THE INTERNATIONAL BESTSELLER

THE UNIVERSE IN YOUR HAND

A JOURNEY THROUGH SPACE, TIME AND BEYOND

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A Journey Through Space, Time and Beyond

MACMILLAN

To Marius & Honoré

Contents

Foreword

Before we start, there are two things I would like to share with you.

The first is a promise, the second is an ambition.

The promise is that the book contains only one equation.

Here it is:

$$\mathbf{E=mc^2}$$

The ambition, my ambition, is that in this book I will not leave any readers behind.

You are about to start a journey through the universe as it is understood by science today. It is my deepest belief that we can all understand this stuff.

And that journey begins a very long way from home, on the other side of the world.

Part One

The Cosmos

1 | *A Silent Boom*

Picture yourself on a faraway volcanic island on a warm, cloudless summer night. The surrounding ocean is as still as a lake. Only the tiniest of waves wash against the white sand. All is quiet. You are lying on the beach. Your eyes are closed. The warm, sun-baked sand heats up air saturated with sweet, exotic scents. There is peace all around.

A wild shriek in the distance makes you jump and stare into the darkness.

Then: nothing.

Whatever shrieked is now quiet. There is nothing to be afraid of after all. This island may be dangerous for some creatures, but not for you. You are a human, the mightiest of predators. Your friends will soon be joining you for a drink and you are on holiday, so you lie back on the sand to focus on thoughts worthy of your species.

A myriad of tiny lights flickers throughout the vast night sky. Stars. Even with the naked eye you see them everywhere. And you remember questions you had as a child: what are they, these stars? Why do they flicker? How far away are they? And now you wonder: will we ever *really* know? With a sigh, you relax back on the warm sand and put these silly questions aside, thinking why should we care?

A tiny shooting star gently streaks across the sky overhead and, just as you are about to make a wish, the most extraordinary thing happens: as if to answer your last question, 5 billion years suddenly pass and the next thing you know, you are no longer on a beach, but in outer space, floating through emptiness. You can see and hear and feel, but your body is gone. You are ethereal. Pure mind. And you don’t even have the time to wonder what just happened or to shout and call for help, for you are in the most peculiar of situations.

In front of you, a few hundred thousand miles ahead, a ball is flying against a background of tiny distant stars. It glows with a dark orange light, moves towards you, spins. It doesn’t take you long to figure out that its surface is covered with molten rocks and that what you are facing is a planet. A liquefied planet.

Shocked, a question comes to your mind: what monstrous source of heat could liquefy an entire *world* like this?

But then a star, immense, appears to your right. Its sheer size, compared to that of the planet, is just astounding. And it spins too. And it also moves through space. And it seems to be growing.

The planet, although much closer, now looks like a child’s tiny orange marble facing a gigantic ball that continues to grow at an astonishing rate. It is already twice the size it was a minute ago. Presently, it has a red hue, and it angrily ejects huge filaments of million-degree-hot plasma that blast through space at what seems to be very close to the speed of light.

Everything you see is of a monstrous beauty. In fact, you are living through one of the most violent events the universe can provide. And yet there is no sound. All is silence, for sound does not spread in the vacuum of space.

Surely the star won't be able to keep growing at this rate; and yet it does. It is now beyond any size you could have imagined and the liquefied planet, pounded by energies beyond its strength, is blown to nothingness. The star did not even notice. It keeps growing, reaches about a hundred times its initial size and then, quite suddenly, it explodes, firing all the matter it was made of into outer space.

A shock wave passes through your ghostly form, and then only dust remains, blown in all directions. The star is no more. It has become a spectacular and colourful cloud that now spreads into the interstellar void at a velocity worthy of gods.

Slowly, very slowly, you come back to your senses and, as you realize what just happened, a strange lucidity fills your mind with a fearsome truth. The star that died was not a random star. It was the Sun. Our Sun. And the molten planet that vanished within its brightness was the Earth.

Our planet. Your home. Gone.

What you witnessed was the end of our world. Not a speculative end, not a far-fetched fantasy of supposedly Mayan origin. The real one. One that mankind has known would happen since some time before you were born, 5 billion years before what you just saw.

As you try to pull these thoughts together, your mind is instantly sent back to the present, inside your body, on the beach again.

Your heart races and you sit up and look around, as if waking from a strange dream. The trees, the sand, the sea and the wind are there. Your friends are on their way. You can see them in the distance. What happened? Did you fall asleep? Did you dream what you saw? An uncanny feeling spreads throughout your body as your queries start to shift: could it have been real? Will the Sun really explode one day? And if so, what will happen to humanity? Can anyone survive such an apocalypse? Will everything up to the very memory of our own existence vanish into cosmic oblivion?

Gazing once more up at the starlit skyscape above, you desperately try to make sense of what happened. Deep down, you know that you did not just dream it all. Although your mind is back on your beach, reunited with your body, you know you really *did* travel beyond your time, into a faraway future, to see something no one should ever see.

Slowly breathing in and out to calm down, you start hearing strange noises, as if the wind, the waves, the birds and the stars are all whispering a song that only you can hear, and you suddenly understand what they are all singing about. It is both a warning and an invitation. Of all possible futures available, they murmur, only one path will allow humanity to survive the inevitable death of the Sun and most other catastrophes.

The path of knowledge, of science.

A journey open to humans only.

A journey that you are about to take.

Another wild shriek pierces the night, but you hardly hear it this time. As if a seed just planted in your mind was already starting to sprout, you feel the urge to find out what is known about this universe of yours.

Humbly lifting your sight again, you now gaze at the stars with the eyes of a child.

What is the universe made of? What lies in the vicinity of the Earth? And beyond? How far can one look? Is anything known about the universe's history? Does it even have one?

As the waves gently wash over the shore, as you wonder if one will ever be able to probe these cosmic mysteries, the twinkling of the stars seems to lull your body into a half-conscious state. You can hear your approaching friends' conversations but, strangely, you already feel the world differently than you did a few minutes ago. Everything seems somehow richer, more profound, as if your mind and body were both part of something much, much bigger than anything you had ever thought of before. Your hands, your legs, your skin . . . Matter . . . Time . . . Space . . . Intertwined fields of forces all around you . . .

A veil you didn't even know was there has been lifted from the world to reveal a mysterious and unexpected reality. Your mind yearns to be back among the stars, and you have the feeling that some extraordinary journey is about to take you very far away from your home world.

2 | *The Moon*

If you're reading this, it means you've already travelled 5 billion years into the future. A good start, by anyone's standards. So you should be confident that your imagination is working well, and that is perfect, because imagination is all you'll need to travel through space and time and matter and energy, to discover what is known about our reality from an early twenty-first-century perspective.

You didn't ask for it, but you did happen to see what fate awaits mankind, indeed all life forms on Earth, if nothing is done to understand how nature works. To survive in the long run, to avoid being swallowed by a furious dying Sun, our only chance is to learn how to take our future into our own hands. And for this to happen, we need to unravel the laws of nature itself, and learn how to put them to good use. It's fair to say that we have a lot to get through. In the following pages, however, you shall see pretty much everything that is known so far.

Travelling throughout our universe, you will discover what gravity is about and how atoms and particles interact with each other without ever touching each other. You will find out that our universe is mostly made up of mysteries and that these mysteries have led to the introduction of new types of matter and energy.

And then, once you've seen everything that is known, you will jump into the unknown and see what some of the brightest theoretical physicists of today are working on to explain the very strange realities we happen to be a part of. Parallel universes, multiverses and extra dimensions will enter the picture. After that, your eyes will probably be shining with the light of knowledge and wisdom that mankind has been gathering and improving for millennia. But you should prepare yourself. Discoveries made during the past decades have changed everything about what we believed to be true: our universe is not only unfathomably bigger than expected, it is also immensely more beautiful than any of our ancestors could have imagined. And while we're at it, here is another piece of good news: to have figured out as much as we already have makes us humans different from all the other life forms that have ever lived on Earth. And that is a good thing, for most of the other life forms became extinct. The dinosaurs ruled the surface of our planet for about 200 million years, whereas we have done so for no more than a few hundred thousand. They had plenty of time to start questioning their environment and figure a few things out. They didn't. And they died. Today we humans could at least hope to detect a threatening asteroid early enough to try to deflect it. So we already have some powers they did not have. It might be unfair to say it, but with hindsight we might thus link the dinosaurs' extinction to their lack of awareness of theoretical physics.

For now, you still are on the beach, though, and the memory of the dying Sun is still vivid in your mind. You don't have that much insight yet and, to be honest, the twinkling dots that stud the night seem utterly oblivious to your existence. The life and death of earthly species makes no difference to them whatsoever. It appears that time, in outer space, works on scales that your body cannot grasp. The entire existence of a species here on Earth probably lasts no more than a snap of the fingers for such distant shining gods . . .

Three hundred years ago, one of the most famous and brilliant scientists of all time, British physicist and mathematician Isaac Newton, the man who gave us gravity from Cambridge University, England, actually thought in such terms about time: for him, there was the time of humans, felt by us all and measured by our clocks, and there was the time of God, which is instantaneous, which doesn't flow. From the point of view of Newton's God, the infinite line of human time, stretching backward and forward into infinity, is but an instant. He sees it all in one blink.

You are not God, though, and as you watch the stars, as a friend of yours silently pours you a drink, the immensity of the task at hand starts to feel overwhelming. All this is too big, too far away, too strange . . . Where to begin? You are not a theoretical physicist . . . but you are not the type to give up either. You have eyes and your mind is curious, so you lie down on the sand and start by focusing on what you can see.

The sky is mostly dark.

And there are stars.

And in between the stars, your naked eye perceives a dim band that glows with a faint whitish light.

Whatever this light is, you know the band is called the Milky Way. Its width looks to be about ten times that of a full Moon. You stared at it many times when you were younger, but not that much recently. As you now see it, you realize that it is so conspicuous that it must have been known to your ancestors since forever, and you are right. Ironic to think that, after centuries during which men and women debated its nature, we now know what it is – although light pollution makes it invisible from most inhabited places.

From your tropical island, however, its presence is overwhelming and, as the Earth spins as the night advances, the Milky Way moves through the sky, like the Sun during the day, from east to west.

The possibility that the future of humanity lies somewhere out there, beyond the Earth's sky, starts to become real in your mind, and spellbinding. Focusing, you wonder if it is possible to see all there is in the universe with the naked eye. And then you shake your head. You know that the Sun, the Moon, some planets like Venus, Mars or Jupiter, some hundreds of stars[1] and that fuzzy streak of whitish dust called the Milky Way don't add up to being Everything. There are mysteries hiding up there, out of sight, between the stars, mysteries that are just waiting to be unravelled . . . If only you could probe it all, what would you do? You would start with the vicinity of the Earth, of course, and then . . . then you'd shoot away and go as far as possible, and then . . . Your mind obliges!

As amazing as it sounds, your mind *does* start to move away from your body, upwards, towards the stars.

A spinning sensation of vertigo hits you as your body, and the island it is lying on, recede rapidly beneath you. Your mind, shaped as an ethereal you, is heading up, and east. How that is even possible, you do not have a clue, but there you are, higher than the tallest of mountains. A very red Moon appears, suspended above a distant horizon, and in far less time than it takes to say it, you find yourself out of the Earth's atmosphere, flying across the 380,000 kilometres of emptiness that separate our planet from our only natural satellite. From space, the Moon appears as white as the Sun.

Your journey through knowledge has begun.

As only a dozen humans have done before, you've reached the Moon. Your ghostly body is now walking on it. The Earth has disappeared below the lunar horizon. You are on its so-called *dark side*, the side that never sees our planet. There is no blue sky, nor any wind, and not only do you see many more stars above your head than from anywhere on Earth, they don't twinkle. All this because there is no atmosphere on the Moon. On lunar soil, space begins a millimetre above the ground. No weather ever erases the scars that scatter its surface. Craters are everywhere, frozen memories of what once hit that barren soil.

As you start walking towards the Earth-facing side of the Moon, the history of its birth magically pours into your eager mind and you stare, dumbfounded, at the ground beneath your feet.

What violence!

About 4 billion years ago, our young planet got hit by another one, the size of Mars, which tore a huge chunk of it off into space. During the following millennia, all the debris from that collision settled into a single ball in orbit around our world. When that was done, the Moon you are now standing upon was born.

Were it to happen today, such a collision would be more than enough to wipe out all life forms on Earth. At the time, though, our world was bare, and it is funny to think that without such a catastrophic bang, we would have no Moon to illuminate our nights, no significant tides, and life as we know it probably wouldn't exist on our planet. As the blue Earth appears in front of you, above the lunar horizon, you realize that catastrophic events, on a cosmic scale, can be for the best just as they can be for the worst.

Your home planet, seen from out here, is the size of four full Moons put together. A blue pearl floating in front of a black, star-sprinkled background.

Our world's true extent in space is, and will always be, a humbling sight.

And as you walk some more and watch it rise in the lunar sky, even though all seems quiet and safe, you already know better than to trust such an apparent peace. Time has another meaning out here and given the eons that continue to unfold, the universe's violence seems unavoidable. The craters that scar the Moon's surface are but a reminder of it. Hundreds of thousands of mountain-sized boulders, adrift in space, must have pounded it over the ages. And they must also have hit the Earth – but our planet's wounds have healed, for our world is alive and hides its past away deep under its ever-changing soil.

Still, within such a universe, you suddenly sense that your home world, despite its ability to heal, is fragile, almost defenceless . . .

Almost.

But not quite. It now has us. It has you.

Collisions such as the one that led to the birth of the Moon mostly belong to the past. Today there are no stray planets menacing our world, just loose asteroids and comets – and the Moon partly protects and shields us from such hazards. Danger, however, looms everywhere and, as you watch the Earth's blue-hued image hang in the dark sky, an extraordinarily bright ball of light suddenly rises behind you.

You turn around to face a star, the brightest and most violent object that can be found near our home planet.

We have named it the *Sun*.

It lies 150 million kilometres away from our world.

It is the source of all our power.

And as your mind becomes passionately overwhelmed by the sheer amount of light that emanates from this extraordinary cosmic lamp, you leave the Moon behind and start flying towards it, our local star, the Sun, to find out why it shines.

3 | *The Sun*

If mankind could, one way or another, harvest all the energy the Sun radiates in one second, it would be enough to sustain the entire world's energy-needs for about half a billion years.

As you fly closer and closer to that star of ours, however, you realize that the Sun is not as big as when you saw it 5 billion years in the future, as it reached its end. Still, it is big. To put things into perspective, if the Sun were the volume of a large watermelon, the tiny Earth would lie some 43 metres away – and you'd need a magnifying glass to see it.

You've reached a few thousand miles above the Sun's surface. Behind you, the Earth is but a bright dot. In front of you, the Sun fills half your sky. Bubbles of plasma are erupting all around. Billions of tonnes of beyond-hot matter are ejected right before your eyes and shoot through your ethereal body, as huge, seemingly random loops open up in the Sun's magnetic field. The scenery is extraordinary, to say the least, and, exhilarated by its power, you suddenly wonder what it is that the Earth lacks that makes the Sun so special. What makes a star a star? Where does its energy come from? And why on Earth does it have to one day die?

To figure this out, you head for the harshest place that can be, the heart of the Sun, more than half a million kilometres below its surface. The Earth, by comparison, is about 6,500 kilometres from surface to core.

As you jump head first into the bright furnace, you remember that all the matter we breathe or see or touch or feel or detect, even the matter your real body contains, is made of atoms. Atoms are the building blocks of everything. They are the Lego bricks of your environment, if you will. Unlike Lego, however, atoms are not rectangular. They are mostly round and consist of a dense, ball-shaped nucleus with tiny, distant electrons swirling around it. Like Lego, however, it is possible to classify atoms by size. The tiniest of them all has been called *hydrogen*. The second smallest has been named *helium*. Take these two atoms together, and you have about 98 per cent of all the known matter in the known universe. A lot, certainly, but a smaller proportion than it was in the past. Some 13.8 billion years ago, it is believed these two atoms accounted for near enough 100 per cent of all known matter. Nitrogen, carbon, oxygen and silver are examples of atoms that can be found today which are *not* hydrogen nor helium. So they must have appeared later. How? You are on your way to find out.

You dive deeper and deeper inside the Sun; the temperature rises and becomes mind-bogglingly hot. As you reach its core, we are talking 16 million degrees Celsius. Maybe even more. And there are plenty of hydrogen atoms everywhere, although they have been stripped naked by the surrounding energy: their electrons are loose, leaving bare nuclei. The pressure is so high, these nuclei are so tightly packed by the weight the whole star exerts on its own heart, that they barely have any freedom to move at all. Instead, they are forced to fuse into one another to become a bigger nucleus. You see it happening right in front of you: a *thermonuclear fusion reaction*, the creation of big atomic cores out of smaller ones.

Once built, as they move out of the furnace that gave them birth, these heavy cores will team up with the lone, free-moving electrons that were stripped away from the hydrogen nuclei, and become new, heavier atoms: nitrogen, carbon, oxygen, silver . . .

For a thermonuclear fusion reaction to occur (the creation of big atoms out of small ones), a stupendous amount of energy is needed, and that energy is here provided by the Sun's crushing gravity, which effectively pulls everything towards its core, thus compressing it immensely. Such a reaction cannot take place naturally on (or inside) the Earth. Our planet is too small and not dense enough, so its gravity cannot make its core reach the temperature and pressure needed to trigger one. By definition, that is the main difference between a planet and a star. Both are roughly round cosmic objects but planets are basically small, with rocky cores that are sometimes surrounded by gas. Stars, on the other hand, can be viewed as huge thermonuclear-fusion power-plants. Their gravitational energy is so big that they are forced by nature to forge matter in their hearts. All the heavy atoms the Earth is made of, all the atoms that are necessary for life, atoms that your body contains, were once forged in the heart of a star. When you breathe, you inhale them. When you touch your skin, or someone else's, you touch stardust. You wondered earlier why stars like the Sun had to die and explode at the end of their lives, and here is our answer: without such endings, there would only be hydrogen and helium around. The matter we are made of would be for ever locked within eternal stars. The Earth would not have been born. Life as we know it would simply not exist.

To look at this another way, since we are not made out of hydrogen and helium alone, since our bodies and the Earth and everything that surrounds us also contain carbon and oxygen and other atoms, we know that our Sun is a second- or maybe even third-generation star. One or two generations of stars had to explode before their dust became the Sun, and the Earth, and us. So, what is it that triggered their death? Why are stars doomed to end their shining lives in a spectacular explosion?

One of the amazing properties of a nuclear fusion reaction is that however huge the amount of energy needed to start it in the first place – the weight of a whole star! – it then releases even *more* energy.

The reason for this may seem surprising, but since you see it happening right in front of your eyes, you have no choice but to accept it: when two atomic cores fuse into a larger one, some of their mass disappears. The fused core has less mass than the two that created it. It is as if mixing one kilogram of vanilla ice-cream with another kilogram of the same ice-cream did not give two kilograms of ice-cream, but less.

In everyday life, that wouldn't happen. In the nuclear world, however, it happens all the time. Rather fortunately for us, the mass is not lost, though. It is turned into energy, and Einstein's famous $E=mc^2$ gives the exchange rate.[2]

In our daily lives, we are more used to exchange rates relating one currency to another rather than mass to energy. So, to see if $E=mc^2$ is a good deal for nature, imagine the same exchange rate is being offered at JFK airport to change pounds sterling (that's the initial mass) into US dollars (the energy one gets for it). The exchange rate is then c^2, where 'c' stands for the speed of light, and 'c^2' is the speed of light multiplied by itself. For one pound, you'd get 90 million billion dollars. A pretty good deal, I'd say. In fact, it is the best exchange rate in nature.

Obviously, the missing mass in each single nuclear-fusion reaction is rather small. But there are so many atoms fused every second within the Sun's heart that the energy released is enormous, and it has to go *somewhere*. So it pushes out into space, away from the star's core, in as many ways as is possible. In the end, the energy from this nuclear fusion balances the gravity that presses everything down into the core, making our star's size stable. Without it, were gravity the only player, the Sun would shrink.

Nuclear fusion emits a tremendous amount of light and particles, which happen to turn everything nearby into a shining soup of nuclei and electrons that is called *plasma*.

This outburst of light and heat and energy is what makes stars shine.

The Sun, being a star, is not a big ball of fire – fire needs oxygen, and although the Sun creates bits of it along with other heavy elements, there's not enough free oxygen in outer space to sustain any fire whatsoever. A struck match would never catch fire in space. The Sun, like all the stars in the sky, is simply a bright ball of shining plasma, a hot mixture of electrons, of atoms stripped of *some* of their electrons (they are called *ions*), and of atoms stripped naked of all their electrons – the bare atomic nuclei.

As long as there are enough tiny nuclei to press together within its core, the Sun's gravity and fusion energy will remain in equilibrium, and we are lucky enough to be living near to a star that is in such a state.

Actually, it has nothing to do with luck.

Were our Sun *not* in that state, we would not be here.

And as you now know, the Sun won't be in that state of equilibrium for ever: our star's core will some day run dry of its atomic fuel. That day, there won't be any more outward push radiating from the core to compete with gravity. Gravity will then take over and trigger the final sequence of our star's life: the Sun will shrink and get denser, until a nuclear-fusion reaction is triggered again, but away from the core, closer to the surface. This reborn fusion reaction will not balance gravity, but overpower it, and the surface of the Sun will be pushed away, making our star grow. You saw it happening during your trip into the future. A final burst of energy will then herald the death you've already witnessed, spreading into space all the atoms the Sun has forged throughout its life while creating some more – the heaviest ones of all, such as gold. Eventually, these atoms will mingle with the remains of other nearby dying stars to form huge clouds of stardust that will, perhaps, seed other worlds in the far future.

It is by estimating the amount of hydrogen left in our star's core that scientists can guess when this explosion will happen, and the result says that the Sun will blow up in about 5 billion years from now, on a Thursday, give or take three days.

4 | *Our Cosmic Family*

What you've discovered about the Sun so far makes you more familiar with it than any human who lived before the middle of the twentieth century. All the light that showers your body day after day comes from atoms being forged in the heart of our star, from parts of their mass being transformed into energy. The Earth, however, is not the only celestial object that profits from the Sun's energy.

In the blink of an eye, your mind is back on the Sun's bubbling hot surface and you look around, like a hawk. Eight bright dots are moving against a seemingly fixed background of distant stars. These dots are planets, matter-filled spheres too small to ever dream of one day becoming a star. Four of them, the four closest to the sun, look like tiny rocky worlds. The furthest four are mostly made out of gas. They are still tiny with respect to the Sun, but they are giants compared to the Earth, the biggest of the four small rocky worlds. Apart from the Earth, however – and even though they were all born out of the same cloud of dust from long-dead stars – none of these worlds and none of their hundreds of moons are a potential shelter for humanity's future. They all are bound by the Sun's gravity, and they will all be gone with our star's ultimate boom. Shelter, if any is to be found, must lie further still.

With a feeling of urgency, your mind shoots as far away as is possible, to have a look at what lies beyond the Sun's sphere of influence. Along the way, you will pay a visit to our planet's distant cousins, the giants of our cosmic family.

You are about three times further away from the Sun than the Earth is. Mercury, Venus, Earth and Mars, the four small rocky worlds closest to the sun, are already behind you. From there, our star is a shining dot half the size of a penny held at arm's length. A typical July midday in the United Kingdom, the hottest day of the year, say, would feel colder than the coldest winter in Antarctica, were the Earth to be here.[3]

Sunlight gets scarcer and scarcer as you move away from our star.

You shoot past some rocks, leftovers from the early days of our planet's formation. They are mostly potato-shaped asteroids that, together, form what astronomers have come to call the *asteroid belt*, a huge ring of rocks that encircles the Sun, separating the four small terrestrial planets from a world of giants. The rocks themselves are pretty scattered and, as you fly through the belt, you realize there's hardly any chance of your hitting one of them. Many human-made satellites have flown through unhindered.

Leaving the belt behind, you now fly past Jupiter, Saturn, Uranus and Neptune, the gas giants, all enormous planets with relatively tiny rocky cores deeply hidden beneath huge, tumultuous atmospheres. All these planets seem to be blessed with a magnificent ring system, although Saturn's by far surpasses, in size and beauty, all the others combined.

You fly by them all and watch them with the respect such gigantic worlds deserve, even though they are not suited for life.

Beyond Neptune, the furthest planet orbiting the Sun, you may have expected to see nothing, but that is not the case at all. Another belt lies there, made of all sorts and sizes of dirty snowballs, again likely by-products of our solar system's birth, when its current members aggregated from the leftover dust of long-gone exploded stars. This belt is called the *Kuiper belt.* The Sun looks like a pinhead from out there, just another star. Hardly any warmth seems to reach these distant parts, but there is some action.

Every now and then, due to collisions or other perturbations, one or more of these dirty snowballs is expelled from its quiet and distant orbit around the Sun. Pushed towards our star, it slowly reaches warmer climes and begins to melt as it speeds against the solar radiation, leaving long tails of small icy rocks shining in the dark; it becomes one of those celestial wonders we call *comets*. The European Space Agency's sturdy Philae probe landed on one in November 2014, to study its surface. The Rosetta spacecraft that took it there, on the other hand, is currently following it, as it approaches the Sun, to watch its outermost layers turn into gas . . .

Poor Pluto – which recently got stripped of its planet title to be reclassified as a dwarf planet – is part of that icy belt too, together with (at least) two other dwarves, called Haumea and Makemake. It is funny to think that Pluto, with its moon Charon, is so far away from the Sun, and has so much space to travel to complete a single revolution of it, that less than one of its own years has passed between the moment it was discovered and called a planet, and the moment it got stripped of that title, seventy-six Earth years later. It indeed took astronomers decades to see that it was actually just a quarter of the size of our own Moon. The dirty-brown Pluto that you now fly by of course hasn't been affected in the slightest by its renaming, and you soon leave it behind too, heading further away still from the safe protection of our shining star.[4] Yet more dwarves cross your path, and more comets, and you even see frozen worlds that no living person has yet discovered, but your attention quickly turns entirely to a gigantic sphere that encompasses everything you've seen so far.

All the planets, dwarf planets, asteroids and comets you've seen lie more or less on a flattened disc at whose centre shines the Sun. But what you are seeing now does not. A reservoir of billions of billions of billions of potential comets forms a huge spherical cloud that seems to occupy all the space there is between the Sun and the realm of other stars. This reservoir is called the *Oort cloud*.

Its size is astounding.

It marks the boundary of our star's realm, which contains all the members of our cosmic family, a family called the *solar system*.

Beyond, you enter uncharted territories and head for what you reckon is the star closest to ours. It was discovered in 1915. A century ago. Just when our universe began to be understood. Its name is *Proxima Centauri*.

5 | *Beyond the Sun*

Your body is still on a beach somewhere on our planet, but your mind is now as far from the Earth as the furthest man-made object has ever been.[5] As you crossed the edge of the Oort cloud, you exited the solar system and entered the realm of another star. As you crossed that fuzzy line – as if for you to truly understand what the boundary meant – you saw some of the solar system's outermost comets switch orbit: from a faraway curve centred on the Sun, their trajectory became a faraway curve centred on another star, the star you are now heading for, Proxima Centauri.

Proxima Centauri belongs to a family of stars called red dwarves. It is much smaller than the Sun (about one seventh its size and mass) and has a rather red hue. Hence the name. Red dwarves are very common, indeed scientists believe they account for most of the stars in the sky.

As you get closer and closer to it, you continuously see it undergo violent changes in its brightness and expel huge amounts of burning hot matter in a rather erratic way.

Now, are there any planets around that angry red dwarf? You don't see any.

Which is a shame, in a way – for although it would be very hard to live comfortably on a planet orbiting Proxima, a civilization rising here would be able to plan for a very, very long future. When our star, the Sun, blows up, Proxima won't have changed a bit. As far as we know, it will still be shining the way it shines now for about 300 times the present age of the universe. A long time by any standards.

Being smaller than the Sun, the tiny atomic cores that make up Proxima are fused into bigger cores at a much, much slower pace. Size, starwise, does matter: the bigger the star, the shorter its lifespan . . . And for the planets that orbit them, distance is the key. To have liquid water on its surface (and be able to sustain life as we know it there), a planet needs to be not too cold and not too hot. For that, it has to be neither too close nor too far from the star it orbits. The zone around a star that allows for liquid water to remain on the surface of a planet there is called the *Goldilocks zone*. So what if you could find another red dwarf, with an Earthlike planet orbiting it at just the right distance? Then it could resemble our gentle world, and basically last for ever . . .

Feeling somewhat guilty for having had such a thought, you turn around to look at your home solar system, at your home world, expecting the Sun to outshine all the other bright dots in the sky, but that is not the case at all, and the sheer size of cosmic distances suddenly hits you.

Were you not pure mind but instead a real space traveller, how long, you wonder, would it take to send a signal home from here?

Were you to be equipped with an interstellar mobile phone, you could have tried to call some friends of yours at each of your stops, to share your discoveries with them. Mobile phones transform your voice into a signal that travels at the speed of light, making communication on Earth seem instantaneous. In outer space, however, distances are usually too large, and nothing seems instantaneous any more. From the Moon, light takes about one second to reach the Earth. And another to return. Had you asked a friend on Earth if he could see you when you were up there, with binoculars, his answer would have reached you two seconds later.

From the Sun, it would have been worse. Light takes about eight minutes and twenty seconds to travel the distance between the Earth and the Sun. Conversations start to become tricky, since one must wait more than sixteen minutes between a question and an answer. But the Sun is still only next door in cosmic terms. A call dialled now, from where you are, near Proxima Centauri, would send a signal that would make a phone ring on earth in about four years and two months. Any reply to a query of yours would take no less than eight years and four months to reach you.

You have still only got to the star second closest to the Earth after the Sun, but it feels a very long way from home, so you look for something to help locate yourself, so as not to get lost.

Remembering the beautiful Milky Way you saw from your tropical-island beach, you look around to see where its cloudy white patch of light now lies. To your great surprise, you immediately see that it does not appear as a thick straight line any more but like a tilted ring, with some parts brighter than others, and you somewhere inside it. You realize that if it looked like a streak from the Earth it was because the Earth itself, under your feet, was hiding most of it.

Without a second thought, having found no planet around Proxima Centauri, you head straight for the brightest part of the Milky Way.

You do not know it yet, but you are now travelling towards the centre of a gathering of about 300 billion stars. A gathering that has been called a *galaxy*.