The Mirzakhani Issue

She used to
work out Marvels.
With her magic wand.
As a mathematician she
was unique, but never alone.

Walter Leoni inside!

Comics & Science

WHERE
ENTERTAINMENT
AND SCIENCE
MEET

UMI

#May12

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Under the sign of TORUS

DAVIDE LA ROSA
SILVIA ZICHE

edizioni

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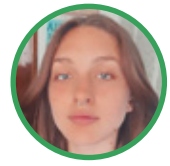

WALTER LEONI
Creator of comics, humorous and satirical cartoons, emptier of wine cellars. He's seen it all but he's not talking.

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INTRO

What is math billiards? What path does the ball take, bouncing off the sides of the table? Is it possible to find billiards where, given the ball's point of departure, there are any inaccessible points? And what does that have to do with donuts and pretzels? Some of these curious questions – in reality, profound mathematical issues – were answered by Maryam Mirzakhani, the first woman to win the Fields Medal. Maryam Mirzakhani was an exceptional mathematician, one of the most remarkable minds of this millennium, born May 12, 1977. At her death, on July 15, 2017, many mourned in the math community, so that in 2018, on the occasion of the first World Congress of Woman in Mathematics, May 12 was declared a holiday celebrating women in mathematics.
In observing this day in collaboration with the Italian Mathematical Union, Comics & Science is featuring a story with Maryam as its star, thanks to the Davide La Rosa's surreal pen, Silvia Ziche's magisterial illustrations, and - last but not least - of Dario Grillotti's precious watercolors. Surrounded by her math family, Maryam is a one-of-a-kind, but definitely not alone.

Roberto Natalini
Andrea Plazzi

The Mirzakhani Issue

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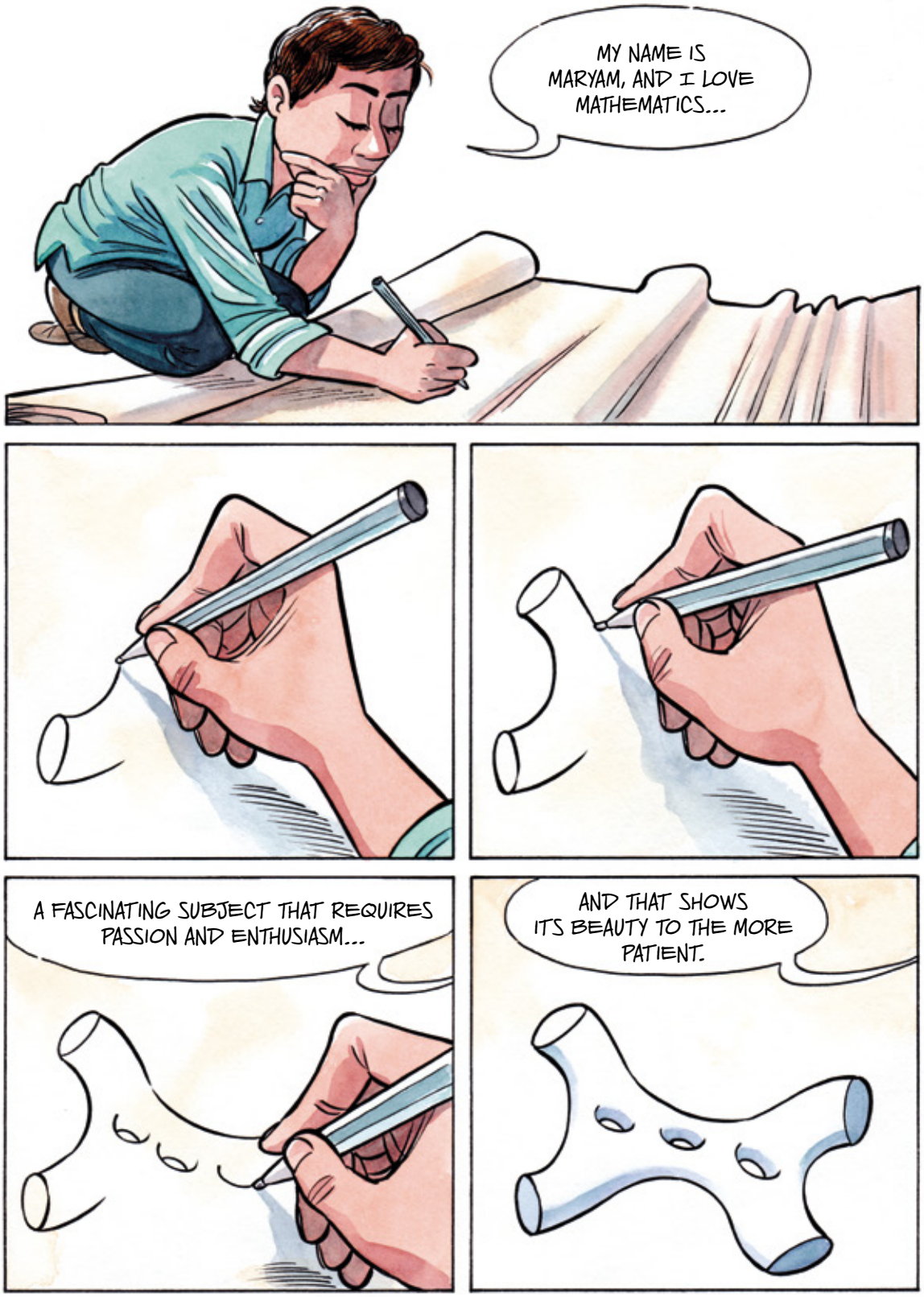
UNDER THE SIGN OF TORUS

SILVIA ZICHE
DAVIDE LA ROSA

THE RIGHT TO ERR

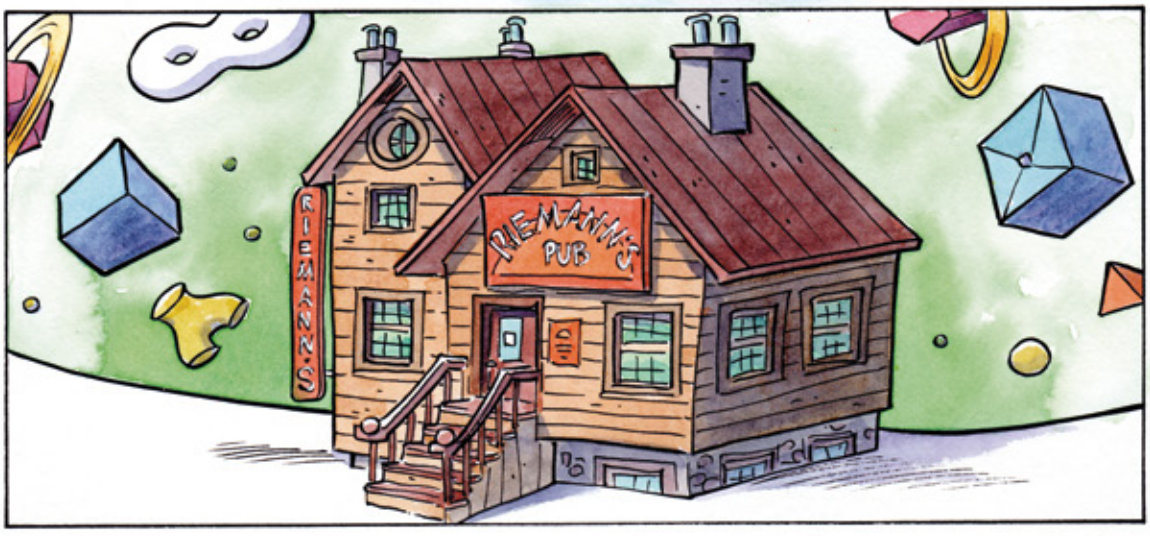
CHIARA DE FABRITIIS
Coordinator of the Equal Opportunity Commission of the Italian Mathematical Union

"Teacher, I don't get it..." – "It's wrong, you idiot!"
This exchange is the sort typically associated with mathematics in our collective imagination. If one were to go around and ask what sorts of feelings the subject brings up for people, adults and teens alike, both male and female, will respond with adjectives like "hard," "complex," "incomprehensible," "mysterious." It almost seems as if mathematics is an esoteric discipline for a select number of initiates, naturally endowed with special powers unknown to ordinary mortals. These godlike heroes (all men, incidentally) are incapable of making a mistake, whereas everyone else are inferior beings incapable of reaching the heights of understanding. The message we want to convey is exactly the opposite: mathematics is a discipline that can appeal to an incredible number of people, including women and girls who might decide to pursue what is a highly enjoyable and rewarding profession.
"For every complex problem there is a solution that is simple, neat—and wrong" is the motto posted on the doors of so many math department offices. Contrary to popular belief, it takes time, effort, and patience (as the protagonist of our story points out) until, slowly but surely, the beauty and fascination of math wins us over. But above all it takes self-understanding and persistence, because only by allowing ourselves to err can we discover our skill, know what it's like to return to the point where we made a mistake, figure out where we went wrong and find the right track to a solution. It fulfills us in a way that makes us better people. This is all the more true for young women. So to those of you reading this story, I hope that Maryam Mirzakhani's shining example inspires you to embark on a path of study or profession that sparkles through math.


MY NAME IS MARYAM, AND I LOVE MATHEMATICS...
A FASCINATING SUBJECT THAT REQUIRES PASSION AND ENTHUSIASM...
AND THAT SHOWS ITS BEAUTY TO THE MORE PATIENT.

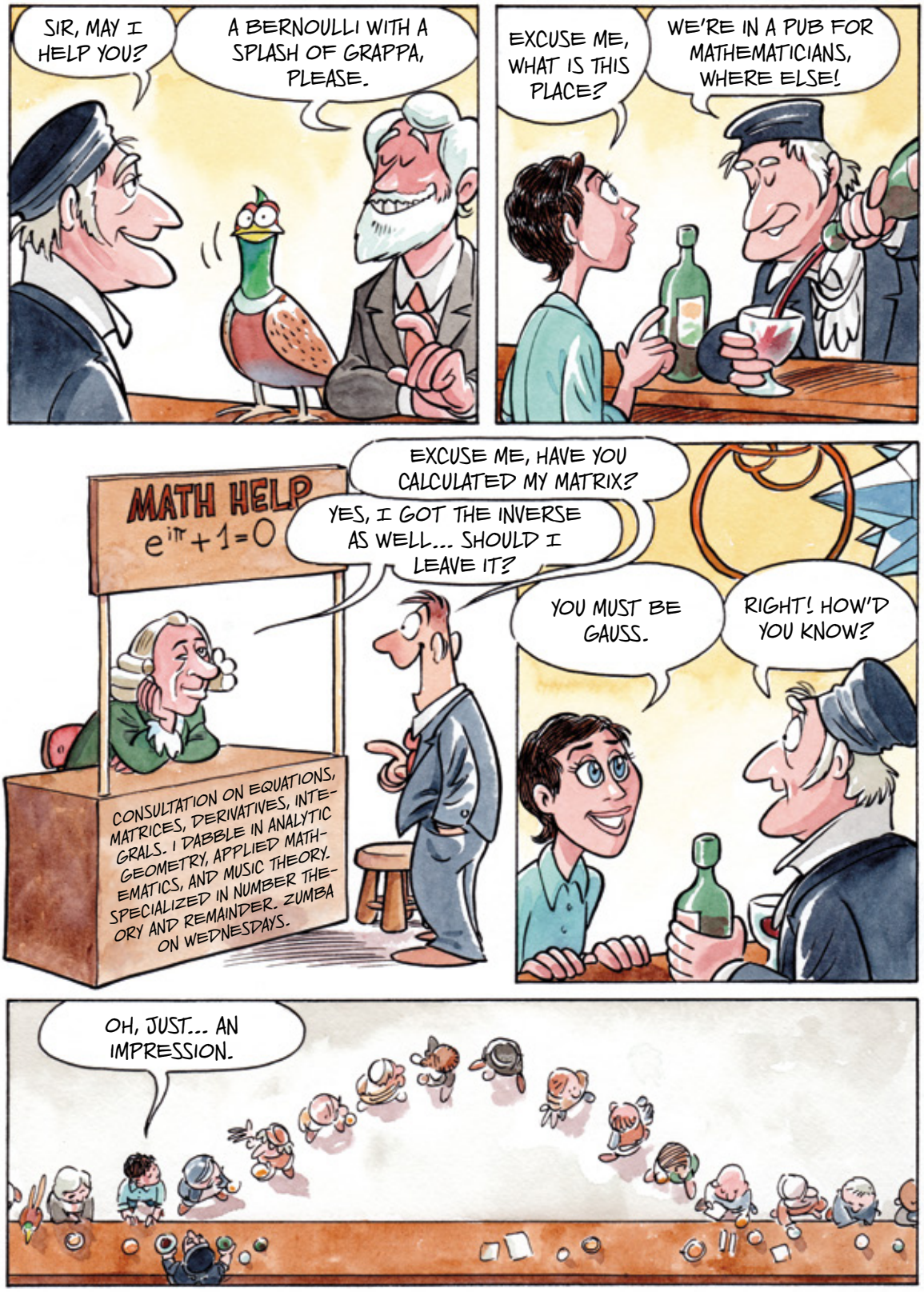
Under the sign of TORUS

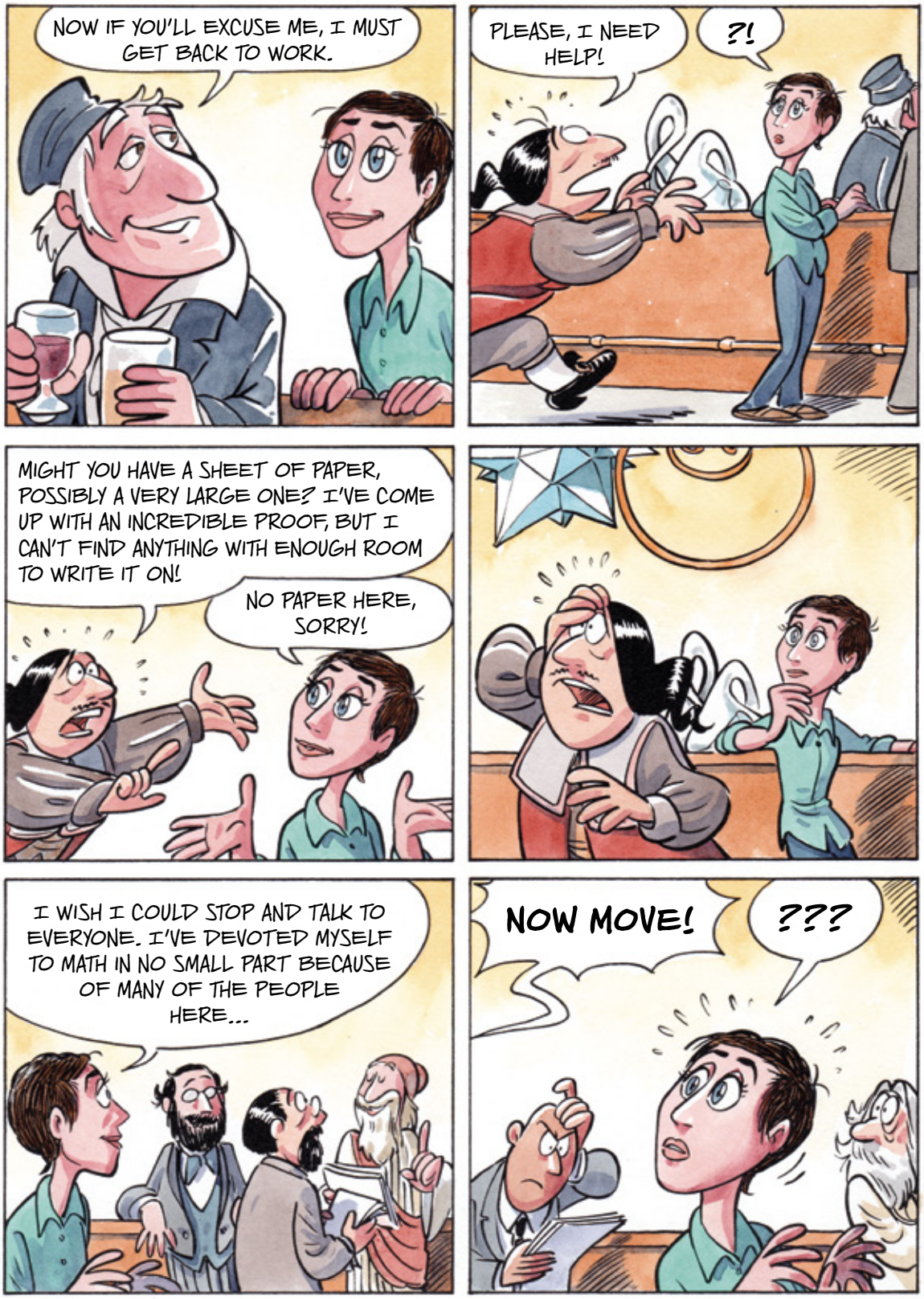
TEXT: DAVIDE LA ROSA • DRAWINGS: SILVIA ZICHE



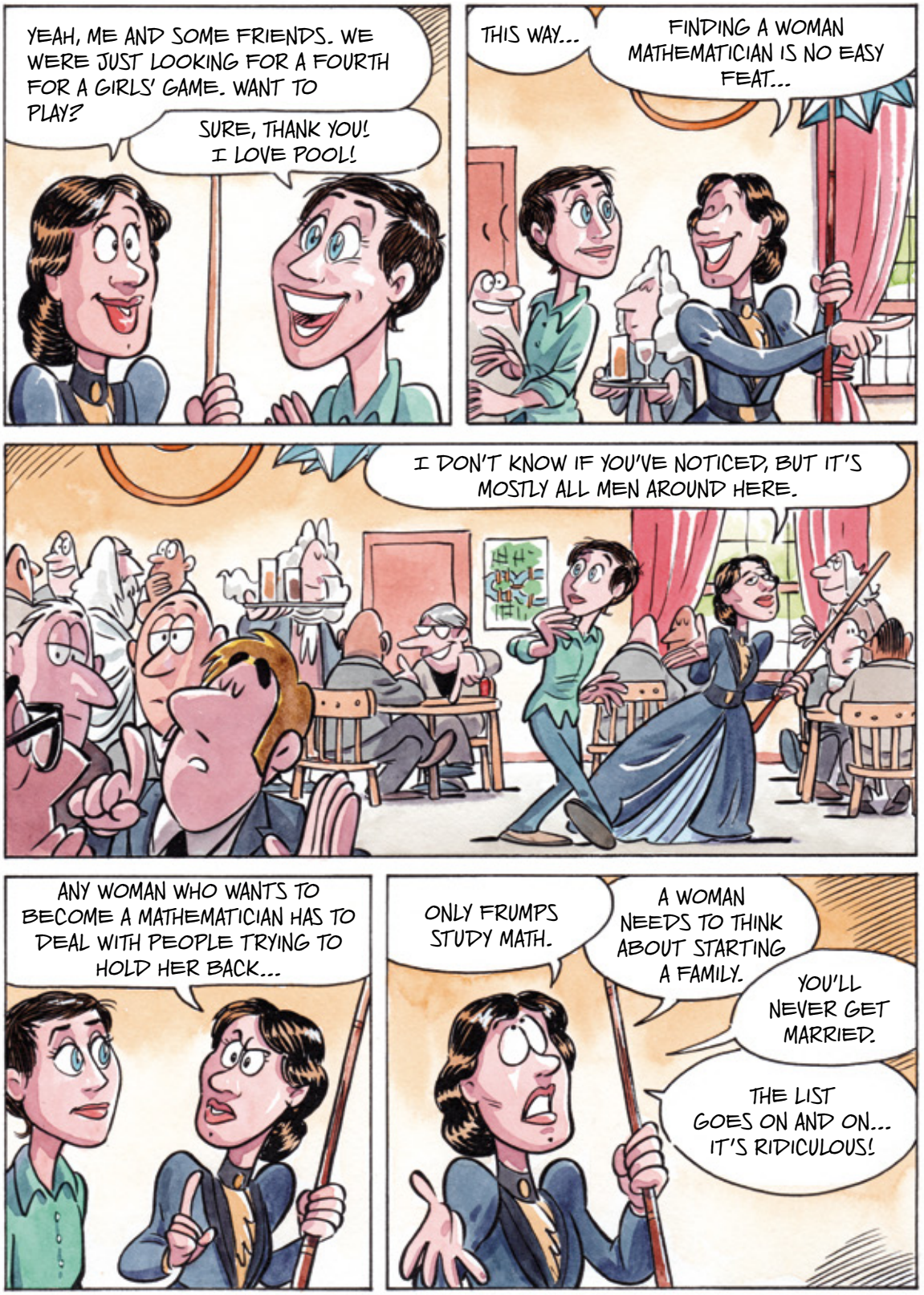

APÉRY TIME
NICE PLACE...
MAYBE I WOULDN'T LIVE HERE, BUT IT'S NOT BAD.
I WONDER WHAT IT'S LIKE INSIDE.
RIEMANN'S PUB
OPEN: 3!
(SATURDAYS AT 0111_2)
CLOSE: $e^{\pi i}\cos\pi$
(SATURDAYS AT $\int_1^2 2x\,dx$)
APÉRY TIME


WHAT'LL IT BE, GENTLEMEN?
HALLEY, MY DEAR CHAP, I'LL HAVE A ROSOLIO. MY FRIEND LEIBNIZ HERE WOULD LIKE A TAMARINDO.
SAME OLD NEWTON... I SAID I WANTED TO ORDER A ROSOLIO FIRST.


SIR, MAY I HELP YOU?
A BERNOULLI WITH A SPLASH OF GRAPPA, PLEASE.
EXCUSE ME, WHAT IS THIS PLACE?
WE'RE IN A PUB FOR MATHEMATICIANS, WHERE ELSE!
MATH HELP
$e^{i\pi}+1=0$
CONSULTATION ON EQUATIONS, MATRICES, DERIVATIVES, INTEGRALS. I DABBLE IN ANALYTIC GEOMETRY, APPLIED MATHEMATICS, AND MUSIC THEORY. SPECIALIZED IN NUMBER THEORY AND REMAINDER. ZUMBA ON WEDNESDAYS.
EXCUSE ME, HAVE YOU CALCULATED MY MATRIX?
YES, I GOT THE INVERSE AS WELL... SHOULD I LEAVE IT?
YOU MUST BE GAUSS.
RIGHT! HOW'D YOU KNOW?
OH, JUST... AN IMPRESSION.

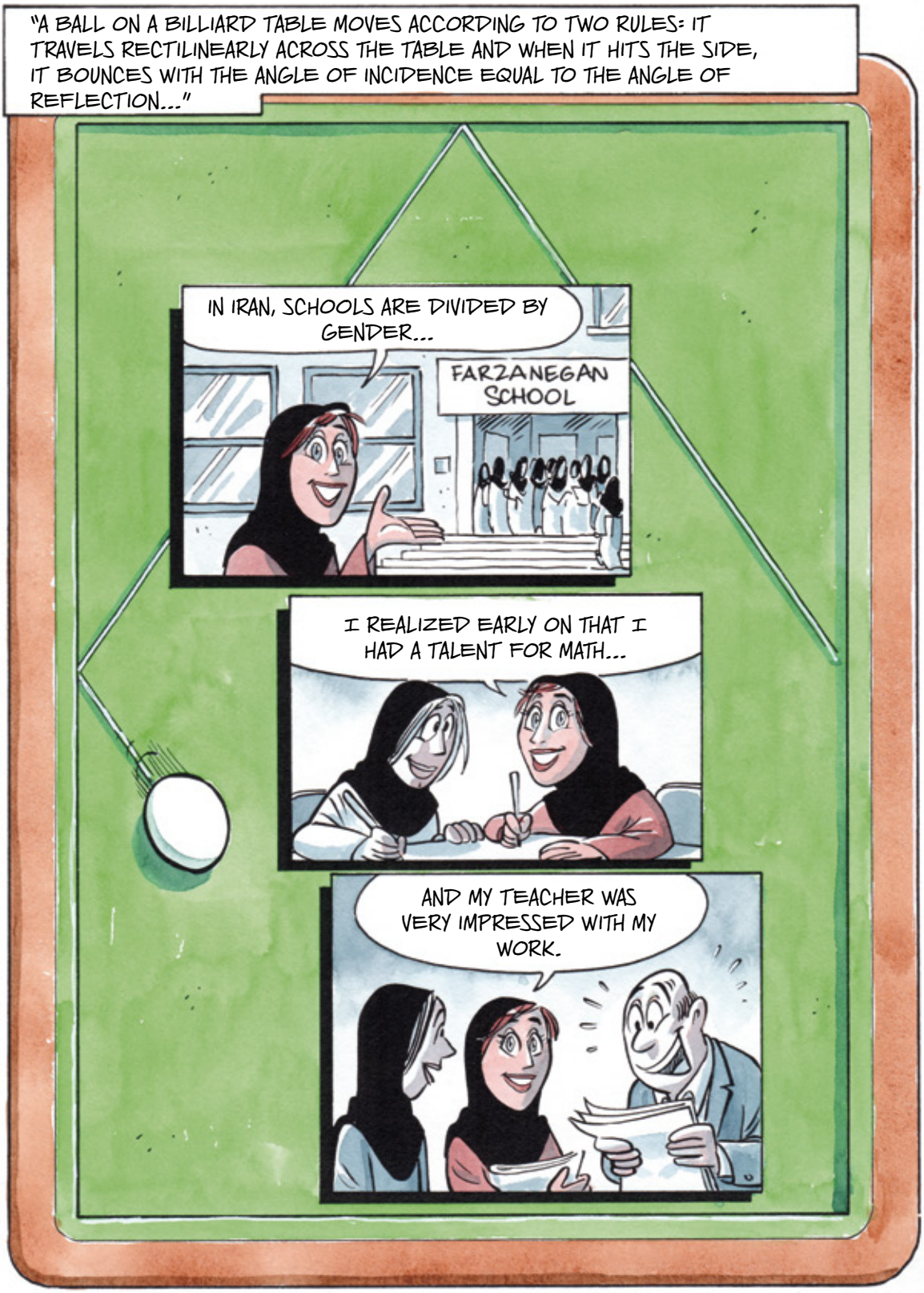

NOW IF YOU'LL EXCUSE ME, I MUST GET BACK TO WORK.
PLEASE, I NEED HELP!
?!
MIGHT YOU HAVE A SHEET OF PAPER, POSSIBLY A VERY LARGE ONE? I'VE COME UP WITH AN INCREDIBLE PROOF, BUT I CAN'T FIND ANYTHING WITH ENOUGH ROOM TO WRITE IT ON!
NO PAPER HERE, SORRY!
I WISH I COULD STOP AND TALK TO EVERYONE. I'VE DEVOTED MYSELF TO MATH IN NO SMALL PART BECAUSE OF MANY OF THE PEOPLE HERE...
NOW MOVE!
???


I DON'T HAVE ENOUGH CARROTS FOR ALL OF YOU, PLEASE!
WHAT THE...
TH-THANKS FOR SAVING ME!
DON'T MENTION IT. ALL THESE RABBITS ARE BECOMING A PROBLEM... AND IT'S ONLY GOING TO GET WORSE.
HI, I'M SOF'JA, BUT YOU CAN CALL ME SONYA OR SOPHIE.
HI, I... WAIT, ARE YOU PLAYING POOL?


YEAH, ME AND SOME FRIENDS. WE WERE JUST LOOKING FOR A FOURTH FOR A GIRLS' GAME. WANT TO PLAY?
SURE, THANK YOU! I LOVE POOL!
THIS WAY...
FINDING A WOMAN MATHEMATICIAN IS NO EASY FEAT...
I DON'T KNOW IF YOU'VE NOTICED, BUT IT'S MOSTLY ALL MEN AROUND HERE.
ANY WOMAN WHO WANTS TO BECOME A MATHEMATICIAN HAS TO DEAL WITH PEOPLE TRYING TO HOLD HER BACK...
ONLY FRUMPS STUDY MATH.
A WOMAN NEEDS TO THINK ABOUT STARTING A FAMILY.
YOU'LL NEVER GET MARRIED.
THE LIST GOES ON AND ON... IT'S RIDICULOUS!


THIS IS EMMY AND SOPHIE.
LADIES, THIS IS MARYAM.
HI!
FINALLY, WE CAN PLAY!
ABOUT WHAT YOU WERE SAYING BEFORE, I KNOW HOW HARD IT IS FOR A WOMAN TO GET ESTABLISHED...
DON'T GET ME STARTED, I WAS FORCED TO PUBLISH MY STUDIES UNDER A MALE PSEUDONYM, OTHERWISE NOBODY WOULD'VE TAKEN ME SERIOUSLY.
EXCEPT FOR GAUSS... HE WAS OPEN-MINDED FOR A MAN OF THE TIME, AND HE RESPECTED ME AS A MATHEMATICIAN.
BUT FOR ME, MATH ITSELF WAS MY PATH TO EMANCIPATION.
AND A LITTLE CREDIT GOES TO BILLIARDS, TOO...
STOCK

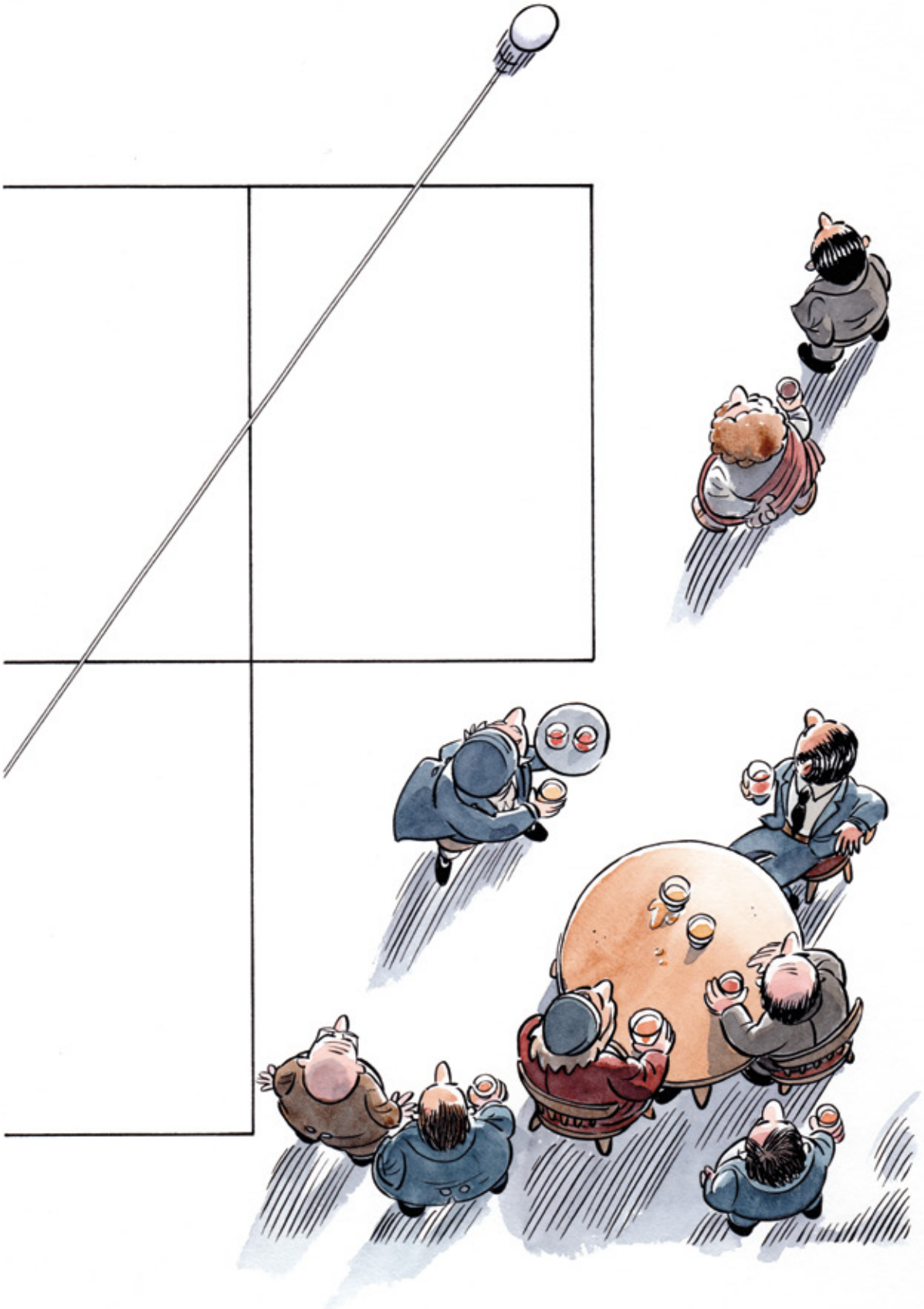
"BILLIARDS IS THE TYPICAL EXAMPLE OF A DYNAMICAL SYSTEM THAT OFTEN DEMONSTRATES CHAOTIC BEHAVIOR..."

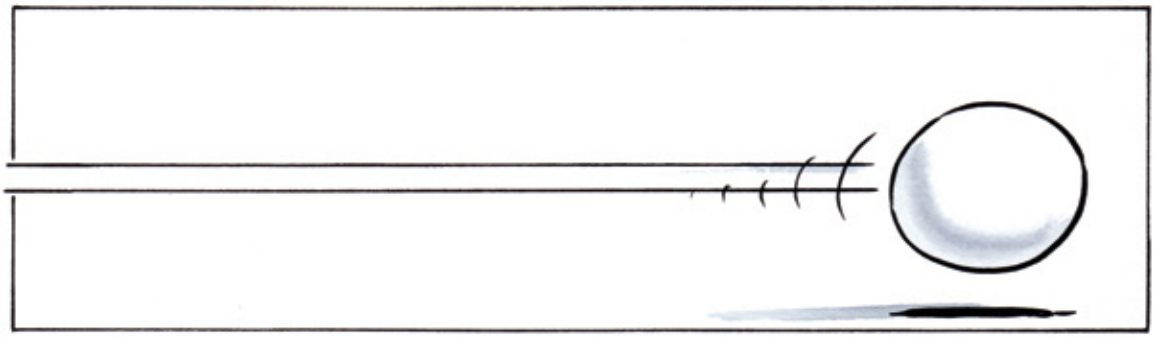

"A BALL ON A BILLIARD TABLE MOVES ACCORDING TO TWO RULES: IT TRAVELS RECTILINEARLY ACROSS THE TABLE AND WHEN IT HITS THE SIDE, IT BOUNCES WITH THE ANGLE OF INCIDENCE EQUAL TO THE ANGLE OF REFLECTION..."
IN IRAN, SCHOOLS ARE DIVIDED BY GENDER...
FARZANEGAN SCHOOL
I REALIZED EARLY ON THAT I HAD A TALENT FOR MATH...
AND MY TEACHER WAS VERY IMPRESSED WITH MY WORK.

"AT THIS POINT THE PROBLEM IS WHETHER THERE ARE PATHS THAT RANDOMLY PASS ARBITRARILY CLOSE TO EVERY POINT ON THE PLAYING SURFACE..."

"ONE WAY TO FIGURE IT OUT IS TAKING THE BALL OUT OF A CLOSED CONTEXT, FREEING IT..."


ONE EXCELLENT METHOD IS HAVING IT MOVE ACROSS HYPOTHETICAL MIRROR SURFACES.



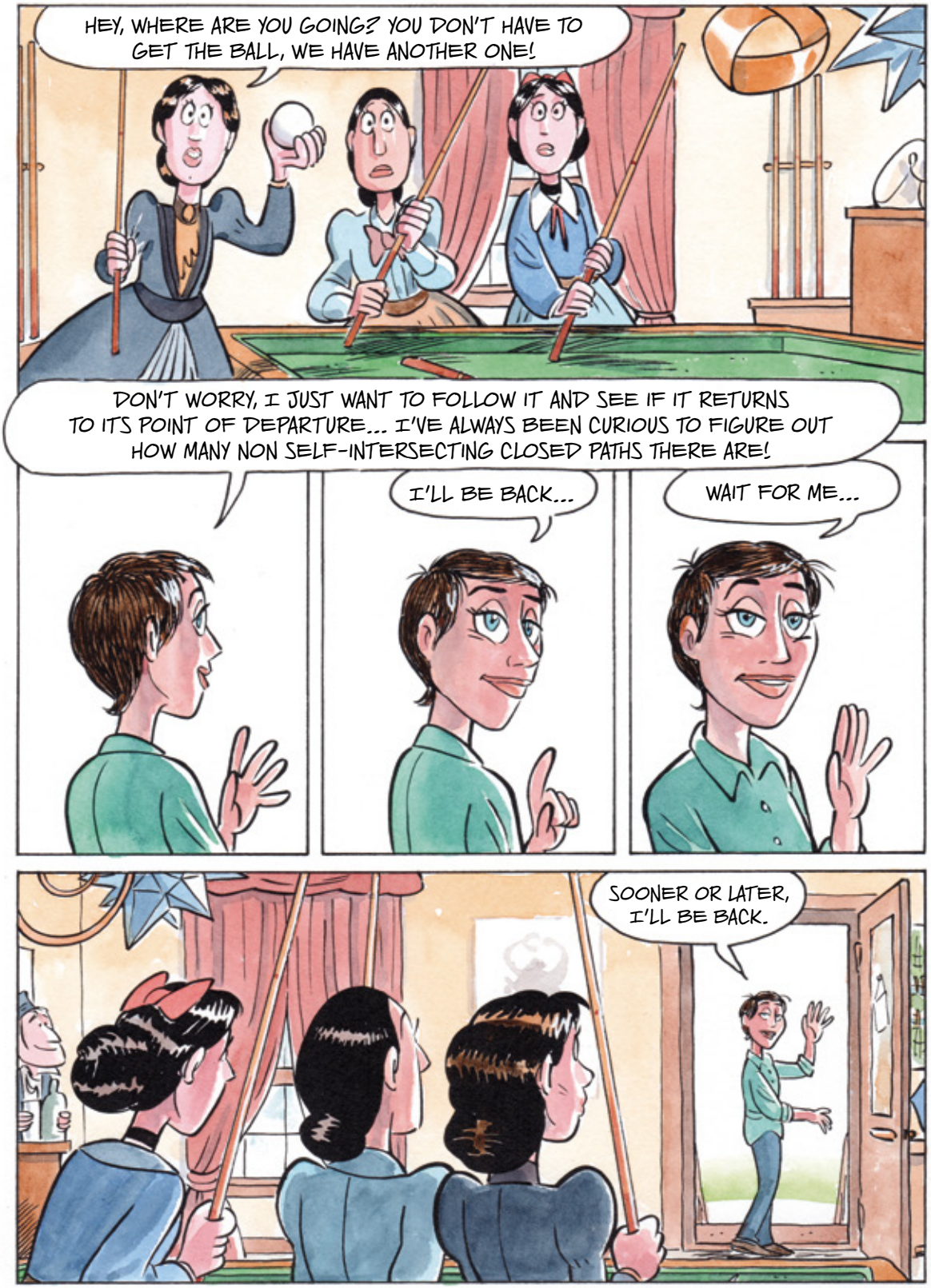


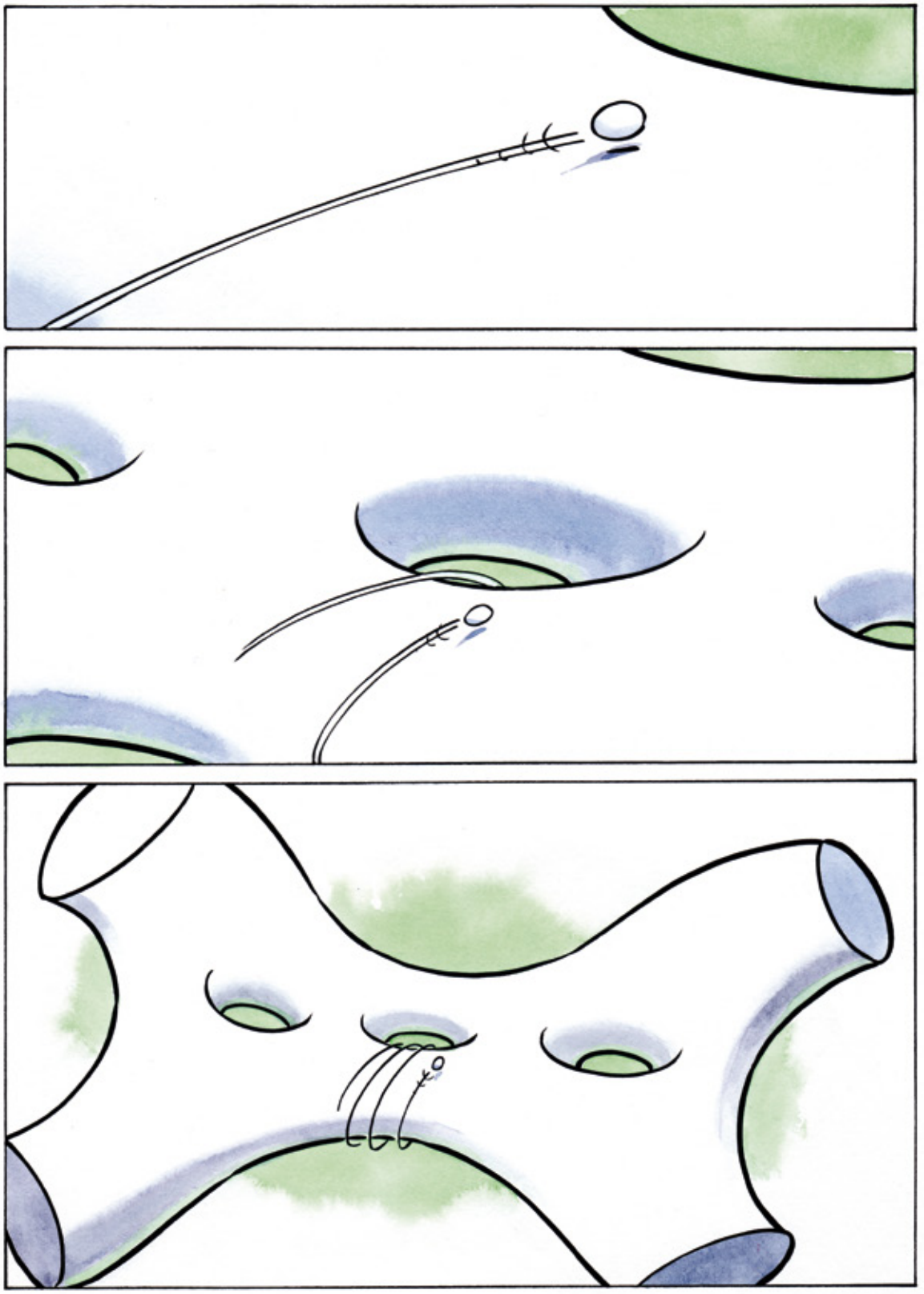

IT ALL SEEMS PRETTY COMPLICATED, RIGHT? BUT IT'S KIND OF LIKE LIFE... THERE'S NO GUARANTEE OF AN EASY SOLUTION...


YOU MUSTN'T LIMIT YOURSELF TO PICKING ONLY THE LOWEST-HANGING FRUIT.

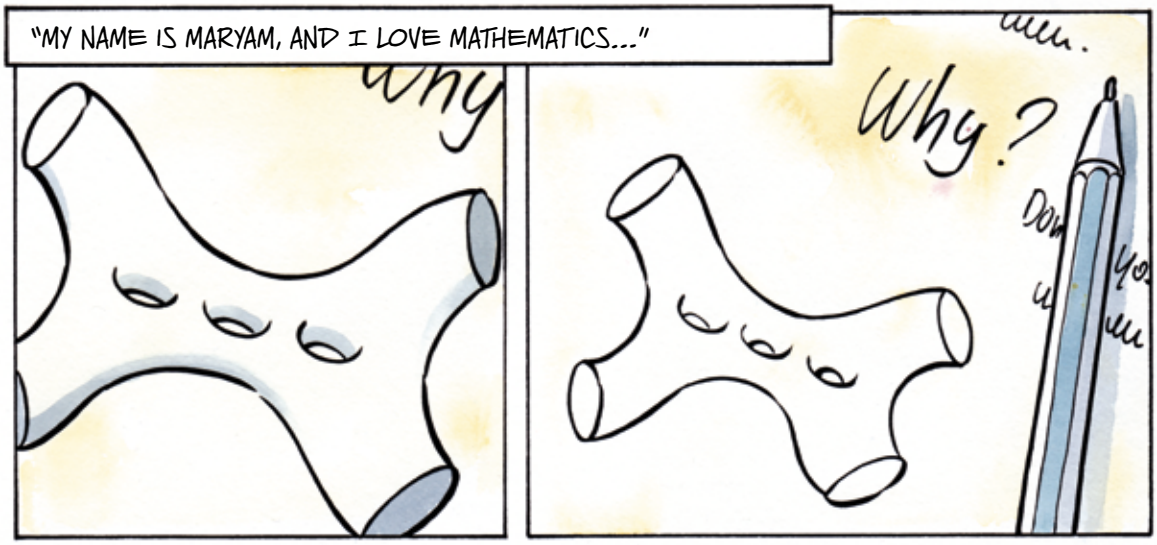

WHEN I WON THE FIELDS MEDAL, IT WAS THE FIRST TIME FOR A WOMAN.
IT WOULD BE WONDERFUL IF THAT COULD HELP ERADICATE OLD PREJUDICES.


?!
EXCUSE ME, MY DEAR COLLEAGUES, BUT I'VE GOT TO GO...
?
?
?

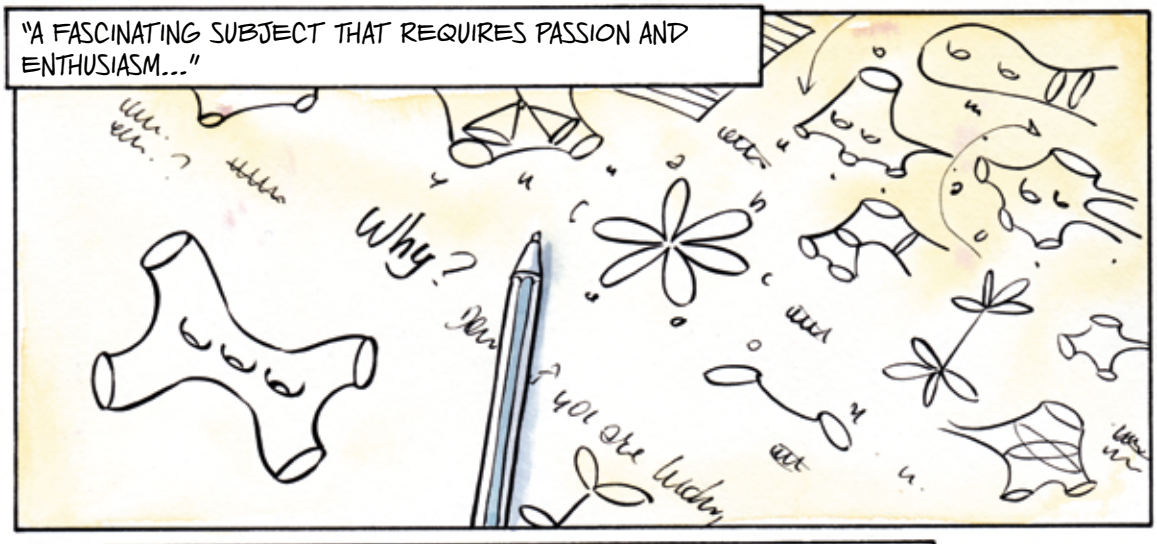

HEY, WHERE ARE YOU GOING? YOU DON'T HAVE TO GET THE BALL, WE HAVE ANOTHER ONE!
DON'T WORRY, I JUST WANT TO FOLLOW IT AND SEE IF IT RETURNS TO ITS POINT OF DEPARTURE... I'VE ALWAYS BEEN CURIOUS TO FIGURE OUT HOW MANY NON SELF-INTERSECTING CLOSED PATHS THERE ARE!
I'LL BE BACK...
WAIT FOR ME...
SOONER OR LATER, I'LL BE BACK.



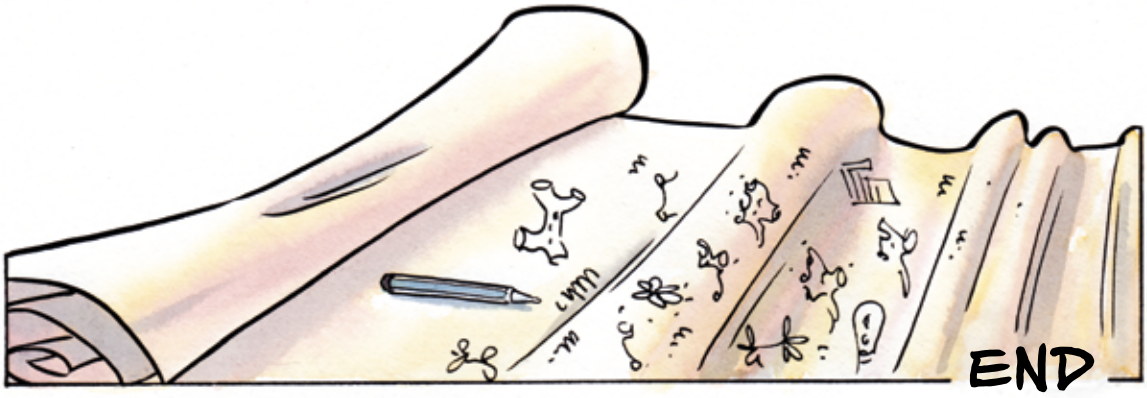
"MY NAME IS MARYAM, AND I LOVE MATHEMATICS..."



"A FASCINATING SUBJECT THAT REQUIRES PASSION AND ENTHUSIASM..."



"AND THAT SHOWS ITS BEAUTY TO THE MORE PATIENT."



To make good **comics**,
you need **study**, preparation, figures,
formulas, and lots of **trial and error**.
Like **math**.

Formulas and Drawings, Thinking of Maryam

by CHIARA DE FABRITIIS and BARBARA NELLI

Chiara de Fabritiis Ciao, Silvia. Making comics isn't a common profession. How did you get started?

Silvia Ziche It's always been an obsession. I learned to read from *Topolino*, then I proceeded full steam ahead: at 15-16 I started out with local magazines, so very early, still with that youthful enthusiasm you have when you're young. I didn't even raise the question of whether I should do anything else with my life. Now as an adult I realize that maybe I didn't know any alternatives. But it all worked out!

Chiara de Fabritiis What kind of training have you had?

Silvia Ziche I studied art, generally, not comics-specific. I grew up outside Vicenza, an area that doesn't have a lot of schools. I went to an art institute and specialized in ceramics, nothing to do with what I'm doing now. Then I did a program in graphic design (or something like that) but I didn't finish. I've always kept drawing and making comics on my own. I just liked it. I'd go bug authors I'd met going to the different fairs and try to figure out how the job worked: these weren't just doodles, to draw and write in a certain way it took a particular kind of study, which I carried out on my own, self-taught.

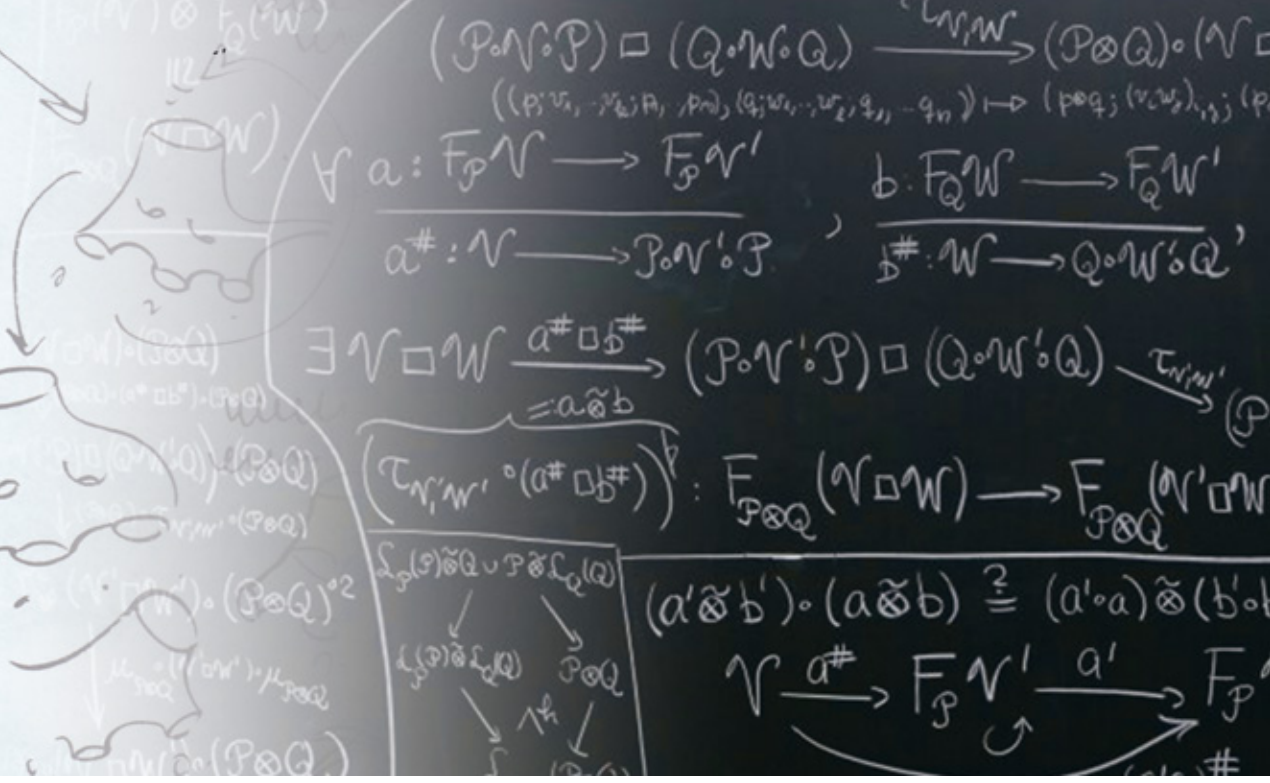
Barbara Nelli What about you, Davide?

Davide La Rosa I'm from a little town on Lake Como where George Clooney lives (people always mix us up). There's nothing there. To find comics or schools you had to go to Milan.
I've always read comics: growing up, you encode language as you read, so to speak, and vice versa, when you see

something you encode it using the language you've learned. At some point I did a program and that's where I realized it was the only thing I was good at. So I kept on in that direction.

Barbara Nelli I imagine that the environment isn't necessarily evident... we were wondering whether Silvia encountered any trouble as a woman and how she handled it.

Silvia Ziche First of all, I must say I never perceived that comics were a guy thing. I have my parents to thank for that. I always read them, I thought they were something for everyone and nothing else ever occurred to me. When I was little I loved *Topolino* and *Asterix*, then around 14 Claire Bretécher's social criticism comics. She's a huge French artist, she's amazing. I was so into it but that actually heightened my confusion: no one had told me that comics weren't for girls and I hadn't asked myself whether I was the only one, but objectively there were few. Then at age 19-20 I went and knocked on the door of *Linus*, the magazine... I buzzed up to editorial and introduced myself. The editorial director was a woman, the editors were all women... to me it was obviously completely normal and my misapprehension of the comics world went on (and by the way, they hired me, and I'm endlessly grateful to the director Fulvia Serra). The first time I had a twinge of doubt was when someone asked me: "Why do you do such a male job?" And I fell off my chair. There were women everywhere! From then on I got asked that question more or less every day and at that point—I was still very young—I started looking around. Pretty much all the editorial staff were men and at the time the creators were 98% men. And I started to see. A little later on I had a few problems due to the fact that I was a woman, with people who had the power to keep me from working, and who wondered what I was doing there. But I must say something else: for that one particular person, and others a little less, who created problems, there were just as many—and I'm saying men and women—who helped me to overcome them. So yes, problems, but also well-intentioned people thanks with whose help they were possible to solve.



Chiara de Fabritiis You both have a privileged channel of communication with teenagers, even with children. And Silvia publishes in *Topolino*... how do communicate with these age groups? It must take a certain charisma...

Davide La Rosa I don't have Silvia's experience, I base myself on my 6 year-old son. When we were little, kids were different than they are today... I have no idea how I do it, it comes out spontaneously. This is a very complicated question!

Silvia Ziche It's true, in reality when you do creative work things simply "come" to you. Explaining how you do something is much harder than doing it. So in reality something comes to me, after which I—and I think Davide as well—rely heavily on humor... I do almost exclusively very funny things, even for adults, not just in *Topolino*. Humor is a form of expression that remains fairly constant over time.

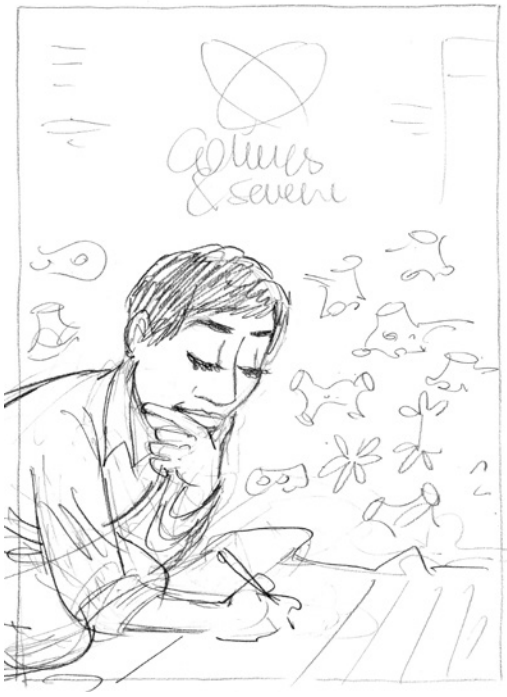
Davide La Rosa Humor... for starters, an unanswerable question is "how do you make people laugh?" Either you have comic timing or not, if it works, okay, if not, forget it...

Chiara de Fabritiis If you don't have comic timing they'll heckle you off stage and send you off to teach math: the prototypical type-A.

Silvia Ziche Can I say one thing? I think that to teach math you also need to be a great communicator. I've watched lots of videos of Maryam Mirzakhani's classes. I don't understand math, but I know English, so I understood the words but not what they meant. She was so dynamic and passionate when she explained things, she was completely captivating... Happy, smiling, enthusiastic. She didn't stop for a second. A high-speed train. Absolutely wonderful.

Barbara Nelli The other thing our professions have in common is creativity: in math you need quite a lot. And creativity is your whole realm...

Chiara de Fabritiis Another commonality is that beneath the creativity there is



a calling that you can't do without. You have to study first, then by the time you've worked up a sweated, an idea comes to you.

Silvia Ziche Yeah, you study and work a lot to improve, for sure. With time and experience you refine techniques for coming up with ideas. Even if it's like Davide said, that you don't know where they come from or when they're going to come. Let's say you make yourself more predisposed to receive them. Like with any jobs, this too entails industry, dedication, and therefore, effort.

Davide La Rosa Also because then you happen to get stuck in the middle... One time I was stuck on a page for three months, the story wouldn't flow. Usually ideas come to me when I'm in line at the Post Office.

Silvia Ziche When you get distracted and do something else and stop thinking about it, somehow things come together...

Barbara Nelli Like in math! If you've thought about something enough, you might get an idea in line at the post office... as long as you've thought about it long enough!

Davide La Rosa For example, this story had to include mathematical concepts as well as the protagonist's biography and so it needed another framework in addition to the main narrative, which wasn't easy. I studied mathematicians' lives, there are some great stories... Andrea told me about some of them and I tried to put them in. Various elements that must be squared. And then the billiards part... not easy at all!

Silvia Ziche Not so easy to draw, either... certain things were hard to get right.

Davide La Rosa People say the artist redeems the scriptwriter's work because they fill in all the blanks and make the story work much better than it was written in the first place.

Silvia Ziche It's always a two-part job: visualizing and imagining (I think math can also be that way). Sometimes a scriptwriter can visualize exactly what they want and the artist has to step in.

Davide La Rosa Knowing who's going to draw the story makes it much easier to write. When you don't know, it takes more effort because you don't know how it's going to be rendered, what the strong points are of the person who will draw it.

Barbara Nelli Davide... Paco Lanciano?!

Silvia Ziche In the end, you managed to sneak him in!

Davide La Rosa I'm sorry, Silvia, let me take this opportunity to apologize to everybody. Paco Lanciano is my favorite character from SuperQuark because he's an outsider, everyone knows who he is but doesn't know his name, and then he does these mega experiments... a few years ago I used him for one of my books, *Paco Lanciano e il Fagiano Crononauta* (Paco Lanciano and the Time-Traveling Pheasant). A badly drawn book, naturally. That's how I started doing comics for *Comics&Science*, and I pull it out every chance I get. Drawn by Silvia, too... I'm also very attached to the pheasant, because I have a stuffed one at home that my grandmother had found dead in the garden and we've passed down from generation to generation.

Barbara Nelli And Lucrezia?

Silvia Ziche She's the filter through which I try to represent reality the way I see it... using a "flawed" character like Lucrezia, with her difficult personality, is actually very easy. She's my window on the world, and I can tell the story better from her point of view. One observation: we're in a moment in which everyone is trying to represent themselves, to write "auto-fiction," to talk about their own life. I'm from another generation and I don't like this so much. It's clear that the point of view is clearly mine—I'm the one writing the stories. Even if someone invents a character completely different from themselves, the filter between world and story remains the author and this is a given. But I don't like to write about myself, so I always try to take inspiration from the reality around me and filter it - otherwise I wouldn't be able to carve a story out of it - and then mix it all up until none of it is recognizable.

Chiara de Fabritiis What will stick with you from this encounter with mathematics and with Maryam in particular?

Silvia Ziche With math, I'm not sure... I was left curious to understand Maryam's work a little better. I won't really be able to, but I found her extremely fascinating... a beautiful character. I think what will stick with me is this curiosity about her.

Davide La Rosa Three things will stick with me. 1) I'll never look at a pool table the same way, in fact I might not want to even see one for a while. 2) Something that really struck me was that in the end Maryam appeared with her head uncovered in the newspapers in her country: an incredible thing, the power of science. 3) In one video she says she was interested in finding multiple ways of resolving the same problem. It seems like such a beautiful thing, and I'll use it to expand my peripheral vision.

Paco Lanciano and the time-traveling pheasant explain Davide La Rosa

Creativity, holiday, celebration, memory.
And a **look** to the future.
All in a **birthday**.
What is ***May12***?

A Date to Remember

ELISABETTA STRICKLAND

May 12, 1977 is Maryam Mirzakhani's birthday (therefore she was born under the sign of Taurus, April 21-May 20; the word "Taurus" has a mathematical homophone in the word "torus," referring to a donut-shaped surface), the first and only female to win a Fields Medal, the most prestigious prize in the math world. It was awarded to her in Seoul in 2014 before a jubilant audience of five thousand. Unfortunately, even then she knew she was afflicted with a serious disease, which she battled for another three years, until finally she couldn't fight it off anymore, and she passed away.
The loss was felt so acutely in the math world that in 2018, at the first World Conference of Women in Mathematics, it was decided that May 12 would become a day celebrating women in maths, an initiative approved by a sweeping majority to be called May12. Since 2019, thanks to the work of the May12 coordination group, thousands of events around the world are organized every year and included on the website may12.womeninmaths.org.
There has also been a film about Maryam's life, "Secrets of the Surface: The Mathematical Vision of Maryam Mirzakhani", by George Csicsery. It was shown at many events in 2020. Other short films followed, two of which are available directly on the May12 website: "Women in Science in Africa: A Silent Revolution," and "Words of Women in Mathematics in the Time of Corona."
The idea is to make May12 not just an anniversary, a commemorative holiday, but a joyful occasion for the mathematics community in which to celebrate the women who have chosen to devote themselves to what Gauss called the "queen of the sciences."
To ensure a balanced offering of events, the coordination group includes

representatives from every continent and raises funds from various international associations. Initially the project was first led by European Women in Mathematics and the Association for Women in Mathematics, later along with the International Mathematical Union's Committee for Women in Mathematics, providing funding to create the website. Thus this is a day meant to celebrate the passion for math that so many women and girls share with the petite young woman with striking, incredibly expressive blue eyes. Even in school in Tehran as a girl, an expert teacher took notice of her unusual comprehension skills in algebra and encouraged her to continue in that direction. Maryam was also a great lover of literature and her extensive reading granted her a remarkable facility with language and a captivating way of talking about math. The man she later married in the United States, computer scientist and theorist Jan Vondrák, maintained that her thoughtful manner of approaching math problems came from the way she reflected on literary texts. And she even called herself a "slow mathematician." By her account, when she arrived in the US, Maryam didn't understand much of her advisor's lectures, but she still found them simple and elegant. Her gift was indisputably solving extremely difficult problems efficiently and brilliantly, ones which great mathematicians like Edward Witten and Maxim Kontsevich, also Fields Medalists, had grappled with. In fact, her thesis was something like an academic earthquake. When she won the Fields Medal in Seoul, she became a celebrity in her home country of Iran. She was even depicted in portraits bare-headed, that is, without the otherwise obligatory veil. When she died, Iranian President Hassan Rouhani had an obituary published in the newspapers that highlighted "her unique brilliance and her contribution to the emancipation of Iranian women." Interviewed at her most glorious moments, she stated very simply that she hoped her success would be of help to young women who wanted to pursue a career in math. That it did.

Her **brilliant** beginnings.
Then, study combined with **passion**,
enthusiasm, and intuition.
The ingredients for an **exceptional** career.

One of a Kind, But Definitely Not Alone

BARBARA FANTECHI

"One of a kind" is perhaps one of the most apt expressions for describing Maryam Mirzakhani. The only woman to have won the Fields Medal, but also the only Iranian national to have received the prestigious award. One of a kind, but definitely not alone: to accomplish this, to develop her talent and her work, an entire community, or rather many of them, families even, have nurtured and supported her.
The first of these communities is Iran, her home country.
A nation that perhaps many of us associate with a rigidity not particularly favor to a figure of this caliber, yet which has not just a history, but a very complex and rich cultural history, in truth has been fertile ground for many great scholars and intellectuals. In multiple ways, it resembles another important cultural touchstone, Italy.
The climate is remarkably varied: it ranges from mountains to deserts, famous for their delicious dates and historic wine production.
The aforementioned cultural history involves the most disparate fields: architecture, art, literature, and of course, science. The words "algebra" and "algorithm" derive from the Persian mathematician Al-Khwarizmi. A tradition that extends to the present, and which also includes women.
Although it may seem like a paradox, the possibility of going to school as long as the head is covered, has led to a veritable explosion in the number of girls and women who choose to continue their studies, to the extent that some institutions have considered compensatory measures like "blue" quotas to ensure an even number of male students in programs with a limited number of participants.
This "native" community was later

supplemented by another, the International Mathematical Olympiad, an annual competition for teenagers all over the world that brings people together and unites minds.
As in traditional sports, the team is formed after local and national trials, and they train intensively, doing hours of high-level math and exercises. Competitions are not segregated by gender but male participation has always been dominant.
Yet that didn't stop Mirzakhani from finding a family. She made it to the national team along with her friend Roya, a classmate similarly brilliant and in love with mathematics. The importance of this relationship cannot be overstated; it accompanied Mirzakhani on international trips, where the two girls shared rooms and talked late into the night about the future. Together, they earned bachelor's degrees at the notably difficult Sharif University of Technology in Tehran, a hotbed for talent of all scientific disciplines. Among harsh but capable professors and classmates of a comparable - though probably not quite equal - skill level, Mirzakhani grew even more, publishing her first original work.
Her next step took her away from Iran, to a doctorate at MIT in Boston under Curtis McCullen. Here, a third community welcomed Mirzakhani, the world of differential and symplectic geometry.
A family that lined up next to the others, with her Iranian origins firmly in her mind and her notes, and her friend Roya, also at MIT but in algebraic geometry. Others, men and women scientists of Persian origin like her, helped her to keep traditions, celebrating holidays, sharing food from home and conversations in their mother tongue. The doctorate is the period when one makes the leap from "mere" student to "creator."
A creator of math, in this case: at first with baby steps, little extensions of pre-existing results or even proving a hypothesis, or an idea that another

researcher shared in the hope that someone would be able to demonstrate whether it was true (or false). And for her dissertation, Mirzakhani proved a conjecture fundamental to the study of Riemann surfaces that had been unresolved for many years.

The impact was enormous immediately, and this established her more firmly in math research. From there she continued her work, partly on her own, but increasingly with other highly accomplished mathematicians, like the renowned Alex Eskin, as collaborators and as muses and advisors. Although the brilliant and superior results may suggest otherwise, this is the standard working method behind nearly every math article, which in fact usually has multiple authors and an acknowledgements section to give appropriate recognition to all those who contributed. The Fields Medal itself is the crowning achievement of an entire process and individual success, which in turn is the culmination of a journey that began with the prestigious postdoctoral Clay Fellowship and continued with a professorship at Princeton.

A brilliant career, nonetheless in its beginnings, with enormous future potential, was cut short by a cruel fate in the form of incurable disease. Even through cancer, the community continued to support her, to help her, allowing her to work, collaborate, teach, and create beauty up to the end.

Math is not done in isolation, but as part of a community. There is room for everyone, both for rare gems and for non-professional enthusiasts, and indeed it is often hard with young people to predict who go on to great success.

In any case, everyone's contribution, whether big or small, is fundamental; not even a person as brilliant as Mirzakhani, as special as she was, did it alone.

And given all the people around her - and who she surrounded herself with - surely she wouldn't have had it any other way.

An **original mind** with a taste for challenges and **tough problems**. The creator of a **magic wand** for proving theorems.

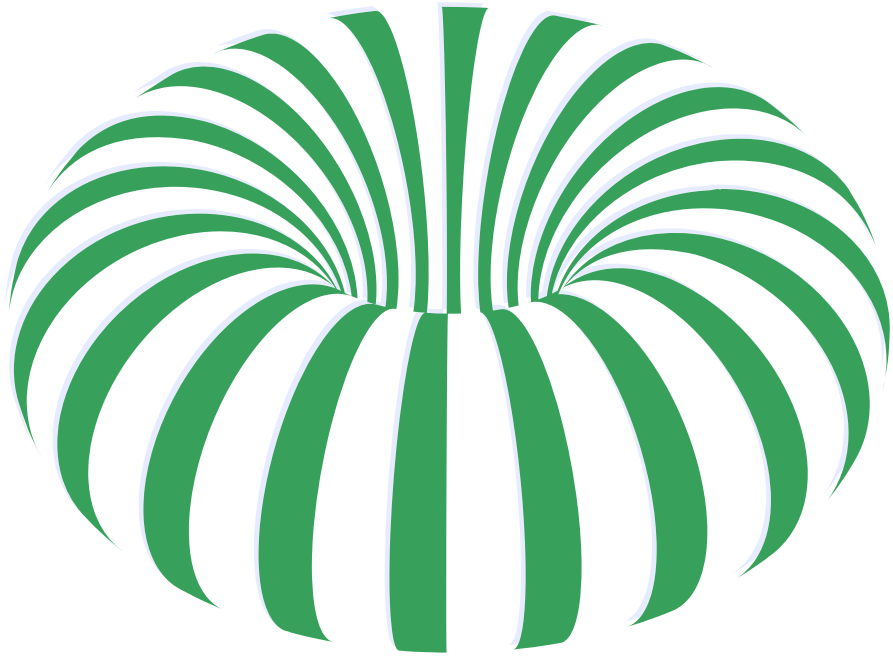
Maryam's Mathematics

by the EDITORS
in collaboration with CORINNA ULCIGRAI

Maryam Mirzakhani was an exceptional mathematician, one of the most remarkable mathematical minds of the last millennium. Born in Tehran in 1977, she won two gold medals at the International Mathematical Olympiad as a young woman, and then graduated with a mathematics degree from her home city's Sharif University of Technology. Her achievements earned her admission to Harvard University, where she wrote an extraordinary doctoral thesis under Curtis McMullen; her findings were published in some of the major international math journals. In 2009, she became a professor at Stanford University, where she spent the remainder of her career. In 2014, she became the first woman to receive the Fields Medal, considered one of the most important awards in mathematics.
Over the years, Maryam Mirzakhani worked on some of the most compelling mathematical challenges in her field, throwing herself into the study of very profound problems which in some cases took several years to solve. Indeed, she always had an original perspective on the problems she studied and relished difficult endeavors. She was never afraid to aim high and was an incorrigible optimist, both in math and in life. In this article, we'd like to outline the fundamentals of her work and the type of problems she took on and solved or in trying to solve created powerful mathematical tools.
Part of her research focused on the study of dynamical systems, the area of mathematics that seeks to understand how sets of objects evolve over time (a ball, a planet, gas molecules) and what their collective behavior is like. However, her point of departure were the curves on Riemann surfaces. To picture these surfaces, which are named after the

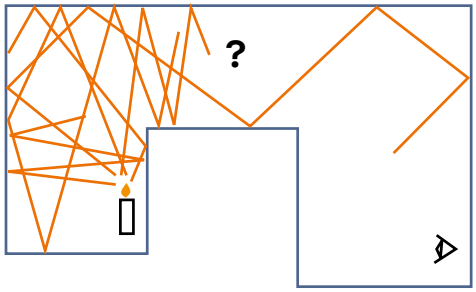
19th century German mathematician Bernhard Riemann, you can think of an object in space, something like a sphere, donut, pretzel, or even several pretzels attached to one another. Each point might have a slightly different curvature: the outside of a donut is more rounded, while the inner part is shaped more like a saddle. On the other hand, if you look at a sphere, you see that it is equally curved at all its points. If you take a piece of clay, which can have various kinds of curves and dimples but no hole, if you shape it without breaking it you can make it into a sphere, i.e. an object that has the same curvature at every point. But then we can ask ourselves if it is possible to gradually make holes in a surface and find an object that still has the same curvature at every point. From the mathematical point of view, the answer is "yes," but it is not easy to do, especially not in our three-dimensional space and in any case a surface can be transformed in all kinds of ways. For example, it can be reshaped (although not always in three-dimensional space!) to make it equally rounded at every point, i.e. so that every point has what in math is called "constant curvature." Surfaces with constant curvature are related to so-called non-Euclidean geometry, which

was discovered in the 1800s, particularly "hyperbolic geometries"; the space that describes them is what is called a "moduli space". Mirzakhani, in her thesis, posed the analogue of the following problem: how many ways are there to roll a certain length of elastic around a donut or a pretzel without ever crossing itself, if the surface being studied has constant curvature (and one of these hyperbolic geometries)? Mirzakhani manages to link this counting problem to calculating a certain volume in space of the moduli spaces with an ingenious formula. And thanks to this formula, it is also possible to re-prove various theorems that have applications in quantum field theory. In various subsequent works, Mirzakhani studied how a ball moves on a billiard table. We're talking about mathematical billiards, which means frictionless areas of a plane, where the ball (which becomes an idealized point) moves forward at constant speed in a fixed direction until it hits the side of the billiard table. At that point, it bounces in a perfectly elastic way (i.e. without dispersing energy) according to the laws of geometric optics: the angle of reflection is equal to the angle of incidence. Since there is no friction, the ball remains in motion infinitely, bouncing off the sides, also because, as in "international billiards," there are no pockets! And there's another important difference: the billiard table can be any shape: it can be a rectangle, but also a circle, or a trapezoid. There can also be obstacles or barriers inside, and they can also be convex or concave in shape, with several inlets. Polygonal billiard tables delimited by simple segments are very frequently studied. These types of seemingly abstract problems have always been of interest mathematicians, in part because many of them that come from physics (optics, acoustics, mechanics, thermodynamics) are modeled by billiards, and also because billiards constitutes a "simple"

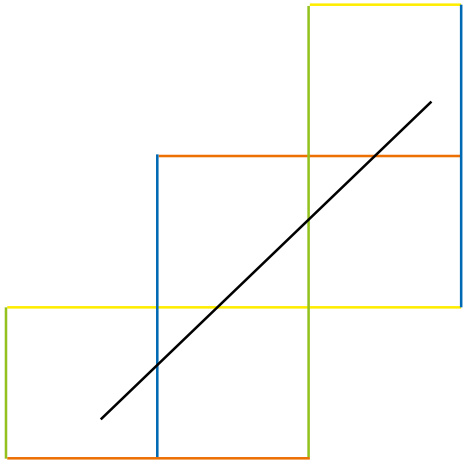


model of a chaotic system; it's easy to describe, but filled with often difficult questions, with answers that require great imagination and that delve into the field of dynamical systems.
To introduce a little terminology, the trajectory of the ball is called an orbit, and in fact the study of dynamical systems can often be reduced to understanding the properties of the orbits of the objects being studied. For example one asks whether the orbits are periodic or not, i.e. whether the ball passes over the same points and with the same speed and direction after a certain time. This will generally not be true and will strongly depend on the geometry of the billiard table and the starting point and perhaps with a starting point there can be various types of periodic orbits. Then one can ask if an orbit is dense, i.e. if given any point on the billiard table and a circle of a given radius around the point, sooner or later the orbit will pass through the small circle. Performing mathematics on billiards requires seeing them in much more abstract environments and thus considering them in spaces where every point is a surface with particular characteristics. And it is on these very spaces that Maryam Mirzakhani, in collaboration with Alex Eskin from the University of Chicago, proved a fundamental theorem, inspired by another similar, surprising mathematical phenomenon discovered some years earlier by Marina Ratner. Justifying this theorem requires a number of techniques from different areas of mathematics, and the theorem itself turned out to be a very powerful tool for solving problems related to billiards (and more) that previously seemed impossible to solve, in fact it came to be called "the magic wand." Even just stating the magic wand theorem isn't easy, but we can point to effects of this result obtained in the years thereafter by other mathematicians.
Here is an interesting problem to which we can apply Maryam's magic wand: given a point P on a polygonal billiard table, which Q points can I reach in a finite time with a ball bouncing off the sides? This problem corresponds to a theoretical illumination problem. Suppose we're in a room with polygonal or curved walls and walls with mirrors. If I

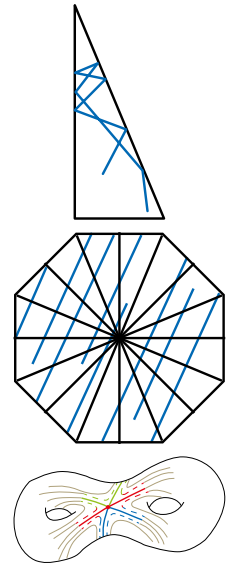
place a candle at point P, which points in the room will be illuminated, assuming that the light propagates according to the laws of geometric optics and without scattering? With some examples that had been found in the ’50s (such as the famous room with curved walls designed by mathematician Roger Penrose) we learn that there are some rooms in which there is always at least one point of shadow. What can we conclude, very broadly speaking?



For certain billiard tables, such as rectangular ones, the problem of the ball’s reflection on the sides of the table can be transformed into a problem on surfaces. Rather than making the ball reflect, we reflect all of billiards, so that the ball doesn’t bounce but go straight, entering the adjacent table. In the case of a rectangular billiard table, you can just consider four reflected copies (since reflecting again gives us a copy identical to the original one).



By opportunely identifying the edges in, it can be shown that the rectangle with opposite sides identified two by two is actually equivalent to a donut, a shape that in geometry is called a "torus" (from the Latin "torus," which was a donut-shaped cushion).
So, at least with rectangular billiards, the study goes back to the trajectories of the ball against the various sides to the motion of a ball spinning without obstacles over the surface of a torus!
And this construction can be repeated with polygonal billiards where the angles are rational multiples of ϖ. For example, using a triangle with the angles ϖ/8, 3ϖ/8, ϖ/2, and using this reflection technique, you find an octagon with identified sides and by sticking them together, you get a surface with two holes: a pretzel!



Reformulating the illumination problem in this way for rational polygonal billiard tables, with the magic wand it is then possible to demonstrate that for each point P on the billiard table, there exist at most a finite number of points that are not illuminated. This result was demonstrated by Samuel Leliévre, Thierry Montheuil, and Barak Weiss in 2017 substantially using Mirzakhani’s ideas.


I LOVE MATH! I'M ESPECIALLY INTERESTED IN HYPERBOLIC GEOMETRY AND...
THAT'S NICE DEAR... BUT WHAT ABOUT A BOYFRIEND?
LEONI

A **model** for so many **young women** in her country. The **first** female mathematician to win the **Fields Medal**. Modest and unpretentious. This is how those who knew her remember her.

In Memory of Maryam

INGRID DAUBECHIES

"It set a bell ringing in my heart." That is how my friend and Australian colleague Nalini Joshi described her elation when she learned in June 2014 that Maryam Mirzakhani would be awarded a Fields Medal at the 2014 International Congress of Mathematicians to be held a few month later in Seoul, Korea. It was the first time that a woman would receive this prestigious award, establishing unequivocally that women can be as brilliant in mathematics as the highest achieving men.

Maryam Mirzakhani was already a hero to many young Iranians interested in science or mathematics—she had been the first Iranian (male or female) to obtain two gold medals (in two consecutive years) at the International Olympiad for Mathematics, the annual world championship competition for high school students, with a perfect score the second year. The Fields Medal catapulted her to worldwide name recognition.

Maryam Mirzakhani was a bit taken aback when she first learned that she had been selected for a Fields Medal. As then-President of the International Mathematical Union, the organization that awards the Fields Medals, I had the job in the Spring of 2014 to contact the four awardees selected by the Fields Medal Committee. It took a few days before I could get hold of Maryam—I had left messages that I was trying to reach her, and when I finally spoke to her, she admitted that she had received the messages but thought they were a prank. According to people who knew her well, this unassuming attitude was entirely characteristic of Maryam.

Although we were colleagues at Princeton University for a few years, I didn't know Maryam very well. In 2009, I took part in a short course organized by Anna Wienhard during Spring Break, in which she and

several graduate students were going in detail through some papers by Marina Ratner. It seemed a great opportunity to learn beautiful mathematics that lay completely outside my own field, and I attended several of the presentations; apart from Anna herself, Maryam and I were the only faculty. One time, when I had gotten completely lost, Maryam and Anna gently explained to me the point I had missed.

I was looking forward to getting to know Maryam better, but that Fall she and her husband Jan Vondrák moved across the US, to Stanford University.

Many mathematicians expected that it was only a matter of time, now that more significant numbers of women were working in mathematics, and obtaining results at the highest levels, before a Fields Medal would be awarded to a female mathematician for the first time. It was nonetheless a great joy when it did happen, and it was all the more special for me because the award went to Maryam who so absolutely deserved it, and also because it just so happened that it was "on my watch".

Unbeknownst to most of the Fields Committee members, Maryam had been diagnosed with breast cancer the year before, in 2013; for a while it was not clear whether she would be well enough to attend the ICM in July 2014. By the time of the ICM she was still experiencing many side effects of the cancer treatments she had undergone and from which she was slowly recovering. Her illness was not really a secret, but she preferred not to discuss it with the media, and the mathematics community respected her wishes. In order to help protect Maryam from possibly excessive and intrusive media attention, a small number of other prominent women mathematicians (including Nalini Joshi) were told the momentous news ahead of time, in the greatest confidence—they were to constitute the "MM shield", hovering discreetly in the background, ready to "run interference" whenever needed.

We all felt so happy that Maryam and her family could come celebrate in Seoul with the whole international mathematics community; her little daughter Anahita was often by her side in these celebrations, enjoying the attention and the occasional pageantry.

At the 2014 ICM, Maryam wasn't well enough to give her plenary talk; it was expected she would simply give it at the next ICM, in 2018. Sadly, this was not to be—the cancer recurred in 2016, and took Maryam away in 2017. Although our loss cannot be compared to that of her immediate family, many female mathematicians, including myself, experienced her passing as that of a family member.

Let me end here by paraphrasing Nalini again:

> *Somewhere in the world, now or in the future, there is a little girl or a woman, brave, persistent, driven to discovery through relentless questioning, who is deeply talented, who may win a Fields Medal again.*

The bell is still ringing in my heart.

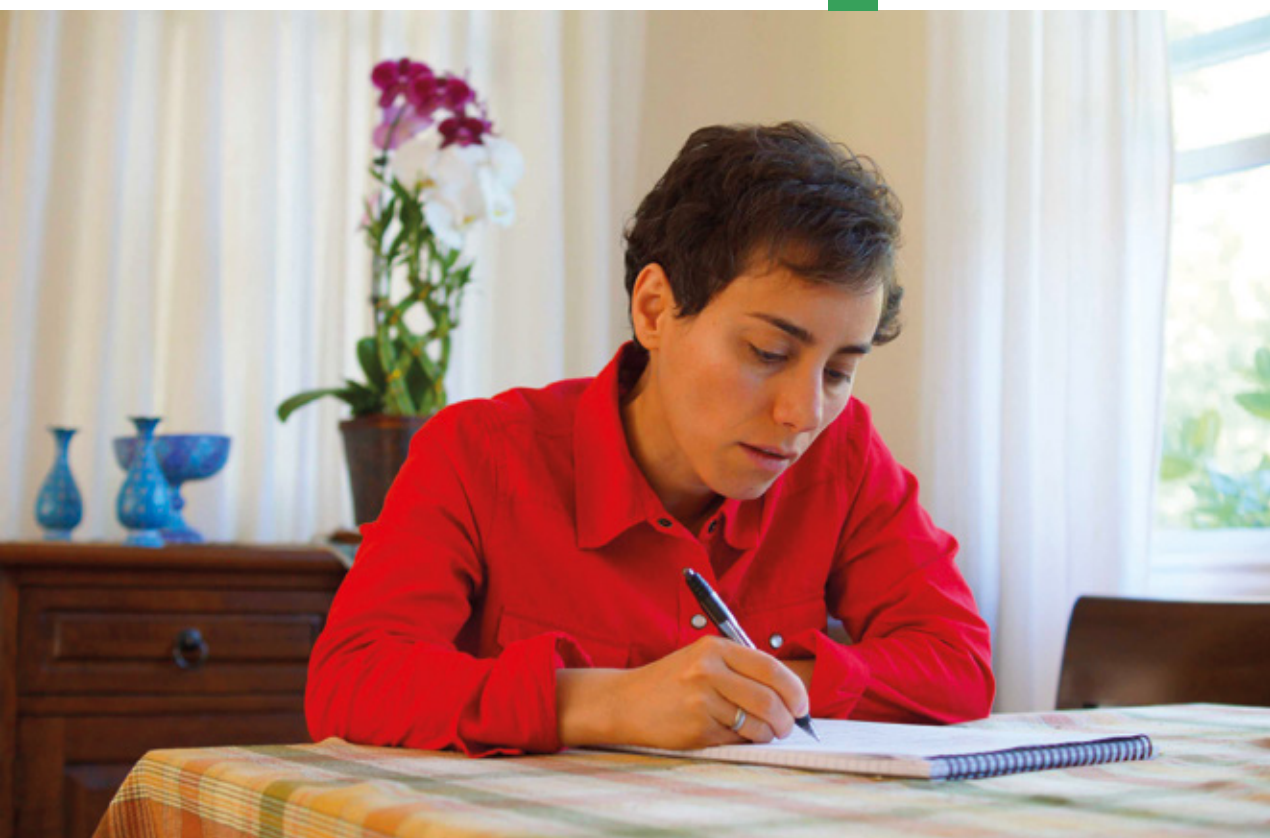
When **the ball** goes beyond billiards and strikes new generations.

Open Letter

DONATA MOSCHELLA

Dear Maryam,
My name is Donata. I'm 17 and I am in my final year of art high school. A few days ago, a friend of my mother's asked her if I wanted to read an advance of a comic about you. I didn't know anything about you, but this woman, who teaches at the university, told me that Silvia Ziche had drawn you (an idol of mine ever since I read Topolino as a child and even more so now that I'm studying art!) and I agreed immediately. I did a little internet research and I found out who you were: an incredible mathematician who was originally from Iran who won a prize, the Fields Medal, which everyone calls "the Nobel Prize of math."
I don't have a great passion for scientific subjects and the thing that really interested me was seeing how the panels were constructed, the lettering, what is the procedure by which they're colored, but I confess that I was just as fascinated by you and your story.
Many things about the comics were explained to me by my math and physics teacher, a quirky but very cool guy, who when he teaches us about Galileo takes an orange, puts a pin in it and spins it around the trash can.
That the bartender was Gauss (and why the line of customers was in that shape) or the strange guy sitting behind the counter who looks like Lucy from Peanuts (what is a "matrix"? Does it really serve a purpose?) I didn't know, and had to look up, while the story of Fermat who found a proof too long to be written on the border of the book and that of poor Fibonacci chased by all those rabbits I had already heard about.
What I didn't expect about math and that at the beginning left very puzzled is the fact you say has to do with creativity: you learn prefabricated things in school, and nobody thinks there's anything left to

discover. For us students it is absolutely amazing to imagine that there are still things to explore in this subject. To be honest, I never really understood what my mom's friend did for a living and reading your story has given me at least an idea of the meaning of what she talks about so passionately and calls "doing research."
Something else that really struck me about your story is what it says about the difficulties that women encounter in your field: certainly there are still many prejudices about what women can do, and to see that there have been very few women mathematicians in the past - because it was commonly believed at the time that they weren't capable of innovative ideas and therefore couldn't teach at the university - makes me sad and also a little angry: I have no desire to live in a world where what I can and cannot do depends on the fact that I am female and not male!
But the images of the billiard ball bouncing and leaping over the side in order to keep going made me think that there's always a way out of an enclosure.
No woman ever won that award before you did and you were the first. I hope there will be many other girls who will be able to follow their passions without someone saying that they're not good enough or will wind up alone because they decide to become scientists.
At one point in the comic you explain how the fact that you chose math is also because of some of the people depicted in the comic.
It's nice to hear, because it's like there's a kind of chain that binds people together, each descending from the other, and that really makes me think that there will be many more boys and girls who might be inspired to become mathematicians thanks to your story.
I don't think I'm going to study science when I go to university, but certainly reading your story showed me that people who are fascinated by math aren't as weird as I thought—in fact, seeing that they are as curious and creative as artists really touched me and made me realize what we have in common.
Thank you Maryam, for your story.




YOUR STUDIES HAVE MADE AN ESSENTIAL CONTRIBUTION TO SCIENCE, YOU'VE RECEIVED PRIZES AND HONORS, BUT NOW, I ASK YOU: DO YOU FEEL COMPLETELY FULFILLED? ISN'T SOMETHING MISSING?
DON'T YOU FEEL REMORSE FOR THE TIME IT'S TAKEN AWAY FROM YOUR FAMILY?
IN WHAT SENSE?
BUT WHAT...
WINNING THE NOBEL IS GREAT, BUT DON'T YOU THINK, AS A **MOTHE... OOPS! SORRY!** THOSE QUESTIONS WERE FOR YOUR **COLLEAGUE!**
LEONI