ICMAT
INSTITUTO DE CIENCIAS MATEMÁTICAS

Quarterly newsletter
Fourth quarter 2015
CSIC - UAM - UC3M - UCM

EDITORIAL

The ICMAT is once again awarded the Severo Ochoa seal of excellence

In late October of this year the Spanish Secretary of State for R+D+i informed us of the renewal of the Severo Ochoa accreditation of excellence for the next four years. This represents an additional funding of one million euros per year, but above all it is a recognition of the ICMAT as a mathematical research center of excellence at an international level.

The report we received from the international assessment committee reads as follows: "The ICMAT is a first-class mathematical research center that covers a broad range of mathematical areas with scientific contributions of the highest order, including some remarkable achievements". The international experts state that: "Over recent years, the capability of the Institute for assiduously conducting high-quality, interdisciplinary research work is notable; for instance, the resolution of the Nash problem in singularity theory; the resolution of the Sidon problem in number theory; the resolution of Arnold's conjecture in hydrodynamics; the work on how waves break, and the results on Lagrangian transport and their application to the study of the ozone layer, among others". The report goes on to say that: "The ICMAT can count on researchers of international prestige, including many first-rate young researchers. The notable research careers of these scientists provide a guarantee of quality for the Center... The diversity of their backgrounds constitutes a healthy trend; there are no signs of in-breeding and they bring to the ICMAT mathematical traditions from the different schools throughout the world. There is no doubt that the ICMAT has attained sufficient critical mass to become a center of the highest quality, which can be extended by the introduction of new topics". These words are a further confirmation of the international standing of the ICMAT that fills us with pride, but also a reminder of the responsibility involved in the tasks we wish to undertake.

The Institute aspires to consolidate its position among the leading mathematical centers throughout the world, and thanks to the renewal of the Severo Ochoa program it is now possible to continue with our ambitious scentific project. However, as stated in the report by the assessment committee: "The ICMAT still cannot count on the same levels of support and financial autonomy that these centers" [its international counterparts]. It is precisely because of this that the Severo Ochoa program is important, since it will enable the center's research programs to be strengthened with front-line initiatives such as the ICMAT Laboratories, as well as to carry on with their intense research activity, contracting PhDs and PhD students as part of our commitment to young researchers, organizing international meetings, and maintaining a management structure for all the researchers belonging to the center: in administration, in national and international projects, in communication and outreach, in transfer and so on. In a word, to continue to pursue the path that has marked out a difference


Rafael Orive Illera.

ICMAT

CONTENTS

and has made the ICMAT a leading center in the space of just a few short years.

This accrediation constitutes a recognition of the work that has been accomplished over the last four years. In the same assessment report, the committee highlights the work of CSIC researcher and founder of the ICMAT, Manuel de León: "The scientific director for the period 2011-2015, Manuel de León, has carried out a remarkable administrative task and has established excellent international connections. The new scientific director, Diego Córdoba, is a renowned mathematician and it is to be hoped that he will be able to benefit from the experience of his predecessor."

In the report, it is also stated that "the level of European funding is spectacular. The post-doctoral training program is of excellent quality and the outreach activities are exceptional. The External Advisory Committee includes outstanding international mathematicians". Moreover, the strategic plan designed for the next four years should raise the center's level of excellence even further, as the report points out: "The proposal for the coming years contains an excellent analysis of the strengths of the ICMAT and its (few) weaknesses, with a coherent plan to improve them... The challenges facing the new Director include the launching of the joint *Madrid Graduate School in Mathematics* in collaboration with the three Madrid universities, thereby improving collaboration among the different research groups and strengthening cooperation with the industrial sector".

I conclude by asking all ICMAT researchers to carry on with the spectacular work conducted by everyone in recent years, without forgetting that it has been the result of an intense and disinterested effort on a daily basis. To our friends who follow our activities by reading this newsletter, I would like to assure them that the ICMAT intends to keep up the good work, which is also due in part to their encouragement.

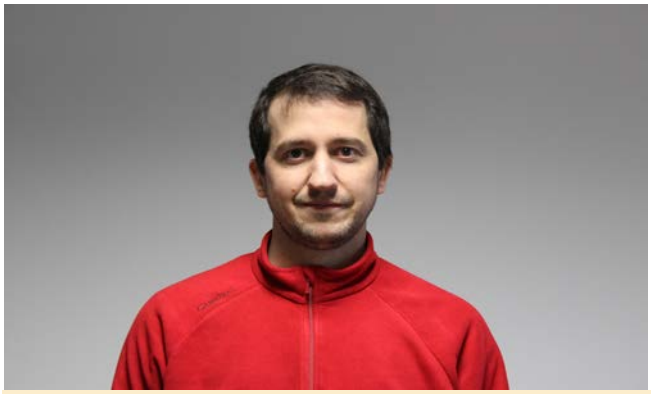
Many thanks to everyone!

Rafael Orive Illera

Director

INTERVIEW: David Pérez-García, UCM-ICMAT researcher and ERC Consolidator Grantee

ICMAT



"We want to find a *periodic table* of all the possible quantum characteristics of matter"

David Pérez-García's (Guadalajara, 1977) project "Spectral Gaps in Interacting Quantum Systems" was one of those chosen by the European Research Council (ERC) in the 2014 call for the Consolidator Grants. This work involves the analysis and classification from a mathematical point of view of the properties that may appear in materials at very low temperature. Although the work belongs to the field of mathematical physics, Pérez-García began his career in the field of functional analysis while doing his Ph.D in mathematics at the Complutense University of Madrid (UCM). That was in 2005, when he was on a post-doc stay at the Theoretical Division of the Max Planck Institute of Quantum Optics in Munich, where he switched his research subject. Since then his research work has been focused on quantum information and computation and its application to the study and characterization of the quantum phases of materials. In 2006 he obtained a Ramón y Cajal contract that enabled him to return to the UCM, where he has been a associate professor at the Department of Mathematical Analysis since 2007. Later, in 2013, he joined the ICMAT team.

Q: Before working on quantum information, your field of research was functional analysis. What made you change subject?

A: It didn't happen all at once; I started out looking for references for my research when I was completing my thesis. I found results that were related to the field I was working in then and which came from quantum information. That summer, with the encouragement of a good friend of mine, I attended a course at the Menéndez Pelayo University on quantum information given by Ignacio Cirac. I got talking to him and he invited me to visit his institute. It seemed like an exciting subject to me and I decided to switch. That's how I began and I'm happy with the change.

Q: What attracted you to that field?

A: It combines mathematics with physics, both theoretical and experimental. It's a very rich and dynamic field and is constantly changing. The questions we study require very advanced mathematics; it even leads to the creation of new, specific mathematics for solving problems that are motivated by cutting-edge problems in physics. What's more, the potential applications, such as the quantum computer, could have an enormous impact on society in the near future.

Q: Specifically, could you describe the problem you're going to tackle in the project for which you have received the ERC grant?

A: The aim is to catalogue the possible global properties that may be present in a material at very low temperature and provide models that possess each one of them. In this way we would have a kind of *periodic table* of all the possible characteristics or phases of matter as regards conductivity, magnetism and so on. Our main interest is in the properties that may be useful for future quantum technologies, such as characterizing what systems could serve as quantum memories, because they enable information to be maintained for longer. That's the goal, but there are also many interesting intermediate results.

Q: What's the background to this problem?

A: This is a mathematical problem motivated by physics. We start from a system with many particles whose interactions are modeled by using quantum mechanics, and from this model of given local interactions we intend to deduce what global properties, which are those that are observed, the system has. It is one of the central problems of materials physics. It's very complicated and possibly may not be solvable in many cases. Some of the best physicists and mathematicians have addressed these questions since the beginning of the last century.

"That knowledge could point the way to materials with new properties"

Q: But your approach is a bit different, isn't it?

A: Yes, we've put forward a different approach: we classify all the possible properties directly on the basis of a description of all the possible states, not the interactions. Thanks to a recent result, we now know the *map* of all the possible states, but we still don't know which state corresponds to which interaction. Moving from a description of the interactions to a description of a state is extremely complicated. What's more, mathematical results exist that show that it's impossible to do it in full generality.

Q: What's the difference between the state of the system, its properties and its interactions?

A: The state is a mathematical object which, once it is known, enables us to predict the result of any measure performed in the system. The properties of the system, which is what interests us, therefore depends solely on the state of the system. With a description of all the possible states, we can try to classify all the possible properties, without knowing what the exact connection is with the interactions that govern the system.

Q: What types of tools are you going to use?

A: In order to be able to characterize and distinguish the different quantum properties of the material, even if you make a map of the states I mentioned before, it's vital to know certain properties of the mathematical operator (called the Hamiltonian) that models the interactions of a system and governs its evolution. The spectral gap, which represents the energy the system needs (assuming it's at 0 temperature) so that its properties change, is particularly important. Among many other things, the gap is related with the stability of the system: if the gap is bigger, you need to apply more energy to the system so that the properties change, and when this does not exist we find ourselves at an unstable point (called a phase transition) where small perturbations can radically change the properties of the system. One of the main avenues of the project is to characterize the spectral gap of certain types of Hamiltonians. It's a problem that a lot of people are working on and is crucial for our project.

Q: What consequences would obtaining the result you seek have?

A: We could identify unknown phases that still haven't been found in nature, and since we'd have examples of all of them, this knowledge could point the way to materials with new properties or to their synthesis in a laboratory.

Q: In your project you speak about materials at very low temperatures. Why is that?

A: Because it's there where the properties are purely quantum. The project is basically focused on two dimensions; on things that occur in very fine layers, and there it's known that most of the quantum properties that interest us – the so-called topological properties – disappear rapidly when the temperature increases.

Q: The properties classify the different phases; what type are they?

A: Of course, they'll be something *exotic* for everyday intuition. We hope they'll be topological properties. Topological means that the characteristics of the system change according to the shape of the material. For example, a material with the shape of a donut will have properties that are different from one in the shape of a sphere, although the local interactions that govern it may be the same. In some way the system detects the shape the material has and its gobal characteristics change. These types of properties are interesting for the development of quantum memories, because they are more robust against errors that may occur due to noise or imperfections in the implementation.

Q: At the moment these results are still theoretical. When do you think the quantum computer might be a reality?

A: We won't have a totally powerful computer in 10 years' time, but we'll certainly be able to employ quantum systems for resolving problems that at the moment are impossible to solve: quantum simulators for solving very complex materials problems that at present are beyond us. Right now very rapid progress is being made at an experimental level and the separation between theory and experiment is narrowing every day. When the quantum computer becomes a reality, all theoretical development will have a basis for further implementation. I'm not an experimentalist, but experiments take time, they have their own bottlenecks... From the outside it's difficult to know, but given the rapid progress in recent times it's no exaggeration to think that in 10 years there'll be some spectacular results in this field.

"These types of properties are interesting for the development of quantum memories"

Q: Looking back over your career, what result would you mention in particular?

A: We've recently shown that certain central properties in the study of matter – such as the spectral gap – can't always be deduced on the basis of a mathematical description of the interactions of a system. This involves, for example, the existence of a new type of exotic materials that detect their own size. Furthermore, we've found a demonstration about the stability of a mathematical model for the noise that occurs in many quantum systems. Basically, we've proved mathematically that it is possible to model noise, and even though the model is not perfect the expected result is stable if the model is reasonably good. Experimental physicists already know about this, but a mathematical demonstration settles the question definitively.

Q: As regards the problem posed in the ERC, there are also some previous results of great importance.

A: With regard to the description of all the possible states, we saw how to characterize very well, on the basis of the local descriptor (a tensor), the global properties of the system we're seeking to understand. In this relation between global property and local descriptor, which is key to the study, we have two results: one on topological properties and the other on symmetry in the system, which are very important and have had a great impact on these kinds of questions. Another important result was establishing a connection between an abstract mathematical theory, that of operator spaces, complexity theory, and the so-called quantum non-locality, which is one of the key resources for the applications of quantum information that are on the table at the moment, such as quantum cryptography, the generation of random numbers, etc. We saw what the right mathematical theory was for addressing these types of questions, and we use that theory for solving some important open problems.

Q: These are some of the outcomes arising from your work, but if you had to chose one moment from your career, what would it be?

A: I think the decisive moment was when I met Ignacio Cirac on that summer course. Ignacio has always helped and supported me in a change that was radical for my career. I wouldn't be where I am today if it hadn't been for him.

"What I enjoy about research is the moment when you understand something you didn't understand before and you start to put order into chaos"

Q: What do you enjoy most in your day-to-day work as a mathematician?

A: I think it's the creative process. The moment when you understand something you didn't understand before and you start to put order into chaos; the moment when you get an idea and see that it works, that it's going to produce something new. In exchange, of course, for all the times you thought that an idea was going to work and it didn't. It's just the continuous ups and downs of scientific research.

REPORT: Statistics Consultancy Unit

A STATISTICAL *SPIN-OFF* FOR CHRISTMAS

At the end of December, 2015, the ICMAT will present a Statistics Consultancy Unit consisting of a research team devoted to providing a service to the different Institutes belonging to the CSIC. As a spin-off project, the SPOR (Statistics, Probability and Operations Research) team will launch a network portal as a communication channel for establish cooperation and problem-solving in frontier science subjects. Virtually all disciplines that gather data (health sciences, social sciences, engineering, astrophysics) or that require probabilistic or operations research techniques can benefit from this pilot scheme.

For the SPOR team, the development of statistical models for meeting the needs of other research groups is a challenge in itself, while for the CSIC it could become a big step forward both qualitatively and quantitatively for its scientific productivity.

Lucía Durbán Carmona. For the uninitiated, statistics seem almost synonymous with mathematics. Many of us may have imagined that the corridors of one of the leading international centers in mathematics are full of people who keep a copy of Gauss' *"Theoria combinationis observationum erroribus minimis obnoxiae"* in a place of honor on their bookshelves, who complete the pools coupons for their friends every Sunday, or maybe sometimes post on their Facebook page messages like "out of every 10 people who watch TV, 5 make up the half", or "statistics is a science according to which all lies become graphs"... But no, not until a year and a half ago, with the arrival of Antonio Gómez Corral (Complutense University of Madrid - the ICMAT), Bernardo D'Auria (Carlos III University of Madrid - ICMAT), Isabel Molina Peralta (Carlos III University of Madrid - ICMAT) and David Ríos (AXA – ICMAT Chair), did the Institute of Mathematical Sciences have the right profiles for setting up an elite, multidisciplinary Unit of Statistics.

CCO Public Domain

The SPORS team aims to solve complex problems in the frontier of science: motivation and challenge.

Today we are able to speak about the SPOR Group, coordinated by Gómez Corral, and now, with the incorporation of David Gómez-Ullate (Complutense University of Madrid - ICMAT), Kurusch Ebrahimi-Fard (Ramón y Cajal Researcher with the ICMAT) and Carlos Escudero (Autónoma University of Madrid - ICMAT), the SPOR is able to count on "seven members determined to become the leading group on Statistics, Probability and Operations Research in the Community of Madrid, not to mention the aim of establishing connections with industry. This is something that is obviously going to contribute to the ongoing improvement of the ICMAT", says Gómez Corral. Furthermore, the terms "Big Data", "Data Science" and "Data Engineering" will figure in every study program leading to a good job in the current century. Indeed, statistics acquired the status as one of the vital tools for the management of big data some time ago.

"seven members determined to become the leading group on Statistics, Probability and Operations Research in the Community of Madrid, not to mention the aim of becoming international and establishing connections with industry"

The possibilities of the SPOR Group are as many as the requirements and opportunites its members have detected during the preparation of their global research project. They have drawn up a plan of action with the backing of the ICMAT management, which has already launched several of its initiatives in the short term. Among other actions undertaken, various research projects have been applied for, setting in motion scientific collaborations among SPOR members; a cycle of talks between the three universities (UAM, UC3M and UCM) and the Institute has been set up; the group has become involved in the renewal of the Severo Ochoa award, and various international conferences and congresses have been organized. But perhaps the most noteworthy of all will take place at Christmas: the presentation of the Statistics Consultancy Unit and its new web portal.

Statistics groups already exist in universities, but the new feature of this spin-off proposed by the SPOR Group is the consultancy service it provides to the CSIC institutes. The aim is to solve complex problems in frontier science: this is its motivation and its challenge. Teams engaged in molecular biology, astrophysics, engineering, economics, linguistics and so on require special management of data and the development of *ad hoc* statistical models in order to make progress in their work, and now they will be able to collaborate with this group specializing in statistics. As Ríos points out; "We have already entered into contact with a group working on genetics, and although we are still designing the protocols and the different compensation formulas, I think that we'll have developed something solid by June next year".

The original idea is to provide an internal service for the CSIC, so for the moment it all remains in-house, but the group is open to external collaborations. In fact, David Gómez-Ullate has a project with the BBVA Foundation on fraud detection and David Ríos with the State Agency for Aerial Security, etc.

For Gómez Corral, the goal is to turn SPOR group into a well-founded and well-balanced team within two years, with a stable source of funding, the capacity to attract human resources, and even the possibility to develop its own post-graduate program. To that end, experienced researchers will be required, as well as highly qualified young and post-doc researchers who do their Ph.D theses within the SPOR. Furthermore, the success of the Statistics Consultancy Unit within the CSIC will have to exceed expectations as a fully fledged spin-off in order to go on to provide services to other Public Research Bodies (*Organismos Públicos de Investigación* - OPIs) as well as companies in the private sector.

Face to face with the SPOR team

The aim of SPOR is to be a strong research team in the mid-term and to improve the ICMAT by bringing it closer to real-world applications, such as those currently being developed by members of the group.

Isabel Molina works on estimation problems in small areas, with application to measuring levels of poverty and inequality in regions; Antonio Gómez Corral, the coordinator of the SPOR Group, develops epidemiology models to determine how long an epidemic will last and how many individuals will be affected; David Ríos' work is focused on questions of security, risk analysis and decision-making analysis; David Gómez-Ullate works on the application of machine-learning algorithms to classification problems and data processing, such as the detection of banking fraud; Bernardo D'Auria and Carlos Escudero collaborate on a detection problem in the use of privileged information in financial markets by studying financial stochastic models, and finally, Kurusch Ebrahimi-Fard, the latest researcher to join the team this summer, develops mathematical models for the proper management of ecological resources, together with control theory.

ICMAT

From left to right: David Ríos, Antonio Gómez Corral, David Gómez-Ullate and Kurusch Ebrahimi-Fard.

ICMAT

Antonio Gómez Corral completed his doctorate on applications of stochastic processes to telephone models at the UCM. He is currently an associate professor at the UCM Department of Statistics and Operations Research. Since October 2013, he has been an ICMAT researcher and coordinator of the scientific and outreach activities of the SPOR group. His field of expertise is applied probability; in particular, stochastic models for epidemics and population dynamics. He currently coordinates research in the project *"Stochastic Models and Statistical Aspects in Epidemics"*, which is funded by the Spanish Ministery for the Economy and Competitiveness. Among the activities organized by Antonio Gómez Corral at the ICMAT are the conferences *"A Two-Day Meeting on Mathematical Biology"*.

Gómez Corral has published more than fifty articles on stochastic models for queueing theory and mathematical biology and is the co-author of the book *"Retrial Queueing Systems: A Computational Approach"*, published by Springer-Verlag. As regards his editorial work, among other scientific journals he is an associate editor of *Applied Mathematical Modelling, Asia-Pacific Journal of Operational Research* and *Top*, and guest editor of special volumes of the *European Journal of Operational Research* and *The Annals of Operations Research*.

"The new feature of this spin-off proposed by the SPOR Group is the consultancy service it provides to the CSIC institutes"

David Ríos is holder of the AXA-ICMAT Chair of Adversarial Risk Analysis and a member of the Royal Spanish Academy of Sciences. He works on the improvement of methods for data processing, in which support is provided for decision-making in real-world complex problems, in areas such as social robotics, security and political participation.

ICMAT

Ríos graduated in Mathematics at the UCM and obtained his doctorate in Computer Science from Leeds University. He has occupied teaching and research positions at SAMSI, Duke, Purdue, Paris-Dauphine, Leeds, Manchester, IIASA, CNR- IMATI and the Madrid Polytechnic universities. He is professor of Statistics and Operations Research at the Universidad Rey Juan Carlos (currently on leave).

He has written 13 books, published seven special issues and published more than 110 papers on his areas of interest, which include decision analysis, risk analysis, negotiation analysis and Bayesian statistics, and their applications to social robotics, aerial security and safety, the protection of infrastructures and the management of water resources, among others.

ICMAT

David Gómez-Ullate is professor of Applied Mathematics at UCM. His activity as a member of the SPOR Group pursues two lines of research. On the one hand, the study of Infotaxis, which is a Bayesian searching strategy based on information theory for detecting sources that emit volatile substances in noisy or turbulent environments with intermittent information, where the lack of well-defined gradients make traditional methods fail. On the other hand, he works on the application of machine-learning algorithms to classification problems and data science; in particular, fraud detection in electronic payments.

Gómez-Ullate has completed post-doctoral stays at the University of Bologna, McGill University and the Centre de Recherches Mathématiques (Montréal). His work focuses on different fields in mathematical physics, dynamical systems, special functions and complex systems. He has recently been developing a new activity in data science and machine-learning. His first project on fraud detection in electronic payments has been awarded a BBVA Foundation Grant for Researchers and Cultural Creators.

"For the CSIC it could become a big step forward both qualitatively and quantitatively for its scientific productivity"

Isabel Molina completed her Ph.D in Statistics and Operations Research at the Universidad Miguel Hernández in Elche and is currently professor at the Carlos III University of Madrid Department of Statistics. She conducts research into estimation in small areas of socioeconomic or environmental indicators that are not well covered by official surveys. Together with J.N.K. Rao, she has developed one of the basic methods currently employed for the estimation of nonlinear parameters, such as indicators of poverty at a local level.

ICMAT

Molina is an elected member of the *International Statistical Institute* (ISI) since the beginning of 2015 and is the co-author of the reference book on "Small area estimation". She was the team leader in the European SAMPLE Project (*Small Area Methods for Poverty and Living Condition Estimates*) and has been advisor for the Swiss National Institute of Statistics (Federal Statistical Office), the Chilean National Statistical Institute (INE), the Mexican National Council for the Evaluation of Social Development Policy (CONEVAL), the European Agency of Statistics (Eurostat) and the World Bank. She has been awarded with different research prizes, including *Sociedad de Estadística e Investigación Operativa* (SEIO) Ramiro Melendreras Prize and the "Best paper award" by the Canadian Statistical Society for the best article published in the Canadian Journal of Statistics in 2010.

ICMAT

Bernardo D'Auria is an electronics engineer and doctor in Telecommunications Engineering from the University of Salerno. He is currently an Associate Professor at the Carlos III University of Madrid Department of Statistics. He is an expert in the theory of stochastic processes, with a particular interest in queueing theory. His present subject of research is the study of adaptative and stable algorithms for large-scale complex telecommunications networks. His other recent interests include the applications of modeling techniques and optimal stochastic control in finance and insurance. In particular, he studies financial stochastic models that seek optimal search strategies incorporating privileged information.

D'Auria has worked at different prestigious centers during his career in research, such as Cornell University (Ithaca, NY, USA), the Mittag-Leffler Institute (Stockholm, Sweden) and the Hebrew University of Jerusalem (Israel), among others. He worked as a post-doctoral researcher at EURANDOM (Eindhoven, Holland) as part of the "Queueing and Perfomance Analysis" team and was a Ramón y Cajal researcher at the Carlos III University of Madrid. He is actively engaged in research at an international level and collaborates with prestigious researchers in Europe and the United States. He currently works as the research leader of the Spanish national project "Optimal Equilibria in Large Networks" and collaborates actively with the ICMAT SPOR team of which he is a member.

ICMAT

Kurusch Ebrahimi-Fard studied for his degree in Mathematics and Physics in both Europe and the USA and obtained his doctorate in theoretical physics from the University of Bonn (Germany). He is presently a Ramón y Cajal researcher at the ICMAT and his long-term research program is focused on the development of applications of the combinatorial algebra theory in applied mathematics; in particular, in the theory of stochastic equations, free probability theory, numerical integration methods and nonlinear control theory. In parallel with this, he also works on number theory in relation to theoretical physics. In this context, his research work benefits from collaborations with mathematicians, physicists and engineers.

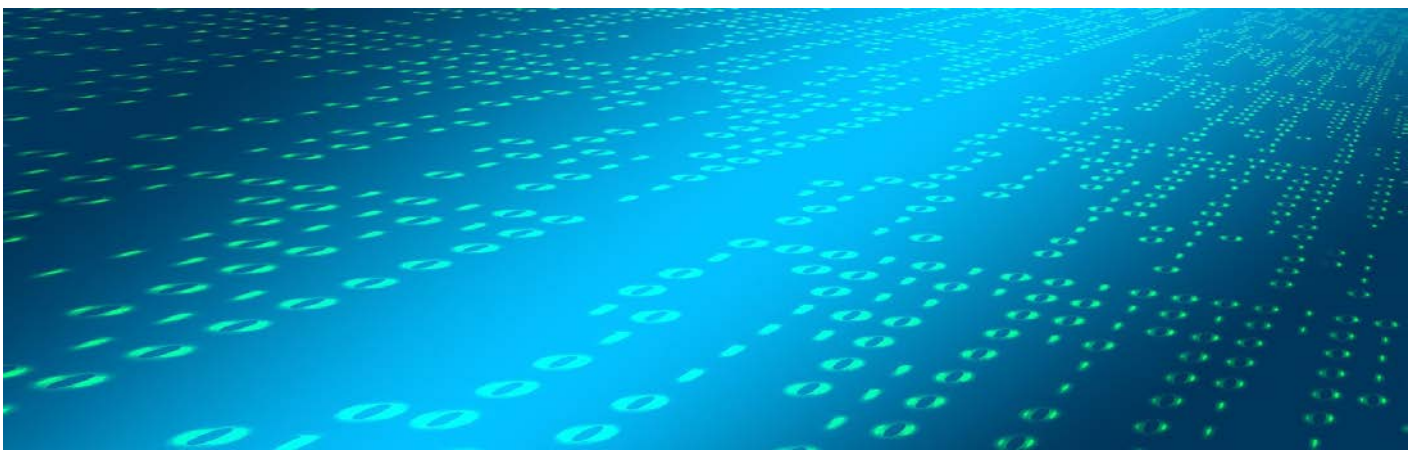
He was previously a Juan de la Cierva researcher at the University of Zaragoza and completed post-doctoral stays at the *Max-Planck-Institut für Mathematik* in Bonn and the *Institut des Hautes Études Scientifiques* (IHÉS) in Bures-sur-Yvette, France. His previous work centered on quantum field theory and the underlying mathematical aspects.

In 2014 he was awarded a BBVA Foundation Grant for Researchers, Innovators and Cultural Creators for the research Project "Mathematical methods for ecology and industrial management (MMEGI)".

During his time in Spain he has co-organized two research trimesters, a Clay Mathematics Institut summer school (the only one to be held in Spain), and more recently a CIMPA summer school in Brazil on the interaction between combinatorics and probability. Next year he will co-organize the 2016 Abel Symposium in Norway.

"Teams engaged in molecular biology, astrophysics, engineering, economics, linguistuics and so on require special management of data and the development of ad hoc statistical models in order to make progress in their work, and now they will be able to collaborate with this group specializing in statistics"

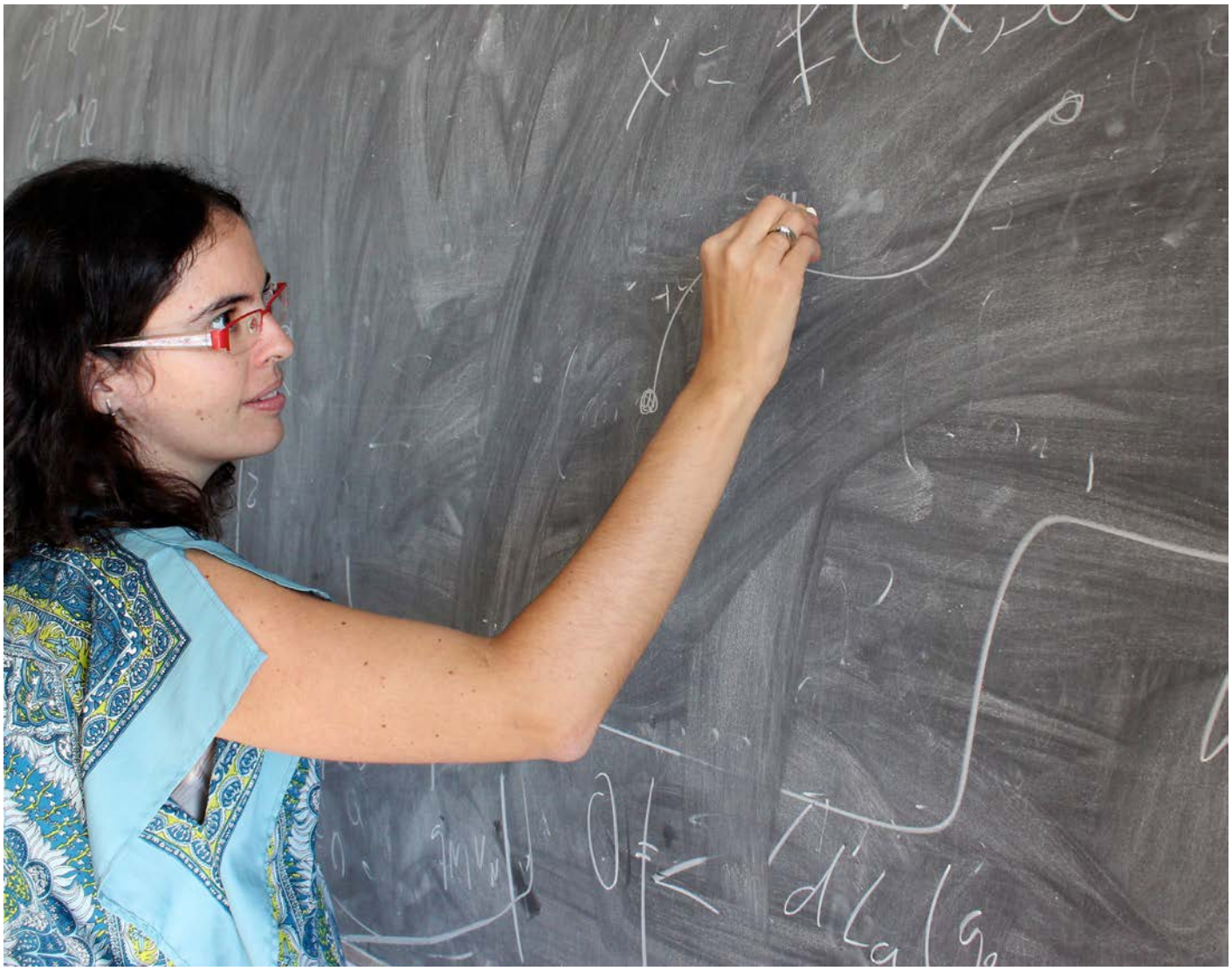
Although he occupies no fixed position in the SPOR team, **Carlos Escudero Liébana** has collaborated with the rest of the group for almost a year. His main research lines are statistical mechanics and its applications as well as the analysis of ordinary, partial and stochastic differential equations. He is a member of the ICMAT and is under contract as a Ramón y Cajal researcher at the Autonomous University of Madrid Department of Mathematics.



CC0 Public Domain

Virtually all disciplines that gather data can benefit from this pilot scheme.

ICMAT



SHE MAKES MATH: María Barbero

MARÍA BARBERO

Professor at Technical University of Madrid and member of the ICMAT.

Research field: Control Theory.

Problem she is working on: Construction of geometric integrators.

Why does our body move the way it does? Why do we make the joints in our arm work in a certain way when we eat? Without actually realizing it, we are solving optimization problems every time we make these movements. The aim is usually to minimize time, distance or energy. Behind these processes, and many others that surround us, control theory remains hidden. These days control theory is employed in many fields such as medicine, aeronautics, robotics or economics. And among its applications is the design of self-driving cars, solar sails, etc.

Advanced mathematics derived from mechanics is necessary for the development of these applications. Control theory consists on the study of dynamical systems that can be influenced by us through the degrees of freedom that are added to the system by the controls. A trajectory of such systems is a solution to a system of first-order differential equations. Once the control has been established and an initial condition is given, there exists a unique solution of the differential equations.

In her research work, María Barbero studies this theory from a geometric point of view; that is, when the solutions to the systems of differential equations are understood as integral curves of vector fields depending on the controls. Differential equations are often very difficult to solve and in many cases it is impossible to obtain exact solutions, so mathematical software programs are employed to generate approximations to the solutions. Among the new methods for obtaining these approximations are geometric integrators, the theoretical construction of which María Barbero is involved in her work.

An extended version of this article will be available at: http://mujeresconciencia.com/

SCIENTIFIC REVIEW: Methods of Differential Geometry in Classical Field Theories k-Symplectic and k-Cosymplectic Approaches

Title: *Methods of Differential Geometry in Classical Field Theories k-Symplectic and k-Cosymplectic Approaches.*

Authors: Manuel de León (Instituto de Ciencias Matemáticas), Modesto Salgado (Universidade de Santiago de Compostela), Silvia Vilariño (Centro Universitario de la Defensa).

Publisher: World Scientific.

Date of Publication: October 2015.

The field known as *symplectic geometry* is the most commonly used tool for studying classical mechanics. In fact, it is the geometric structure of space phases in mechanics (positions and moments).

However, when other types of macroscopic physical phenomena are considered, such as the electromagnetic field or the gravitational field, another kind of mathematics are required. This branch of physics belongs to *classical field theories*. These *fields* depend on several variables (of space and time) and their dynamics involve derivatives of these variables, and thus the symplectic structure is no longer valid.

In the late 1960s and early 1970s, various attempts were made to develop a suitable framework for the study of classical field theories. In a parallel way, the Polish school (led by W.M. Tulczyjew), the Spanish school (led by P.L. Garcia and A. Pérez-Rendón) as well as two North American researchers (Hubert Goldschmidt and Shlomo Sternberg) found a suitable geometric construction for addressing the task: the so-called *multisymplectic formalism*.

However, other geometric alternatives also exist, as described in the recently published book "Methods of Differential Geometry in Classical Field Theories k-Symplectic and k-Cosymplectic Approaches", which sets out the two most important approaches to the study of first-order classical field theories: k-symplectic and k-cosymplectic geometry.

This book by Manuel de León (Instituto de Ciencias Matemáticas), Modesto Salgado (Universidad de Santiago de Compostela) and Silvia Vilariño (Centro Universitario de la Defensa), is aimed at researchers working on classical field theories as well as Ph.D students who are interested in pursuing a scientific career in this field. This research field has been consolidated by its purely geometric interest and for its applications, and dozens of questions exist therein that have yet to be answered.

The foundations of Hamiltonian and Lagrangian mechanics are dealt with in the first part of the book. The geometric developments (k-symplectic geometry) underlying first-order classical field theory, in certain concrete cases, are then introduced. In the third chapter, these results are extended to general cases, and finally in the third part the k-symplectic and k-cosymplectic formalisms are related.

QUESTIONNAIRE: Daniel Azagra

DANIEL AZAGRA

Daniel Azagra was born in 1970. He studied for his degree in Mathematics at the UCM from 1990 to 1994 and gained his doctorate in 1997 under the supervision of Jesús A. Jaramillo. He is currently a professor at the UCM and a researcher with the ICMAT.

Q1: **Why did you chose mathematics from among all other subjects?** When I was at school I didn't like mathematics. I think that was because I had bad teachers and the study plan wasn't exactly the best. When I was 15 or 16 I started to like Physics, and at 17 I realized that what I liked about it was precisely the underlying mathematics. It wasn't a difficult choice; it just came naturally.

Q2: **Apart from mathematics, what other things do you like doing?** Listening to music and playing the piano.

Q3: **Could you recommend a film, a book or a play?** That's difficult to answer. Two essential books for me, although radically different, are Julio Cortazar's collection of stories and the novel "The Count of Monte Cristo" by Alexandre Dumas. When you read the first one you say to yourself "it's impossible to write better". As for the second, "there is no more exciting plot narrated in a more effective way". All the rest of literature falls between these two extremes. When it comes to cinema it's something similar, but for example I'd say "Blade Runner" by Ridley Scott, and as for the theatre, any play by Shakespeare.

Q4: **What was you first experience in mathematical research like?** Without realizing it, you're already researching when you're in high school, when you start solving difficult problems (if you are set them), and of course at university. It doesn't matter if the teacher knows the solution to the problem, because the sense

of satisfaction students have when they find for themselves the miraculous argument that makes everything fit into place is the same at those early stages as in one's professional career when you tackle open problems. The only difference is the time it takes: solving a problem in research requires much more time and effort.

Q5: **What would you highlight from your first introduction to research?** Looking back, I'm amazed at how much free time I had to read and think without having to worry about teaching duties or bureaucracy, and how little I made of it. If I could relive that time again, knowing how valuable it was to have so much time to myself, I'd use it to much better effect and learn more things.

Q6: **Which scientist has impressed you most in your professional career?** If I understand the question correctly, it refers to mathematicians I've interacted with personally, so I'd say David Preiss, from the University of Warwick. He and his school have solved extremely difficult problems on the differentiability of Lipschitz functions. Not only that, David Preiss is a person of great human and scientific integrity, not to mention his generosity, that you don't find very often.

Q7: **If you could speak for an hour with a mathematician from the past, who would you chose and what would you talk about?** Uff! An hour wouldn't be much use because we'd be speaking in very different languages. Let's say 500 hours and I'd chose Archimedes or Newton, or even more modern mathematicians like Euler or Gauss. First I'd have to teach them more modern mathematics, and I'm sure they'd be flabbergasted. But after that first shock they'd learn very quickly, and it wouldn't take long for them to make spectacular theorems that would leave me astounded and way behind.

Q8: **Is there any theorem or formula that you especially like?** The Area and Coarea Formulas, which are overwhelming generalizations of change in variables and Fubini theorems, and in relation to this, the Rademacher theorem, which states that every Lipschitz function in Euclidean space is differentiable at almost every point. It seems incredible to me that you can get so much out of Lipschitz functions.

Q9: **What is your favorite book on mathematics?** If you're talking about a text book, "Calculus" by Michael Spivak; I think that it's thanks to having studied this book in the first year of my degree that I went on to devote myself to Mathematical Analysis.

Q10: **How would you describe your research work in a few words?** At the moment I'm interested in this problem: given an infinite set of points in Euclidean space, how can we find out if there's a convex and differentiable hypersurface that contains this set?

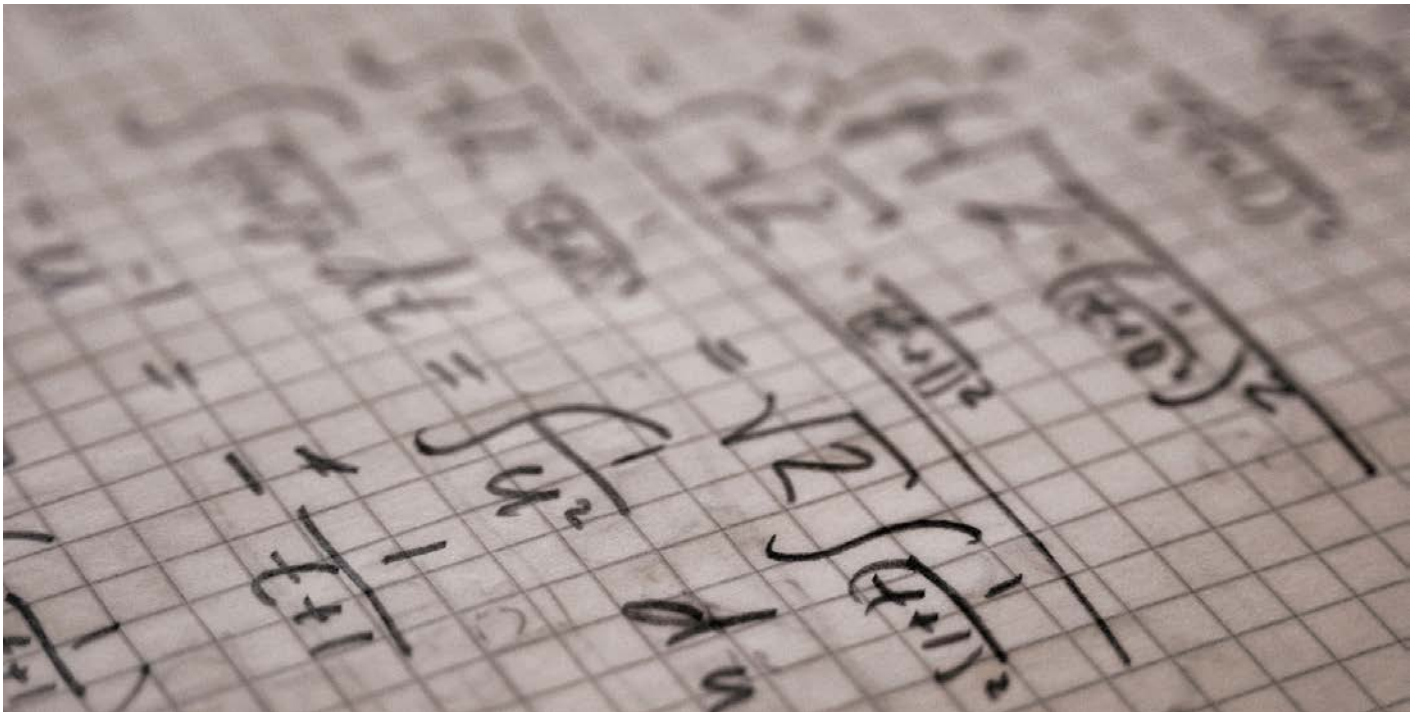
Q11: **What recent results in your field would you mention in particular?** Charles Fefferman's solution to the Whitney extension problem (published in 2006).

Q12: **Which mathematical problem do you think is the greatest challenge at the moment?** I don't think it makes much sense to talk about the greatest challenge; in every area of mathematics there are several big problems to solve, and until they are all solved we won't know which was the most difficult. And even then we won't know for certain, because there will always be the possibility of finding simpler solutions.

Q13: **What subjects outside your field would you like to learn more about?** I have big gaps in algebraic geometry and probability theory, and in the future I'd like to have enough time to make up for that lack.

Q14: **What interaction between the different branches of mathematics will be the most fruitful in the future?** I think that in the not too distant future mathematics as we know it now is going to change a lot. Quite likely, within fifty years at most, really intelligent machines will be built that will do our work better than we do, and those machines will be experts in mathematics and will combine all the branches of mathematics we know at present, and certainly will discover yet more new branches. It's sad, but probably inevitable. In my opinion, research into Artificial Intelligence should be forbidden. It's as dangerous for humanity as the atomic bomb.

Q15: **Do you have any message or advice for young mathematicians?** Yes: make the most of your time and prove good theorems before intelligent machines put us out of work.



By Kim Andre Silkebækken

PROFILE: Víctor José García Garrido

"I learnt how to put my head in order

VICTOR JOSÉ GARCÍA GARRIDO

Since May, 2014, Victor has been a postdoc researcher with the ICMAT, where he works in the Stephen Wiggins Laboratory. He graduated in Mathematics at the Complutense University of Madrid (UCM), enjoyed a JAE Predoc Grant from July 2009 to July 2013, and in December of that same year he completed his doctorate at the Autonomous University of Madrid (UAM) with his thesis *"The Mathematical Models of Rotating Droplets with Charge or subject to Electric Fields"*, under the supervision of Marco Antonio Fontelos, who is also an ICMAT researcher. His Severo Ochoa contract comes to an end in December, 2015, and next year he will join the Department of Atmospheric and Oceanic Sciences at the University of California Los Angeles (UCLA) in the USA.

Foto de Lucas Cardoso Laurindo

Lucía Durbán Carmona. If Víctor had been born a little over 20 years ago he would have been one of the first students in the interdisciplinary degree in Mathematics and Physics. The fact is that his love affair with mathematics came to him via Astronomy; his nighttime excursions to gaze at the stars with family and friends kindled his attraction to science, and later he realized that mathematics was behind all the problems that aroused his curiosity. He is a pragmatic type of person who likes applied science and studied a degree in Mathematics with a specialization in Applied Mathematics and Astronomy. But it was not until the last year of his degree that he was drawn directly toward fluid mechanics: "The behavior of water is something we see every day in nature, and stopping to think about the complexity behind it fascinated me."

"The behavior of water is something we see every day in nature, and stopping to think about the complexity behind it fascinated me"

Among his hobbies are photography and cooking, and among the books he read this summer there was volume on one of his favorite subjects, science in the kitchen. He likes literary characters such as Sherlock Holmes and Dracula, and although he hesitates when being asked to choose his favorite dishes, he finally opts for dim sum and sushi. However, when it comes to chosing his favorite scientists he has no doubts – Newton! Probably because of that "very rich" fusion between mathematics and physics.

While waiting for the grant to arrive to pursue his doctorate, he had the chance to work on topics concerning computer security for two years. The experience he gained while working in the private sector helped him to develop a high degree of mental structuring: "I learnt how to put my head in order in a spectacular way". Nevertheless, Víctor is interested in spending the rest of his life working on research, and only in the case he can no longer continue with this path, he would look for a post with a private company that had a lot to do with mathematics. "I think the field of Big Data would provide me with a great deal of motivation", he says. This is probably because this young mathematician works in the area of geophysics, where data management plays a significant role.

One of the most noteworthy projects on which Víctor has been working during his Severo Ochoa period at the ICMAT is the study of how the pieces of the Malaysia Airlines plane, which disappeared on March 8th, 2014, could have scattered over the ocean surface, the results of this study have just been published in the *Nonlinear Processes in Geophysics journal*.

"I think the field of Big Data would provide me with a great deal of motivation"

This involves a Lagrangian technique that enables the processes of transport and mixing in a fluid to be described, and according to Víctor the application of this technique to the consequences of the disaster has been very complicated: "We've been working on our own account with the data that has gradually come to light throughout a long and confusing process". Nevertheless, by combining the official information about the accident with data on the ocean currents, the team has managed to develop a model that may have helped to improve the search strategies in the first months of the operation, particularly with respect to to the distribution of sea search and rescue resources and services. And now, since a wing section of the plane appeared on the island of La Reunión last July, the researchers intend to use the model to follow the track of the object back in time and thereby estimate the place where it might have come from.

The same technique used to trace the Boeing 777-200ER had already been used by the team to which Víctor belongs in order to study transport in the atmosphere its consequences on the ozone hole, but it had never been used in real time until April, 2015. As Víctor says, "unfortunately we were able to test it with success and predict the movement of the oil spill caused by the sinking of the *Oleg Naydenov* off the Canary Islands. This constituted the confirmation of this model as a vital tool for drawing up contingency plans in catastrophes such as this one".

"*Unfortunately* we were able to test it with success and predict the movement of the oil spill caused by the sinking of the *Oleg Naydenov* off the Canary Islands"

Next year Víctor will study the processes of formation and destruction of the Stratospheric Polar Vortex and its effects on seasonal variations of ozone depletion. This he will do at the UCLA Department of Atmospheric and Oceanic Sciences (USA), a project he is really looking forward to, although it will not be too long before we can expect him back, because this researcher from Madrid eventually plans to continue his work in Spain.

NEWS ICMAT

THE BBVA FOUNDATION FUNDS A PROJECT FOR TACKLING BANKING FRAUD WITH MATHEMATICS

David Gómez-Ullate, a professor at the Complutense University of Madrid (UCM) and a member of the ICMAT, has obtained one of the 63 grants provided by the BBVA Foundation; in this case, for the development of a project whose aim is to tackle banking fraud with innovative mathematical techniques. The project, known as "Artificial intelligence and data science: applications to the detection of fraud in methods of payment", is funded to the amount of 40,000 and is based on the use of the large sets of data recorded during electronic transactions in order to detect fraud in real time.

Gómez-Ullate has a year to explore and implement different self-learnng algorithms. By means of satistical techniques, data mining and artifical intelligence it is possible to construct user behavior patterns on the basis of the data recorded in digital payment processes; that is, data provided by banks in which fraudulent transactions have been detected *a posteriori*.

As Gómez-Ullate explains, "the aim of the project is to enable fraud to be predicted, raising the alarm in real time if the transaction data does not conform to the pattern recognized as legitimate. In this way we open up a new means of preventing fraud before it is actually committed, or at least before it causes significant loss or breakdown".

Among the 1,900 applications to this second call for the 2015 Financial Assistance for Researchers and Creators Program,

The novel mathematical techniques can anticipate the bank fraud.

Gómez-Ullate has been the only mathematician to be awarded this funding. In 2014, CSIC-ICMAT researcher, Kurusch Ebrahimi Fard, obtained funding for a project called "Mathematical methods for ecology and industrial management (MMEGI)", and was likewise the only mathematician on the list of successful applicants. In the words of the Foundation statement, these grants, which are awarded in 11 different areas of science and culture, "seek to stimulate individual talent and are extended to people with a highly productive background and who are at the mid-stage of their career".

MORE THAN 200 PEOPLE ATTEND THE FIRST "100XCIENCIA" FORUM IN LA PALMA

More than 200 people attended the big scientific outreach meeting "100XCIENCIA: *Communicating Frontier Science*", which was held in La Palma between October 7th and October 9th. Communication specialists, researchers and directors from the 20 Spanish centers with the Severo Ochoa distinction of excellence got together with journalists and other communication specialists to discuss the current situation of science and its social impact both nationally and internationally. The *Instituto de Astrofísica de Canarias* (IAC – Canary Islands Institute of Astrophysics) was the host for this first 100xCIENCIA meeting.

This forum included a full program of talks. In addition to the directors and representatives from all the centers, who explained their respective lines of research, the following invited speakers from the sphere of communication in science also took part: Kenneth Chang, scientific journalist from The New York Times; Patricia Fernández de Lis, editor-in-chief for Science and Technology from *El País*/*Materia*; Hanns J. Neubert, president emeritus of the European Union of Science Journalists' Associations, and Pampa García Molina, coordinator and editor-in-chief for the Information and Scientific News Service (SINC), among others.


ICMAT
Manuel de León together with the BCAM representant took part in the Math's session.

One of the main features of this forum was a discussion about scientific outreach and information as a mainstay of the R+D+i system. Thus, this meeting provided the opportunity to consider how science is portrayed in the media and conveyed to the public, as well as the changes that should be adopted in this process of dissemination.

THE ICMAT WELCOMES ONE OF THE NINE AFRICAN FEMALE RESEARCHERS TO SPAIN AS PART OF THE *ELLAS INVESTIGAN* PROGRAM

This month of October sees the start of the arrival of the African women researchers chosen within the framework of the Spanish *Fundación Mujeres por África* "Ellas Investigan – Women Also Do Research" Project, an intiative with the aim of promoting and supporting the work being carried out by women on the African continent in important fields such as energy and climate change, healthcare, agriculture and food security and safety. The ICMAT is welcoming one of these nine scientists, **Coumba Niang** from Senegal.

Niang will continue her research work over a period of six months, during which time she will bring her experience to the ICMAT as well as acquiring fresh knowledge that she will subsequently be able to apply when she returns to Africa. Niang is a scientist who works at the Laboratory of Physics of the Atmosphere and the Ocean Simeon-Fongang (LPAO-SF) at the Cheick Anta Diop University Higher Polytechnic College in Dakar. She has a Master's in Meteorology, Oceanography and Management of Arid Areas from the Higher Polytechnic College, and gained her doctorate via a joint program of the Akure Federal University of Technology in Nigeria and the Cheick Anta Diop University in Dakar.

This program of stays is one of the lines of action undertaken as part of the *Ellas Investigan* Project, which was launched last year with the celebration of the 1st day session on Science and Technology. Thirty candidates applied for the selection process in which various centers are participating as well as the *Ellas investigan* Scientific Committee, which in turn is made up of leading national and international scientists.

Further information on the nine African female scientists selected:

MATHEMATICS AND SOCIAL ROBOTS IN RESEARCHERS' NIGHT

For the fourth year running, the Institute of Mathematical Sciences participated in the Community of Madrid and the Autonomous University of Madrid (UAM) Researchers' Night with the activity entitled: "Friends or Enemies? Social Robots Inside Out". This was a talk given by David Ríos, AXA-ICMAT Chair in Adversarial Risk Analysis and member of the Royal Spanish Academy of Sciences, which took place last September 25th at the UAM Faculty of Medicine, with two sessions held at 7.00pm and 8.30pm, respectively.

The talk focused on the role of mathematics in artificial intelligence; specifically, on the development of social robots, that is, those which interact with people in accordance with social patterns. Over the next few years, social robots are going to play an increasing part in our lives, but will they be friends or enemies?

Prototypes already exist that act as help in the home, as pets, as interactive teaching tools, assistants for senior citizens and so on. But they could also become active in war situations, which in the opinion of experts may constitute a great risk for humanity. A few months ago, some 1,000 researchers in robotics and artifical intelligence signed an open letter in which they warned of the dangers of using autonomous robots for military purposes. Part of the letter read as follows: "Artificial intelligence technology has reached a point where the deployment of [autonomous weapons] is, practically if not legally, feasible in a matter of years rather than decades, and there is a grerat deal at stake. Autonomous weapons have been described as the third revolution in war technology after gunpowder and nuclear weapons". The debate has already been tabled, and as in so many others, it is one in which mathematics will have a significant influence.

The aim of this activity is to bring the work of researchers into first-hand contact with the general public in order to show the benefits that it can provide to society as well the influence that this work has on daily life, and to do so in an entertaining and accessible way. Researchers' Night forms part of the European celebration of this event that has been held simultaneously in more than 200 towns and cities since 2005. The European Madrid Researchers' Night is a project funded by the European Union Framework Program for Research and Innovation, Horizon 2020 (2014-2020), as part of the European Commission Marie Sklodowska-Curie Actions.

ICMAT

David Ríos presented the built-in Aisoy1 robot sensors.

AGENDA

ICMAT
INSTITUTO DE CIENCIAS MATEMÁTICAS

Quarterly Newsletter
Instituto de Ciencias Matemáticas
#11 IV Quarter 2015

Edition:
C/ Nicolás Carrera nº 13-15
Campus de Cantoblanco, UAM
29049 Madrid ESPAÑA

Editorial Committee:
Manuel de León
Ágata Timón
Kurusch Ebrahimi Fard

Coordination:
Ignacio F. Bayo
Ágata Timón

Production:
Divulga S.L
C/ Diana 16-1º C
28022 Madrid

Design:
Fábrica de Chocolate

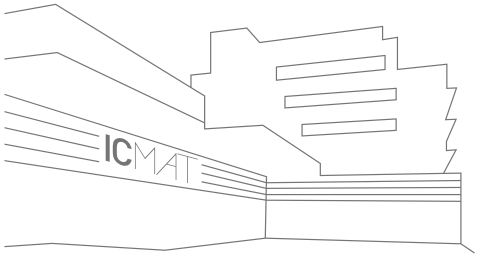
Layout:
Equipo globalCOMUNICA

Translation:
Jeff Palmer

Editorial department:
Lucía Durbán
Ágata Timón
Patricia Delgado

ICMAT

INSTITUTO DE CIENCIAS MATEMÁTICAS



C/ Nicolás Cabrera, nº 13-15
Campus Cantoblanco UAM
28049 Madrid, Spain
www.icmat.es