Barbara Sciascia

FROM HERE TO THE BIG BANG

Illustrations by Agostino Iacurci

Istituto Nazionale di Fisica Nucleare

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Laboratori Nazionali di Frascati

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Preface to the first English edition

For over ten years primary and junior high schools have been visiting the Frascati National Laboratories (LNF) of the Italian National Institute of Nuclear Physics (INFN), welcomed by willing searchers who accompany them to explore the experimental areas.

From Here to the Big Bang arose from a lecture given on the platform in front of the KLOE experiment during the European Researchers' Night, on September 28, 2007.

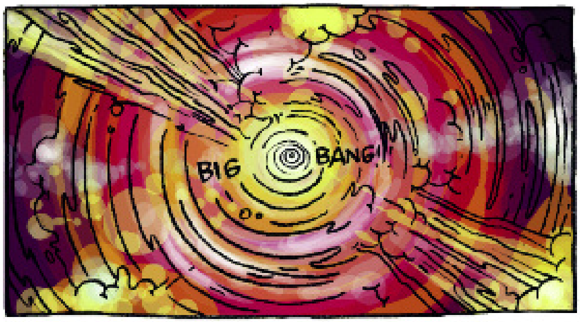
The challenge was to write a book that would explain "hard science" to children trying to satisfy, at least in part, the curiosity they express in a thousand questions: "But how can scientists see what you can't see?" or "how did scientists dream up the idea of the Big Bang?" And again, "But what's the point of all this research?"

For the first time an English version of *From Here to the Big Bang* is being printed. We hope to please both our younger and older visitors to Frascati in the coming years with a memory of their visit to our laboratories, of their conversation with the scientists, and, perhaps, as a starting point for further investigation.

Who knows? Someone might return in a few years time, having decided "to become a scientist".

Umberto Dosselli
LNF Director

– How was the universe born?
– With the Big Bang,
– What's that?
– Just what it sounds like. A big bang.



– So?
– In the beginning, there was nothing. Then, there was a bang. And then, there was everything.
– And before the beginning?
– I told you: nothing.
– Are you sure?
– Yes!
– Really sure?
– Yes ... Well no ... I'm not quite sure.
– Ah!
– But, I'm sure about the Big Bang.
– Why?

– Everyone says.
– Everyone who?
– Scientists.
– Cool! And who are the scientists?


...NOTHING...
BIG BANG!!!
...SOMETHING

Who are these scientists?

Good question! I have often tried to ask children this question, and the answers were usually that scientists are crazy, absent-minded, messy, very bad (or perhaps very good), and often dangerous. They also know everything, but do not think about the consequences of what they do; they want to destroy the world (or perhaps to save it). Then, I tried to ask those children what sort of people they imagined scientists to be. And it turned out that they imagined them as being male, and always wearing white coats. Then, there was usually a description of tinkering test tubes and glassware, of mixing colored and perhaps smelly steaming liquids. Or they imagined them building complicated machinery, full of small lights and switches—so complex that no-one even understands how it can hold itself together without falling apart, much less how it works. It often ends up blowing everything up, destroying machinery, glassware, and scientist.

But this is absolutely not true!

Let's start from the coat. In movies and cartoons, scientists always wear a coat to distinguish themselves from the others, so that we recognize them. But in reality, only some scientists, chemists or biologists, for example, put on a white coat, and only when they have to do things where they might get dirty. Then, the world is also full of female scientists, who are as brave as their male colleagues, if not braver. Anyway, no scientist, man or woman, with or without coat, would want to blow up just for the sake of an experiment. Indeed, in general, scientists are very careful to avoid this. And do you know why? Because they are normal people. They have a mom and a dad, they are often married and have children. They go to the grocery store, and also to the doctor's, when they are sick. When they can, they go to the cinema, and also on vacation to the beach or to the mountains. They sometimes build complicated machinery, this is true (things such as telescopes, or even worse, particle accelerators), but they have good knowledge of it. They know how it works and know every piece of it. And they do all this only because they want to understand how things in the world work.


MAGICIAN
MAD SCIENTIST
WOMAN SCIENTIST
MAN SCIENTIST

– And how do scientists say how things work?
– They have their own special way—the scientific method.
– Scientific method? What's that?
– The first thing that scientists do is to look around for something intriguing to explain.
– So, are they nosy?
– More or less. Scientists are generally very curious, and ask themselves a lot of questions.
– So, if you want to become a scientist, do you need to be curious?
– Yes, but after asking yourself questions, you have to look for answers.
– How?
– You have to make assumptions, that is, you have to come up with ideas that explain things. All these new ideas, put together, are called a theory. You need to have a lot of imagination to create new theories, and you must also study very well what other scientists have discovered before you.
– And how can you be sure that your theory works?
– You have to do appropriate experiments, then compare your theory with the old ones, that is with all the experiments, observations and results that have been done before.
– How?
– With math.
– What does math have to do with all this?
– For example, to check a theory that describes how the planets move, you must first measure where they are, and use math. Then, you calculate where they should be according to your theory, and you use math again. Finally, if your theory works, your measurement results and your calculations must agree. To show that they agree, you use math again.
– Then?
– If it works, then you go and tell your theory to other scientists, so they can check what you've done and maybe find an even better theory.
– What if the other scientists realize that it doesn't work? Or, if you do an experiment, and you notice something that doesn't agree with your theory?
– You have to change your theory or analyze it carefully, until it explains what you saw in the experiment, or directly in nature.

For example, at school everyone studies the universal theory of gravitation, the same one that implies that the Earth is a planet revolving around the sun, or that the Moon revolves around the Earth. Or, that Jupiter revolves around the Sun and all the moons of Jupiter revolve around Jupiter: a universe of turning planets.

Today, it all seems very simple, clear, and almost predictable, not least because men finally went to the Moon, and saw how things worked from there. But Newton, who was British and lived in 1600, had no way of going to the Moon to see things. At best, the Moon could be seen from our Earth through a telescope. In his days, scientists used to say that the sun revolved around the Earth. That seemed to be a good theory. Too bad it didn't work very well. It got some things wrong.

Newton thought of a theory that would work better: universal gravitation. But, first he had to make a series of assumptions; then, he had to do some experiments and do all the calculations and see if his hypotheses were correct.

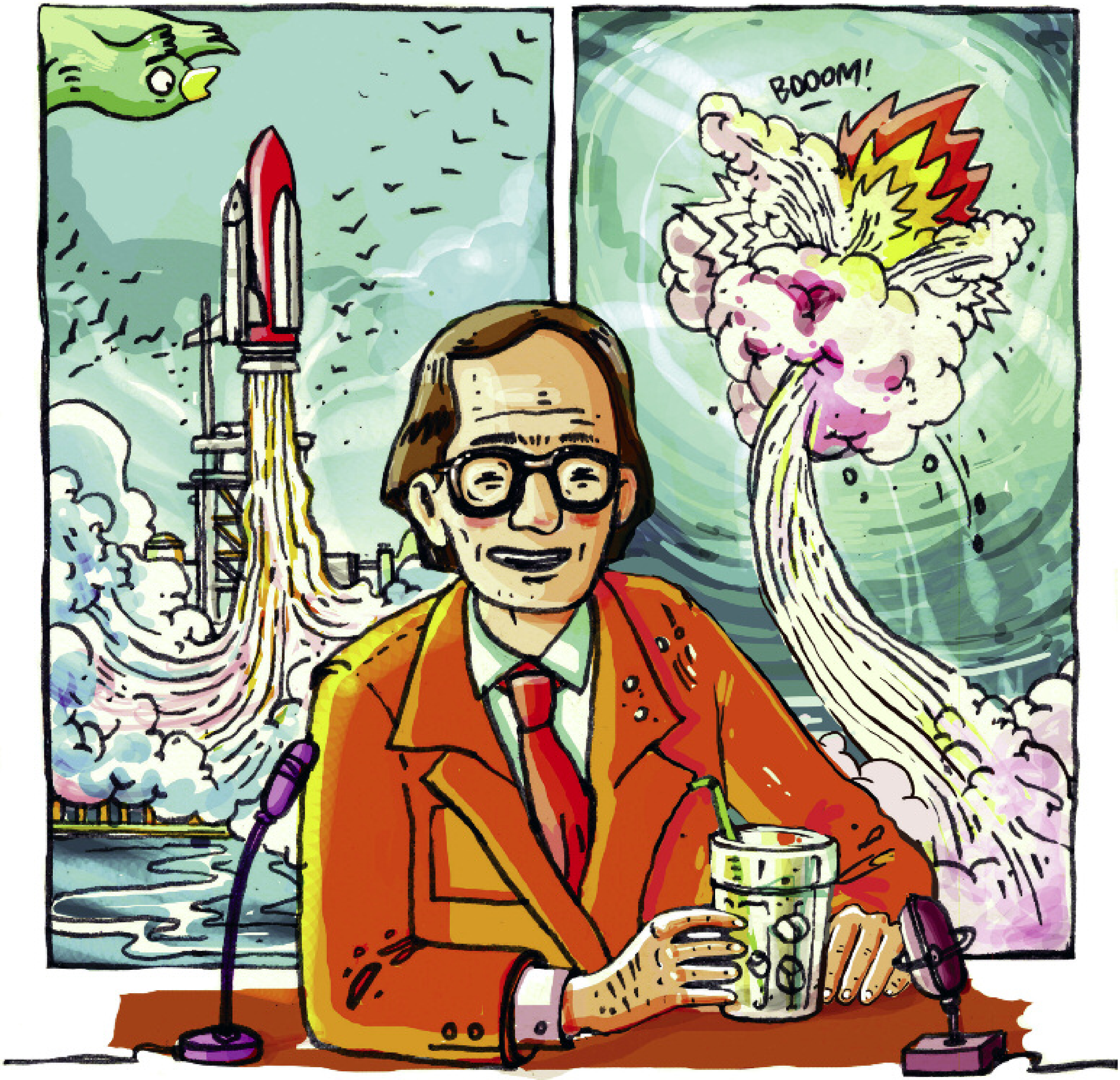
Now, he knew all about how objects, things like stones or pencils, work—about how, for example, they end up on the ground when they are dropped. Well, he came up with the hypothesis that the planets were like stones, but a little bigger, and that planets would work in the same way as stones.

Imagine you are throwing a stone from a high place—for example, a mountain. The harder you throw it, the farther away the stone will fall. Newton could calculate these things very well. Then, he made an assumption: he tried to imagine planets as huge rocks that someone had thrown with a lot of strength. This is not what really happened, of course, but this idea allowed him to do his calculations, and also experiments, to test whether his new hypothesis worked. Indeed, he saw that with his explanations the new theory worked much better than the old one.

Another example is when the Challenger exploded, right after liftoff. The story is a little sad, but it explains a lot.

On January 28th, 1986, the shuttle Challenger exploded in the air a few seconds after launch, and all of the crewmembers died. The U.S. government gathered a group of experts to study why the shuttle had exploded. Among the experts there was Richard Feynman, one of the greatest physicists of the twentieth century. Feynman found himself arguing with politicians, astronauts, lawyers, soldiers, engineers, and aviation experts. But, instead of spending so much time arguing, at some point he decided that the best thing to do was to talk to the engineers who had built the shuttle, to better understand how each piece of the spaceship operated. Eventually Feynman became convinced that the cause of it all was a defective O-ring. An O-ring is a rubber ring, a gasket similar to the one inside a water faucet. The rubber was defective and, when the weather was too cold, it became hard and could not hold a seal anymore, and so let out the very hot gas produced by the combustion of the rocket fuel. A similar thing happens when the gasket in the water fuacet gets too hard—the faucet begins to leak. This fact was known for many years, but it was not considered important. The day of the tragedy the weather was cold, so one of the Challenger's O-rings became too hard. Hot gas came out from where it was not meant to, piercing the hydrogen tank, and everything blew up.

Even though the rest of the committee did not agree, Feynman wanted to show everyone how the hardened O-rings could break, because of the cold. So, during a meeting with journalists, he dipped one of these O-rings in a glass of ice water, right in front of everybody. The O-ring became brittle and broke. Nobody at the meeting could believe that something so small could have been overlooked, causing such a great disaster. Feynman used to say that, for a technology to be successful, "reality must take precedence over public relations, for Nature cannot be fooled."


BOOOM!

– To study Nature, scientists like Newton, or like Feynman, use instruments. Sometimes, they even invent them. In any case, they trust the instruments they use.
– What do you mean by "trusting instruments"?
– Take for example a pair of glasses. We are so used to wearing them that we don't even notice them. We no longer wonder if what we see through our glasses is true or not. We use them, that's all.
– Are glasses instruments?
– Of course. Your cell is an instrument, too. When we are on the phone, we do not wonder if we are really talking to mom or dad, or if a microscopic dwarf lives in our cell, imitating their voices.
– Then, our cell is an instrument too, and can we trust it?
– Both for glasses and mobile phones, there are scientists, usually engineers, who study and check to make sure these tools work properly. For example, that what you see through your glasses looks the way it does in real life. The same is true for your cell. As a result, we can use our glasses and mobile phones without thinking.
– All right, but what does this have to do with scientists?
– Scientists need increasingly sophisticated and complicated instruments to measure things in nature.
– What things?
– I don't know: things like galaxies in the universe, or atoms, or even things that are smaller than atoms.
– And, do they measure them with instruments? Like you measure temperature with a thermometer?
– Yes, only that much more complicated numbers may come out.

To understand how big the universe is, physicists have made some measurements using their instruments. The best measurement they that have managed to obtain is that the universe is a hundred million billion billion meters across.

That's a very large number. It should be written with the digit 1 followed by 26 zeroes. Just like a thousand is written with 1 followed by three zeroes (1,000) and one million is written 1 followed by six zeroes (1,000,000). Only writing twenty-six zeroes can become rather boring:

100000000000000000000000000.

So, mathematicians have invented a trick, a mathematical trick. Instead of 26 zeroes after the 1, they write:

$$10^{26}$$

(pronounced "ten to the twenty-sixth").

That is, they write 10 and, above the 10, in small digits, they put the number of zeroes following the 1, in this case 26. It's as if a baby koala were clinging to its mother's back. This way, you can write very large numbers in a small space, and it is easier to do operations.

Now, the smallest distance that man has ever measured is a tenth of a billionth of a billionth of a meter. This number is written with a 1 at the nineteenth place after the decimal point:

0.0000000000000000001

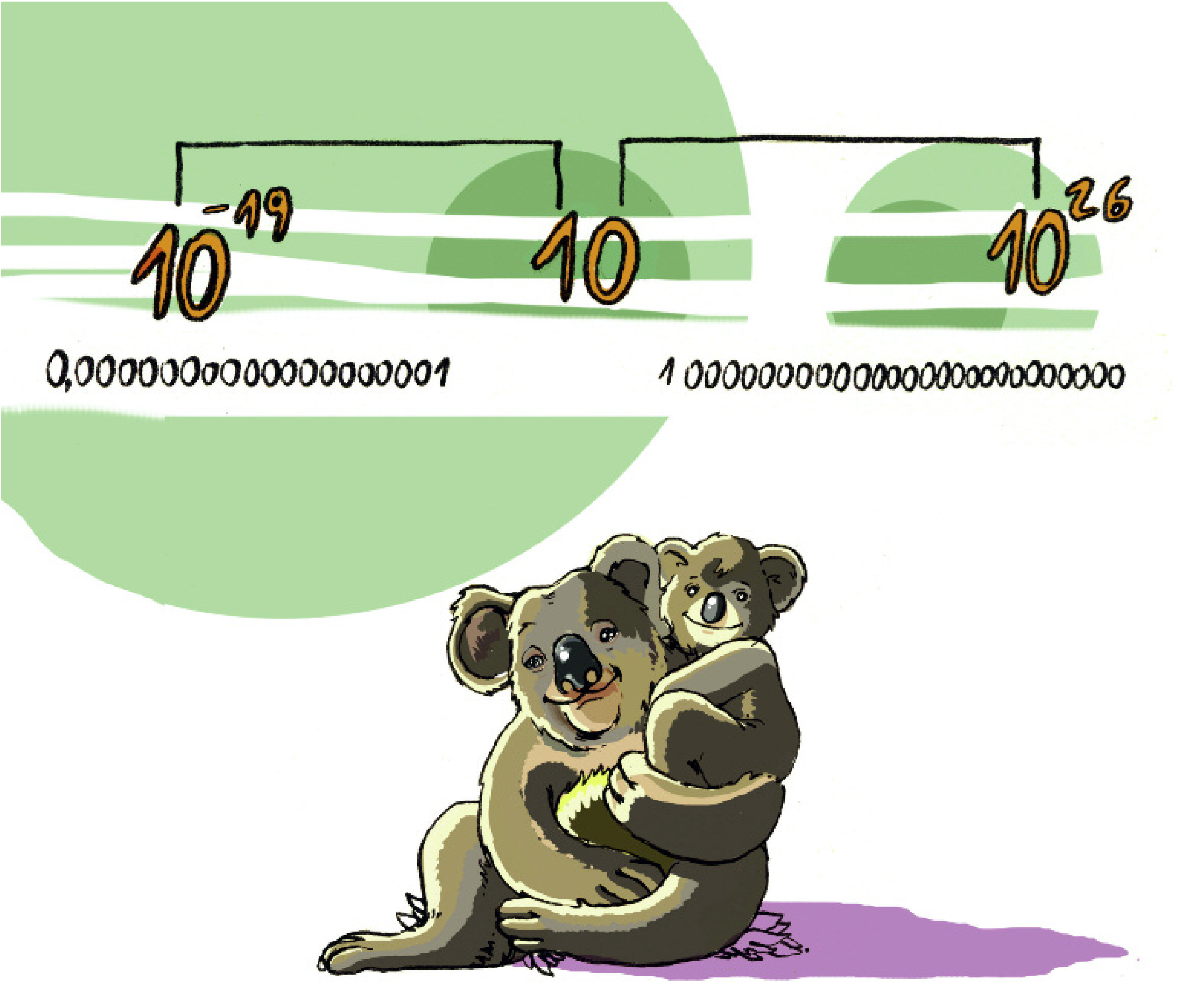
Here too, instead of writing all those zeros, we write:

$$10^{-19}$$

(pronounced "ten to the minus nineteenth"),

where the minus indicates that I have to count the places after the decimal point, and 19 tells me in which place the 1 goes, in this case the nineteenth.

Well, now that we know how to write very large numbers and very small numbers, we can also try to imagine them.



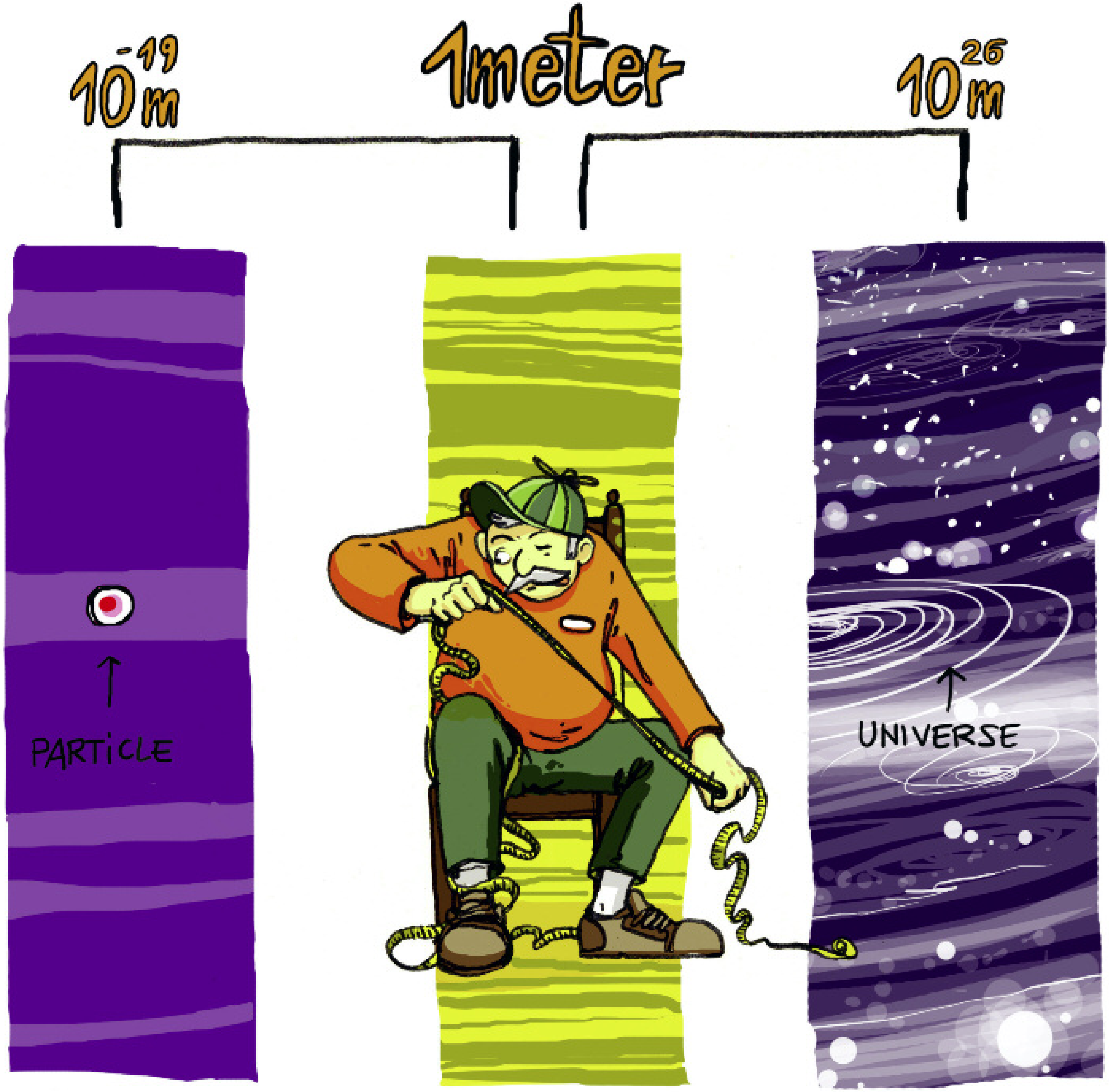
10^{-19}
10
10^{26}
0,0000000000000000001
1 00000000000000000000000000

Being able to imagine big or small numbers also tells us how much man understands about science.

Let's start with the big ones: 10^{26}. It's hard to imagine such a big number. So let's start by considering something that is closer to us: a hundred meters. We know this number (we can also write 10^{2}). If we take a one-meter ruler, we have to move it a hundred times to cover one hundred meters. So far, it's a piece of cake. To cover a thousand meters (10^{3}), we need to repeat 10 times what we did to cover one hundred meters. And to cover ten thousand meters, (10^{4} meters), we have to repeat ten times what we did to cover a thousand meters, and a hundred times what we did to cover one hundred meters. Now try to imagine a hundred million billion billion meters (10^{26}): the distance across the universe.

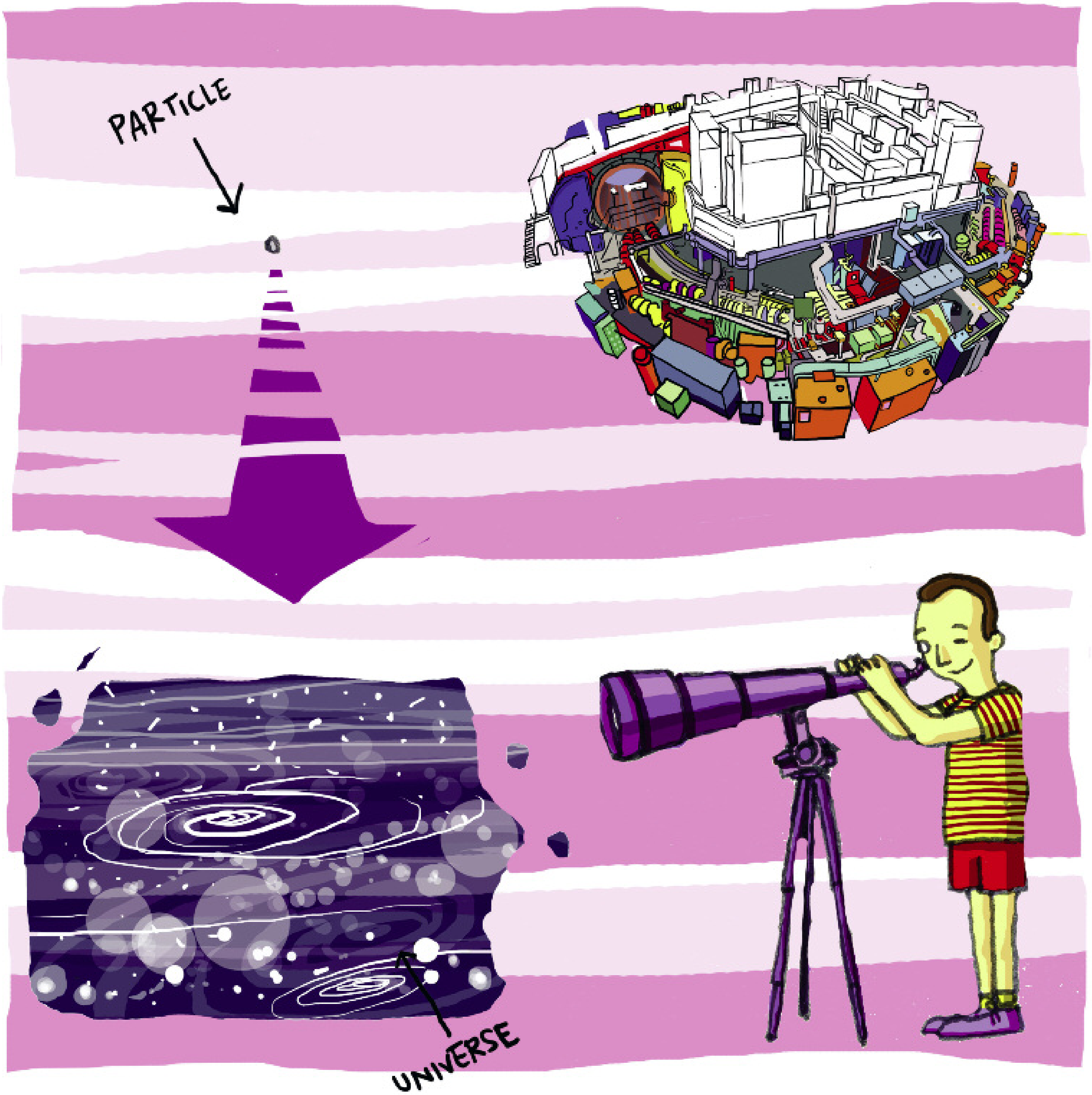
To imagine small numbers is even more difficult than to imagine big ones. At first, it seems easy. A hundredth of a meter (10^{-2}) is a centimeter, as everybody knows. And you also know a thousandth of a meter (10^{-3}): a millimeter.

Now, a cell in the human body is a hundredth of a millimeter across (10^{-5}). What happens if you take a ruler and divide the smallest notch (one millimeter) into one hundred parts? Although not visible to the naked eye, an object this size can still be seen through an optical microscope. One of those viruses that give you a common cold is a tenth of a millionth of a meter across (10^{-7}), and you can no longer see it even through an optical microscope. But scientists have invented another instrument, the electron microscope, to see things that are as small as one billionth of a meter across (10^{-9} m). Whenever the instruments they have already invented are not enough to satisfy their curiosity and understand the world around them, scientists invent new ones. To study things that are a tenth of a billionth of a billionth of a meter in size (10^{-19} meters), physicists invented and built very large instruments, sometimes even larger than a football stadium, and called them particle accelerators.



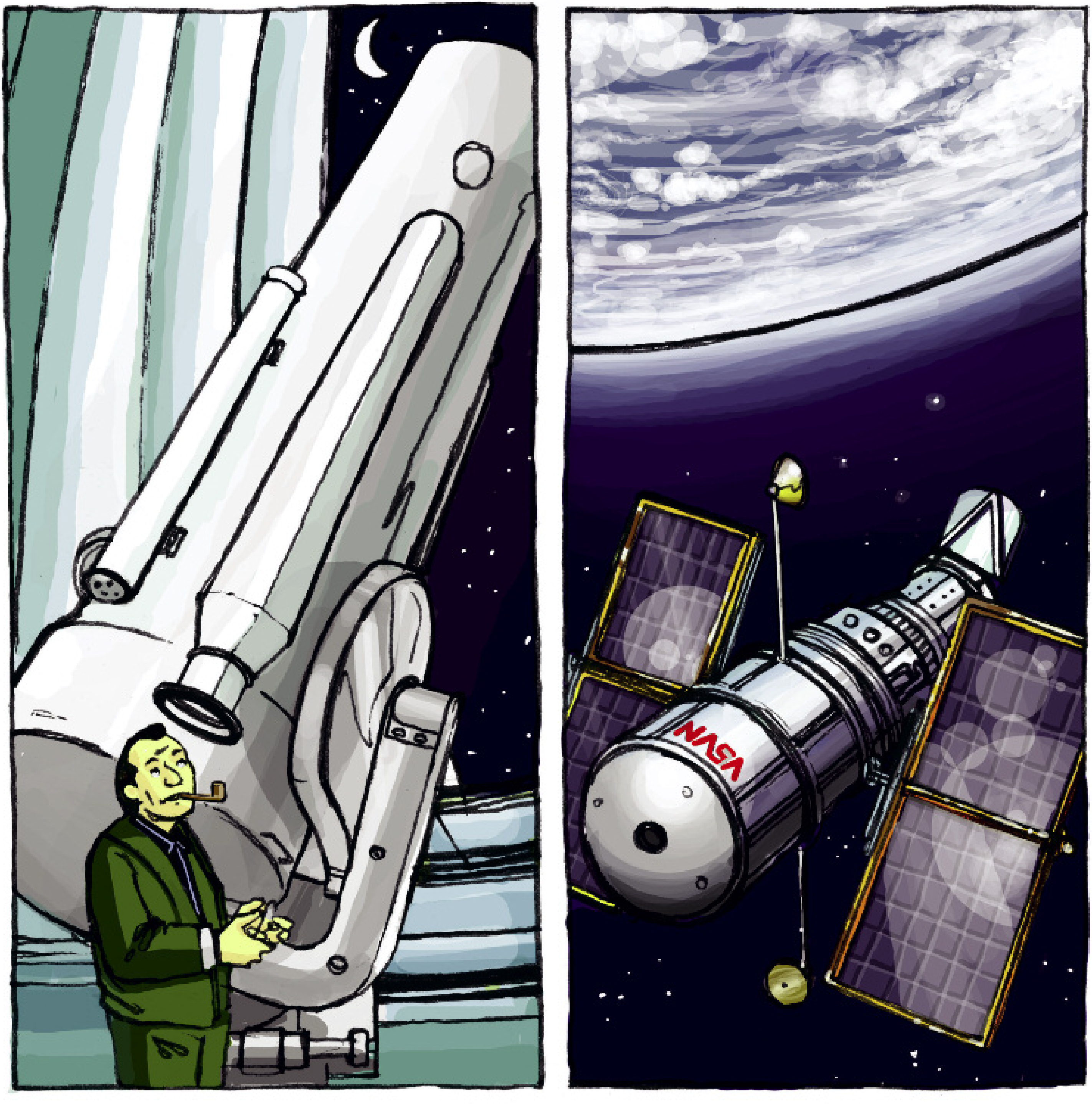
10^{-19}m
1meter
10^{26}m
PARTICLE
UNIVERSE

– Ok, but how does the Big Bang come into it?
– It does, because now that we know how to write very large or very small numbers, and we have more or less an idea of how large a large number is, and how small a small number is, we are able to know what we are talking about.
– The Big Bang?
– Of course. The "Big Bang" is the best theory scientists have come up with so far to answer the question "How was the universe born?" The theory says that the universe began 13 billion 800 million years ago (which we can also write 13.8×10^9 years). It also says that, at that time, the universe was very small and very hot.
– How small and how hot?
– Smaller than anything we can measure, and hotter than anything we can think of, even the Sun.
– Then?
– With time, the universe became bigger and bigger and colder and colder.
– And how big is it now?
– As we said before, 10^{26} meters. To measure how big the universe is today, we use increasingly powerful telescopes.
– And can you measure how small the universe was in the beginning, when it was smaller than the smallest dot you can imagine? Smaller than 10^{-19} meters?
– That's something that physicists around the world are trying to determine. They invented particle accelerators, because, at some point, it occurred to them that the universe could have been small before getting so big.

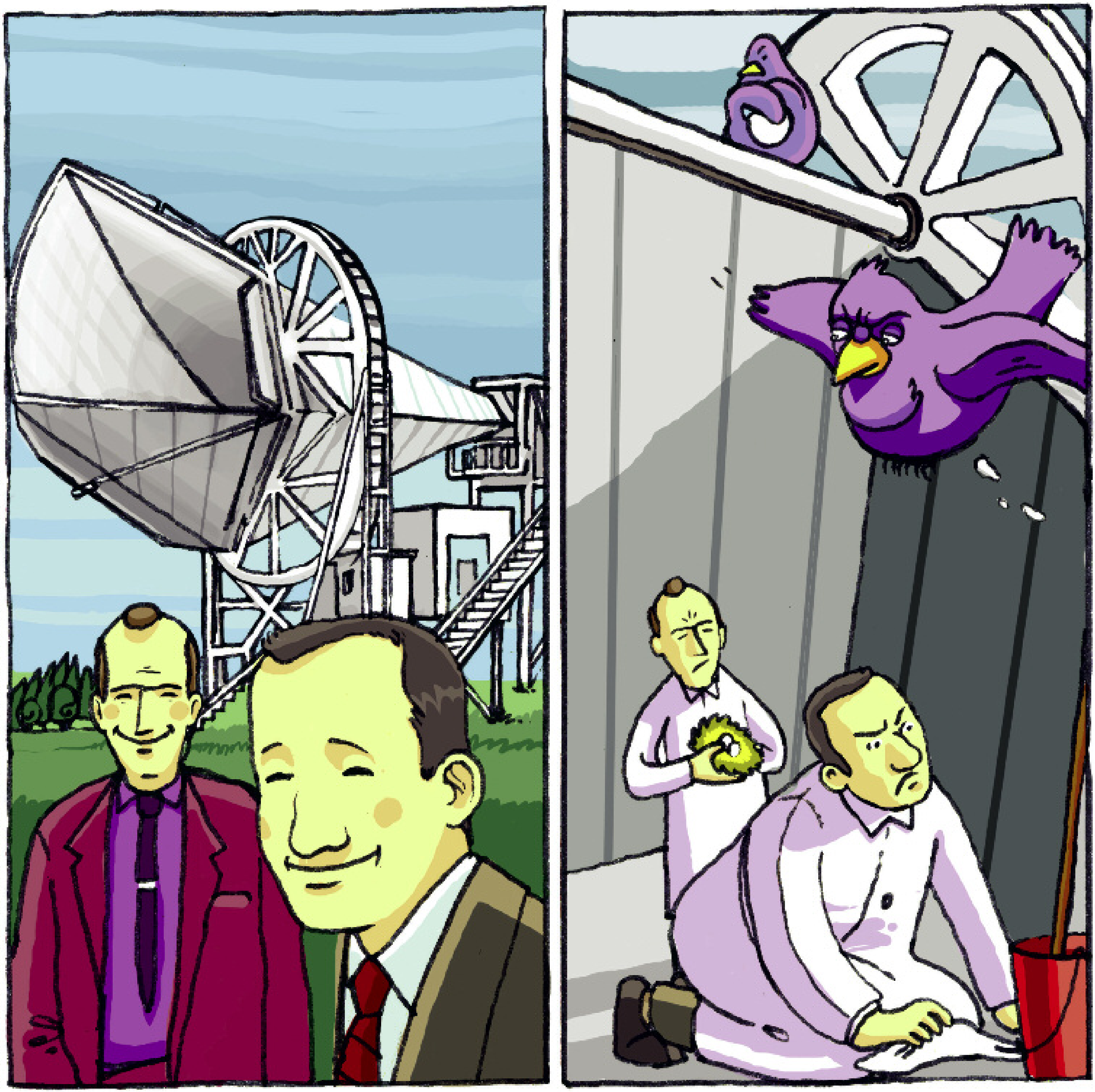

PARTICLE
UNIVERSE

OK, so now we've gotten to the idea that the size of the universe is changing. This idea was originally from Edwin Hubble, an American astronomer. When he was young he was undecided about whether he wanted to become a lawyer or an astronomer, but luckily he chose astronomy. Between 1920 and 1930, he spent many nights watching the sky through the telescope on Mount Wilson. Those nights turned out to be very useful, because he discovered a lot of things. The first one is that our galaxy is not the only galaxy in the universe: many points of light that looked like stars to the naked eye appeared as groups of billions of stars if seen through the telescope. They were so far away that they looked like a single star. As he was measuring the light coming from different galaxies, Hubble realized that it was a little different from what was predicted by scientists' theories about stars. A few years before, scientist Henrietta Leavitt had discovered a method to measure how far away stars are. The method used a special type of star called "Cepheids." Now, the galaxies that Hubble discovered also had Cepheid stars in them, so he was able to measure how far away they were. What he discovered was that the more distant they were, the more the light they gave out was different from the kind of light scientists expected. The only explanation he could think of to account for these differences was that all these galaxies were moving away from us—and in fact, that everything moves away from everything else. It's not really easy to explain, but to understand better, you can do a little experiment with a balloon. You have to inflate it a little, and draw dots on it with a marker. Say each dot represents a galaxy. Then, if you inflate the balloon even more, you can see that every dot has moved away from all the others. For the universe, it's a little bit more complicated, but the idea is the same.

OK, then, if each galaxy is moving away from the others, they all must have been closer together a long time ago, as if they were coming from the same point in space. The idea that the universe was born from a single point was called the "Big Bang" by physicist Fred Hoyle. In the beginning, it seemed like a strange idea, but other scientists made other measurements and became convinced that the Big Bang was the best theory that could explain the universe. Hubble's discovery is so important that his name was given to a very powerful telescope mounted on a satellite, with which some of the most important studies of the Big Bang were made.

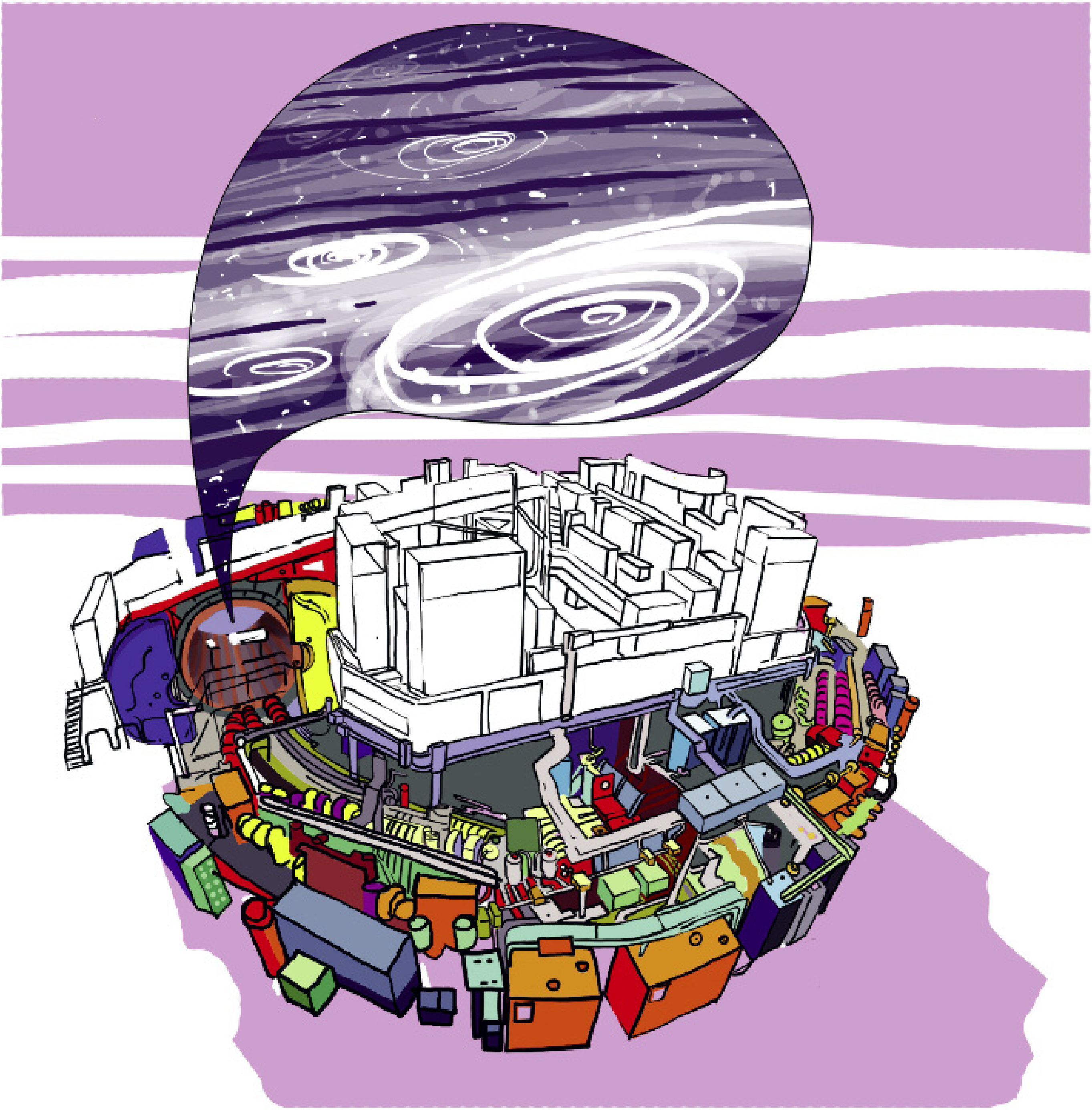

NASA

– But if there was the Big Bang, it must have left some traces.
– Of course. After Hubble's measurements, many people, like the Russian scientist George Gamow and the American scientist Robert Dicke, thought that if the universe was indeed born with the Big Bang, we should still be able to find traces of it.
– Which traces?
– It's a bit as if you drop a stone into a quiet lake and the wave caused by the stone continues to be seen much later and much farther away. Maybe it will be very small, but we can still see it.
– Can we see the waves in the sky?
– Not with the naked eye: the leftovers of the Big Bang are radio waves. We need instruments that are similar to a TV satellite dish, but larger and more complicated. The funny thing is that this signal, predicted by scientists, was discovered by chance.
– By chance?
– In 1963, the American telephone company AT&T asked two of its scientists, Arno Penzias and Robert Wilson, to understand why its satellite dishes were making an annoying background noise ... crzzz ... like a untuned radio. The two began to check everything they could think of, really everything. Whether there were radio stations nearby that could cause interference. Whether the noise was changing with time. They even ended up climbing up the antennas to remove nests and pigeon droppings.
– Pigeon droppings?
– Yes, but it was useless. The noise continued. They tried to point the antenna in all different directions, but nothing changed. The only explanation was that the noise was coming from far away. Very far away—from outside our galaxy. So, they went and talked to Dicke. Together, they made calculations and realized that it was the signal that Gamow and Dicke thought the Big Bang might have left.
– Did they also calculate how long ago the Big Bang occurred?
– More or less ... they were able to calculate that that kind of noise would correspond to a Big Bang that happened between 10 and 20 billion years ago. Later, they built better instruments and the best theory now says that the universe began 13.8 billion years ago, from something small and hot. Very small and very hot.
– How small? 10^{-7} like the cold virus?
– No, much smaller!

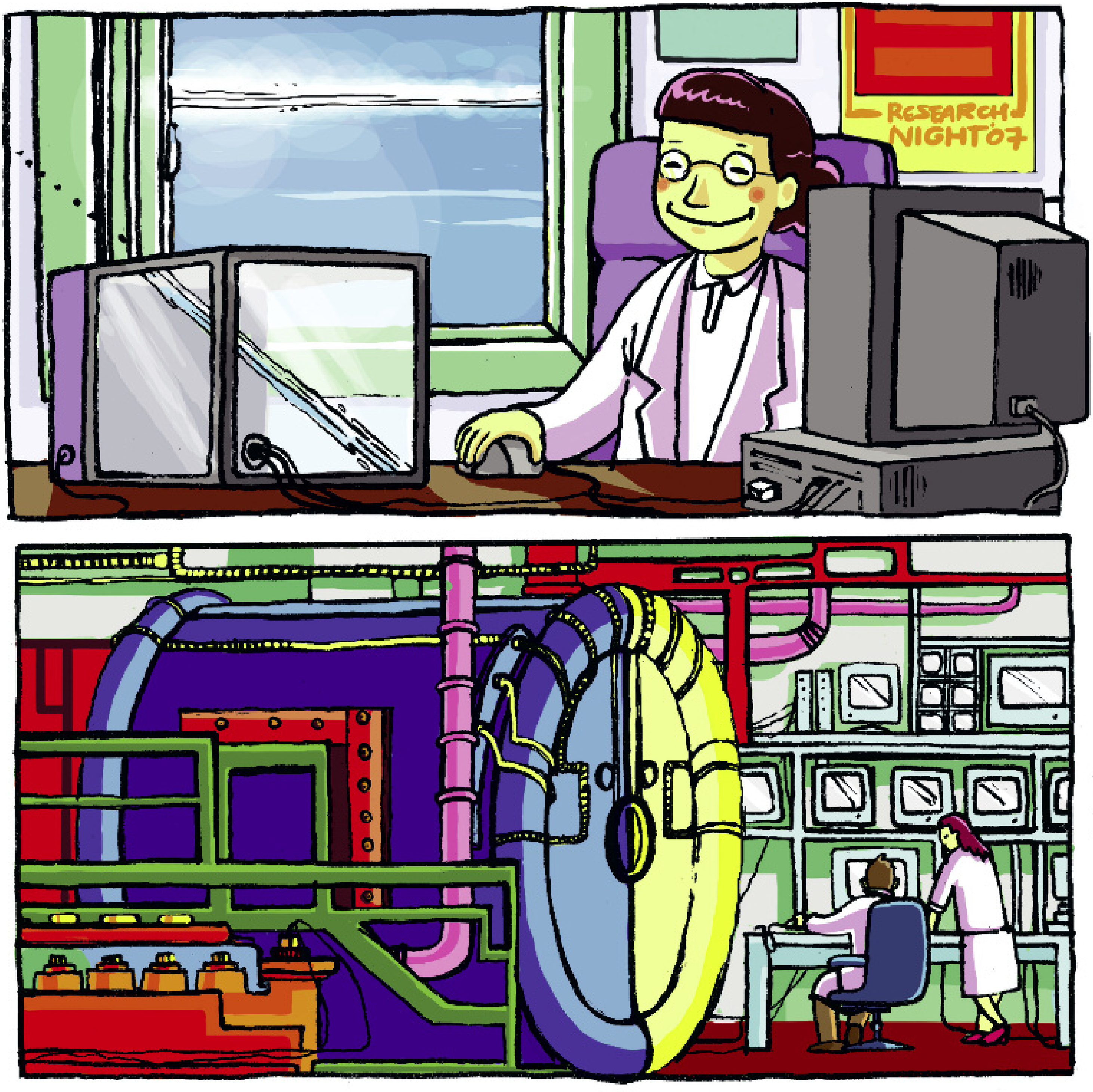


So, the early universe was very small, and was made of very small particles. Too small to be seen even with the most powerful microscope. But in any case, most of the particles that were part of the early universe no longer exist. To understand a little better how the universe worked when it was so small, scientists have built particle accelerators. Particle accelerators are very complicated machines. They were invented more than eighty years ago, and today there are several types. Some are useful for very important things, like treating some types of cancer. Others, like the LHC accelerator in Geneva or the Dafne accelerator in Frascati, allow scientists to study the tiny particles themselves (the ones that can't be seen) and to recreate the types of particles that were present at the beginning of the universe.

A "particle accelerator" accelerates particles and then makes them collide with one another. When two particles collide, new particles are created, different from the ones involved in the collision. The production of new particles is difficult to explain; to really understand it you need to study hard and learn a lot of math. But producing these particles is a little bit like going back in time: it's possible to produce particles that were around a long time ago but which are not there anymore. Depending on how fast the particles go inside the accelerator, we can produce different types of new particles after the collision. For example, the accelerator Dafne can produce some kinds of particles that were present when the universe was only 4 millionths of a second old (4×10^{-6} seconds), at which time it was already a hundred thousand billion meters across (10^{14} meters). But to get to the very beginning of the universe, we must go back even further. Up to now, with the help of LHC, scientists have been able to study the universe when it was only a tenth of a billionth of a second old (10^{-10} seconds), but they still haven't reached the very beginning. But the fact is, by studying the particles produced at accelerators, we can better understand the Big Bang. Besides, it wouldn't even be possible to recreate the whole Big Bang in the laboratory. So, at each accelerator, we try to reproduce a particular moment of time after the Big Bang, so that we can study the particular particles that were present at that time.



– What I don't understand is how you can study particles that you can't see. With a new instrument?
– That's right. That's why scientists invented "particle detectors." The name says it all. They're used to detect where the particles go.
– Do they really work?
– Of course! It's just like what we said about eyeglasses and cell phones. Scientists have invented and refined more and more sophisticated particle detectors for over 100 years now. The first ones were simple and small enough to fit on a table. But as scientists wanted to study smaller and smaller things, they built bigger and more complicated detectors.
– How big?
– It depends. For example, KLOE, the detector used to see the particles produced by Dafne, is like a big tin can made of iron and cables, 6 meters high and 6 meters long, weighing more than 1,000 tons. That's more or less as much as 100 trucks. But in Switzerland, we have another detector used to see the particles produced by LHC: ATLAS, which is 25 meters high and 46 meters long, as big as an 8-floor building! It weighs more than 7,000 tons.
– Ok, but how do they work?
– It's like with aircraft. When a plane is high up in the sky, can you see it?
– Yes, I guess. It depends. Typically, you only see its trail. Sometimes, however, you only hear its noise.
– Particle detectors work in the same way. A particle cannot be seen, but if we get it to leave a trail—a track—we can see if it moved, and what kind of particle it was. In the first detectors, the ones that were smaller than a box, you could see the particle tracks with the naked eye.
– What about the big ones, like KLOE and ATLAS?
– KLOE and ATLAS are more complicated, with a number of detectors inside one another, so that when the particle passes through, it leaves several tracks and can be studied much better from various points of view. In these large and complex detectors, the tracks are transformed into electrical signals that you can study on the computer.
– So, is this how we found out how the universe started and how it is made?


RESEARCH NIGHT'07

– Well, it's not exactly everything.
– Ah.
– There are many questions scientists just cannot answer.
– Which ones?
– For example, what was there before the Big Bang.
– Why?
– Don't you remember? Science starts from observation, followed by measurements. And there's nothing from before the Big Bang that we can observe or measure, and so science can't really tell us anything about it.
– Ah, and do we know everything about the universe after the Big Bang?
– No, no. Science has allowed us to understand many things in the world around us, but there are still many more to understand and study. Apart from the question of when and where the universe was born, we have to study animal behavior, how stars work, how you can heal from cancer and other diseases…
– So, there's still much more to be done?
– Yes, there is.
– And can I be a scientist too?
– Of course! If you are curious and willing to study, why not?


1♡ + √3☺ − 5✿ = ?

For the curious

For you:
You can take a wonderful trip through large and small numbers in the film http://www.powersof10.com/film, or in the book by Philip and Phylis Morrison (1982, revised 1994), *Powers of Ten: A Book About the Relative Size of Things in the Universe* and the Effect of Adding another Zero. Scientific American Library.
Richard Feynman tells many episodes that are both amusing (he used to crack his colleagues' safes) and interesting (he participated in the building of the first atomic bomb) in his book: *Surely, You're Joking, Mr. Feynman!* by Richard P. Feynman, W. W. Norton & Company, 1997.
At the web site:
http://en.wikipedia.org/wiki/Space_Shuttle_program, you can find a lot of interestin information about the shuttle. You can also read: http://www.nasa.gov/.

For your parents or your teachers: *The First Three Minutes: A Modern View of the Origin of the Universe* (1977) by Steven Weinberg, Bantam Books, presents a slightly dated but very clear introduction to the basic ideas of the Big Bang theory.

Acknowledgements

"I'm just a curious man," Einstein used to say. It was actually thanks to the curiosity of the many children I got to meet during the more than 10 years of my activity in science communication that I found the drive to find the necessary time and energy to reconcile my research work with scientific popularization. I would like to thank these children (and their teachers) who, with their so many questions (often confusing, sometimes difficult or just plain impossible) but also with their unexpected suggestions, have shown me one way to explain science without cheating, without saying it's all easy, or magic.

B.S.