Newsletter Interview

DISCOVERING THE SECRETS OF THE UNIVERSE: A NEW TOOL FOR COSMOLOGY IS AWARDED THE BREAKTHROUGH PRIZE

Interview with Marko Simonovic, researcher at the University of Florence and at INFN, winner of the 2024 Breakthrough Prize "New Horizons in Physics"

Marko Simonović, researcher at the University of Florence and at INFN was awarded the 2024 Breakthrough Prize "New Horizons in Physics", for his contributions to our understanding of the large-scale structure of the universe and the development of new tools to extract fundamental physics from galaxy surveys, together with Mikhail Ivanov, researcher at MIT, and Oliver Philcox, researcher at the Columbia University and at the at the Simons Foundation.
The Breakthrough Prizes are also known as the "Oscars of science", and the New Horizons in Physics Prize is awarded to promising early-career researchers who have already produced important work. The physics prizes were founded by Yuri Milner, a former physicist now entrepreneur, and are funded by a grant from the foundation established by Yuri and Julia Milner.
Marko recently moved to Florence, after having worked at CERN, at the Institute for Advanced Study in Princeton and at the Scuola Internazionale Superiore di Studi Avanzati (SISSA) in Trieste, where he got his PhD. We asked him to tell us about his research interests and his works that led to this internationally renowned prize.

What are your research interests? What are you working on at the moment?

I'm a cosmologist, so my interests are mainly in theoretical cosmology. This means I study the small density fluctuations that we observe either in the late universe or the early universe, and I try to infer the history and the composition of the universe from these observations. For example, in the cosmic microwave background (CMB), which is the oldest form of radiation that can be observed with our telescopes, we see that the temperature across the entire sky is not perfectly uniform, there are small fluctuations in the temperature of the CMB. So, comparing the observations of some properties of these fluctuations with the different theoretical models, we can tell, for example, what was happening in the early universe and what kind of matter exists in our universe. This is how many interesting things were discovered. Similarly, when we look at the late universe, we can see fluctuations in the number density of galaxies in space. This means that the distribution of galaxies across the sky is not perfectly uniform, there are some fluctuations in the number density of the galaxies, and these fluctuations are similar to those observed in the CMB. They are basically the same fluctuations seen at very different times: the fluctuations we observe today are the evolved version of these early fluctuations. Therefore, it is important to study them because they have a lot of information about the properties of the universe. This is somehow similar to when you throw a rock into a pond: studying how the sound waves propagate and how the ripples form and then die off in the water, you can learn about properties of the medium (water). In conclusion, my work mainly revolves around making theoretical predictions and comparisons to observations, at the moment, I am manly interested in late universe density fluctuations.

What could be discovered by studying these density fluctuations?

To give you an example: if we didn't already know from other observations that dark matter exists, we would be able to discover it looking at the density fluctuations in the galaxies. I believe that in the future, one important goal is to study dark matter in more detail than what we can do with the current observations. Indeed, new relevant observations are on the way with big scientific missions, like the European satellite Euclid or the large US observational program, called DESI. These two telescopes are going to collect a lot of new data that are going to be used to test the possible extensions of the Lamba CDM cosmological model, also known as the "Standard cosmological model". This is extremely interesting because these new observations could lead to new discoveries, not yet achievable with the current data. For example, we could find out that in the dark sector, there are different types of dark matter particles, or we could also be able to measure the sum of neutrino masses using cosmology, which is a very spectacular result not achievable in the laboratory. Furthermore, these new data can tell us a lot about inflation, early universe, the so-called "Hubble tension" or dark energy. This is a really exciting period in theoretical and observational cosmology.

Could you explain why you were awarded the Breakthrough prize? Was it to awarded to particular research you worked on?

Most of my work has been on theoretical description of evolution of fluctuations in number density of galaxies and comparisons to the data. This is quite challenging, because sometimes we work with things which we do not quite understand on small scales, such as the details of galaxy formation. So, together with many other colleagues, I have been working on a popular approach in theoretical cosmology, which is called the "effective field theory for large scale structure", where we can describe the long-distance behavior of fluctuations without knowing the details of what happens at small scales. However, more importantly, I think the particular reason for the award to me, Mikhail Ivanov and Oliver Philcox was that we took the theoretical developments in this field, some of which we made ourselves, and we were able to convincingly show that all these theoretical predictions are actually correct enough to be used in the experimental data. Furthermore, by comparing these theoretical predictions to the data, we derived cosmological constraints using, for the first time, the density fluctuations I mentioned before. To summarize, I believe we got the award because we contributed to the theoretical developments in the "effective field theory for large scale structure" and we showed that this theory can be used with real data leading to very interesting constraints on new physics.

What is there that we do not yet understand about our universe?

We have a very good understanding of our universe at the moment, in the framework of the so-called "Lambda CDM cosmological model". One aspect of this model is the mechanism for the generation of the initial conditions that could have happened very early in the history of the universe (inflation), leading to our universe which is big, flat, homogeneous and has the small fluctuations I mentioned before. We also understand that there are normal matter, dark matter and dark energy. So far, we can basically explain all the phenomena we observe using the "Lambda CDM cosmological model". However, there are still some open questions: does dark matter have multiple components like ordinary matter? Do these dark matter particles have some additional long-range interactions that are not there in the visible sector? Are there some processes we do not know yet that happened in the early universe? How did inflation happen? Trying to answer these questions with the new data that will come could lead us to something new or, otherwise, could confirm that our universe is just described by the "Lambda CDM cosmological model". Going in this direction, the framework we developed could be helpful because it is a tool that allows us to make theoretical predictions and then compare them with the data for any particular cosmological model. It's a tool that gives cosmologists a way to use the data in the most optimal way, connecting the theoretical predictions to the galaxy surveys.

Why did the committee of the Breakthrough Prize find your research promising?

I believe that the tools we developed is something that the community has been waiting for a long time. I think that the committee recognized its importance for two reasons. The first is that in the next couple of years there will be a huge amount of new data coming and the second reason is that these tools will be able to show us much more than what we know at the moment. Furthermore, our papers got a lot of attention from the whole community and people are already using the tools.

Since you mentioned that your papers have many citations already and that the community was using the tool that you have developed, did you expect to win such a prize?

This prize is usually awarded mainly for what is called a little breakthrough in theoretical physics. So far, it mainly went to people who contributed more to high energy theory, while we are working in a field which is between astrophysics and theoretical physics. In that sense, this prize was a bit of a surprise. However, I think that we knew from the beginning that this work, regardless of the prize or not, is important. We were aware of its relevance.

Will there be an award ceremony?

Yes, this prize is awarded by the Milner Foundation. Yuri Milner is a former physicist who became an entrepreneur, who decided to support fundamental research. Every year this foundation makes a very nice ceremony where these prizes are awarded. It is similar to the ceremony for Oscars, with many movie stars, singers and other celebrities and it is broadcasted live on US public television. It is a very special ceremony and this year it's going to be in April, in Los Angeles, which is followed by a symposium which lasts for a couple of days. It is really a great event conceived to bring the focus on science and on the most recent theoretical developments in physics, a chance to put physics in the center of attention for the broader audience for a couple of days.

On a personal level, what does it mean to you to be awarded such a Prize? How did you feel when you got the news?

I was pleased because I have a lot of respect for people who were previous winners and who are sitting in this committee, and I was very happy that they recognized that this work was something worth of winning this prize. It was like getting approval from people that you think very highly of, and you respect a lot. It really means a lot. I also think that the beyond the personal feeling, it is also useful for the broader community in cosmology. As I said, we are always working on this interplay between astrophysics and theoretical physics, and we never quite belong to any of the two sides. Ours is a field which doesn't get much attention usually. So, I think that this kind of award also gives some visibility to my colleagues, and it was a prize also for the community, not only for ourselves.

After this prize, what do you wish to yourself for your future career?

Well, first of all, since I moved to Florence very recently, I have to learn Italian so that I can teach. Then, I believe that our work is not finished, there are always more things to be done. I will continue working in a similar direction, refining our predictions. I will be very happy if within my career, with the new coming data, we are able to see something new. One more surprise that cosmology has for us. However, even if it doesn't happen, I think that we are going to have very tight and precise constraints in our cosmological model.

Would you like to stay in Italy and in Florence?

I came to Florence with the idea to stay. I think that Florence has many interesting features and, since I did my PhD in Italy, I feel like being at home when I'm here, I like the people, the language, and the culture. Florence has a very good university and there are many other excellent universities nearby in Pisa, Rome, Bologna, Parma or Milan, where I have potential collaborators. It is very easy for me to take a train and go and talk to them. In general, in this part of Europe and Italy, there are many people working in my research field. Professionally, it is a good place where to stay. Furthermore, the Galileo Galilei Institute (GGI) in Florence is really an amazing resource because it is becoming one of the focal points for the international theoretical physics community and it has many excellent schools and workshops that call researchers and PhD students from all over the world. You never feel isolated here in Florence.