WONDER AND KNOWLEDGE
The origin of the universe and the role of wonder in scientific discovery

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Introduction by	*Prof. Robert POLLACK*
Moderated by	*Msgr. Lorenzo ALBACETE*

Crossroads: Good evening, and welcome on behalf of Crossroads Cultural Center. We would like to thank our co-sponsors: the Columbia Catholic Ministry and the Center for the Study of Science and Religion also here at Columbia. We are pleased to have with us Prof. Michał Heller and Prof. Marco Bersanelli, both accomplished scientists and deep thinkers about the meaning and value of the scientific enterprise.

If we must try and point out a common feature of their work, we will notice that both of them view science as a deeply human activity. To them, science does not stand in isolation, separate from the rest of human experience, but rather is deeply rooted in it. As is well illustrated by both Prof. Bersanelli's new book and the numerous publications by Prof Heller, science requires men and women who face reality full of wonder and curiosity. There is a common misconception that science is all about objectivity and detachment, like some kind of mechanical process. But history shows us again and again that the greatest scientists were those who were the most passionate about knowledge, those most fascinated by nature. Only interest in the mystery of the universe, and the desire to know it, have made them able to look with open eyes and to go beyond the preconceptions of their time. Scientist ideology which denies what Einstein called "the Mystery," is an enemy of real science, precisely because by denying the fundamental human experience of it, it cuts off scientific research from its deepest sources.

Dr. Bersanelli, presenting his recently published book, will help us to explore what lies at the root of true science, while Prof. Heller will develop the theme of the role of wonder in the process of knowledge, by facing one of the most fascinating topics that has always captivated humankind’s attention: the origin of the universe. At this point, who could be better equipped to moderate tonight’s discussion than the chairman of our Advisory Board, Monsignor Lorenzo Albacete. He holds a degree in Space Science and Applied Physics as well as a Master’s Degree in Sacred Theology from the Catholic University of America in Washington, DC, and a doctorate in Sacred Theology from the Pontifical University of St. Thomas in Rome. But before Msgr. Albacete introduces our panel, I would like to invite to the microphone our great friend Dr. Robert Pollack, distinguished scientist who teaches Biological Sciences here at Columbia and who is the director of the Center for the Study of Science and Religion. Prof. Pollack…

Pollack: I am the Director of a small unique collection of people from all over the world, the Center for the Study of Science and Religion, a Center within the Earth Institute at Columbia University. We are pleased to co-sponsor this event, because Awe and Wonder are at the heart of our own enterprise.

I’d like to say just a few words about that in my own personal terms, in honor of the great gift of my long friendship with Monsignor Albacete.

At the beginning of every day – or to be precise, every day that I remember to do it – I say a brief prayer:

"Reshit Chochma Yirat HaShem"/
"The beginning of wisdom is Awe of the Lord."

But Awe of what, exactly, is the beginning of Wisdom?

Many think this Awe is the internal subjective emotional state instilled by contemplation of the incomprehensible grandeur of nature, as in Psalm 92, a Psalm the Levitical priests would recite in the Temple on Shabbat:

"Ma gad'lu ma'asecha HaShem, me'od am'ku mach'sh'votecha"/
"How vast are your works Lord, your designs are beyond our grasp."

But in this age of science we no longer have the luxury of incomprehensibility. The natural world is all too comprehensibly dependent upon death for novelty. In earlier times there were no humans, and even earlier times there were no mammals, nor vertebrates, nor any organism bigger than a single cell. From those earliest times until now, all that we might want to think of as progress has been simply the selection of one subset of DNA sequences or another from a constantly refreshing pool of copying errors. We can be fairly certain that replacement or death will be the fate of all humanity as a species, just as death is the certain fate of every person.

Worse, we also know – if we are honest about the data of natural selection and cosmology – that nature is devoid of data suggesting intentionality, direction other than death, perfectibility, or purpose. The living world, ourselves included, is intrinsically imperfect and intrinsically unperfectable. It changes, but even the changes that make each of us individually unique and interesting to each other are meaningless differences in DNA, creating the differences among us toward no purpose beyond the possible improvement in survival of one or another particular version of DNA over time.

I am not exaggerating the seriousness of this problem: scientific insight into the meaninglessness of DNA-based life is not simply missing meaning. It is the demonstration that a satisfactory, even elegant explanation of the workings of this aspect of nature actually conflicts with the assumption of purpose and meaning. Poets seem to have an easier time accepting these facts than people less skilled at self-awareness. Here, for example, is how Edna St. Vincent Millay sees the emptiness of the natural world's beauty, in her poem "Spring:"

"To what purpose, April, do you return again?
Beauty is not enough.
You can no longer quiet me with the redness
Of little leaves opening stickily.
I know what I know.
The sun is hot on my neck as I observe
The spikes of the crocus.
The smell of the earth is good.
It is apparent that there is no death.
But what does that signify?
Not only under ground are the brains of men
Eaten by maggots.
Life in itself
Is nothing,
An empty cup, a flight of uncarpeted stairs.
It is not enough that yearly, down this hill,

April
Comes like an idiot, babbling and strewing flowers."

Yet I see grounds for Awe in what we may choose to do. Nothing is more inexplicable in terms of nature, than the fact that I or anyone else may choose to act, and to act in a context of what is right, instead of merely behaving rationally. Awe for me emerges not from nature's beauty, but from the thought that despite the dismal facts of nature that allow such beauty to emerge, right choices exist for me to make.

And what determines the right choice, the ethical one? The capacity to choose is necessary but not sufficient for an ethical life. For that, one must choose to act out of love as well as self-love, and to do so even against one's own individual interest.

In the first book of the *Mishna*, "Pirke Avot," Rabbi Hillel distilled down the burden of choosing right to an obligation to ask oneself three necessary questions at all times when a decision is at hand. The actions that a person will take without delay on proper consideration of each of these questions form, I think, that person's ethical behavior:

> "Im Ain ani li, mi li?
> Uch'she'ani l'atz'mi, ma ani?
> V'im lo ach'shav, aymatai?"/
>
> > "If I am not for myself, who will be for me?
> > And if I am but for myself, what am I?
> > And if not now, when?"

One must slip the constraints of natural selection when choosing an action that confronts these three questions. What is right according to them is not merely to act or not to act in self-interest, but to act out of self interest for the sake of another person, even at the risk of one's DNA's survival. That is the intersect of awe and science, in my terms.

[These remarks are adapted from an article in the October 2009 issue of Sh'ma. Robert Pollack is a Professor of Biological Sciences and the Director of the Center for the Study of Science and Religion at Columbia University.]*

Albacete: I feel like the Oprah Winfrey of the science and faith world. We have two very distinguished guests. I will introduce them, they will do their show, and we'll have questions and answers.

Michał Kazimierz Heller is a professor of philosophy at the The Pontifical Academy of Theology in Kraków, Poland, and an adjunct member of the Vatican Observatory staff. He also served as a lecturer in the philosophy of science and logic at the Theological Institute in Tarnów. A Roman Catholic priest belonging to the diocese of Tarnów, Dr. Heller was ordained in 1959.

Michał Heller graduated from the Catholic University of Lublin, where he earned a master's degree in philosophy in 1965 and a Ph.D. in cosmology in 1966.After beginning his teaching career at Tarnów, he joined the faculty of the Pontifical Academy of Theology in 1972 and was appointed to a full professorship in 1985. The recipient of an honorary degree from the Technical University of Cracow, he has been a visiting professor at the Catholic University of Louvain in Belgium and a visiting scientist at Belgium's University of Liège, the University of Oxford, the University of Leicester, Ruhr University in Germany, The Catholic University of America, and the University of Arizona among others. Dr. Heller is a member of the Pontifical Academy of Sciences.

He has published nearly 200 scientific papers not only in general relativity and relativistic cosmology, but also in philosophy and the history of science and science and theology and is the author of more than 20 books. In March 2008, Heller was awarded the Templeton Prize for his extensive philosophical and scientific probing of "big questions." His works have sought to reconcile the "known scientific world with the unknowable dimensions of God."

Marco Bersanelli is Professor of Astronomy and Astrophysics and Director of the Ph.D. School in Physics, Astrophysics and Applied Physics at the University of Milan, Italy. His main field of research is cosmology, in particular observations of the cosmic microwave background, the relic radiation from the early universe. After graduating from the University of Milan (1986) he worked as a Visiting Scholar at the Lawrence Berkeley Laboratory, University of California, with Professor George Smoot, and then at Istituto di Fisica Cosmica, CNR, Milan. He worked on several experiments on the cosmic microwave background, including two expeditions to the Amundsen-Scott Station at the South Pole. In 1991 he received the National Science Foundation Medal in recognition of his work in Antarctica. Since 1992 he has been playing a leading role in the PLANCK space mission, the European Space Agency satellite dedicated to cosmology, successfully launched on May 14th 2009 from Kourou, French Guiana. He is the Instrument Scientist of one of the two instruments onboard the PLANCK satellite and has been a member of the PLANCK Science Team since its formation in 1995. He is author of more than two-hundred scientific papers as well as of several interdisciplinary essays and popular articles.

Professor Bersanelli is President of EURESIS, a cultural association promoting interdisciplinary dialogue on frontier topics in science. He has given many public seminars, coordinated over 12 scientific exhibitions visited by tens of thousands of people and published essays exploring the links between science and the wider horizons of human knowledge and religious experience. He is author of the recently published *From Galileo to Gell-Mann: The Wonder that Inspired the Greatest Scientists of All Time: In Their Own Words* by Templeton Press, about the human adventure of scientific research.

Professor Heller, you’re on.

Heller: Thank you for the possibility to be in such a privileged place.

My talk tonight is in two parts: The origin of the universe in science, and the second part, in philosophy. How, when and where did the universe come into being? This will be the topic for tonight. [slide 3]

But I will begin with a small page from the history of science. This is Newton and his *Law of Gravity*. [slide 4] During the time of Newton, there was a very interesting man, a cannon, Bentley, who asked Newton several philosophical questions related to his work, and Newton kindly answered him in a couple of letters: Isaac Newton to Richard Bentley (1693). And Bentley noticed that if we have a collection of points, and the law of gravity is acting upon all of them, then the question is: Why doesn’t this collection of points fall into a single pole. Why doesn’t it collapse, because gravity is attracted? And Newton shared that difficulty. He says, “The reason why matter evenly scattered through a finite space would convene in the midst you conceive the same with me, but that there should be a central particle so accurately placed in the middle as to be always equally attracted on all sides, and thereby continue without motion, seems to me a supposition as fully as hard as to make the sharpest needle stand upright on its point upon a looking glass.”

So such a configuration of points is unstable. It should collapse. Such points as these are stars, and stars should collapse into a single point.

And Newman says that in an infinite space there should be an infinite number of stars."It is much harder is to suppose all the particles in an infinite space should be so accurately poised one among another as to stand still in a perfect equilibrium. For I recon this is as hard as to make, not one needle only, but an infinite number of them stand accurately poised upon their points."

Newton was a genius. He felt that the gravitational field is unstable and he had no answer to that question.

Today we have a better theory of gravity, a general theory of relativity, invented by Albert Einstein. And all of modern cosmology is based on general relativity, and the same question is also a very vital question in general relativity, and to some extent we know the answer.

This is a picture of the center of a galaxy, and in the center of this galaxy [slide 5] there is something called a black hole, namely the matter around the center of the galaxy is collapsing under the force of gravity. It cannot stand on the looking glass, so it is going down, and this is called a black hole. And gravity is so strong that every photon emitted from the inside of the black hole will be reversed, and it will come back again into the black hole; therefore, from outside, the black hole cannot be visible. This is why it's called a black hole. So a black hole is not visible; it cannot be observed. But if there is matter around the black hole, then we can see that matter forming into a black hole. This is the so-called accretion disc, a technical term. Most probably such black holes are in a majority of galaxies. Also in the center of our own galaxy there is a black hole. So the gravitational field as you can see is unstable.

But we have another sort of instability even more dangerous because a black hole is a normal phenomenon, only in the center of the galaxy, or perhaps if you get a very heavy star which consumes its neutron sphere, the star will also collapse to form a black hole. But there is another one; it's a much bigger disaster. It's our own universe.

This picture literally shows that our universe is gravitationally unstable, [slide 6] but there is a difference—mainly a black hole is engulfing matter, but the universe, just the opposite. Everything started out as something that was similar to the black hole. So this picture shows our present cosmic era and other eras....And everything is going to be reversed if we follow the evolution of the universe...then we go here to what is called initial singularity, or more popularly, Big Bang. So if this configuration could be called a black hole, because it absorbs everything, the universe could be called a white hole because everything is emerging out of the Big Bang, out of the initial singularity.

What is the initial singularity? What is its nature? Now we must turn from the observational part of cosmology to its theoretical aspect.

This picture here, [slide 7] in a very simple manner, presents the main idea of Einstein's general theory of relativity. In his view, the gravitational field is but a curvature of spacetime. You combine space and time into one geometric entity, which is called spacetime, and here in my picture it is represented by this line. You can imagine that this is a piece of rubber, for instance, and if you put a heavy ball on that piece of rubber, then the curvature will form here. And let's imagine that we put a smaller ball here, and it looks like the bigger one attracts the smaller one. This is the main idea of Einstein's general relativity theory. Of course, in order to change that idea, that intuition for the real physical theory it must be expressed in a mathematical way. And here you have Einstein's theory...equations...but this represents....(inaudible) And if we put a heavier ball here, the curvature will be more pronounced and we say that gravity...(inaudible) Could you check the correctness of that equation? Of course there are many empirical tests which corroborate Einstein's theory.

And this is a very beautiful picture taken by the Hubble Space Telescope. [slide 8] And this configuration here is called gravitational lensing...and the situation is the following: You have here a big galaxy which of course curves spacetime, spacetime is curved around the big galaxy, and behind that galaxy there is another galaxy which is not really visible from outside from our perspective...but since the gravitational field is a curvature of spacetime, the light coming from that galaxy is bent around here. This is a galaxy of gravitational lensing phenomenon, and we know much more of such phenomena observed by astronomers, and we can see here almost literally the curvature of space around this big mass.

Okay, but now the interesting question: If we put an even heavier ball here, what would happen? Finally the ball would be heavy enough that what's around it would be broken down. And this is what theoroticians call singularity. So singularity is not just a point to which everything collapses, or out of which everything expanded from the Big Bang, but the initial singularity is the limit of our science. Spacetime loses its meaning here in the singularity. The microstructure of spacetime is broken down. So this is really a gap or hole in our knowledge.

[slide 9] Here is a picture taken from a textbook on general relativity showing the nature of singularity. Here we have spacetime which went far away from the axis...and here perhaps there is a black hole, and the curvature is very pronounced, more and more pronounced. And here there is a break down of spacetime, and we have a big, big question mark. So it is a hole in our knowlege, but scientists do not like gaps and holes. They always try to fill them in. And this is what we are doing now.

[slide 10] This picture shows the history of the universe up to our modern era. We go back in time to a certain moment when there are no more galaxies. The universe is filled with radiation. Professor Bersanelli will show you a beautiful picture because he's investigating that part of cosmic evolution...the universe was filled with very hot plasma, and in the beginning probably there was (inaudible) But if we agree that initial singularity we assume that time is zero, our cosmic clock is just starting, then what we do not know lasts only that short period of time. Starting from 10 to -43 seconds our knowledge of physics starts working. In other words, when we go back, and we go to that moment, 10 to -43 seconds, then it's what we call the Planck Era. At the Planck threshold, our present knowledge breaks down.

But as I said, we try to fill in this gap in our knowledge [slide 11], and there are several theories now being investigated which try to create what is called the quantum gravity theory. There are two big theories on the universe now—general relativity, which regards the cosmos on a big scale, and quantum mechanics, which is responsible for the behavior of elementary particles, but these two theories should be one theory—the quantum gravity theory. We do not know at the present moment the correct quantum gravity theory, but there are many candidates being investigated, and perhaps one of them will win. Perhaps something new will emerge out of present research. I will only name a couple of candidates—the Superstring theory, very popular in the media. A new modification or generalization of that theory is called M-theory. People do not know why *M*—some say matrix theory, others say it's a mysterious theory. There is a Loop gravity theory, Quantum group theory not connected to geometry, and there are also some which try to construct the very beginning of the universe. For instance, there is a very famous model proposed some time ago by Stephen Hawking and James Hartle which is called the quantum creation model of the universe all out of nothingness.

All these attempts, all this hunting for the primary theory, is based on an assumption: the laws of physics are valid. [slide 12] If we do not assume the validity of the laws of physics, we can do nothing. No step forward can be made if we do not assume the laws of physics. And then the question comes: Where do the laws of physics come from? If we ask this question, we go from the field of cosmology to the field of philosophy. And this is the second part of my talk. [slide 13]

This is a very great philosopher whom I like very much. He is my favorite—G.W. Leibniz. [slide 14] Here he is talking to Princess Caroline who was very intellectual. He dedicated a lot of her work to her. And this is a famous quotation from Leibniz's book: "Why is there something rather than nothing? After all, *nothing* is simpler and easier than *something*." Of course this question was asked by many philosophers before Leibniz, but he tolerated it in such a dramatic manner. "Why is there something rather than nothing? After all, *nothing* is simpler and easier than *something*." Think of another question. If there is nothing, absolutely nothing, no physics, no space, no time, nothing, then there are no questions; there is nobody to ask questions to. But nevertheless, there is something. And this is really a very deep question. And the doctrine of creation is a philosophical attempt to answer this question. So if you are asked what creation means, it is an attempt to answer Leibniz's question, "Why is there something rather than nothing?"

[slide 15] But in Greek philosophy there was no answer to the beginning of the universe. There were three main standpoints. One was of the Atomists. According to them, the universe had no beginning, it was an eternal motion of atoms, and there were some random collisions of atoms, and out of them the universe was formed just casually. Another answer was given by Aristotle. According to him the universe was also eternal, had no beginning, but it differed in causality, finality, final causes are responsible for the order of the universe. This is called *telos* in Greek meaning final cause, an aim or a goal. The third is Plato. Plato explained that there was eternal chaos. In Greek, chaos was not something that was disordered, but something which was next to nothingness, so this is perhaps the closest to the concept of the beginning of the universe.

[slide 16] But the idea of creation is a biblical idea. And I would like to quote two sources. The first, the first chapter of *Genesis* is perhaps the best one because it is very powerful, created in seven days. And this chapter of Genesis begins with the sentence, "In the beginning, God created…" The word "created" is used. In Hebrew, *bara*. "In the beginning God created the heavens and the earth." But the word "created" is used but not explained. The first explanation of this word we find in the Book of Machabees, 7:28. The mother is exhorting her son to enter martyrdom. And she says, "I beseech thee, my son, look upon heaven and earth, and all that is in them, and consider that God made them out of nothing, and mankind also." For the first time this phrase was used. And the mother was a very simple, not very educated woman, so it means that the doctrine of faith was in circulation.

But there were Christian theologians, Church founders who elaborated that concept in a more detailed way. It would be nice if I presented the evolution of this concept, but I have no time for that. I can only say something about St. Augustine who probably was the main contributor in antiquity to the concept of creation. [slide 17] There is a story which is very often repeated in many popular books that Augustine was considering the question: What was God making before He created heaven and earth? And the story goes, Augustine answered that question that God was preparing hell for those who asked difficult questions. But if you open Augustine's *Confessions*, you read carefully something absolutely different:

> See, I answer him that asketh, "What did God before He made heaven and earth?" I answer not as one is said to have done merrily (eluding the pressure of the question), "He was preparing hell (saith he) for pryers into mysteries." It is one thing to answer enquiries, another to make sport of enquirers.

So he said it's a very important question. It's something that causes us to think. And the idea of St. Augustine was that if it was a common idea in Greek philosophy that time is limited to change, to the material world which is changing. Time is only when there is a change. If there is no change, there is no time. And before the creation of the world, there was no change, so there was no time. And according to St. Augustine, God's existence is outside time. Eternity is outside time. And he says, this is a sort of prayer: "But if before heaven and earth there was no time, why is it demanded, what Thou then didst? For there was no "then," when there was no time." So the creation of the universe was a central act.

[slide 18] Another great Christian thinker of the Middle Ages, St. Thomas Aquinas, wrote a special treatise about the eternity of the universe. His main thesis in that little work is the following: He said, "There is no contradiction in asserting that the world was created, but has no beginning." So he distinguished two things: Creation and beginning—they are two different concepts. He says that it is possible, it is not an illogical contradiction that the universe had no beginning, but nevertheless it is created by God. And he quotes an example, the comparison taken from St. Augustine, and he says that if we imagine a man standing barefoot on the sand of the seashore, then he makes his footprint, he asks, (let's assume that this man is standing from minus infinity, always, from eternity), is the footprint eternal? Yes, it is eternal. But is it caused by that man? Yes, it is caused. So the beginning does not exclude creation. As St. Thomas wrote, "Creation is a relationship between the creature and the Creator consisting of the continual dependence (in the existence) of the creature on the Creator." So we can say it in a popular way: God has given existence to the universe every moment, continuously, and this is exactly what creation means—the dependence on a Creator. A good comparison would be the following: Look at this red spot from the laser. When I press the button, you see this red dot. If I suppress it, it disappears. So if God stopped giving existence to the universe we would turn to vast nothingness. In this sense we can say that creation is production out of nothingness. So the universe is created continuously. Creation is not only the initiation, but a continuation.

[slide 19] Let's go to modern times to the polemics between Newton and Leibniz. Newton claimed that there is an absolute time and absolute space. This means that space and time are a sort of stage on which physical processes occur. But these processes have no influence on time and space. And we can imagine empty time and space and before the creation of the universe there was absolute empty space and empty time. Leibniz believed that such a doctrine was nonsense. He said that space is a relationship between material events. If there are no material events, there is no space. The same with time. Time is a relationship which orders events one after the other, and if there are no events, there is no time. So Leibniz went back to the Augustinian concept of time. And this polemic between Newton and Leibniz has some repercussions giving the modern philosophy, but also as far as the concept of creation is concerned.

[slide 20] So according to Newton, eternity is existence from temporal 'minus infinity' to temporal 'plus infinity' and creation is creation at a certain moment of absolute time. And according to Leibniz, eternity is atemporal existence, and creation is not in time, but with time. Time was created together with the universe. Before the creation of the universe there was no time and no space.

And now let's make a little experiment. What's our idea of creation? In the majority of cases, the present idea of creation is Newton's. There was nothingness and at a certain moment the universe started to exist. But this is a very interesting modern idea. Before Newton, nobody claimed to believe like that. There was an Augustinian conception, St. Thomas Aquinas conception, but not that. This means that the influence of Augustine on Newton's physics is powerful till nowadays; it shapes our imagination of the world.

And now I'd like to say something about my own ideas. [slide 21] This question of something rather than nothing is a very pressing question, but I think there is another equally pressing question, and this question was noted and formulated by Albert Einstein. He asked, "Why is the universe comprehensible?" Science tried to comprehend the universe with great success, but why is the universe comprehensible? And this is a mystery we will never comprehend. Comprehensibility of the universe is incomprehensible. And I think that these two questions are in fact the same question or two faces of something one. Something which is not comprehensible, not for us but in itself, which is contradictory, which is irrational, cannot enter into existence because God is rational and He would never create something which is irrational. This is why I believe that these two questions are in fact two aspects of the same.

This is the theory of Einstein who tries to comprehend the universe, to enclose the rationality of the universe into equations. [slide 22] And following Einstein we would say that the world is rational in the sense that it can rationally be investigated.

But the idea of the comprehensibility of the earth is an old idea. [slide 23] It goes back to Greek times. In Greek philosophy there was a technical term, *logos*, (λόγος). It was used by Heraclitus and other Greek philosophers. Greek philosophers believed that the universe is not a mechanical contraption or a computer, like today you would be inclined to think. But their idea of the universe was something like a kind of organism. And an organism must have a soul, a principle of rationality, a kind of cosmic intellect. And the word *logos* literally means "word." It was used by Greek philosophers to denote this cosmic intellect. This idea of cosmic logos was borrowed by Philo of Alexandria in Jewish philosophy of the first century.

[slide 24] And of course we have the beginning of the Gospel of St. John. "In the beginning was the Word." The Gospel was written in Greek, *logos*. So the term was borrowed by St. John from Greek philosophy and endowed with a Christian thumbprint. "And all things were made by him; and without him was not anything made that was made." I think this is the crucial biblical text as far as the concept of creation is concerned. This is what St. John identified, calling *Logos* the person of Christ. This is why the Gospel was, as St. Paul wrote, "A scandal for Jews, and foolishness for pagans." Because cosmic knowledge became man. And this became the crucial text as far as the idea of creation is concerned.

[slide 25] Here are Einstein's equations, and these equations are written in a very compact form. In fact, Einstein's equations are highly complicated ones, very rich. If you'd like to write them down in their full richness they would contain more than ten thousand terms. But notice something interesting with these equations. Einstein wrote them down in 1915. At that time people did not know about the expansion of the universe. Einstein was absolutely ignorant, everybody was ignorant about the existence of black holes, gravitational waves, things like that. But all these things are contained in these equations. Somebody said that mathematical equations are wiser than the one who writes them down. And the next generation of physicists and mathematicians solved these equations and they discovered some information about black holes, the latest star evolution, and so on. It's contained here. And they asked astronomers to look at the stars, and they looked and they discovered in most cases what the equations suggested. This is why Einstein believed that the universe is rational, can be rationally investigated. When we are doing science, we are confronted with this rationality. This is something objective which we cannot penetrate. We decipher this objectivity step by step with a very great pain, and we feel it is something much bigger that we are, and even more that this big mystery comprehends also us. And I think this is what Greeks would call *Logos*.

Thank you.

Bersanelli: Good evening and thank you very much for inviting me. It's really an honor to have this opportunity to share some of the things that I do for my work. The questions I ask myself in doing my work…one of the reasons for this invitation was that it was mentioned before, the translation of this book that I wrote with Mario Gargantini, a friend of mine, and I'd like to just start by telling you how this book happened. [slide 2] I mean, my job is not to write books about science. My job is really to try to do some hard science, cosmology, and I will tell you a little bit about that. But this is something that happened. First of all, what I started to realize by doing my work and living in the scientific community for several years, was that science is perceived often as an impersonal enterprise, that the people who do science are irrelevant, marginal, not really part of the business, not really part of what science is. And so the progress in science and also technology appears as an automatic outcome of some predefined mechanism that happens, that is by itself impersonal or detached from the humanity of the people that are working on this. And, in fact, the results of science are presented and often expected from the public as something disconnected from any other aspect of human experience, of human knowledge. So all of this appeared more and more as time went on, as years went on, as far from my own experience of what it means to do research. Some writers, some of the greatest scientists…this is very far from the experience of the greatest scientists as well. So I started collecting, with Mario, many of the pages in which scientists talked about the human experience of what it means to do science, research. And we collected them in this book—scientists in action, not talking about theory or epistemology, but expressing their own direct experience of research, scientists from different fields and also from different philosophical positions. And I think it's been very interesting for me to work n this. I would like to tell you what it means starting from my own experience of doing research in cosmology, and this will track the path that the book is offering.

Indeed, cosmology and astronomy is the oldest science. Well before modern science started, thousands of generations of human beings have been contemplating the sky—something that we lack nowadays more and more. But the presence of the sky, the beauty, the attraction, the mystery, the vastness of the sky is powerful, has been extremely powerful in developing imagination, rationality, and observation in ancient civilizations. Here I'll just show you five different beautiful representations of the sky. I chose one for each continent just to make a synthesis—North America, China, Australia, Africa, Europe. Every civilization according to the sensitivity and the culture they were living in represented the sky as something deeply connected with their people's life and death—something deeply regarded in human existence. And in fact, even more than the sun, the stars identified this wonder about the universe, an important or decisive factor for science to be instructive. He said, "Those who have reached the stage of no longer being able to marvel at anything simply show that they have lost the art of reasoning and reflection." "Reasoning and reflection," says Mr. Planck, one of the greatest physicists of the modern era, are enkindled by marvel, by wonder. And indeed the technology that we have today allows us to look at the universe, at the stars, in much greater depth than it used to be for the ancient people.

You see this little square in this slide [3]? If you look at that with the modern telescope, the panorama that we see is incredible. The vastness of the universe appears much greater than we think. This is what we see. [slide 4] The number of stars that surround us is immense, and if we look at the same region of the sky just at a wider angle, [slide 5] every single point is a star. Our own sun is one of these stars...billions of stars. And this portion of stars does not go on forever.

We know today that stars are structured in something that we call our galaxy, [slide 6], or the Milky Way...something like 200 billion stars. Our sun is one of them. And the size of the galaxy is huge; it's well beyond what we can visualize, and even people who work on these things cannot visualize, but we can measure quite accurately how big it is, and it is about 100,000 light years.

What is a light year? You know the laser that I'm using to point to the screen, like every aspect of an electro-magnetic field, travels at 300,000 kilometers per second. In one second light comes from the moon to the earth. And light would take 100 millenia with that speed to go across our galaxy. And we live here.

But there is more. Today we know that our galaxy is not the only galaxy in the universe. There are billions of galaxies, and in fact, the closest galaxy is Andromeda [slide 7]. This is beautiful and similar to our own. And this is only 2.5 million light years away. It's the closest galaxy. It means that the light that the Hubble Space Telescope has captured in this beautiful picture, has traveled for 2.5 million years, covering every second the distance that goes from the earth to the moon. So this is far, but this again is the closest galaxy.

Today we have the ability to map many galaxies, millions of galaxies, and not only to measure where they appear on the spherical visual impression that we have of the sky. We can also measure the distance, and so we can build three-dimensional maps of slices of the universe, of portions of the universe.

What I'm going to show you is a slide [8] 2df Galaxy Redshift Survey, which mapped hundreds of thousands of galaxies. You have to imagine an ocean of galaxies. Every single spot here is not a star but a galaxy. And there are so many of them. The number of galaxies that we can see in the visible universe is similar to the number of stars that are in a single galaxy. So this is the size of the universe that we can investigate today.

So you see its size, starting from the wonder in the beginning, from the ancient times when people looked at the sky with the naked eye, it's led us to a much greater wonder.[slide 9] And indeed, I think that the first step in our relationship with reality in science, not only to start our research, but to continue the motivation of research, is wonder. And, in fact, the greatest scientists in many situations expressed very deeply their understanding of what this wonder is.

It's very interesting what Richard Feynman [slide 10] has to say: "The same thrill, the same awe and mystery, come again and again when we look at any problem deeply enough." This wonder is not just a sensation or emotion; it's something deep. You have to look at reality in depth, and that starts a process of knowledge. And he says, " With more knowledge comes deeper, more wonderful mystery, luring one on to penetrate deeper still." This is interesting because we think of science as something that the more it progresses, the more it gets rid of wonder and mystery. Mr. Feynman, one of the greatest physicists, said exactly the opposite. "With more knowledge comes deeper, more wonderful mystery." Indeed when we learn about the mechanism, the physical mechanism of the rainbow, it doesn't prevent us from marveling at the beauty of the rainbow. Actually, the understanding of the density, the beauty, the way in which the world is constructed, is much deeper.

And indeed there is a wonder of the unknown and there is a wonder of the known [slide 11], as Professor Heller said in his beautiful contribution. There is a great mystery. The very fact that we can understand how the rainbow works, or how the universe expands, as Einstein said, "The eternal mystery of the world is its comprehensibility." It's amazing that with an equation like this we can describe accurately the evolution of the universe. We can see how the data, the observations fit in a very nice way what the theory of general relativity is predicting for the mystery of the universe, and we can go back to the very first moments of the existence of the universe.

So what happens to a scientist who is living attracted by a phenomenon? Well, I think it's very similar to what happens to a child [slide 12] when he is attracted by something that he wants to grasp, he wants to look at. He opens his eyes. He wants to look closely, to touch. Observation. Wonder by itself doesn't lead very far. But it's the beginning of the process of knowledge. And the next step is observation and experiment. And experiment is what a scientist does to have a better observation, to select that part of reality that is really interesting , to ask a more clear question to reality in order to get a more clear answer. And so people get creative about how to ask questions. The ability to ask questions (I can see that in my class with my students) is a clear sign of a wide and deep intelligence. To be able to ask the right question, that is to make an experiment.

And observation is far from being an obvious activity or a passive activity. Observation requires training, requires learning. And I would like to quote Alexis Carrel [slide 13], a famous Nobel Prize winner in medicine. He said, "As everyone knows, few observations and much discussion are conducive to error; much observation and little discussion to truth." I don't think that Mr. Carrel meant that discussion or reasoning are bad things, but to be sound reasoning, it has to be continuously submitted to observation. We have to verify our theories all the time with anything we can in order to compare the observation with what we are...I'd like to go back to Dante Alighieri in his *Divine Comedy*. So many times he stresses the importance of observation for reaching truth. This is the origin of a certain rational position in front of reality which is essential for the birth of science. Dante says in the words of Beatrice, one of the many examples we want to take, "…Tu stesso ti fai grosso col falso imaginar, sì che non vedi ciò che vedresti se l'avessi scosso." The false imagination, the preconception, the fact that we think that we already know what we are looking at—this is what prevents good observation. To be open-minded about what is in front of us, this requires training, requires poverty of spirit, one could say. It requires a simplicity, to say it better. And this is really something that is crucial for a scientist.

And then when we are lucky, and when we are clever, once in a while we find something new. [slide 14] A scientist can discover something new that was not known before, it cannot be reduced to what was known before. And it can be a small discovery or it can be a major one.

But I would like to mention as an example the discovery that is at the root of the research that I am doing personally. So this goes back to the mid-6os when Penzias and Wilson discovered a strange or an unexpected signal coming from all over the sky [slide 15]. And the signal was luminosity in the microwaves, luminous energy in the microwaves which they could not make sense of. And this is in fact the first piece of paper where they recorded this signal. It was May 20, 1964. And that light, that very faint light, turned out to be something extremely important. They were not looking for it, of course. They were looking for a radio signal from our galaxy, and it led into this clue, and this turned out to be the left-over from the Big Bang. The light, the most ancient light, the first light in the universe that was released in space 14 billion years ago when the expansion of the universe was just at its beginning. Indeed these guys were lucky, but I'd like to quote here Charles Nicolle, "Chance favors only those who know how to court her." It's true here. In fact, historically it's interesting to see how this faint light was seen by others before. But no one really paid attention. It was only Penzias and Wilson who were attentive enough, careful enough, curious enough, open enough to follow this through up to the end. And so they got the Nobel Prize, quite appropriately, I think.

So from discovery to discovery, and this is another example for many of us, in this case a theoretician. [slide 16] And I like the way he describes his experience of discovery. He says, "I am fain to compare myself with a wanderer on the mountains who, not knowing the path, climbs slowly and painfully upwards and often has to retrace his steps because he can go no further—then, whether by taking thought or from luck, discovers a new track that leads him on a little, till at length when he reaches the summit he finds to his shame that there is a royal road, by which he might have ascended, had he only had the wits to find the right approach to it." *(Hermann Von Helmholtz)* When you are in front of the answer, only then can you see the best path to it; only then can you see what is the set of questions that you are trying to answer. When you climb, you are in the darkness. It's only when you are at the top, when you are in front of the answer, that all the questions become fully clear.

And of course, from discovery to discovery, after a few details, this very original cosmological light was investigated, and this was the first map [slide 17] of the early universe using this primordial light that was produced when the TOPEX satellite in 1992, and this is literally the first image that we have of the universe 14 billion years ago. Before galaxies and stars formed, and what you see is a very hot and dense, very uniform ocean of matter and emission in which you can see the seeds of the structure that will form in the billions of years to come. And these are these reddish regions. So we are really looking back at the origin of the structure and of the richness of the universe. And George Smoot and John Mather got the Nobel Prize for this first map of the universe.

And as always happens in trying to understand the details of what triggered the universe, what were the conditions in the early universe, and what are the factors that made the universe evolve in the way we have seen it? [slide 18] And so after COBE, the WMAP satellite of NASA was launched and it gave a much cleaner vision of what the universe was in the beginning, and then the PLANCK satellite, of which I've been working on for 17 years now, was designed and was recently launched, which is expected to give a crystal clear image of the early universe.

Why are we so interested in digging so deeply into this ancient light? Because there are a lot of open questions. Every time a discovery is made, it coincides with new, deeper questions. We want to reach deeper. Just an example of how deep the questions of the universe are today: [slide 19] Only 5% of the matter energy content of the universe is in forms that we understand. In other words, 95% of the ingredients of the universe are unknown. There are two different kinds of unknowns: There is the dark matter part which makes 25%, there is the dark energy part which makes 70%, but the physical nature of these ingredients is unknown, and with the PLANCK satellite we hope to be able to understand better—What are the constituents of the universe? What is the future of cosmic expansion? And what happened in the very first moments? By looking at the details of these differences in amptitude of the ancient light we can help answer these questions.

And indeed this is the PLANCK satellite [slide 20] which is right now collecting light from the bottom of the observable universe, and it's giving us a picture of what that universe was from which we can really hope to gain new insight. And what I'm showing you here is not imagination, is not a simulation, but is real data from the PLANCK satellite. It was launched on May 14 from Kourou, French Guiana, and this is the first fraction of the strata that the satellite is observing so far [slide 21], and you can see clearly that this is a superimposed picture of our galaxy that I showed you before. You can clearly see that we had a catastrophic scene here, but outside we have a very clear clue of the structure of the early universe. From there we can basically say that our instruments are really working properly, and so we are really excited about collecting the entire data. The next couple of years will give us a better view of the early universe and try to answer some of those big questions.

Now this is not really a discovery. This is just making sure that the instrument is working fine, but for me after almost 18 years of work to see this is well described by these words by Subrahmanyan Chandrasekhar, a great physicist. He expresses himself about discovery. He says, "In some strange way, any new fact or insight that I may have found has not seemed to me as a discovery of mine, but rather as something that had always been there and that I had chanced to pick up." Discovery is to pick up something that has always been there. It's a great experience to realize that something that has always been there since 14 billion years ago, and now we have the priviledge to unveil some of that.

So my final comment would be on the word "purpose." [slide 22]. Is there a purpose to what we do in science? Is there a purpose in the object of our study on the universe, on nature at large? And indeed, as Professor Heller pointed out, we can extract synthetically that wonderful history of the universe [slide 23] starting from the inflationary moment at the very beginning, the creation of the first...then the graduation...and then the formation of galaxies, and in some galaxies, the formation of stars, and stars that continue the evolution of matter, the elements that are necessary for life—carbon, oxygen, of which our bodies are made were produced inside stars, and it took billions of years to prepare all this. And so we have complex structures that take into account the whole cosmic history. So you see, we are not only a small point in space. We are at a certain moment in time, and our presence in the universe is deeply rooted in this cosmic history. It's a wonderful scene that we have the privlege to see. It's a cosmic panorama that science allows us to have in front of our eyes.

And so it's unavoidable, inevitable to ask the question: Is there a purpose in all of this? Is all of this a sign of something greater? Or is all of this just meaningless? And all the scientists feel strongly about these questions, one way or another, with different positions, but they are in front of this same great mystery. And I will just mention one very famous who had a pessimistic view, if you like. [slide 23]. Steven Weinberg had a very famous quote: "The more the universe seems comprehensible, the more it seems pointless." I guess it's similar to what Professor Pollack was mentioning earlier. And this quote created a lot of debate in the scientific community. And many scientists commented on it. For example, Margaret Geller, a famous astronomer said, "Why should [the universe] have a point? What point? It's just a physical system, what point is there?" Or cosmologist Jim Peebles from Princeton: "I'm willing to believe that we are flotsam and jetsam." And it's interesting that Steven Weinberg, when he heard about Jim Peebles comment said, "Well, he must've had a bad day." Maybe that's true.

The interesting thing is to see what Weinberg himself, after all this debate, said about his own sentence, and the comments that he received a few years later. [slide 24] A few years later he said, "My favorite response was that of my colleague at the University of Texas, the astronomer Gerard de Vaucouleurs. He said that he thought my remark was "nostalgic." Indeed it was—nostalgic for a world in which the heavens declared the glory of God." It's interesting, because even from a pessimistic position, there is a nostalgia that doesn't go away.

Einstein's position was very different. [slide 25] He affirms the reality of the mystery, of something beyond. He said, "The most beautiful and deepest experience a man can have is the sense of the mysterious. It is the underlying principle of religion as well as of all serious endeavor in art and science."

And similarly, Max Planck, [slide 26] to which our satellite is dedicated, and so I couldn't finish with anyone other than him. He said, "The greatest joy of a thinking man is to have explored the explorable, and just to admire the unexplorable."

So my conclusion is, [slide 28] let's not forget, science requires very specific and rigorous methodologies: experiment, mathematical language. This is what makes scientific inquiry extremely narrow, if you like. It can answer only a certain kind of question. But it is also so powerful in its own field. So it is narrow, but nevertheles if we look at scientists "in action", and I've collected so many witnesses from scientists, it's clear that the spectrum of rational and affective capabilities is much wider than it is normally realized. The entire personality is involved. And in most great scientists, motivation for research is rooted in aestethics, the sense of mysterious, and a deep appreciation of ultimate questions in very different ways. It can be from different positions, but that is really something at the core of what motivates scientists. And I think it's fair to say that as in any other kind of knowledge, science is an encounter between a human being and a reality that is out there. And I think a problem with science today is that there has been for too long a time a tendency to eliminate the subject of the inquiry and just treat it as something other than human. I think it's important to realize the broader human context in which scientific research is rooted, first of all for the image that science has towards, but even more importantly within the scientific community. I think there is a strong need to regain awareness of where science begins and can continue.

You know that there is a tendency in the western world, disaffection towards science from young generations. And I think it has a lot to do with this partial presentation and awareness of what science is really about. And I think this is also important that we remain open-minded on the purpose of scientific research which is the utility that technology can give us, but it's also the opportunity for everybody, not only for those who do research, to contemplate a greater beauty than we could do otherwise.

Thank you very much.