Emili Elizalde. Perspectives on his Life and Work

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Abstract The goal of this paper is to present a broad picture of Emili[1] Elizalde's unfolding as a person and as a researcher in physics and in mathematics. In addition to biographical information, we include his answers to a number of questions on his experience as a researcher and his role as a leading figure in his fields of expertise.

1 Prelude

The "Facultat de Matemàtiques i Estadística" (FME) of the "Universitat Politècnica de Catalunya" (UPC) dedicated the academic year 2003-2004 to Henri Poincaré. This started a practice that was followed by Albert Einstein (2004-2005), Carl F. Gauss (2005-2006), Leonhard Euler (2006-2007), Bernhard Riemann (2007-2008) and Emmy Noether (2008-2009). At the end of each of these years, the FME published a volume with the lectures delivered by the invited speakers (see [10] for more details).[2] All these names were on top of the mathematics and the physics of their times and thus it should not be a surprise, especially by those that know him, that Emili Elizalde was one of the very few that were invited twice. The first time was for the Einstein year and the second time for the Riemann year. The titles of the lectures he delivered were, respectively, *On the cosmological constant, the vacuum energy, and divergent series* and *Riemann and Physics* (see [1, 2]).

The close relation of these lectures with the topics of this symposium are obvious in the case of the first lecture. In the case of the second lecture, they become manifest

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[1] The real scientific name is Emilio, but I shall use Emili instead, the Catalan version, as this is the way old friends have been calling Elizalde since he was a freshman at the University of Barcelona. His nickname in those years was 'Eli'.

[2] The year 2009-2010 was devoted to John von Neumann and the year 2010-2011 will be dedicated to Paul Erdős, but there are no plans to publish the corresponding volumes of proceedings.

if we bear in mind that Riemann's approach to geometry was a key ingredient in the development of General Relativity and that the Riemann Hypothesis (on the zeros of Riemann's ζ function) is one of the deepest unsolved problems in mathematics. The aim ot this lecture was to show that "the importance of the influence in Physics of Riemann's purely mathematical works exceeds by far that of his papers that were directly devoted to physical issues", and this was accomplished by stressing:

a) The influence of Riemann's work on the zeta function to the regularization of QFT's in curved space-time (in particular, quantum vacuum fluctuations).
b) The uses of the Riemann tensor in general relativity and in very recent generalizations of this celebrated theory, which aim at understanding the presently observed acceleration of the universe expansion (the dark energy issue).

Q1. To which of the other four years (Poincaré, Gauss, Euler and Noether) would you have liked to be invited and which would have been, for each of your choices, the subject of your proposed lecture?

A1. I definitely would have liked to be invited to *Euler's* year too. Part of my research on zeta functions owes so much to Euler. I would have used the opportunity, in preparing my talk, to learn a lot more about Euler's contribution to the subject. To wit, the starting point of several of my explicit derivations of new zeta functions—that are actually useful for the analytic continuation of some divergent series in Quantum Field Theory—is to be found in Riemann's work and I am afraid I can have missed some of Euler's original insight, purely based on real calculus. The title of my talk could have been: *The zeta function: from Euler to Riemann, Selberg, and beyond*.

A mathematician all physicists most admire is Emmy Noether. Her work has had, and still has, a tremendous influence in the interface mathematics/theoretical physics. The difficulties she encountered as a female mathematician also move me a lot. I have been involved in some translations concerning her life and work, from German to Spanish and Catalan and I would have been ready to talk on this historical perspective and on some specific work I did in Group and Quantum Field Theory in my early years as a scientist that uses her celebrated theorem. A possible title could have been: *Emmy Noether and her perennial influence to modern Physics*. It goes without saying that my research has been much influenced by Poincaré and Gauss too and I could have delivered some related talks, but I understand I should not abuse. I really enjoyed to take part in the corresponding sessions as a simple participant.

The idea of writing about Elizalde's life and work took shape toward the end of the Riemann year and it was triggered by the wake of a rather special event. On April 25, 2008, Sir Michael Atiyah was awarded an honorary degree by the UPC. For that occasion, in addition to the usual *laudatio* [11], a poster exhibit on Atiyah's life and work was produced [12].[3] The reception of that work by the visitors convinced me that it might be useful to have other distinguished biographical studies of living mathematicians and physicists and in that mood the name of Emili Elizalde, with his rather high scientific impact, was a natural candidate. Since then, I have kept the project in mind. An occasion in point was the celebration of the symposium *Cosmology, the Quantum Vacuum, and Zeta Functions* to celebrate Elizalde's 60th Birthday. I prepared a set of slides [14], but I could not present them due to the snow

[3] Later this was expanded into a long paper [13].

storm (8 March 2010) that forced the authorities to close the Universitat Autònoma de Barcelona (UAB) on the afternoon of the very first day of the workshop. This text is essentially an elaboration of those slides.

2 A biographical sketch

Emili Elizalde was born on March 8, 1950. That was the year in which the comet cloud hypothesis was formulated (Jan H. Oort).[4] It was also the year in which Alan Turing introduced the concept of what would thenceforth be called the Turing machine. The family name is also intriguing, but quite common in the Basque region (specially in Navarra): Elizalde is a Basque town, in Gipuzkoa, and it is formed out of *eleiz* 'church' and the suffix *alde* 'by' or 'near'.

Balaguer, the town where Elizalde was born, and where he lived until he was seventeen, is located about 25 km northeast of Lleida, the province capital.[5] Today it has a population approaching seventeen thousand, but in 1950 it had only a little over six thousand. The river Segre, a tributary of the Ebre river, is one of its most cherished features. Gaspar de Portolà i Rovira (1716-1784), explorer and founder of San Diego and Monterrey, epitomizes the industrious nature that is attributed to the people born in La Noguera.

The following table summarizes the main discoveries in the period 1951-1959 that have a significant relation to Elizalde's future work:

1951	21cm H radiation, predicted by Van der Hulst.
	Structure of our galaxy.
1955	Galaxy explosions. Birth of new stars.
1956	Antineutrinos.
1957	Sputnik. Jodrell Bank.
1958	Mössbauer effect.
1959	Pound–Rebka experiment

From primary school, age six to ten, the event that he remembers most vividly is the launching of the Sputnik, in the fall of 1957. As he recalls now:

> By age 10 I had long decided (had not the least doubt about it) that I would become an astronaut. It was such a clear and strong feeling! Nothing on Earth could be compared to the pleasure of flying through the skies towards other worlds. The Sputnik trips propelled me towards the whole Universe. *I myself was up there, flying on the Sputnik!* This is maybe the strongest, the more lively remembrance I keep of my whole childhood. Eventually I would make a job of my most precious dream.

[4] Oort's contribution is actually an independent discovery of an idea postulated in 1932 by the Estonian astronomer Ernst Öpik, so it would be better named as the Öpik–Oort hypothesis.

[5] Balaguer itself is the capital of La Noguera county ('comarca' in Catalan).

This impression was much reinforced at the end of next decade, when he was a sophomore, by the landing on the Moon.

From age ten to age seventeen, Elizalde attended secondary school at the *Instituto Laboral de Balaguer*. His quiet ways caused that at first he went largely unnoticed by peers and teachers. But this changed suddenly at the end of his second year, as he surprised everybody when he got the highest grade, in 1962, in a school problem contest on mathematics.

Asked on his recollections on how he felt in that period at the *Instituto*, he says:

> Those seven years were very important in my life. This does not mean at all that they were happy years. My family had to go through rather hard times and I actually suffered from that. I had no money to buy say an ice cream, or to go to the cinema on Sundays, as most of my schoolmates actually did. Nevertheless, I was quite happy at the school. I liked learning things, mathematics in particular. But when I was not reading my books, on weekends, I did not know how to spend my free time. It did not help that I was not a very friendly person and so I remember many boring Sundays there.

Fig. 1 Emili Elizalde at age 12

Here are a few important discoveries produced during the secondary school years of Elizalde:

1961	Quark eight-fold way.
1963	Quasars. Arecibo radio-telescope. X-rays sources.
	Atiyah-Singer index theorem
1964	Cosmic micro-wave radiation.
1967	Pulsars.

It would be wrong to conclude, as it is plain from the answer to next question, that Elizalde's ties to Balaguer and to his peers were weak or inconsequential. The answer also hints at an interesting literary bent of Elizalde's character.

Q2. What kind of ties have you maintained with Balaguer all along? What impact have they had on your career?

A2. My ties to Balaguer have been mainly related with the *Instituto*, which now is called *Institut de Batxillerat Ciutat de Balaguer*. I have given several talks there and also at the Town Hall Auditorium. Recently we celebrated the 50th Anniversary of the *Institut*. I wrote some poems and a short story for the occasion, which you may find on my webpage. Some of my former classmates are now ruling the Town, some are Member of Parliament, in Barcelona and Madrid. Others are medical doctors or teachers in Balaguer itself. Some are really skillful in agricultural research —they are also based there and yet they lead some important company well known at European level. I am proud that our generation —that grew up in the scorned Franco time— gave rise to such brazen good professionals in so very different domains. Public education was extremely good then, I must say, and, in a way, I do owe my whole scientific career (the possibility to pursue it later) to these years at the *Instituto*.

In contrast, I do not think any of the ties I have kept with my hometown has had any direct, significant impact in my professional life or career later. Maybe only at the psychological level: more than once I have found myself recalling Balaguer's river and its porched streets when I have felt depressed. Also, its famous Saint Christ Sanctuary, which I have always considered to be one of the most peaceful places one can be in anywhere, only matched (but not surpassed) by some selected Tibetan or Japanese shrines. Anyhow, I am extremely proud to be a *Balaguerí*.

The undergraduate years at the university were also very intense. In 1967 he began the five-year degree in Physics offered by the University of Barcelona. This institution had also a five-year degree in Mathematics and Elizalde enrolled in it in 1969. He finished these degrees in 1972 and 1973, respectively. He was a systematic and thorough student, in all subjects. His retrospective view is that his education in physics and mathematics was very good. This is a quite remarkable assessment, as those years were, from a political and social point of view, rather difficult, and more so at the university, where the student unrest and the clashes with the police were the rule rather than the exception. In all, he was especially strong in analysis and differential geometry. With regard to physics, he ended with a good knowledge of classical mechanics, thermodynamics, statistical physics and quantum mechanics.

1968	Electroweak theory. Solar neutrinos defect.
1969	Landing on the Moon.
1970	Black-body radiation.
1971	Black-body X-1 in the Swan constellation.
1972	QCD
1973	Universe, a quantum fluctuation of the vacuum?

At the end of his undergraduate studies of mathematics (1973), Elizalde widened his education in physics with a master thesis on the solar neutrino problem[6] that earned him the extraordinary distinction of his class. His advisor was Pere Pascual (1934-2006), who at that time was Full Professor of Quantum Mechanics at the Department of Theoretical Physics of the Universitat de Barcelona.

[6] That problem had been discovered in the late 1960s by John N. Bahcall (1934-2005) and Raymond Davis (1914-2006) and its satisfactory solution three decades later was the result of a sustained effort by many theoretical and experimental physicists. At the start, in the late 1960's, the experimental design of Davis to measure the flux of solar neutrinos reaching the Earth found a value that was only one third of the theoretical quantity calculated by Bahcall. These observations were confirmed later by several other experimental designs. The solution came from experimental work in the 1990s that was sensitive enough to find not only electron neutrinos, as in Davis approach, but also muon and tau neutrinos. The 2002 Nobel Prize in Physics recognized these researches by awarding Raymon Davis and Masatoshi Koshiba (Kamiokande experiments) a share of the Prize.

Immediately after his master thesis, Elizalde began his doctoral program in physics, advised by Joaquim Gomis and Pere Pascual.[7] Another decisive event in his life also happened around this time: Emili met Maria Carmen Torrent (Carme), his future wife, at the Faculty of Physics of the University of Barcelona, where she was working for her master thesis.

1976	Idea of cosmic strings.
1977	Inflationary universe.
	Atiyah begins his work on gauge theories

Elizalde defended his thesis in 1976, with the title *Galilean equations and gyromagnetic ratio in the light-cone system*. It was qualified *summa cum laude* and later obtained the doctoral extraordinary distinction of his year. As a result of his research for the master and doctoral thesis, Elizalde published his first five papers in the years 1976 and 1977. These were the initial steps of a scientist that soon would appear to be a prolific mathematical physicist.

The year 1977 was very special for Emili Elizalde from another side: he married Carme on the 23rd of April.[8] Carme has pursued her own career in Physics and at present she is a Professor of Applied Physics at the Technical University of Catalonia (UPC). Her research is focused on semiconductor lasers.

Carme and Emili have two sons: Sergi (1979) and Aleix (1982) —see Fig. 5 at the end. Sergi is a well-known mathematician. He won the Spanish Mathematical Olympiad and also medals at mathematical international competions. He got PhD degrees from UPC and MIT, with Marc Noy and Richard Stanley as respective advisors. After a postdoctoral stay at MSRI, Berkeley, with Bernd Sturmfels, he is a Professor at Dartmouth College with Peter Winkler. He married Helen, a lawyer, in 2008, and now they have a son, Guillem, born in 2009.

Aleix displayed early impressive dexterities, like mono-cycle riding. He studied internal medicine and at present he is about to finish his internship specialty at the Valle de Hebron Hospital in Barcelona. Recently he was in the news of the Spanish Medical Gazzette for having displayed one of the best performances in the MIR examinations. His girlfriend, Laia, is a pediatrist working in a different Hospital.

Sergi, Aleix and Laia are also professional pianists, with a degree from the famous Liceo Conservatory in Barcelona. As for many educated people of his generation, this touches a deep chord in Elizalde's feelings:

> They have made true my old dream of becoming a musician, which I could never fulfill, first for lack of money and later for lack of time.

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[7] Officially, Elizalde was the first PhD student of Joaquim Gomis. Even if he also discussed his progress with Pere Pascual, at that time it was not permitted to have co-advisors and as a result the academic records do not reflect the role of the latter.

[8] The choice of the date, St. George's Day, is particularly significant in Catalonia. If it does not fall on a Sunday, it is a working day, but a rather special one. Everybody goes to work, but the general mood is that of a joyful and cherished festivity. Very early in the morning the streets everywhere are invaded by swarms of improvised sellers of roses, by bookstore stands taken out of the shop, and by the crowds that are eager to follow the ritual of buying roses and books for the loved ones.

And then, displaying a concerned fatherly look, whispers:

> It is doubtful that Sergi is coming back to Spain any soon. And Aleix and Laia have a very hard life right now, with a lot of work on night shifts at their respective hospitals. We are very proud of them since they do an important service to society, but this prevents them from having a family life at all.

For Carme and Emili, however, not all were roses, especially during the first few years after getting married. Franco's dictatorship was over, but the uncertainty about the future was overwhelming. The life in the universities was rather chaotic and seemingly with few perspectives. As a consequence, many gifted young graduates with no financial backup tried to secure a means of living outside the academic circles. In the case of Elizalde, the detour was to take the 1974 competitive examinations required to earn a post as an upper level high school mathematics teacher ('catedrático'). This is the way he came to hold offices in the high schools of Tàrrega (1975-7), a town not far from Balaguer, and Bellvitge (1977-8), in the Barcelona area.

Fig. 2 Carme and Emili at Villa Hammerschmidt (Germany), on the occasion of the 1980 Humbolt fellows reception by the President of the Federal Republic of Germany.

The escape path, for a vocational researcher as Elizalde, was provided by a prestigious scholarship of the Juan March Foundation and later by an even more illustrious Alexander von Humboldt fellowship. These grants allowed him to take a leave of absence from the high school (at that time this was still possible) and spend the academic year 1978-9 and part of next (in fact 16 months in a row) doing postdoctoral work with Rudolf Haag in the II. Institut für Theoretische Physik of the Hamburg University. The fellowship was for two years, but it was flexible and generous enough to allow the splitting (and extension) of the second year in four three-months Summer visits. These visits took place in 1981, 1985, 1987 and 1989, the latter in the Freie Universität Berlin.

> **Q3.** What would you underline of your stay in Hamburg and the research facilities there?
>
> **A3.** The Institut is in the middle of the Deutsches Elektronen Synchrotron installment (DESY), an impressive research center only second to CERN in Europe and one of the world's leading centers for the investigation of the structure of matter. The theoretical group consisted at the time of several of the most prominent QFT physicists alive, as Harry Lehmann, Kurt Symanzik, Rudolf Haag, Hans Joos, T.T. Wu, who was visiting, and several others, and a handful of younger people who did impressive careers later. The Nobel laureate Sam Ting, Wu's wife, Gustav Kramer, etc. and an extraordinary number of particle physicists, engineers and technicians (over two thousand, I think) worked for DESY.

Q4. How was your first encounter with Professor Haag?

A4. I remember very well my first encounter with him. He had told me on the telephone, repeatedly, how to arrive to his office but I got lost in that impressive place, I entered from one side, the Notkestrasse, and after forty minutes of near random walking I found myself at the other exit, on the Luruper Chaussee, almost opposite to the first. I was too shy in order to keep asking on each turn, but finally I had no other choice and so I was able to reach room 501, on the 5th floor of Building 2a. On the door it was written plainly "Rudolf Haag". In spite of arriving one hour late, Prof. Haag was utmost kind and helpful to me. During the months that followed I could discover that most of the geniuses there were extremely normal people and, what impressed me even more, that many of them had such a good sense of humor (what contradicted all I had previously heard about northern Germany). This included also the prominent visitors (several of them Nobel laureates, as C.N. Yang and later S. Weinberg) who passed by for short visits, to deliver talks on the very famous Friday seminar. The coffee served there was excellent too.

1983	W^+, W^-, Z_0.
1987	Supernova in the Magellanic cloud.
1990	The Hubble telescope. Internet
1991	WWW
1992	COBE findings on CMB

That time in Germany, and the position he subsequently took as an assistant professor ('adjunto interino') at the Department of Theoretical Physics of the University of Barcelona, meant a full recovery of Elizalde for research. This recovery was consolidated in 1984, the year that his position was made permanent as an associate professor ('profesor titular'). This happened after being classified as number one, *ex aequo* with Joaquim Gomis, in the extraordinary state-wide massive habilitation process called on the preceding year. This also meant the end of the four-year struggle sustained by the 'interinos' in favor of 'work contracts' and against the old promotion system through competitive examinations ('oposiciones').

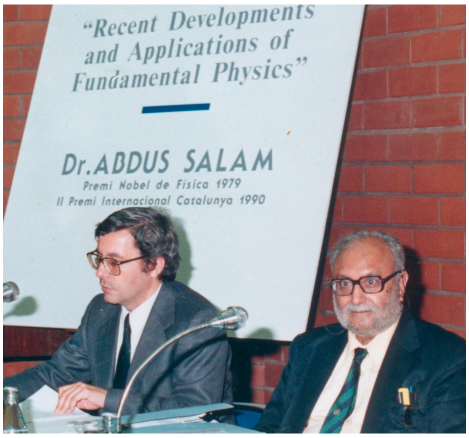

Fig. 3 Emilio Elizalde introducing Abdus Salam on the occasion of having been awarded the "II Premi Internacional Catalunya".

If we needed an image to visualize Elizalde's academic welfare in the 1980's, there is one that is especially eloquent. In 1979, Abdus Salam shared the Nobel Prize in Physics with Sheldon L. Glashow and Steven Weinberg "for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including, *inter alia*, the prediction of the weak neutral current" (Nobel Prize citation). Over a decade later, Salam was distinguished with the "II Premi Internacional Catalunya 1990" and the striking picture is that Elizalde, aged 40, was the person appointed to introduce the distinguished scientist.

The next promotion occurred in 1992, when he won, again as number one, a research position at the Spanish Higher Research Council (CSIC, “Consejo Superior de Investigaciones Científicas”). The level of this position was between associate professor and full professor and for several years he was allowed to combine the new job, attached to the “Centre d’Estudis Avançats de Blanes” (CEAB), with collaborative research and teaching at the University of Barcelona. His celebrated book *Ten Physical Applications of Spectral Zeta Functions* (LNP, Springer-Verlag, 1995) was written during the first two years of his association with the CEAB.

The mission of CEAB, created in 1985 as a CSIC unit, was to foster interdisciplinary research groups. It was an ambitious initiative, together with many others,[9] that was mainly driven by the desire to make up for the gloomy years that were lost before the advent of democracy. The “Nuclear Astrophysics Group” was formed in that atmosphere, as early as 1988. This group grew steadily in the next ten years into the larger group of “Cosmos Sciences”. In the year 1996, it moved to Barcelona as the starting unit of the newly founded “Institut d’Estudis Espacials de Catalunya” (IEEC), a research structure created by the the Catalan Government (“Generalitat de Catalunya”). Emili Elizalde played a prominent role in that move, and he is proud of “having been one of the scientists involved in the creation of IEEC”.

Q5. In retrospect, how do you remember and assess the CEAB initiative?

A5. It was very advanced for Spain at that epoch. The CEAB was an attempt to make the dreams of interdisciplinarity come true by putting together, in one of the most beautiful spots of the Costa Brava, a collection of specialists in artificial intelligence, cosmologists, biologists, and sea experts who put up the first Spanish base on the Antarctica. Artists were absent, however, and, even more regretfully, the success of the attempt was rather limited. Still, after the splitting of two big groups to create separate Institutes in Barcelona, the CEAB has become a reference Center in the domain of marine ecology and environmental sciences.

In the structure of the IEEC, the CSIC participated as one of the partners. In order to provide administrative support to this relation, in 1999 the CSIC created the Institute of Space Sciences (ICE, “Instituto de Ciencias del Espacio”). Elizalde, who played again a key role in setting up this arrangement, was attached to ICE from the very beginning. It is thus that he has been able to combine his adscription to CSIC with his leading research role in the IEEC in the areas of “Theoretical Cosmology” and “Fundamental Physics”.

The ICE-IEEC is the roof under which Elizalde has been working in the last decade. In the year 2003, he was promoted to Senior Research Professor, the highest possible level at the CSIC (again as number one, in the yearly national appointments in his subject).

[9] For example, the creation of CEAB coincided in time with the celebrated meeting “Culture and Science: Determinism and Freedom”. Inspired by Salvador Dalí, already seriously ill, and organized by the Faculty of Physics of the University of Barcelona, it gathered in Figueres the Nobel laureate Ilya Prigogine, the Fields medalist René Thom and other distinguished scientists of very different fields (see [8]).

At present the ICE is housed at the Autonomous University of Barcelona, where it moved about ten years ago, but at the start it was housed at the Nexus-1 building of UPC.

1993	GPS becomes operative
1994	Black hole of 3 billion solar masses in M-87
	Top quark
1998	Acceleration of the Universe expansion
	Neutrino mass
2002	Hubble estimate age of Universe (13-14 Giga years)
2003	WMAP: 4% matter, 23% dark matter, 73% dark energy
2004	First binary system of pulsars

3 Scientific achievements

Table 1 provides a rough quantitative summary of the Elizalde's scientific production to this day. Without counting the items of types T (Technical notes and other articles) and B (Books), it gives an average of about ten papers per year, a fact that lends a strong support to our earlier appraisal that he qualifies as a prolific mathematical physicist.

Types	Description	Total
J	Papers in international journals (SCI)	235
P	Proceedings and Other journals	86
C	Book chapters	14
B	Books and Monographies	12
T	Technical notes and other articles	22
R	Reviews (ZBl and MR)	200
A	Articles in newspapers and magazines	60
O	Other original contributions	32

Table 1 Quantitative overview of Elizalde's publications. Of the 14 titles of type B, 5 are in English and 7 in Spanish. Type O includes 12 original contributions to encyclopedia and dictionary entries and translations of books and articles (20 in all) from English/German into Spanish/Catalan.

These findings are even more eloquent when we consider the following evidence for its scientific impact. The overall number of accumulated citations is above 6,000, and of these more than 4,500 appear in SCI. The book [3], of which Elizalde is the single author, has accumulated more than 250 citations and the book [7], in collaboration with four coauthors, more than 460. As far as the citations of papers, there are more than twenty with 50 or more citations. Table 2 shows the number of citations for the 10 best-cited papers.

#	Year	#Co	Area
350	2004	2	Cosmology
200	2005	3	Quantum vacuum
180	1996	2	Zeta functions
170	2005	4	$f(R)$-gravity
150	2006	4	Modified gravity
130	2008	5	$f(R)$-gravity
120	1997	3	Quantum vacuum
110	2006	4	Modified gravity
100	2003	3	Quantum vacuum
100	1998	2	Quantum vacuum

Table 2 Elizalde's ten best-cited papers. The first column contains a lower bound of the number of citations, in decreasing order. The second column indicates the publication year and the third the number of co-authors (besides Elizalde) of the corresponding paper. The fourth column gives a rough indication of the main area of the paper. The most cited paper so far is *Late-time cosmology in (phantom) scalar-tensor theory: dark energy and the cosmic speed-up* (with S. Nojiri and S. D. Odintsov), Physical Review **D70**, 043539 [1-20] (2004).

Areas	#J	#P
Cosmology	19	22
Gravity	89	25
Mathematics	57	24
QFT	165	72

Table 3 The second and third column refer to the number of papers published in indexed journals and in proceedings, respectively. About one third of the papers appear in more than one area.

Another general perspective is given by the Table 3, where we can see the distribution of the contributions according to four wide areas: Cosmology, Gravity, Mathematics and QFT. We observe that QFT is the dominant area, as its weight is roughly equal to the weight of the other three areas.

If we now look more closely to each of the four areas, by subdividing them into subareas, we get the tables 4, 5, 6 and 7.

Cosmology		
Subarea	**#J**	**#P**
Cosmological constant	11	13
Large scale	8	9

Table 4 Distribution of the Cosmology papers into two subareas.

Gravity		
Subarea	**#J**	**#P**
Quantum gravity (semiclassical)	34	15
Modified gravity	19	2
General relativity	17	6
String theories	17	1

Table 5 Distribution of the Gravity papers into four subareas. Here we may also include a J-paper in the subarea of Classical gravity and two papers is the Braneworlds subarea.

Mathematics		
Subarea	**#J**	**#P**
General	2	0
Lie theory	8	5
Neural networks	4	1
Statistics (information theory)	11	3
Chowla-Selberg formula	1	2
Heat kernel	3	1

Table 6 Distribution of the Mathematics papers into six subareas.

Table 7 Distribution of the QFT papers into ten subareas.

Quantum Field Theory		
Subarea	**#J**	**#P**
Multiplicative anomaly	22	6
Casimir effect	20	19
Curved space-time	35	11
Equations (Dirac, KG, Proca, ...)	13	4
QCD	27	5
QED, neutrinos, magnetic fields	7	2
Regularization and renormalization	26	10
Vacuum energy	3	5
Yang-Mills	3	5
Quantum mechanics	6	3

As we said earlier, the dominant area in Elizalde's research has been QFT, which is the reason why we have subdivided it into more subareas (ten) than the others (see Table 7).

One of the characteristic features of Elizalde's work is that it often is carried out in collaboration with colleagues. Table 8 is like and X-ray image of this fact.

To round the picture of Elizalde's collaborations, see Table 9.

Collaboration statistics							
	0	**1**	**2**	**3**	**4**	**5**	
J	51	80	62	31	9	2	**235**
P	40	22	12	7	5	0	**86**
T	8	7	2	3	1	1	**22**
B	7	1	2	0	2	0	**12**
C	12	1	1	0	0	0	**14**
	118	**111**	**79**	**41**	**17**	**3**	**369**

Table 8 Columns headed by a number k in 0..5 indicate the number of papers with k co-authors. Thus $k = 0$ indicates the number of works published with no co-authors (118 in total). At the other end, there are 3 papers published with 5 co-authors: 2 in indexed journals and 1 as a technical report.

Table 9 This table shows that Elizalde's main collaborator is Sergei Odintsov. The number of papers they have published jointly is about the same as the number of those written with the next four collaborators together (August Romeo, Sergio Zerbini, Sin'ichi Nojiri and Guido Cognola). The collaborations with Bytsenko, Kirsten, Gaztañaga and Naftulin have similar magnitudes, and Haro, Leseduarte, Shil'nov, Gomis, Hildebrandt and Soto follow a little behind.

Collaborators		
Name/s	**J**	**P**
Sergei Odintsov	82	21
August Romeo	29	6
Sergio Zerbini	22	4
Sin'ichi Nojiri	17	1
Guido Cognola	15	5
Andrei Bytsenko, Klaus Kirsten	10	1, 5
Enrique Gaztañaga	9	4
Sergei Naftulin	8	4
Jaume Haro	7	0
Leseduarte, Yuri Shil'nov	6	1, 6
Gomis, Hildebrandt, Soto	5	0, 2, 1

To finish this overview, we include a list of the PhD thesis supervised by Elizalde:[10]

1985, Joan Soto
Effective Action of QCD and the Confinement Problem.
1989, Enrique Gaztañaga
Statistical Models for the Description of the Large Scale Structure of the Universe.
1990, August Romeo
New Aspects of Zeta Function Regularization Procedures with Incidence on QFT Vacuum Effects.
1994, Sergio Gómez
Models of Learning in Artificial Neural Networks and Applications.
1996, S. Leseduarte
Applications of the Zeta Regularization Procedure in Quantum Field Theory.
1998, Pablo Fosalba-Vela
Cosmological Perturbation Theory and the Spherical Collapse Model (co-advisor).
2001, Sergi R. Hildebrandt
Kerr-Schild and Generalized Metric Groups, with some Applications to Regularized Black Holes (co-advisor).
2002, José Barriga
Mathematical Analysis of Microwave Density Fluctuations (co-advisor).
2008, Miguel Tierz
Random Matrix Models in Chern-Simons Theory.

Q6. You belong to the 'publish-or-perish' scientific generation, whose influence was particularly striking in Spain. How did you experience that move?

A6. The pressure to publish (or perish!) was particularly strong at our University, in my generation. I remember how everything started. When I was an undergraduate, most of the Professors (*Catedráticos* in Spanish) in the Departments of Physics and Mathematics of Barcelona University had not published even a single paper in their lives. One of them, a mathematician, having published two papers, was more respected there, at that time, than Nobel Prize winners are at Harvard or MIT (I know of that through unforgettable talks with John Bardeen, who had won two of them, and thus I can compare). It is easy to imagine that the following step taken by the Spanish authorities, in order to close this gap, was to make us publish at any price. And this we did like mad (impact was not a concept then).

Q7. You were born the same year as the Turing machine and it seems that it has not been until the last years that you have become also an explorer of the worlds that were discovered after that breakthrough. How did this evolution occur?

A7. I already heard something about Alan Turing and the Turing machine when I was a University student in Barcelona, in the late sixties and early seventies. However, complexity theory and computer skills were not among my strongholds, and my real discovery of Turing occurred much more recently, about ten years ago, when I began to connect all these many different pieces of knowledge I had accumulated in my head for years and years. But the publish-or-perish pressure is the reason why during a large period of my scientific life I had no time to pause, recollect, relate, and try to explain in a unified way

[10] In addition, there are four PhD thesis in progress: Diego Sáez Gómez: *Fluid models for the dark energy*; Antonio Jesús López Revelles: *Viable models for alternative gravities*; Gloria García Cuadrado: *Gravitational wave detection with orbiting satellites*; and Roger Oliva: *Observational effects of rotating black holes with XMM-Newton*. In the case of Sáez and López, Elizalde acts as co-advisor.

> all these pieces of knowledge I was gathering. When I finally did, some time ago, I was able for the first time to put Turing's work in the very prominent place it has in the History of Mathematics. In particular, in its key role to bypass (in a practical, down-to-earth way) the terrible impact of Gödel's incompleteness theorem, which removed in a blow the very foundations of the construction by Hilbert of the entire building of Mathematics. And this can be also connected (I do that now) with the great revolutions in last century Physics, and so forth. I have never stopped to recommend Penrose's *The Emperor's New Mind* to my students as one of the best books they could ever read, together with the *The First Three Minutes* by Weinberg. Anyway, other than that, the Turing machine has not had such a direct influence on my research, I must say.

Emili Elizalde's has been a leading researcher of about eighty projects, endowed with an average of close to 300 K$ per year. These resources have included over 65 research grants or post-doc positions and have allowed his group to hire six Full Professors and one ICREA researcher.

Fig. 4 Lecture on the occasion of the Honorary Professorship Award by the TSPU (Russia, 2010).

He serves on the Editorial Board of five international journals, does referee work for forty journals and has been evaluator of scientific projects for a dozen national agencies of different European and American countries. He is a Fellow of the Institute of Physics (UK) and member of several societies, including the AMS and APS. Elizalde has participated in countless international meetings (conferences, schools and workshops), serving for over twenty occasions on the organizing committee and being himself the organizer of six conferences. The participation has been as a plenary speaker for over sixty times and as a chairman for over fifty.

Emili Elizalde has received many distinguished awards in recognition to his contributions to science. During the present year (2010), for example, he has been awarded an Honorary Professorship and the Gold Medal of the Tomsk State Pedagogical University (Russia). He has also been appointed Secretary General of the Alexander von Humboldt Association of Spain and, moreover, he has been invited, 'as internationally recognized figure in the area', to the key Conferences of the Spanish Presidency of the EU Council: ERA Board, Science Against Powerty, and Biotech for a Complex World.

4 Sources

Emili Elizalde maintains an audacious Web page [4] in which the visitors can access a wealth of materials about many aspects of his professional and personal life. From the point of view of finding out about Elizalde's scientific trajectory, one of the most valuable pieces is the book [5], whose goal, as stated at the beginning, is to be

> [...] a compendium of the more outstanding contributions of Prof. Emilio Elizalde and several of his collaborators as they have appeared in international journals during the last thirty years. A good number of original results can be here found on zeta function regularization, the extension of the Chowla-Selberg series formula, heat-kernel coefficients, fluctuations of the quantum vacuum and the Casimir effect in different configurations, as the bag model, its thermal properties, quantum gravity and black hole physics, large scale structure of the universe, and alternative cosmological models that deal with the dark energy issue from a rigorous theoretical perspective, which seeks its roots in fundamental theories and physical phenomena.

In addition to a large collection of pictures, and a short preface by Professors V.V. Obukhov and S.D. Odintsov, it contains the much informative three-page introduction "Some personal remembrances of my scientific life". This piece, together with the complete list of publications included at the end, should deserve, considering its polyhedral nature, extensive analysis from different viewpoints.

Table 10 summarizes the six parts in which the papers in [5] are grouped and the years in which they were published.[11]

> **Q8.** It seems to me that your book [5] is also a recognition of your former students and other collaborators.

> **A8.** Indeed, I am extremely proud of the fact that a good number of my former students are now quite well known scientists, university professors, and qualified professionals in different countries worldwide. A success accomplished, moreover, in a wide spectrum of different fields: from heavy quark physics to informatics engineering, from observational cosmology to sport physics, from financial mathematics to large-scale structure, from data compression to Casimir effect applications.
> As for my other collaborators, I am also proud not only for the work done jointly, but also for their excellent independent accomplishments.

Quantum Field Theory	1984, 2002, 2003, 2004 (4)
Zeta Functions and Heat Kernels	1989-3, 1996, 1998-2, 1999, 2001 (8)
Vacuum Fluctuations, Casimir Effect	1991, 1994-2, 1997, 1998, 2001, 2006-2 (8)
Gravitation and Black Holes	1994, 2002, 2006, 2008 (4)
Statistics and Large Scale Structure	1992, 1998 (2)
Theoretical Cosmology	2003-2, 2004-2, 2005, 2006, 2007-2 (8)

Table 10 Summary of the Table of Contents of [5]. 1989-3 means that three papers are included that were published in 1989. The numbers in parenthesis are the total number of papers in each section (34 in all). This amounts to 18 papers belonging to the last decade and 15 to the preceding one.

[11] Four articles are revised versions of the published papers. The ten best-cited papers so far (cf. Table 2) were published, ordered by decreasing number of citations, on the years 2004, 2005, 1996, 2005, 2006, 2008, 1997, 2006, 2003 and 1998, respectively. We note that this amounts to seven in the last seven years and three in the preceding seven-year period.

In the case of Zeta functions, we already mentioned the monograph [3], which is "a commented guide that invites the reader to plunge into the thrilling world of zeta functions and their applications in physics". This quote is from the Preface, in which we are also told that "the level is elementary", that "everything is explained in full detail, in particular the mathematical difficulties and tricky points", and that it is "to be considered as a basic introduction and exercise collection for other books that have appeared recently" (say like [7], published in 1994). Several original 'zeta-function regularization techniques' are presented, including 'The zeta-function regularization theorem' (Section 2.2). "Physical applications [...] include the proper definition of the vacuum energy, the Casimir effect, spontaneous compactification in quantum gravity, stability analysis of strings and membranes, etc., and embrace also very recent experiments of solid state and condensed matter physics employing liquid helium (those will be described in the following chapters)" (p. 28). One of the highest points in the book is an important generalization (formula 4.32) of the Chowla–Selberg formula [9]. Currently the monograph seems to be out of print and it would be interesting to have a second edition, which by now it should be supplemented, perhaps as a second volume, by many other applications obtained since its publication fifteen years ago. Meanwhile, readers interested in a quick overview of the main issues involved in this domain could start with the excellent survey [6].

Q9. For some the vastness of the Universe is apprehended by degrees, from the small to the very large scale. How did it happen in your case? Under what circumstances did you begin research in Cosmology?

A9. In my school years, I did not realize that my understanding was only the very local universe. The big jump was in 1986, when the first map of the universe was published, including some three thousand galaxies and clusters (De Lapparent, Huchra). This was a breakthrough: the presence of large voids, the clustering of points into large pictures, one of which seemed to be a human being, another, kind of God's finger, was something astonishing and this put some of the best physicists in the world down to work to explain such structures as coming naturally from fundamental theories (which in fact was only partially accomplished). In my case this was the birth day of the celebrated *Barcelona School on Large Scale Structure* whose creation I started this very same day, by putting my student Enrique Gaztañaga to work on the analysis and explanation of the matter distribution in this map. COBE, the CMB map, WMAP, and the PLANCK satellite followed, the thousand points became many millions, and the expansion of our universe turned out to be accelerating (the most important discovery in physics of the last decades). By the way, Enrique is now a leading figure in cosmology at international level and two more of my former students, namely Pablo Fosalba and Sergi R. Hildebrandt, are scientists belonging to the core team of PLANCK.

Acknowledgements. It is very pleasing to thank Emili for his unfailing patience in answering my questions, for his generosity in allowing me to use his archive materials and for having led me to discover many aspects of a scientific milieu that have turned out to be even richer than what I imagined in setting up to write these notes. Thanks also to the coeditors of this volume, Sergei Odintsov and Diego Sáez-Gómez, for many fruitful interactions and discussions, and to Jaume Puigbó and Cristina España for having pointed out several corrections.

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List of acronyms

AMS	American Mathematical Society
APS	American Physical Society
CEAB	Centre d'Estudis Avançats de Blanes
CERN	European Organization for Nuclear Research
COBE	Cosmic Background Explorer
CMB	Cosmic Microwave Background
CSIC	Consejo Superior de Investigaciones Científicas
DESY	Deutsches Elektronen Synchrotron
ERA	European Research Area
EU	European Union
GPS	Global Positioning System
ICE	Instituto de Ciencias del Espacio (CSIC)
ICREA	Institució Catalana de Recerca i Estudis Avançats

IEEC	Institut d'Estudis Espacials de Catalunya
IOP	Institute of Physics
FME	Facultat de Matemàtiques i Estadística (UPC)
MIT	Massachusetts Institute of Technology
MR	Mathematical Reviews
MSRI	Mathematical Sciences Research Institute
QCD	Quantum Chromodynamics
QFT	Quantum Field Theory
SCI	Science Citation Index
TSPU	Tomks State Pedagogical University
UPC	Universitat Politècnica de Catalunya
WMAP	Wilkinson Microwave Anisotropy Probe
ZBl	Zentralblatt für Mathematik

Fig. 5 Emili, Carme, Sergi, Helen, Aleix and Laia celebrating New Year's Eve 2008.