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1 The quest begins

The discovery of the exoplanets is undoubtedly a technological feat. But without exceptional people, there would not be any technological feats. So it's equally – and maybe even primarily – a human adventure, a personal experience, and, for this reason, is better narrated in the first person singular, in the voice of Michel Mayor. This will essentially be the case in the first chapter, but also every now and then in later chapters (especially Chapters 6, 7 and 8). These uses of 'I' are like memories which suddenly bubble up to the surface during particular scenes. And during the numerous interviews that took place between the scientist and the journalist, there were many of these bubblings. So, henceforth, 'I' and Michel Mayor will be indistinguishable.

Having made this comment, all that remains to be done is to set the scene by beginning with a trip through time and space. It's October 1995, in Florence, the seductive Tuscan town where art and science live hand in hand in idyllic happiness. It's there that it all starts, where the discovery would see the light of day.

For Didier Queloz, my young collaborator, it's his first trip ever to Italy. Given the (happy) circumstances which brought us here, he decided to celebrate the event, sharing a room in a beautiful hotel, combining luxury and quaint charm, with his wife, Valérie. Each evening, a housekeeper elegantly prepares their bed and brings each of them a pair of slippers. My wife, Françoise, and I have chosen a nice, small hotel which I liked the last time I came here.

The conference which we are participating in should last from 2 to 8 October 1995, and my presentation is planned for the 5th. This week of science is devoted to cold stars. This is what, in our specialist

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jargon, we call stars that are the least hot. By this yardstick, our Sun, with its average surface temperature of 5800 °C, is a member of the cold star family. It's far too cold to compete with stars with temperatures above 20 000 °C.

Paradoxically, Didier and I are not here to talk about stars, instead we want to talk about planets. Or rather about *a* planet, the first one ever discovered outside of the Solar System around an ordinary star. We discovered it a few months ago around 51 Pegasus (also called 51 Peg), a star more or less like the Sun, located in the northern constellation called Pegasus.

Officially, we're bound to secrecy until the public release of our article in the British magazine *Nature* in a few weeks. But the editors finally agreed that we could give a lecture during this conference. In any case, the rumour according to which a team from the Observatory of Geneva had possibly discovered an exoplanet (a planet located outside of the Solar System) has already been circulating for some time among astronomers.

I arrived in Florence, and the hotel receptionist gave me the key to our room, together with an impressive pile of faxes. It was clear that the rumour had spread beyond the private circle of astronomers. It had reached the general public. Newspapers from around the world were asking me and even begging me to call them back as quickly as possible to agree on an interview regarding the first exoplanet around an ordinary star. Unfortunately, there was nothing that I could do. The *Nature* team were unequivocal. They agreed that we could talk to our colleagues, but they forbade us from giving the merest hint of an interview before publication of our article.

This half-solution yielded an ironical result. After my presentation, I was obliged to refuse to answer all the questions fired at me by the press, radio and TV journalists, who, instead, turned to my colleagues for comments. Everybody's talking about our discovery. Except for us! Didier and I watched this ballet without bitterness. We'd been overtaken by the pace of events. Our nights of work at the Observatoire de Haute-Provence (OHP) were certainly not enough to prepare us for all this fuss.

STARS FIRST

I was not born – in 1942, by the way – as a planet hunter. In fact, I got there rather late, many years after the great American experts Geoffrey Marcy and Paul Butler, or the Canadians Gordon Walker and Bruce Campbell. However, as far back as I can remember, science has always attracted me. Whether it's physics, chemistry or biology, I've always enjoyed exploring the secrets of Nature. Where does this curiosity of mine come from? I haven't got the foggiest idea. My parents were not scientists. Maybe I owe some of my interest to Edmond Altherr, an extraordinary man who was responsible for teaching the sciences in my college in Aigle, in the Vaudois region. He had studied biology and wrote a thesis on nematodes, those microscopic worms much utilised by geneticists today. Hundreds of Aigle children are indebted to this man not only for his knowledge of nematodes but also for his enthusiasm, pedagogical sense and most especially for his lectures covering the full glory of Nature, the flowers, trees and animals.

After completing my high school final exams, known as the 'maturity' in Switzerland, or the 'baccalauréat' in France, I found myself at the threshold of starting university. I hesitated between studying maths and physics, and finally chose physics. I hesitated again after obtaining my first degree in 1966. Two thesis subjects were proposed to me. The first was to do with solid state physics, the second was in astrophysics. The decision was made during drinks with a friend from my graduation class, who was, I think, as undecided as I was. Finally, he chose solid state physics while I chose the road to the stars. Maybe because I liked watching the sky and the flickering of stars when I was a young scout and we spent the night outdoors.

I joined the staff of the Observatory of Geneva, and I got stuck into stellar dynamics, a subject bubbling with interest. At the time, astronomers were especially excited about the spiral arms of certain galaxies such as our own, the Milky Way. How, they asked themselves, is it possible that such structures, measuring up to 100 000 light-years in size, could not only be created, but also remain in existence for hundreds of millions of years? A galaxy doesn't rotate as a solid body. Its main elements, stars, don't support each other, even if

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they do influence one another. For the stars at the edge of the galaxy to remain perfectly synchronised with the stars at the galactic centre, they would have to accelerate at speeds which are simply unimaginable. An impossible feat. So, the heart of the galaxy turns faster than its edges, in a grand ballet that specialists call 'differential rotation'.

This particular aspect of galactic dynamics provides a good explanation of astronomers' observations, but it fails to enlighten us as to why certain galaxies, such as the Milky Way, have huge spiral arms, usually two, sometimes four.

This puzzle was solved by two American theorists, Frank Shu and C. C. Lin. They proposed, in a paper that became very famous, the existence of density waves in a galaxy, which were generated by the mass in the galaxy. These waves were proposed to propagate through the carpet of stars with a constant angular speed: in other words, like a windscreen wiper that sweeps the galaxy, slowly, but uniformly. It is these waves that create the spiral arms. Not only do the waves create the spiral arms, but inside of the arms, they initiate the gravitational collapse of numerous clouds of interstellar gas into tight, dense objects, which light up and burst forth to the eye as myriads of bright, blue, young stars.

The pioneering work by Shu and Lin trailed in its wake an explosion of related research. My thesis was part of this revolution. I had to study one particular aspect of their theory. The two Americans had predicted that stars that fall into the field of one of these gravity waves must initially slow down, but then accelerate again once they are freed from the grasp of the wave. Are these changes measurable on small scales? In other words, among stars in the solar neighbourhood, is it possible to discover differences in speed that reveal the discreet, but significant influence of these cosmic waves? These were the questions that I had to tackle.

There was not much choice about what had to be done. My absolute priority was to gather data on stellar speeds in the solar neighbourhood. In order to avoid long and boring observations, I delved into stellar catalogues, patiently compiled by generations of astronomers, which gathered together thousands of stars classified according to their properties. It was a painstaking task and I found that samples were too small, measurements were not precise enough, nothing really satisfied me. The technology of the time had its limits, and it's these that pushed the theorist that I am to think about instruments and the way to improve them. But I lacked the know-how. Luckily, a meeting with a man and his machine allowed me to progress from thought to action.

In the summer of 1970 I went to Cambridge to participate in a conference on one of the most intractable problems of stellar dynamics, that of *N*-body systems, which has to do with gravitational interactions between many objects (*N* bodies). This is a research field that concerns galaxies as much as stars.

George Contopoulos, an eminent theorist from the University of Athens, was also at the conference. I was itching to ask him some questions related to my thesis. When I asked him to spare me a few minutes, he just gave me a blank look. Clearly, I was not the only one wanting his attention. His diary was overflowing with appointments and I was only a twenty-eight-year-old postgraduate student. Despite everything, he agreed to listen to me while we visited the domes of Cambridge Observatory, which, I think, don't particularly excite him. It's just that Contopoulos is a pure-blooded theorist, one of those who don't pay much attention to the world of instruments.

I was so busy listening to Contopoulos that I barely glanced at the telescopes that were being presented to us until we entered the umpteenth dome, where a man of some thirty-five years was going about his business. Roger Griffin is one of those scientists fashioned by legend, who cultivate solitude and discretion with the same intensity. He's a perfect example of man–science symbiosis, an observational fanatic. His house is less than a kilometre from Cambridge Observatory. Each night, he pokes his nose outside, looks at the sky, and if the night is clear, jumps on his bicycle and rides to the Observatory. It's easier to understand his haste when you know just how little suited the English climate, often grey and rainy, is to the study of the stars.

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A REVOLUTIONARY INSTRUMENT

At the time, Griffin was working on a new spectrograph, which was inspired by the work carried out fifteen years earlier by one of his compatriots, Peter Felgett. The radial velocity spectrograph, as it is called, measures one of the components of a star's velocity. Projected on the celestial sphere, stars can move either to the left or right, or up or down. And if they move fast enough, their movement becomes visible over the years. Also, the same stars can either approach or recede from the Sun along our line of sight (the radial viewpoint). But we cannot observe this latter movement by eye. It's here that the spectrograph comes into play, due to its ability to decode all sorts of light, in particular that of stars. By separating out the light rays, according to the principle of the prism, the spectrograph shows whether a bright source is approaching or receding, and at what speed it is moving.

The apparatus that Griffin was using to study radial velocities was a huge improvement relative to everything else that was available at the time. In relative efficiency, his equipment was a thousand times better than the best instrument elsewhere. I understood in that instant, while listening to the words of my British colleague, that his ingenuity had sky-rocketted us from the age of the wooden wheel to that of the Formula 1 tyre! The power of this new spectrograph was exactly what was needed to revolutionise stellar dynamics, to create star catalogues of unheard-of precision, and finally to look for much less massive binary stars than was possible in the past.

A binary star is a system of two stars, close enough together that they attract one another. Sometimes, the two components are of equal mass and luminosity. Sometimes one of them is so faint, drowned by the light of its neighbour to such an extent, that it's invisible to us. In that case, how can we know whether a star is solitary or not? There are various techniques. One of them is based on the influence that every body exerts on every other body due to the force of gravity. This is a universal law. Just as the Sun attracts the Earth, the Earth attracts the Sun, except that it does it in proportion to its tiny mass.

This reciprocal attraction is particularly valuable because it's this that allows us to see the invisible, to detect a star too faint to see, by recording the perturbing movements that it causes on the main star. Under the gravitational influence of its companion, the main star moves over a small circular path, which is revealed by changes in the light that it sends us. The lighter the companion and the heavier the main star, the more subtle these changes are. Thus, the greater the sensitivity and precision of a spectrograph, the better it can detect the slight perturbations of the stars whose light it analyses.

It was by increasing precision that, many years later, we would succeed in detecting some of the first exoplanets. Several years passed, inspired by these new, useful techniques. At the time, even though it constituted a real technological breakthrough, Roger Griffin's instrument was only a prototype: with rudimentary electronics, cogged wheels and lamps. That spectrograph deserves to be displayed in a scientific museum as an example of high quality do-it-yourself. You have to realise that given only a few thousand francs of funding, my British colleague was condemned to a pretty heterogeneous result. Luckily for him, his genius inspired him well. As an excuse for a cooling system, he put end-to-end an old refrigerator, a fan and a tray of silica-gel which he used to prevent the humidity in the air from condensing and blinding the spectrograph. As for thermal insulation of the mirror, he tied a down jacket to the frame with a few strings. However, despite this unbelievable construction, the instrument worked marvellously.

After Griffin's spiel, I continued to fire questions at Contopoulos during the rest of the Observatory visit. I didn't see Griffin again during my entire stay, but back in Geneva, I talked of nothing but him and his spectrograph. I had to persuade my Genevan colleagues to try to build a spectrograph ourselves. The answer given to me by Marcel Golay, the director of the Observatory of Geneva at the time, was 'Well, if you want to do it, then do it!' He was challenging me to put my words into action, undoubtedly to see how determined I really was.

Before thinking of how to finance the spectrograph, I had to start with some theoretical calculations. Some of my colleagues gave me some heavy duty help in making the first numerical simulations. The optical system of the telescope was a particular source of worry. I understood nothing, or next to nothing, of the subject. I really tried to read several specialised papers, but in vain. Optics was another world, the inhabitants of which were scarce. At the time, I only knew one, someone famous: André Baranne, from the Observatoire de Marseille.

Although not expecting his active participation – he is in great demand – I hoped to get some advice from him. I telephoned him to fix an appointment. I hoped to take advantage of a week of work at the Observatoire de Haute-Provence, in May 1971, in order to go to Marseille and meet him. André immediately agreed to my visit. He's not the sort who wastes time in procrastination. He's very direct, to the point of talking quite bluntly, with everything implied by this when it comes to making friends or enemies. Born in 1933 in Bagnères-de-Bigorre, a region that breeds many rugby players, André is of a thickset build, which perfectly matches his straight talking character. He is someone who enjoys life, taking as much pleasure from eating as laughing. My three children have greatly enjoyed his tall tales, told in his magnificent Gascon accent.

I couldn't have been more surprised when, a quarter of an hour after the beginning of our interview, André Baranne burst out with: 'OK, I'll handle the optics!' Not only did he not send me back to square one, but he wanted to be part of the adventure. I couldn't contain my excitement. With astonishing speed, he spotted all the difficulties, all the points with which he would have to deal. He was already outlining solutions. Without a doubt, I had before me a worthy representative of the École supérieure d'optique in Paris, whose reputation goes well beyond the French border.

André immediately came up with a trick of optics that would improve the performance of our spectrograph. Without going into details, it's a certain way of separating the light arriving from stars in order to give a two-dimensional spectrum, so that much more precise

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measurements become possible. At the time, nobody believed this technique would work. Two studies concluded that it was not feasible. Ironically, one of them was written by Roger Griffin himself. I also remember that Jim Brault, an American optical astronomer visiting the Observatory of Geneva, had told us how pessimistic he was of our chances of success. But it would have required a lot more to shake the faith of André. He was convinced of the feasibility of the technique. He was right.

I put the finishing touches to my thesis in the summer of 1971. The day after submitting the thesis, I jumped on a plane heading to London. Roger Griffin, the astronomer magician, had agreed to act as my host for a few weeks, giving me time to understand how the spectrograph worked. This was a big task, but the friendliness of my British colleague lightened the workload. I returned from Cambridge with my head full of plans and projects, and back in Geneva, I applied for a grant from the Fonds national suisse de la recherche scientifique (FNRS). In 1972, I obtained a hundred and fifty thousand Swiss francs [translator: roughly a hundred thousand euros, ignoring inflation] for a period of two years.

Roger Griffin's instrument had certainly made a deep impression on me, but I was also alarmed by the large number of hand calculations required. Much of the data reduction was done by ruler, pen and paper. Griffin could do this with uncanny ease, but I personally didn't have the stomach for it. I preferred to do all calculations on a computer and let a young doctoral student in physics specialising in electronics, Jean-Luc Poncet, do the work of programming the machine.

It took us five years to design and construct our two spectrographs, one for each terrestrial hemisphere. The first was installed at the Observatoire de Haute-Provence (for the North) and the second in the Chilean observatory at La Silla (for the South). Five years can seem like a long time. However, in the early 1970s, computers had neither the speed nor the power of those of today. It turned out to be painfully difficult – apart from opting for a perfected machine, which was beyond our means – to get them to carry out several tasks simultaneously. But multi-tasking was something we direly needed. Jean-Luc Poncet had no choice other than to completely rewrite the operating system. We wanted our computer to be a sort of computerised Shiva, able to seize everything that we prepared for it with its multiple arms.

For a long time the multi-tasking programme remained too big for the memory of our machine. Eight kilobytes was the entire capacity that we had at the time, compared with the basic office computer of today which can easily store a million times more. Two months before the date at which it was planned to put Coravel (CORrelation Velocity), the spectrograph destined for the OHP, into service, Jean-Luc, after having tried all the tricks he could think of, gave up. Nothing helped. The programme refused to be adapted to the tiny memory. Luckily, we found a second-hand memory extension card for the modest sum of twenty thousand francs. Well, that was the dawn of the computer age!

The first experiments using Coravel started in April 1977, after it had been attached to the 1-metre telescope at the OHP. As the designer of the instrument, I had to take on certain additional tasks. Even though, thanks to computerisation, the spectrograph gave almost instantaneous measurements, these still required further refinement before being catalogued. It was the work of a beast of burden which had to be added to my other research. In essence, the latter consisted of looking for all the ways in which Coravel could be used. It turned out, for example, that Coravel is perfect for measuring the radial velocity of stars, and for measuring their rotation and the elementary composition of their atmospheres.

GRADUALLY APPROACHING THE PLANETS

Five years later, I decided I needed reinforcements. There was a young Frenchman, Antoine Duquennoy, who had been at the Observatory of Geneva for several months. He was an astronomer and a signal analysis expert who had obtained permission to carry out his military conscription duties with us. He was a lad from Amiens, introverted, very discreet, highly intelligent and gifted with a rare capacity for hard