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EDITORIAL

Mathematics for a just and sustainable development


Image: José María Martell

José María Martell

UNESCO has declared 2022 as the International Year of Basic Sciences for Sustainable Development. This celebration provides us with a great opportunity for highlighting the importance of basic sciences and, in particular, mathematics for attaining the Objectives of Sustainable Development (OSD).

The goal of basic science is the generation of theoretical knowledge about the world that surrounds us, without necessarily taking into account concrete and immediate applications. Knowledge about the nature of black holes, deciphering the mechanisms that led to the development of life on Earth or understanding the atomic interaction of the chemical elements are advances that entail the enrichment of society as a whole.

Mathematics constitutes the paradigm of basic science; it deals mainly with abstract objects and their interrelations, the development of which, in general, takes place at a theoretical level that does not necessarily have to reflect or take into consideration the reality surrounding us. For example, in the 18th century the French physicist and mathematician Joseph Fourier, who was studying the diffusion of heat, introduced the theoretical concept of trigonometric series in order to break down a function into basic blocks using sines and cosines. This brought about the appearance of a highly active field in mathematics known as Fourier or Harmonic analysis in which these trigonometric decompositions – Fourier series – are studied as abstract objects.

Much basic research work is motivated by questions regarding applications. Basic science, on the other hand, tackles problems from a theoretical point of view, thereby developing new tools and new languages that enrich the original problem. In the other direction, basic progress forms the substrate by which the other applied sciences and technologies are nourished. In other words, the availability of an extensive body of knowledge and basic tools enables us not only to tackle current problems but also those that will arise in the future.

Mathematics is the language in which science is written and thus plays a vital role in all scientific fields. In this regard, in recent years the importance of statistics, simulation, modelling and data processing has become increasingly evident for solving a whole range of problems, from the response to the COVID-19 pandemic to any question concerning computers and the internet.

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The Fourier decomposition referred to above, and the theoretical development to which it has given rise, have become crucial for the transmission of signals, and for addressing everyday questions such as the storage and sending of photographs we take with our cell phones.

Likewise, the role of mathematics is also essential in reaching the OSD objectives. For instance, thanks to graph theory, operational research and big data we are able to design effective strategies for the obtention, use and sharing of resources (food, energy, water, vaccinations and medicines, etc.). Furthermore, topology and computation help us to understand a wide variety of complex phenomena, such as the propagation of disease, contamination of the oceans and climate change, while geometry provides us with very precise geolocation instruments such as GPS.

In addition, mathematical education is a mainstay for the comprehensive education of society at large, since it contributes to the development of the reasoning faculty. The solving of mathematical problems provides exercise of our capacity for reasoning, abstraction and formalization. Strengthening of mathematical education is one of the objectives of sustainable development and should be within the reach of everybody, irrespective of gender, race, country of origin or acquisitive capacity.

There is no doubt that mathematics can be directly translated into the economic development of a country. According to a report issued by the Spanish Strategic Network of Mathematics (REM) and to the body of International Financial Analysts (Afi) in 2019, mathematics in Spain accounted for more than 10% of the GDP and generated 6% of all employment. Nevertheless, in other countries such as the United Kingdom, France and the Netherlands the figures vary between 13% and 16% of the GDP and between 10% 11% in terms of employment.

In order for the Spanish figures to increase, one of the main aims over the coming years should be convergence with those European countries that support and spend the most on science. At present, investment in R+D in Spain continues to be below the average in Europe (1.27% of GDP in Spain compared with 1.43% in Europe, according to Eurostat figures).

A further challenge facing the Spanish scientific system is to bring the public and private sectors into closer alliance. For example, according to a recent report, *Research and Innovation in Spain and Portugal*, issued by 'la Caixa' Foundation, while Spain is around the European average in terms of the production of doctors of science, we still lag behind when it comes to the incorporation of research personnel in the private sector (the number of researchers in the private sector is 38% of the total, as compared with an average of 55% in the EU). This imbalance between supply and demand in terms of young researchers may accentuate the much-commented brain drain, which threatens to place the sustainable development of the country in jeopardy.

The Pact for Science and Innovation and the ratification of the Bill for Science, Technology and Innovation provide a unique opportunity for achieving solutions to these problems. It is vital for Spain to pledge its commitment to science by means of a bold and sustained investment in R+D+i. It is also necessary for us resolve the issues of instability and uncertainty by providing professional opportunities for our young doctors in science, in both the public and private sectors, thereby ensuring an effective renewal of the research substratum.

The development of basic science, and mathematics in particular, must figure among the priorities of our governments. It is very important to give full backing to a long-term strategy and not remain blinded by the short-term tendencies that appear to predominate in our society today. We are in need of mathematics and a basic science in order to equip ourselves with the tools to address the challenges of the present – some of which form part of the OSD – and those of the future, whenever they may appear in the education and culture of society at large, as well as in the economy and our general well-being. Tackling these challenges in the framework of international cooperation is a crucial factor for attaining a degree of just, sustainable and stable development over time.

Article first published on May 23rd, 2022, on the Somos Iberoamérica portal.

José María Martell, ICMAT director until July 2022, holds, since then, the vice-presidency of Scientific and Technical Research (VICTY) at the Spanish National Research Council (CSIC).

REPORT: Geometry for analyzing the impact of quantum gravity on particle physics

The workshop on Geometric Aspects of the Swampland, held in May and June 2022, brought together 100 mathematicians and physicists in Madrid. Jointly organized by the Institute of Mathematical Sciences and the Institute of Theoretical Physics, this meeting was focused on geometric aspects of the so-called Swampland Program, a series of conjectures about the mathematical characteristics that must be fulfilled by a particle theory in order to be compatible with quantum gravity. This research field could be used to explain the genesis of the universe, why it was possible to discover the Higgs boson with the LHC or the accelerated expansion of the universe.

Ágata Timón G Longoria

There are currently two paradigms on which fundamental physics is based; general relativity and quantum field theory. For decades now physicists have been seeking a theory that unifies both paradigms and thereby provide a complete understanding of the universe, from subatomic interactions to the macroscopic evolution of the cosmos. Such a theory, which should include an explanation of the force of gravity over very short distances, is known as the theory of quantum gravity.

The development of this theory, which constitutes one of the major challenges in current research, is directly related with physics of very high energies that are much greater than the energy that is generated in experiments currently conducted in particle accelerators. Fortunately, it is possible to study quantum gravity and its effects by other means such as algebraic geometry. This is one of the consequences of the so-called Swampland Program, a research field consisting of theoretical physics and geometry to which the Geometric Aspects of the Swampland (GAS) workshop was devoted, organized by the Institute of Mathematical Sciences (ICMAT) and the Institute of Theoretical Physics (IFT) in May and June of this year, 2022.

"The aim of the Swampland program is to understand the effect of quantum gravity on the so-called *effective field theories*, or particle theories, which we use to describe our universe at energies made accessible by means of particle accelerators, as well as to determine what happens at higher energies," explains Irene Valenzuela, an IFT and CERN member, a Ramon y Cajal researcher at the Autonomous University of Madrid, and a co-organizer of GAS. She goes on to say that "the main idea of the program is that even though many particle theories appear to be consistent, they are not compatible with quantum gravity theory, so they are never going to describe our universe and therefore can be ruled out."

The Swampland conjectures may have important consequences for particle physics and for cosmology. As Valenzuela says, "above and beyond the theoretical interest of the program, they could be used to explain the moment at which the universe was formed, for example, or why it was possible to detect the Higgs boson with the LHC and why the accelerated expansion of the universe is so small."

The search for theories compatible with quantum gravity

The Swampland conjectures enable us to distinguish between the particle theories that are compatible with quantum gravity and those that are not. To this end, concrete properties are proposed that should satisfy a particle theory so that it guarantees concordance with quantum gravity. As IFT member, senior CSIC scientist and co-organizer of the event, Fernando Marchesano says: "In recent years, several conjectures or refinements of the same have been proposed, but at the moment there are three main conjectures around which the others are arranged."

Image: IFT

Attendees at the first part of the Geometric Aspects of the Swampland workshop.

Image: ICMAT

Irene Valenzuela (IFT-UAM), organizer and speaker at the workshop. She is one of the leaders worldwide of the Swampland program.

First of all, the global symmetry conjecture, which postulates that certain symmetries on the quantum level are not compatible with gravity. The second is the weak gravity conjecture, which states that gravity is always the weakest force, and lastly the distance conjecture, which proposes that the particle theories compatible with quantum gravity possess an associated space, known as the *field space*, where the distances between points are always less than a finite quantity, which mathematically speaking is a manifold with geodesics of infinite length. "According to this conjecture," says Marchesano, "along infinite distances field theory must cease to be valid in a fairly precise way."

Despite what they are called, these conjectures are of quite a different nature to the typical mathematical conjectures. "The Swampland conjectures are physical postulates about qualitative properties of a consistent quantum gravity theory, which so far is unknown to us," explains Mario García Fernández, ICMAT member, Ramón y Cajal researcher at the Autonomous University of Madrid and co-organizar of GAS. "They cannot be proven as physical postulates; they could only be disproven if we constructed a consistent theory of quantum gravity that fulfilled these postulates and we conducted experiments to check such a theory against reality."

At the moment, a great deal of evidence has accumulated In recent years, all of which has been verified, showing that in a considerable number of effective theories it comes from solutions to string theory. Consequently, most of the theoretical community is currently convinced that the first conjecture, of global symmetry, is indeed correct, and that the other two conjectures are going the same way. "But furthermore," says Marchesano, "relations between these and other conjectures have been discovered, which leads one to believe that there exists a fundamental principle behind all of them. One of the most important objectives of the program is to discover what such a principle may be, and thereby understand its consequences for physics at this time."

The mathematical formulation of string theory, an instrument for progress in Swampland

In this last regard, string theory appears to play a decisive role. "The Swampland conjectures refer to a theoretical context, quantum gravity, the formulation of which we do not know in its full generality, and so it is not possible to prove them with any mathematical rigour," cautions Marchesano. "However, they can be proved rigorously if we confine ourselves to concrete formulations of quantum gravity, such as string theory." Indeed, in recent years string theory has enabled the accumulation of evidence for the Swampland conjectures. As Marchesano remarks: "This is the quantum gravity model we understand the best, and the one with which these conjectures can be analyzed quantitatively."

A large part of this theory is described by a type of algebraic space known as the Calabi-Yau space. From the point of view of physics, this means dimensions additional to the four – those given by three-dimensional space and time – required for a consistent theory. "The Calabi-Yau spaces are extraordinarily rich geometrically and have enabled important advances in mathematics to be made over the last 30 years," says García Fernández, who goes on to say that: "Where Swampland is concerned, the weak gravity and distance conjectures can be formulated in terms of a geometric space that describes an entire family of Calabi-Yau spaces simultaneously. Surprisingly, this is linked in with other modern geometric theories."

It is precisely the interaction between string theory and mathematics that has prompted physicists to call these postulates *conjectures*. "In a certain way, in nature they resemble 'Euclid's postulates', which deal with constructing geometry on the basis of *a priori* postulates, when the theoretical framework required for building geometric models as we understand them today is lacking," says García Fernández. "It could be that in many years' time a theory of quantum gravity is developed that violates some of the Swampland postulates, which when all is said and done are based on string theory and arguments concerning the behaviour of black holes, about which we know very little."

This avenue of research constitutes a new approach to string theory, against which some years ago voices were raised, even questioning whether it was a predictive and disprovable theory. This was due in part to the conjecture that string theory describes and infinite number of possible universes, each of which is governed by different laws of physics. However, as a consequence of the Swampland program, a current of thought has emerged that refutes the foregoing, stating that the number of possible universes associated to string theory is finite and far fewer than the ingenuous estimates put forward to date, and that the physical laws of these worlds should obey the rules dictated by the Swampland conjectures. As Valenzuela points out, "there is currently a lively open debate about the solutions to string theory that are capable of describing our universe at a cosmological level, and many in the scientific community are now of the opinion that string theory is a theory with the predictivity required for arriving at new and surprising discoveries in the coming years."

Ground for new physico-mathematical advances in quantum gravity and geometry

In any event, the Swampland program aspires to obtain predictions, regardless of the advances in string theory and ruling out

a considerable number of field theories that are incompatible with quantum gravity. According to Valenzuela, "what is vital is the formulation of key aspects of physics in quantum gravity in terms of mathematical properties that can be rigorously proven, which would enable precise predictions to be obtained."

As the organizers point out, this was the prime objective of the Geometric Aspects of the Swampland workshop. It was divided into two sections; the first was held between May 23rd-26th and the second between June 8th-10th. Both took place at the facilities shared by ICMAT and the IFT.

This event was a clear example of the fruitful interaction between theoretical physicists and mathematicians. "By mathematically formulating aspects of theoretical physics, they acquire greater value and a deeper scope in their applications to the understanding of nature," says García Fernández. "In the case of the quantum gravity question, the techniques currently being employed require to a large extent the theoretical body of the most recent algebraic geometry."

Furthermore, the development and understanding of this physical problem constitute a challenge for mathematics, since it gives rise to conjectures, open problems and also new research lines. "Future understanding of this fundamental problem is undoubtedly going to require a closely knit interaction between these two areas," concludes García Fernández.

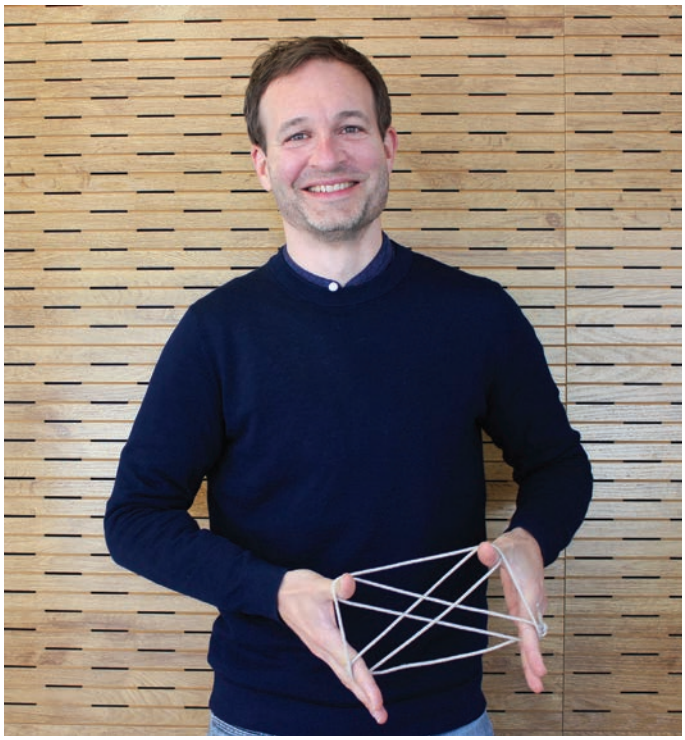

Image: ICMAT

Timo Weigand (University of Hamburg), specialist in string theory and the Swampland program, was one of the leading speakers at the meeting.

Speakers at the Geometric Aspects of the Swampland workshop

Georg Oberdieck, researcher in algebraic geometry at the University of Bonn (Germany), was one of the most notable speakers at the event. He was awarded the Heinz Maier-Leibnitz Prize 2020 for his contributions to different problems in enumerative geometry arising in mathematical physics. His result, jointly with Aaron Pixtin, "Gromov-Witten theory of elliptic fibrations: Jacobiforms and holomorphic anomaly equations", has been of great influence in the field.

A member of the organizing team and also appearing as a speaker, Irene Valenzuela conducts her research on quantum gravity (specifically focused on string theory) and its implications in particle physics and cosmology. She is one of the leading figures worldwide in the Swampland program. In 2021 she obtained one of the prestigious European Research Council Starting Grants for her research work in this field. Also in 2021 she was awarded the Young Researcher in Theoretical Physics Prize (RSEF-BBVA).

A further speaker at GAS was **Timo Weigand**, a professor at the Hamburg University Institute of Theoretical Physics, a subject in which he conducts research, although his work is closely associated with algebraic geometry and differential geometry. In particular, Weigand studies string theory and belongs to the Swampland program, in relation to the theory of enumerative invariants in algebraic geometry. He gained his doctorate at Cambridge University in 2003 and has held posts as a post-doctoral researcher at the universities of Pennsylvania and has been a member of the CERN junior staff.

INTERVIEW: Eva Gallardo, president of the Royal Spanish Mathematical Society

"Mathematics has enabled me to meet people with a very different outlook on life than mine"

In February 2022, Eva A. Gallardo, a professor at the UCM and a member of ICMAT, was appointed president of the Royal Spanish Mathematical Society (RSME). Up to that time she had been deputy director of ICMAT (from 2020), vice-dean of Research at the UCM Faculty of Mathematics (from 2018) and first vice-president of the RSME, from 2019. An expert in complex analysis and operator theory, fields in which she has published more than 50 articles, she is currently engaged in a research stay at the University of California, Berkeley (USA). This interview was conducted over a nine-hour time difference.

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What is your experience of Berkeley like so far?

Up to now, very good. It's a great university with a powerful Maths Department and top-rank researchers in all the fields of mathematics. What's more, there's a high number of PhD and postdoctoral students, which gives us a good supply of up and coming talent.

Is your stay part of a particular research project?

Yes, it forms part of a research line in operator theory, which I've been working on in recent years, and also in technical discussions with professor Dan-Virgil Voiculescu, a professor here at Berkeley and in international specialist in operator algebras and free probability.

What specific questions are you studying?

In general, I'm interested in the properties of linear and continuous operators when they act in Hilbert spaces of analytic functions; in particular, their interrelation with these. As far as the operators are concerned, it's about determining their structure by means of their invariant subspaces. Right now we don't know whether every linear and continuous operator in a complex, separable and infinite-dimensional Hilbert space has closed non-trivial invariants. This problem, known as the *invariant subspace problem* in Hilbert spaces, has its origin in the work by John von Neuman in the 1940s. We are considering different approximations to enable us to understand the complexity of the problem. For example, we're studying *universal operators* in the *sense of Rota,* and analyzing relevant classes of operators for which at the moment the existence of invariant subspaces remains unknown.

Have you obtained any results in this regard?

Recently, in the article "Invariant subspaces for Bishop operators and beyond", published in *Advances in Mathematics* (2020) in collaboration with Fernando Chamizo (ICMAT-Autonomous University of Madrid (UAM)), Miguel Monsalve (ICMAT-Complutense University of Madrid) and Adrián Ubis (UAM), we study the existence of invariant subspaces for the class of Bishop operators. These operators were proposed by Erret Bishop in 1950 as possible counterexamples of the invariant subspace problem, but at present it is not known whether every Bishop operator has a closed, non-trivial invariant subspace. We determine a subclass of these that do in fact have infinite, closed non-trivial invariant subspaces.

Furthermore, in "Finite rank perturbations of normal operators: spectral subspaces and Borel series", published in the *Journal de Mathématiques Pures et Appliquées* (2022), together with my PhD student, Javier González Doña (ICMAT-CSIC), we consider the class of compact perturbations of normal operators. Surprisingly, the question of whether or not every operator of this class has a closed invariant subspace still remains open.

These problems are related to other areas beyond operator theory and complex analysis.

That's right. On many occasions, resolving them, even in concrete cases, requires techniques belonging to other areas of mathematical analysis, such as the geometric theory of functions, harmonic analysis, combinatorial analysis and even analytic number theory. The interrelation of different research lines yields results that in my opinion are always surprising.

When did you decide to devote yourself to mathematical research?

When I finished my degree in Mathematics, I wanted to go on studying and learning about certain subjects, so I started a PhD and then went on quite naturally to post-graduate studies. I think that one thing just led to another. I don't think one says to oneself: "I want to be a researcher when I grow up". At least, in my case, it wasn't like that.

How did you get interested in research?

The discovery that there are questions still unsolved in mathematics, and even problems and conjectures that have remained open for more than a century, was something that surprised me a lot when I was at university. Thinking about "particular cases"

Image: Eva Gallardo

Eva Gallardo has been the president of the Royal Spanish Mathematical Society since February 2022.

that may help you comprehend these questions better is a challenge, and even in a certain sense a contest that unfortunately on many occasions you lose, but when you win you manage to gain a better understanding of these questions.

What was it about the discipline that captivated you?

Mathematics has a beauty that is incomparable with anything else I've ever seen. When things click into place, when I conclude a proof, I think to myself: "How is it possible that this works?" And when you publish an article or get the recognition of your colleagues, it's a pleasing reward. What's more, mathematics has enabled me to get to know people with an outlook on the world very different from mine, and that completes you as a person.

On the other hand, it's frustrating when things don't work out. There are times when you feel down; there are many hours of training, of sacrifice... It seems to me that a career in research is very much like that of a professional sportsperson.

Following the sports analogy, which of your achievements deserve to be on the podium?

Maybe that's something you ought to ask researchers who work in the same field as me. It often happens that the results you thought were less important turn out to be the most cited, because they lead to new research lines, give rise to different points of view or pose new questions. Personally, I'd say "The role of the spectrum in the cyclic behaviour of composition operators" (with Alfonso Montes-Rodríguez (University of Seville)), published in *Memoirs of the AMS* in 2004, and which was distinguished with a 'Featured Review' in *Mathematical Reviews*. Also "On the connected component of compact composition operators on the Hardy space" (with María José González (University of Cádiz), Peka Nieminen and Eero Saksman (University of Helsinki), published in *Advances in Mathematics* in 2008, and 'Rota's universal operators and invariant subspaces in Hilbert spaces' (with Carl Cowen (Purdue University-Indiana University), published in the *Journal of Functional Analysis* in 2016, in which we resolve questions in the field that had remained open for quite a long time.

In addition, the paper 'Operators having no non-trivial closed invariant subspaces on ℓ^1: A step further', in the *Proceedings of the London Mathematical Society* (2019), in collaboration with Charles Read has a special importance. It was Read's last research project. He died shortly after a research stay in Madrid, where we completed the work. In it, we resolved conjectures made by Read in the 1980s, and showed counterexamples of an intricate nature in the context of the Invariant Subspace in the classical Banach space ℓ^1 problem.

"The results you think are the less important turn out to be the most cited because they lead to new research lines"

Apart from your work as a researcher, you are also the president of the Royal Spanish Mathematical Society (RSME). Tell us a little about this.

I was the vice-president of the RSME, although I never thought I'd be president. Of course it's exciting, but it's also a challenge. It's also an honour and obviously a difficult challenge in many respects. I have a highly committed management team and we're all trying to make the transversality of mathematics more visible. These days we have a tremendous technological applicability in everything concerning information, databases and so on. Mathematics is also important socially. It enables the development of critical, logical and coherent thought. In society today, thinking logically is a tool for analyzing situations and making us less prone to manipulation. It's a fundamental discipline for building a fairer, more advanced world and a greater solidarity.

"There are more and more of we women in science, and this means that more women will rise to positions of responsibility"

What are the main axes of action of your team?

There are several specific strands that we set out in our project, among which I'd stress first of all providing support for young male and female researchers. The average age of university teachers in Spain is nonetheless surprising, as well as the age of young researchers who obtain their first work contract at a university or research institute. As a scientific society, we have to think carefully about academic-scientific careers in our country and urge the relevant institutions to take effective steps to increase the appeal to fresh talent, as well as recognition of research activity based on the criteria that we as a mathematical community both know and respect.

Furthermore, we want to promote a greater presence of the RSME in education, both before and during university. As we know very well, education is the best way of transforming society. As part of the mathematical community in Spain, the RSME has to participate in the training and education of free and critical people, able to make decisions based on well-founded criteria.

We also intend to develop different activities for stimulating mathematical talent and encouraging a sense of vocation among young people, such as the Mathematical Olympiads, or action aimed at attracting female talent to fundamental mathematics.

"We want to consolidate the RSME as a benchmark for the different public administrations in every aspect concerning mathematics"

Ultimately, our aim is to consolidate the RSME as a benchmark for the different public administrations in every aspect concerning mathematics.

You are the second woman to occupy this position. How do you feel about that?

The fact of being the second woman in this post is just circumstantial. I'm sure there are going to be more women presidents in the future. I'm very optimistic about that. There are currently more and more women engaged in science, and this means there'll be more women who rise to positions of responsibility and management. We have to keep on leading the way so that more of us will aspire to follow in our wake. Diversity is a plus, and the different points of view that both women and men have – by nature, for our social parameters – are all positive for making progress in science.

Do you have any advice for encouraging young people to get involved mathematics?

If they feel they might like it, then go ahead. It's a long-distance undertaking. To paraphrase Barack Obama: *Yes, we can*. Every discipline has its own peculiarities and complexity, but nobody should be put off or censure themselves when it comes to pursuing a career in research. If they like it and really feel that it's what they want to do, then go ahead without hesitation.

Commitment to excellence

Doctor in Mathematics at the University of Seville, Eva Gallardo was a professor at the University of Cádiz and the University of Zaragoza before joining the UCM in 2010. She has also made pre-doctoral visits at Michigan State University (East-Lansing), post-doctoral visits at Purdue University (West-Lafayette) and research stays at the University of Michigan (Ann Arbor), Purdue University, the University of Washington and Indiana University (Bloomington), among others. Throughout her career she has belonged to many committees, both at the National Evaluations and Prospective Agency (ANEP), the European Commission Research Executive Agency (REA) and private entities such as La Caixa Foundation and the BBVA Foundation.

She has been an ICMAT member since 2011, and since January 2018, she has also been a member of the ICMAT Severo Ochoa Programme Executive Committee. She was deputy director of the centre between 2020 and 2022. "I feel proud and honoured to form part of ICMAT," she says. "In my opinion, the Institute is a top-rank research centre and serves to enhance excellence in mathematics, not only in the Community of Madrid but also in Spain and on the international scene".

TELL ME ABOUT YOUR THESIS: Alexandre Anahory Simoes

Title: "Geometric and numerical analysis of nonholonomic systems"

Author: Alexandre Anahory Simoes

Supervisors: Juan Carlos Marrero y David Martín de Diego

Date of publication: 2021

Link: https://www.icmat.es/Thesis/2021/Tesis_Alexandre_Anahory.pdf

Alexandre Anahory Simoes (1993, Lisbon, Portugal) has always been interested in the relation between mathematics and physics. In fact, he started studying for a degree in Physics and later realized that "what I liked most about the discipline was not the experimental side, but the mathematical study of the models that appeared." It was then when he decided to do his PhD in Mathematics, at ICMAT. Five years later he read his thesis, "Geometric and numerical analysis of non-holonomic systems," supervised by David Martín de Diego (ICMAT-CSIC) and Juan Carlos Marrero (University of la Laguna), who, apart from introducing him to this field, have also "taught me what it means to be a researcher", says Anahory. His work is focused on the study of non-holonomic systems; that is, those in which the constraints to which the system is subject are non-integrable. In particular, it answers a question asked more than 20 years ago: "How to find an exact discrete version of a non-holonomic dynamical system?" He tells us about it in what follows.

Alexandre Anahory Simoes

"Geometric and numerical analysis of non-holonomic systems" analyzes the geometric properties of non-holonomic systems and their numerical simulation. These are the central issues in the field of the geometric integration of mechanical systems; that is, the field that studies how to preserve the geometric properties of mechanical systems in their simulations.

If a simulation fails to preserve any type of property, apart from being less real it is also more costly from the computational point of view. Consequently, the capacity of a simulation to preserve geometric properties can improve its efficiency. This could be useful in the development of algorithms for self-driving cars or other types of vehicles equipped with very small processors that require highly efficient simulations.

When mechanical systems are simulated it is vital to detect any error in the numerical method employed. To that end, one normally has the theoretical knowledge about what the exact solution should be, and then the numerical method is compared with a truncated version of this solution. This technique is known as *backward error analysis*. Prior to our work, there was no theoretical framework for which this technique could be applied to non-holonomic systems.

In the thesis we have made some progress in this direction. In particular, we have been able determine what the exact discrete version is for the non-holonomic dynamic. This knowledge can be used in the future for calculating the numerical error of the methods used in non-holonomic mechanics. This could lead to practical applications in the development of effective algorithms for wheeled-vehicle systems.

Furthermore, in the thesis we demonstrate various geometric results for non-holonomic systems that were previously unknown in this context, and which could give rise to significant theoretical implications.

One of the most notable advances made in the thesis is the derivation of the exponential application for non-holonomic mechanics. This application is one of the most fundamental concepts in Riemannian geometry. Its introduction into non-holonomic mechanics enables various bridges to be established with non-holonomic geometry. In fact, in this thesis we open up a new research line with the aim of studying an important class of non-holonomic systems using techniques of Riemannian geometry that are already widely known in the mathematical community.

In this chapter it is important to stress the derivation of the Jacobi equation for non-holonomic systems and the corresponding study of Jacobi fields. These are objects that can be used for understanding how non-holonomic trajectories that start from the same point may be related, and which in future research may help to detect the presence of curvature of space induced by the non-holonomic constraints.

In addition, we have also obtained a result that is surprising in the geometric mechanics community: for certain systems, the non-holonomic trajectories that start from the same point are geodesic for a modified Riemannian metric. This result is quite surprising because until now non-holonomic trajectories were believed to behave differently from the geodesics, which in particular are solutions to a variational problem, while it has been demonstrated on many occasions and in many ways that non-holonomic solutions are not the solution to a variational problem.

SHE DOES MATHS: Sara Abdelsalam (British University in Egypt)

Image: ICMAT

Sara Abdelsalam completed a three-month stay at ICMAT thanks to the Women for Africa Foundation 'Science by Women' scheme.

Sara Abdelsalam (British University in Egypt) is a researcher specializing in the fields of applied mathematics and fluid mechanics. She studies the movement of blood and the effect of nanoparticles on the human body. She has been working on these subjects at ICMAT during three months (June to September) this year, 2022, together with Ángel Castro (ICMAT-CSIC), as part of the Women for Africa Foundation 'Science by Women' programme. This mathematician will return to ICMAT next year for a further three-month stay to complete her fellowship.

Research fields: Applied mathematics, fluid mechanics, nanofluids, nanoparticles

Laura Moreno Iraola

When Sara Abdelsalam, an associate professor at the British University in Egypt (BUE) since 2019, had the opportunity of participating in the Women for Africa Foundation 'Science by Women' programme, she did not hesitate to enrol. "I try to make the most of all the grants available to women because they are few and far between," she says. "This opportunity is going to mean a plus in my career and give added value to my work." By means of this scheme, senior female African researchers have the chance to spend six months at a centre of excellence in Spain, of which ICMAT is one, in order to work on a project as the member of a research team. Although it was three years ago when Abdelsalam was awarded the grant do research at ICMAT, it was not until June of this year (2022) that she was able to begin her stay at the Institute due to bureaucratic problems caused by the covid-19 pandemic.

After completing her PhD at the University of Helwan (Egypt), this researcher has been working in the area of fluid mechanics applied to other scientific fields such as biology and physics. In recent years, her research work has been focused on the study of blood flow and the effect of nanoparticles on the human body by means of mathematics. As Abdelsalam explains, "one of the first tasks to arise in this field was to study the effect of gold nanoparticles (colloidal gold) on the treatment of areas of the body affected by cancer. On reading about it, I wondered how nanoparticles might be studied using fluid mechanics."

This is exactly the project to which she has devoted herself at ICMAT, where she has been collaborating with a member of the

Institute, Ángel Castro. Over this three-month period they have been exploring together how to combine their research work in order to study a specific type of nanoparticle. "In applied mathematics it's often necessary to use theoretical tools in the applied area where they do not currently exist. However, we who work in the most theoretical fields don't know if what we are studying is going to result in an application, and for that reason we need people well-versed in applications," says Castro.

Thanks to the 'Science by Women' programme, Abdelsalam says she has extended her knowledge of this more theoretical type of mathematics, which has enabled her to address new problems, pursue new avenues of research and get to know other scientific fields. This researcher has decided to divide her time at ICMAT into two stays, the first of which she finished in September, and the second next year, when she returns for another trimester.

Abdesalam has also been a member of the African Academy of Sciences (AAS) since 2020 and of the Egyptian Young Academy of Sciences (EYAS) since 2021. Furthermore, she belongs to the Organization for Women in Science for the Developing Countries and is a member of the Egyptian Mathematical Society and the International Society of Muslim Women in Science. She was awarded the Egyptian State Encouragement Award in Mathematics in 2020 and also the Obada Prize in 2021. She has also been the beneficiary of other fellowships such as Fulbright Scholar Award, which she completed at the Universidad de California, Riverside; another at Caltech (California Institute of Technology) between 2015-2016, as well as that at the TWAS (The World Academy of Sciences)-UNESCO, and at the UNAM Institute of Mathematics (Mexico), which she visited in 2017 and 2019. Likewise, she received a grant from the International Centre for Theoretical Physics in Lebanon, which she fulfilled in 2021, and that same year was chosen for the Royal Academy of Engineering (UK) 'Leaders in Innovation' scheme as well as support from the Newton-Mosharafa Fund. She is also a member in different editorial committees of international scientific journals.

Image: ICMAT

Sara Abdelsalam worked in the group led by ICMAT member Ángel Castro.

The Women for Africa Foundation 'Science by Women', at ICMAT

ICMAT has been collaborating with the Women for Africa initiative since it was first introduced in 2015. Thanks to this project, senior women scientists from African countries are able to undertake six-month stays at the centres participating in the scheme, most of which are endorsed with the Severo Ochoa seal of excellence, in order to conduct a research project. The main aim is to provide African women scientists with a leading role in the transformation of an economy based on knowledge and innovation in their respective countries of origin by means of science and the transfer of scientific knowledge.

Women researchers who have worked at ICMAT:

1st Edition (2015): Coumba Niang

2nd Edition (2016): Atinuke Adebanji

3rd Edition (2017): Latifa Debbi

5th Edition (2019): Sara Abdelsalam

6th Edition (2021): Faguèye Ndiaye

7th Edition (2022): Narjisse Amahjour

PROFILE: Enrique García Sánchez, predoctoral researcher at ICMAT

"A teacher encouraged me to participate in a spring maths competition and I got hooked on mathematics"

Image: Enrique García Sánchez

Enrique García Sánchez has recently joined ICMAT as a predoctoral researcher.

Enrique García Sánchez (Alcobendas, Madrid, 1998) was the beneficiary of a Severo Ochoa JAE INTRO master grant for research at ICMAT during the 2021-2022 academic year. He worked under the supervision of Pedro Tradacete in the field of functional analysis; specifically, on space theory and Banach Lattices, a research line that he will also continue to pursue at ICMAT as part of his doctoral studies.

Laura Moreno Iraola

Until a short time ago, Enrique García Sánchez thought about becoming an inventor, for which he was required to study engineering. However, when in his fourth year at secondary school he changed his mind. "I was doing a course on cryptography at one of the FECYT Summer Science Campus activities when I realized that I felt more comfortable in a more theoretical context," he explains. Although this was not his first contact with mathematics outside of school, during his early years there he had actually enjoyed doing maths. "A woman teacher of mathematics encouraged me to take part in a spring maths competition organized by the Complutense University, and it was there I got hooked on this discipline."

He decided to do a Double Degree in Mathematics and Physics at the Complutense University of Madrid (UCM), initially with the idea of becoming a theoretical physicist, although he was eventually drawn towards mathematics. "What I most enjoyed was the rigour required for maths subjects, a philosophy that fitted very well with my personality," says García. His involvement in university life and studies led him to become a student representative, the legacy of which is his current position as a member of the National Association of Mathematical Students. "I've always tried to take constructive action when I see something that's not working well," he says, "and I think that student representation is a good effective way of bringing about positive change."

A Master in Advanced Mathematics, also undertaken at the UCM, served to introduce García to mathematical research, which is what resulted in a JAE INTRO master scholarship funded by the ICMAT Severo Ochoa project. Throughout this academic year 2021-2022 he has been working at the Institute under the supervision of Pedro Tradacete (ICMAT-CSIC), with whom he has been completing his End of Master course assignment in functional analysis, focusing on space theory and Banach lattices. "We've even come up with some ideas that have led to new results, so I'm very satisfied with the outcome of this grant," he says.

In addition, this grant has convinced him that he wants to pursue a professional career in research. In fact, in September he joined ICMAT as a doctoral student. He will continue his work where he left off with his End of Master assignment, also with Tradacete as his supervisor. His intention is to complete his PhD and then work abroad, but with the expectation eventually to return to Spain.

SCIENTIFIC REVIEW: Entanglebility of Cones

Título: "Entangleability of cones"

Authors: Guillaume Aubrun, Ludovico Lami, Carlos Palazuelos and Martin Plávala

Source: *Geometric and Functional Analysis,* volume 31, pages 181–205 (2021)

Date of publication: May 2021

Link: https://link.springer.com/article/10.1007/s00039-021-00565-5

Summary

Two of the most fundamental – and most surprising – principles in the theory of quantum mechanics are superposition and entanglement. The former refers to the capacity of microscopic particles to be in different states at the same time, while the latter indicates the existence of certain correlations between two or more microscopic particles that cannot be explained by classical physics. From a theoretical point of view, quantum entanglement stems from superposition and the way in which physical systems are composed. However, the question arises of whether this relation concerns something specific to quantum theory or if it also occurs in other theories of physics.

The article entitled 'Entangleability of cones', published in *Geometric and Functional Analysis*, resolves a mathematical conjecture posed in 1976 by the mathematician George Barker concerning convex cones. These mathematical objects appear in the field of generalized probability theory, which enables physical theories that go beyond quantum theory to be taken into account.

The study of general physical theories is one of the topics of interest in current research. Although quantum mechanics is a theory that currently is generally accepted and is extremely useful, it is not unlikely that in the immediate future it will have to be revised and some of its aspects refined. This may be necessary in order to clarify some of the questions surrounding the theory that remain open, as well as for experimental results that may be obtained in the future, which could contradict predictions made by this theory.

Mathematically speaking, a generalized probability theory is defined by three elements V, C and u: V is a finite-dimensional vector space; C is a proper cone contained within this vector space, that is, a closed convex cone that satisfies $C-C=V$ and $C\cap(-C)=\{0\}$; and u is an element of the dual cone C^*, which is called "unit". In this context, a theory is known as "classical" if its associated cone has a particular property (of being simplicial), since this feature can be interpreted as the absence of superposition in the said theory. Furthermore, given two theories described by the cones $C_1\subset V_1$ and $C_2\subset V_2$, the presence of entanglement in the composition of these theories can be characterized by a property of the minimal tensor product of its cones $C_1 \barwedge C_2 := \mathrm{Conv}\{x_1\otimes x_2 : x_1\in C_1, x_2\in C_2\}$. Specifically, providing that this product is strictly contained in the maximal tensor product $C_1 \between C_2 := (C_1^* \barwedge C_2^*)^*$.

Thus, the relation between superposition and entanglement can be formulated in purely mathematical terms; it suffices to analyze the relation that exists between the property of being "simplicial" and the properties of the composition of the cones, and this by means of their tensor product. This question was posed by Barker in his study of the properties of convex cones and their tensor products. In particular, he observed that if one of the cones C_1 or C_2 is simplicial, then the minimal product of these cones coincides with their maximal product, and thus conjectured that the reciprocal case of this statement was also true. The proof of this conjecture is the main result of the 'Entangleability of cones' principle. Specifically, in this present work the following characterization is obtained:

Theorem: Given two proper cones C_1 and C_2, we have that $C_1 \barwedge C_2 = C_1 \between C_2$ if and only if one of the two cones is simplicial.

The authors subsequently simplified certain parts of the original proof, and it was then that they understood all the physical implications of the mathematical result. Although the equivalence between superposition and entanglement may appear to be a purely theoretical statement, it also has potentially practical implications. One of the most important applications of quantum technology consists of cryptographic protocols in which a secret key is distributed; that is, it is known only to an emitter and a receiver – by means of a public channel – accessible to everyone – the security of which is based on the ability to detect whether an adversary is spying on the transmission, something that is not possible in a purely classical world.

In a second article, published in the journal *Physical Review Letters,* the authors show that these types of protocols are not only confined to quantum theory, but can be developed in any theory beyond classical theory. Thus, even though in the future it may be necessary to consider a theory different from quantum theory, these cryptographic protocols will still remain within the bounds of possibility.

SCIENTIFIC REVIEW: Matrix product states and projected entangled pair states: concepts, symmetries, and theorems

Title: "Matrix product states and projected entangled pair states: concepts, symmetries and theorems"

Authors: J. Ignacio Cirac, David Pérez-García, Norbert Schuch, and Frank Verstraete

Source: *Rev. Mod. Phys.* 93, 045003

Date of publication: December 17th, 2021

Link: https://journals.aps.org/rmp/abstract/10.1103/RevModPhys.93.045003

Summary

"Matrix product states and projected entangled pair states: concepts, symmetries and theorems" is a review article that summarizes the state of the art of the mathematical results for classifying quantum phases of matter and for understanding the exotic behaviours that appear in quantum systems. It incorporates the main mathematical contributions made in recent years.

Its aim therefore is to act as a reference for researchers who are starting to study many-body quantum systems. This is a field that is closely connected to quantum computation theory, because quantum computers consist precisely of many-body quantum systems. Many of the ideas behind the results that appear in the article are motivated by quantum information theory.

The origin of the mathematical techniques analyzed in the article resides in two contributions of principles made in the 1990s concerning one-dimensional systems. First of all, the DMRG algorithm invented by Steve White, which is a numerical method designed to approximate fundamental states in one dimension for closely correlated systems, for which other methods of a *mean-field* type do not work very well. Secondly, the construction by Mark Fannes, Bruno Nachtergaele and Reinhard Werner of a class of quantum states - today known Matrix Product States (MPS) - with very good analytical properties. These two postulates turned out to be equivalent; shortly after, it was shown that the DMRG algorithm could be interpreted as a variation search in the class of MPS states.

In 2004, together with other researchers, Ignacio Cirac realized that it was possible to understand the class of MPS states, and therefore the DMRG algorithm as well, from the point of view of quantum information theory. In fact, it was possible to see MPS as entangled pair states, to which a local operation could be applied. From this perspective, Cirac and his colleagues generalized and improved this numerical method, and extrapolated it to other cases in two or more dimensions; such states are called Projected Entangled Pair States (PEPS).

PEPS are defined mathematically by a set of tensors; that is, a generalization of the matrices to lists of complex numbers with an arbitrary quantity of indices. The contraction of these tensors in the graph – normally a lattice – that codifies the interactions between the particles of the system is what defines the PEPS as a family of quantum states.

Thereafter, much numerical work has been done in which it has indeed been shown that this methodology certainly functions with two-dimensional systems. Furthermore, this class of PEPS is interesting for the analytical understanding of the whole spectrum of exotic properties that appear in two-dimensional systems.

J. Ignacio Cirac, David Pérez-García, Norbert Schuch and Frank Verstraete began their collaboration on this subject in 2005 at the Max Planck Institute of Quantum Optics (Germany). They realized that the symmetries present in the tensors defining the PEPS enabled, in a very simple way, the understanding of how highly complicated properties emerged at a microscopic level, when the entire system is considered with all the particles. It is thereby possible to explain exotic behaviours in a reasonably simple way.

Research Results

ICMAT researchers explain the origin of a large oil spill off the eastern coast of the Mediterranean

In February 2021, more than 1,000 tons of tar was washed up on the coast of Israel and Lebanon. Its origin remained unknown until a fluid dynamics research team led by CSIC researcher at ICMAT Ana M. Mancho, together with collaborators at the University of Las Palmas de Gran Canaria and the University of Bristol, managed to determine where it came from. Contrary to what the authorities first believed, it turns out that the spill did not originate from a single source, but from several that converged together on the eastern coast of the Mediterranean.

In order to arrive at this result, which was published in March this year in the journal *Scientific Reports*, the researchers made use of the theory of nonlinear dynamical systems, which describes the behaviour of the trajectories of large ensembles of particles. To that end, they identified geometric structures, known as Lagrangian coherent structures, which on the basis of current flows provide a dynamic skeleton of the oceans.

Image: IDF Spokesperson's Unit

More than 1,000 tonnes washed up on the beaches of Lebanon and Israel cause serious environmental damage.

Mathematics for studying the contagion of COVID-19 in Africa

After more than two years of the pandemic, much progress has been made in learning about the spread of COVID-19. Different studies have shown that one of the channels of contagion consists of airborne particles of the virus coming from an infected person and affecting another who is prone to the virus. One such study, "Computational Fluid Dynamics modeling to reduce risk of the spread COVID-19 of different isolation room in the hospital," is a projected conducted by the Moroccan researcher, Narjisse Amahjour (Abdelmalek University, Morocco), that seeks to model air flow with the aim of finding means of distribution and ventilation in hospitals in order to prevent infection. Amahjour joined ICMAT in May of this year on a postdoctoral contract under the auspices of the Women for Africa Foundation "Science by Women" programme, and will remain at the Institute until November. She has been working with the Geophysical Fluid Dynamics research group, led by Ana María Mancho, a CSIC researcher at ICMAT.

Image: ICMAT

Narjisse Amahjour is working at ICMAT thanks to the Women for Africa Foundation 'Science by Women' scheme.

Awards

The BBVA Foundation provides grants for two projects undertaken by ICAMT researchers: one on maritime transport and the other on fluid equations

The BBVA Foundation provided 35 grants for scientific research projects in the 2021 call for submissions. Among the four awarded to mathematical projects, two include projects in which ICMAT researchers are engaged: David Martín de Diego, in 'Mathematical optimization for a more efficient, safer and decarbonized maritime transport (SMART SHIPPING)', and Ángel González Prieto, Eva Miranda and Daniel Peralta Salas, in 'Computational, dynamical and geometrical complexity in fluid dynamics (COMPLEX FLUIDS)'. The first is devoted to the development of system for optimizing maritime shipping routes using meteorological data and navigation conditions in real time, while the aim of the second is to explore a new approach to the study of the complexity of fluids, in particular, in one of the so-called Millennium Problems – the regularity of the Navier-Stokes equations. Both projects have been granted 150,000€ over the next three years.

Image: CC

The BBVA Foundation awards grants for two projects of ICMAT researchers, one on maritime transport and the other on fluid equations.

ICMAT members, Ana María Mancho and Guillermo García Sánchez, receive the CSIC Technology-Based Companies Award (EBTONSIC)

The Digital Earth Solutions project, devised by ICMAT researchers Ana María Mancho and Guillermo García Sánchez, enables the movement of any oil spill over the surface of the ocean to be predicted, and thereby reduce by up to 50% the environmental, social and economic impact it may have. The software has been awarded the EBTONSIC Prize, sponsored by the CSIC Vice-Presidency for Knowledge Transfer and consisting of 20,000€ in order to commercialize the idea make it accessible to the market.

Image: CSIC

Ana María Mancho and Guillermo García Sánchez, members of ICMAT (centre), are the creators of Digital Earth Solutions.

Charles Fefferman, director of one of the ICMAT Laboratories, winner of one of the latest BBVA Foundation Frontiers of Knowledge Awards

The BBVA Foundation has awarded its Frontiers of Knowledge Prize for Basic Sciences as part of its 14th edition to Charles Fefferman, a professor at Princeton University (USA), and director of one of the ICMAT Laboratories. The jury highlighted his introduction of "powerful techniques of analysis for solving long-standing mathematical problems, some of which arise from fundamental questions in theoretical physics."

Image: ICMAT

Charles Fefferman awarded the BBVA Foundation Frontiers of Knowledge Prize.

Ángela Capel awarded one of the Vicent Caselles Mathematical Research Prizes for the PhD thesis he undertook at ICMAT

Amongst those recognized by one of the 2022 RSME and the BBVA Foundation Vicent Caselles Prizes for Mathematical Research is Ángela Capel, a junior professor at the University of Tübingen (Germany), who completed her doctorate at ICMAT under the supervision of David Pérez-García (ICMAT-UCM) and Angelo Lucia (ICMAT-UCM). Capel did her thesis in the field of quantum Information theory and many-body quantum systems.

These prizes are awarded annually to six mathematicians of either gender in the initial stages of their careers. This is in recognition of "the creativity, originality and excellence in mathematics during the early years of their research work", as stated by the BBVA Foundation.

Image: University of Tübingen

Ángela Capel awarded one of the Vicent Caselles Prizes for Mathematical Research.

Institutional

José María Martell (ICMAT), the new vice-president of CSIC Scientific and Technical Research, and Fernando Quirós (ICMAT-UAM), the new acting director of ICMAT

José María Martell, a CSIC scientific researcher at ICMAT, was appointed as the CSIC Vice-president of Scientific and Technical Research (VICYT) in July of this year, 2022, at which time he left his position as ICMAT director that he had occupied since 2020. Since then, Fernando Quirós, an associate professor of Applied Mathematics at the Autonomous University of Madrid (UAM) Department of Mathematics, and since 2020 deputy director of ICMAT, has occupied the position of deputy director of the Institute.

The new CSIC management team, chaired by Eloísa del Pino, a researcher at the Institute for Policies and Public Goods, also includes the political scientist Carlos Closa as the vice-chair of Organization and Institutional Relations; the political scientist Javier Moreno as vice-chair of International Relations; the chemist Isabel Martínez as director of the Chairperson's Cabinet, and Ignacio Gutiérrez Llano as general secretary. Also joining the team is the chemist Ana Castro, who will be working in the area of Knowledge Transfer, while a member of the advisory board in the field of biomedicine will subsequently be appointed. In addition, the assistant vice-chairs will be headed by Elena Cartea in Scientific-Technical Areas; Jaime Carvajal in Scientific Programming; Isabel Díaz in International Cooperation, and Pura Fernández in Scientific Culture and Citizen Science.

Images: José María Martell and UAM

José María Martell (left) and Fernando Quirós (right).

ICMAT researcher Eva Gallardo is the new RSME chairperson

In February of this year, Eva Gallardo, a professor at the Complutense University of Madrid (UCM) and a member of ICMAT, was appointed to the position of chairperson of the Royal Spanish Mathematical Society (RSME). Her team consists of Victoria Otero Espinar, professor at the University of Santiago de Compostela, as first vice-chair; Luis J. Rodríguez Muñiz, a professor at the University of Oviedo as second vice-chair; Yago Antolín Pichel, also a researcher at the UCM and ICMAT, as secretary, and Angélica Benito, a researcher at the Autonomous University of Madrid, as vice-secretary.

Gallardo, who was also deputy director of ICMAT between 2020 and 2022, is the second woman to occupy the position of RSME director, after Olga Gil, a professor at the University of Valencia. Gallardo earlier formed part of the previous RSME governing team in the capacity of vice-chair, when it was presided over by Francisco Marcellán, professor at the University Carlos III of Madrid.

Image: Eva Gallardo

Eva Gallardo

Scientific activities

World experts on moduli spaces and geometry celebrate the 60th birthday of Oscar García-Prada at ICMAT

In September, ICMAT hosted a conference to honour Oscar García-Prada, a CSIC research professor at ICMAT: Moduli spaces and geometric structures. Conference in honour of Oscar García-Prada on the occasion of his 60th birthday. 21 male and female researchers, recognized experts in these fields and habitual collaborators with García- Prada, were invited to give talks in this activity.

Image: ICMAT

Specialists in moduli spaces and geometry meet to celebrate the 60th birthday of Oscar García Prada (ICMAT-CSIC).

Geometry and its applications to mechanics and physical mathematics at ICMAT

The International Fall Workshop on Geometry and Physics has been held every year since 1992. This workshop brings together geometers and physicists from different countries with the aim of discussing new developments in the fields of differential geometry and its applications to mechanics and mathematical physics. It is organized successively every two years in Spain and one in Portugal since its inception, and this year between August 29th and September 2nd it fell to ICMAT to host this activity. On this occasion it was once again an in-person event, after being held for two years online due to the pandemic. The workshop included two mini-courses, eight invited talks, different short talks and a poster session.

Image: ICMAT

After two years, the International Fall Workshop on Geometry and Physics was held again in-person.

Meetings on Poisson geometry

The 2022 celebration of the International Conference on Poisson Geometry in Mathematics and Physics was divided into a school and a congress hosted at the Centre for Mathematical Research (CRM) and ICMAT, respectively. The school was held over a week from July 18th to 22nd, and the congress took place at ICMAT and the CSIC headquarters in Madrid.

The inauguration of the congress included an award ceremony of the André Lichnerowicz prizes, which on this occasion distinguished Álvaro del Pino Gómez, assistant professor at the University of Utrecht (Netherlands) and a former PhD student at ICMAT, and Yiannis Loizides, assistant professor at Cornell University. In addition, as part of this conference, the latest celebration of the 'Matemáticas en la Residencia' informative cycle was held on July 26th. With the title 'Emmy Noether, one of the great mathematical minds of the 20th century', Yvette Kosmann-Schwarzbach and Tudor Ratiu (Shanghai Jiao Tong University, China) highlighted some aspects of this outstanding German mathematician and outlined some of her main contributions to mathematics and physics. The 2022 Poisson conference and school form part of the Poisson thematic programme, jointly organized by ICMAT and the CRM.

Image: Poisson Congress

The congress was inaugurated at the CFTMAT conference hall.

The NET4IMPACT network presents its results on the social impact of science at ICMAT

The last conference of the NET4IMPACT project took place at ICMAT this June. The main objective of this event was the exchange of information, methodologies and evidence on the social impact of research, and also proposals for indicators to measure such impact. The event was attended by male and female experts in the social impact of science, such as Teresa Riesgo, the general secretary of innovation at the Spanish Ministry of Science and Innovation; Marta Soler Gallart, the coordinator of NET4IMPACT; Ramón Flecha, coordinator of the team of experts on the European Commission methodologies for monitoring the research programme; Eduardo Oliver, vice-chair of the Science in Parliament initiative, and Luis Miller, chief of staff of the CSIC Presidency and senior scientist at the Institute of Policies and Public Goods.

Image: ICMAT

Final conference of the NET4IMPACT project, attended by experts on the social impact of science.

Outreach Activities

ICMAT launches a school of mathematics for young people

ICMAT is launching the Pequeño Instituto de Matemáticas (PIM), a project aimed at young people between the ages of 14 and 18 and based on the so-called reflexive teaching method, which consists in encouraging curiosity as the driving force behind learning. The aim is to enable students to enjoy mathematics by solving problems that are not covered by the school curriculum.

The school begins on October 14th, 2022, and consists of sessions to be held every Friday during the academic year between 5.30pm and 8.00pm, except on holidays. These sessions will be take place at ICMAT facilities on the Cantoblanco Campus in Madrid. They will be conducted in accordance with the methodologies belonging to the so-called math circles in which students work together in groups to complete exercises using solutions they have obtained at home, before pooling them in class. The teachers of the PIM are master and PhD students belonging to ICMAT, the UAM and the Complutense University of Madrid (UCM). Their task consists in supervising discussions in class as well as stressing the importance of what can be learned from mistakes that may have been made.

This initial edition is assisted by the collaboration of the Autonomous University of Madrid (UAM) Department of Mathematics and the Real Sociedad Matemática Española (RSME).

The so-called math circles methodology will be followed at PIM

ICMAT researchers explain in a book how to manage the risk entailed by epidemics, robbery and cyber attacks

Two CSIC researchers at ICMAT, David Ríos and Roi Naveiro, are the authors of *Risk Analysis*, a new title to appear in the collection 'What do we know about…?' (CSIC-Catarata). The book describes the tools and methodologies employed to quantify and manage risk, a fundamental issue in modern society. The authors address the three main phases of risk analysis: an assessment of the threats under study, which covers the degree of probability that such threats may really materialize, as well as the evaluation of their impact should they do so; the management of risk, which includes the activities undertaken to reduce the probability that it may actually transpire, or to minimize its impact if it does so; and communication, which refers to the exchange of opinions and information about risk, whether between evaluators, managers or any other agents involved in the problem.

Image: CSIC/Catarata

David Ríos and Roi Naveiro (ICMAT-CSIC) are the authors of *Risk Analysis*.

The mathematics hidden behind Indian and African art

In April, the following day session was held at ICMAT, 'Mathematics and Art: An Ethnomathematical Exploration', which included two talks: "Mathematics of Kolam," given by Oscar García-Prada (ICMAT-CSIC), and "Mathematics and Art in Africa," given by Steven Bradlow (University of Illinois at Urbana-Champaign). The session opened with some kolams – geometric drawings made on the ground with rice flour, which took place at the entrance to the centre. The day before, in the exhibition hall of the UAM, the inauguration was held of a photographic exhibition entitled 'Kolam: an ephimeral art practised by women in the south of India,' by Claudia Silva.

Image: ICMAT

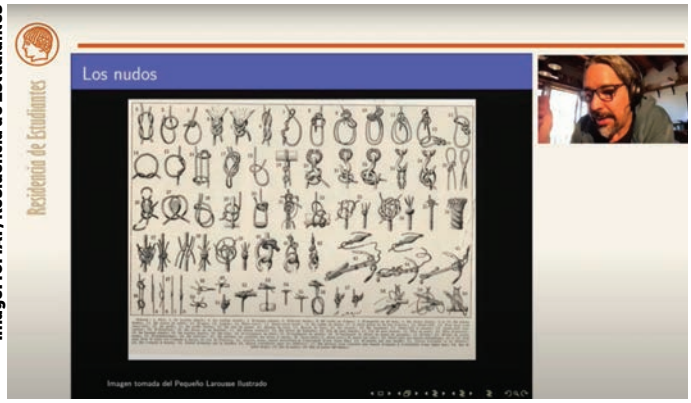
Kolams are geometric designs made on the ground with rice flour by women from the south of India.

Mathematics and the art of knots, at the Residencia de Estudiantes

Aubin Arroyo, a researcher at the National Autonomous University of Mexico (UNAM) Institute of Mathematics, gave a talk called "Tame knots and wild knots" as part of the 'Matemáticas en la Residencia' cycle, organized by ICMAT in collaboration with the Residencia de Estudiantes and the CSIC Scientific Culture Unit. In his address, Arroyo showed how knots are conceived and studied in mathematics as well as explaining some notions of knot theory, including even infinitely complex knots, the so-called "wild" knots.

This talk is available on the ICMAT YouTube channel.

Image: ICMAT/Residencia de Estudiantes



Aubin Arroyo during his talk.

ICMAT celebrates the women in mathematics day with a conference in honour of Maryam Mirzakhani and a conversation about unconscious gender bias

Celebrating Women in Mathematics was held on May 12th, an international celebration that this year was devoted to honouring Maryam Mirzakhani and to the recognition of achievements by women mathematicians. Among the hundreds of events and activities that took place worldwide, two were organized by ICMAT. The first was a conversation held at the Institute with Christina Brech (University de São Paulo) about unconscious gender bias in the world of mathematics. The second activity was a talk devoted precisely to Mirzakhani on the 5th anniversary of her death. This was given by Javier Aramayona (ICMAT-CSIC) and took place as part of the outreach cycle 'Matemáticas en la Residencia' at the Residencia de Estudiantes. This talk is available on the ICMAT YouTube channel.

Image: ICMAT

Javier Aramayona explains the mathematics of Maryam Mirzakhani at 'Matemáticas en la Residencia'.

CALENDAR 2022/2023

Science and Technology Week 2022

- **Simetrías, rocas y otras herramientas para el desarrollo sostenible**
  Date: 10-11 de noviembre de 2022
  Place: Sede central del Instituto Geológico y Minero de España (IGME), Madrid
- **El lugar de la ciencia básica en la investigación y en el desarrollo sostenible**
  Date: 14 de noviembre de 2022
  Place: Real Academia de Ciencias Exactas, Físicas y Naturales de España (RAC), Madrid
  Online: Canal de YouTube de la RAC

Research term: Quantum Information Theory (QIT)

February – March 2023, ICMAT

- **Advanced School: Optimization methods in Quantum Information**
  Date: 27 February - 3 March, 2023
- **Focus Week 1: Tensor Networks**
  Date: 6 - 10 March, 2023
- **Focus Week 2: Quantum Many Body**
  Date: 13 - 17 March, 2023
- **Focus Week 3: Functional Analysis and Quantum Information**
  Date: 20 - 24 March, 2023
- **Advanced School: Operator algebras, quantum information and quantum many body systems**
  Date: 27 - 31 March, 2023

Research term: Moduli Spaces and Geometric Structures

April – June 2023, ICMAT

- **Workshop on The Hitchin system, Langlands Duality and Mirror Symmetry**
  Date: 24 – 29 April, 2023
- **Workshop on Higgs Bundles, Character Varieties and Higher Teichmüller Spaces (joint activity with the ICMAT Agol Laboratory)**
  Date: 22 – 26 May, 2023
- **Workshop on Gauge Theory, Canonical Metrics and Geometric Structures**
  Date: 19 – 23 June, 2023
- **Moduli Seminar**
  Date: 1 April – 30 June, 2023

Workshop: 13th Bayesian Inference for Stochastic Processes

Date: 22 – 24 May, 2023

Place: Real Academia de Ciencias Exactas, Físicas y Naturales

7th Symposium on Games and Decisions in Reliability and Risk (GDRR

Date: 24 - 26 May, 2023
Place: Real Academia de Ciencias Exactas, Físicas y Naturales

Research term: 2023 Thematic Period on PDEs Diffusion, Geometry, Probability and Free Boundaries

June – December 2023

- **BIRS-IMAG Workshop: Nonlinear Diffusion and Nonlocal Interaction Models – Entropies, Complexity, and Multi-scale Structures**
  Date: 28 May – 2 June, 2023
  Place: IMAG (Granada)
- **Summer Program on Conformal Geometry and Non-local Operators**
  Date: 19 – 30 June, 2023
  Place: IMAG (Granada)
- **Nonlinear PDE Workshop**
  Date: 10 – 14 July, 2023
  Place: ICMAT

Boletín semestral
Instituto de Ciencias Matemáticas
N.23 – Segundo semestre 2022

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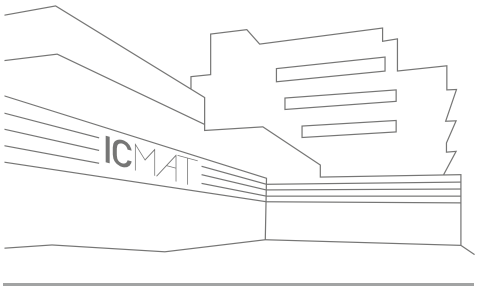

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