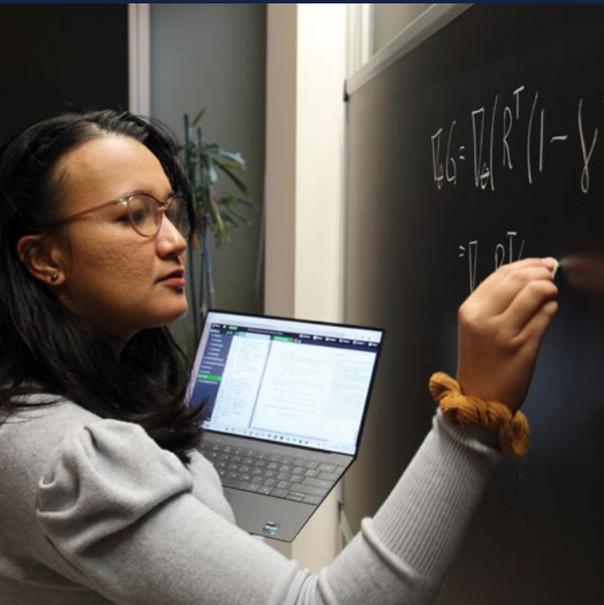
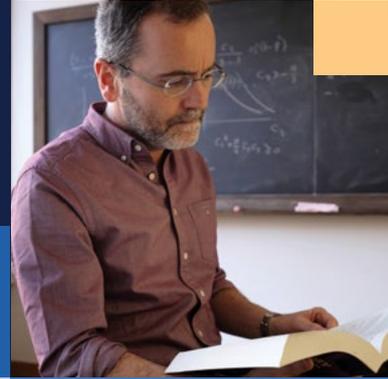




The Abdus Salam
International Centre
for Theoretical Physics



2023: A Year in Review



The Abdus Salam
**International Centre
for Theoretical Physics**

2023:

**A Year
in Review**

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In Memoriam

2023: A Year in Review
The Abdus Salam International Centre for Theoretical Physics

Compiled by the ICTP Public Information Office
Designed by 400 Communications

Public Information Office
The Abdus Salam International Centre for Theoretical Physics (ICTP)
Strada Costiera, 11 I – 34151 Trieste Italy

e-mail: pio@ictp.it
www.ictp.it

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Foreword

The year 2023 was a time of new collaborations, new activities and new efforts to expand the ICTP community using innovative techniques. Significantly, two themes underscored all of these advances: digitisation and open science.

In January 2023, ICTP launched the first stage of its long-awaited global scientific portal. The interactive internet portal aims to promote the Centre's activities and achievements as well as encourage international scientific networking. Accessible at www.ictp.it, the portal represents the first phase of what the Centre plans to be a global portal encouraging networking amongst ICTP's vast international community of physicists and mathematicians. The goal is to reinforce the connections that scientists make through their participation in ICTP activities and programmes, in a virtual environment where they can nurture these connections and create new ones throughout their careers. The global portal addresses one of the key reasons why Abdus Salam established ICTP: to overcome the isolation that many scientists from disadvantaged parts of the world face when they return to their home countries after attending international science events.

The portal supports ICTP's commitment to Open Science, making research available to all, regardless of borders. Simply stated, with more resources online, more scientists are able to participate in physics and mathematics. This, perhaps, explains an important, historical milestone reached by ICTP in 2023: nearly one-third of its scientific visitors attending ICTP conferences and programmes were women, the highest percentage the Centre has ever seen. We suspect that with a majority of its seminars and conferences now livestreamed, ICTP is reaching scientists who, for cultural reasons or family obligations, cannot attend ICTP activities in person. The trend has been rising steadily, starting even before the heavy presence of ICTP's activities online.

An important aspect of Open Science is the notion of open access to computing resources. ICTP has been working towards this objective to make resources in high performance computing, machine learning and artificial intelligence or quantum computing globally available for scientific research, in the framework of an International Consortium for Scientific Computing, comprising partners from around the world with national commitments. The ultimate goal of the Consortium is to be an enabler of research developments requiring scientific computing in any field of fundamental science and open to scientists from all over the world. Thanks to its historical strength in the field of scientific computing and to its global scientific network, ICTP is ideally positioned to lead global efforts to enhance the impact of scientific computing in addressing the scientific challenges that are at the core of a sustainable future for the Earth.

In support of the Consortium, ICTP became a member of two important, international collaborations. In November, the Centre signed on to a new international initiative called the Open Quantum Institute (OQI), along with a number of Europe's top research institutes. The OQI aims to unlock the potential of quantum computing for the benefit of all, irrespective of geographical, economic, or scientific constraints. In December, ICTP joined the AI Alliance, an elite group of international research institutes and high-tech companies, led by IBM and Meta, who aim to shape the evolution of Artificial Intelligence (AI) by working together for the advancement of open, safe and responsible AI.

It is worth emphasizing the following important point about ICTP's strategic thinking: being open to innovations in machine learning and quantum computing is not to be viewed as being at odds with our intentions to remain true to our core competence and roots in fundamental science and theoretical physics. Rather, it should be viewed as being complementary. ICTP embraces these powerful tools as a means to discover more about the deepest mysteries of physics and as essential ingredients of more applied fields. Applied mathematician Stéphane Mallat, who recently delivered the 2024 Salam Distinguished Lectures on the deep connections between computing and theoretical physics, gave this perspective: "Hopefully also physics can make use of the different mathematical perspectives brought by machine learning, to get a deeper understanding of complex physical problems. It is somehow as if the boundaries between machine learning and physics were breaking and cross fertilising both fields."

Atish Dabholkar
ICTP Director

"It is somehow as if the boundaries between machine learning and physics were breaking and cross fertilising both fields."

ICTP Director Atish Dabholkar introducing Edward Witten, who gave a well-attended colloquium titled "What Every Physicist Should Know About String Theory"
Roberto Barnaba/ICTP Photo Archives

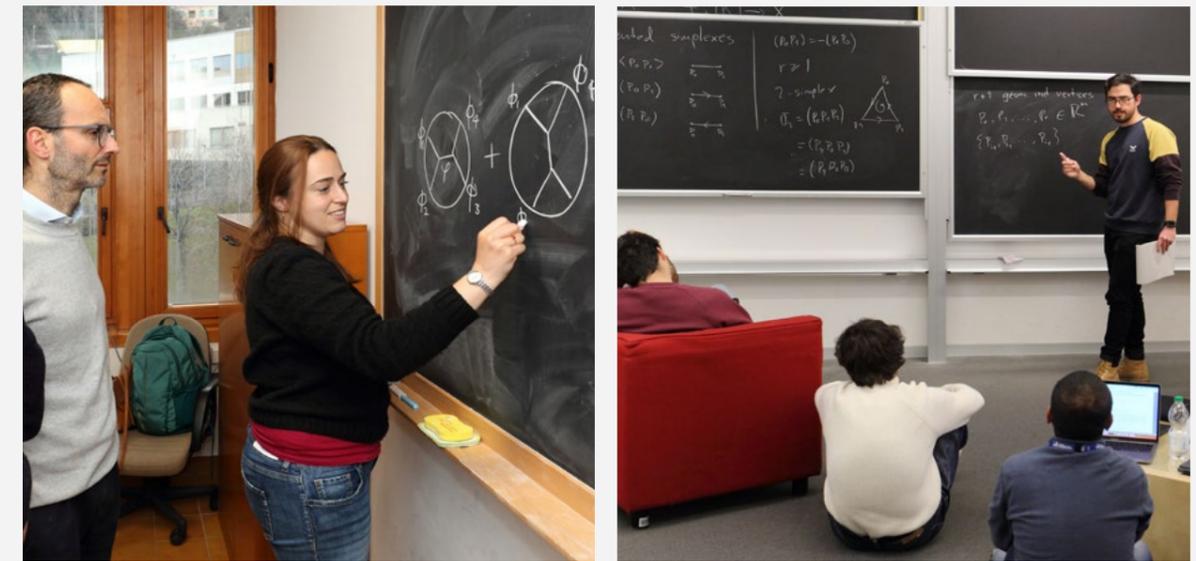


ICTP Research

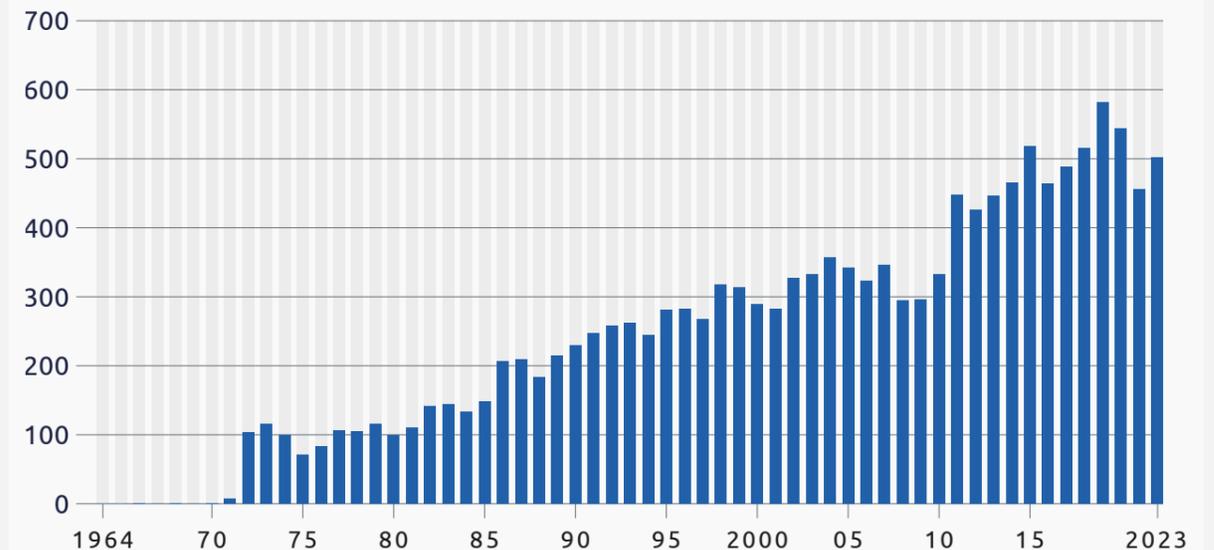
ICTP is widely regarded as an extraordinary environment for advancing knowledge in the physical and mathematical sciences, with a permanent faculty of distinguished scientists who conduct rigorous, world-class, curiosity-driven research in frontier and interdisciplinary science ranging from string theory, cosmology, and black holes to quantum computing, climate science, and quantitative life sciences.

They teach and mentor hundreds of students and young researchers every year, equipping them to go on to study, teach, and conduct research in the world's finest universities, and to contribute to the development of science in their home countries. Research at ICTP has been linked, directly or indirectly, to five Nobel prizes.

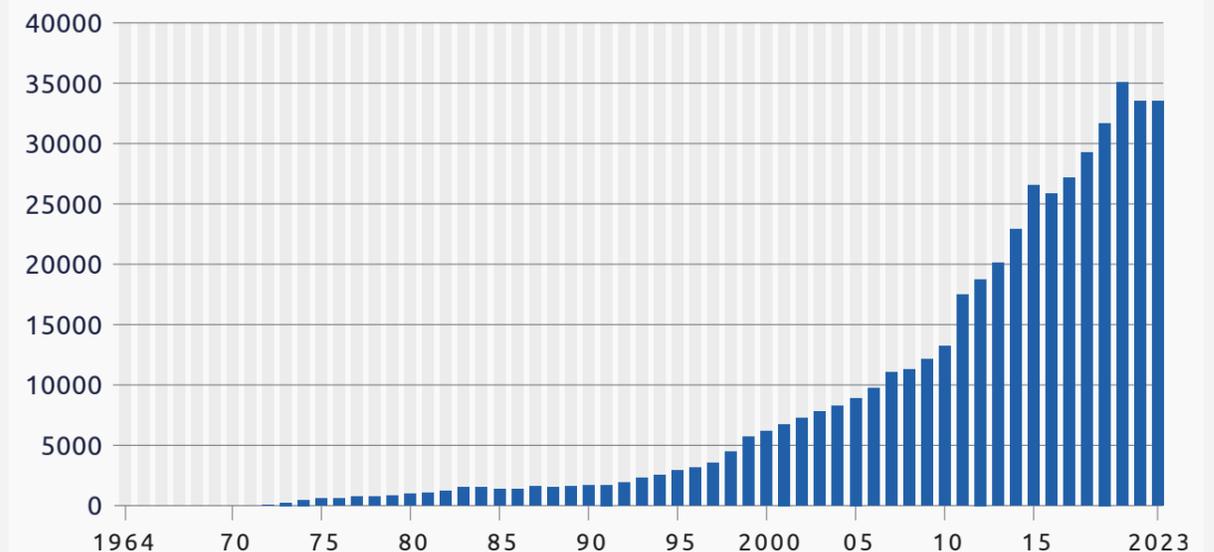
Today, ICTP supports cutting-edge research on wide-ranging topics in physical science and mathematics, organised under the following main groups: High Energy, Cosmology and Astroparticle Physics; Condensed Matter and Statistical Physics; Mathematics; Earth System Physics; Quantitative Life Sciences; and Science, Technology and Innovation. Read more about these research lines on the following pages.



NUMBER OF ICTP PAPERS LISTED BY FINAL PUBLICATION YEAR



TOTAL NUMBER OF CITATIONS OF ICTP PAPERS



NUMBER OF ICTP RESEARCHERS

Staff, consultants, longterm visiting scientists, postdoctoral fellows

187

NUMBER OF COUNTRIES REPRESENTED BY ICTP RESEARCHERS

44

RESEARCH AREA:

High Energy, Cosmology and Astroparticle Physics (HECAP)

As a direct descendent of Abdus Salam’s original research group at ICTP, the HECAP section tackles fundamental questions in physics to understand the basic laws governing the universe.

RESEARCH AREAS INCLUDE:

COSMOLOGY

New experimental results have driven fundamental changes in our understanding of the large-scale structure and evolution of the universe. HECAP cosmologists explore a variety of topics, such as dark energy, gravitational waves, black holes, and inflation.

STRING THEORY AND QUANTUM GRAVITY

String theory, which aims to unify general relativity and quantum mechanics, could be used to describe spacetime in extreme conditions, such as near a black hole or the big bang singularity, where quantum gravitational effects are significant. HECAP researchers study topological string theory and connections with new mathematics, the physics of quantum black holes, strongly coupled quantum field theories, string compactifications, and the fundamental principles of holographic correspondence.

PHENOMENOLOGY OF PARTICLE PHYSICS

HECAP researchers study the phenomenology of particle physics using an approach that combines modelling and data interpretation. Quantum Field Theory and experimental particle physics are bridged to investigate physics beyond the Standard Model, the phenomenology of high-energy colliders and precision experiments, dark matter, axions, neutrino, and flavour physics.

EXPERIMENTAL PARTICLE PHYSICS

The joint HECAP/University of Udine ATLAS group collaborates with experimentalists working on CERN’s Large Hadron Collider (LHC). HECAP researchers study the top quark and Higgs boson, and work on detector development, Monte Carlo simulation/validation, and computing performance.

HECAP IN NUMBERS 2023

07

SCIENTIFIC ACTIVITIES ORGANISED AT ICTP

04

SCIENTIFIC ACTIVITIES ORGANISED ABROAD

55

SEMINARS ORGANISED

85

SHORT-TERM VISITORS

HECAP scientists study inflationary cosmology, black holes, physics beyond the Standard Model, general properties of Quantum Field Theory and string theory. Although HECAP has a mostly theoretical focus, with researchers using analytical methods to solve fundamental and sometimes purely mathematical problems, the ATLAS group at HECAP also collaborates with experimental scientists at CERN. This combination of experimental and theoretical groups in the section is key, as there is a great deal of feedback between theory and experiment in the field, with certain ideas sometimes gaining or losing popularity as a consequence of experimental results.

HECAP researchers study the cosmological properties of axions, a compelling candidate for dark matter. Another line of research focusses on the general constraints imposed by the fundamental properties of quantum mechanics and special relativity. HECAP plays an important role in the Institute for the fundamental Physics of the Universe (IFPU), which brings together the Trieste community working on cosmology.

Future research directions at HECAP depend on the results of ongoing experiments, such as gravitational wave measurement, dark matter detection and results from surveys of the distribution of matter in the universe. HECAP researchers use key results from such experimental studies to open new lines of investigation, and adapt to changing conditions within this evolving field.

PUBLICATION HIGHLIGHTS

Bissi, A., & Sarkar, S. (2023). A constructive solution to the cosmological bootstrap. *Journal of High Energy Physics*, 2023, 115. [https://doi.org/10.1007/jhep09\(2023\)115](https://doi.org/10.1007/jhep09(2023)115)

Acharya, B. S., & Baldwin, D. A. (2023). Ricci Flat Metrics, Flat Connections and G2-Manifolds. arXiv:2312.12311. <https://doi.org/10.48550/arXiv.2312.12311>

Dabholkar, A., & Moitra, U. (2023). Finite Entanglement Entropy in String Theory. arXiv:2306.00990v1. <https://doi.org/10.48550/arXiv.2306.00990>

Miro, J. E., Guerrieri, A., & Gumus, M. A. (2023). Extremal Higgs couplings. arXiv:2311.09283. <https://doi.org/10.48550/arXiv.2311.09283>

Putrov, P., Wang, J. (2023). Categorical Symmetry of the Standard Model from Gravitational Anomaly. arXiv:2302.14862. <https://doi.org/10.48550/arXiv.2302.14862>

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RESEARCH AREA:

Condensed Matter and Statistical Physics (CMSP)

Research at CMSP spans various key areas of theoretical condensed matter physics, including nanostructure properties and many-body quantum systems; quantum information processing; computer simulations of fluids and solids using atomistic, molecular, and electronic structure-based methods; new material design for sustainable energy applications; and synchrotron radiation-related physics. Unsupervised machine learning methods are also applied to complex quantum systems at CMSP.

RESEARCH AREAS INCLUDE:

THE PHYSICS OF NANOSTRUCTURES

Nano-device development has a fundamental impact on modern technology, and both quantum coherence and strong interactions play a key role in these systems. CMSP researchers study the quantum transport of energy, charge, and mass; examining anomalous transport in quantum and classical low-dimensional systems, energy transport through impurities and nanostructures, and the fundamental properties of quantum heat engines.

ATOMISTIC, MOLECULAR, AND ELECTRONIC STRUCTURE SIMULATIONS

A wide range of systems and phenomena may be studied in-depth by modelling at the electronic structure, atomistic, and molecular levels. At CMSP, systems simulated using these approaches include multiferroic materials; nanostructures and nanostructured phases of graphene on metal; ultra-high-pressure systems; the development of polarisable force-fields for oxides; acid-base chemistry in water and interfaces; hydrogen-bond networks in biological systems; and the chemical physics of solvation.

EQUILIBRIUM AND NON-EQUILIBRIUM MANY-BODY QUANTUM SYSTEMS

CMSP researchers investigate a wide spectrum of topics related to many-body quantum systems, such as superconductivity and magnetism in strongly-correlated systems, superfluids, cold atoms in optical lattices, localisation in disordered systems, many-body physics and light, dynamics and relaxation in complex systems, quantum simulators, and quantum computing.

MATERIALS FOR RENEWABLE ENERGY APPLICATIONS

Advanced functional materials are required for the efficient collection and storage of sustainable forms of energy. At CMSP, quantum mechanical modelling is combined with machine learning to investigate the physics and chemistry of material interfaces, which are key to the development of catalysis, new kinds of batteries, and solar cells.



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CMSP IN NUMBERS 2023

08

SCIENTIFIC
ACTIVITIES
ORGANISED
AT ICTP

02

SCIENTIFIC
ACTIVITIES
ORGANISED
ABROAD

60

SEMINARS
ORGANISED

121

SHORT-TERM
VISITORS

CMSP plays a pivotal role in the Sustainable Energy Initiative, which focuses on computational investigations into materials relevant for sustainable energy applications. Quantum atomistic simulations are employed to understand the behaviour of various materials and processes.

The CMSP section is also home to scientists who perform theoretical research and training in condensed matter and applied physics topics that are experimentally investigated using synchrotron radiation (SR). There are close collaborations with experimentalists at the nearby SR source Elettra and other similar facilities.

PUBLICATION HIGHLIGHTS

Tarabunga, P. S., Tirrito, E., Chanda, T., & Dalmonte, M. (2023). Many-body magic via Pauli-Markov chains—from criticality to gauge theories. *PRX Quantum*, 4(4). <https://doi.org/10.1103/prxquantum.4.040317>

Mirón, G. D., Semelak, J. A., Grisanti, L., Rodriguez, A., Conti, I., Stella, M., Velusamy, J., Seriani, N., Došlić, N., Rivalta, I., Garavelli, M., Estrin, D. A., Kaminski Schierle, G. S., González Lebrero, M. C., Hassanali, A., & Morzan, U. N. (2023). The carbonyl-lock mechanism underlying non-

aromatic fluorescence in biological matter. *Nature Communications*, 14. <https://doi.org/10.1038/s41467-023-42874-3>

De Filippis, G., de Candia, A., Di Bello, G., Perroni, C. A., Cangemi, L. M., Nocera, A., Sassetti, M., Fazio, R., & Cataudella, V. (2023). Signatures of dissipation driven quantum phase transition in Rabi Model. *Physical Review Letters*, 130(21). <https://doi.org/10.1103/physrevlett.130.210404>

Deng, D., Si, R., Wen, B., Seriani, N., Wei, X.-L., Yin, W.-J., & Gebauer, R. (2023). Self-doped p–N junctions with high carrier concentration in 2d GaN/Mosse heterostructures: A first-principles study. *Journal of Materials Chemistry A*, 11(41), 22360–22370. <https://doi.org/10.1039/d3ta04322c>

Sierant, P., Lewenstein, M., Scardicchio, A., & Zakrzewski, J. (2023). Stability of many-body localization in Floquet Systems. *Physical Review B*, 107(11). <https://doi.org/10.1103/physrevb.107.115132>

RESEARCH AREA:

Mathematics (MATH)

The MATH section covers a broad range of traditional themes in mathematics, such as algebraic geometry; harmonic analysis and PDEs; dynamical systems and ergodic theory; differential geometry, topology and geometric analysis, with a focus on general relativity and condensed matter physics; and both algebraic and analytic number theories.

RESEARCH AREAS INCLUDE:

HARMONIC ANALYSIS AND ANALYTIC NUMBER THEORY

Harmonic analysis is used to study various oscillatory phenomena in nature, while analytic number theory involves the analysis of structures related to integer numbers. MATH researchers explore a range of themes that lie at the interface between these two fields.

HIGH-DIMENSIONAL STATISTICS, INFERENCE AND THEORY OF MACHINE LEARNING

MATH and QLS researchers investigate fundamental questions related to inference and learning efficiency, data requirements, and performance. Their mathematically rigorous approach is often rooted in statistical physics combined with information theory, random matrix theory, high-dimensional statistics, and the mathematical physics of spin glasses.

DIFFERENTIAL GEOMETRY AND GEOMETRIC ANALYSIS

Differential geometry is the mathematical theory describing the curvature of spaces with arbitrary dimension. MATH researchers combine techniques from the calculus of variations, PDEs, and algebraic geometry to investigate various aspects of differential geometry, and their connection to general relativity, cosmology, and condensed matter physics.

DYNAMICAL SYSTEMS AND ERGODIC THEORY

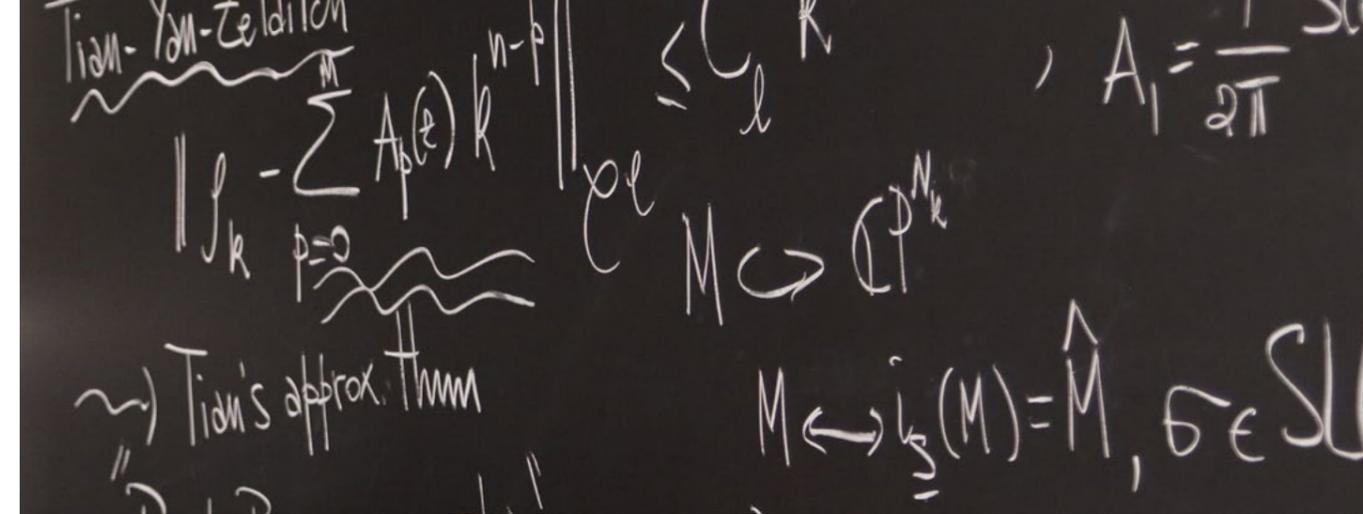
MATH researchers use (smooth) ergodic theory, which combines ideas from analysis, topology, geometry, probability theory, to understand and explain the phenomena of unpredictability and chaos in dynamical deterministic systems, and their statistical properties.

ALGEBRAIC GEOMETRY

Algebraic geometry is closely linked to algebra, complex analysis, differential geometry, topology, number theory, and mathematical physics, and utilises their methods and results. MATH researchers in this field focus on moduli spaces: algebraic varieties that parametrise interesting objects in algebraic geometry, such as curves, vector bundles, and sheaves on varieties..

MATHEMATICAL PHYSICS

MATH researchers explore mathematical concepts that are closely related to theoretical physics. Quantum field theory and string theory are mines for non-trivial mathematical conjectures and constructions such as topological quantum field theory, which incorporates topological invariants of manifolds and embeddings into convenient algebraic structures.



Roberto Barnaba / ICTP Photo Archives

MATH IN NUMBERS 2023

05

SCIENTIFIC ACTIVITIES ORGANISED AT ICTP

02

SCIENTIFIC ACTIVITIES ORGANISED ABROAD

51

SEMINARS ORGANISED

62

SHORT-TERM VISITORS

In 2023, MATH researchers proposed a robust generalised framework for the so-called sign Fourier uncertainty principles. They were also able to define a significant generalisation to a large family of intermittency maps, including a huge number of maps which had not been studied before. MATH obtained various results about the differential geometry of algebraic compact and complete varieties, especially regarding the existence of constant curvature metrics, their best submanifolds such as stable minimal spheres, and the complex version of the Nash isometric embedding problem. MATH researchers studied the cohomology of a series of geometric moduli spaces of sheaves, from a representation-theoretic point of view, as one varies a discrete parameter, the degree. They found that the entire cohomology is built by acting with a finite collection of commuting operators on a one-dimensional "ground" space. MATH researchers also formulated a Verlinde formula for surfaces, a higher dimensional analogue of the famous Verlinde formula for curves. Various generalisations of Vafa-Witten invariants motivated from physics were also studied using algebraic-geometric methods.

MATH continues to strengthen its ties with the International Mathematical Union (IMU), CIMPA and Istituto Nazionale di Alta Matematica (INdAM), who sponsor joint programmes with ICTP. Collaborations with the Vietnamese Institute for Advanced Studies, the Vietnamese Academy of Science and Technology and its UNESCO Category II Institute in Math in Hanoi were strengthened. The EAUMP-ICTP School on Enumerative Combinatorics took place in Tanzania. Upcoming invited seminars at MATH are aimed at highlighting future lines of research across machine learning, artificial intelligence, and mathematics. MATH researchers continue to consolidate their work on algebra, geometry, differential geometry and number theory, with a view to increasing collaborations within ICTP and beyond.

PUBLICATION HIGHLIGHTS

- Arezzo, C., Della Vedova, A., & Shi, Y. (2023). Constant scalar curvature Kähler metrics on ramified Galois coverings. *Journal Für Die Reine Und Angewandte Mathematik* (Crelles Journal), 799. <https://doi.org/10.1515/crelle-2023-0026>
- Carneiro, E., & Quesada-Herrera, E. (2023). Generalized sign fourier uncertainty. *Annali Scuola Normale Superiore - Classe di Scienze*, 1671–1704. https://doi.org/10.2422/2036-2145.202105_026
- Coates, D., Luzzatto, S., & Muhammad, M. (2023). Doubly intermittent full branch maps with critical points and singularities. *Communications in Mathematical Physics*, 402(2), 1845–1878. <https://doi.org/10.1007/s00220-023-04766-x>
- Marian, A., & Neğuț, A. (2023). The cohomology of the Quot Scheme on a smooth curve as a Yangian representation. arXiv.2307.13671 <https://doi.org/10.48550/arXiv.2307.13671>
- Calegari, F., Garoufalidis, S., & Zagier, D. (2023). Bloch groups, algebraic K-theory, units, and Nahm's conjecture. *Annales Scientifiques de l'École Normale Supérieure*, 56(2), 383–426. <https://doi.org/10.24033/asens.2537>

RESEARCH AREA:

Earth System Physics (ESP)

The ESP section encompasses a range of research topics related to the interior and fluid (atmosphere and oceans) components of the Earth System.

One major focus of ESP is anthropogenic climate change, together with the impact of climate phenomena on humans and ecosystems. Global models are used to study global patterns of variability, such as the North Atlantic Oscillation, whereas high-resolution regional models provide local climate information. The role of oceans in the climate system as a whole is also studied at ESP. Cloud behaviour is investigated from a physics perspective, along with the impact of climate change on various human sectors.

Very high-resolution regional climate modelling is performed at ESP using a non hydrostatic version of RegCM, in particular for the study of extreme events, such as floods. In 2023, the group contributed to the development of the climate model's most recent version, REGCM-5, which is more effective and efficient than older versions. ESP is also one of two research groups involved in the worldwide CORDEX-CORE programme, in which regional climate models are used to obtain high-resolution projections for nine continental land areas.

RESEARCH AREAS INCLUDE:

SOLID EARTH GEOPHYSICS

ESP researchers use seismology, space geodesy, tectonics, and numerical experiments to conduct large-scale modelling of faults and cracks in the Earth's crust; examining active earthquake and volcanic regions, the physics of transient deformation, and earthquake hazard.

CLIMATE APPLICATIONS

Dynamical and statistical modelling techniques are employed at ESP to assess the socio-economic impacts of climate variability and change on human resources such as energy, water, and health. The ESP-developed VECTRI dynamical model is employed to describe malaria transmission, and determine its response to climate variability. ESP scientists use the CHyM hydrology model with regional climate models to describe water systems.

EARTH SYSTEM MODELING

A suite of earth system models are developed to represent the key processes that determine the Earth's climate, such as atmospheric and ocean circulation, and land surface processes. ESP researchers use tools such as recent evolutions of the regional climate model RegCM and the intermediate complexity global model SPEEDY to understand our climate, its natural variability, and its response to anthropogenic forcing.

ESP IN NUMBERS 2023

09

SCIENTIFIC
ACTIVITIES
ORGANISED
AT ICTP

02

SCIENTIFIC
ACTIVITIES
ORGANISED
ABROAD

03

SEMINARS
ORGANISED

15

SHORT-TERM
VISITORS

ESP researchers recently proposed a new 3D shear velocity model to describe the crust–uppermost mantle structure beneath the Caribbean down to a depth of 150 km. A 2023 paper from ESP investigated the forcing mechanism and predictability for early-winter tropical Western-Central Indian Ocean precipitation anomalies and teleconnections to the North Atlantic region. ESP researchers also presented a new stochastic reaction-diffusion model for the tropics, which is able to simulate aggregated and random convective states.

In the future, ESP researchers will move to viewing the Earth system as an interconnected whole, rather than as compartments of ice, ocean, land, and atmosphere. A possible avenue of investigation for the section could be to add a human component to climate models. This is a complex problem as human behaviours such as migration depend on various factors, and it is difficult to disentangle responses to environmental stresses from factors such as war and poverty. AI methods could also be integrated into climate research within the section. Another future direction for ESP could be to create a regional digital twin for the Earth, i.e., a complex software that is able to mimic the behaviour of the Earth system at the regional scale. Also in this case, the effective incorporation of the human factor will be essential.

PUBLICATION HIGHLIGHTS

Giorgi, F., Coppola, E., Giuliani, G., Ciarlo, J. M., Pichelli, E., Nogherotto, R., Raffaele, F., Maluzzi, P., Davolio, S., Stocchi, P., & Drofa, O. (2023). The fifth generation regional climate modeling system, Regcm5: Description and illustrative examples at parameterized convection and convection-permitting resolutions. *Journal of Geophysical Research: Atmospheres*, 128(6). <https://doi.org/10.1029/2022jd038199>

Nnamchi, H. C., Farneti, R., Keenlyside, N. S., Kucharski, F., Latif, M., Reintges, A., & Martin, T. (2023). Pan-Atlantic decadal climate oscillation linked to ocean circulation. *Communications Earth Environment*, 4(1). <https://doi.org/10.1038/s43247-023-00781-x>

Moreno Toiran, B., Aoudia, A., Manu-Marfo, D., Kherchouche, R., & Pachhai, S. (2023). Crust–uppermost mantle structure beneath the Caribbean region from Seismic Ambient Noise Tomography. *Bulletin of the Seismological Society of America*, 113(3), 1064–1076. <https://doi.org/10.1785/0120220062>

Biagioli, G., & Tompkins, A. M. (2023). A dimensionless parameter for predicting convective self-aggregation onset in a stochastic reaction-diffusion model of tropical radiative-convective equilibrium. *Journal of Advances in Modeling Earth Systems*, 15(5). <https://doi.org/10.1029/2022ms003231>

Abid, M. A., Kucharski, F., Molteni, F., & Almazroui, M. (2023). Predictability of Indian Ocean precipitation and its North Atlantic teleconnections during early winter. *Npj Climate and Atmospheric Science*, 6(1). <https://doi.org/10.1038/s41612-023-00328-z>

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RESEARCH AREA:

Quantitative Life Sciences (QLS)

The QLS section focuses on problems at the interface between statistical physics, biology, ecology, neuroscience, information theory and artificial intelligence.

RESEARCH AREAS INCLUDE:

QUANTITATIVE ECOLOGY AND EVOLUTION

QLS researchers study species coexistence and evolution using a broad approach that lies between data-inspired modelling and model-driven data analysis. Community ecology and population genetics theories are developed at QLS using stochastic processes, random matrix theory, statistical mechanics, and nonlinear dynamics.

EFFICIENCY OF NEURAL COMPUTATION

QLS researchers use statistical physics and theoretical machine learning to study how computation emerges from the complex dynamics of neural systems. Data-driven models are built to describe neural population dynamics using large-scale recordings of behaving animals performing tasks.

STOCHASTIC THERMODYNAMICS

Nonequilibrium fluctuations in microscopic systems are studied at QLS using stochastic thermodynamics, and a combination of theory, numerical simulation, and experimental data analysis. QLS scientists investigate the relevance of the martingale theory of stochastic thermodynamics to biological, soft matter, condensed matter, and active systems.

EMERGENT COLLECTIVE BEHAVIOUR IN INTERACTING AGENT SYSTEMS

QLS researchers employ statistical mechanics-based methods to explore economical phenomena such as loss of transparency in financial transformations, the relationship between inequality and growth, and the unintended consequences of technological innovation.

HIGH-DIMENSIONAL STATISTICS, INFERENCE, AND THEORY OF MACHINE LEARNING

QLS researchers study inference and learning efficiency using a quantitative approach based on statistical physics, addressing questions about the impact of data structure and the required amount of data on performance. An information-theoretic approach to featureless inference is employed to determine relationships between maximally relevant representations and statistical criticality.

PHYSICS OF BEHAVIOUR AND SENSING

QLS researchers study decision-making in several model systems such as chemotaxis in bacteria and cancer cells, olfactory search, and flight. Statistical physics, information theory, computer science, and biology are used to form an algorithmic understanding of animal search behaviour and decision-making guided by sensory information.



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QLS IN NUMBERS 2023

08

SCIENTIFIC
ACTIVITIES
ORGANISED
AT ICTP

03

SCIENTIFIC
ACTIVITIES
ORGANISED
ABROAD

21

SEMINARS
ORGANISED

36

SHORT-TERM
VISITORS

One research theme in the section is quantitative physiology: a recent work involving QLS scientists showed how protein degradation plays an important role in determining resource allocations in slow-growing cells. QLS scientists also model realistic data structure algorithms designed for the cleaning and dimensionality reduction of large data sets.

Statistical physics is applied to social sciences to quantitatively address sustainability and human societal problems at the community level. Ongoing work at QLS integrates ideas from economics, demography, social sciences, biology, and neuroscience to shed light on the underlying mechanisms of inequality. A recent QLS study used data from natural bacterial communities and

mathematical modelling to unveil macroecological laws relating correlations in species abundance with genetic similarity. Another work investigated how the information-theoretic limits to inference are impacted by correlations in the measurement noise. Researchers in the section published a paper on the use of memory in complex animal and robotic navigation tasks which revealed its hidden low-dimensional structure.

Future avenues of exploration for QLS include increased links with computational neuroscience; investigations into human ecology, with possible applications in infectious disease modelling; and sustainability research.

PUBLICATION HIGHLIGHTS

Sireci, M., Muñoz, M. A., & Grilli, J. (2023). Environmental fluctuations explain the universal decay of species-abundance correlations with phylogenetic distance. *Proceedings of the National Academy of Sciences*, 120(37). <https://doi.org/10.1073/pnas.2217144120>

Barbier, J., Camilli, F., Mondelli, M., & Sáenz, M. (2023). Fundamental limits in structured principal component analysis and how to reach them. *Proceedings of the National Academy of Sciences*, 120(30). <https://doi.org/10.1073/pnas.2302028120>

Loos, S. A., Arabha, S., Rajabpour, A., Hassanali, A., & Roldán, É. (2023). Nonreciprocal forces enable cold-to-hot heat transfer between nanoparticles. *Scientific Reports*, 13(1). <https://doi.org/10.1038/s41598-023-31583-y>

Bouchaud, J.-P., Marsili, M., & Nadal, J.-P. (2023). Application of spin glass ideas in Social Sciences, Economics and Finance. *Spin Glass Theory and Far Beyond*, 561–579. https://doi.org/10.1142/9789811273926_0027

Verano, K. V., Panizon, E., & Celani, A. (2023). Olfactory search with finite-state controllers. *Proceedings of the National Academy of Sciences*, 120(34). <https://doi.org/10.1073/pnas.2304230120>

RESEARCH AREA:

Science, Technology and Innovation (STI)

The STI unit finds technological solutions to scientific and societal problems that impact humanity, through both in-house laboratory work and collaborations with UN agencies.

The unit has a broad scope, encompassing the development of wireless communication and AI on embedded devices; advanced instrumentation for sensors, optics

and lasers, nuclear and particle physics applications, and supercomputing; and ionospheric physics, modelling and space weather.



Roberto Barnaba / ICTP Photo Archives

STI IN NUMBERS 2023

11

SCIENTIFIC ACTIVITIES ORGANISED AT ICTP

01

SCIENTIFIC ACTIVITIES ORGANISED ABROAD

06

SEMINARS ORGANISED

19

SHORT-TERM VISITORS

RESEARCH AREAS INCLUDE:

WIRELESS ICT AND INTERNET OF THINGS

STI researchers employ unlicensed frequencies to provide broadband connections between academic institutions, while connecting Internet of Things-based scientific devices using narrowband alternatives. The Marconi Laboratory focuses on providing assessments and technical solutions in the rapidly evolving fields of wireless communication, Internet of Things applications, and ionospheric data sources.

IONOSPHERIC PHYSICS, MODELLING AND SPACE WEATHER

STI researchers study the near-Earth plasma environment, explore ionospheric physics and develop ionospheric models. The Marconi Laboratory focuses in particular on space weather phenomena and their influence on the performance of technological systems like the Global Navigation Satellite Systems (GNSS). Special attention is devoted to ionosphere monitoring, mainly through total electron content data analysis and radio occultation data inversion.

ADVANCED SCIENTIFIC INSTRUMENTATION

STI researchers develop advanced scientific instrumentation for particle physics experiments, nuclear applications, supercomputing, and multidisciplinary experimental research, including projects on cultural heritage and optics. The unit's Multidisciplinary Laboratory (MLab) focuses on developing scientific instruments and methods to address a range of scientific problems through internal and external collaborations.

DIGITAL FABRICATION AND SCIENCE DISSEMINATION

The STI unit's Scientific FabLab (SciFabLab) boasts state-of-the-art manufacturing equipment for digital fabrication and rapid prototyping, as part of a larger world-wide FabLab network. The Laboratory is open to ICTP researchers and to the public proposing projects in science, education and sustainable development. The SciFablab is also actively involved in science dissemination through laboratory visits and outreach events such as the Maker Faire Trieste.

Development of low-cost scientific equipment is a key theme at the STI unit: STI researchers design low-cost devices, easily exportable to developing countries.

In 2023, the Marconi Lab researchers specialised in Tiny machine learning (TinyML), a small, energy-efficient and low-cost technology for the implementation of applied artificial intelligence (AI). The unit organised workshops and trainings aiming to develop a network of skilled researchers in developing countries.

The STI unit's FabLab regularly organises trainings on the creation and management of Maker Spaces.

Researchers at the unit's MLab have been developing the data processing system of the multichannel electromagnetic calorimeter (ECAL2) of the AMBER experiment at CERN, in an ongoing collaboration with INFN. In collaboration with IAEA's Nuclear Science

and Instrumentation Laboratory, they have also been developing a 2D-XRF scanner for cultural heritage and a UAV radiation monitoring system. The team also designed and built a cluster of systems-on-chip for reconfigurable supercomputing.

The team specialising in ionospheric modelling at STI has been working on assembling and deploying low-cost GNSS receivers that will participate in building Africa's capacity in space-weather and ionospheric monitoring.

Many of the research lines and projects developed at STI involve AI, which is also going to drive the Unit's future research directions. Technology ethics is a fundamental concern of the Unit, where device affordability is considered together with electronic waste, the ownership of technological projects in the developing world, and the impact of projects on local communities.

PUBLICATION HIGHLIGHTS 2022

Altayeb, M., Zennaro, M., Pietrosevoli, E., Manzoni, P., & Nordin, R. (2023). A LoRaWAN uplink range-extender (lure) for extended and energy-efficient wireless IOT Communications. *ICC 2023 - IEEE International Conference on Communications*. <https://doi.org/10.1109/icc45041.2023.10279021>

Samayoa, W. F., Crespo, M. L., Cicuttin, A., & Carrato, S. (2023). A survey on FPGA-based heterogeneous clusters architectures. *IEEE Access*, 11, 67679–67706. <https://doi.org/10.1109/access.2023.3288431>

Canessa, E., & Fonda, C. (2023). Science and inclusion. *Technology and Disability*, 35(1), 1–9. <https://doi.org/10.3233/tad-220387>

Osanyin, T. O., Candido, C. M. N., Becker-Guedes, F., Migoya-Orue, Y., Bosco Habarulema, J., Obafaye, A. A., Chingarandi, F. S., & Moraes-Santos, S. P. (2023). Performance of a locally adapted nequick-2 model during high solar activity over the Brazilian equatorial and low-latitude region. *Advances in Space Research*, 72(12), 5520–5538. <https://doi.org/10.1016/j.asr.2023.07.018>

ICTP Impact

Science is a powerful driving force in the success of any nation, contributing to its economic well-being and the individual fulfilment of its people. Many countries, however, do not have the infrastructure or educational provision to support the growth of science and technology and to keep pace with the developed world. Technology unsupported by science simply does not take hold or flourish. It is not enough to have the know-how; countries also need the know-why. ICTP is committed to addressing and eliminating those inequalities.

ICTP's reach and impact is global. The Centre's **four regional centres of excellence** in Brazil, China, Mexico and Rwanda bring ICTP's unique blend of high-quality physics and mathematics education and high-level science meetings closer to scientists everywhere. Our **Physics Without Frontiers** programme spreads the joy and wonder of physics to students in science- and technology-lagging countries, helping to build the next generation of scientists.

ICTP also builds scientific capacity through programmes coordinated by its **External Activities Unit**. These include support for scientific meetings, research networks, visiting scholars, and collaborative agreements with universities in developing countries. The latter, which ICTP considers 'affiliated centres', receive ICTP support for their postgraduate programmes in physics or mathematics, and are encouraged to enrol staff and students in ICTP programmes.



ICTP regional centres of excellence

MEXICO:

The Meso-American Institute for Sciences (MAIS) was established in collaboration with the Universidad Autónoma de Chiapas (UNACH) as a regional headquarters of ICTP in Mexico, Central America and the Caribbean.

BRAZIL:

The ICTP South American Institute for Fundamental Research (ICTP-SAIRF) is a regional centre for theoretical physics created in collaboration with the State University of Sao Paulo (UNESP) and the Sao Paulo Research Funding Agency (FAPESP).

RWANDA:

Inaugurated in 2018, the East African Institute of Fundamental Research (EAIIFR), based at the University of Rwanda's Kigali campus, offers an important educational and research hub for the region and for Africa.

CHINA:

In Beijing, the International Center for Theoretical Physics-Asia Pacific (ICTP-AP) is hosted at the University of the Chinese Academy of Sciences (UCAS) and provides opportunities for advanced training, research and education in theoretical physics and related interdisciplinary areas.

04 ICTP Partner Institutes



17 ICTP Schools and Workshops



08 ICTP-EAU Affiliated Centres



07 ICTP-EAU Networks



39 ICTP-EAU Scientific Meetings



25 Physics Without Frontiers Activities



ICTP: A Hub for Global Scientific Activities

ICTP's work at the very frontiers of research makes it a destination of choice for leading physicists and mathematicians from all over the world. Each year, ICTP brings together thousands of world-leading and early career scientists from more than 150 countries to participate in advanced workshops and conferences that explore topics at the cutting edge of physics and mathematics.

This rich intellectual atmosphere is enhanced by resources such as our Library – one of Europe's finest research libraries – our high-performance computing facilities, and residential and community facilities that promote informal social and intellectual interactions where ideas are discussed over meals or coffee.

Over the years, more than 100 Nobel laureates, 20 Fields medallists, and members of our distinguished Scientific Council have spent time at ICTP, offering unparalleled opportunities for the brightest minds in the world, whether established or early-career scientists, to learn from each other.

ICTP also reaches directly into the developing world. Our four partner institutes in Brazil, China, Rwanda, and Mexico give scientists in those countries access to our networks, expertise, and convening power and have flourishing research and training programs of their own and in collaboration with ICTP.

ICTP has been the anchor of the "Trieste Science System" – a network of institutes including the International School for Advanced Studies (SISSA), Elettra Synchrotron Facility, and the University of Trieste – which offers even broader opportunities for collaboration within a short distance of our campus.

ICTP ACTIVITIES IN NUMBERS, 2023

6269

PARTICIPANTS, INCLUDING THOSE
WHO PARTICIPATED REMOTELY

157

NATIONS REPRESENTED

61

CONFERENCES, SCHOOLS
AND WORKSHOPS

32%

OF PARTICIPANTS
WERE WOMEN



Roberto Barnaba /ICTP Photo Archives

At the ICTP-Quantinuum Quantum Hackathon held at ICTP in April, 18 international teams competed on challenges related to quantum computing).



DEVELOPING STATUS OF PARTICIPANTS' COUNTRIES, 2023

7%

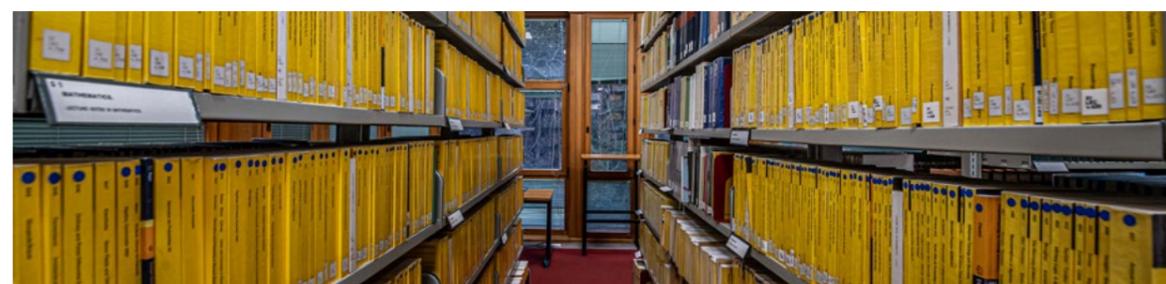
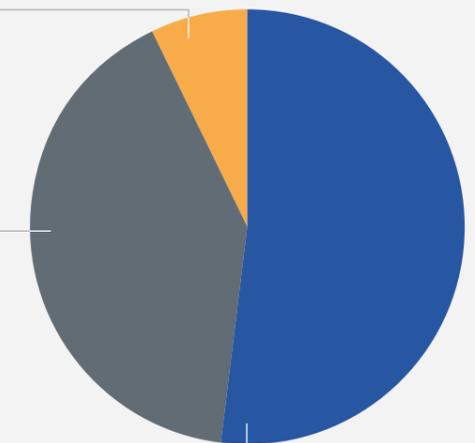
Least
Developed
Countries

41%

Developed
Countries

52%

Developing
Countries



Higher Education and Career Development

Scientists at all stages of their careers can advance their knowledge in physics and mathematics through ICTP's education and training programmes. These include pre-PhD programmes that help prepare students for the rigors of doctorate study. The Centre offers a number of masters and PhD degree programmes jointly with Italian and European universities. Scientists who want to maintain their connection to ICTP can participate in the Centre's Associates Scheme, which supports sabbatical visits over a period of several years.

Educational Programmes

Postgraduate Diploma Programme: Supporting its mission to promote advanced scientific research in developing countries, ICTP offers a Postgraduate Diploma Programme that prepares talented students for PhD studies. The intense, one-year course of study is competitive: From about 180 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 2023-2024 course that began in September 2023, the students came from Algeria,

Bangladesh, Benin, Botswana, Cameroon, Colombia, Ecuador, Egypt, Eritrea, Ethiopia, Ghana, Guatemala, Indonesia, Iran, Iraq, Lebanon, Mongolia, Nigeria, Oman, Pakistan, Palestine, Peru, Philippines, Sudan, Thailand, Uzbekistan, Venezuela, and Viet Nam.

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 studies in their home countries. In the 2022-2023 batch of 41 students who received their Postgraduate Diplomas, the MSc/PhD placements included Max Planck Institute, McGill University, Massachusetts Institute of Technology (MIT), Ludwig Maximilian University of Munich, University of Houston, Institut Polytechnique de Paris, University of Padova, among others.



Roberto Barnaba/ICTP Photo Archives

Masters' Programmes: ICTP, in collaboration with local universities, offers study opportunities to scientists from the developing world, helping them attain master's and doctoral degrees in physics and mathematics. Thanks to these collaborations, students from disadvantaged countries can pursue masters degrees in the following programmes:

- *Master of Advanced Studies in Medical Physics (MMP):* a two-year advanced training programme run jointly by the ICTP and the University of Trieste designed to provide young, promising graduates of physics or related fields (mainly from developing countries) with postgraduate theoretical and clinical training so that candidates may be recognised as clinical medical physicists in their home countries. The programme comprises a year of basic and advanced courses (taught in English) prepared with the assistance of experts from the ICTP, the University of Trieste, the International Atomic Energy Agency (IAEA) and appointed external advisors. This is followed by a year of professional clinical training in a medical physics department of an Italian hospital in the programme's training network.

The MMP is co-sponsored by the IAEA, and is supported by the International Organisation for Medical Physics (IOMP), the European Federation of Organizations in Medical Physics (EFOMP), the

Italian Association of Medical Physics (AIFM), in collaboration with Trieste University Hospital. The Master's Programme is accredited by the International Organisation for Medical Physics (IOMP). In 2023, 46 students (15 female and 31 male) from 33 different countries were enrolled in the 2023-2024 academic year, while 29 students (8 female and 21 male) graduated from the programme.

- *Master in High Performance Computing (MHPC):* an innovative degree programme that prepares students for exciting careers in the fast-growing field of high performance computing (HPC). Set in the stimulating research environment of ICTP and SISSA, the programme combines lectures with hands-on and applied projects to prepare future HPC specialists for academia and industry. Courses are delivered by an international faculty composed by local HPC experts complemented by international well-renowned experts in the field. Practical HPC experience allows students to work side-by-side with scientific groups and/or stimulating industrial environments. In 2023, 4 students (2 female and 2 male) from Egypt, Kenya, Morocco and the Philippines were registered in the MHPC with the ICTP Fellowship, while 3 students (2 female and 1 male) graduated.

ICTP EDUCATION IN 2023

155

STUDENTS ENROLLED IN MASTERS, PHD, DIPLOMA AND STEP PROGRAMMES

66

COUNTRIES REPRESENTED (INCLUDING 16 LEAST-DEVELOPED COUNTRIES)

222

SCIENTISTS FROM 50 COUNTRIES (INCLUDING 11 LEAST-DEVELOPED COUNTRIES) ENGAGED IN CAREER DEVELOPMENT PROGRAMMES: ASSOCIATES, TRIL, ELETTRA AND ATAP



Isma Javed and Ramna Khalid of Pakistan with Humberto Cabrera Morales of ICTP's Multidisciplinary Laboratory (MLab) performing an optics experiment.

- In addition, ICTP offers a limited number of scholarships to students from developing countries selected to follow the training track in Condensed Matter Physics of the International Master in Physics of Complex Systems, offered through an international consortium of universities. Each scholarship includes a travel grant, insurance and tuition fees. In 2023, 2 students (1 female from Brazil and 1 male from Colombia) were funded by ICTP.

PhD and Sandwich Programmes: ICTP, in collaboration with local universities, offers study opportunities and fellowships to scientists from the developing world, helping them attain master's and doctoral degrees in physics and mathematics. Thanks to these collaborations, students from disadvantaged countries can pursue doctoral degrees in the following programmes:

- Physics PhD Programme, University of Trieste:** ICTP offers a scholarship for students from developing countries who want to do research in areas of interest to ICTP to enroll in this PhD programme. In 2023, 3 students (2 female and 1 male) from India, Rwanda and Tunisia were enrolled in the programme with an ICTP scholarship, while one male student from India graduated from the programme.
- Joint ICTP/SISSA PhD Programme in Physics and Mathematics:** ICTP partners with SISSA to offer students who have successfully completed ICTP's Postgraduate Diploma Programme the opportunity to enroll in a PhD programme in Trieste. The Programme offers courses in: applied mathematics, mathematical analysis, geometry, mathematical physics; astroparticle physics, astrophysics; elementary particles; physics and chemistry of biological systems; statistical physics; condensed matter theory and numerical simulation. During 2023, 23 students (5 female and 18 male) from 14 countries were enrolled in this PhD programme; 6 students graduated in 2023.

- Joint PhD Programme, Earth Science, Fluid-Dynamics, and Mathematics. Interactions and Methods:** Co-sponsored by ICTP, the University of Trieste and the Italian National Institute of Oceanography and Experimental Geophysics (OGS), this programme aims at the interdisciplinary training of students in the field of the Earth system science, with special attention to the interactions between earth science, fluid-dynamics and applied mathematics, as well as to the interplay of methodological aspects, modeling and applications. In 2023, 5 students (2 female and 3 male) from Brazil, Colombia, Italy, Mexico and Palestine were enrolled in the Programme, and 3 students (1 female and 2 male) graduated.
- PhD Programme, Industrial and Information Engineering, University of Trieste:** ICTP provides fellowships to students from developing countries to enroll in this programme that prepares researchers in design methods, theoretical analysis, soft-computing and advanced experimentation. During 2023, two male students from Guatemala were enrolled in the programme with ICTP fellowships. Also during 2023, 2 students from Argentina (1 female and 1 male) graduated from the programme.

In addition, through its **Sandwich Training Educational Programme (STEP)**, ICTP and its UN partner, the International Atomic Energy Agency (IAEA), offer fellowships to PhD students from developing countries in the fields of physics, mathematics and related fields. PhD students study at their home universities but have the financial support to visit ICTP or a collaborating institute for a three- to six-month stay each year for up to three successive years. Fellows work on their PhD theses with their advisors at their home institutes and co-advisors at the hosting institutes. Their PhD is awarded at their home institutes. During 2023, 30 fellows (17 female and 13 male) from 16 countries participated in the STEP programme.

Career Development Programmes

Associates Programme: ICTP's Associates Programme enables individual scientists at different stages of their careers to maintain long-term formal contacts with ICTP's stimulating and active scientific environment. Researchers who hold a PhD and are working in developing countries are eligible for the programme. The programme supports regular visits to ICTP, where ICTP Associates have the opportunity to remain in touch with the experts and also with the most modern aspects of their scientific fields. To a large extent, this helps to eliminate the brain-drain in their home countries and the sense of isolation.

ICTP Associate are active scientists in their countries, and they are expected to play a major role in the process of building their scientific communities, enhancing physics and mathematics education at all levels, and planning research projects related to the specific needs of their region. During 2023, 118 Associates (24 female and 94 male) from 38 countries visited ICTP.

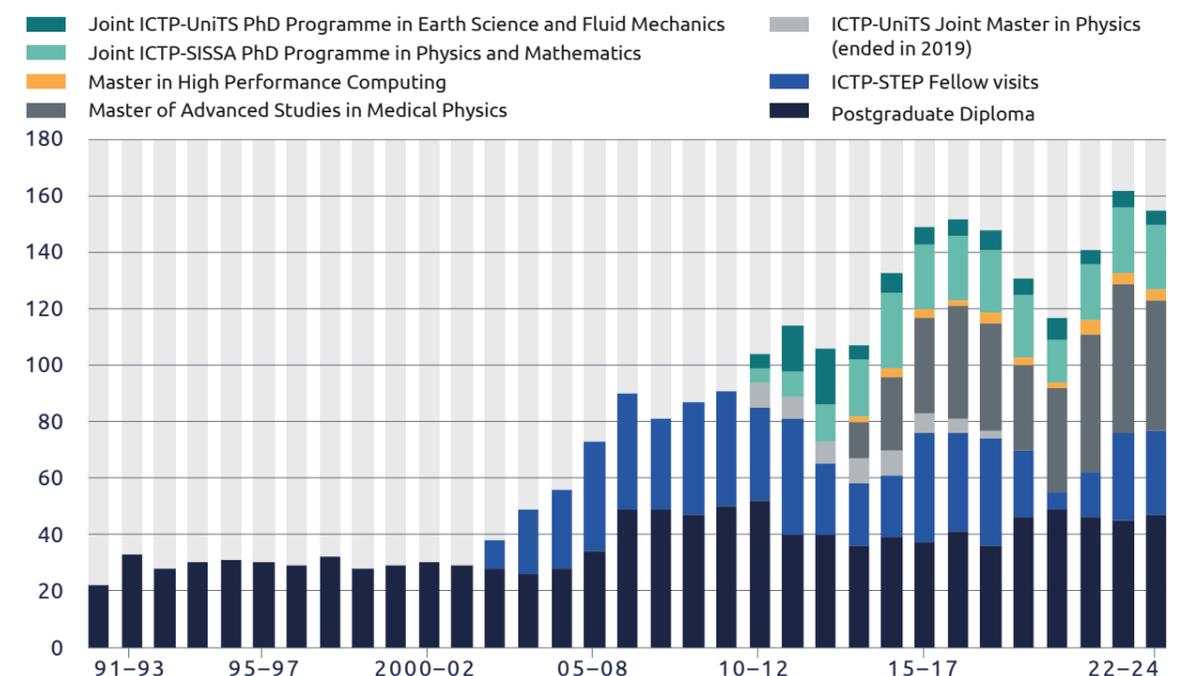
Postdoctoral Opportunities: ICTP Postdoctoral Fellowships are intended for young scientists or mathematicians with a strong research record. Fellows must have completed a PhD in a related field prior to the start of their Fellowship. The Fellowships typically have a two-year duration with a possible extension for a further period of 12 months. The starting date can be negotiated. Preference is given to candidates who will benefit most from the time spent at ICTP in pursuit of their own research, using the ICTP facilities and participating in ICTP activities, and who will interact with local scientists and visitors and will contribute to the intellectual vitality of the Centre. In 2023, ICTP supported 80 postdoctoral students (24 female and 56 male) from 28 countries.

Laboratory Opportunities: Access to modern, well-equipped research laboratories can be a challenge for scientists working in the developing world. ICTP helps by supporting visits to its on-site laboratories as well as to those located elsewhere in Trieste and throughout Italy. Laboratory programmes include ICTP's Training and Research in Italian Laboratories (TRIL), which offers scientists from developing countries the opportunity to undertake training and research in an Italian laboratory in different branches of the physical sciences. In 2023, 69 scientists (35 female and 34 male) from 29 countries participated in the TRIL programme.

Further laboratory opportunities are available through the ICTP-ELETTRA Users Programme, offering access to Trieste's Elettra synchrotron radiation facility for scientists from developing countries who work in those countries. Support includes a limited number of grants to cover travel and living expenses of individuals and small groups who participate in the beamtime at Elettra. During 2023, 30 scientists (12 female and 18 male) from 7 countries benefited from the Elettra Users Programme.

In addition, ICTP has partnered with the American Physical Society (APS), the European Physical Society (EPS), and the APS Forum on Early Career Scientists (FECS) to support research visits to laboratories in Europe (excluding Italy) and North America, or to a more advanced developing country. In 2023, this APS-EPS-ICTP Travel Award Fellowship Programme supported 5 scientists (3 female and 2 male) from 5 countries.

TREND IN ICTP PROGRAMMES AND ENROLLMENT



Science Outreach



A Physics Without Frontiers activity held in Zimbabwe helped to increase awareness and provide some basic notions about high energy physics.

ICTP has a long tradition of scientific capacity building in developing countries. Over the last few decades, ICTP has supported numerous activities throughout the developing world, including training programmes, networks, and the establishment of affiliate centres.

Activities are initiated by scientists and scientific institutions in the developing world and are carried out at sites located within the region. The purpose is threefold:

- To initiate, stimulate or make applicable research and training in the fields of physics and/or mathematics related to locally available resources or local problems of specific relevance to the development of the region.
- To form and strengthen national and regional communities and research groups by supporting institutions or national societies for physicists and mathematicians at all levels.
- To enhance physics and mathematics teaching.

ICTP achieves these goals through a number of science outreach programmes:

- **External Activities Unit:** ICTP supports research and training activities of physicists and mathematicians living and working in developing countries, primarily by providing assistance for regional activities. The goal is to boost the scientific level of individuals, groups or institutes in developing countries to an international level through North-South collaboration, and to stimulate networking of scientists in the developing regions to reach a critical mass of researchers through South-South collaboration. Assistance is coordinated by ICTP's External Activities Unit, through which ICTP directly supports postgraduate courses and students as well as early career scientists in Affiliated Centres, research group networks, scientific meetings, and visiting scholars and consultants. In 2023, the External Activities Unit funded 8 affiliated centres, 7 Scientific networks and 39 scientific meetings, involving a total of 58 countries from Africa, Asia, Europe and Latin America.

- **Physics Without Frontiers:** Physics Without Frontiers (PWF) targets the far reaches of the developing world to inspire and engage undergraduate and masters physics students. The programme embarks on physics roadshows, run by working groups comprising young volunteer PhD students and postdocs who visit university physics or maths departments in a developing country to give one-day, intensive masterclasses to undergraduate and master's students. The outreach is extended to high school students, the general public and policy makers via events throughout a country. In 2023, PWF organised a physics roadshows in Zimbabwe, that included visits to 5 universities, inspiring more than 250 students. PWF also brings high-level masters courses to universities that lack such courses. In 2023, PWF taught courses in Iran, instructing a total of 10 master's students. They also organised 25 different activities in 15 countries, with a total of 1,175 participants.
- **Partner Institutes:** ICTP has set up regional centres of excellence around the globe. These partner institutes bring ICTP's unique blend of high-quality physics and mathematics education and high-level science meetings closer to scientists everywhere. They include the following:
 - The **ICTP South American Institute for Fundamental Research**, ICTP SAIFR, is a regional centre for theoretical physics created in collaboration with the State University of Sao Paulo (UNESP) and the Sao Paulo Research Funding Agency (FAPESP).
 - The **ICTP East African Institute of Fundamental Research (EAIIFR)** is based at the University of Rwanda's Kigali campus.
 - The **ICTP-Asia Pacific** was created in collaboration with the University of the Chinese Academy of Sciences.
 - In Mexico, the **Meso-American Institute for Sciences** operates in collaboration with the Universidad Autónoma de Chiapas (UNACH).

Public Outreach

Throughout the year, ICTP engages with the public through numerous outreach activities aimed at spreading the joy of science to the young and old. Some events are highlighted here. ICTP's Public Information Unit coordinates a visiting programme for students of all ages to meet ICTP scientists and tour facilities such as the ICTP Library and the Centre's SciFabLab. During 2023, 17 such visits to ICTP took place, introducing more than 400 visitors to the magic of ICTP physics and mathematics.

PHYSICS: WHAT REMAINS TO BE DISCOVERED?



ICTP was pleased to host a public outreach event in Trieste featuring a moderated dialogue between physicists and Nobel Laureates David Gross and Giorgio Parisi. The event, titled "Physics: What Remains to be Discovered?", was moderated by Italian science journalist Simone Regina and attracted an audience of hundreds, both in person and online.

TRIESTENEXT 2023



ICTP participated in Trieste's annual science festival, TriesteNext, with an exhibit, interactive activities, panel discussions and outreach to local schools. The ICTP exhibit space highlighted a programme of activities for schools as well as hands-on activities for people of all ages.

ASTRONAUTS FOR A DAY

Children of ICTP staff and scientists were treated to an activity called "Astronauts for a Day", billed as a venture into space. Participants were tasked with building a small spaceship (from recycled materials) that would protect them during this journey, while learning about some basic astrophysics concepts. In the photo, ICTP science communicator Sara Anzuinelli explains how a cloud chamber particle detector works.



TRIESTE MAKER FAIRE



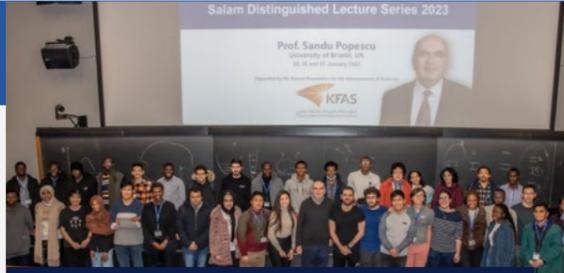
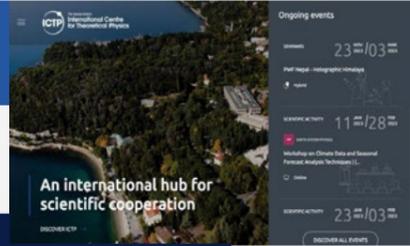
The tenth edition of the Trieste Maker Faire was held in Trieste's Piazza Unita on 2 and 3 September, providing a showcase for the innovation and creativity of some 200 "makers" in the Trieste region. ICTP was the first organizer of the event when it was launched in Trieste in 2014 as a Mini Maker Faire; in 2020 the event became a bigger Trieste Maker Faire in light of its growing popularity.

2023 Timeline

January

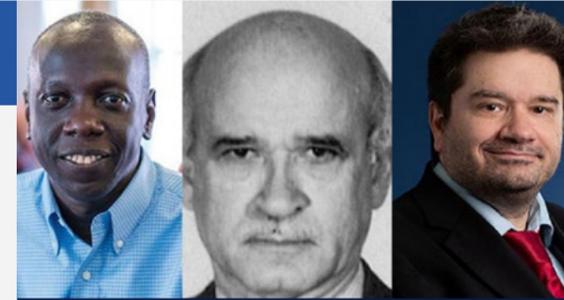
ICTP LAUNCHES GLOBAL SCIENTIFIC PORTAL

ICTP greeted the new year with the launch of a dynamic, interactive internet portal that aims to promote the Centre's activities and achievements as well as encourage international scientific networking. Accessible at www.ictp.it, the portal represents the first phase of what the Centre plans to be a global scientific portal that will encourage networking amongst ICTP's vast international community of physicists and mathematicians. The goal is to reinforce the connections that scientists make through their participation in ICTP activities and programmes.



SALAM DISTINGUISHED LECTURES 2023

ICTP's 2023 Salam Distinguished Lecture Series featured theoretical physicist Sandu Popescu, professor of physics at the University of Bristol, UK. Popescu delivered three lectures on topics related to the fundamental aspects of quantum physics. Popescu is a pioneer of quantum information, best known for his work on entanglement and the associated phenomenon of non-locality, which are crucial for our current understanding of quantum theory.

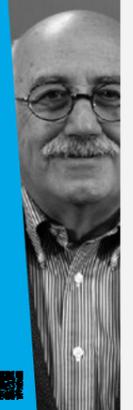


SPIRIT OF SALAM AWARDEES ANNOUNCED

Three members of the ICTP community received the 2023 Spirit of Abdus Salam Award: Tino Nyawelo (Sudan), for founding a program that encourages underrepresented students to pursue science, technology, engineering, and math (STEM) education at the university level; Hugo Celso Perez Rojas (Cuba), for his advocacy for basic science in his home country; and Federico Rosei (Italy), for his global efforts in science capacity building.

THE PHYSICS OF CATALYSIS

A JOINT ICTP-SISSA COLLOQUIUM
 PROFESSOR MICHELE PARRINELLO
 ITALIAN INSTITUTE OF TECHNOLOGY,
 GENOVA, ITALY
 MONDAY 30 JANUARY 2023 AT 16:00
 BUDINICH LECTURE HALL
 ICTP LEONARDO BUILDING



JOINT ICTP-SISSA COLLOQUIUM

"The Physics of Catalysis"

Michele Parrinello, Italian Institute of Technology (IIT), Genoa, Italy

February

CELEBRATING OPTICS EXCELLENCE

ICTP celebrated the recent recipients of the ICO/ICTP Gallieno Denardo Award (whose ceremonies were cancelled due to the pandemic) with a ceremony honouring three years' worth of winners: David Hayrapetyan (in photo, right) (2021 award) from the Russian-Armenian University at Yerevan, Armenia, for his breakthrough contributions to the theory of semiconductor nanosystems; VR Supradeepa (2022 award) from the Center for Nano Science and Engineering, IISc Bangalore, India, for his significant contributions to the field of high power fibre lasers and integrated non-linear optics; and Muhammad Qasim Mehmood (in photo, left) (2023 award) from the Information Technology Institute of the Punjab at Lahore, Pakistan, for his remarkable contribution to the field of nanophotonics.



March

ICTP COLLOQUIUM

"The Conformal Bootstrap: From Boiling Water to Quantum Gravity"

Agnese Bissi, ICTP

ICTP COLLOQUIA 2023

The conformal bootstrap: from boiling water to quantum gravity

Dr. Agnese Bissi
 Uppsala University, Sweden



Wednesday 15 March 2023 at 16.00
 Budinich Lecture Hall

JOINT ICTP-SISSA COLLOQUIUM

"On Some Variational Problems Involving Functions with Bounded Hessian"

Luigi Ambrosio, Scuola Normale Superiore of Pisa

ON SOME VARIATIONAL PROBLEMS INVOLVING FUNCTIONS WITH BOUNDED HESSIAN

A JOINT ICTP-SISSA COLLOQUIUM
 PROFESSOR LUIGI AMBROSIO
 SCUOLA NORMALE SUPERIORE, PISA,
 ITALY
 WEDNESDAY 12 APRIL 2023 AT 16:00
 BUDINICH LECTURE HALL
 ICTP LEONARDO BUILDING



2023 TIMELINE

April



AFRICAN COLLABORATION

ICTP Director Atish Dabholkar (second from left) and University of Rwanda Acting Vice Chancellor Dr. Didas Kayihura Muganga (third from left) at the signing of the new agreement for ICTP's partner institute in Rwanda, the East African Institute for Fundamental Research. To their left: Ralf Kaiser, Senior Coordinator for Programmes and Advancement at ICTP; and to their right: Professor Paul Davenport, Chairperson of the University of Rwanda Board of Governors, Dr. Raymond Ndikumana, Deputy Vice Chancellor for Strategic Planning and Administration, University of Rwanda, and Mike Hughes, Special Advisor to the Rwandan Minister of Education.

The agreement, signed by ICTP Director Atish Dabholkar and University of Rwanda Acting Vice Chancellor Dr. Didas Kayihura Muganga, extends the partnership for five years.

Ramanujan Prize winner Mouhamed Moustapha Fall (centre) with ICTP Director Atish Dabholkar and Ulrike Tillmann, Vice President of the International Mathematical Union



RAMANUJAN PRIZE CEREMONY

ICTP held a ceremony to honour Mouhamed Moustapha Fall, recipient of the 2022 DST-ICTP-IMU Ramanujan Prize. Fall was awarded the prize for his outstanding work in the theory of Partial Differential Equations. He is Professor and President of the African Institute for Mathematical Sciences (AIMS) in Senegal, and an alumnus of ICTP's Diploma Programme.

2023 TIMELINE

May

JOINT ICTP-SISSA COLLOQUIUM

"Large Random Matrices and Beyond"

Alice Guionnet, École normale supérieure de Lyon, France

LARGE RANDOM MATRICES AND BEYOND

A JOINT ICTP-SISSA COLLOQUIUM
PROFESSOR ALICE GUIONNET
ÉCOLE NORMALE SUPÉRIEURE, LYON, FRANCE
TUESDAY 9 MAY 2023 AT 16:00
SISSA, VIA BONOMEA, ROOM 128
OR FOLLOW ONLINE VIA ZOOM WEBINAR:
WEBINAR LINK



ICTP COLLOQUIA 2023

Fifty Years of Quantum Chromodynamics



Professor **David Gross**
Nobel Prize Laureate
Kavli Institute for Theoretical Physics (KITP)
University of California, USA

Tuesday 23 May 2023 at 14.00
Budnich Lecture Hall

ICTP COLLOQUIUM

"Fifty Years of Quantum Chromodynamics"

David Gross, Kavli Institute for Theoretical Physics (KITP), University of California, Santa Barbara

June



ICTP PRIZE 2022 CEREMONY

Two scientists shared the 2022 ICTP prize and were honoured in a ceremony in June at ICTP. The two recipients from Iran — Shant Baghram (in photo, right) of the Sharif University of Technology and Mohammad Hossein Namjoo (in photo, left) of the Institute for Research in Fundamental Sciences — share the Prize for their pioneering contributions to developing robust theoretical, computational and statistical frameworks to compare theoretical predictions for various cosmological and astrophysical phenomena with high-precision observational data.

ICTP COLLOQUIUM

"What Every Physicist Should Know About String Theory"

Edward Witten, Institute for Advanced Study, Princeton



ICTP COLLOQUIUM

"Cosmology and Unification"

Raman Sundrum, University of Maryland

July

ICTP, SISSA RENEW STRATEGIC RESEARCH COLLABORATIONS



ICTP and SISSA signed a five-year agreement to conduct joint research in Artificial Intelligence (AI) and data science, and in quantum technology. The goal is to develop new projects and research lines by combining their significant expertise in the basic science behind these fields. The new agreement also underscored ICTP and SISSA's long-term commitment to developing the advanced computing resources needed to drive advances in AI and data science: the two institutes agreed to continue their joint Master's programme in High Performance Computing (MHPC). The MHPC combines lectures with hands-on and applied projects to prepare future HPC specialists for academia and industry. In photo, ICTP Director Atish Dabholkar (right) with SISSA Director Andrea Romanino.

August



DIRAC MEDAL 2023

ICTP ANNOUNCES 2023 DIRAC MEDALLISTS

ICTP has awarded its 2023 Dirac Medal to four physicists who have made wide-ranging contributions to string theory, a mathematical framework in fundamental physics that aims to describe the entirety of the whole universe. The 2023 Dirac medallists are (in photo, from left): Jeffrey Harvey, University of Chicago, USA; Igor Klebanov, Princeton University, USA; and Stephen Shenker and Leonard Susskind of Stanford University, USA. The award cites "their pioneering contributions to perturbative and non-perturbative string theory and quantum gravity, in particular, to the aspects related to anomalies, duality, black holes and holography".

ICTP POSTGRADUATE DIPLOMA GRADUATION



Forty-one young scientists have completed an important step in their career paths: they have received ICTP's Postgraduate Diplomas after a year of intense study in various fields of physics and mathematics.

A ceremony marking the occasion took place at ICTP on Monday 28 August. Of the 41 graduates, six students were recognized as the top scholars in their sections, including the following:

- High Energy, Cosmology and Astroparticle Physics: **Raji Ashenafi Mamade**
- Condensed Matter Physics: **Ronald Santiago Cortes**
- Earth System Physics: **Deborah Osei-Tutu**
- Mathematics: **Fatemeh Zeinabadi, Rubio Gunawan**
- Quantitative Life Sciences: **Adrielle Theresa Cusi**

This year, for the first time, a special prize funded by and named for long-time friends and supporters of ICTP Qaisar and Monika Shafi was presented to one of the best students of the year. Deborah Osei-Tutu of

Ghana, whose Diploma thesis focussed on earthquake dynamics, received the prize. She will pursue a master's and then a doctoral degree in Germany at the Ludwig Maximilian University of Munich.



Deborah Osei-Tutu holds the inaugural Qaisar and Monika Shafi Prize. With her are (from left) ICTP Director Atish Dabholkar, Monika Shafi and Qaisar Shafi.



ROAA OMER

Sudan

Diploma in Qualitative Life Sciences; admitted to PhD programme in the physics and chemistry of biological systems at SISSA

“ I want to have my own research group back in Sudan in such a way that it is open and connected with the rest of the world. I don't want to really spend all my life traveling from country to country, that's a big thing. I would love to use whatever knowledge I can to help at least a fraction of my people, and establish this type of research back in my country in one of the universities. It is a long-term dream. It's not easy, but I will try my best to do it. ”



DEBORAH OSEI-TUTU

Ghana

Diploma in Earth System Physics; admitted to combined master's and PhD degree programme in computational geoscience at Ludwig Maximilian University of Munich

“ After my PhD and getting more into research, I will certainly go back home because I absolutely want to setup an institute like ICTP in Ghana that does mathematical and computational physics and modern programming for geoscience. We have a lot of geoscientists because of the minerals and other earth resources there. It's also my great desire to be an advocate for female education, especially in physics. I sat in a physics class of 90 % male students and was never taught by a female lecturer during my 4-year undergraduate studies. Much more ladies have to be encouraged to pursue higher education in physics and science, and this I will passionately get involved in when I go back home. ”



RUBIO GUNAWAN THE

Indonesia

Diploma in Mathematics; admitted to PhD programme at SISSA

“ I've learned a lot in one year, I think. My bachelor's degree was four years long, and I think in this one year, I've probably learned more than I did in all those four years. Also, I feel more confident in my ability to learn higher mathematics and to do research because doing my thesis taught me a lot. It's been challenging but I think I've made good progress. ”



RAJI MAMADE

Ethiopia

Diploma in High Energy, Cosmology and Astroparticle Physics; admitted to PhD programme at the Center for Theoretical Physics at the Massachusetts Institute of Technology (MIT)

“ The really good thing about the ICTP environment is that it was completely new to me. New and complicated: perfect. It's like a dream for me. The program was amazing: it was immersive in terms of just understanding the courses. It was very difficult for me, and intensive. At times, I was almost at breaking point, but I look back at most of my experience, how much I've learned, and how far I've come, and I thank God that I came to ICTP. ”



RONALD CORTES

Colombia

Diploma in Condensed Matter and Statistical Physics; admitted to PhD programme in condensed matter physics at SISSA

“ Being a developing country, Colombia has many challenges to face. Unfortunately, this means science doesn't really get the attention it deserves, especially when it comes to financially supporting fundamental scientific research. Consequently, many science graduates seek well-paid jobs outside academia. Nevertheless, we have excellent research groups across different universities, and I am optimistic that things will change in the future. ”

2023 TIMELINE

August

ICTP DIRAC MEDAL 2022 CEREMONY



ICTP celebrated the scientific achievements of three physicists who received the 2022 Dirac Medal at a ceremony held in August at ICTP. The physicists — Joel L. Lebowitz of Rutgers, The State University of New Jersey, USA, Elliott H. Lieb of Princeton University, USA, and David P. Ruelle, Institut des Hautes Études Scientifiques, France — have received the medal for their important work in the field of statistical mechanics that has very significantly deepened and expanded our mathematical understanding of physical systems in many new directions, sometimes different from the traditional ones. Their major contributions include, among others, the study of non-equilibrium physics and large deviations; the proof of the stability of matter; the analytic solution of two-dimensional models; seminal results in quantum information theory; the definition of Gibbs states for infinite systems; and the analysis of chaos and turbulence. All three scientists were previously awarded the Boltzmann Medal, a prize awarded to physicists who obtain new results concerning statistical mechanics.

2023 TIMELINE

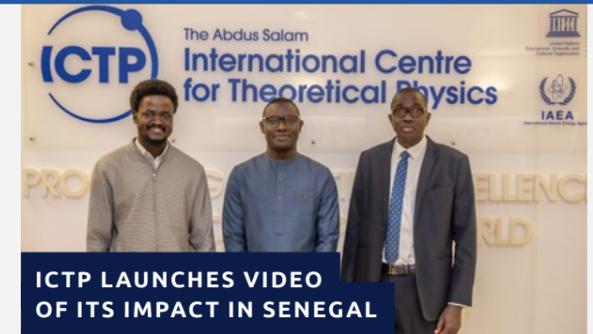
September

ICTP COLLOQUIUM



"Statistical Learning Theory for Modern Machine Learning"

John Shawe-Taylor, University College London



ICTP LAUNCHES VIDEO OF ITS IMPACT IN SENEGAL

In recognition of its profound impact on science and mathematics in Senegal, ICTP released a short video featuring ICTP Senegalese alumni Mouhamed Moustapha Fall (in photo, centre) (recipient of the 2022 Ramanujan Prize), Khadim War and Mamadou Sy (left).

November

Career Development Workshop for Women in Physics



CAREER DEVELOPMENT WORKSHOP FOR WOMEN IN PHYSICS

ICTP held the latest edition of its bi-annual Career Development Workshop for Women in Physics, an activity that combine a variety of highly interactive exercises, talks, panel discussions, training sessions and other activities designed to help women in physics share their experiences, gain self-confidence and acquire extra skills they need to become successful in their professions. Some 118 participants (in person and online) benefitted from the workshop.



ICTP PARTNERS WITH OPEN QUANTUM INSTITUTE

ICTP joined a number of Europe's top research institutes to form a new international initiative called the Open Quantum Institute (OQI). OQI aims to unlock the potential of quantum computing for the benefit of all, irrespective of geographical, economic, or scientific constraints. The OQI will bring together public and private stakeholders for inclusive access to quantum computing, offering concrete solutions to address the United Nations Sustainable Development Goals (SDGs).



Mohit Kumar Jolly

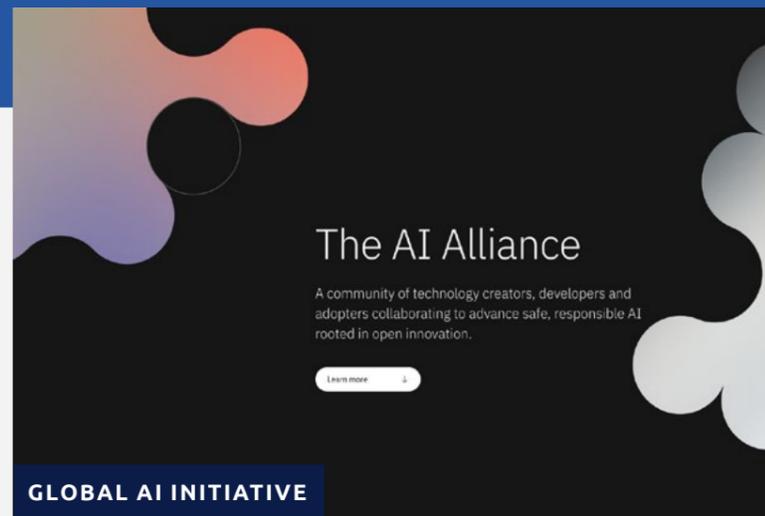


Xinan Zhou

2023 ICTP PRIZE ANNOUNCED

The ICTP Prize 2023 honoured two scientists: Mohit Kumar Jolly of the Indian Institute of Science (IISc) in Bangalore, for innovative contributions to understanding the emergent dynamics of cellular transitions during cancer metastasis and therapeutic resistance, and for unravelling the latent design principles of cellular networks that can determine a cell's fate; and Xinan Zhou of the Kavli Institute for Theoretical Sciences (KITS), University of Chinese Academy of Sciences (UCAS), Beijing, and ShanghaiTech University, for novel and outstanding contributions leading to new techniques to compute correlation functions in conformal field theories in the context of the AdS/CFT correspondence, and for developing new approaches to the analytic conformal bootstrap.

December



GLOBAL AI INITIATIVE

ICTP has joined an elite group of international research institutes and high-tech companies aiming to shape the evolution of Artificial Intelligence (AI) by working together for the advancement of open, safe and responsible AI. The AI Alliance, spearheaded by IBM and Meta, is focused on fostering an open community and enabling developers and researchers to accelerate responsible innovation in AI while ensuring scientific rigor, trust, safety, security, diversity and economic competitiveness.



ICTP RESEARCHER WINS ERC GRANT TO STUDY QUANTUM MANY-BODY SYSTEMS

Marcello Dalmonte, a research scientist with ICTP's Condensed Matter and Statistical Physics section, has won a five-year grant from the European Research Council (ERC) to investigate quantum computers and simulators — two emerging branches of science, with potentially groundbreaking impact in physics and beyond.

GRADUATION CEREMONY, MASTER IN MEDICAL PHYSICS

Twenty-nine students from 24 different countries became the latest graduates of ICTP and the University of Trieste's joint Master of Advanced Studies in Medical Physics (MMP) programme, capping a two-year course of study that includes valuable clinical field experience. More than 140 students from over 70 countries have already graduated from the programme since its launch in 2014. The large majority of students arrived in Trieste from Africa and about one third of them are women.



Photos: Roberto Barnaba/ICTP Photo Archives

Governance

ICTP operates under a tripartite agreement between the Italian Government, the International Atomic Energy Agency (IAEA), and the United Nations Educational, Scientific and Cultural Organization (UNESCO). Each party has a representative on the Centre's Steering Committee, which sets general guidelines for the Centre's activities, determines budgeting levels, and considers proposals from the Director for the programme, work plans, financial plans, and budget.

ICTP also has a Scientific Council that comprises distinguished specialists in disciplines relevant to the Centre's activities who represent a broad geographical range. The Council advises ICTP on its programmes of activities, taking into consideration major academic, scientific, educational and cultural trends relevant to the Centre's objectives. ICTP is a UNESCO Category 1 Institute.

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ICTP would like to express its deep gratitude to all who supported us in 2023.

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In Memoriam

The ICTP community was saddened by the passing of the following members in 2023; they will be missed.

SUFYAN TAYEH

Sufyan Tayeh was a prominent researcher in theoretical physics and applied mathematics and was the President of the Islamic University of Gaza, the largest university in Gaza. He visited ICTP in 2001 and again in 2004 as a fellow in the Training and Research in Italian Laboratories programme. He had recently been appointed the UNESCO Chair for Physical, Astrophysical and Space Sciences in Palestine.



VLADIMIR E. ZAKHAROV

Vladimir E. Zakharov was a Russian mathematician and physicist and longtime friend of ICTP. His research interests included physical aspects of nonlinear wave theory in plasmas, hydrodynamics, oceanology, geophysics, solid state physics, optics, and general relativity. He received ICTP's Dirac Medal in 2003, together with Robert H. Kraichnan, for their distinct contributions to the theory of turbulence, particularly the exact results and the prediction of inverse cascades, and for identifying classes of turbulence problems for which in-depth understanding has been achieved. In 1991, Zakharov was elected an academician of the Russian Academy of Sciences. In 1993, he became the director of the Landau Institute for Theoretical Physics.



ICTP Photo Archives



The Abdus Salam
**International Centre
for Theoretical Physics**

