alice guareschi

CONVERSATION WITH ANDREW SONNENSCHEIN ON THE DARK MATTER

(…)

Andrew Sonnenschein: The level of poetry… is a different way of thinking about the things we do. I often go to parties and talk to people about nonsense concerning my work, mega particles in space and things like that, and we talk about them in a very general way, but with physicists that doesn't happen, perhaps it wouldn't help much to talk poetically because we have a very specific way of thinking, concrete, and if we move away from this it is as if we are talking about nothing. Often this is the problem with physicists: that they always want to talk in a very definite way. Chatting with artists, and with other academics in other fields, I have noted a great difference, on the one hand because the subject of physics is already in itself sufficiently complex and difficult and then because we physicists must always work on the same project, and this means having a level of clarity that often does not exist in art, since the common knowledge must be very specific. We force ourselves to always use the same basic words, the least poetic: we try to avoid the poetic.

Alice Guareschi: Perhaps when I wrote to you I didn't explain myself clearly: the question of poetry is not so much concerned with the fact of speaking in poetical terms, so much as the poetic or the images that can derive even from a scientific description. Let me give you an example: the image of a triangle, or of a molecular structure, and the words themselves: molecular structure, you know exactly what that is from a scientific point of view, yet if I talk about it I only know what it is in terms of image. It would seem that two very different senses derive from the use of the same word, therefore it would be really interesting to try to understand, beginning from your descriptions, what kind of image forms in the mind of a person who, like me, knows almost nothing of physics.

AS: We physicists always think in terms of images. Perhaps we could say that physics is like a sort of balance between mathematics and every day's world concepts, and the bridge between the two are these images that concern both the world and mathematics. We can use as an example a function that describes a field of energy in space, and then superimpose it on a physical object such as a galaxy or an atom. So that when the physicists think of the molecules, they always think of a mathematical concept with its visualisation, and visualisation for a physicist means the superimposing of a mathematical idea on the top of a physical idea, in an attempt to transport the physical intuition into the world of mathematics, and to bring something of the mathematics into the physical world. The activity of a physicist, what distinguish it from the mathematical, it is the attempt to bring the real world to its comprehension into the mathematical dominion.
But perhaps I should have talked of general problems concerning the dark matter…

AG: To begin with, maybe you could explain better what you are working on: I know you are looking for the dark matter.

AS: There are various signals that indicate the existence of missing matter, and we also know exactly what some of the components of this matter are, for example neutrinos, which are missing in the sense that they are invisible and out of contact with the everyday world.

AG: What the neutrinos are?

AS: The neutrinos are little particles originally invented by Enrico Fermi as an abstract idea to explain why in certain nuclear reactions there could be a non-conservation of energy. Following the discovery of nuclear energy, either we abandoned the conservation of energy, or we kept it and invented a new particle which left the field taking away energy with it. The purpose of the invention of the neutrinos was to re-balance the two terms of the equation: there is energy before the reaction and there is energy after the reaction, but the energy after the reaction seems to be less; the neutrinos, being invisible particles, can carry away the energy without our seeing them, and this balances the equation. This occurred during the thirties, then during the fifties, working with reactors where an infinite number of neutrinos were created due to the continuous nuclear reactions, it was discovered that these particles really exist. Just as in chemistry every reaction can go in opposite directions (for example, hydrogen and oxygen can combine to make water, or water can be separated into hydrogen and oxygen by passing electricity through it), so also in physics almost every reaction is reversible. That is why it has been possible to find the inverse reaction to the mission of the neutrinos which implies the absorption of energy in another type of nuclear reaction in which the neutrinos are absorbed, and by observing this reaction there was the proof that the neutrinos are produced by the nuclear reactions and that they pass through matter in a way that is extremely difficult to observe. The reactions were later produced in another place, and this proved the physical existence of the neutrinos which at first were considered only an abstract concept; now we also know that the neutrinos are produced by the sun and that there is an enormous number of them crossing even this room right at this moment. In mathematical terms, something like ten billions of neutrinos per square centimetre per second.

AG: What does it mean that the neutrinos are produced by the sun?

AS: There are many nuclear reactions occurring in the sun, and most of these reactions produce both light and neutrinos. This is actually interesting because the neutrinos follow a more direct trajectory than the trajectory of the light: if a particle of light from the centre of the sun takes about a million of years to reach the surface because it gets trapped and bounces back and forth, remaining in the sun and only finally finding the way to cross the surface and reach us, the neutrinos in fact reach us from the centre of the sun in about ten minutes, just the time needed to travel to earth at the speed of light, and this is because the matter of the sun does not interfere with their journey. The neutrinos are not reflected by the sun, they travel directly.

AG: And why do they come in this direction? Is it due to the force of gravity?

AS: They actually go in every direction, like the light, but if the sun is in one place and the earth is in another, it is obvious that only some of them will be intercepted.

AG: So the others go in all the other directions of the Universe… but does is what is behind the sun still called Universe?

AS: Yes, certainly. We can say the Universe, or the galaxies; in any case the neutrinos travel through space and theoretically it should be possible to see other stars by means of the neutrinos, just as we can see them by means of the light, but the problem is that measuring the neutrinos is very difficult. There is only one other star measured using neutrinos. At the end of their lives, in fact, many stars explode in a supernova, and the supernova implies a much higher percentage of neutrinos, in effect a large fraction of the old star transforms into neutrinos at the moment of the supernova.

AG: And when was the time of the supernova?

AS: The last one in our galaxy was in 1987. In that explosion about ten neutrinos were seen.

AG: Ten?

AS: Yes, ten. As I said before, the neutrinos are very difficult to measure. Today we have enormous neutrino detectors, there is one in Japan, until recently there was one in the Gran Sasso mountain, the National Laboratory of the Gran Sasso, that is still there, and they are building another one which is not finished yet.

AG: Why must the laboratory be underground?

AS: Because there are interferences from cosmic rays.

AG: And what happens down there?

AS: In effect there are many different ways of building neutrinos's detectors. The technique used in Japan was to build a big tank of water underground, an enormous volume, about a hundred thousand tons of water surrounded by devices for measuring the light; every so often it may happen, in a very small percentage, that a neutrino hits an electron and transfers energy to it, so that the electron moves through the water producing what is called the Cherenkov radiation, after the Russian scientist who first thought that such radiation could exist.

AG: Therefore the fact that a neutrino hits an electron is a totally casual event?

AS: Completely random, and also very rare.

AG: Why is it so rare if there are so many neutrinos?

AS: This is one of the mysteries of physics: why the interactions of the neutrinos are so much weaker than those of other particles. But something similar happens with X rays: the reason we can see our bones with an X ray is because the X rays do not interact much even with bones. Normal light travels a very short distance before it hits an atom, the X rays travel further, in a solid material perhaps even a few millimetres.

AG: But, for example, can we see through a wall with the X rays?

AS: With a sufficiently powerful machine, I would think so.

AG: Can we think of X rays as the beam of light from a torch? The more powerful the light, the further we can see?

AS: There is no difference in quality between the light that comes from a torch and X rays, only in quantity: the light is composed of particles, and normal light and X rays are composed of the same particles, the photons, but the energy is different, because the energy in the X ray's photons is greater. Statistically speaking, if the average distance that normal light can travel in a solid material is about one micron[1], then we can suppose that the possibility that a photon can pass through a wall

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[1] The micron is a unit of measurement of a length corresponding to one millionth of a metre (also written: micrometer, 1/1000000, μm)

is practically equal to zero: some would go further, others less, but the first photon is stopped by the second and so on, they would have to be extremely lucky to arrive on the other side of the wall. On the other hand, since their average flow in a solid is around one millimetre, X rays have a greater probability of passing through the wall, and that probability depends on the density of the material. That is why we can see our bones, and in fact if we think of what happens to the X rays in that first millimetre in which they don't hit anything, that is exactly what happens to the neutrinos, with the difference that for them it is not a question of centimetres but of millions of kilometres, or something like that. So we have a question, which is a truly profound question in physics: why is the distance for an X ray a millimetre, while for a neutrino endowed with the same energy it is a million or a billion of kilometres? Qualitatively the behaviour is the same, the only difference lies in the quantity.

AG: Let's go back for a moment to the previous question, about the randomness with which a neutrino passing through the water could hit an electron…

AS: The percentage of neutrinos that hit anything in the water is very tiny.

AG: So your research is also based on waiting. But can you at least calculate how often it happens or when it will happen?

AS: Yes, it is possible to calculate it numerically.

AG: So, if you know for certain that this phenomenon exists, and even when and how it happens, it is just a question of finding a way to make it visible?

AS: It's a long matter. For the neutrinos there are still many things to be discovered, but since the thirties when Enrico Fermi had this intuition, there also has been already the idea of how to calculate how many neutrinos should stop in a given material. The history of the neutrinos is important for the dark matter since it is an example of a kind of matter that we can't see but that we know exists, because the existence of the neutrinos is beyond any doubt, they have been produced and measured in different ways in many laboratories. The neutrinos are a true example of dark matter.

AG: So the neutrinos are not the only component of the dark matter?

AS: No, there could be many other similar particles of whose existence we still know nothing, because they are very difficult to measure. We are almost certain about it, but they have not yet been discovered.

AG: What makes you think this?

AS: There are several kinds of reasons that all converge on the same result. The first comes from astrophysics: in many astrophysical situations there is mass missing from an astronomical object, and this concerns both the galaxies and the objects that form them. There are astronomical methods for measuring the mass of an object in space: one, for example, is the fact that the galaxy turns, and there is a centrifugal force that pushes the stars outwards, but since the stars do not move towards the outer limits, remaining more or less where they are, this force must be balanced by an internal force which we assume to be normal gravity. But even assuming that the balancing force is the force of gravity, there doesn't seem to be sufficient matter in the centre of the galaxy to produce the necessary gravity, it would need about 200 times more, so it is not a problem to be underestimated:

even counting the number of stars, including all the gaseous material that surrounds them and which contains neutrinos in various forms, the mass remains about 200 times smaller than the necessary.

AG: Usually when we think of stars, we think of them in a certain sense as objects. In the common imagination, we think of a star as something that exists and around which there is the sky, therefore an empty space, the space, while in fact a star is already a gaseous material itself?

AS: Yes, but a star is also a kind of object because it has precise dimensions, which coincide more or less with the area that produces light, and then there is also the gas that doesn't produce any light. When we look at the sun through dark glasses, we see a ball of fire that has a precise size, and yet there is gas around it.

AG: If on a different scale I could stand at the centre of the sky, at the centre of the Universe, and see the sun, and see the stars, clearly there would be a distance between these objects that would in theory be an "empty" distance…

AS: We know that the stars are organized into galaxies…

AG: …But are the galaxies like orbits or are they like shapes, instead?

AS: There are various kinds of galaxies, but the galaxies like the Milky Way, the one that we are in, orbit round a centre. Not like the solar system's one however: in the centre of our galaxy in fact there is a black hole, but that's another story. In the galaxies the majority of the mass is not in the centre, while in the solar system the 99% of the mass is constituted by the sun, and that is why we orbit round it.

AG: The earth is such a small planet. Has anyone ever managed to go beyond the Sun?

AS: I believe that some spacecraft have managed it, but without people on board, because there would be no way to get back … Going back to what I was saying, in the galaxies all the stars in a certain way orbit one around the other, and each of them feels the average of the gravitational forces of all the others, so that the type of orbits are slightly different. There may be a group of stars in orbit around the centre, but there are also other types of galaxy where there is no rotary movement of this kind.

AG: Is our rotation horizontal?

AS: Yes. In the centre our galaxy has a flat disc around which all the rest moves, but what I was trying to say is that this is not the only way in which a galaxy can exist: some of them, for example, just look like fluffy balls of cotton, or there are others instead in which the stars fall passing each others in various directions, but in any case in each of these galaxies there is not enough mass to explain the motion of the stars.

AG: Can I ask a silly question: why is it important to discover this mass?

AS: As we all know, a discovery of this kind has no immediate practical value, such as saving the world, nor will it produce advantages for technology, nor can it be used as a new form of energy or anything of that kind, but it is important for understanding the nature of matter, the nature of the Universe and the way it has evolved. There is another important aspect that I should probably mention: we know that there was a Big Bang probably about 13 billion years ago, and we also know that after the Big Bang the Universe was very smooth.

AG: What do you mean by smooth?

AS: If we look at the Universe now, there are large concentrations of mass such as the stars or the galaxies, and in the middle of these concentrations of mass there are enormous spaces in which there is nothing, completely empty, and the average distance between each atom is also very big. The Universe today is much rougher and more knotty, at least on a small scale, there are stars, planets and galaxies, and in between them there is just emptiness, but at the beginning of the Universe the distribution of matter was more similar to a fluid, like water or air, for example.

AG: The image would seem to be that of lots of objects – planets, stars – sort of suspended in space…

AS: That's true. As I said, after the Big Bang the Universe was essentially homogeneous, smooth on almost all scales, like a gas, without structures, while now there are a lot of structures, points of concentrations of mass such as stars and planets, which leads to the question: how has the Universe which was smooth thirteen billion years ago become so full of the lumps we see today? There is a natural explanation for what has happened called 'gravitational collapse', and in this case the words suggest what really happened. Let's suppose that the Universe is smooth, but not perfectly so, that there are miniscule differences in density between one point and another…

AG: But is the difference in density something that can be seen? When you talk to me of a Universe more similar to something fluid with different densities, are these densities that can be seen by the naked eye, or do they concern only the molecules?

AS: Earlier we were talking about this aspect of physics which consists of taking ideas from mathematics and combining them with images… for example I imagine the density as a field of light, or something similar. But now we are talking about a different concentration of mass and therefore of a difference in density in one place and not in another. Let's suppose that where my hand is there is by chance a little more mass than in any other place, because the Universe is made of particles of atoms that fluctuate in all directions, and it may be that at a certain point, by chance, right here there is a bit more matter than elsewhere. Since every particle feels the gravity of all the other particles, and here there is more matter, all the particles will tend to go in this direction, and since more matter produces more gravitational force, when the particles move towards the area in which there is already greater density, an unstable situation will be created.

AG: So a simple movement of the hand can render the whole situation around it unstable?

AS: Let's see if I can make you understand: if by chance in one point there is a higher mass than normal, the other particles feel it and move towards it attracted by the force of gravity, so that the mass increases even more, and having even more mass than before it attracts other new particles, and so it goes on. All the particles produce approximately the same force of gravity and where there is mass there is gravity, this was Newton's great discovery: all the particles of the Universe produce gravitational force in proportion to their mass. Any two masses attract each other, this can be measured with sensitive instruments and there are famous experiments, such as the one of the two steel balls hanging from a long thread that tend to approach each other. The basis for the concept of gravity is that all the particles produce gravity. To return to what we were saying before, the force of gravity produces unstable situations in which all the masses precipitate together, and this is essentially the response to the formation of all the stars and the planets, and of all the rest of the Universe, because in the beginning the Universe was only a gas, or something similar to a gas, and in effect the density has increased considerably as soon as it began to expand. The expansion of the

Universe means that something very dense becomes very thin, this kind of low density gas we were talking about, and then it condenses into the knots we see today, the galaxies, the stars and the planets. But the question is another: has there been sufficient time for the gravitational process to produce the things that we see in the Universe today? The answer is that in fact it is not possible to arrive in time at this type of Universe if we only calculate the visible matter. I don't know if I have explained myself clearly, but the time is not enough, because we know that the Universe was extremely smooth immediately after the Big Bang, and now it is very knotty: we have tried to calculate how much time is needed to pass from very smooth to very knotty using the force of gravity and the force of amplification called 'gravitational collapse', and it is not possible to do that in the amount of time that we have… But if we had particles of dark matter, particles that have masses like the others but which for some reason we have never seen, like neutrinos, perhaps, it might be possible, the calculations work out: with the addition of the dark matter it is possible to obtain from the Big Bang the Universe that we see today.

AG: But when you talk about "the Universe that we see today", what scale are you talking about?

AS: All scales, from the stars to the biggest object that we can see. There are visible objects much bigger than galaxies.

AG: What if we wanted to fix some parameters, a maximum and a minimum?

AS: As the maximum I would say the maximum distance that can be reached with the telescope, as a minimum, the scale of a galaxy. Although it is also possible to understand concepts from smaller things, but in general we deal with very large scales.

AG: And then obviously the microscopic components that make up the object in that macro-scale, I would imagine.

AS: This is an interesting topic, because the smaller things are in close relation to the larger scale, and also because particles like neutrinos are fundamental to the sense of the structure of the Universe and its evolution. As I said, simply in order to explain the internal dynamics of the galaxies we need particles of dark matter, and we also need something similar to explain how the Universe arrived from the Big Bang to the present.

AG: It is practically as if you had the solution to a problem and one of the two elements that lead to the result, and yet you were lacking the other element; as if, let's say, X with Y equals Z, you know X and Z and you have to find Y?

AS: Yes, this is what is missing, the dark matter, which makes all these topics work in a very precise manner. If you give me the dark matter I can make calculations on evolution from zero to the present, and I can explain the rotation of the galaxies and all the rest.

AG: Defining the dark matter in this way, what you need to know then are the elements that form it, the neutrinos and the other similar particles, which being calculable contribute to reconstructing the whole?

AS: No, this is another aspect. Apart from the cosmological and astronomical argumentations, there are also various argumentations that derive from the physics of particles, where there is a complex mathematical theory to explain, for example, how the neutrinos interact and which also explains the various types of particles that exist, the protons that make up common matter, and how these things interact with each other. This theory is called the 'standard model' of particles in physics: it is a standard equation that explains the nature of the smallest particles and the way they interact, but it also has an aesthetic-mathematical aspect which is not wholly satisfactory, so there are scientists who would like to change it. Changing an equation is a common strategy in physics: for some reason the physical world can be explained with mathematics and the equation is often revealed to be symmetrical and even beautiful, but perhaps imperfect, and if the imperfection is corrected by making an even more general and even more symmetrical equation, then we may discover a phenomenon that had not been noted before. In other words, the reason the equations that we examine are symmetrical as they should be lies in the fact that there is a part of the physical Universe that should be already included in the description, but which in reality we do not know yet. It is a very abstract question, but the fact is that if we take the equations that govern the known particles, they can be made even more perfect by postulating the existence of new particles not yet discovered. And this has actually been the case for a long period of time, since new particles have not yet been discovered.

AG: But couldn't the fact of postulating the existence of things that in actual fact are not known lead to error?

AS: Yes, it could in theory produce errors, but there is a long history of interesting discoveries which started from argumentations. The anti-matter, for example: it was noted that the equations that describe common matter would function much better if for each particle of matter there was also an anti-particle, that is a particle with identical properties but with an opposite electrical charge. It was only a mathematical property, since the equation makes much more sense if we also consider the particles of anti-matter, but the scientists began working hard to find it, until they really did find it. This is just one example of the success of this kind of argumentation, but there are many more: the discovery of anti-matter dates from the thirties, if I'm not wrong, and then in the seventies and eighties there were other even more important successes, and new mathematical equations were reviewed on the grounds of argumentations of symmetry, which are often very difficult to explain and very abstract, but since it is essentially possible to describe the world in its various dimensions, often beyond what we can see, by making the equation symmetrical we may discover, for example, that we also need all these particles, amongst which is anti-matter.

AG: So anti-matter does not deny matter, it is just that it has an opposing force: it is 'anti' in the sense of contrary, not of negation, of something that does not exist. If it were a 'without matter' we would probably call it 'a-matter'.

AS: Yes, 'anti' means another type of matter.

AG: To return to the image we used previously, in which we have an equation for which we know the solution and one of the elements, while the other element is unknown, the aim is to try to define this missing element. It is basically a question of fitting in a missing piece in which the matter is missing not because it doesn't exist, but only because it has not been discovered yet. If I have understood correctly, in physics there actually cannot be a void as such, but a void is something for which the nature of the content is not yet known, and it is therefore each time a question of finding ways to describe it and define it.

AS: That's true, it's a bit like a mystery story…

AG: Exactly. You have clues and you must find a solution, but the missing element is not missing because things work in a given way precisely because it is absent: it is missing only because it has not been discovered yet.

AS: You are right, perhaps it is not in keeping with the theme of the magazine… But I agree with the things you have said. To return to our topic, anti-matter exists, and it has the characteristic of having a negative charge while matter has a positive charge, or vice versa (in the case of an electron with a negative charge, for example, the anti-matter is a positron with a positive charge), and when these two particles meet, the final object has a neutral charge equal to zero, and can transform itself into another object with a neutral charge, for example two photons. But since only conservation of an electrical charge makes matter stable, and when the charge is zero there is no longer stability because there is nothing to conserve, in practice when matter and anti-matter meet they destroy each other and are transformed into energy. In a certain sense therefore, anti-matter is really the negation of matter.

AG: But it is the physical negation, it is not a void.

AS: It is a physical object, yes.

AG: Does this mean that in the explanation of the origin of the Universe, for example, the empty slots are not empty because they must remain so, but because they haven't been filled with knowledge yet? That void won't come into play inasmuch as it is void, it is only something that is not known, that does not have a name yet.

AS: True. Once we had discovered dark matter, we would probably no longer think of it as an absence. We can't see an atom, but we have been able to accept that an atom is in a certain sense something missing, I think perhaps because we can see atoms when they are together, so it is a little bit different, but in any case there are many other things that we can't see.

AG: Therefore in physics *nothing* does not exist. Nothing is nothing.

AS: Physics is the science of things that exist. Something that did not exist would be outside our frame of reference.

AG: If physics cannot conceive the nothing, that means that everything that is not, it is simply something that has not yet been discovered.

AS: Right. Dark matter does not have a different metaphysical status from the particles that we already know: it is merely composed of a type of particle that is difficult to observe.

AG: Interesting. But then how can the concept of void be defined in physics?

AS: In physics the vacuum, the void, is simply absence of matter.

AG: Does it exist, or can it only be created artificially?

AS: Space without matter exists in the laboratory, but also in this room: if we look at what lies between two atoms or two particles in space, there is nothing there, only small portions of space that have not been occupied, like an empty apartment.

AG: What, is there nothing there… Isn't there anti-matter? Aren't there any neutrinos?

AS: The neutrinos are out there somewhere, and if we zoom in and enlarge the view, we will see that there is space even between one neutrino and another, because the elementary particles do not have natural dimensions, they are like dots, so that the closer we zoom in on them, the more there will be spaces in the pattern between one element and another, and I believe this is something to ponder on very carefully, because there is a concept of quantum mechanics that says that the particles must in a certain sense fill the space, but actually I don't think that this changes the fact that a void exists: it is just another word for space.

AG: Let me give you an example: if you take a blank sheet of paper and you draw some dots on it, and you think that the dots are the space (full) that you have filled on that sheet, and that the white part is the void, can't you apply the same image to space, for example to the space between the objects. Or am I wrong?

AS: Do you mean like pixelling, like in a newspaper or a photograph where enlarging creates spaces between one dot and another? But perhaps I didn't understand the question.

AG: If we draw some dots on a sheet of paper, we can think that the dots that we have drawn are objects and that all the rest, the part that is still white is empty, that there is nothing there. I was wondering if it was possible to think in these terms of the physical Universe.

AS: Sure. Quite simply, the white would be space and the dots would be matter, and between each of the two dots there would always be a bit of empty space.

AG: But if we take a blank sheet, for example, the white on which nothing is drawn, on which there is no ink, can be considered zero, if instead we use the same image for the Universe, the white is also in a certain sense a colour.

AS: I see what you mean and I think you are right. It is a concept that to some extent remains outside the field of physics.

AG: You would probably say to me that the white is already a sum of the colours, that it is made up of light and so on, but you wouldn't consider the white as the nothing, as the empty part or the lacking part respect to the signs.

AS: True. We always refer to the space as a something. For us the space *is* something. You are right: physics only deals with things that exist.

AG: The concept of empty space would seem not to exist. For example, in the large scale of the visible I can say: this space is empty. But in truth physics tells me that it is not empty at all.

AS: That's not true, the concept of empty space also exists for us.

AG: But from what I have understood it is always a question of a microscopic scale: the empty space is at most that between a neutrino and another similar particle. At this point the concept of empty, the word itself seems to me to assume a totally different significance according to the context in which it is used.

AS: Alright, there are no large portions of empty space. It is a microscopic concept, in effect, because every ten centimetres in any point in the Universe there are an enormous quantity of particles.

AG: If you shot me into space, even what would seem to me empty space would actually not be empty…

AS: In space you would meet some sporadic atoms about every ten centimetres. A totally blank space does not exist, if you were to try to draw the Universe, you would have to cover the sheet with lots of tiny dots. But perhaps in the future this will not be true any more, since the Universe is expanding continually while the number of particles is finite, so logically one day there should be lots of empty space. I think you can conceive the idea of a completely empty space, it's just that in practice in the Universe as it is today it does not exist. In effect there are voids in space, they are decidedly rare and devoid of matter, and I have never thought about what the density of matter could be in the void, but I think it is true that there is always something around, there are probably neutrinos and other particles passing through it… Yes, there are particles everywhere.

AG: Tell me about the experiment you are currently working on at the Fermilab[2] in Chicago.

AS: We are looking for the dark matter and I will try to explain why. Before, I talked about three types of arguments: the first, the dynamics of galaxies; the second, the need to create the Universe that we see now from the Universe of the post-Big Bang; the third, the argument that comes from the physics of particles, that says that by making an equation more symmetrical we discover new things. If we only begin to use slightly more beautiful equations for the Universe than those we habitually use to describe visible things, if we only exaggerate a little bit by making them more symmetrical, than actually the equation says: "Oh, there are other particles…!" The particles of dark matter that we are thinking of now should be similar to neutrinos, but heavier, with a mass similar to the atoms.

AG: And the name? I imagine that they will be called something other than neutrinos.

AS: Yes, they are called neutralinos. Neutrino was an Italian name, since the inventor was Enrico Fermi, while the neutralino was invented by an American: the sound is similar, but the particles are different.

AG: And why are you looking for the neutralinos and not the neutrinos?

AS: Because numerous experiments were carried out during the eighties and nineties, and even more recently, that show that the neutrinos do not have enough mass. Actually, the fact that the mass of the neutrinos is similar to the mass of all the visible things, like the stars, is quite interesting. In a neutrino and in the stars there is about the same mass, but because it is a question of dark matter it will need about a hundred times more, and the neutrinos are not heavy enough. The dark matter must be composed of another type of particle, some of which are similar in a certain way to the neutrinos but heavier. The equation that foresees the neutralinos can also tell us a lot about their properties and about the possibility that a neutralino would hit another particle of common matter, like the calculations that Fermi would use to understand how many neutrinos can hit a big tank of water underground, and it has been used to measure the neutrinos from the sun and from other places. It requires a lot of luck if a neutralino is to hit a common atom, and we know how much energy would be transmitted to the atom if it were struck: now we are trying to establish whether this thing really exists. But the problem is that the neutralinos don't hit atoms very often.

AG: More or less, how often?

AS: The experiments have recently shown that it's about one event per chilo per month, and we also know something about the type of atoms that the neutralinos prefer to hit: they usually prefer heavier things, like lead, so if we take a kilo of lead, we think that it could be struck by one

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[2] Fermi National Accelerator Laboratory, Batavia, IL, USA (www.fnal.gov)

neutralino once a month, although there are billions and billions passing through it every second. The problem now is to find exactly the one it will strike, since it does not happen very often, and the amount of energy is similar to that of a single X ray: we can think of this phenomena as a photo of X rays in a single point, and that can occur only one time in a month.

AG: And you don't know when, nor how, nor where…

AS: Exactly, and this is what makes the discoveries and the research so difficult. We are working on new techniques to find this type of interaction: I have personally been working on it for about fifteen years, more or less since I began dealing with physics, and I am one of the first generation of physicists essentially trained to resolve this problem. That's how it works in the world of science: each generation is trained to resolve the main problems of their time, and I belong to the first generation of physicists who have dedicated their entire career in the attempt to resolve the problem of the dark matter.

AG: What was the previous generation seeking, for example?

AS: They were looking for other particles, for other reasons.

AG: So basically will you dedicate your professional career to the search for the neutralino?

AS: Yes, up to now my professional goal has been to find a way of measuring neutralinos. Three or four years ago we found a new system that seems really practical, the bubble chamber's device, in which it is possible to have a liquid in a particular state, that is hot to the point where it is almost boiling, like water in a pan just before the first bubble appears: if the neutralino hits an atom in the water a bubble would form, and we could photograph it.

AG: So the photo of the silver bubble that you sent me is a photo of a neutralino…

AS: No, that is what a neutralino would look like. We can use the neutrons, which are one of the components of an atom, to make bubbles that are wholly similar to the bubbles produced by the neutralinos, if they really exist. We use the neutrons to see what the phenomenon would look like.

AG: But would this bubble be visible to the naked eye, or would it be registered by the machine?

AS: It's also visible to the naked eye.

AG: Is it necessary to be there, right at that precise moment in the month?

AS: The bubble expands very quickly, if we saw it in real time, it would be like seeing a big explosion.

AG: On the surface or inside?

AS: Inside. You would see a tiny bubble that expands very fast.

AG: So is it a bubble, but without air?

AS: It has vapour. The bubbles in water are not made of air.

AG: Strange, we usually imagine a bubble on the surface, as if it filled with air, or like a wave.

AS: It's true that if we boil water, the bubbles usually begin on the surface, but if we keep the water sufficiently hot, the bubbles will begin to form both in the middle and on the surface. Anyway, in this case the bubbles are in the middle and they expand very quickly, and while they are expanding we photograph them with two machines, which means fifty frames per second, so that by comparing the two images we can measure their position in space.

AG: So are these cameras taking photographs continuously, twenty-four hours a day?

AS: Exactly.

AG: Do you have to examine all these images every day, or does the machine select the images that are different from the other ones?

AS: The computer memorises only the last half second, and then it maintains the visualisation of the previous half second, it compares the images and if it finds a difference, it preserves the last half second and stores it on the hard disk.

AG: Did you write this program at the lab?

AS: Yes, for example, I wrote this one, but it is only a question of hardware and software: the images are stored on the hard disk and we write a program that analyses them, so that we can see the bubbles produced by the neutrons.

AG: When you were designing this machine, did you first think about the function and then about the way to build it? Did you say to yourself: I want to obtain this result and I need a machine that does this, and from here you built every single element such as the various programs or the other functions that would allow it, or did you follow an experimental path, that is adding the elements one by one as you realised that you could attain the result?

AS: I don't understand the question. In any case, the difficult thing in experiments in the field of physics is to find a way to measure precisely. In this case we wanted to measure the bubbles so we thought: we need two cameras, we must produce a liquid at this temperature, and we designed a device with the aid of the engineers and the technicians. Today at Fermilab, where I work, we have a team of about twelve people working on this project, half of them are physicists and the other half are engineers or technicians. We register the images every day, and we now have about two or three bubbles an hour.

AG: Does this mean that the machine works?

AS: Yes, but the problem is that not only the neutralinos can produce the bubbles, but even the neutrinos, and the neutrons, and perhaps other half particles.

AG: How can you tell what effectively produced the bubbles?

AS: That is the point. Amongst the two challenges of this research one is that of constructing a device in which the neutralinos produce bubbles, which must be sufficiently large since the neutralino only makes one bubble per chilo per month: we would like to have something like a number of tons of material in the bubble chamber.

AG: When you talk about the "chamber", is it a room for real?

AS: No, the one we have is about one metre square, but we would like to build a much bigger one.

AG: So it is called chamber, but in fact it is much smaller than a room.

AS: Exactly, chamber is just the word we use.

AG: What are the problems involved in building a bigger one?

AS: Technical details, but it is also a question of the cost.

AG: How much did the one you have now cost?

AS: The one we have now costs about fifty thousand dollars, to build a bigger one would probably cost a million… To return to our topic, the second challenge, apart from the fact of managing to see bubbles from the dark matter, is also not to see bubbles from anything else. To establish the difference between a bubble produced by the neutrons and a bubble from the dark matter is the greatest difficulty, but we have various ways of doing this, I could go into details although I don't know how interesting it would be with respect to our conversation. One of the principal techniques derives from the fact that near the earth's surface there are lots of neutrons produced by cosmic rays, so to make the experiment valid we have to move the equipment underground. That's the reason for the Gran Sasso National Laboratory.

AG: Is the scale of the laboratory a physical scale, is it a habitable space?

AS: The experiments on neutrinos are very widespread today, because not much progress had been made since the fifties, so it is a new form of research and the experiments are still relatively small with regard to the detectors of dark matter. The laboratory was built for neutrinos, and the solar neutrino detector in which I worked, called Borexino, is an enormous room, about a hundred metres long and twenty metres wide. In fact, we are trying to build a laboratory on the same scale in the United States, perhaps even bigger and further underground.

AG: Will you go to work there?

AS: Yes, I will spend some time there, but the equipment we are constructing is controlled by computers.

AG: Are you working on the creation of this laboratory?

AS: A bit, but not a lot. In any case, it is not really necessary to spend a long time underground, because once the detectors are installed you can sit in your office and look at what is happening on the computer. For example, the small detectors in the ten centimetres chamber installed in our laboratory near Chicago are working at the moment.

AG: Thinking about the name 'bubble chamber', I was wondering whether the bubble was the only way of making the phenomenon visible, or did you choose this method and then give the neutralino this opportunity of being seen?

AS: We chose this technique for various reasons, but there could be other ways to see the signal.

AG: So, someone else could decide to see a flare rather than a bubble?

AS: Yes, but ours is in any case the most visual way of seeing it. The others are electronic systems, they produce a small electrical signal.

AG: Could that signal be transformed into an electrical charge, or into an audible signal?

AS: Yes, into a sound, perhaps. But ours is the most visual system.

AG: I am interested in this question because recently with another artist, Margherita Morgantin, we presented a project for a permanent installation to be created next year in Milan, and the sense of it is close to the things we are discussing: how to visualise a physical phenomenon. The project consists of a device that transforms visible light into colour and into sound using an instrument called spectroradiometer, commonly used in agriculture, for example, for registering the variations in visible light, and the relative software that translates these variations in light into series of numbers. We liked the idea that once you have these numbers they can be translated into something else, in this case into a corresponding emission of monochrome colour, and into a sound frequency, which becomes in a certain sense another perceptible form of the variation of the light over the twenty-four hours of the day. It is curious to think that when you have numerical data you can visualise a given phenomenon in one way or another. In our case, for example, given a series of numbers that vary, it is a question of establishing parameters, such as a hypothetical level zero in which the light at midday corresponds to white, so that starting from that variation there will be a slightly different hue until we reach the black of midnight. The same thing for the sound. That's why I was curious about the bubble chamber, because after all you have chosen one of the possible forms of visualisation of this phenomenon, but you could also have chosen another method and therefore visualised the existence of the neutralino in another way.

AS: You are right, it is a very common phenomenon: this is what a transducer does, it is an instrument that from one type of signal produces another one. But in this case it is interesting because the bubbles are big enough to be seen with the naked eye. They become very big, in less than a second they are already two centimetres across.

AG: Does this depend on the way you have set the machine?

AS: The speed of growth of the bubbles depends on the temperature of the liquid and on the pressure.

AG: So, in a certain sense you have established it, it doesn't derive from the neutralino itself…

AS: It depends on the machine, which is designed to produce large bubbles.

AG: So we could say that in the end it is a question of aesthetic choices?

AS: Aesthetic choices, but also the fact that it must be something measurable. It is perhaps more a work of engineering than of aesthetics, but at times these things go hand in hand. For the light system that allows us to see the bubbles, for example, I studied books on photography to understand how to photograph a transparent object inside another transparent object: with uniform diffused light, backlighting, and we tried to use this system. There is a light, and a white translucent screen that creates the most uniform counter-light possible, and starting from there all the relative problems of lenses, focus and other photographic techniques. I had to choose the angle of the lenses, the speed of the shutter, the opening of the diaphragm, in fact we have now involved an optical technician because for the new bubble chamber we will need a totally new design for the lenses and the rest of the system.

AG: When the bubble will become visible will it also be measurable? Do the two things go together?

AS: The photograph is already the measurement.

AG: Strange. A photograph would seem to show the existence, not the size or similar things.

AS: By changing the temperature of the liquid it is possible to measure something of the particles, for example it is possible to measure how much the number of bubbles vary, and whether by changing the type of liquid it is possible to measure something, but the simplest measurement remains the photograph of the bubble. The question to ask is this: is there a bubble, yes or no? The point is the presence or absence of the bubble.

AG: If there is a bubble then the mission is in a certain sense accomplished…

AS: Yes, because unfortunately the shape of the bubble in itself doesn't mean anything.

(…)

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