Women in Charge of Mathematics

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In 1937 a collection of biographical essays was published by Eric Temple Bell, a Scottish born mathematician and science fiction writer. It covered the lives of about 40 mathematicians, from ancient times to the beginning of the twentieth century. The book inspired many boys to become mathematicians, but we believe it did not inspire many girls, as the only woman mentioned was Sofia Kovalevskaya, the brilliant Russian mathematician and the first woman to obtain a doctorate in mathematics.

Things did not change a lot after about almost 70 years, as Ioan James, a British mathematician working in topology, published in 2003 a collection of biographies about "Remarkable mathematicians: from Euler to von Neumann," where, in addition to Kovalevskaya, were mentioned Sophie Germain (see Fig. 1), the outstanding French mathematician, and Emmy Noether, known as "the mother of modern algebra".

A strong change took place in 2014, when Maryam Mirzakhani, a mathematician born in Iran, full professor at Stanford University, was awarded the Fields Medal, the most coveted prize in mathematics, for her research [1].

This award is as important for mathematics as the Nobel Prize is for other sciences and Mirzakhani was the first woman to win the Medal in its 80-years history. Born in Tehran on May 12th, 1977, she was the first girl to compete for Iran in the International Mathematical Olympiad and she won gold medals in Hong Kong in 1994 and in Toronto in 1995. This was a remarkable achievement. Mirzakhani specialized in the geometry and dynamics of complex curved surfaces. She died in 2017 from breast cancer at the age of just 40.

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Fig. 1 The stamp issued by the French post in honor of the mathematician Sophie Germain in 2016. https://i.ebayimg.com/images/g/4j4AAOSwbb5eOaCb/s-l1600.jpg

Mirzakhani, when she received the award in Seoul (see Fig. 2), said that she hoped that her work would inspire more women in mathematics and for sure her example has been a strong one.

After that exploit, Karen Uhlenbeck (see Fig. 3), the American mathematician known for her pioneering work in geometry, analysis, and mathematical physics, in 2019 was the first woman in the 16-year history of the Abel Prize, named in commemoration of the outstanding Norwegian mathematician Niels Henrick Abel, to receive it.

Uhlenbeck in 1990 presented a plenary lecture at the International Congress of Mathematicians, the ICM, the largest and most important gathering of mathematicians in the world; she was the second woman to give a plenary lecture, the first being Emmy Noether in 1932. This indicates how difficult it has been for women to reach the pinnacle in a male-dominated field.

At the World Meeting for Women in Mathematics in Rio de Janeiro in 2018, Mirzakhani's birth date, May 12th, was chosen for the celebration of women in mathematics. The aim was to inspire to follow careers in math and to encourage an open and inclusive environment for all. Many events took place in the last 2 years throughout the world as part of the celebrations.

All these events not only support those who participate in them directly but also help influence the mathematics culture more generally, so that young women entering the field today encounter an environment that is more nurturing than that of the past.

Currently, there is an international dialogue around the lack of representation of women at the highest levels: across academia, government and industry. These

Fig. 2 Maryam Mirzakhani, first and only woman Fields Medalist, at the ICM 2014 in Seoul, together with the other Fields Medal winners: Arthur Avila, Manjul Bhargava and Martin Hairer and Ingrid Daubechies, President of IMU (2010–2014). https://kongres-magazine.eu/wp-content/uploads/2014/10/SEOUL-ICM-2014_0813-348.jpg

Fig. 3 Karen Ulhenbeck, American mathematician, first woman Abel Prize Winner in 2019. https://www.europeanwomeninmaths.org/marini-uhlenbeck/

institutions need to continue to review their organizational cultures and adjust their internal promotional practices, otherwise increases to the numbers of women who move through the career pipeline will still fail to affect the representation of women at the top.

This is the reason why all associations of women in math, national and international, have to work in continuing to foster and maintain the pool of female mathematicians: this is a key piece in bringing about these long-term goals.

Moreover, in this era of big data and fast-paced technological changes, both of which require mathematical expertise, we cannot afford to leave so much of the population behind. The deficit of women in STEM (Science, Technology, Engineering, Mathematics) and particularly women in math, is not just a women's issue [2].

We know very well that these fields have remained predominantly male with historically low participation among women since their origins and we also know that scholars and policymakers have been exploring the various reasons for the continued existence of the gender disparity in STEM fields and studies suggest that many factors contribute to the attitude toward the achievement of young people in mathematics and in general in science, including encouragement from parents, interactions with teachers, curriculum content, high school achievement in mathematics and resources available at home.

Research findings are mixed concerning when boys' and girls' attitudes about mathematics diverge. Few differences are found in girls' and boys' attitude toward mathematics in the years of early secondary school. Student's aspirations to pursue careers in mathematics influence both the courses they choose to take in this area and the level of effort they put forth in these courses.

Apparently, girls begin to lose self-confidence in middle school because they believe that men possess more intelligence in technological fields, while boys are more likely to gain skills because they are culturally and socially encouraged to work in scientific areas, but research shows that girls can develop these same skills if they have the same form of training.

At the post-secondary level, women are less likely than men to earn a degree in mathematics.

This of course is a problem, as it has been estimated that doubling women's high skills would largely benefit the economy.

The differences in salary among graduates are related to the differences in occupations entered by women and men; women are less likely than men to be employed in scientific occupations and so there remains a wage gap between men and women in comparable positions [3].

UNESCO, among other agencies, has been outspoken about the underrepresentation of women in mathematics globally, even if it is not possible to use the same indicators to determine the situation in every country. The significant statistic might be the percentage of women teaching at the university level, or the proportion of women at research institutes and academies of sciences, or the percentage of women who publish, or the proportion of women who go abroad for post-graduate

study and conferences, or the percentage of women awarded grants by national and international funding agencies.

This is just to say that indices have different meanings in different countries and the prestige of various positions and honors can vary considerably, but in any case, the main fact is that the underrepresentation of women in careers in mathematics is worldwide.

Luckily changes in society and the ubiquity of computers in everyday life are pushing women toward a deeper understanding of scientific matters at large, inducing a breaking down of gender distinctions in information technology. Both genders have acquired skills, competencies and confidence in using a variety of technological, mobile and application tools for personal, educational and professional use, but the gap still remains when it comes to enrollment of girls in mathematics and computer science classes: as a matter of fact for higher educational programs in information and communications technology, women make up only 3% of graduates globally.

Stereotypes about what someone in these fields should look and act like may cause established members of such areas to overlook individuals who are highly competent. The stereotypical mathematician is usually thought to be male and perceived incongruity between gender and a particular role or occupation can result in negative evaluation.

In addition, negative stereotypes about women's quantitative abilities may lead people to devalue their work or discourage these women from continuing in mathematics.

There have been several controversial statements about innate ability and success in mathematics. A notable example is given by Lawrence Summers, former president of Harvard University, who, in a 2005 speech, suggested that "the underrepresentation of women in science and engineering could be due to a different availability of aptitude at the high-end positions". Summers after this statement had to step down as president [4].

Fortunately, although women entering traditionally male professions face negative stereotypes suggesting that they are not "real" women, these stereotypes do not seem to deter women to the same degree that similar stereotypes may deter men from pursuing nontraditional professions. There are historical evidence that women flock to male-identified occupations once opportunities are available.

On the other hand, examples of occupations changing from predominantly female to predominantly male are very rare in human history.

Women in mathematics in addition are more likely than established men to help career women who display sufficient qualifications.

A very good example is offered by the reaction of the members of the European Women in Mathematics association (EWM) (see Fig. 4) during the Covid-19 pandemic. The virus and the full and partial lockdowns that swept across Europe and the world caused an impact on research and training in academia which was disastrous: conferences were canceled and collaborations stood still.

Time slated for research splintered among the competing demands of homeschooling, eldercare, and quarantines. Networking and mentorship stalled, common

Fig. 4 General Assembly in 2018 at Graz, Austria, of the European Women in Mathematics (EWM). Courtesy of European Women in Mathematics. Permission granted by the Organizer of the 2018 General Assembly, Karin Baur

but often unaddressed mental health issues mushroomed, at a time when getting help was harder than ever.

But the crisis was not experienced equally, untenured faculty lost more. Women lost more and caregivers lost more. The more vulnerable the population, the greater the disadvantage. Therefore a Working Group on the Corona Crisis was formed (https://www.womeninmathematics.org) in order to choose how to respond and to support current employees in temporary positions and future job applicants in mathematics in light of the crisis. The main concern was that we could lose talented women mathematicians during and following the crisis, that women could choose to leave their profession or reduce their hours, that women in temporary positions could choose security and settle for lesser positions, that young women may opt not to pursue careers in science.

As we know, the COVID-19 pandemic has exacerbated existing gender inequities in mathematics and of course in other sciences. And gender-blind measures do not correct gender inequity. It appeared to the members of the Working Group that to

those who say we should relax and trust the system, it should be answered that the system has not produced a gender-balance representation to date and it would be naïve to expect an automatic correction in the face of enormous burdens.

Therefore the women involved in this project advocated proactive measures in order to encourage universities, government and funding agencies to invest in extending the contracts of researchers in temporary positions to offset the loss of productivity during the crisis, to encourage universities and funding agencies to award release from teaching or teaching reductions to untenured mathematicians who lost significant research time to digital teaching and caregivers responsibilities, of course giving particular consideration to women.

In addition, evaluators of hiring, tenure, prize, grant, and other committees should be reminded that the crisis has impacted individual differently and that more flexibility in deadlines and meeting times should be advocated, especially for women with dependent children.

These proactive measures have been listed in a letter that was sent to all authorities in institutions and academia all over Europe, after being signed by a very long list of members of EWM and others (https://www.europeanwomeninmaths.org/signatories-ewm-open-letter/).

This meant that women in established positions could do something important for other women in untenured positions, for the very simple reason that Europe needs more women in the sciences and the only solution is to shape smart policy to recruit and retain a diverse group of talented young scientists.

This example gives also a clear idea of how important is that women can reach leading roles in the world of mathematics, in order to promote gender-balanced policies.

Actually, one of the proposed methods for alleviating stereotype threat is through introducing role models. One study found that women who took a math test that was administered by a female experimenter had a better performance when compared to women whose test was administered by a male experimenter. Additionally, these researchers found that it was not the physical presence of the female experimenter but rather learning about her apparent competence in math that buffered participants against stereotype threat.

Female mathematicians who read about a successful woman, even though these successes were not directly related to performance in math, perform better on a math test. Both female and male role models can be effective in recruiting women to STEM fields, but female role models are more effective at promoting the retention of women in these fields. And of course female teachers can also act as role models for young girls, as reports have shown that the presence of female teachers positively influences girls' perceptions of STEM and increases their interest in STEM careers [5].

So at this point, we would like to give a look to what has been achieved by women in top positions in mathematics who therefore became role models, often overcoming institutionalized infrastructures, behaviors and beliefs, so that women could continue advancing.

We are going to focus on this aspect because the role-model intervention has a positive and significant effect on mathematics enjoyment, importance attached to math, expectations of success in math and women's aspirations in this field and help to reduce gender stereotypes.

Removing the barriers that prevent women from accessing the sector of mathematics and in general science, research and technology sectors will be the key to changing the current academic orientation, which is essential for fighting new forms of gender inequalities [6].

A good way of overcoming stereotype barriers is through the intervention of female role models, who can increase the sense of belonging to mathematics and reinforce the idea that hard work is the way to succeed [7].

Indeed, not only do role models help broaden the perspectives of who can work in mathematics, they also expand perceptions of researchers of their own potential. Therefore women are more motivated (in terms of expectation of success, enjoyment, and importance) to engage in subjects like math, after interacting with female role models. Being exposed to the professional and personal experiences of actual female role models with a successful professional trajectory in mathematics is the optimal way to encourage women to pursue emerging high-growth roles, requiring math skills.

Last but not least, an increase in women's presence within professions in math and in general in the STEM area is particularly important so as to enable women to seize the new opportunities offered by digital transformation. If women continue to be underrepresented in STEM fields, they may fall further behind in the labor market: the World Economic Forum (WEF) suggests that there is an urgent need to increase the supply and visibility of women with technical skills to close the gender gap in the professions of the future.

In this regard, it has been estimated [8] that, globally, between 40 million and 160 million women may need to undergo a transition between occupations by 2030, often into higher-skilled roles. To make these transitions, women will need new skills. In particular, they will need to overcome their low participation in STEM fields compared to men, as an important barrier that, if not broken, will make it harder for women to make transitions.

We are going to consider two main structures in the world of mathematics, the International Mathematical Union and the European Mathematical Society, where women in charge, meaning that they were elected Presidents, appeared only recently.

The International Mathematical Union is an international non-governmental and non-profit scientific organization. IMU's objectives are to promote international cooperation in mathematics, to support and assist the International Congress of Mathematicians (ICM) and other scientific meetings or conferences, to encourage and support other international activities considered likely to contribute to the development of mathematical science in any of its aspects, pure, applied, or educational. The IMU was officially founded in September 1920 in Strasbourg.

Shortly before the ICM, the General Assembly takes place, which is a gathering of a kind of parliament of mathematics. Usually, when the Program Committee is established, the Adhering Organizations of the IMU and mathematical societies

Fig. 5 Ingrid Daubechies, Belgian physicist and mathematician, first woman President of the International Mathematical Union (IMU). https://www.europeanwomeninmaths.org/wp-content/uploads/2018/08/087916_daubechies007-high-rez-1170x750.jpg

worldwide are invited to nominate plenary and sectional speakers and nominations should be made to the Chair of the Program Committee within the month of November of the year before the one in which the ICM takes place. The next one is going to be held in Saint Petersburg, Russia, between 6 and 14 July 2022. Moreover, the IMU grants a number of prestigious prizes and awards every 4 years at the ICM. The IMU members worldwide are 88. All this gives a clear idea of the importance of this organization and its enormous prestige.

There is nothing in mathematics comparable with the honor of being invited as speaker at the ICM and of course the Fields Medals which are awarded each time are the most coveted prizes.

Among the Presidents of IMU, which were 18 since its foundation, only one has been a woman, Ingrid Daubechies, a mathematician and physicist, who served from 2010 to 2014 (see Fig. 5). Just recently women appeared among the Vice-Presidents: Christiane Rousseau, Alicia Dickenstein, and Nalini Joshi, in chronological order since 2010. So if we are speaking of role models, Ingrid Daubechies is a very good one: taking care of the most important duties in mathematics is quite challenging.

At this point, we would like to say something about her, in order to understand how she reached this prominent position. She was born in 1954 at Houthalen, in Belgium. She is best known for her work with wavelets in image compression.

Her study of the mathematical methods that enhance image-compression technology gave her an international reputation, which made her member of the National

Academy of Engineering in the US, the National Academy of Sciences and the American Academy of Arts and Sciences. She is also a 1992 MacArthur Fellow.

The name Daubechies is widely associated with the orthogonal Daubechies wavelet and the biorthogonal CDF (Cohen-Daubechies-Feauveau) wavelet. A wavelet from this family of wavelets is now used in the JPEG 2000 standard.

Her research involves the use of automatic methods from both mathematics, technology and biology to extract information from samples like bones and teeth. She also developed sophisticated image processing techniques used to find out the authenticity and age of some world's famous works of art including paintings by Vincent van Gogh and Rembrandt.

What took Ingrid Daubechies to the Chair as President of IMU? It is quite a fascinating story and it is worthwhile to say something about it.

She is the daughter of Marcel Daubechies, a civil mining engineer, and Simonne Duran, a criminologist. She remembers that when she was a little girl and could not sleep, she did not count numbers, as you would expect by a child, but started to multiply numbers by two from memory, so she already familiarized herself with the properties of exponential growth.

After finishing the Lyceum in Hasselt, she entered the Vrije Universiteit Brussels at 17 and there completed her undergraduate studies in physics in 1975. She obtained her Ph.D. in theoretical physics in 1980 at Free University Brussels, after a collaboration with Alex Grossmann in quantum mechanics. She continued her career until 1985 in Brussels, first as assistant professor, then as associate professor.

After she went as a guest-researcher at the Courant Institute of Mathematical Sciences in New York and there she made her best-known discovery: based on quadrature mirror filter-technology, she constructed compactly supported continuous wavelets that would require only a finite amount of processing, in this way enabling wavelet theory to enter the realm of digital signal processing (see Fig. 6).

In July 1987, Daubechies joined the Murray Hill AT&T Bell Laboratories' New Jersey facility, where in 1988 she published the result of her research on orthonormal bases of compactly supported wavelets [9]. From 1991 to 1994, she taught as a professor at Rutgers University in the Mathematics Department. In 1994 she moved to Princeton University, where in 2004 she became the first female full professor of mathematics at Princeton.

After moving to Duke University in 2011 at the Department of Mathematics and Electrical and Computer Engineering, she founded together with Heekyoung Hahn the Duke Summer Workshop in Mathematics (SWIM) for female rising high school seniors. Moreover, she has been on the board of directors of Enhancing Diversity in Graduate Education (EDGE), a program that helps women entering in graduate studies in the mathematical sciences.

At this point, it is clear why she became the first woman to be President of the International Mathematical Union (2011–2014).

It was under her direction that for the first time a Fields Medal was awarded to a woman, Maryam Mirzakhani, in 2014 at the ICM in Seoul, South Korea. Of course, the procedure to award the Medal officially does not take under consideration the gender of the winners, but it is a fact that she brought good luck to this enormous

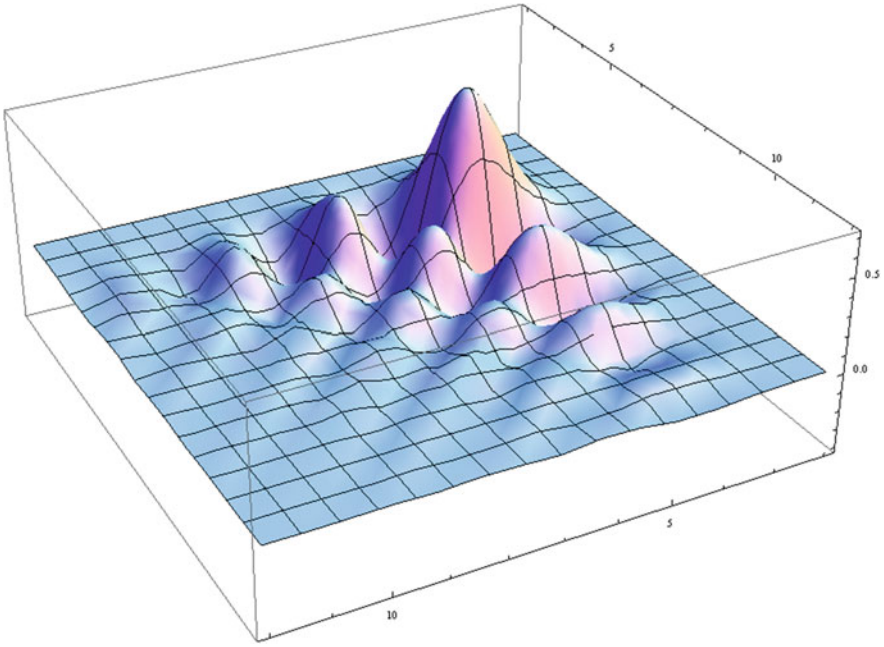

Fig. 6 Daubechies wavelets, mathematical methods used in image-compression technology. https://en.wikipedia.org/wiki/Daubechies_wavelet

achievement, which was extremely important to promote mathematics among young female researchers.

Among the long list of prizes that Daubechies received during her career, we would like to mention for its gender significance the 2019 L'Oréal-UNESCO International Award For Women in Science: since 1998, the award annually recognizes five outstanding women in chemistry, physics, materials science, mathematics and computer science worldwide.

Daubechies was chosen for North America, along with Najat Aoun Saliba (Africa and Arab States), Maki Kawai (Asia Pacific), Karen Hallberg (Latin America) and Claire Voisin (Europe).

One could think that so much work could have prevented her from having a family, but not in her case: she has been married since 1985 to mathematician Robert Calderbank, and they have two children, Michael and Carolyn. So she represents a successful example of work-life balance.

Another achievement of a similar kind was the one of Marta Sanz-Solé, who became the first and up to now only woman president of the European Mathematical Society (EMS), from 2011 to 2014 (see Fig. 7).

The EMS is a European organization dedicated to the development of mathematics in Europe. Its members are different mathematical societies in Europe, academic institutions, and individual mathematicians. The current president is

Fig. 7 Marta Sanz-Solé, Catalan mathematician, first and only woman President of the European Mathematical Society (2001–2020). https://www.ara.cat/2016/07/07/videos/avancaments/Marta-Sanz-Sole-mentalitat-que-Trobem_1609069082_30008435_1132x636.jpg

Volker Mehrmann, professor at the Institute for Mathematics at the Technical University of Berlin. Before him eight Presidents took care of the EMS, the first one was Friedrich Hirzebruch in 1990.

The precursor to the EMS, the European Mathematical Council, was founded in 1978 at the International Congress of Mathematicians in Helsinki. The informal federation of mathematical societies was chaired by Sir Michael Atiyah. The EMS as we know it now was founded in 1990 in Madralin, near Warsaw, Poland, and the first European Congress of Mathematics (ECM) was held at the Sorbonne and Panthéon-Sorbonne universities in Paris in 1992.

The Society seeks to serve all kinds of mathematicians in university, research institute, and other forms of higher education. Its aims are to promote mathematical research, both pure and applied, assist and advise on problems of mathematical education, concern itself with the broader relations of mathematics to society, foster interaction between mathematicians of different countries, establish a sense of identity amongst European mathematicians, represent the mathematical community in supra-national institutions. The EMS is itself an Affiliate of the International Mathematical Union.

The governing body of the EMS is its Council, which comprises delegates representing all of the societies which are themselves members of the EMS, along with delegates representing the institutional and individual EMS members. The Council meets every 2 years and appoints the President and Executive Committee, who are responsible for the running of the society.

Besides the Executive Committee, the EMS has standing committees on: Applied Mathematics, Developing Countries, Mathematical Education, ERCOM (Directors

of European Research Centers in the Mathematical Sciences), Ethics, European Solidarity, Meetings, Publications and Electronic Dissemination, Raising Public Awareness of Mathematics, Women in Mathematics. The EMS is headquartered at the University of Helsinki.

One of the important issues of the Society is the organization of the European Congress of Mathematics (ECM), which is held every 4 years, at which ten EMS Prizes are awarded to "recognize excellent contributions in Mathematics by young researchers not older than 35 years".

In addition, since 2000, the Felix Klein Prize has been awarded to "a young scientist or a small group of young scientists (normally under the age of 38) for using sophisticated methods to give an outstanding solution which meets with the complete satisfaction of industry, to a concrete and difficult industrial problem," and since 2012 the Otto Neugenbauer Prize has been awarded to researchers "for highly original and influential work in the field of history of mathematics."

We have pointed out these prizes because in many cases (Maxim Kontsevich 1992, Richard Borcherds 1992, Timothy Gowers 1996, Grigori Perelman (declined) 1996, Wendelin Werner 2000, Elon Lindenstrauss 2004, Andrei Okounkov 2004, Stanislav Smirnov 2004, Artur Avila 2008, Cédric Villani 2008, Alessio Figalli 2012, Peter Scholze 2016) the winners later have been awarded the Fields Medal at the ICM, so the EMS prizes represent a springboard for reaching the coveted prize.

We described the EMS in order to make clear how important it was for a woman to become its President and the significance that this represented for all the community of women in mathematics.

Marta Sanz-Solé, born in January 1952 in Sabadell, Barcelona, is a Catalan mathematician specialized in probability theory. She obtained her Ph.D. in 1978 from the University of Barcelona under the supervision of David Nualart.

Currently she is professor at the University of Barcelona and head of a research group on stochastic processes. She was Dean of the Faculty of Mathematics at UB from 1993 to 1996 and Vice-President of the Division of Experimental Sciences and Mathematics from 2000 to 2003.

In May 2015 she was appointed chair of the scientific Committee of the Graduate School of Mathematics and from May 2018 until October 2019, she held the position of Director.

Her research interests are in stochastic analysis, in particular stochastic differential and partial differential equations.

Sanz-Solé served in the Executive Committee of the European Mathematical Society in 1997–2004. She was elected President in 2010 and, as we already pointed out, held the post from January 2011 to December 2014. She is a member of several international committees overseeing the mathematical sciences, such as the Board of Directors of the Institut Henri Poincaré in Paris and the Scientific Committee of CIRM (Centre des Rencontres Mathématiques, Luminy, France) and in June 2015 she was appointed member of the Abel Committee for the Abel Prize 2016, 2017.

For her scientific contributions and relevant international positions and service, she was awarded the Real Sociedad Matematica Espanola Medal in 2017. In 2019

Fig. 8 Ingrid Daubechies and Martha Sanz-Solé pictured at the ICM in Hyderabad, India, in 2010. https://owpdb.mfo.de/detail?photo_id=13137

she became numerary member of the Royal Academy of Sciences and Arts of Barcelona.

During her term as President of EMS, two women were awarded the EMS prizes in Krakow, 2012, Sophie Morel and Corinna Ulcigrai. Even if the choice is up to the panel which has the responsibility of choosing the winners, having a woman as President probably inspires to be for a change more gender oriented (see Fig. 8).

It is quite obvious from our excursus through the lives of these two women that in order to reach a really relevant position that allows to be in charge of mathematics, a broad experience in research and responsibilities in mathematics is absolutely necessary, but of course all this comes together with an attitude toward taking care in a positive and effective way of the goals at stake.

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