phases of Graphene on Ferromagnetic Metal Surfaces

Condensed Matter & Statistical Physics
Synchrotron Radiation Related Theory

The aim of the group is to perform theoretical research and training in areas of condensed matter and applied physics that are experimentally investigated by synchrotron radiation (SR). There is close collaboration with experimentalists at the nearby SR source Elettra and at other similar facilities.

Within the relatively large scope of problems that fall under this description, the group has two main focuses of activities. The first field of activities is the investigation of electronic, magnetic, and structural properties of systems with strong electron correlations, including transition-metal oxides and related materials. The second main area of interest is the physics of low-dimensional systems and nanostructures.

Control of magnetism by electrical means has a great potential for low-power spintronic applications, and the newly discovered two-dimensional (2D) van-der-Waals magnetic materials are promising systems for this type of applications. Ab-initio computational studies have been carried out in the group to identify approaches and mechanisms to induce and control ferromagnetic transitions by non-magnetic means in the prototypical 2D van-der-Waals CrI3-bilayer antiferromagnet. In particular, a combination of perpendicular strain on the bilayer and electrostatic doping was shown to open the possibility of controlling magnetism by hole doping and also conveniently lowering the spin-flip field for potential switching applications. More generally, the study clarified the factors that may be used to induce or inhibit the presence of a magnetic transition upon electrostatic doping in the 2D layered-AFM insulators.

Graphene interfaces with ferromagnets are highly relevant for spintronics and the graphene/Co(0001) interface is particularly interesting given the recent observation of “mini-cone” of single-spin Dirac fermions at the epitaxially-aligned graphene/Co(0001) interface. However, growth of a homogeneous phase of epitaxially-aligned graphene at large scale on cobalt thin films presents great challenges and most often leads to the creation of rotational graphene phases. Research has been carried out in collaboration with scientists of the VUV and Nanospectroscopy beamlines at Elettra to investigate the properties of the graphene rotational phases. This joint study demonstrated the existence of highly spin-polarized mini-cone states near the Fermi energy also in rotational phases of graphene on Co(0001). The work opens new possibilities for the inclusion of graphene/Co(0001) interfaces in future spintronics applications.
Magnetism of Carbon Coated Ultrathin Cobalt Layers

Research has been carried out in collaboration with scientists of the Nanospectroscopy beamline at Elettra, and within the CERIC-ERIC project, to investigate how different carbon overlayers influence the spin-reorientation transitions of ultrathin Co films. The study showed a dramatic change in the magnetic anisotropy of the Co ultrathin films with the type of carbon overlayers, including graphene, defective graphene, carbidic, C2H4 and CO overlayers. This in turn makes it possible to have a remarkably interesting lateral manipulation of the magnetic anisotropy through ad-layer nano-patterns obtained with different molecules and via photon-lithography.

Training Activities

Coordination of the ICTP-Elettra users programme and of the ICTP-IAEA sandwich training and educational programme (N. Binggeli)

Participation in teaching the ICTP Diploma programme in condensed matter physics (N. Stojic, S. Ghosh, N. Binggeli)

Staff and Long-Term Visitors

Professional Staff
N. Binggeli, Switzerland

Long-term visiting fellow scientist
N. Stojic, Croatia

Post-doctoral Fellow
S. Ghosh, India
The activity of the Mathematics Section in 2020 has been completely influenced by the outbreak of the Covid19 pandemic at the beginning of the year. All planned scientific visits and the whole programme of Schools and Conferences had to be put on hold to comply with safety rules.

The first few months of the year were characterized by the need to guarantee the safety of all people present in Trieste under our responsibility (Faculty members, Staff, Postdocs, Students and others) and to redefine tele-working working methods, including providing everybody with the necessary technological tools.

Thanks to this effort we could guarantee a safe and successful second semester for the 2019-20 Diploma Programme students as well as the recruitment and first semester for the 2020-21 class, with almost all students physically present in Trieste. We are happy to report that many of our 2019-20 Diploma graduates managed - with our assistance - to get accepted in first class Graduate schools worldwide (e.g. SISSA, Padova, Edinburgh, Ecole Normal Lyon, Montreal).

The Math Section is now composed of 6 permanent Faculty members (one of which shared with the High-Energy Section) and a Distinguished Staff Associate (Prof. Zagier). Our postdoc group, made of 5 young mathematicians per academic year (2 of which female), has become very present in the scientific planning of our activities. For example, two bi-weekly (with few stops during the highest peaks of the pandemic) "working groups", one on Algebraic Geometry and the other in Kahler Geometry, have been organized by A. Rincon and Z. Sjostrom, in collaboration with postdocs and PhD students from SISSA and the University of Trieste.
Online weekly seminars were organized by Fernando Rodriguez Villegas, with several of the ICTP associates and visitors who could not come to the Centre in person because of COVID. Since the research interests of the attendees (around 14 total, see below) were quite various, we settled on an interesting middle ground on Elliptic Surfaces as well as a general description of available computational tools. The seminars ran in an informal atmosphere and were felt to be productive for all involved.

The group consisted of:
- C. Araujo (Simons associate, Brazil)
- C. Salgado (Simons associate, Brazil)
- A. Pacetti (associate, Argentina)
- G. Tornaria (visitor, Uruguay)
- I. Nonkane (visitor, Burkina Faso)
- A. Dickenstein (Simons associate, Argentina)
- J.-L. Cisneros (associate, Mexico)
- M. Chara (visitor, Argentina)
- A. El-Guindy (associate, Egypt)
- T. Ezome (associate, Gabon)
- M. Mereb (associate, Argentina)
- L. Vendramin (associate, Argentina)
- A. Solotar (associate, Argentina)

During 2020, the Math Section organized various high-level online events which attracted hundreds of online participants and are now available on the Math Section Youtube Channel. Most notably, three Math Colloquia were given by:

- Alessio Figalli (ETH Zurich, 2018 Fields Medallist) during the ESOF Meeting.
- Nigel Hitchin (Oxford, FRS) on the occasion of the Spirit of Salam Prize to M.S. Narasimhan.
- Caucher Birkar (Cambridge, FRS, 2018 Fields Medallist) on the occasion of the Ramanujan Prize.

A new series of online seminars ("Math Associates Seminar") has been created to keep our community of Associates in touch and to create a virtual space for important mathematical discussions. Our usual thematic and divulgative seminars (such as the Basic Notions Seminar) have continued regularly online.

Important discussions for the creation of joint programmes which could greatly improve our outreach have moved forward and we expect to conclude the agreements within 2021. In particular:

- Ongoing discussion with various representatives of the Italian Government to promote ICTP towards the internationalization of the Italian university/research system.
- Cooperation agreement with a network of Chinese Scientific Institutions, including the Chinese Academy of Sciences, Beijing University and Hefei’s USTC, to co-fund an "International Chair" (as for the new ICTP Strategic plan), and welcome Postdocs and Visitors from China.
- Creation with CIMPA (UNESCO Cat II Institute) and the European Math Society of a European Research in Pairs programme, modelled on the existing experience of ICTP’s TRIL and ICTP-Indam Programmes with Italy.

The finalization of these agreements and the launch of these programmes will radically change and improve ICTP’s outreach impact.

An extremely important event for ICTP’s outreach mission has been the opening in October 2018 of the new EAIFR Institute in Kigali, Rwanda. Arezzo and Villegas have been collaborating
with the various local scientific entities and the external organizations operating in the region such as SIDA and EAUMP, to plan Math activities in the new Institute. These activities should lead to the opening of a formal programme and to the appointment of permanent Faculty in Mathematics in the future. Villegas is coordinating all such activities.

An important outreach programme that was developed in 2020 is the International Mathematics Master in Lahore, Pakistan, coordinated by Prof. Luzzatto at an ICTP Affiliated Center. Various Master-level courses have been given by members of the Math Section. This project has the goal to create high-level Master courses in selected places in developing countries and to assist students scientifically and in building their career. This pilot programme has been approved for 3 years and will be reviewed in 2022.

We continue to administer the selection and award of the Ramanujan Prize for a mathematician under the age of 45 from a developing country through an agreement with IMU and DST from India. The 2020 recipient of the prize is Prof. C. Araujo from IMPA (Br).

Finally, we should point out that the section has the great fortune to have the wonderful secretaries Mabilo Koutou (full time) and Margherita Di Giovannantonio (part time), without whom we would not have been able to achieve any of the above. The pandemic has forced our staff to change dramatically the working procedures, from in-person to teleworking modality, and to take care - under much more delicate circumstances - of the safety of the people working in or connected to the Math Section.

Staff

*Virtual Collaborations

Professional Staff
Section Head:
Claudio Arezzo
Emanuel Carneiro
Lothar Göttsche
Stefano Luzzatto
Pavel Putrov
Fernando Rodriguez Villegas

Distinguished Staff Associate
*Don B. Zagier

Scientific Consultants
Giovanni Bellettini
Francesco Pappalardi

Postdoctoral Fellows
Tarig Abdelgadir

ICTP/ISSA Joint Phd Programme
Asem Abdelraouf
Andrea Grigoletto
Mubarak Muhammad
Blessing Bisola Oni
Hamza Ounesli
Song Ji RI
Samreen Samreena

STEP Fellows
*Cristian Andres Gonzalez Riquelme
*Oscar Emilio Quesada Herrera
Math Lecture Series on "Dynamics of the Geodesic Flow on Surfaces without Conjugate Points" by Khadim War (IMPA)

★ Lecture 1: Geometry of surfaces without conjugate points.
★ Lecture 2: Measure of maximal entropy via Patterson-Sullivan measures.
★ Lecture 3: Some statistical properties of the geodesic flow.
★ Lectures 4 and 5: Counting the closed geodesics.

Basic Notions Seminars:
★ Phase transitions: from physics to computer science, by Jean Barbier
★ On mean Curvature Flow of closed Hypersurfaces, by Giovanni Bellettini
★ On Tropical Geometry, by Lothar Göttsche

Furthermore, the Math section organized:
★ 17 Online Math Seminars
★ 4 Onsite Math Seminars
★ 15 Online Math Associates Seminars
★ 4 ICTP/SISSA Algebraic Geometry Seminars
★ ICTP/SISSA Kahler Geometry Seminar
★ Online Working Group on Elliptic Surfaces and Computation

ICTP MATH Colloquia
"Generalizations of Teichmüller space" by Nigel Hitchin (University of Oxford, UK), on the occasion of the presentation of the Spirit of Salam Award to M.S. Narasimhan.

"Algebraic Geometry and Beyond" by Caucher Birkar (University of Cambridge, UK), on the occasion of the presentation of the 2020 Ramanujan Prize Award to C. Araujo.

ICTP HECAP & MATH Colloquium
"Hidden Algebraic Structures in Topology and Quantum Field Theory" by Sergei Gukov (California Institute of Technology, USA)

Joint ICTP/SISSA MATH Colloquium
"Generic regularity in obstacle problems" by Alessio Figalli (ETH Zurich)
Earth System Physics

The ESP section conducts research and organizes educational and outreach activities in fluid (atmosphere and ocean) and solid Earth Sciences. The section’s main research lines are: Anthropogenic Climate Change (ACC), Natural Climate Variability and Predictability (NCVP), Climate Impacts (CI), Aerosols, Atmospheric Chemistry and Climate (AACC), Oceanography (OCE) and Solid Earth Geophysics (SEG). The ESP section currently includes 7 research staff members: F. Giorgi, F. Kucharski, K. Aoudia, A. Tompkins, E. Coppola, and R. Farneti; one software engineer (PA, G. Giuliani); one consultant (C. Solidoro from OGS); three staff associates (J. Shukla, I.-S. Kang and F. Molteni); and additional 25-30 members on term contracts (post-doctoral fellows and long-term scientific visitors). Andrea Pozzer became staff member in September 2019, but decided to leave the ICTP in November 2020, leaving again the area of atmospheric chemistry and chemistry-climate interactions without a staff scientist as lead.

The year 2020 was challenging because of the consequences of the COVID-19 pandemic. Many educational activities were cancelled or carried out remotely, and participation in international conferences was severely limited. On the other hand, this allowed scientists in the section to concentrate more on research (also carried out remotely), which resulted in the highest scientific productivity ever, as measured by the number and quality of publications.

As in previous years, external funding is an important component of the ESP budget, with grants from ENEL, the European Union (EUCP and a Marie Curie fellowship for Susanna Strada), GENERALI and KAU. During 2021 the project EUCP will come to an end, but the new European project XAIDA will start. The grant from ENEL ended in 2020 as well, but negotiations are under way for a renewal starting in 2021. Susanne Henningsen provides administrative support to the section concerning external grants.
The ESP section research lines can be briefly described as follows:

The ACC research line aims at improving the understanding of anthropogenic climate change. The section investigates the global and regional climate response to increased atmospheric greenhouse gas concentrations and the effects of land use modifications. These issues are addressed using a range of modeling tools, the central one being the regional climate modeling system RegCM (currently version RegCM4), which has been developed for over a decade and is maintained for community use. The ESP section also coordinates the Regional Climate Research NETwork, or RegCNET, a network of scientists mostly from developing countries involved in regional climate research, which includes more than 800 participants.

The NCVP research line focuses on natural climate variability and predictability at temporal scales from intra-seasonal/seasonal to multi-year/multi-decadal. Particular attention is devoted to tropical variability phenomena, such as the El-Niño Southern Oscillation (ENSO), the Madden-Julian Oscillation (MJO) and the monsoon systems, and how they interact with extratropical variability and flow regimes (e.g. the North Atlantic Oscillation, or NAO). To study climate variability and predictability, the section uses a range of modeling and observational tools and products (e.g. the SPEEDY intermediate complexity global model and ECHAM5 global climate model). Activities in this area also focus on physical process studies, such as for clouds and tropical convection.

The CI research line investigates the effects of climate variability and anthropogenic climate change on human activities and natural ecosystems. In particular, a focus is on human health, agricultural productivity, water resources and forest response. The issue of climate impacts is addressed via the use of different impact models: the hydrological model CHYM, the crop model GLAM, the malaria model VECTRI and the forest model FOREST-SAGE. These impact models take as input climate information and can be used for a wide variety of applications and regional settings, from studies of disease outbursts to the investigation of the hydrological effects of long-term climate change. They are also made available for use by the outside scientific community.

The AACC research line investigates the interactions between atmospheric chemistry/aerosols, air quality and climate, including pollutants of both anthropogenic and natural sources. This is accomplished through the development and use of coupled climate/aerosol/chemistry models, with particular emphasis on the regional scale. This research line also aims at a better understanding of the Earth’s biogeochemical cycles and how they are affected by, and influence, global and regional environmental changes.

The OCE research line is devoted to understanding the role played by the ocean in the mechanisms behind natural variability and predictability of the climate system at interannual, decadal and centennial time scales, and how this might change under future climate conditions. To carry out its research, OCE uses theory, a hierarchy of physical ocean models at both global
and regional scales, along with their coupling with global and regional atmospheric models. Research interests span a wide range of topics from the low frequency variability of the global meridional overturning circulation to the energy transport in the climate system, tropical-extratropical interactions, and regional ocean studies. In collaboration with C. Solidoro of OGS (consultant), this line of research includes marine biogeochemistry modeling.

The SEG research line investigates the way earthquake faults develop in time and how the Earth’s interior deforms. It relies on geophysical methods blending space geodesy, seismology and tectonics, tied through realistic physical numerical modeling using High Performance Computing. This contributes to the physical understanding of the length and time scales of active deformation processes and to a more realistic assessment of earthquake hazards. Specifically, topics addressed in the section include: mechanics of earthquakes and faulting; structure and rheology of the lithosphere in active earthquake and volcanic regions; physics of transient deformation; active tectonics and earthquake hazard.

During 2020, the non-hydrostatic version of the RegCM4 model (RegCM4-NH) was further tested and utilized at convection-permitting resolutions in different domains and projects. This version, which is described in Coppola et al. (Submitted), is now fully operational and released for community use.

Most of the model development work, however, focused on the next version - RegCM5 - based on the implementation in the RegCM system of the more efficient and accurate dynamical core from the Italian weather prediction model MOLOCH. Extensive testing of this new version of the model was carried out and is currently ongoing. The use of the model at high, convection-permitting, resolutions appears to function well and without evident numerical problems. However, the use of the model at coarser resolutions, where convection schemes need to be used, still presents some problems of stability and mass conservation. Further testing is thus required and the release of the model for community use will likely occur in late 2021 or 2022.

In terms of model applications, the RegCM4 system is being used in several international projects. As part of the CORDEX-CORE initiative, a set of 21st century climate projections at 25 km resolution over 9 domains covering most land areas of the world and two scenarios was completed in collaboration with institutes in the USA, China, India, Africa, South-east Asia, South America, and Central America. This was a major effort completed only by two regional model communities worldwide. During 2020 the main activity within this program was to finalize a series of 14 papers belonging to a special issue of the Climate Dynamics journal and presenting a first order analysis of several aspects of the CORDEX-CORE simulations, including: tropical and extratropical storms; ENSO signal; thunderstorm environments; low level jets; changes in mean and extreme temperature and precipitation indices and hazard indicators; changes in variables important for renewable energy production. An example of output from the CORDEX-CORE effort is shown in Figure A1.
Another major program in which the hydrostatic version of the model was used in 2020 is the COPERNICUS EU program, for which we are completing a set of 8 scenario simulations for Europe at 12 km grid spacing, to be added to a large ensemble produced by different European groups. All the simulations should be completed by mid-2021.

The third major area of model application is convection-permitting modeling (few km resolution). ESP has a leading role in a CORDEX Flagship Pilot Study on high resolution modeling over the greater Alpine region (Coppola) and the EU project EUCP (Giorgi). The model is applied over multiple domains, both within continental Europe and in overseas territories. Most simulations planned under these projects have been completed and ESP is also taking the lead in the first analysis of the results, as shown in the example in Fig A2.

The use of the model in these projects is extremely intensive from the computational point of view, both in terms of computing time and data storage. So far, the supercomputing centre CINECA has provided the necessary computational resources via some special agreements with the ICTP, however a long-term sustainable strategy needs to be developed within the envisioned creation of a computing consortium led by ICTP.
The main research and development activity in 2020 was related to the investigation of the impact of intra-basin climate interactions on ENSO teleconnections. Particular focus in this research was on the role of the Indian Ocean in mediating ENSO teleconnections in winter to the South Asian and European region. Using re-analysis data and idealized simulations with the ICTP General Circulation Model (ICTPGCM), Abid et al. (2020) showed that heating anomalies in the Indian Ocean, that co-vary with ENSO SST anomalies, are an important factor to mediate ENSO teleconnections to the South Asian winter monsoon. These heating anomalies are strongest in early winter and therefore dominate over the direct ENSO teleconnection in December and January. This has important consequences for the predictability of South Asian winter precipitation as it crucially depends on much less predictable (compared to ENSO SST anomalies) heating anomalies in the Indian Ocean. Indeed the Indian Ocean teleconnection (as measured by the Tropical West East Indian Ocean index) with the Central Southwest Asian (CSWA) precipitation is stable even after removing the ENSO impact, whereas the ENSO impact changes sign if the Indian Ocean heating anomalies are removed from ENSO statistically (Fig. B1).

For the purpose of investigating the role of Indian Ocean heating anomalies in the ENSO teleconnection, the ICTPGCM has been further developed to include a term in the thermodynamic equations that can be used to add diabatic heating anomalies that mimic an ENSO response. This version of the model has been tested and large ensemble simulations have been performed using ENSO-induced heating anomalies in the Indian Ocean. The results have been used in the research studies discussed here.

The seasonal transition of the ENSO response in the Euro-Atlantic region has been also further investigated (Abid et al., 2020, in press). Joshi et al., 2020). It was found that in response to a warm ENSO event in early winter, a positive NAO-like response prevails, whereas in late winter a negative NAO-like response becomes dominant. The opposite is true for a cold ENSO event. Trans-basin teleconnections turned out to be relevant in this case as well. Again, the aforementioned heating dipole teleconnected to ENSO was found to be the crucial factor in this transition (Fig. B2). This observational result has been confirmed in ECMWF system 5 re-forecasts, CMIP5 simulations and idealized ICTP GCM simulations.

Figure B1: Correlations between the standardized CSWA, Niño3.4, and Tropical West East Indian Ocean (TWEIO) precipitation indices, (b) same as of (a) but with linearly independent Niño3.4 and TWEIO indices. (From Abid et al., 2020).

Figure B2: Schematic of early versus late winter teleconnections. (From Abid et al. 2020, in press).
One of the ICTP publication highlights of 2020 in the area of tropical climate feedbacks was an article in AGU advances co-authored by A. Tompkins with Sandrine Bony (Bony et al. 2020), which shows how the top-of-the-atmosphere radiative budget balance can be explained by variations in the low level, estimated inversion strength (EIS), which determines the prevalence of low cloud (which increases the albedo - a measure of how much sunlight is reflected back to space), and a parameter that measures the degree of organization (clustering) of tropical deep convection (Iorg) [see figure B3]. The Iorg parameter was introduced by ICTP scientist A. Tompkins in a previous paper on AGU in 2017, and the clustering of convection that it describes controls the radiation budget through the impact on the water vapour budget, with clustered scenes being drier. This feedback, working in much the same way as the iris controls the light entering the eye, is negative, reducing climate sensitivity and could be missing at small scales in present generation climate models.

A collaboration between ICTP and the university of Thessaloniki in Greece led to a study on the future spread of malaria vectors in Greece. The study compares an ensemble of statistical niche models with a version of the ICTP dynamical malaria model calibrated for the local vector in Greece. The study showed that with careful calibration using independent lab data, the dynamical model could well reproduce the present-day distribution of vectors, and all was in good agreement with the statistical models trained on the field survey data (Figure C1). All models agreed in general on how the vector will spread to higher attitudes with climate change, although in the high end RCP8.5 scenario there was a conflict in the end-of-century estimates of population impacts, due to the fact that the statistical models push the vector into high density urban areas, which was not the case with the ICTP dynamical model. The paper thus highlighted the importance of focusing on the challenge of estimating climate impacts in urban environments in a warming world.
In 2020 the CORDEX-CORE regional model simulations were used as input to the CHyM hydrological model for 6 hydrological simulations for 2 different scenarios (RCP2.6 and RCP8.5) over 9 domains covering almost all the land areas of the world (Figure C2). An example showing the change of peak discharge corresponding to the 100 year return period for the RCP8.5 scenario over all domains analyzed is reported in Figure C2. This return period value is used in the literature as a proxy of flood hazard.

In 2020 the CORDEX-CORE regional model simulations were used as input to the CHyM hydrological model for 6 hydrological simulations for 2 different scenarios (RCP2.6 and RCP8.5) over 9 domains covering almost all the land areas of the world (Figure C2). An example showing the change of peak discharge corresponding to the 100 year return period for the RCP8.5 scenario over all domains analyzed is reported in Figure C2. This return period value is used in the literature as a proxy of flood hazard.
In the year 2020, the research focus was on the impact of air pollution within the context of the COVID-19 pandemic. Specifically we investigated how air pollution might influence mortality related to the COVID-19 virus. Using a blend of global atmospheric modelling and epidemiologic approaches, it was shown that air pollution has a significant impact on COVID-19 mortality, and this effect was quantified in the range of 5-35 % (Figure D1). In addition, the importance of fossil fuel alone was estimated, showing that reducing fossil fuel use could have a strong impact on COVID-19 mortality. This research was published in Pozzer et al. (2020).

Figure D1. Estimated percentages of COVID-19 mortality attributed to air pollution from all anthropogenic sources (top), and from fossil fuel use only (bottom). The regions with high attributable fractions coincide with high levels of air pollution. (From Pozzer et al. 2020)

OCE develops and maintains several ocean and ocean-atmosphere coupled models, participating in international collaborations and multi-model intercomparisons. The models are also used by associates, visitors and students on different projects.

We continued to develop and use an ICTP version of the global ocean climate model MOM, at both coarse and fine horizontal resolutions. The global ocean model was used extensively to explore mechanistic understandings of the ocean climate system, both as part of internationally coordinated activities and as independent research studies, often conducted together with students, postdocs and ICTP visiting scientists.

As an example, the ICTP global ocean model was used in the analysis of annual and seasonal mean characteristics of the Indian Ocean circulation and water masses, together with 16 global ocean–sea-ice models, as part of the Coordinated Ocean-ice Reference Experiments (CORE). In Rahaman et al., 2020, we uncovered a previously unidentified secondary pathway of northward cross-equatorial transport. This secondary pathway is most prominent in models that represent
topography realistically, thus suggesting a need for more realistic bathymetry in ocean climate models.

However, refinement in model horizontal resolution does not significantly improve simulations.

The group also participated in the continuing development of a regional coupled model based on the ICTP RegCM and the ocean model MITgcm. In Reale et al., 2020, we introduced a new version of the Earth System Regional Climate model RegCM-ES and evaluated its performances for the first time over the Mediterranean region. The novel aspect of this coupled system is the possibility to simulate the dynamics of the marine ecosystem through a biogeochemical model coupled online with the ocean circulation model. Overall, RegCM-ES has the potential to become a suitable tool for the analysis of the impacts of climate change on the ocean and marine biogeochemistry in the Mediterranean region and many other domains.

OCE has continued to work on several aspects of variability of the coupled ocean-atmosphere system at interannual, decadal and longer time scales, in collaboration with NCVP activities.

As part of a PhD thesis, Graffino et al. (2021) analyzed the low-frequency variability of Pacific Subtropical Cells (STCs) in CMIP5 and CMIP6 models as well as in reanalysis data sets. CMIP6 models showed little improvement compared to CMIP5 in simulating several key aspects of STC variability. Also, compared to models, ocean reanalyses better reproduce the link between interior mass transport convergence and tropical Pacific sea surface temperature anomalies. In terms of future projections, Pacific STCs are expected to experience opposed hemispheric changes in a warming climate, with the Southern Hemisphere cell strengthening its energy transport.

Observational records and climate model projections reveal a considerable decline in AMOC, as sustained warming due to increased greenhouse gas emissions is projected to weaken the AMOC, which in turn can lead to changes in the location of the inter-tropical convergence zone (ITCZ), oceanic and atmospheric large-scale circulation, tropical precipitation, and regional monsoons. Using proxy records, observations and CMIP6 simulations, Narayanasetti et al., 2020 investigated the changes in the AMOC and associated changes in the large-scale circulation and precipitation patterns over the South Asian monsoon region. The weakening of AMOC is associated with a reduction of northward oceanic heat transport and an enhanced northward atmospheric heat transport. Changes in AMOC lead to weakening of large-scale north–south temperature gradient and regional land-sea thermal gradient, which in turn weakens the regional Hadley circulation and monsoon circulation over the South Asian region. The suite of observational and numerical analysis provided a mechanistic hypothesis for the weakening of South Asian monsoon circulation, concomitant with a weakening of AMOC in a warming climate (Fig. E1).
There is large uncertainty in the future regional sea level change under anthropogenic climate change. Within the framework of the international project FAFMIP, the group has developed a new framework for studying sea-level and ocean heat uptake in ocean models. In the study of Todd et al., 2020, we presented and used a novel design of ocean general circulation model experiments to investigate the ocean’s response to surface buoyancy and momentum flux perturbations without atmosphere-ocean feedbacks, as part of the CMIP6-endorsed Flux-Anomaly-Forced Model Intercomparison Project (FAFMIP). Simulated dynamic sea level (DSL) and ocean heat content (OHC) change demonstrate considerable disagreement. In the North Atlantic, the disagreement in DSL and OHC change between models is mainly due to differences in the residual (resolved and eddy) circulation change, with a large spread in the Atlantic meridional overturning circulation weakening ranging 20 to 50% (Fig. E2). Besides the Atlantic Ocean, the Pacific plays a large role in present and future ocean heat uptake and redistribution as well. Navarro-Labastida and Farneti, 2021 tried to identify the different physical processes responsible for equatorial Pacific OHC change and quantified its different magnitudes by using similar FAFMIP numerical simulations.
Eastern boundary upwelling systems (EBUS) are regions located on the eastern boundaries of subtropical gyres and characterized by coastal upwelling. These regions occupy merely 0.1% of the global ocean volume but are characterized by profound fish productivity. A long-lasting problem in state-of-the-art climate models is the simulation of warmer than observed SST in the EBUS, and the bias is warmest in the southeastern tropical Atlantic (SETA) region, the home to the Benguela upwelling system. Farneti et al., 2021 evaluated the performance of the newly released phase 6 of the Coupled Model Intercomparison Project (CMIP6) in relation to its predecessor CMIP5 in the SETA region. Biases in the SETA region remain large across the CMIP models, with magnitudes greater than 4K in all seasons and only limited improvement in high-resolution models. Both ocean-atmosphere feedback and small-scale ocean mixing are responsible for the incorrect representation of some fundamental physical processes in the region, which would lead to biological misrepresentations in earth system models.

Marine ecosystem and biogeochemical cycles modeling (Solidoro)

In 2020, this activity focused on the analysis and modelling of oceanographic and ecological connectivity, and its relationships to conservation ecology (definition of connectance among patchy habitats and related meta-communities), management of sustainable fish exploitation (identification of stock subpopulation boundaries and of essential fish habitats), and pollutant dispersal. Research activities also addressed the topic of climate change and ocean acidification, also with reference to European policies and legislations, the characterization of waves of extreme events, and the impact of multiple pressures on biogeochemical dynamics Mediterranean Sea and its coastal area and lagoons. Some research has been devoted also to the reconstruction of long term dynamics of persistent pollutants through the industrial and post-industrialization phases.

We use a non-standard method for the detection of microseismicity at depth for augmenting the available catalogue. The enhanced seismicity distribution is coupled with the observable deformation on a geodetic network of continuous GPS to infer a better comprehension of the earthquake behaviour. The earthquake patterns in Central Apennines reveal a segmentation at depth along an almost flat base of seismogenic layer with alternating low and high seismicity rate segments. The deformation recorded at the surface seems to follow the seismicity variations at the base of seismogenic layers along the Apennine chain, also determining a possible seismic-aseismic mode. We suggest that aseismic deformation has a fundamental role in the tectonic loading and that seismicity, even if heterogeneously distributed, could represent a tracer of it. This conclusion is also supported by the evidence of a transient propagating from south to north during the 2016 Central Italy sequence.
We compiled a dataset of continuous recordings from the temporary and permanent seismic networks to compute the high-resolution 3D S-wave velocity model of the South-eastern Alps, the western part of the external Dinarides, and the Friuli and Venetian plains through ambient noise tomography. Part of the dataset is recorded by the SWATH-D temporary network and permanent networks in Italy, Austria, Slovenia and Croatia between October 2017 and July 2018. We computed 4050 vertical component cross-correlations to obtain the empirical Rayleigh wave Green's functions. The dataset is complemented by adopting 1804 high-quality correlograms from other studies. The fast-marching method for 2D surface wave tomography is applied to the phase velocity dispersion curves in the 2-30 s period band. The resulting local dispersion curves are inverted for 1D S-wave velocity profiles using the non-perturbational and perturbational inversion methods. We assembled the 1D S-wave velocity profiles into a pseudo-3D S-wave velocity model from the surface down to 60 km depth. A range of iso-velocities, representing the crystalline basement depth and the crustal thickness, are determined. We found the average depth over the 2.8-3.0 km/s and 4.1-4.3 km/s iso-velocity ranges to be reasonable representations of the crystalline basement and Moho depths. The basement depth map shows that the shallower crystalline basement beneath the Schio-Vicenza fault highlights the boundary between the deeper Venetian and Friuli plains to the east and the Po-plain to the west. The estimated Moho depth map displays a thickened crust along the boundary between the Friuli plain and the external Dinarides. It also reveals a N-S narrow corridor of crustal thinning, to the east of the junction of Giudicarie and Periadriatic lines, which was not reported by other seismic imaging studies. This corridor of shallower Moho is located beneath the surface outcrop of the Permian magmatic rocks and seems to be connected to the continuation of the Permian magmatism to the deep-seated crust. We compared the shallow crustal velocities and the hypocentral location of the earthquakes in the Southern foothills of the Alps. It revealed that the seismicity mainly occurs in the velocity band between ~3.1 and ~3.6 km/s.

In this work, we study the crust and the uppermost mantle structure beneath the Sicily Channel, by applying the ambient noise and earthquake tomography method. After computing cross-correlation of the continuous ambient noise signals and processing the earthquake data, we extracted 104 group velocity and 68 phase velocity dispersion curves corresponding to the fundamental mode of the Rayleigh waves. We computed the average velocity of those dispersion curves to obtain tomographic maps at periods ranging from 5 s to 40 s for the group velocities and from 10 s to 70 s for the phase velocities. We inverted group and phase speeds to get the shear-wave velocity structure from the surface down to 100 km depth with a lateral resolution of about 200 km. The resulting velocity models reveal a thin crust with a thickness value of 15 km beneath the southern part of the Tyrrenhian basin and a thickness value of 20 km beneath Mount Etna. The obtained thickness values are well correlated with the reported extension of the Tyrrenhian lithosphere due to the past subduction and rollback of the Ionian slab beneath the Calabrian Arc. The crustal thickness increases and reaches values between 28 and 30 km beneath the Tunisian coasts and Sicily Channel. The S-wave
models reveal also the presence of a high velocity body beneath the island of Sicily. This finding can be interpreted as the presence of the Ionian slab subducting beneath the Calabrian Arc. Another high velocity body is observed beneath the southern part of the Tyrrenhian basin, and it might be interpreted as the presence of fragments of the African continental lithosphere beneath the Tyrrenhian basin.

The crust-uppermost mantle structure in the Caribbean to depths of 160 km was obtained by ambient noise tomography and shear wave velocity inversion. Both group and phase dispersion curves between periods from 10 to 70 seconds were calculated from cross-correlation up to 4 years of continuous data. Perturbations in group and phase surfaces wave velocities within a resolution of 1x1 degrees show the relevant geotectonic units in the Caribbean plate. Plate boundaries, ocean basins, rises, rifts and microplates are well defined by shear wave velocity impedances. The 3D shear wave velocity inversion along profiles shows the thickening of the crust from the ocean to continental margins. We present a new Moho interface map with depths ranging from 11 km to 17 km at most parts of the sea and 25 to 45 km in the continental areas. Low velocities zones were found in the upper mantle indicating a highly laterally heterogeneous area.

The joint Bayesian inversion of group and phase velocity dispersions for periods 5 - 35 s extracted from the ambient noise tomography indicates a pronounced low shear (S)-wave velocity region in the lower crust and uppermost mantle affecting much of the Main Ethiopian Rift (MER), Afar and Ethiopian plateau. Both tomography maps and inversion results demonstrate relatively stronger low-velocity anomaly beneath the western plateau and MER than that in the Afar Depression neighbourhood. We also find high velocity features in the crust and uppermost mantle beneath Afar overlapped with major magmatic segments that may indicate the voluminous cooled magmatic and dike intrusions. Our Moho–depth map suggests the thin crust beneath the entire Afar Depression and thick crust beneath MER and central western plateau where the lowest S velocity is observed in all depth ranges which may be due to the underplating. The observed low S velocity spatial pattern in the Cenozoic Ethiopian Volcanic complex inferred
in this study resembles the Ethiopian flood basalt regime and the consistent low S velocity observed in the Tana basin marking the Afar plume head.

Figure F2. Vertical sections through the 3-D shear wave velocity model along the profiles shown in the map: TT’(Plateau - Afar) and KK’ (Afar). The velocity slice at 3.75 km/s used as an indicator for crustal thickness. The black solid lines are fault lines. The white line corresponds to the Moho depth. The horizontal lines are distance in km and the vertical lines are depth in km.

Activities & Events

Diploma Course in Earth System Physics (R. Farneti, coordinator)

Public Health and Water Resources - Adaptation to Climate Change in the Eastern Mediterranean

Organizers: Yara Dahdal (Nature Palestine Society, Palestine)
Robin Twite (Arav Institute for Environmental Studies, Israel)
Assaf Hochman (Tel Aviv University, Israel)
Local Organiser: Filippo Giorgi

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Table 4. Number of participants in training activities by gender and country development status.

International Projects and External Funding

 ICTP Generali Earthquake Hazard Programme, funded by Generali Group, 2015 – June 2020 (Aoudia)
 Climate Change and Resilience funded by ENEL Italia S.r.l, 2018 - 2020 (Gior- gi)
 European Climate Prediction System - EUCP, funded by the EU, 2017 - 2021 (Giorgi, Coppola)
 Unravelling the role of water stress in Mediterranean isoprene emissions to better project future regional climate-air quality interactions - IDIOM2 fund- ed by the EU, 2018 - 2021 (Strada, Giorgi)
Participation in International Programmes

- Intergovernmental Panel on Climate Change (IPCC) (Coppola)
- Mediterranean Experts on Climate and Environmental Change (MedECC) (Giorgi)
- Co-chair of International CLIVAR Southern Ocean Regional Panel (Farneti)
- International Collaborator of SOCCOM project, Princeton University (Farneti)
- CMIP6-endorsed FAFMIP project (Farneti)
- Coordinated regional climate Downscaling EXperiment (CORDEX) - WCRP (Giorgi, Coppola)
- International Union of Geophysics and Geodesy (Aoudia)
- Earthquakes Without Frontiers, UK's Natural Environment Research Council and Economic and Social Research Council (Aoudia)
- North African Group for Earthquake and Tsunami studies, naget.ictp.it (Aoudia)
- South Asia Earthquake Network, shake.ictp.it (Aoudia)
- Member of World Climate Research Programme's Working group on seasonal to interannual prediction (WGSIIP) (Tompkins)
- Member of Science Advisory Committee of West African based WASCAL competence centre (Tompkins)
- International collaborator of NERC DOCCOP project (2017-2022) (Tompkins)
- Member of CLIVAR Research Focus on Tropical Basin Interactions (Kucharski)

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Hari Ram Thapa
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PhD STEP Students
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Mahjoobeh Meskaranian
Sandeep Narayanasetti
Applied Physics Multidisciplinary Laboratory

Created in 1985 by Professors Abdus Salam and Nicola Cabibbo, the MLab is a Multidisciplinary Laboratory for research, training, and development of advanced scientific instrumentation, and is open to scientists from developing countries.

The main activities of the MLab are focused on the development of scientific instruments and methods based on modern technology for the frontiers of experimental particle physics and multidisciplinary experimental research. By working on advanced projects, the MLab gains precious experience and knowledge that can later be transferred to larger communities of researchers, engineers and teachers who can apply the acquired knowledge in a vast variety of fields.

An important role of the MLab is to organize hands-on schools and workshops. The training subjects are selected by taking into account not only its scientific relevance but also its potential socioeconomic impact for most developing countries. The knowledge obtained through experimental training strengthens the ability of scientists to propose and autonomously conduct research under the prevailing conditions in their home countries.

The MLab works with many international research institutions, including CERN, IAEA, INFN and Elettra Synchrotron Trieste, and regularly hosts visiting scientists, PhD students, and other collaborators.
Experimental particle physics and multidisciplinary experimental research frequently relies on scientific instrumentation with consistently increasing data collection capacities, with many channels operating at high working frequencies. This results in massive amounts of data: the MLab specializes in developing new instruments and methods based on modern technology to efficiently and effectively deal with this extreme data production rate. MLab research activity focused on the development of advanced scientific instrumentation for novel particle detectors and multidisciplinary experimental projects, including X-ray analytical instruments and techniques for cultural heritage and high channel count systems for electrophysiology.

**COMPASS Experiment at CERN**

MLab continues its participation in the COMPASS experiment at CERN. The scientific program of the experiment provides a wide spectrum of physics results related to hadronic structure.

MLab, in collaboration with INFN Trieste and the Technical University of Munich, is currently working in upgrading the data acquisition and processing system (DAQ) of the COMPASS spectrometer at CERN. In particular, the collaboration focuses on the development of a new generation of trigger-less data acquisition and real-time feature extraction architecture based on FPGA for the particle detectors of the "COMPASS Beyond 2020" experiment.

In 2020, the group designed and built three electronic boards for experimental studies of the electrical signals of the second electromagnetic calorimeter (ECAL2) of the COMPASS spectrometer. The first two boards (see Figs. 1 and 2) are hardware adapters to interface ECAL2 front-end electronics (MSADC) with standard FMC carrier platforms based on powerful SoC-FPGA devices to allow research and development of ad hoc hardware algorithms through experimentation with real data. The main purpose of these algorithms is the online feature extraction of pulses produced by the absorption of high-energy particles. The extracted information comprises amplitude and arrival time of detected pulses, as well as its low-latency and high-rate transmission to a new-generation high-level trigger processor for increased data acquisition with

Figure 1. Both sides of the small adapter board to interface a MSADC front-end card to any standard FMC carrier board
improved data selectivity according to specific requirements of different physics programs.

The third platform (see Fig. 3) is a large motherboard designed to host a 16-channels front-end CARD (MSADC) and a System-on-Module (SoM) based on a large SoC-FPGA (Xilinx UltraScale+ FPGAs family). The combination of these interacting boards constitutes the first prototype for a dedicated electromagnetic calorimeter for an experiment devoted to a high-precision proton charge radius measurement using muon-proton elastic scattering. This experiment is foreseen to take place at the COMPASS experimental area at CERN’s Prevesin site in 2021. These boards have been designed at the MLab in collaboration with INFN Trieste COMPASS group, and the cost of the production has been mainly covered by INFN COMPASS.

In order to develop and optimize new hardware algorithms for feature extraction, the group processed and analyzed a large amount of ECAL2 raw data. The numerical research focused on two aspects: (1) Modeling of ideal noiseless pulses and parameter extraction, and (2) Noise characterization in the time domain by means of the normalized autocorrelation function. The group has also studied inhomogeneity among the 3068 channels of the ECAL2. Some of the partial results have been presented at the COMPASS Front-End, Trigger and DAQ Workshop held at CERN from 2 to 5 March, 2020.

The project counts on the active involvement of the Ph.D. students Bruno Valinoti (Argentina) and Luis Guillermo García Ordoñez (Guatemala), and the TRIL fellow Werner Florian Samayoa (Guatemala). In the framework of this project, four scientific papers have been published in 2020.

Figure 2. Both sides of the improved large adapter board to interface an ECAL2 front-end card to any standard FMC carrier board.
Distributed network of HVPS with System-on-Chip control for Multi-Pattern Gaseous Detectors

MLab is involved in a research and development project on large area photon detection, using multi pattern gaseous photomultipliers (MPGD). In collaboration with INFN Trieste, this project aims at developing a distributed network of HV systems for Thick-GEM gaseous detectors of single UV photons. These systems, based on programmable SoC and fast analog to digital conversion, implement features such as automatic local control, dynamic adaptation, remote access and high performance data acquisition capabilities for monitoring picoampere currents at high voltage, and high time-resolution to study electrical discharges in real time.

The project foresees a network of several computational units connected through a time division multiplexed (TDM) communication protocol with master-slave modality. The master will be connected to a control computer with a graphical user interface for remote Ethernet access to the experimental area where the detectors are deployed. Each computational unit employs a high-voltage low-noise DC/DC converter and is coupled to a custom high resolution ammeter connected to a custom data acquisition card with 8-bit data resolution at 500 MHz sampling rate.

A computational unit prototype was partially tested at CERN where the system was able to provide high voltage to each stage of a MPGD (up to 2kV), measure low current variations (~10 pA) in the MPGD, and detect and time stamp high speed voltage transients with a resolution of about 2 ns. Fig. 5 shows the Thick-GEM detector setup for a beam test held at CERN.

System-on-Chip boards grant local intelligence, flexibility and high speed inter-connectivity. A custom interposer card provides high voltage decoupling for TDM networks. The custom hardware boards of the system were designed by MLab and INFN Trieste. During 2020, seven computational units were mounted (as shown in fig. 4) and partially tested with a TDM communication protocol among the units.

The project counts on the active involvement of Ph.D. student Luis Guillermo García Ordoñez (Guatemala) with the collaboration of the TRIL fellow Werner Florian Samayoa (Guatemala). In the framework of this project, four scientific papers have been published in 2020.
A replica of the system prototype was given on loan to the University of San Carlos, Guatemala, where it is being used as a data acquisition platform for high resolution time stamping in cosmic ray detection for the Latin American Giant Observatory (LAGO) project.

The increased popularity of investigations and exploits in the fields of neurological rehabilitation, human emotion recognition, and other relevant brain-computer interfaces demands the need for flexible electrophysiology data acquisition systems. Such systems often require to be multi-modal and multi-channel capable of acquiring and processing several different types of physiological signals simultaneously in real-time. Developments of modular and scalable electrophysiological data acquisition systems for experimental research enhance understanding and progress in the field.
Research

MLab continues its research and development activity for an advanced multichannel system for electrophysiological signals. This system is based on a modular architecture which exploits modern programmable systems-on-chip for high performance and low latency data processing. The main hardware components are a custom mezzanine data acquisition board (HiCCE-128) connected to a commercial FMC Standard Carrier based on a SoC-FPGA, and a host computer for remote operation and data storage. Two hardware prototype versions of the HiCCE-128 board were designed and produced in collaboration with Prof. M. Magnasco (Rockefeller University, NY, USA) and S. Abeytunge (Memorial Sloan Kettering Center for Cancer research, NY, USA).

The system comprises 128 independent channels capable of acquiring signal at 31.25 kHz, with 16 effective bits per channel with a measured noise level of about 3 μV. The reliability and feasibility of the implemented system have been confirmed through a series of tests and real-world applications.

The system was used to acquire different electrophysiological signals such as EEG alpha waves, EOG eye blinking, ECG and EMG. Fig. 6 shows the typical number of channels and sampling rates for acquisition of electrophysiological signals. Our HiCCE-128 allows a simultaneous and synchronous acquisition of all these channels with high time and amplitude signal resolutions. The implemented architecture enables end users to add various high-response electrophysiological signal processing techniques in the FPGA part of the system-on-chip device on each channel in parallel according to application specification.

During 2020, three new boards of the version 2 of HiCCE-128 have been produced by the MLab. The 2020 activities have been mainly carried out in collaboration with the STEP Ph.D. Students Kasun Sameera Mannatunga (Sri Lanka) and Charn Loong NG (Malaysia); and Profs. Sawal Hamid MD Ali and Mamun Bin Ibne Reaz from University of Kebangsaan, Malaysia. In the framework of this project, two scientific papers have been published in 2020.
Other research activities

In collaboration with the MLab associate Dr José Lipovetzky and Dr Martin Perez (Balseiro Institute, Argentina), an experimental research on X-ray spectroscopy and advanced imaging using low-cost CMOS Image Sensors and a Medipix detector was carried out. Experimental measurements were carried out at the MLab with emphasis on applications to radiation measurement and particle identification. In the framework of this collaboration, two scientific papers have been published in 2020 (see publications section).

In collaboration with the MLab associate Dr Luciana De Micco and Dr Maximiliano Antonelli (National University of Mar del Plata, Argentina), asynchronous automata networks have been implemented in FPGA for high-quality true-random number generation and Poissonian triggering applications. Ongoing theoretical studies aim at understanding the fundamental mechanisms of randomness and the conditions for possible chaotic regimes. For this purpose, mathematical models were proposed that are being investigated experimentally and through numerical simulations. Part of this work was prepared as a lab activity for the Hands-On Research in Complex System School (smr3472), scheduled to take place at ICTP during summer 2020 and later canceled due to the sanitary restrictions imposed in Italy in the same period.

X-Ray Imaging and Applied Science for Palaeontology, Archaeology and Culture Heritage

This project focuses on developing X-ray analytical instruments for the non-invasive characterization of cultural heritage materials and paleontological objects. The project is in collaboration with ELETTRA Sincrotrone Trieste, IAEA, the Regione Friuli Venezia Giulia, and the Centro Fermi in Rome.

The origin of the group is related to the EXACT (Elemental X-ray Analysis and Computed Tomography) project, funded by Regione Friuli Venezia Giulia (FVG) during 2010-2014. The aim of the project, a collaborative effort with Elettra Sincrotrone Trieste, was to build and operate a set of advanced X-ray analytical instruments for the non-invasive characterization of cultural heritage materials. The research activity on the application of advanced physical methods in the study of archaeological, paleontological, and artistic materials has continued with the financial support of the Centro Fermi (Rome) in the framework of a project entitled “Microtomography for Archaeology and Paleoanthropology” (2014-2016). The project is mainly based on the EXACT instruments, but also on other facilities that provide complementary capabilities to characterize microstructure, composition and age of the materials of interest. The project has been extended (2016-2019) with the name S.A.P.I.E.N.S (Scienze per l’Archeologia e la Paleoantropologia: Interpretare la Nostra Storia).

In addition, a research programme for the study of ancient landscapes through geophysical and remote sensing techniques has been developed in collaboration with the University of Trieste, the Soprintendenza Archeologica del FVG and
other Italian and foreign institutes. In particular, the ICTP group has coordinated a triennial collaborative agreement (2016-2018) involving the above mentioned institutions to develop advanced scientific technologies for the study, protection and enhancement of the archaeological heritage and ancient landscape of the FVG region. This also includes fieldwork campaigns in Italy and abroad, consisting of archaeological and geophysical surveys.

In 2020, the group was included in the Advanced Technology Lab for Cultural Heritage (ATLACH), a consortium including the Universities of Udine and Trieste, Elettra Sincrotrone Trieste and other institutions of the FVG region. The consortium funded the acquisition of a new X-ray tube and a computer for the MLab microCT system.

The group, which has become a centre of excellence for the application of applied science in cultural heritage, is involved in a large number of scientific collaborations and provides and facilitates the training of ICTP associates, scientists and students.

Scientific collaborations

- Elettra Sincrotrone Trieste (Italy): Joint research activity related to the application of microCT and other techniques to the study of archaeological, paleoanthropological and paleontological samples (since 2009).
- Università degli Studi di Siena, Dipartimento di Scienze Fisiche, della Terra e dell’Ambiente, U.R. Preistoria e Antropologia (Italy): Zooarchaeological applications of X-ray microCT such as study of dog domestication (since 2014).
- University of California, Irvine (US): Paleo-neurological studies, combining morphological analysis of microCT-derived virtual brains and ancient DNA sequencing (since 2014).
- Institut Català de Paleontologia Miquel Crusafont (Spain): Taxonomic and phylogenetic study of Spanish hominoids from the Middle and Upper Miocene through the analysis of the structural properties of dentognathic remains; structural characterization of fossils of different periods (since 2014).
- Soprintendenza Archeologia del FVG, Protezione Civile of FVG (Italy) and Department of Mathematics and Geosciences of Trieste University (Italy): Study of the archaeological landscape of FVG by means of LiDAR and other remote sensing techniques (since 2013).
- Nuclear Analysis and Radiography Department, MTA Centre for Energy Research (Budapest, Hungary) in the frame of the CHARISMA project (Cultural Heritage Advanced Research Infrastructures: Synergy for a Multidisciplinary Approach to Conservation/Restoration): Study of prehistoric stone artefacts and pottery by non-destructive Prompt Gamma Activation Analysis (PGAA) (since 2012).
- Exploration Geophysics Group of Trieste University (Italy): Geophysical investigation of archaeological sites of Trieste Province (since 2013).
- Department of Mathematics and Geosciences of Trieste University (Italy) and Institute of Archaeology of the Slovenian Academy of Science (Slovenia): Study of lithic Neolithic and Copper Age stone artifacts (since 2009).
- University of Rome “La Sapienza” and Soprintendenza per i Beni Archeologici del Lazio (Italy), Centre for Archaeological Science of the University of Wollongong (Australia) and GeoScience Southern Cross University, Australia: Study of the Ceprano (H. heidelbergensis) skull by X-ray microCT, OSL and U-Th dating (since 2011).
- Natural History Museum of Trieste and MUSE, Science Museum of Trento, Italy: MicroCT study of archaeological, paleoanthropological, and paleonto-
Research

logical remains (since 2010).

- Institute for Anthropological Research (Croatia): MicroCT scanning, and analyses of the human skeletal/dental remains for the purposes of the research project Reconstructing prehistoric (Neolithic to Bronze Age) lifestyles on the territory of Croatia – a multidisciplinary approach (since 2017).

- University of Bologna, Laboratory of Physical Anthropology and ancient DNA, Department of Cultural Heritage (Italy): MicroCT study of paleoanthropological samples (since 2017).

Training Activities

The MLab promotes training for research through research and hands-on activities. Advanced experimental setups based on novel particle detectors, modern electronics devices, and development boards; and X-ray equipment and instruments are available at MLAB for training and research. MLab also hosts and organizes regular training activities, aimed at reaching larger communities of researchers, engineers, and students, particularly those from developing countries.

Ph.D. Students under STEP programme

- Jerome Folla Kamdem (University of Yaounde, Cameroon), Ph.D. thesis: “Microelectronics for the Readout of Particle Detectors”.


PhD Students in collaboration with University of Trieste

- Luis Guillermo García Ordoñez (Guatemala), Ph.D. thesis: “High performance data acquisition and processing based on programmable SoC for multichannel particle detectors”.

- Bruno Valinoti (Argentina), Ph.D. thesis: “FPGA-based trigger-less data acquisition and real-time feature extraction for particle detectors”.


PhD Students in collaboration with University of Moratuwa, Sri Lanka


TRIL fellows

- Werner Florian Samayoa (Guatemala), Research Topic: “SoC-FPGA cluster architecture for supercomputing and scientific applications”.

Ph.D. students and TRIL fellows supervised by the MLAB personnel
A. Cicuttin and M.L. Crespo are members of the COMPASS Collaboration at CERN.

M.L. Crespo is also:

↗ Member of the Editorial Board of the Journal Electronics, a peer-reviewed, open access journal on the science of electronics and its applications (IF: 2.412).


↗ Member of the Selection Committee Advisory Board for the 2021 OWSD-Elsevier Foundation Awards for Early Career Women Scientists in the Developing World.

Hardware Loan Programme: ICTP-MLAB hardware platforms based on FPGA are given on loan to external collaborators through a simple written agreement for research and education purposes. Among the beneficiaries of this program there are teachers, researchers and students from Argentina, Bangladesh, Cameroon, Colombia, Costa Rica, Cuba, Guatemala, India, Malaysia, Mexico, Nigeria, Pakistan, Peru, Sri Lanka and Ukraine.

MLab Ph.D. students collaborated as volunteers for ICTP’s ESOF booth and in the event “World Science Café” at the Caffe’ Tommaseo on Saturday 5 September 2020.

Professional Staff
Maria Liz Crespo

Technical Staff
Andres Cicuttin

Scientific Consultants
Claudio Tuniz

STEP students
Jerome Folla Kamdem
*Charn Loong NG

Visiting Scientists
Federico Bernardini
Werner Florian Samayoa
Luís Guillermo García Ordoñez
Romina Molina
Bruno Valinoti
Giacomo Vinci

Administrative Staff
Federica Delconte, Italy

The Centro Studi e Ricerche “Enrico Fermi” (Rome) supports the X-ray research activities and in particular the salary of Dr. Federico Bernardini from 2017, within the framework of the project S.A.P.I.E.N.S devoted to the study of human past.

The project “AQUILEIA VIRTUAL ARCHEOLOGICAL TOUR IN ANCIENT ROME – Aquileia, la via verso est”, submitted to Regione FVG by Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) in collaboration with ICTP and Società Alpina delle Giulie, has been funded with about 30 000 euro. The project supports the salary of Dr. Giacomo Vinci.

University of Trieste, Department of Engineering:

↗ One Ph.D. fellowship for the period 2018-2021 (Luis Garcia Ordoñez)

↗ 50% Ph.D. fellowship for the period 2019-2022 (Bruno Valinoti)

↗ 50% Ph.D. fellowship for the period 2020-2023 (Werner Florian)
The group is mainly interested in the use of wireless Information and Communications Technologies (ICT) to support scientific institutions in developing countries. In particular, work has been done on Long Distance Wireless Links to improve internet connectivity for academic institutions, on the Internet of Things (IoT) for scientific instrumentation and on open-source tools to support research and academic networks in developing countries. The group’s researchers have been active in organizing and participating in training activities in the field and, given the COVID emergency, online.

In addition to research and training, group members have been involved in several outreach activities:

- They have organized the UNESCO Regional Consultation on Open Science for Western Europe and North America, July 23, virtually hosted by ICTP.
- They have organized the EuroDIG 2020, June 10-12, virtually hosted by ICTP with over 1200 participants and with keynote speeches from Vint Cerf, UNESCO’s ADG Shamila Nair-Bedouelle and Italian Minister for Technological Innovation and Digitalisation, Paola Pisano.

Most of the activities of the section are organized in collaboration with the International Telecommunication Union - Telecommunication Development Bureau (ITU-BDT). The ITU-BDT was established to help spread equitable, sustainable, and affordable access to information and communication technologies as a means of stimulating broader social and economic development. ICTP has been selected as “ITU Center of Excellence in IoT, Big Data and Statistics” and M. Zennaro, Section’s Coordinator, has been designated as Focal Point.
Our research focuses on reliable, affordable, and sustainable wireless solutions to help foster science in developing countries. We leverage unlicensed frequencies to provide broadband solutions such as TVWS and other novel data communications technologies to connect academic institutions, as well as narrowband alternatives to connect scientific devices based on IoT technology. Ongoing research includes:

This research direction focuses on finding solutions to the particular challenges of scientific IoT applications in developing countries, such as intermittent energy availability, low speed Internet connections, harsh environmental conditions and privacy issues for underrepresented communities. We focus on specific applications such as weather monitoring using IoT technology, which have a significant local impact while contributing to the improvement of global climate models. We design low-cost stations to monitor weather and environmental conditions. This will allow data collected from observations of dozens, or even hundreds of scientific institutions or educational organizations to be fully and seamlessly integrated. These devices complement the present high-cost sparse network methodology of collecting weather data on the ground. While such an array will have inferior measurement accuracy due to the low-cost nature, the high spatial density of the array is unique and will prove invaluable for research and operational applications.

It is widely recognized that in many regions of the developing world, poor Internet access in universities and research institutions is one of the causes of the scientific divide. We are researching the use of TVWS (TV white spaces) to improve connectivity options for academic institutions in developing countries. We developed open-source tools to measure the availability of TVWS frequencies and made pilot broadband installations in several countries.

With the growth of IoT deployments there are many reports of very long wireless links, well beyond the line of sight, which can be explained by anomalous tropospheric propagation. Disruptions on the temperature and humidity profiles in the troposphere on frequencies from about 50 MHz to 10000 MHz cause a change in the refraction index that can significantly change the propagation range. The main goal of the TROPPO platform is to examine radio trajectories from end-nodes to LoRaWAN gateways to understand if anomalous propagation has occurred. This citizen science paradigm approach can be extended to many other fields.
During 2020, the section participated or organized several training activities.

Applications of satellite based IoT networks

Satellite technology has an important role in driving the growth momentum behind the Internet of Things (IoT) and unlocking the promise of connected devices worldwide. Satellites serves as a key enabler for IoT applications across industries and across geographical borders. In this capacity building activity we cover technologies of GEO (geostationary) satellites in C-, Ku- and Ka-band, new LEO (low earth orbit) or HEO (highly elliptical orbit) constellations, as well as developments in nanosatellites. As controlling the cost per device is of essence for the success of IoT applications, we cover the sustainability issue of satellite-based IoT applications.

5G technologies for IoT

5G technologies address a variety of applications in many fields, but those related with IoT are of particular interest given the great number of devices that are being connected. There is no doubt that 5G will play a pivotal role, both in massive and in critical applications. This capacity building course aims to provide the audience with an understanding of the 5G aspects relevant to IoT. Participants will be exposed to the general aspects of wireless networking with the particular requirements of machine type communications and will then dive into specifics of LTE-M and NB-IoT. Practical examples of 5G technologies for IoT will be demonstrated.

Workshop para América Latina y el Caribe (WALC)

Contribuir a satisfacer las necesidades de capacitación de técnicos y profesionales de países de América Latina y del Caribe, en el área de las tecnologías de información y comunicación, con énfasis en los aspectos prácticos de las redes, la organización y administración de proyectos en TIC y en los desarrollos tecnológicos recientes en estos campos, continuando una tradición que comenzó en 1992.

Workshop on LPWAN Solutions for the Internet of Things

Organizers: Lourino Chemane (Mozambique Research and Education Network) Meoli Kashorda (Kenya Education Network, KENET) N. Mbonimpa (Research & Education Network for Uganda, RENU) Magreth Mushi (Tanzania Education and Research Network, TERNET) Julianne Sansa-Otim (Makerere University)

ICTP Scientific Contact: Marco Zennaro

Co-sponsors:
Internet Society, Makerere University
UbuntuNet Alliance For Research & Education Networking
Research and Education Network for Uganda
Kenya Education Network
The Mozambique Research and Education Network
Tanzania Education and Research Network
Network Startup Resource Center

Machine Learning for IoT Applications

Co-organized with the Kobe Institute of Computing this three day workshop provided applicable skills in Machine Learning in the development of IoT Applications. From MMQT communications protocol to software development to hands-on hardware application.
Participation in International Programmes

Members of the group have participated in several international activities:

- Invited lecture at Kobe Institute of Computing, Japan: IoT4D, July 30.
- Invited lecture at Sabanci University, Turkey: IoT in Academic Institutions in Developing Countries: Lessons learned, November 18.
- Invited talk at Engineering Resilient Systems (EReS) group at Linnaeus University: IoT4D, October 2.
- Invited talk at EuroBioHighTech 2020: IoT training in Developing Countries: lessons learned, September 3.

Staff and Long-Term Visitors

Professional Staff
Coordinator:
Marco Zennaro

Consultants
Ermanno Pietrosemoli
Marco Rainone

Visiting Scientists
Seid Salahadin
Moez Altayeb Alhag

Post-doctoral Fellows
Mary-Jane Sule

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Table 5. Number of participants in training activities by gender and country development status.
Our Team carries out research on the near-Earth plasma environment, with particular focus on ionospheric physics and ionospheric modelling. Studies have been carried out on the low latitude ionosphere, also using Global Navigation Satellite Systems (GNSS) derived data.

The researchers of the Team had also an active role in organizing and participating in training activities which, due to the COVID situation, have been held mainly online.

In addition to research and training, the members of the Ionospheric Radiopropagation Section have been involved in externally funded R&D projects.

Ionospheric Radiopropagation-related research activities include the development of 3D and time dependent global ionosphere electron density models. In collaboration with the colleagues of Graz University, Austria, our Team has developed the NeQuick 2, a model widely used internationally for scientific purposes. One of its main applications concerns the assessment of ionospheric effects on GNSS.

The research activities are also focused on the analysis of ionospheric data from different sources, especially GNSS-derived ground based, space-based and altimeter total electron content (TEC) data, for model validation and to study space weather effects (e.g. geomagnetic storms) in the ionosphere.

In addition, radio occultation (RO) techniques are applied to obtain ionospheric information from specific satellite signals. TEC and electron density profiles in the Earth’s ionosphere are obtained from GNSS signals acquired by low Earth orbit satellites. Furthermore, in relation to a project funded by the European Space Agency, a simulation study has been carried out to implement an inversion algorithm able to invert RO data between satellites orbiting around Mars.

The ICTP partnership with the Institute of Scientific Research of Boston College of the United States of America to promote training activities related to the ionosphere and its effects on satellite navigation in Africa and the consolidated support of the UN Office of Outer Space Affairs (UNOOSA) allowed to enhance the publications in the field of ionospheric research by African scientists working in Africa. It has to be noted that several publications of the Ionospheric Radi-
opropagation Group done during 2020, like in previous years, have been done in collaboration with researchers from different countries, especially from the developing world.

In 2020, the growing trend of years 2018-2019 related to the number of publications concerning the NeQuick model has been confirmed, also in relation to the establishment, in 2019, of a “NeQuick Working Group”.

**Training Activities**

5 - 6 October 2020
held virtually

smr 3479

African Workshop on GNSS and Space Weather

Organizers: Sharafat Gadimova (UNOOSA, International Committee on GNSS), Patricia Doherty (Boston College, USA)
Bruno Nava (ICTP)
Sandro Radicella (ICTP)

Local Organiser: A. Emran (CRASTE-LF, Morocco)

c- Sponsors:
African Regional Centre for Space Science and Technology Education (CRASTE-LF)
Boston College
International Committee on Global Navigation Satellite Systems

During 2020, members of the group have participated in the following international activities:


↗ Invited talk at: Leicester’s Planetary Webinar #3: “In-situ Radio Occultations between ExoMars TGO and Mars Express: a simulation study”, 12 Aug 2020


↗ “Mutual Occultation Experiment between the Trace Gas Orbiter and Mars Express” Project (under a European Space Agency contract; 40000 Eur).

↗ “Deep LIM” project (in the framework of a European Space Agency contract; 10000 Eur).

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**Funding**

**Staff and Long-Term Visitors**

*Virtual Collaborations*

**Professional Staff**
Bruno Nava
Yenca Olivia Migoya-Orue’

**Visiting Scientists**
Katy Alazo Cuartas

**Scientific Consultants**
Sandro Maria Radicella

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Table 6. Number of participants in training activities by gender and country development status.
The ICTP Fluid Dynamics Laboratory is a world-class research facility whose activities range from quantum to classical fluid flows and whose centrepiece is an apparatus utilizing helium gas near absolute zero. This apparatus is capable of producing extreme values of the control parameters characterizing controlled buoyancy-driven turbulence. Operating near the critical point of helium, it provides high-resolution data for fundamental studies of turbulent fluid dynamics.

From its position atop a rotating platform, ICTP’s turbulent convection experiment provides data applicable to large-scale natural phenomena like atmospheric and solar convection in a range of control parameters not possible elsewhere. Recent experiments have taken particular advantage of the possibility to apply more realistic boundary conditions, particularly the more two-dimensional aspect ratios characteristic of natural extended systems. Taking rotating convection to the limits has shown that the enhancement of convection with rotation at moderately high Rayleigh numbers obtained with conventional apparatus essentially vanishes at higher Ra and even changes sign. Since the range of parameters is not available to fully resolved numerical simulations, the experiment provides important input for guiding thinking about common turbulent flows in nature.
Research

Applied Physics
Anchor Optics Research

The programme is a collaboration between the international Society for Optics and Photonics (SPIE), ICTP and INFN.

The research activities are presently centred on collaborating laboratories in the INFN and Elettra Sincrotrone Trieste. The purpose of the research, which is co-funded by the International Society for Optics and Photonics (SPIE) is to use high power, narrow line-width mid-IR laser light for both spectroscopy and for accurate measurements of the proton charge radius, based on resolving hyperfine splitting in muonic hydrogen. The two methods being investigated are the use of a quantum cascade laser (QCL) which is tuneable in the mid-it range, and difference frequency generation (DFG), taking advantage of improvements in nonlinear crystals.

The laboratory activities have involved researchers from Italy (ICTP, INFN, Sincrotrone Trieste S.C.p.A.), Bulgaria, Togo, Ghana and India. Researchers from developing countries were supported through STEP (sandwich training) programme, the TRIL (Training and Research in Italian Laboratories) programme, and ICTP’s Associates programme.

Elettra joined as a partner to the Quantum Cascade Laser project in 2012, making available resource and personnel from the laser laboratory.

In addition, an activity in Applications of Optical Tweezers was added in October 2012 under the umbrella of the AOR program. This brings a new partner—IOM-CNR—to the AOR.

Finally, we added a third component on the ICTP campus, namely a training and research facility dedicated to photothermal spectroscopy and microscopy mainly directed to the identification and determination of toxic compounds in the environment. Recently, another experimental setup was developed, and the aim is the separation and detection of biomolecules using electrophoresis coupled with thermal lens spectrometry.
Quantitative Life Sciences

Created in 2014, the Quantitative Life Sciences Section was established to respond to recent changes in the scientific landscape.

The progressive integration of a wide range of different disciplines, including physics, statistics, information theory, biochemistry, genetics, neuroscience, population genetics and game theory, and the increased availability of quantitative data on the most diverse domains of life sciences — from the cell and the brain, to terrestrial and oceanic ecology, economics and quantitative finance — have led to the consolidation of a new research domain, which we describe as "Quantitative Life Sciences" to provide a sense of its breadth.

In this scenario, new challenges are emerging for physicists at all scales of organization of life, from signalling cascades and the regulation of gene expression or metabolism in a cell, to the large-scale structure of multicellular organisms, the brain, or ecosystems. The early focus of physicists on the fundamental units of life (DNA, proteins and their interactions, neurons) has gradually expanded to include whole cells and tissues, as well as organs (for example the brain) and organisms, and even entire ecosystems. A detailed understanding of complex biological processes in terms of their constituents and motifs, requires a proper grasp of fundamental concepts and tools in the theory of stochastic processes, statistical and non-linear physics.

Notwithstanding the breadth of its scientific interests, the section maintains a strong identity rooted in a common language, based on quantitative methods of theoretical physics, as well as a shared focus on conceptual issues. Indeed, at all scales of life we see emergent collective behaviours: identifying universal signatures that can shed light on their origin, or on life’s organizing principles, is a major goal of current front-line research. The emergence of universal principles is particularly evident for traits under strong evolutionary pressure, where biological behaviour is expected to satisfy optimization principles. Understanding behaviour in these cases calls for the integration of methods from Artificial Intelligence (e.g., Reinforcement Learning) and game theory, jointly with the physical description of a system that is needed to describe embodied intelligence. Besides evolution, living systems stand out from physical systems because of their information processing abilities. From this viewpoint, understanding the roots of the success of machine learning (and its limitations), does not only shed light on machine learning itself, but also provides insights on the principles that organize living systems. That is also why Artificial Intelligence and Machine Learning have become one
of the key subjects in our section, across the research of all QLS members. Not surprisingly, the field of computational neuroscience, which is the one that traditionally deals with information processing in living systems (namely, the brain) and which had already been identified as central in the 2014-2019 strategic plan for the development of the QLS Section, still remains of great importance for its consolidation.

The QLS Section aims at promoting scientific excellence in this highly dynamic scientific landscape. It is currently composed of five staff members, six postdoc fellows, seven PhD and nine graduate students (see detailed list below).

The Section collaborates with a group of Staff Associates in order to enhance its outreach and visibility in the international community. The support of this “external faculty” is particularly important to maintain a high scientific level, given the disciplinary range and diversity of the activities that the Section aims to carry out. The QLS Section has also established research and training collaborations both with other Trieste-based institutions (ICGEB, University of Trieste and SISSA), and with institutions outside the region (Politecnico Torino, Univ. Paris Sud).

Since 2019, the QLS Section started the QLS Diploma Programme, an innovative training program aimed at providing students with a quantitative and theoretical background that can allow them to access postgraduate programmes in a broad range of disciplines, including biophysics, quantitative biology and neuroscience, theoretical systems ecology, economics, data science, and machine learning (https://diploma.ictp.it/courses/qls.aspx).

The programme is coordinated by Antonio Celani. All first year students successfully went on to higher graduate programs. Nine students started their courses in September 2020 and are currently on campus.

The Diploma Programme lessons are recorded and available, together with other QLS activities, on ICTP YouTube Channel at https://www.youtube.com/channel/UC3cvRkofO-76JKosmx1tiXw/playlists?view=50&sort=dd&shelf_id=1.

In 2020, due to the Covid emergency, most ICTP scientific activities were cancelled or postponed; some of them were held on-line.

The core activity of the QLS Section, the 4-week long Spring College on the Physics of Complex Systems, started in the peak of the Covid emergency outbreak, and was cancelled after one week. This school aimed at second-year master’s students and early PhD students, with five courses ranging from traditional statistical physics to all aspects of Quantitative Life Sciences.

Another core activity of the QLS Section, the Winter School on Quantitative Systems Biology in collaboration with ICTS-TIFR Bangalore, was held on-line. This activity aims at bringing young researchers in contact with the forefront subjects of research in different areas of Quantitative Biology. The ninth edition focused on ecosystem ecology.
Since their first editions, both the Winter School and the Spring College have witnessed an increase in quantity and quality of applicants, showing that there is a growing interest in these initiatives.

In 2020 the QLS Section has been active in the following research directions:

- Physics of behaviour and sensing.
- Quantitative ecology and evolution of large communities.
- Stochastic thermodynamics in living systems.
- Rigorous aspects of high-dimensional inference and learning.
- Featureless statistical inference.

Individuals must make effective decisions in order to increase the amount of reward they can get from the environment. Choosing how and when to move is one specific behaviour that is often central to survival and proliferation of cells and organisms. This decision is often guided by chemical and mechanical cues, as well as by social interaction when the process happens at a collective level. These issues are studied in several model systems, ranging from chemotaxis in bacteria and cancer cells, to olfactory search in insects and soaring in birds. Combining ideas from statistical physics, information theory, computer science and biology, we aim at an algorithmic understanding of animal search behaviour and decision-making guided by sensory information.

Many species coexist in the same communities. How the coexistence of many species is generated and maintained is a fundamental and unanswered question in ecology. Coexistence is a puzzle because we lack a quantitative link between mechanisms and variation of species presence and abundance. We aim at understanding the fundamental mechanisms determining the dynamics and composition of ecological communities. We combine tools and ideas from statistical physics, data science, biology, and ecology. The research ranges from the study of theoretical models with many interacting species to the formulation of novel, theory-driven, ways to analyse data. Trying to bridge the gap between theory and biological data, most of the recent focus has been devoted to studying quantitative laws characterizing the taxonomic and functional composition of microbial communities at multiple scales, from genes to species.

An important challenge of nowadays science is to develop a quantitative understanding of the fluctuating nature of energy conversion at mesoscopic scales. Only very recently, universal features of non-equilibrium small systems have been discovered in the framework of stochastic thermodynamics. These universal relations have shed light on fluctuation phenomena that have been experimentally validated in biological systems (molecular motors, active gels, mechanosensory cells), colloidal systems and nanoelectronic devices, among others.

Using methods from Martingale theory — a mathematical framework widely used in finance — Edgar Roldán is investigating new universal fluctuations of the energetics and entropy production of small nonequilibrium systems. Pioneering
the so-called “Martingale theory for thermodynamics”, he and his collaborators are investigating, with theory and experiments, the so-called “extreme second law violations” corresponding to events of extreme transient entropy reductions. Currently, the theory is being extended to quantum systems and active matter, with application to spontaneous oscillations in the ear of the bullfrog and extreme excursions for molecular (collaboration with University of Bordeaux and Max Planck Institute).

Universal signatures of stochastic fluctuations also manifest in the dynamics of water near biological interfaces, which is of key relevance in the exchanges of matter and chemical interactions that are essential for life. For example, the dynamics of water near glutamine surfaces serves as an important model system for studying neurodegenerative diseases. First-passage time statistics obtained from molecular dynamics simulations offer the possibility for extracting a space-dependent diffusion coefficient in complex, in-homogeneous environments that are commonplace in living matter. This collaboration, led by E. Roldán and A. Hassanali (CSMP section), has expanded to include young researchers from Pakistan, Iran, Ghana, Congo, Russia, Argentina, Serbia, and Cuba.

Information thermodynamics is acquiring the status of a universal language, cutting across different disciplines. As an example of this, M. Marsili and L. Touzo (a master student of the École Normale Superieure, Paris) established connections between information thermodynamics and source coding theory (in collaboration with E. Roldán and N. Merhav of Technion University) and finance (in collaboration with D. Zagier, Univ. Bonn). In the first, we show that optimal coding in terms of minimum description length is efficient both from the point of view of information theory, and from that of energy consumption. This connection offers insights on the design of efficient information channels. The paper has been selected as one of the 2020 highlights in JSTAT. Secondly, we analysed a paradigmatic model of market microstructure that shows how efficient markets incorporate the private information of traders. We found that the gain that an informed trader can extract from trading based on private information is bounded above by the maximal work that can be extracted, using that information from an analogous physical system. This suggests a deep analogy between the second law of thermodynamics in physics and the no-arbitrage principle in finance. In collaboration with the CMSP section (G. Manzano and R. Fazio) we have further applied these principles in proposing and realizing experimentally a Gambling Demon, which stops a nonequilibrium process at a random time, following a prescribed gambling strategy. Notably, such demons enable the extraction of work above the limits given by the standard second law, as we prove with experimental data from a single electron box. These results will appear in a highlighted article in PRL in 2021.
This decade is witnessing a burst of mathematical studies related to high-dimensional inference and learning. A theoretical physics approach provides deep insights into the organization of the free energy landscape underlying these problems. Yet rigorous results have been restricted to very specific models. Theorems are of crucial importance in this young interdisciplinary field at the intersection of physics, data science, information theory and applied mathematics. Indeed, despite the tremendous advances on the applications side, a theoretical understanding of the success (and limitations) of machine learning is still lacking. Jean Barbier is actively participating in the development of a stable mathematical basis to the statistical physics predictions in the context of high-dimensional Bayesian inference and learning. Examples of problems where the physics approaches are now rigorously settled thanks to these new tools include low-rank matrix and tensor factorization, generalized linear estimation, models of neural networks, or sparse graphical models such as error-correcting codes and block models for community detection. Recently his effort has been devoted to go beyond "standard" high-dimensional regimes of inference, with the aim of establishing information-theoretic limits of neural-networks learning from structured data, in realistic scaling regimes.

For systems such as the brain, cells or an economy, the lack of knowledge on the system’s "laws of motion" and the high dimensionality of the data call for a statistical approach that makes no a priori assumptions on the generative model. Within this setting of featureless inference, Ryan Cubero and Matteo Marsili have derived quantitative measures for identifying relevant variables (e.g. neurons responsible for spatial cognition). These results stem from a characterization of relevance in finite samples, as a measure of information content that the sample contains on the generative model. Within this approach, critical fluctuations in samples arise as signatures of efficient representations. This theory also predicts how learning machines should morph their energy landscapes in order to learn structured datasets and how the thermodynamics of trained machines differs from that of physical systems.

A further line of research deals with extracting simple models from high dimensional datasets. As G. Box once wrote, "All models are wrong, but some are useful". Useful models are those that provide easily falsifiable predictions on symmetries and invariances. Focusing on models of binary variables, we found that these are also simple, in the information theoretic sense. Surprisingly, we find that simple models are also simple to infer from a computational point of view. This makes it possible to identify the best simple model, in spite of the fact that their number grows very fast with dimensionality.
Due to the Covid emergency, scientific activities at ICTP were held on-line; the Quantitative Life Sciences Section contributed to the ICTP 2020 Scientific Programme with five on-line activities. QLS members acted as local organisers and/or directors.

QLS Staff members are active in a number of training courses. Each of them teaches one or more courses in the QLS Diploma programme. They also teach courses at University of Trieste (e.g. Master in Data Science and Scientific Computing), in joint programmes (e.g. International Master in Mathematics at Lahore University, International Master’s programme in Physics of Complex Systems), as well as in SISSA PhD programmes. They regularly give series of lectures (e.g., at the School on Mathematical and Computational Aspects of Machine Learning at Scuola Normale Superiore, Pisa; at CSRS Summer School, Beijing) and in outreach activities (e.g. Master in Scientific Communication at SISSA).

### Training Activities

<table>
<thead>
<tr>
<th>Event</th>
<th>Dates</th>
<th>Location</th>
<th>Organizers</th>
<th>Local Organisers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Youth in High-dimensions: Machine Learning, High-dimensional Statistics and Inference for the New Generation</td>
<td>29 June - 3 July</td>
<td>held virtually</td>
<td>Organizers: Florent Krzakala (ENS Paris, France) Jean Barbier (ICTP)</td>
<td>Local Organizer: Matteo Marsili</td>
</tr>
</tbody>
</table>
ICTP-SISSA-CECAM Workshop on Molecular Dynamics and its Applications to Biological Systems
Organizers: Giovanni Bussi (SISSA)
Angelo Rosa (SISSA)
Alessandro Laio (SISSA)
Alessandra Magistrato (SISSA)
Christian Micheletti (SISSA)
Alex Rodriguez (ICTP)
Edgar Roldan (ICTP)
Local Organiser: Ali Hassanali (ICTP)
Co-sponsors:
International School for Advanced Studies
Centre Européen de Calcul Atomique et Moléculaire

Winter School on Quantitative Systems Biology: Quantitative Approaches in Ecosystem Ecology
Organizers: Simon Levin (Princeton University)
Jacopo Grilli (ICTP)
Matteo Marsili (ICTP)
Local Organiser: Antonio Celani

<table>
<thead>
<tr>
<th>smr</th>
<th>male</th>
<th>female</th>
<th>subtotals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>least developed</td>
<td>developing</td>
<td>developed</td>
</tr>
<tr>
<td>3517</td>
<td>6</td>
<td>96</td>
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</tr>
<tr>
<td>3486</td>
<td>5</td>
<td>95</td>
<td>66</td>
</tr>
<tr>
<td>subtotals</td>
<td>24</td>
<td>296</td>
<td>171</td>
</tr>
<tr>
<td>totals</td>
<td>491</td>
<td>231</td>
<td>722</td>
</tr>
</tbody>
</table>

Table 7. Number of participants in training activities by gender and country development status.
ICTP cooperates with SISSA Trieste, Politecnico di Torino and a consortium involving Universities Pierre & Marie Curie (Paris 6), Paris Diderot (Paris 7), Paris-Sud (Paris 11) and the École Normale Supérieure at Cachan in providing education to graduate students from developing countries on the Physics of Complex Systems, leading to a Laurea Magistralis degree.

The aim of the International Master Course in Physics of Complex Systems is to shape professionals and/or potential researchers to be able to jointly apply knowledge and methodologies from modern physics, applied mathematics, information engineering and computational biology to the analysis, modelling and simulation of complex systems. Matteo Marsili is the ICTP contact for the Master Course.

Within this program, ICTP organizes, in collaboration with its partner institutions, the annual Spring College in the Physics of Complex Systems, a month-long intensive training activity.

Recently created jointly between Lahore University and ICTP, this international Master in mathematics aims at training the next generation of applied and pure mathematicians. Jean Barbier has been teaching a course on "machine learning" at the Master.

Antonio Celani
European Community Innovative Training Network "CoperMix", ~210,000 EUR, for the period 2020-2024, PI: Antonio Celani

Edgar Roldan
SNF Grant
"Modelling a desynchronization strategy from the COVID-19 pandemic"
CHF 296,250 (275,400 EUR), for the period 2020-2022
PI: Guido Beldi, co-PI: Daniel Sanchez-Taltavull
Project members: Alexander Benedikt, Michael Gerfin, Edgar Roldan

Grant from the Ruth & Arthur Scherbarth Foundation
"Multiscale stochastic reset modelling to optimize therapeutic protocols to reduce drug resistance"
CHF 70,000 (64,918 EUR), for the period 2021-2024
PI: Daniel Sanchez-Taltavull
Project members: Deborah Stroka, Jose Perico Esguerra, Edgar Roldan
In 2020, the permanent staff of the Quantitative Life Sciences Section consisted of five staff members and six postdoctoral fellows. There were seven PhD and nine Master’s students supervised by QLS staff members in 2020. The total number of short- and long-term visiting scientists to the QLS Section in 2020 was sixteen (including two associates) from seven countries. Of them, four were nationals of developing countries, and ten were nationals of developed countries. There were also six Staff Associates, who contributed to the research activities of the Section.

**Professional Staff**
Section Head: Matteo Marsili
Antonio Celani
Jean Barbier
Jacopo Grilli
Edgar Roldan Estebanez

**Consultants**
*Chris Mathys
Fernanda De Castro Reis

**Staff Associates**
Mahesh Bandi
Fakteh Ghanbarnejad
*Rami Pugatch
*Massimo Vergassola
*Yasser Roudi Rashtabad
*Riccardo Zecchina

**Visiting Scientists**
Melanie Bondorevsky
Mihir Durve
Annwesha Dutta
Hou Tianq

**Post-doctoral Fellows**
Roman Belousov
Alessandro Ingrosso
Andrea Mazzolini
Manuel Saenz
Anjan Roy
Silvia Zaoli

**Associates**
*Rami M. A. Amro
*Jonathan Oyebamiji Babalola
*Debashis Chowdhury
*Stephanie Brigitte Christiane Depicker
*Mohammad Reza Ejtehadi
Wael El-Deredy
*Abdo Abdal Abdellah Elfky
*Shamik Gupta
*Junghyo Jo
*Chalermpol Kanchanawarin
*Pal Jun Kim
*Sanjay Kumar
*Marcelo Nestor Kuperman
*Feng Liu
*Ricardo Martinez Garcia
*Graciela Lujan Mazzone
*Eligene Edjem Etchri Jean Megnassan
*Roberto Genicio Mulet
*Maryse Dadina Nkoua Ngavouka
*Fernando Antonio Nobrega Santos
*Sergio Fabian Pantano
*Silvina Martha Ponce Dawson
*Jomar Fajardo Rabajante
*Mohammad Sohel Rahman
*Soumen Roy
*Areejit Samal
*Moises Santillan Zeron
Bailu Si
*Sumedha Sumedha
*Mendeli Henning Vainstein
*Mina Zarei

**PhD Students**
Claudio Leone
Mihir Durve
Lorenzo Fant
Gennaro Tucci

**Step Students**
*Solmaz Golmohammadi
*Rita Majumdar
*Alfredo Gonzalez Reyes

**Master’s students**
Nicole Orzan
*Johnson Oyero
Ashwin Gopal
Yi-Zhang Chen
Léopold Touzo Touzo
*Francesco Martinuzzi
*Davide Scassola
Emanuele Massa
*Mattia Corigliano
Talented young science students in developing countries are sometimes limited in achieving their full potential by the absence of advanced postgraduate-level training that is up to international standards. It was in 1991 that Prof. Abdus Salam instituted an intense 12-month Diploma Programme in the (then) main research fields of the ICTP, namely Condensed Matter Physics, High Energy Physics, and Mathematics. Starting from September 2006, the Diploma Programme also includes the branch of Earth System Physics. Starting September 2019 also the branch of Quantitative Life Sciences was included.

The ICTP Postgraduate Diploma Programme is a gateway for young people who might otherwise never have had a chance to reach international-level standards in physics and mathematics, and to more fully realize their intellectual potential. Former students from the very earliest batches, who have returned home (having completed the usual academic training of a PhD and a couple of postdoc positions), are now applying for ICTP Junior Associateships, and for participation in ICTP Activities. They are training students of their own, some of whom may apply to the ICTP Postgraduate Diploma Programme, thus closing Salam’s virtuous circle.

This programme differs from other ICTP training/research activities such as Schools/Colleges in the following ways: the Diploma period is one year; the level is pre-PhD; the participants are younger; and the number of participants is small. From about 150 applicants to each of the five regular Diploma programmes, only 10 students are admitted in each. All 50 are given
full support, covering airfare, and living costs. The focus is especially on those developing countries for which high-quality advanced scientific training is less accessible. In the 2019-20 batch, the 46 students who joined came from 28 countries: Algeria, Bangladesh, Cameroon, Colombia, Costa Rica, Egypt, El Salvador, Ethiopia, Georgia, Ghana, Guatemala, Honduras, Indonesia, Iran, Jordan, Lebanon, Madagascar, Mexico, Nepal, Nigeria, Pakistan, Palestine, Peru, Philippines, Rwanda, Sudan, Uganda, and Uzbekistan.

The one-year academic programme itself is quite intense, and consists of three terms covering basic courses, advanced topics, and dissertation research under a supervisor. During the first and second terms, covering 9 months of the Postgraduate Diploma Programme, students attend around 10 hours a week of lectures, with problem sets and final exams in each of the 8-10 courses. (See Table on next pages for 2019-20 courses). Standards are maintained: students are asked to leave if they fail in two or more courses; or if their final average grade is below a C; or if their dissertation is unsatisfactory. The vast majority (92%) of the 976 students over the past twenty-nine years, have successfully surmounted these hurdles, whatever their initial background.

After obtaining the ICTP Diploma, most students go on to do a PhD in Europe or North America; or return to jobs as college teachers, or register for PhD in their home countries. In the 2019-20 batch of 43 total students that received their Postgraduate Diplomas, the MSc/PhD placements include:

↗ University of Houston Texas, Hamburg Universität and SISSA for CMP Diploma.

↗ Padova University, Katholieke Universiteit Leuven, University of Dijon, SUNY Albany US, Niels Bohr University Copenhagen and SISSA for HECAP Diploma.

↗ Lille University, Università La Sapienza Roma, University of Notre-Dame Indiana US, Kansas University, École Normale Supérieure Lyon, for ESP Diploma.

↗ Padova and Trieste University, PUC Rio de Janeiro, Porto/Coimbra University, University of Montreal, ENS Lyon and SISSA for MTH Diploma.

↗ Trondheim, Maastricht and Basel Universities and SISSA for QLS Diploma.

The others took up PhD registrations, or teaching positions in their home countries.
The ICTP-IAEA Sandwich Training Educational Programme (STEP) aims at offering fellowship opportunities to Ph.D. candidates from developing countries. The scientific fields covered by the programme are those falling in the scientific and technical competence of the ICTP and its collaborating institutions. In 2020 the programme was funded by the ICTP and the IAEA Department of Technical Cooperation.

The programme is designed for Ph.D. students in developing countries who are offered fellowships of 3-6 month stays at ICTP each year, for 3 successive years, at ICTP or at collaborating Institutions (Synchrotron Light Laboratory Elettra, Laser Laboratory, SISSA, Universities of Trieste, Udine, Bologna, Padua, Pisa, Venice, ARPA, OGS, IAEA Laboratories in Seibersdorf and Monaco, Jozef Stefan International Postgraduate School in Ljubljana, Hospitals of Udine, Trieste and Vicenza, INFN, CNR-IOM TASC and others). Fellows can thus work on their Ph.D. thesis on a sandwich basis with their supervisor at their home institute and a co-supervisor at the hosting institute. Their Ph.D. is awarded at the home institute.

Adwoa Kua-Manza EDJAH (F), Ghana
Period of visit: 12 January - 10 March 2020

Serhii KUPRIIANCHUK (M), Ukraine
Period of visit: 7 March – 7 July 2020
Topic or title of PhD thesis: Increasing the Level of Environmental Safety of the 'Shelter' by Retrieving and Containerizing of Nuclear Materials.

Kasiet SALYMBEKOVA (F), Kyrgyzstan
Period of visit: 2 March – 10 August 2020
Topic or title of PhD thesis: Assessment of mercury content in environmental objects and food products of the Kyrgyz Republic.

Jerome FOLLA KAMDEM (M), Cameroon
Period of visit: 29 October 2020 – 23 April 2021
Topic or title of PhD thesis: Study and Simulation of a Model of Current Reference using CMOS Technology, Subthreshold Region.

Reyhaneh KHASSEH (F), Iran
Period of visit: 1September 2019 – 31 July 2020
Topic or title of PhD thesis: Non-equilibrium Dynamics of Many-Body Systems: from Synchronization to Dynamical Phase Transition.

Zainab NAZARI (F), Afghanistan
Period of visit: 15 August 2018 – 31 December 2020
Topic or title of PhD thesis: Inflation, Local Scale Symmetry and Supergravity.
ICTP cooperates with SISSA, Politecnico di Torino University, Université Pierre and Marie Curie, Paris Diderot, and Paris-Sud/Paris Saclay in providing education to graduate students on the Physics of Complex Systems leading to a Laurea Magistralis degree. The aim of the International Master in the Physics of Complex Systems is to shape professionals and/or potential researchers to be able to jointly apply knowledge and methodologies from modern physics, applied mathematics, information engineering, and computational biology to the analysis, modelling, and simulation of complex systems. Within this program, ICTP also organizes, in collaboration with partner institutions, the annual Spring College in the Physics of Complex Systems, a month-long intensive training program, which is also integrated with the QLS Diploma programme. Because of the Covid-19 pandemic, the Spring College was cancelled in 2020 and has been held virtually in 2021.
Joint ICTP/SISSA Master in High Performance Computing

The Master in High Performance Computing (MHPC) is an innovative degree program that prepares students for exciting careers in the fast-growing field of High Performance Computing (HPC). Set in the stimulating research environment of its co-organizer institutions, SISSA and ICTP, the program combines lectures with hands-on and applied projects to prepare future HPC specialists for academia and industry.

MHPC coursework is driven by challenging scientific and technical problems that require an HPC approach. Lectures are provided by SISSA and ICTP staff and highly recognized international experts. Both institutes have long histories and experience in developing and applying scientific and research computation models.

Students who successfully complete the program will be able to address problems requiring advanced computational techniques in multiple domains and communicate HPC technological issues in all scientific and industrial environments.

The MHPC programme began in September 2014 and is now in its seventh edition (2020/2021). ICTP scientists have been providing several courses and ICTP provides fellowships to three or four students in each edition. The ICTP students Urog Krister Jazz (Philippines), ALIEI Saeid (Iran) and Yousfi Nesrine (Algeria) graduated in between December 2020 and February 2020.

Details are available at www.mhpc.it.
Joint ICTP/UniTS Master of Advanced Studies in Medical Physics

The ICTP-UNITS Master of Advanced Studies in Medical Physics (MMP) is co-ordinated by a Director (Professor Renata Longo, UNITS), an ICTP Coordinator (Prof. Renato Padovani, ICTP), and by the Council (prof. Edoardo Milotti, UniTs, Luigi Rigon, UniTs & Mario de Denaro, Trieste Univ Hospital, & Luciano Bertocchi, ICTP).

The two-year programme comprises a year of academic courses and practical exercises at ICTP, Trieste University Hospital, and a second year of full time clinical training in a Medical Physics Dpt. of the Network of hospitals for the clinical training.

In 2020 the education, training and administrative activity has been developed as follow:

The 12 students of the 6th cycle (2019-2020) attended the full year of supervised clinical training in one of the 26 hospitals in the network of Italian and Croatian hospitals for the clinical training. Due to the Covid-19 pandemic, the training was suspended from the first days of March up to May-June depending on the local situation of the hosting hospitals. During the lockdown period the students were involved in virtual activities (computer exercises, journal club, etc). In order to recover part of the time lost, the training has been prolonged up to the end of January 2021 (for 2 students up to the end of March 2021). The 25th and 26th of January 2021 10 students submitted and defended a thesis work. They got the Degree during a virtual ceremony with the participation of the Trieste University Deputy Rector, the IAEA Director General, the ICTP Director, external advisors and representatives of IOMP, EFOMP and AIFM. The ceremony has seen the participation of most of the teachers and medical physicist supervisors from the hospitals providing clinical training.

The 25 students of the 7th cycle (2020-2021) attended the first year of academic course and exercises at the ICTP and Trieste hospital. The activity began on the 10th of January and ended the 20th of January 2021. From March to November 2020 most of the teaching activities were performed in virtual mode, while some exercises and most of exams were in person. 24 students began the period of clinical training in February 2021.
The academic courses were divided in 3 periods: January–Easter, Easter – Summer, September- January 2021. 29 lecturers from ICTP, Trieste and Bologna Universities, Elettra, various hospitals in Italy delivered a total of 60 CFU (credits). The subjects of the theoretical and practical course covered general medical physics topics, namely physics of radiation, physics of imaging, dosimetry of radiation, anatomy and physiology, statistics and informatics tools, and main professional topics, diagnostic imaging, radiation therapy and radiation protection. More details in the MMP’s ICTP webpage.

8th cycle (2021-22). Following a call delivered in February 2020, 290 applications have been received. From a short list of about 100 eligible candidates, a total of 24 students have been enrolled from 18 countries, 17 with an IAEA fellowship, 5 with full or partial ICTP fellowship, and 1 cost free.

The 25th of January 2021: a virtual meeting with representatives of the IAEA (Dr. Deborah van der Merwe, Human Health Division), External advisors (Ahmed Meghzifene, former head of the medical physics section of IAEA, and Slavik Tabakov, King’s College, London) and head and clinical supervisors from the Medical Physics Dpt. of the Network of hospitals was organized. The agenda included: (i) the discussion on the experience of the clinical training and the delivery of the Portfolio for the clinical training for the year 2021, (ii) the clinical training assessment methodology, (iii) the agreement on the distribution of the students among the hospitals for the year 2021 of full-time clinical training.

IT activity. Beginning in the 3rd quarter 2019 and during the whole of 2020, the ICTP Moodle platform was developed for the activities of the first academic year and the second year of training.

1st year: for every academic course, the training, exercise, and additional material has been developed and uploaded. Teachers and students extensively used these resources. These resources represent a good database to develop some forms of future distance-learning activities in medical physics.

2nd year: areas to support and monitor clinical training and maintain communication with students have been developed and extensively used.
Joint ICTP/UniTS PhD Programme in Earth Science, Fluid Dynamics, and Mathematics. Interactions and Methods

Scientific Objectives

This PhD program aims at the interdisciplinary training of students in the field of the Earth system science (ERC panel PE10), with special attention to the interactions between earth science, fluid dynamics and applied mathematics, as well as to the interplay of methodological aspects, modelling and applications.

This course promotes the preparation of students through the investigation of the scientific themes developed by the research groups belonging to the departments and the research institutions directly involved in the program, as well as through international collaborations with qualified foreign structures that provide students with the opportunity to attend training programs abroad.

In the field of earth sciences, the main objective is the transfer of knowledge on advanced methods of investigation with applications to the study of composition, structure, stratigraphy, and evolution of our planet, from the close surface up to the deep structures and the characteristics at a global scale.

In the context of fluid mechanics, the study of motion of the fluids is mainly addressed with reference to their transport properties, dispersion and mixing in environmental or industrial processes, as well as to their interaction with the solid elements. Fluid mechanics studies the properties and the behaviour of fluids, that is, liquids, gases, plasmas, and more generally of substances whose molecules have no fixed positions in space but can move relative to each other with different relative speeds. It involves physical phenomena of relevant complexity and has a broad range of applications. Most environmental systems involve the dynamics of liquids and gases that is described in terms of fluid dynamics, such as, e.g., oceanic, atmospheric and climate dynamics, physics of earthquakes and volcanoes, estuaries, and lake hydrodynamics. Similarly, biological systems are regulated by transport and dispersion of elements or species in water, air, and blood.

The fundamental laws which these disciplines are based upon are generally expressed through highly complex mathematical models. The qualitative and quantitative study of such models requires the development and the application of sophisticated mathematical tools, and it represents a relevant and topical research
field even from the mathematical point of view. Mathematics therefore pervades the entire program, playing a central and unifying role.

In 2017 this program has been evaluated as an innovative, interdisciplinary, and international PhD course by ANVUR, the Italian Agency for Research Evaluation.

The Doctoral School in Earth Science, Fluid Dynamics and Mathematics is aimed at the advanced training of students in the field of fluid dynamics, applied mathematics, and earth sciences, with particular reference to the topics described above. It promotes the theoretical and applicative formation of students, through the investigation of scientific themes developed in the research groups belonging to the departments involved in the programme and through international collaborations that provide the possibility to attend some training projects at a qualified research level abroad.

The program aims to prepare students for careers in research, teaching and in the industrial use of high technologies in the above-mentioned areas. The final dissertation must be original, it must represent the state of the art in the chosen field and should contain material for the publication of scientific papers in international journals of the field included in the ISI or SCOPUS catalogues. The students will be in contact with several local and international environments and gain considerable experience in both theoretical and applied problems of earth sciences and fluid dynamics. In addition, the students will develop familiarity and competence in the use of more advanced tools (both modelling and experimental) for the analysis of complex physical systems, which will be of great use for future activities in public or private research centres or for any work in companies with high technological content.

To date there are 113 students who have either completed or are working towards their PhD. Of these, 8 have graduated within 2020. In terms of gender, approximately 50% of the total number of students are female, and about a third come from developing countries.
Joint International ICTP/SISSA PhD (JIISP) Programme in Physics and Mathematics

**Admissions 2020/2021**

- **Geometry and Mathematical Physics**
  - Abdelraouf Asem – Egypt (Diploma 2018/19)
  - Hamza Ounesli - Algeria

- **Astrophysics and Cosmology**
  - Boumechta Yacer - Algeria

- **Physics and Chemistry of Biological Systems**
  - Donkor Edward Danquah - Ghana

- **Statistical Physics**
  - Tarabunga Poetri Sonya - Indonesia

- **Theory and Numerical Simulations of the Condensed Matter**
  - Tsitsishvili Mikheil - Georgia

- **Theoretical Particle Physics**
  - Benhaddouche Zakaria – Algeria

**Awardees 2020**

- **PhD in Theory and Numerical Simulation of the Condensed Matter**
  - Yusuf Shaidu – Nigeria
  - Thesis:
    Interatomic Potential for Li-C Systems from Cluster Expansion to Artificial Neural Network Techniques
  - Supervisor: Prof. Stefano de Gironcoli
  - Defence date: 24.11.2020
The Associate Programme, as well as the Federated Institute Programme, represent two main channels through which the mission of the ICTP for the promotion and development of scientific knowledge in Developing Countries has been turned into a reality. The Associate Programme enables individual scientists to maintain long term formal contacts with the stimulating and active scientific environment of the Centre.

Since 2013, we have a new category of Associates: the ICTP Simons Associates, funded by the Simons Foundation, U.S.A. The first round of funding came to an end in December 2019.

However, the Simons Foundation kindly awarded the ICTP a new grant. With the new award a new class of Simons Associates has been formed (2020-2025).

The Associates programme was heavily impacted by the Covid-19 pandemic in 2020 as travel became essentially impossible. However, the ICTP research groups actively interacted with the associates online to ensure the continuity of the relationship with the Associates. The interaction included Associate seminars, research activities and even online lunches.

Junior and Regular Associates have a local individual scientific coordinator and Senior Associates have a scientific coordinator as point of reference. Coordi-

ators are the scientific focal point for Associates’ visits to ICTP. This has led to an ever-growing number of scientific collaborations and strong connections between ICTP scientific staff and the associates. This also leads to the organization of ICTP and other scientific activities in the Associates’ home country.

Associateship allocations are 180 days with a maximum stay of 60 days at a time, with the minimum requirement for travel allocation being 30 days.

Per diems are 40 Euros for Junior Associates, 45 Euros for Regular Associates and 50 Euros for Senior and Simons Associates. All Associates who opt to stay on campus receive single accommodation in the Galileo Guest House, at a special rate of 15 Euro a night.

The new class of Simons Associates are given a fixed grant of 23,000 Euros over the period of the award and which they use for travel and living costs on visits to the ICTP for themselves and for their research students. While at the ICTP they receive...
a monthly stipend of 3,000 Euros.

Special emphasis has been placed on the publications produced by our Associates since the start of their award. We are able to give a snapshot of the current information we have at hand, as follows: 302 Associates produced 1,980 publications since the start of their award, resulting in an average of 6.6 publications for each Associate member.

Efforts to increase the participation of women scientists in the Associates Programme has also been successful. In fact, from 2013 when the total of female associates was 17%, it has reached 24% in 2020.

Applicants interested in an ICTP Associate membership apply through the online ICTP platform Sigma. Applications are usually (but not exclusively) submitted by scientists who have had some interaction with ICTP (typically previous participants in Courses and Workshops). The applications are divided by category (Junior, Regular or Senior) according to the age at the time of nomination. The relevant committees make the selection from priority to final candidates directly on Sigma.

Once the deadline has passed, the Office identifies the number of Associate awards expiring, and takes this as well as the budget allocated for the Programme into account, to define the approximate number of new awards for the subsequent year, so that the committees have a clear indication of how many new appointments would be issued in their field. The committees are also informed of how many current Associates are in their field and which country they are from, as well as their gender, to ensure a correct geographical and gender distribution. We also require the Committees to give priority to young active scientists and to women. When the Head of the programme approves the final selection, the letter of award together with the relevant annexes are generated directly and can be retrieved by the newly appointed associate automatically on their Sigma profile.
The main difference between the Associates and the Federated Institutes Programme derives from the fact that while the former is addressed to individual scientists, the latter involves an institution.

The Federated Institutes represent an interesting complementary programme to that of the Associates:

↗ More scientists can be exposed to the scientifically stimulating atmosphere of ICTP because it is not addressed to an individual but to an institute.

↗ It represents the basis of a long-term and fruitful cooperation between an institute and ICTP.

↗ It should stimulate the institute to invest energy and resources to keep the important link with ICTP alive.

There are two contract types: one granting a travel contribution of €1,500, for institutes situated in Europe, Northern Africa and Middle East and €3,000 for institutes in South & Central America, sub-Saharan Africa and the Far East, for the duration of the agreement. The total number days for visits foreseen for each type of contract is 90.

However, the Federated Institutes Programme is now being reorganized.

For this reason no calls for applications have been opened in the past three years and the programme won’t be advertised until the new policy is implemented. The aim is to improve the offer regarding travel contribution by providing a prepaid ticket instead of partial travel reimbursement, as the office understands that the current arrangements place too high a financial burden on young scientists.

↗ Only institutions of an appropriately high scientific level and in which there is a rather consistent scientific population are considered.

↗ Specific attention is paid to institutes in which there are brilliant, young, scientifically active people.

↗ We try to establish agreements with institutes with which we already have significant collaborations, such as those in which there are (and/or were) prominent Associates or those which are included in other ICTP programmes, or institutes that have an ongoing collaboration with ICTP research scientists or groups.
Summary

In 2020 the ICTP had a total of 16 Federated Institutes, from 10 member states. The total number of visits under the programme was 4.

The total number of days available for the three-year programme is 1,440 (i.e. an average total utilization per year of 480 days). In 2020, 80 days were utilized. Accordingly, in terms of days, the total utilization was 17%.

The total expenditure (daily living allowance and travel contribution when applicable) for 2020 was € 3,000.
The Programme for Training and Research in Italian Laboratories (TRIL) offers scientists from developing countries an advanced experimental counterpart to ICTP’s theoretical research and lecture-based training programmes. The aim of the programme is to promote collaborations between the Italian scientific community and individuals, groups, and institutions in developing countries, working side by side in frontier-level research. The programme addresses important aspects of the mission of ICTP, namely:

- to help with human capital development in the scientific sector within developing countries by making it possible for early career scientists, already cognisant of local needs and resources, to work at the frontiers of science and technology.
- to generally provide support towards sustainable capacity building in basic and applied research that can help their nations’ progress.

The fields covered by TRIL reflect research lines of interest to the Centre: applied physics, high energy physics, physics of condensed matter, energy, environmental science, physics of the living state, and a few miscellaneous interdisciplinary subjects.

TRIL fellows are matched with laboratories that best meet their needs and where there is a mutual benefit. The latter qualification is very important, as it is the basis for a lasting collaboration. This contributes significantly to the success of the TRIL programme and to the mission of the ICTP. Fellows are hosted in universities and/or in national laboratories or laboratories in the national interest, such as CNR (Italian National Research Council), Elettra (Elettra-Sincrotrone Trieste), ENEA (Italian National Agency for New Technologies, Energy and the Environment), INFN (Italian National Institute of Nuclear Physics), INGV (Istituto Nazionale di Geofisica e Vulcanologia), OGS (National Institute for Oceanography and Experimental Geophysics) and others.

While a limited number of fellowships are fully funded by the TRIL Programme, the expectation is that the host laboratory jointly funds a fellowship. Some fellowships are totally supported by the host laboratory.

Fellowships range in length from a few months to one year, depending on the host laboratory, the research/training activity and the funds available. Fellowships may be extended for an additional period, usually for not more than 12 months at a time. The maximum duration of a fellowship is 24 months, referring primarily to
those Fellows receiving the major part of their contribution from the host labora-
tory. This includes the original fellowship period and extensions.

Fellows receive a monthly allowance to cover their living costs, such as lodging, meals, local travel and incidentals while on the fellowship. Other allowances and contributions are granted according to the length of the fellowship for attending scientific conferences or for visiting other laboratories. Requests are examined on a case-by-case basis. The host institution provides the Fellow with laboratory space and other facilities necessary for the project. Host laboratories outside Trieste generally provide assistance to the fellows to find accommodation.

Since 2013, the TRIL Programme is administered and run by the Office of Exter-
nal Activities.

There is an ever-increasing interest from existing and potential host laboratories to participate in the TRIL Programme. Their high-level scientific foundation and financial support provide an integral part of the programme. In 2020, new agree-
ments have been signed and existing ones strengthened and the financial contribu-
tion from external sources exceeded that from ICTP. The available funds were used for both new fellowships and extensions of existing ones enabling certain fellows to continue their research activities in Italy where there was a mutual advantage to do so.

In 2020, there were thirty-six TRIL fellows receiving support to carry out their research/training in Italy, representing a total of 297.94 person-months. Of these fellowships, only ten were new grants awarded in 2020 as the COVID-19 pandemic caused the postponement of at least 17 new visits.

The thirty-six fellows came from twelve countries – Argentina, Brazil, Egypt, Ghana, Guatemala, India, Iran, Nigeria, Pakistan, Philippines, Sudan, and Tunisia. Fifty percent (eighteen fellowships) were awarded to women.

Training and research were carried out in the following areas:
- Applied Physics 14
- High Energy Physics 1
- Miscellaneous 2
- Physics of Condensed Matter 13
- Physics and Environment 3
- Physics of the Living State 3

The visits were carried out at the following laboratories:
- Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste: 9
- Bruno Kessler Foundation, Trento: 1
- Elettra-Sincrotrone Trieste, Trieste: 4
- International School for Advanced Studies (SISSA), Trieste: 1
- 3 Unit in Casaccia
- Italian Institute for Nuclear Physics (INFN): 1
- 1 Unit in Trieste
Dr. Debasree Chowdhury from India had a TRIL fellowship from January 2018 to September 2020, to carry out her training program in the Nanostructure Laboratory at the Physics Department of University of Genova.

Her work, throughout this whole period, was mainly focused on the nano-fabrication of flat optics meta-surfaces based on metal (Au), 2D semiconductors (MoS$_2$) and dielectric (SiO$_2$) nanostructures, aiming at innovative photon-harvesting approaches for high sensitivity sensing in thin film devices.

Her training and work were a good example of the TRIL mission: targeting scientists from developing countries for advanced training in high-end nanofabrication and nanophotonics, leading to the establishment of a high-level scientist able to deliver an important contribution in the advancement of science.

In her research, performed under the supervision of Prof. Francesco Buatier de Mongeot, she worked along two main directions developing novel flat-optics concepts for achieving light manipulation and confinement in the deep subwavelength limit. In the first instance she designed and fabricated plasmonic meta-surfaces, based on Au nanostripe arrays, which enable high sensitivity refractive index sensing in large-area microfluidic devices$^1$. In the second instance she contributed to the fabrication of flat optics nanostripe arrays based on few-layer 2-dimensional semiconductors (MoS$_2$) demonstrating that the nanopatterned film shows enhancement of optical absorption exceeding 400% relative to the flat layer$^3$. Along a similar direction she was also able to demonstrate that continuous thin film semiconductors, atomically thin 2D-MoS2 when grown conformally on one-dimensional (1D) nanorippled substrates, show a relative enhancement of the optical absorption as high as 300% over a broadband spectra from visible to near-infrared range$^4$. Similar results have been found for organic semiconductors films based on PTB7:PCBM$^5$. The relevance of her achievements is reflected in her publications on high impact journals.

2. https://pubs.acs.org/doi/abs/10.1021/acs.jpcc.0c03023
3. https://pubs.rsc.org/en/content/articlehtml/2021/nr/d0nr06744j
4. https://doi.org/10.1021/acsami.0c20387
5. Broadband Photon Harvesting in Organic Photovoltaic Devices Induced by Nanograting Templates (In preparation)
In September 2020, Dr. Debasree Chowdhury won a selection for a post-doctoral scholarship supported by the European Social Fund-Liguria Region, and is now continuing her research work in the Nanostructures Laboratory under the guidance of Prof. Francesco Buatier de Mongeot. The new focus of her work will be on "Innovative materials and devices for sensors and energy" which combine advanced nanofabrication processes and the development of innovative low-dimensional materials with enhanced functionality for sensing and solar energy conversion.
ICTP/Elettra Users Programme

The ICTP/Elettra programme offers access to the synchrotron radiation facility Elettra in Trieste in the years 2012-2021 to scientists from developing countries that work in their home country. A minimum annual total of 1,500 hours is available within this programme for beamtime applications at any of the existing Elettra beamlines.

Experiment proposals are submitted to the Elettra Proposal Review Panel for evaluation, and they are pre-selected for beamtime assignment on the basis of their scientific merit. The ICTP/Elettra Users Programme then selects the proposals that will receive our financial support, based on the funds available for the programme.

Until 2020, the programme offered a limited number of grants to cover travel and living expenses for the individuals of the proposals that were selected to receive ICTP support. In 2020, after the first couple of months, the worldwide COVID-19 pandemic made travelling impossible, and therefore the programme also started to provide small grants to the proposals selected for ICTP support and for which the experiment was feasible in remote mode, so they could send their samples to Elettra and the experiment could be done remotely.

In 2020, 20 proposals were selected to receive ICTP support, but only 6 of these were implemented: one in presence and five remotely. The experiments implemented were on the following beamlines:

- Source for Imaging and Spectroscopic Studies in the Infrared (SISSI): the beamline extracts the IR and visible components of synchrotron emission for applications of spectroscopy, microspectroscopy and imaging.


- High pressure diffraction beamline (Xpress): a dedicated high pressure diffraction beamline, employing a monochromatic x-ray beam, useful in investigating a number of interesting research topics in condensed matter physics, material science, chemistry, geophysics, mineralogy etc.

The six groups that implemented their proposals came from:
- Brazil 2
- Egypt 2
- India 1
- Jordan 1

Total expenditure: Euro 2,011.34.
SESAME Cooperation Programme

SESAME (Synchrotron-light for Experimental Science and Applications in the Middle East) is a cooperative venture by scientists and governments of the region set up based on the model of CERN. It is being developed under the auspices of UNESCO (United Nations Educational, Scientific and Cultural Organization) following the formal approval given for this by the Organization’s Executive Board (164th session, May 2002).

SESAME is an autonomous intergovernmental organization at the service of its Members, which have full control over its development, use, and financial matters. The SESAME Centre, located in Allan, Jordan, was officially opened on 16 May 2017. The synchrotron light source in Allan presently has two beamlines accepting projects: the x-ray absorption/fluorescence spectroscopy beamline and the infrared spectromicroscopy beamline. A third beamline has been installed (Materials Science) and two other beamlines (Soft X-ray; Tomography) are being constructed.

The motivation for SESAME is that it will foster scientific and technological excellence in the Middle East and neighbouring countries, as well as prevent or reverse brain drain, by enabling world-class scientific research in subjects ranging from biology, archaeology and medical sciences through basic properties of materials science, physics, chemistry, and life sciences. In the process, it will build scientific and cultural bridges between diverse societies and contribute to a culture of peace through international cooperation in science.

ICTP has been involved in SESAME from its inception, mainly in providing training opportunities to a core of potential synchrotron users from SESAME member countries, using existing programmes of the Centre. An ICTP representative automatically sits on the SESAME Training Advisory Committee (TrAC). In the year 2020, due to the pandemic situation, only two programmes of the Centre, reviewed below, could be used to support SESAME, and the number of supported participants from SESAME members was also smaller than usual.

TRIL - in 2020, 4 TRIL fellows (50% women) from SESAME members carried out their research/training at Elettra. These fellows came from the following SESAME members:

├ Iran: 2 participants
├ Egypt: 1 participant
├ Pakistan: 1 participant

ICTP-Elettra Users Programme - the programme brought 2 participants (both women) from SESAME members to Elettra Synchrotron Facility in 2020:

└ Egypt: 2 participants
ICTP is actively involved in building scientific capacity in the developing world through its Office of External Activities (OEA).

The purpose of the OEA is to promote scientific cooperation through its support of Affiliated Centres, Networks, Visiting Scholars/Consultants, and Scientific Meetings organized in developing countries. OEA activities are initiated by regional scientists and carried out at external sites within the same region.

Strong input and involvement are sought from ICTP scientists, in order to improve the programmes, and especially to identify potentially new Affiliated Centres, Networks, and Visiting Scholars.

The OEA activities are mainly funded through the ICTP regular budget.

In 2020, the COVID-19 pandemic had a considerable effect on the OEA programmes, as travelling became extremely difficult and physical meetings became nearly impossible to hold worldwide. Therefore, it was decided to modify some of the programmes, to enable the continuation of activities where possible, in the endeavour to not hinder the scientific capacity building of developing countries. Specifically, the scientific meeting grants can now also be used to sustain virtual scientific meetings through early career scientist awards and support for online platforms and conference material. Likewise Networks will also have the possibility to function virtually in the future, and therefore to receive grants to improve their online platforms.
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An Affiliated Centre is an Institute or University Department of Physics or Mathematics, in a developing country, that has either an active postgraduate course that leads to a Masters or PhD, or which has an active exchange programme that enables students to undertake research or training in order to benefit their Masters or PhD studies.

Affiliated Centres have a regional character and must be strongly supported by the local authorities and the hosting institute to ensure continuity.

The purpose of the programme is to award grants to Masters and PhD students from neighbouring countries of the Affiliated Centre, but not from the country of the Institute or University Department itself. The Affiliated Centres propose candidates to the ICTP to receive a grant. All documentation is evaluated, and a limited number of grants are considered/granted to each Affiliated Centre.

The number of students approved each year for funding is determined by the availability of funds for the programme. Support is provided to cover the students' travel and living expenses as well as tuition fees. The full amount is normally disbursed directly to the student. In some cases, the tuition fees can be paid directly to the Institute or University Department.

Grants are initially approved only for the year being requested and may be renewed for up to a maximum of four years, depending on the duration of the course. An ICTP scientist is also assigned to each student as tutor, in order to follow the performance of the student during their studies/research.

Students that are beneficiaries of the grants are required to submit reports throughout the year to document their progress. The Coordinator of the Affiliated Centre must also submit their evaluation of the student. The performance of the student is evaluated on a regular basis. Continuation of the financial contribution of ICTP for the following year depends on the positive evaluation of the reports and the availability of funds.

The Affiliated Centre must also submit a detailed scientific report, outlining the research activity being undertaken. The request for funding for the following year should be submitted by the Affiliated Centre co-ordinator before 31 October. This
allows the relevant Committee to consider funding for the following year.

Upon completion of the studies, the students are expected to submit a final report, which should include a copy of the thesis, transcripts, and diploma. This report should be signed by the student and the ICTP tutor.

In 2020, we had 11 active Affiliated Centres (5 in Africa, 3 in Asia, 2 in Europe and 1 in Latin America), in which we supported 22 postgraduate students. Due to COVID-19 restrictions, two of these students have still not managed to start their course.

▷ The Centre for Atomic Molecular Physics and Quantum Optics (CEPAMOQ), Douala, Cameroon, (two PhD students from Central African Republic and two PhD students from Chad)
▷ Center for Fundamental Physics, Zewail City of Science and Technology, Giza, Egypt (one PhD student from Morocco who did not manage to start)
▷ The Mohammed V University, Faculty of Sciences, Department of Physics, Rabat, Morocco, (one PhD student from Comoros)
▷ The East African Institute for Fundamental Research (EAIFR), Kigali, Rwanda, (one Master student from Sudan, one Master student from Togo, one PhD student from Cameroon, one PhD student from Democratic Republic of Congo, one PhD student from Nigeria who did not manage to start, one PhD student from Pakistan)
▷ University of Tunis El Manar, Faculty of Science, Department of Physics, LSA-MA Laboratory, Tunis, Tunisia (one PhD student from Senegal)
▷ The Joint Laboratory of Theoretical Physics, Yerevan, Armenia, (two PhD students from Iran)
▷ The Department of Mathematics, COMSATS University Islamabad (CUI), Lahore, Pakistan, (two Master students from Nigeria)
▷ The Asia Pacific Centre for Theoretical Physics (APCTP), Pohang, South Korea, (one PhD student from Vietnam)
▷ The Laboratory for Physical Studies at the Gomel State Technical University, Gomel, Belarus, (two PhD students from Ukraine)
▷ CiFRA - Centre International de Formation et de Recherche Avancees en Physique, Bucharest-Magurele, Romania (one PhD student from Morocco)
▷ The Instituto Balseiro, Centro Atomico Bariloche, Bariloche, Argentina, (one Master student from Guatemala)

A OEA Network is a system of research groups in an entire region, or among different regions that pursue a common scientific project over an extended period. The OEA supports networks because they are an efficient approach to overcoming the problem of isolation and counteracting brain drain. ICTP emphasises South-South collaboration, as well as the sharing of expertise and facilities, through supported exchanges of scientific visits within the Network.
Funding for a network is approved on a yearly basis and up to a maximum period of three years, subject to the positive evaluation of progress and annual reports. The number of Networks approved each year for funding is determined by the availability of funds for the programme. The funds cover the travel and lodging expenses of scientists who belong to the Network to visit other member Institutes. The member Institutes are expected to contribute to the local expenses relevant to the visits of the visiting scientists belonging to the Network. Hence, the Network should be strongly supported by the local authorities and the member Institutions. Awarded grants are transferred by ICTP to the Institute of the Network Coordinator, who is responsible for distributing the funds to the members of the network travelling, after receiving approval and the maximum grant amount from the OEA. Grants can be offered to young scientists to work for extended periods at institutes that are part of the network.

Requests for funding for the future years should be submitted every year. At the end of every year, an online report of the past year’s activities should be presented by the Network Coordinator. Continuation of financial support from ICTP for the following year(s) depends on the positive assessment of the previous year’s report, detailed programme for the following year and financial plan for the following year, and availability of funds. This allows the Committee to consider funding for the following year.

Before the end of the three years, a meeting should be organized with all the members of the network. The purpose of the meeting is to assess the results of the programme and the impact the exchange visits has had on the educational and research programme of the visitors and/or host institutions. The outcome of the meeting is very important to enable ICTP to evaluate the accomplishment of goals and consider new applications for funding. Automatic extensions are not envisaged.

In 2020, there were 7 active Networks: 3 in Asia, 2 in Europe and 2 in Latin America and the Caribbean.

- **Artificial Intelligence of Things for Low Power Wide Area Networks** - countries involved: India, Sudan, Nepal, South Korea
- **The Network on Black holes, Supergravity, Strings and Integrable Systems** - countries involved: Armenia, Azerbaijan, Georgia, Iran, Russia, Turkey, Ukraine
- **The Network on Electronic, Magnetic and Superconducting properties of novel 2D heterostructure materials including graphene/MoS2** - countries involved: India, Nepal
- **The Colombian Network on High Energy Physics** - countries involved: Colombia, Brazil, UK
- **The Latin American and Caribbean Network on Quantum Mechanics, Particles and Fields** - countries involved: Argentina, Brazil, Colombia, Cuba, Mexico, Venezuela
- **The South Eastern European Climate Network** - countries involved: Bosnia and Herzegovina, Croatia, Macedonia, Montenegro, Serbia
The Southeastern European Network in Mathematical and Theoretical Physics - countries involved: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Moldova, Republic of Macedonia, Romania, Serbia, Turkey, Ukraine

Due to the COVID-19 pandemic, only 2 visits took place in 2020.

This programme promotes collaboration between scientists working in institutions in the developing countries and leading scientists throughout the world. The visiting scientist is required to make two research visits over two years, each lasting three or four weeks. Longer stays are encouraged. The Visiting Scholar/Consultant carries out joint research with their counterpart and lectures students in their field of expertise, thus also enhancing the teaching faculty and the interaction with young researchers and students.

The programme offers an effective method to counteract the isolation of scientists, allowing them to maintain contacts and collaboration with leading experts from other countries.

ICTP support is provided primarily to cover the travel costs of the visiting scientists for travel to and from the host institution. The host institution is expected to cover all local expenses and make the necessary arrangements for the stay of the visiting scientist. Only in special cases, and concerning only least developed countries, may support be provided to cover subsistence costs of scientists.

After each visit, the Visiting Scholar should submit a report to the ICTP including the following items: a description of the work carried out, a description of the main results obtained, the perceived benefit to the host institution and any other comments. The host institution should also submit a report of the Visiting Scientist's visit, summarising the activities performed and the benefits to their department. Failure to submit the reports in due time delays reimbursements, processing of funding for the next visit or suspension of project.

There were 25 active Visiting Scholars in 2020 distributed as follows:

- 8 in Africa - Benin (2), Kenya, Madagascar, Morocco (3) and South Africa;
- 7 in Asia - Bangladesh, India (3), South Korea, Myanmar and Nepal;
- 10 in Latin America and the Caribbean - Argentina, Brazil, Colombia (2), Cuba (3), Mexico (2) and Peru.

Due to the COVID-19 pandemic, only 2 visits actually took place in 2020.

The OEA encourages the organization of international and regional scientific meetings in developing countries by offering financial assistance to the organizers of conferences, workshops, and schools. Applications are reviewed by experts in the appropriate area both for scientific merit and relevance to the region.
The ICTP funds were normally only utilized to cover the travel expenses of foreign participants and/or speakers from OEA supported countries in the region where the activity is taking place. With the arrival of COVID-19, it was decided that funds could also be used to improve the software and hardware needs of the organizer, thereby enabling meetings to be held online and for early career scientist awards and support for conference material.

After the activity, organizers must submit a scientific report which summarizes the outcomes of the activity, and a financial report, containing receipts for all expenses charged against the OEA grant. These must be submitted together with the final list of participants and the scientific programme.

In 2020, a total of 54 grants were assigned to scientific meetings in 34 countries. Due to the COVID-19 epidemic, only 11 of these scientific meetings could actually take place, and they were distributed as follows:

- 4 in Africa - Egypt (2), Mauritius (1), Tanzania (1)
- 3 in Asia - Indonesia (1), Pakistan (1), Philippines (1)
- 1 in Europe - Romania (1)
- 2 in Latin America and the Caribbean - Argentina (1), Colombia (1)
- 1 in Other - France (1)

The OEA strongly encourages its Affiliated Centres and Networks to collaborate with ICTP scientists in order to intensify their scientific efforts and build more effective partnerships by taking advantage of ICTP programmes and expertise. This is sometimes the case where PhD students can be shared in a type of "sandwich" programme with ICTP faculty having the opportunity to help in the selection. In this case, while the bulk of the training is done regionally, the students gain an association with an ICTP scientist, and the possibility to be selected for a relevant activity at ICTP to further increase the connection. Finally, through jointly-selected students the partnership becomes a real collaboration, strengthening ICTP’s ties to regional centres of excellence.

This is the case for the ICTP Partner Institute ICTP-EAIFR in Rwanda, where the OEA supports through its Affiliated Centre programme, Master and PhD students who have been selected by commissions involving ICTP scientists, who also act as co-supervisors of the students. The research at ICTP-EAIFR is currently in Condensed Matter, Geophysics and Particle Physics and Cosmology. EAIFR is also supported by OEA through its Network programme, with strong involvement of scientists from the ICTP Condensed Matter and Statistical Physics (CMSP) Section. Apart from an intra-Africa Network, this also comprises an Africa-Europe Network, which is funded by European institutions.
In 2020, the OEA collaborated with other ICTP Research Groups, by providing secretarial and administrative support to the:

- **Lightsources for Africa, the Americas, Asia and Middle East Project (LAAAMP)**, and the
- **INdAM Research in Pairs Project**.

**Lightsources for Africa, the Americas, Asia and Middle East Project (LAAAMP)** - ICTP is a supporting and collaborative partner of this IUPAP-IUCr project. Every year, LAAAMP invites Faculty-Student (FAST) Teams to submit an application, to spend two months at participating AdLSs. The LAAAMP Executive Committee meets and selects the FAST teams that will be awarded grants. In 2020, nine new FAST Teams were selected to receive grants, coming from Africa (4), Asia (3) and Latin America (2). However, due to the COVID-19 pandemic, these visits did not take place, but the LAAAMP Executive Committee agreed to support some participants in a course organized by X-TechLab (a LAAAMP partner) in Benin.

**INdAM Research in Pairs Project** - ICTP together with the Istituto Nazionale di Alta Matematica (INdAM) collaborate in a joint program of "Research in Pairs" aimed to fund research projects in mathematics, so that mathematicians from developing countries can collaborate with INdAM members at any research unit of INdAM. The costs are shared equally by INdAM and ICTP. In 2020, 11 applications were selected to receive funding, coming from Africa (1), Asia (3) and Latin America (7). However, due to the COVID-19 Pandemic, none of the visits managed to take place in 2020. It was agreed that these applicants have until the end of 2021 to use the funds.
The ICTP South American Institute for Fundamental Research (ICTP-SAIFR) has now completed its ninth year of theoretical physics activities in Sao Paulo. It is a collaboration between the Sao Paulo Research Funding Agency (FAPESP), the International Centre for Theoretical Physics (ICTP) - a category 1 institute of UNESCO, the Sao Paulo State University (UNESP), and the Instituto de Fisica Teorica (IFT-UNESP) in whose building it is located.

Research at ICTP-SAIFR includes diverse areas of theoretical physics including string theory, field theory, condensed matter, particle physics, cosmology, general relativity, astrophysics, complex systems, and mathematical biology. Researchers are also members of important international collaborations such as the CMS detector at the LHC, the LIGO, and the Dark Energy Survey collaborations.

Despite the onset of Covid-19 in March 2020, there were several highlights for ICTP-SAIFR during the past year. In February, ICTP-SAIFR researchers Riccardo Sturani and Ricardo Martinez-Garcia were approved in a concurso for permanent researchers at IFT-UNESP. Sturani is an Italian physicist and key member of the LIGO-Virgo collaboration which was recently awarded the Nobel Prize for the detection of gravitational waves. He first came to ICTP-SAIFR in 2013 as a FAPESP Young Researcher, then went to IIP-Natal as a visiting professor, and returned to ICTP-SAIFR this year. Martinez-Garcia is a Spanish physicist working on complex systems related to biodiversity and came to ICTP-SAIFR in 2019 with a Simons-FAPESP Young Investigator fellowship. They will join faculty member Pedro Vieira, winner of the 2020 New Horizons in Physics Prize for his research in field theory and integrability. Vieira was granted a 5-year FAPESP Excellence Chair in March, which allows him to spend 6 months each year at ICTP-SAIFR and six months at Perimeter Institute in Canada.
In July, ICTP-SAIFR was awarded a Covid-19 Innovation Grant from the American Physical Society (APS) for its project "Modern Physics in the Latin-American Classroom". Only two such grants were awarded out of sixty eight proposals, and the grant will fund the translation of classroom material on modern physics, developed by the Perimeter Institute, into Spanish by ICTP-SAIFR. And in October 2020, ICTP-SAIFR director Nathan Berkovits was announced as the recipient of the 2021 John Wheatley Award for his "exceptional leadership in fundamental physics research in South America", along with former ICTP director Fernando Quevedo. This award is granted every two years by the American Physical Society to honor physicists who have made contributions to the development of physics in countries of the developing world.

ICTP-SAIFR greatly expanded its activities in the research area of complex systems with applications to biology in 2020. In addition to organizing activities before the pandemic on mathematical biology, community ecology, infectious disease dynamics and biophysics, ICTP-SAIFR hosted the six-month visit of Jose Nelson Onuchic, co-director of the NSF Center for Theoretical Biological Physics at Rice University. In November, the private Serrapilheira Institute approved a new initiative, called the Serrapilheira/ICTP-SAIFR Training Program in Quantitative Biology and Ecology, which will be an annual six-month program organized by ICTP-SAIFR for master's students from all areas of physical sciences who want to apply their quantitative skills in biological problems. And in December, a paper co-authored by ICTP-SAIFR professor Martinez-Garcia on competition in plant growth was the cover article for Science.

Starting in April, all workshops and schools were converted into online activities and covered topics such as integrability, string theory, cosmology, particle physics and dark matter. ICTP-SAIFR also organized online minicourses every Saturday morning for high-school students, biweekly informal talks for the general public, and over 100 classes for high-school physics teachers on how to introduce modern physics topics into the classroom. These online activities attracted thousands of participants from all regions of Latin America as well as from Portuguese-speaking countries in Africa.
The International Centre for Theoretical Physics Asia-Pacific (ICTP-AP) operates in affiliation with the University of Chinese Academy of Sciences (UCAS) and under the auspices of UNESCO. ICTP-AP is run in cooperation with the Chinese Academy of Sciences (CAS), the National Science Foundation China (NSFC), and the Abdus Salam International Centre for Theoretical Physics (ICTP). Its establishment was approved by the 38th session of the UNESCO General Conference in 2015. An agreement for the establishment of ICTP-AP was signed in May 2017 and its formal operation began in November 2018 following the finalization of all internal administrative steps in China.

As China’s first UNESCO category 2 centre in the area of basic science, ICTP-AP is a non-profit organization and will carry out high-level scientific research, education and training in basic science such as frontiers of theoretical physics and the relevant interdisciplinary areas.

ICTP-AP organized a series of scientific activities to facilitate international academic collaboration, the exchange of scholars, the education and cultivation of young talent, and outreach to the public through lectures and activities. ICTP-AP has contributed to the promotion of scientific cooperation, talent cultivation, and development of fundamental physics.

The summer school invited fourteen experienced scientists from Taiji Consortium to give a series of online lectures on gravitational wave related studies. Topics of the lectures mainly focused on gravitational wave detection technology, gravitational wave source, and data analysis and processing.

Due to the influence of the coronavirus pandemic, the summer school was carried out online, which gave more people opportunities to access fundamental science. Nearly 900 participants gathered online to explore the mysteries of gravitational waves and enjoy the charm of science. After the expert group assessment, five students were selected as outstanding students. They will have opportunities to be admitted to ICTP-AP without examination.

The discovery of gravitational waves (GWs) by the LIGO collaboration in 2016 provided a direct test of the prediction made by Albert Einstein a century ago, based on his general theory of relativity. GWs are expected to provide a new window to explore the evolution of the early universe and the nature of gravity.

The Taiji Programme in Space is proposed to detect GWs with frequencies covering the range of 0.1mHz to 1.0Hz with higher sensitivity around 0.01–1Hz than eLISA. The programme proposes to use a triangle of three spacecrafts in orbit around the Sun. Laser beams are sent both ways between each pair of spacecraft, and the differences in the phase changes between the transmitted and received laser beams at each spacecraft are measured. The preliminary design for the Taiji mission is based on 3-million-kilometer separations between the spacecraft, and the expected launch date is about 2033.
The purpose of Taiji programme is to study the most challenging issues concerning massive black holes, such as how the intermediate mass seed black holes were formed in the early universe, whether the dark matter could form a black hole, how a seed black hole grows into a large or extremely large black hole and what is the nature of gravity.

Taiji-1 is the first experimental satellite of the Taiji Programme. It marks the first under the Phase-II of the Strategic Priority Programme on Space Science (SPPSS-II) sponsored by the Chinese Academy of Sciences (CAS). As professor Yueliang Wu, Director of ICTP-AP, is the chief scientist of the Taiji programme, ICTP-AP is responsible for the implementation, scientific research and management work.

ICTP-AP was responsible for the overall planning and coordination of the Taiji-1 project. Moreover, ICTP-AP undertook the construction and development of the scientific application system which was one of the six systems of the Taiji-1 project. Furthermore, ICTP-AP joined the research of the hall-effect microthrust system.

On August 31st, 2019, Taiji-1 launched successfully from Jiuquan Satellite Launching Centre in northwestern China. By the end of 2019, the in-orbit tests were successfully completed, the functions and performance indexes of the satellite met the general requirements, and the results exceeded expectations. The in-orbit tests showed that:

- The accuracy of the displacement measurement of the laser interferometer on Taiji-1 could reach a 100-picometer order of magnitude.
- The accuracy of the gravitational reference sensor on the satellite reached ten billionths of the magnitude of the earth's gravitational acceleration.
- The thrust resolution of the micro-thruster on the satellite reached submicron-Newton scale.

Taiji-1 achieved China's highest accuracy of spatial laser interferometry; successfully conducted China's first on-orbit drag free control technology test; firstly and internationally on-orbit verification of micro-newton level radio frequency ion propulsion technology and dual mode hall-effect micro thruster technology.

Taiji-1 project was selected as one of China's top ten scientific and technological progress news. The experimental results verified the correctness and feasibility of the technical route and scheme of 'Taiji Programme'. It took the first step and laid a solid foundation for the first breakthrough in space gravitational wave detection in China.
We started global recruitment in 2019. We received 70 resumes from all over the world from scientists applying for the position at ICTP-AP. After strict screening and interviews, the selection committee finally decided to enroll Xiaoyong Chu and Nian Jun in tenure track positions at ICTP-AP. Moreover, we have appointed a new associate director Song He to provide intellectual and organizational leadership and strategic guidance to the Centre. All of them have rich working experience of international cooperation. They will support the development of education and scientific research at ICTP-AP.

We have promoted global recruitment of the postdoctoral position in the area of: quantum cosmophysics, gravitational waves and detection, plasma physics, space propulsion and drag free technologies, advanced space materials and laser interference ranging systems. Currently, ten postdocs from three countries and regions have joined the research team of ICTP-AP.

As a UNESCO category 2 centre, ICTP-AP serves the overall goal of global sustainable development and serves UNESCO. It is our obligation to provide opportunities for advanced education, training and research in basic science such as frontiers of theoretical physics and the relevant interdisciplinary areas for scientists from Asia-Pacific region and other countries.

ICTP-AP is jointly cultivating international students with the International College of UCAS to provide advanced education for students from all over the world. The students are mainly coming from five continents, 85% of them are from developing countries. In order to provide equal access to advanced education for students from all over the world, there are several scholarships to sponsor young talents from abroad who have financial difficulties:

1. **ANSO Scholarship**: Master student awardees will receive a monthly stipend of RMB 3000, while PhD awardees will receive a monthly stipend of RMB 6000 or RMB 7000 depending on whether they have passed the qualification test arranged by USTC/UCAS for all doctoral candidates after admission.
2. **The "Belt and Road" Master Fellowship Programme**: Monthly stipend to cover accommodation, local transportation expenses, health insurance, and other basic living expenses (Reference: RMB 4000 per month, within which RMB 1000 is provided by UCAS faculty/CAS institute).
3. **UCAS Scholarship**: The total amount of the monthly stipend will be no less than RMB 3500 for PhD students, senior visiting students and students on joint programs, with RMB 3000 for Master students and regular visiting students.

On average, 65% of international students won the scholarships, which provided financial support for their study and daily life.

In order to promote innovative research in basic science and promote the dissemination and exchange of knowledge, ICTP-AP plans to hold short-term schools with various themes during students' vacations. The schools aim to serve the
Activities in Developing Countries

overall goal of global sustainable development and member states of UNESCO. Students from China and abroad have equal access to apply for the short-term schools.

Apart from daily study and academic activities, international students have lots of opportunities to participate in Chinese traditional cultural activities

**Cultural Exchanges**

**Biennial Plan**

The Biennial Plan is based on the Mid-Term Strategic Plan for 2019-2023, which defines the vision, mission, value and objectives of the work for ICTP-AP. This biennial work plan outlines the actions that will be implemented by ICTP-AP during 2020-2021, so as to ensure satisfactory progress in meeting the targets set by the Mid-Term Strategic Plan. The biennial plan provides the work plan for the next stage, including activities, scientific research projects, talents introduction and budget plan.

Due to the influence of coronavirus pandemic, ICTP-AP could not hold international conferences or people gathering public activities in the first half of 2020. Therefore, lots of activities planned were canceled or delayed. However, after the pandemic, ICTP-AP will start to develop outreach activities in cooperation with national and international institutions. ICTP-AP plans to hold international forums that will enhance international collaborative networks among scientists. Moreover, the meeting of the Taiji consortium is planned to be held annually. Scientists from domestic scientific research institutions will participate in this meeting to report the progress of the Taiji programme and exchange their latest scientific research results. All the activities are open to students without any restrictions. They could not only get access to the top scientists and research results but also enrich their knowledge and cultivate their interest in physics learning.

**Develop Outreach Activities and Strengthen International Collaboration**
To achieve the goal of becoming a world-class research center, training base for talents with global eye sights and international academic exchange center, ICTP-AP will build a professional academic environment and upgrade research facilities. ICTP-AP participated in the construction and management of Hangzhou Institute for Advanced Study, UCAS (HIAS). In order to improve the scientific research and training level, ICTP-AP started global recruitment from 2019 to attract talents who could compete to cultivate students with strong comprehensive ability and international vision.

HIAS was founded in 2019, jointly established by the Hangzhou Municipal People’s Government and the University of Chinese Academy of Sciences. Facing the development of frontier science and technology in the world and centering on the major needs of China and the needs of regional economic and social development, it implements a new type of teaching and scientific research institution that integrates science and education. Its management of affiliated colleges adopts the chief professor studio system. Combining with the basis of economic and social development of Hangzhou, HIAS has set up seven colleges and two key laboratories.

The school of Fundamental Physics and Mathematical Sciences is jointly constructed by ICTP-AP and the Institute of Theoretical Physics, CAS (ITP). The school is seeking major breakthroughs in the field of quantum cosmic physics, space propulsion, key technology of drag-free systems. The school focuses on five directions: applied mathematics and mathematical physics, fundamental mathematics, quantum phase physics and applied fundamental physics, quantum biophysics and the origin of life, and computational physics and data science. HIAS has established cooperation with leading universities and research institutions from domestic and abroad. It is determined to build itself into an international first-class scientific research center, an international talent training base and an open international academic exchange platform.

In order to develop and coordinate research education-oriented advanced studies in theoretical physics and related interdisciplinary areas, ICTP-AP is doing global recruiting for about 56 excellent scientific researchers undertaking scientific research and teaching tasks in Beijing and Hangzhou respectively. The improvement of facilities and human resources will promote integration of advanced scientific research and education, especially in the Asia-Pacific region within the concept of “science for development”.

Along with the School of Fundamental Physics and Mathematical Sciences, HIAS has appointed two tenured professors and eighteen bilateral contractual researchers with institutions from CAS.
The Mesoamerican Centre for Theoretical Physics (MCTP) was created in collaboration between ICTP and the Universidad Autónoma de Chiapas (UNACH), in order to establish a regional headquarters of the ICTP in Mexico, Central America and the Caribbean. MCTP activities take place across several countries of the region. These countries share a common language, some of the greatest biodiversity on the planet, as well as joint problems. Therefore, scientific and technological research needs to be integrated into a regional and international scenario, based on expanding cooperation and opportunities.

In response to these needs, the Federal Government of Mexico, the Government of the State of Chiapas, UNACH and ICTP, have joined forces to provide opportunities for sustainable development and to significantly impact the competitiveness of the region.

The main objective of the MCTP is to develop advanced teaching and research in basic and applied sciences in Physics, Mathematics, Energy and Environment, through professional and advanced teaching, scientific, technological and innovation research, and the union of this knowledge and services to the society.

For the Mesoamerican Centre for Theoretical Physics, the scientific research work of its researchers, guest lecturers, and associated researchers is of vital importance for the generation of knowledge. Therefore, a strong group of researchers has been created within the MCTP.

Research at MCTP has been developed on a regular basis, despite the challenges posed.

In order to supply and reinforce academic and scientific capacities, in addition to ensuring the permanent operation of the programs, the Regional Headquarters of the MCTP, in agreement with the academic and scientific institutions of the region, will promote and guarantee the mobility of researchers and students. These agreements seek to maintain a permanent academic exchange that ensures the presence at the MCTP of scientific staff of recognized level with affiliation in the associated institutions.

The MCTP organizes international conferences, workshops, seminars and colloquia. Every year financial support is available for participants who attend. This program includes the research areas: Energy, Physics, Mathematics and Environment. The 13 events during 2020 held a total of 751 participants.
1. Seminar: Dinámica caótica de condensados polaritonicos  
   Speaker: Mtro. Ricardo Ruiz Sánchez.  
   January 16, 2020  
   17 participants

2. Seminar: Uso de cómputo de alto rendimiento en el modelado de materiales con potencial aplicación en conversión y almacenamiento de energía  
   Speaker: Mtro. Alfredo Guillén López.  
   12 participants

3. Seminar: Invariantes de espacios de configuraciones de tuplas que conmutan  
   Speaker: Mtro. Ángel Jiménez Cruz  
   41 participants

4. Seminar: Una década de simulaciones cosmológicas: de materia oscura a observaciones sintéticas  
   Speaker: Dr. Vicente Rodríguez Gómez  
   34 participants

5. Quinto Ciclo de Talleres y Conferencias sobre Ciencia y Tecnología para Educación Básica y Media Superior 2020  
   312 participants

6. Seminar: Películas de proteínas producidas por el secado de micro-gotas  
   Speaker: Dra. Yojana Jautzi Carreón Herrera  
   33 participants

7. Seminar: La Máquina de Turing y el Código Enigma  
   Speaker: Eduardo Maza  
   31 participants

8. Tercera Olimpiada Mesoamericana de Física  
   30 participants

9. XV Escuela de Física Fundamental  
   39 participants

10. Seminar: Searches for a Lorentz violation with astroparticle Physics  
    Speaker: Dr. Humberto Martínez Huerta  
    October 01, 2020.  
    50 participants

11. V Encuentro de Modelado Matemático en Física y Geometría  
    42 participants

12. IV Mesoamerican Workshop on Cosmology and Gravitation  
    78 participants

13. Avances y Perspectivas del MAIS como Centro Categoría 2 de la UNESCO  
    32 participants

<table>
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<tr>
<th>Country</th>
<th>Number of Participants</th>
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<td>Mexico</td>
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<td>Italy</td>
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<td><strong>Total</strong></td>
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</tr>
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</table>
Located on the University of Rwanda, Kigali campus, International Centre for Theoretical Physics - East African Institute for Fundamental Research (ICTP-EAIFR) is a vibrant, international hub of advanced education and research, poised to become one of the most important physics institutes in Africa. It is a partner institute of the Abdus Salam International Centre for Theoretical Physics (ICTP), and is also a Category 2 UNESCO Institute.

ICTP-EAIFR has been developed in response to a need in Rwanda and the region for both masters and doctoral degrees in various areas of physics, both fundamental and applied. All aspects of ICTP-EAIFR are based on scientific merit with a positive bias to gender equality and geographical distribution. ICTP-EAIFR is a moment’s walk away from the University of Rwanda’s departments of physics and mathematics, with which it enjoys close collaboration.

In 2020 four from our first set of MSc students found PhD positions abroad, we admitted 34 new MSc students and started online courses for those able to join. We enrolled five PhD students, engaged in online teaching of our continuing Masters students, held two workshops face-to-face before the lock downs due to the COVID pandemic, published five papers in high-impact journals, organized 10 seminars in person, nine online seminars, and three online colloquia. We submitted four grant proposals, received equipment (4 computer nodes from a 2019 TWAS Grant), and a grant (5,750 EUR) for a 2021 workshop.

Enrollment

MSc enrollment: 13 new MSc students involved in online learning; 10 Males, 3 Females; 5 Rwandans, 8 non-Rwandans. A total of 150 applied and 68 were shortlisted for interviews. Of the 68, 34 were shortlisted for admission).

PhD enrollment: 2 Rwandans and 3 Internationals. All 5 males. (One Female PhD admitted; to be funded by OWSD and to enroll in 2021. Another PhD who was admitted in 2019 to be enrolled in 2021 – enrollment postponed due to COVID).

Teaching of MSc students

Teaching was mainly done via internet (e-learning). This is fraught with different problems.

- MSc teaching for current (new) 1st year students: Started online in November 2020.
- MSc teaching for current 2nd year students: Started in person and online in November 2020 (most courses taught from ICTP Trieste Italy)
- MSc teaching for outgoing (graduating) 2nd year students: Concluded online and in person.
Activities in Developing Countries

Four students accepted for PhD at:

- University of Houston, USA in Condensed Matter Physics.
- University of Houston, USA in High Energy Physics.
- University Catholique Louvain (UCL) Belgium in High Energy Cosmology and Astroparticle Physics.
- University of the Basque Country, Spain in Materials Physics.

Furthermore:

- Two students hired as secondary school teachers in Rwanda.
- Two students already working at UR Physics Departments as Teaching Assistants.
- One student still awaiting response from a couple of Universities.

Training Activities

2020 African School of Catalysis
20 — 24 January

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<tr>
<td>Total</td>
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Regional African School of Electronic Structure Methods and Application (RASESMA) with ABINIT
27 — 31 January

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<thead>
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<th></th>
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<th>Male</th>
<th>Total</th>
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<tbody>
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International Conference of the African Physical Society

Organizers: Amna Abdalla (Georg August Universitaet Goettingen, Germany)
Akintayo Adedoyin (University of Botswana, Botswana)
Omololu Akin-Ojo (EAFIR, Rwanda)
Gebremedhin Gebreyesus (University of Ghana, Ghana)
Sekazi Mtingwa (TriSEED Consultants, USA)
Lawrence Norris (African Light Source Foundation, South Africa)
Ahmadou Wague (Cheik Anta Diop University, Senegal)

Local Organiser: Ali Hassanali (ICTP)
In collaboration with ICTP and the African Physical Society (AfPS)
**Microscopic Model for Magneto-Electric**  
13 January, Dr. Daniel Cabra Instituto de Física La Plata, IFLP, Argentina.

**Quantum Simulators**  
16 January, Prof. Rosario Fazio, ICTP, Italy.

**Reflections on the Role of Water in Biology**  
3 February, Dr. Ali Hassanali, ICTP, Trieste, Italy.

**Quest for Quantum Gravity, the Necessity and Viewpoints**  
5 February, Prof Mohammad M. Sheikh Jabbari, ICTP, Italy.

**Dark Matter and its Various Candidates**  
6 February, Prof Yasaman Farzan Trieste, Italy.

**The Mathematics of Impartial Games**  
7 February, Prof. Fernando Rodriguez Villegas, ICTP, Italy.

**Measuring Entanglement in Many-Body Systems via Thermodynamics**  
19 February, Dr. Tiago Mendes-Santos, ICTP, Italy.

**Atomic Nuclei for Beyond Standard Model Physics**  
20 February, Dr. Jason D. Holt McGill University, and TRIUMF, Canada.

**Advances in Quantum Chaos**  
26 February, Prof. Alex Altland, University of Cologne, Germany.

**Quantum Smooth Boundary Forces from Constrained Geometries**  
4 March, Prof. Jean Pierre Gazeau, Paris University.

* **Crystal Structure Predictions from First Principles**  
July, Krzysztof Szalewicz, University of Delaware.

* **Accelerating Materials Discovery Through High-Throughput Ab Initio Calculations and Data Mining**  
20 August, Prof. Gian Marco Rignanese, UCLouvain, Belgium.

* **DFT+U and Beyond**  
21 September, Prof. H. J. Kulik, MIT, USA.

* **Cosmic Tides and Structure Formation**  
24 September, Prof. Aseem Paranjape, IUCAA, India.

* **New Pillared Clay and Graphene Oxide Structures**  
October 1, Prof. Petra Rudolf, Zernike Institute for Advanced Materials, University of Groningen, Netherlands.

* **Defect and Dynamic Properties of Perovskite Halides from First Principles**  
8 October, Dr. Maria Chan, Argonne National Lab, USA.

* **Theory & Computation at Work in a Nanoscience Center: Excited States, Machine Learning & X-ray Absorption**  
15 October, Mark S. Hybertsen, Brookhaven National Laboratory, Center for Functional Nanomaterials, USA.

* **Essential Role of the Minority Sites in Catalysis on Small Nanostructures**  
5 November, Prof. Ali Haider, Indian Institute of Technology, Delhi, India.

* **From First- to Second-Principles Modelling of Ferroelectric Perovskites: A Historical Perspective**  
12 November, Prof. Philippe Ghosez, University of Liège, Belgium.

* **New Frontiers for Physics in Africa: From Solar Cells and Light Emitting Devices to Medical Physics**  
16 July, Professor Wole Soboyejo, Worcester Polytechnic Institute, Massachusetts, USA.

* **Perspectives in QFT**  
17 September, Professor Steve Weinberg (University of Texas at Austin, USA.

* **Machine Learning and Molecular Dynamics**  
22 October, Professor Michele Parinello, affiliated with the Department of Chemistry and Applied Biosciences, ETH Zurich, Switzerland, as well as the Facoltà di Informatica, Istituto di Scienze Computazionali, Università della Svizzera Italiana, Lugano, Switzerland, and the Istituto Italiano di Tecnologia, Genoa, Italy.
**Scientific Talks**

- **Exploring mass degeneracies in extended Higgs sectors**
  16 June, Dr. Shoaib Munir, seminar at ICTP.
- **The Multiconfiguration Time Dependent Hartree (MCTDH) Approach and Applications in Gas Phase and Condensed Phase Chemistry**
  May, Dr. Steve Ndengue, seminar at ICTP.
- **Spherical collapse and virialization: numerical analysis and analytical toy models**
  23 April, Dr. Marcello Musso, IFPU Large-Scale Structure Meetings.
- **The Energy of Dark Matter Haloes. A new guideline to model virialized structures**
  23 June, Dr. Marcello Musso, ICTP Cosmology Seminars.
- **UV and IR absorption spectrum of nitrogen dioxide and water dimer: assessing the accuracy of electronic structure calculations and experiments**
  November, Dr. Steve Ndengue, Online African Physical Society International Conference.

**Proposals**

- Co-authors “New Trends in High Energy Physics” for Intra-Africa Academic Mobility Scheme, Call for proposals EACEA/07/2020 with Dr. Shoaib Munir and Dr. Marcello Musso.
- Co-proposals for “HIDDeNPlus” Topic MSCA-RISE-2020 Research and Innovation Staff Exchange. With Dr. Marcello Musso, Dr. Shoaib Munir, and researchers at University of Durham.
- **Excellence in Africa** proposal submitted in April by Dr. Steve Ndengue. [https://actu.epfl.ch/search/exaf/](https://actu.epfl.ch/search/exaf/)
- Grant proposal for student payment at UCLouvain by Dr. Marcello Musso and Dr. Marco Drewes (UCLouvain).

**Funding**

- Acquisition of a four-node computer cluster from TWAS grant funds.
- Received 5,750 EUR grant from Psi-K (Europe) for Machine-Learning Training Workshop scheduled for Feb 2022.
Physics Without Frontiers

Afghanistan/Iran
MSc Programme

Physics Without Frontiers (PWF) partners with the Institute of Advanced Studies in Basic Sciences, IASBS, Iran, to offer ICTP-PWF-IASBS Scholarships for a taught 2 years physics master's degree. Afghanistan currently has no masters programme and, in this way, PWF supports top students to continue their studies to build capacity for the region.

↗ 2019 – 2020 Scholarships 5 students.
↗ 2020 – 2022 Scholarships 7 students.

Lesotho
School on Quantum Computing
National University of Lesotho
14-15 November 2020

Malaysia
School on Quantum Information
Universiti Putra Malaysia (UPM)
2-6 November 2020

South America
Master Thesis Project

The school introduced quantum computing to 30 undergraduate students utilising open-source quantum computing platforms, highlighting how quantum computing can be used as a driver for the Fourth Industrial Revolution. Students received lectures and hands-on tutorials using platforms such as QuTip, Qiskit, Braket, Google Cirq and TensorFlow Quantum.

The school introduced 35 students to frontier topics in quantum information by inviting 7 international prominent researchers in the relevant area. The programme was conducted online providing hands-on training through analysis and problem-solving sessions and educated students about careers and opportunities in research.

After many years of successful PWF programmes across South America, 6 excellent physics students have been identified to be supported by PWF to work with supervisor Arturo Sanchez (ICTP, PWF Latin America group, CEVALE2VE) on a MSc equivalent thesis in High Energy Physics (HEP) using ATLAS Open Data. The created PWF resources will be created in Spanish and made available online for public use in 2021.

BrainGain
Venezuela

Advanced Quantum Mechanics University Course

The PWF’s programme BrainGain aims to support professors and teaching assistants working in Venezuelan Universities with bachelor programmes in physics. The goal of the initiative is to fight brain drain supporting the fellows to focus on their research projects and to provide high-quality education to the students enrolled in the courses.

↗ 2019 – 2020 Fellows 4 professors.
↗ 2020 – 2021 Fellows 8 professors, 2 teaching assistants.

Iraq
Lecturer training, Salahaddin University

PWF partnered with Salahaddin University in the Kurdistan Region of Iraq to provide training and resources to a lecturer to teach advanced quantum mechanics in his university.
ICTP awarded its 2020 Dirac Medal and Prize to three distinguished physicists – André Neveu of University of Montpellier, Pierre Ramond of University of Florida, and Miguel Virasoro of Universidad Nacional de General Sarmiento – “for their pioneering contributions to the inception and formulation of string theory which introduced new Bosonic and Fermionic symmetries into physics”.

String theory is physicists’ latest proposal for a unified theory of physics, attempting to put together Einstein’s general theory of relativity, that describes gravity, and quantum mechanics, that describes the fundamental elements of matter. String theory is of great importance in addressing several questions in fundamental physics, and has been applied in various fields, such as the study of black holes, the early universe, condensed matter, and so on, and has favoured major developments in pure mathematics, thanks to its complex and rigorous formulation.

The first developments of the theory came into being in the late 1960s, when it immediately appeared as a promising candidate for a quantum theory of gravity. Its earliest version was a Bosonic string theory, that is, a formulation that described only the class of particles called bosons. Bosons are particles which have integer spin (0, 1, 2 and so on, measured in units of Planck’s constant), such as photons, gravitons or the famous Higgs boson. On the other hand, fermions are particles with half-integer spin (1/2, 3/2, 5/2 and so on, measured in units of Planck’s constant), such as electrons, protons and quarks.

In the late 1960s, Miguel Virasoro started working on an ambitious project in the field of theoretical physics, at first with Gabriele Veneziano and then later on his own. This work was mainly focussed on the development of the so-called “Veneziano model”, a mathematical model characterized by specific properties that later made it the first recognized string model. Inspired by the work of Veneziano, that described ‘open strings’, Virasoro developed his own model, later recognized as a ‘closed string’ model. At the time these studies were performed, a theory of strings was not yet fully or clearly developed, and these models were only years later recognized as perfectly describing the physics of strings.

Virasoro continued giving important contributions to the field by studying the mathematical properties of these models, and noticed that they featured some symmetries, characteristic of the model. He identified and formalized these symmetries, that are now known as the “Virasoro algebra”, a complex Lie algebra widely used in two-dimensional conformal field theory and in string theory. This
work was of great interest also from the point of view of pure mathematicians, as it is an infinite-dimensional Lie algebra, while until then Lie algebras were normally finite-dimensional.

André Neveu and Pierre Ramond, on the other hand, are responsible for the inclusion of the Fermionic degrees of freedom in the theory. Much of the work done by Virasoro was in fact dedicated to Bosonic strings, the first ones to be studied in the field of string theory. Neveu and Ramond expanded these works, extending the calculations to include the other portion of matter, made up by fermions.

The work done by Andrè Neveu in the early 1970s, together with John Schwarz, and independently by Pierre Ramond, is now known as the RNS formalism, after the initials of its three originators. This was the initial development of superstring theory, generalizing the Virasoro algebra - which is the symmetry algebra that describes boson strings - to an algebra that could also describe fermions, thanks to the property of supersymmetry. This formulation allowed to model all particles and fundamental forces in the Universe as vibrations of tiny supersymmetric strings, thus the name of “superstring” theory, accounting for both fermions and bosons.

The 2020 ICTP Prize was awarded to two physicists in the field of condensed matter physics.

Dibyendu Roy of the Raman Research Institute, Bangalore, India and Mehdi Kargarian of Sharif University of Technology, Tehran, Iran, shared this year’s prize for their groundbreaking work in non-equilibrium properties of mesoscopic systems and topological phases and strongly correlated electrons, respectively.

Dibyendu Roy’s work has led to a deeper understanding of particle, heat and energy transport in open quantum systems. Of particular importance are his seminal works on topological superconductors as well as the interaction of light with matter, including strong photon-photon interactions in waveguide quantum electrodynamic systems. His theoretical predictions have since been verified in spin noise spectroscopy experiments.

Mehdi Kargarian has discovered two of the first examples of fractionalized topological phases where both electron-electron interactions and spin-orbit coupling are important. He also predicted new phases of matter which are known as “weak topological Mott insulator” and the “topological crystalline Mott insulator”. Within Iran, Mehdi has served as mentor to a new generation of scientist and provides a key bridge to global scientific developments in the theory of interacting topological phases of matter.
ICTP awarded the 2020 Ramanujan Prize for Young Mathematicians from Developing Countries to Carolina Araujo of the Institute for Pure and Applied Mathematics (IMPA) in Rio de Janeiro, Brazil. In particular in birational geometry and the theory of extremal rays, of which she gave important applications, in particular obtaining a characterization of projective spaces and hyperquadrics; for her work in the study and classification of Fano varieties, and her study of algebraic foliations. Araujo has also played a key role in promoting women in mathematics and in the organization of important mathematical activities.

Araujo specializes in algebraic geometry, including birational geometry and foliations. She obtained her PhD in mathematics from Princeton University in 2004. She has been a Simons Associate with ICTP since 2015, and is the vice president of the Committee for Women in Mathematics at the International Mathematical Union.

ICTP and the International Commission for Optics announced the recipient of the 2020 ICO/ICTP Gallieno Denardo Award: Kok Sing Lim from the Photonics Research Centre, University of Malaya, Malaysia. Dr. Lim was recognized “for his achievements in the field of optical fibre sensing and optical communications, and his substantial contributions to sustainable development in Malaysia through promoting the use of optics-based technologies in the industrial sector.”

The family of ICTP founder and Nobel Laureate Abdus Salam revealed the winners of the 2020 Spirit of Abdus Salam Award. Announced annually on 29 January—Abdus Salam’s birthday—the award recognizes those who, like Salam himself, have worked tirelessly to promote the development of science and technology in disadvantaged parts of the world. The 2020 recipients were: M.S. Narasimhan, former head of ICTP’s Mathematics section and a member of the Scientific Council, and Erio Tosatti, a co-founder and senior member of ICTP’s Condensed Matter and Statistical Physics section.
The Marie Curie Library provides high-quality resources and services to support scientific research, learning and teaching in the subjects on which ICTP’s research focuses. The Library also preserves and curates documentation on the institution’s history and runs programmes aimed at the dissemination of scientific literature in least developed countries.

Authorized users are scientists, students and staff at ICTP, The World Academy of Sciences (TWAS), the Organization for Women in Science for the Developing World (OWSD) and, based on a reciprocal collaboration, professors and students of the International School for Advanced Studies (SISSA) and of the Department of Physics and other Departments of the Trieste University. Researchers working in other institutions of the Trieste System scientific network can apply for a consultation-only access.

**Library team**

**3 GS staff:**
- Nicoletta Zar (GS-6 eResources and Serials, Library Head ad interim*)
- Gianna Rapetti (GS-5 Cataloguing/Classification)
- Valerio Cappellini (GS-5 Information/Circulation)

**2 PA staff:**
- Tomasz Abramowicz (GS-4 Digital Media and Archives - shared with PIO)
- Dora Tirana (GS-4 Acquisitions)

**1 TA staff:**
- Jana Tufegdzic (GS-3 Library Assistant)

*The international recruitment procedure for the post of Head, Library Services -vacant since August 2017- is underway. The announcement was posted early in August 2020 on the UNESCO Careers webpage.

**A Year in Review**

2020 has been a most unusual year, not a year to be depicted in figures. The year began with momentum on the wave of the beginning of the mandate of the new Director. A Working Group - Library was established to address topics relevant to the library services in collaboration with the Library Committee in office.

At the end of January Ms Zar was invited to participate in the management’s brainstorming session in preparation of the next ICTP strategic plan and did a presentation on the need to reorient the Library services to respond to the ongoing changes in scholarly communication and access to information to better support the institutional strategy.

Mid-February, after 6 weeks only of regular working conditions, following Italy’s Covid-19 containment measures, the opening hours were reduced and limited to
working days (Monday to Friday). This resulted in the non-renewal of the contract of five library assistants who worked on-call in the evenings and weekends.

Starting March 10th all staff was requested to stay home and switch to teleworking, while all in-person activities organized by ICTP were cancelled until further notice. The Library had to close its physical spaces.

As most libraries around the world, the Marie Curie Library had to adapt to new ways of working as external circumstances forced us to change routines and habits, undermining our certainties, and depriving us of most of our users. Due to cancellation of activities, instead of our traditional user base of over 5000 visitors per year, the only users were faculty, postdocs and students of the Masters in Medical Physics and High Performance Computing and the students of the Postgraduate Diploma Programme, who rarely came on campus. The demand for books, articles, and reference services decreased dramatically.

Teleworking both for staff and users brought strong limitations. Remote access to a range of eResources (around 2000 eJournals and over 500 eBooks plus two databases) requires authenticated access, and many users had to be assisted in configuring the VPN access.

Due to the nature of its collections (a print collection of 73,500 books and around 2,500 linear meters of volumes of bound periodicals) the service is mainly based on physical access. One of the benefits of in-person library attendance is the opportunity it provides for serendipitous findings. Moreover in-person reference services make up a lot of a librarians role in normal times, and the switch to online learning and teleworking completely removed the opportunity for librarians to engage with both students and scientists. Tasks requiring physical handling of printed materials were more affected than others by the circumstances, in particular circulation activities. There was still need for print materials, and from March until early June loans of print items were arranged upon request.

Working from home posed quite a challenge, requiring creative problem solving to be able to support learning, teaching and research activities by providing access to eResources and a remote reference service.

Colleagues of the ICTS helpdesk were ready to solve hardware, software, connection problems. The team experimented and self-trained in the use of online collaboration tools. Focus moved to tasks that could be performed remotely: catalogue revision, cataloguing of the digital collection of the theses of Postgraduate Diploma Programme, check of e-journals consistency, among others.

The cataloguing of the Yoccoz collection (a donation of 600 books from the private collection of the late mathematician) was completed, thanks to the collaboration of Dr. Putrov for classification. Unfortunately, the official inauguration, already organized by the Math Section for May, had to be postponed.
The library staff also engaged in learning and expanding their skills and knowledge of IT tools and library topics, through free e-learning modules, conferences, and webinars. The team met regularly online to keep contact, set tasks, coordinate, and check progress. Each staff member contributed to maintain an efficient and useful service in this difficult period. Most of the three months of lockdown involved exploring ways to keep in contact with users and provide them with up to date information regarding changes in library services and resources. The team regularly updated information regarding availability of both licenced and freely available e-resources of established research value, made available by several publishers. Quasi-monthly leaflets on new books or eResources were circulated. Information on freely available resources was distributed also through the Associates and to the Library Donation Programme mailing lists. Particular attention was given to the intensified debate on Open Science posting a series of News on the Library website, alerting on various initiatives on this crucial theme.

Requests of Document Delivery coming from users and from other libraries have been fulfilled without interruption thanks to the continued support of NILDE, the Italian network for inter-library documents exchange.

The lockdown has shown -if necessary- that collaboration and communication at all levels from team to inter-office, to inter-library level is vital. During this period, the collaboration with the Public Information Office has also been strengthened.

From June, in line with the gradual reopening of the Centre, the Library collaborated with the Covid-19 Operational Committee in setting rules and procedures to resume operations on-site and re-open the study spaces in the safest way possible, putting the emphasis on social distancing, hand hygiene, the use of face masks, and the quarantine of returned items. Library hours were set to 9 am to 4 pm. To maintain social distancing seats for study were reduced from 70 to 17, with the possibility to reserve them.

In October, an online session with a virtual introduction to library services and collections was organized for the starters of the new cycle of the Postgraduate Diploma Programme, who were undergoing the quarantine. The library session included the screening of the documentary "Abdus Salam - The Dream of Symmetry" followed by a conversation. Every effort was made by the library staff to offer a friendly service and to enhance the sense of ICTP as a caring community.

With regards to collection development, the purchase of e-books, especially for Diploma and Master courses, was privileged, bringing up the need for an acquisition policy on e-books. Another consequence of teleworking was the final switch to e-only for the remaining journals still received on paper, mostly mathematics journals.

Concerning availability of eResources, the Library is now affiliated with the Library at UNESCO HQs and benefits from access to contents purchased via UNSEIAC -the UN System Electronic Information Acquisitions Consortium. Among
them, the most relevant to ICTP research areas are JSTOR, journals backfiles, and ProQuest, a multi-disciplinary database providing abstract and indexing with select full text.

Regretfully, the negotiation with the publisher Springer Nature to renew a contract expired in 2019, could not come to a positive conclusion, and after a free trial period access to 2020 contents of important Springer and Nature journals was suspended.

Besides the long-awaited change of ILS, the reorganization of physical spaces, the preservation project of the ICTP image archive, and the digitalization of the Abdus Salam’s Archive, circumstances have highlighted, if necessary, the need to revise many of the library services to tailor them to the changing scholarly communication environment.

No doubt that eResources will be the most important source of information, even after a return to in-person activities. Authenticated access needs institutional policy and implementation. License agreements with publishers should be renegotiated if ICTP will opt to organize online or hybrid courses, to provide to remote visitors/course participants a service similar to that given in-person.

Time is ripe to rethink the Book Donation Programme, as there are increasing difficulties in delivering hard copies to university libraries in least developed countries.

Finally, looking at the past year with a view to the future, the Covid-19 health emergency has made clear the need to collaborate globally, for an equitable access to information.

“Open Science can be a true game changer in bridging the science, technology and innovation gaps between and within countries and fulfilling the human right to science.”


Librarians will have to play their role in this endeavour by leveraging their experience in paving the way for Open Science, as information mediators and facilitators. The Marie Curie Library should prepare and be ready to make its contribution.

“[…] the global COVID-19 health crisis has proven worldwide the urgency of access to scientific information, sharing of scientific knowledge, data and information, enhancing scientific collaboration and science- and knowledge-based decision making to respond to global emergencies and increase the resilience of societies.”

First draft of the UNESCO Recommendation on Open Science:
https://unesdoc.unesco.org/ark:/48223/pf0000374837
ICTP’s Information and Communication Technology Section (ICTS) maintains the Centre’s advanced computing facilities. It also plays a key role in all ICTP activities related to technology for high-performance computing, parallel programming and scientific software development, including ICTP’s Master in High-Performance Computing (MHPC), a joint degree program run with the International School for Advanced Studies (SISSA). The programme is centred around the two institutes’ high-performance computing centre. Launched in 2014, the facility expands opportunities not only for MHPC students, but also for staff researchers and the thousands of scientists from developing countries doing collaborative research with the Centre. From simulating molecular interactions to calculating climate forecasts, supercomputers are becoming an increasingly important tool for scientists seeking to solve complex scientific computational problems. The results of these supercomputing exercises are being used in important, practical ways, from the development of improved solar energy cells to input into international agreements such as the Intergovernmental Panel on Climate Change (IPCC) climate assessment reports.
The African Review of Physics

Founded and published by the Abdus Salam International Centre for Theoretical Physics since 2007 The African Review of Physics (www.aphysrev.org) is the official journal of the African Physical Society. It is a free, open access, on-line, peer reviewed, international journal that publishes high quality reviews, research articles, and brief communications in all branches of experimental and theoretical physics.

The African Review of Physics continued its policy of focusing on excellence by publishing high quality research results both from Africa and other emerging nations. African scientists remained highly active during 2020 in all sectors of pure and applied physics by contributing 42% of all submissions.

In 2020, submissions to the African Review of Physics were received from 13 African countries out of 25 countries worldwide with slight increase in all submissions with respect to 2019. Countries in the top 5 ranking in terms of the number of research papers submitted are: India securing the first position, followed by Algeria, Nigeria, Nepal and Iran. Countries contributing this year were: Algeria, Benin, China, Egypt, Ethiopia, Ghana, India, Iraq, Iran, Jordan, Libya, Malaysia, Morocco, Namibia, Nepal, Nigeria, Romania, Russia, Senegal, Sudan, South Africa, Thailand, Turkey, Uganda and USA. Members of the top 5 countries listed above contributed 74.5% of all submissions from all countries worldwide. Research themes in 2020 were applied physics, cosmological models of dark energy and dark matter, atomic physics, material science, plasma physics, medical physics, nuclear physics, nanophysics, and mathematical physics.
The Science Dissemination Unit (SDU) was created in 2004 with the broad aim of disseminating educational, scientific and technological contents throughout the world by using innovative digital media. Website: sdu.ictp.it

In 2014 the SDU opened the Scientific Fabrication Laboratory (SciFabLab) a workshop space encouraging scholars to bring their creative ideas to life and share them openly for the benefit of the society. Website: scifablab.ictp.it

The SDU is a concrete example of helping to bridge knowledge divides by applying cost-effective, open-source digital technologies for the dissemination, support and internationalization of science. The SDU addresses the following main issues of concern:

- The dissemination of scientific data, educational STEM material, and scientific information.
- The development, implementation, and management of open source applications, especially in support of science and education, and in particular for scholars with disabilities.
- The integration of new, innovation rich-media and state-of-the-art apps to facilitate the transfer of knowledge and exchange of ideas.
- Supporting Scientific Fabrication Laboratories (SciFabLabs) around the world. These FabLabs of scientific natures offer work space and equipment to encourage scientists and "makers" --i.e., people who like to design and build technological devices-- to bring their creative ideas to life. Use of such SciFabLabs is subject to the acceptance of a project proposal. Priority is given to science and STEM education for sustainable development, including thesis projects; robotics, electronics, micro-controllers and computer-based science projects; 3D printing for education; green technologies and alternative energies.

The SDU also provides support to many scientific and outreach ICTP activities and organizes many open, hands-on Training workshops, Maker Faire and Hackathon events to create awareness and help to disseminate science and technology in innovative ways for all ages.
The SDU opened in the summer of 2014 its Scientific Fabrication Laboratory (SciFabLab) – a workshop space hosting scientists and “makers”. This open space, having more than 300 sq. meters on ICTP Campus, accepts project proposals from scholars and makers both within and outside the ICTP community.

The SciFabLab was the first FabLab inaugurated in the Friuli Venezia Giulia region and it is part of a large worldwide community of FabLabs. It offers modern and versatile computer-controlled rapid prototyping tools such as 3D printers, 3D scanners, laser engraving and cutting and multi-axes CNC machines, embedded systems, micro-controllers, etc. It aims to open new dimensions of spreading science and education, and of inspiring curiosity. The use of the SciFabLab is free and subject to the acceptance of a project proposal.

After the lockdown measures imposed by the Italian government, following the declaration of the SARS-CoV-2 pandemic emergency in February 2020, the ICTP Scientific FabLab stopped its activities with the public, and shortly thereafter ICTP moved all of its activities to teleworking and closed its activities on campus. This was the beginning of a long period of inactivity nation-wide (and then world-wide after a few weeks). During this lockdown period, the SDU staff and assistants of the SciFabLab did not rest inactively. They were busy teleworking from home, researching as well as developing designs for the digital fabrication of safety and protection devices useful during the pandemic emergency. The availability of personal protection equipment to protect workers in the front line of the pandemic was in this initial period very scarce which allowed to open the way to call the SciFabLab’s community of makers for new ideas. At that time, the availability of safety and protection devices was running low, and purchase was very difficult world-wide because of the high demand.

While TV and social media were reporting a lot of positive stories about makers and FabLabs helping hospitals in the red zones, and about 3D printers used for building medical devices and accessories, the SciFabLab opened its facilities and know-how to help the community with similar projects. As the saying goes, necessity becomes the mother of invention. The local civil protection agency was provided with hundreds of reusable facial shields, fabricated with only the materials and machines available in the SciFabLab, in a short time. This Protezione Civile, as it is known in Italy, is mainly composed of volunteers coordinated by the mayors of each Italian municipality that aid citizens and hospitals during emergencies, although they are not part of the public health service.

These protective devices were also requested by the emergency teams of the Italian Police of Trieste and Monfalcone. This project was the subject of articles in the local newspaper “Il Piccolo”.

A second project of the SciFabLab during the pandemic was tackling a different need. After a request received from a professional of a Trieste healthcare facility: the design and production of simple and cheap devices to alleviate the fatigue of wearing face masks for long hours (specially the elastic bands around the ears)

http://scifablab.ictp.it/
were made. After some days of research and many useful discussions with health workers of the local hospitals, the SciFabLab came up with an open-source design for such gadgets. This design allowed for cost-effective production of devices using a laser cutter. During the year, more than one thousand pieces were produced and given to hospitals and healthcare workers of the whole region.

A third ongoing project related to SARS-CoV-2 developed at the SciFabLab started with an in-house need for the ICTP in order to be ready for its re-opening. Several safety rules and precautions had to be implemented, and an important one was the mandatory installation of large plastic shields on all desks where there is interaction between two or more people (some offices, reception desks, the bar counter, etc). Such items are available commercially but -due to the very high demand- their availability was scarce and delivery times were long. A few pieces were designed and produced in the SciFabLab, using the acrylic sheets that were not consumed by other projects.

During the closure of the SciFabLab to the public, and particularly when the Italian government started to discuss a softening of the national lockdown (so called "phase two"), many messages were received from the most devoted users of the SciFabLab ("makers"), asking when and how it will reopen. Moreover, since the SciFabLab also gets a yearly financial contribution from the Municipality of Trieste for offering its facilities to the public (for free) it became necessary to re-open its facilities.

For this reason a set of initial ad-hoc guidelines were studied and proposed for the gradual reopening of the SciFabLab to the public, with well defined rules to implement all national and regional precautions in place, and considering also general UNESCO guidelines. This draft document was sent to the ICTP committee in charge of the Covid-19 emergency and of the implementation of related safety measures. After a few video-meetings and useful discussions with the committee, the SDU draft proposal was accepted and attached to the official ICTP guidelines for the re-opening to the public of the ICTP centre. This complex process created precise instructions for the users and visitors (on safety, hygiene, etc) and to restart the activities of the SciFabLab in presence.

Among the many precautions to be followed, precautions still in place, there are mandatory information signs for the users and visitors of the SciFabLab, new arrangement of the workbenches, rules for interpersonal distancing and obligations to wear face masks, guidelines for personal hygiene (washing hands with soap or hydro-alcoholic solution), requirements for a proper ventilation and sanitisation of closed spaces within and outside the FabLab, rules for the use of restrooms, procedures for the proper cleaning of tables and tools, measurement of body temperature and self-certification of good health for all visitors entering the campus, and more... Several UV Sanitizers were installed inside the SciFabLab to keep working instruments, tools, keys, cellphones, etc. clean from viruses.

After months of opening to the public with the new procedures implemented, for
a maximum of four simultaneous users inside the space of the FabLab, there have been zero sanitary or health issues to report so far. All users register their projects and book their visits well in advance for traceability.

The opening of the SciFabLab varies according to the Italian National and Regional situation for the SARS-CoV-2 emergency following the official rules and zone classification in place at each step of the pandemic still in course.

Science on the Internet: Education and Dissemination
www.ictp.tv

The popular www.ictp.tv server was kept up and running with more than 15,000 hours of recordings available online. These have received more than one million unique visitors. More than 50% of viewers of the online courses came from developing countries and during the pandemic this viewership increased.

openDante/openEyA: High School Physics and Math Lectures On-line

The project openDante, carried out in collaboration with Prof. A. Pisani from Liceo Classico Dante Alighieri (Gorizia), provides a new, effective option for students to review and learn new concepts at a distance. Students like the fact that by means of openEyA-made recordings, they can see and re-listen to their classroom lectures at home. This helps to increase their level of understanding. SDU continues to support this unique initiative: www.openDante.com to foster future generations of scientists. It proved very useful during pandemic.

7th Edition of the Maker Faire Trieste (2020)—The showcase of ingenuity, creativity and science / ESOF2020

The Maker Faire took place on Friday 4 and Saturday 5 September 2020 in the main square of Trieste (Piazza Unità d’Italia), organised by the ICTP-SDU, the Municipality of Trieste, the Science Centre Immaginario Scientifico (IS) and the Fondazione Internazionale Trieste per il Progresso e la Libertà delle Scienze (FIT). The event, that has been attracting thousands of visitors to the ICTP campus since 2014, in this special “pandemic” edition has grown and moved to the center of Trieste. The Faire was the highlight of the “Science in the City” festival, featured by ESOF 2020. Despite the difficulties posed by this peculiar time, the Maker Faire contributed to honour the title of “European City of Science 2020” assigned to Trieste, by making science and technology fun and more easily accessible to the public. We emphasise our pride in the huge organisational and economical effort put into preventing the spread of SARS-CoV-2 by meeting all the obligations and requirements imposed at the time by the Autonomous Region Friuli Venezia Giulia and the Italian Government.

During this open, free event in the prestigious venue of Piazza Unità d’Italia, all exhibitors, makers and public took extra care in following the safety precautions:
wearing of disposable mask to cover mouth and nose, hand and surface sanitation, physical distancing, and avoiding crowding of people near the stands. Volunteers were carefully instructed and supervised by the organisation to make sure the safety measures were respected. This fact, along with the full cooperation of makers and public, allowed for the Maker Faire Trieste 2020 in SARS-Cov-2 times to take place without any significant problem. This is certainly an example of successful synergy and goodwill among all participants.

As in the past years, the event obtained institutional and financial support by the Autonomous Region of Friuli Venezia Giulia, the Municipality of Trieste, and numerous private sponsors. The Science Centre Immaginario Scientifico did help to manage the complex administrative procedures in this pandemic year. Technical partner was the SciFabLab that, also thanks to the contribution from the Municipality of Trieste, promotes and spreads the name of the city in the international circle of MakerFaires, MAKE Community and Fablabs.

During the two days of this open event, that was also partially broadcasted online and on local TV, more than 100 makers and scientists have led the public on a voyage in creativity, technology and research. Citizens of any age, Maker Faire habitué and passerby had the opportunity to examine the numerous inventions, playing, exploring and experimenting. The event was a gathering of makers, inventors, creatives, digital natives to showcase new inventions (specially inspired by the pandemic), DIY science experiments, recycling and sustainability, archeology and 3D printing, artistic laser exhibitions, water rockets, clocks designed by Leonardo da Vinci and Galileo, cryptography, robotics experiments, computer science, electronics and much more. As always the main goal was to bring young people closer to the creative side of human knowledge, inspiring them towards this fascinating world and maybe into a future career in science, innovation and technology.

The majority of makers reached Piazza Unità from the four provinces of Trieste, Udine, Gorizia and Pordenone, but some, as in the previous editions, arrived from other Italian regions and nearby countries. Among the participants a jury selected the winners for "Lady Maker", "Maker Faire Trieste" and "Young Maker" categories, to whom prizes from prestigious sponsors were given. In addition to the various social communication channels (Facebook, Twitter, Instagram, YouTube, etc.) a dedicated website was created and advertised at this address: http://trieste.makerfaire.com

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ICTP (main contributor).
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Staff

Funding


ATLAS Collaborations


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