**Erik Verlinde interview**

Physics has led to an astonishing range of developments in the last century from transistors, computers, the Internet, atomic bombs and space travel to the recent search for the Higgs boson at CERN.

On closer inspection, there is also a quasi-religious undertone (albeit without the promise of salvation or the threat of eternal damnation). From the cosmos-gazing nature of Newton's Law of Universal Gravitation and Einstein's General Relativity to the subsequent developments in quantum mechanics of Planck, Bohr et al., which studied matter and energy at molecular, atomic and nuclear levels, Physics has searched for the macroscopic and microscopic clues to our very existence. It is no coincidence that the news is awash with stories of the 'God particle' and the quest for a 'Theory of Everything'.

The interest in Theoretical Physics has grown exponentially in recent decades, with 'celebrity' scientists such as Stephen Hawking, Michio Kaku and Brian Greene writing bestselling books and producing popular scientific series on mainstream national television. Moreover, string theory, a branch of theoretical physics that states that the fundamental ingredients of nature are tiny strings of energy and proposes 11 dimensions and parallel universes, has captured the imagination of a generation raised on *Star Trek* and *The Matrix*.

While many of us may be more concerned with trivial quandaries, such as who is responsible for the virus-like proliferation of coffee bars in Western Europe where the price of a latte increases at three times the rate of inflation, Erik Verlinde, professor of Theoretical Physics and world-renowned string theorist, is at the vanguard of efforts to unravel the secrets of our universe.

In January 2010, Verlinde caused a worldwide stir with the publication of *On the Origin of Gravity and the Laws of Newton*, in which he challenged commonly held perceptions on gravity, going so far as to state 'for me gravity doesn't exist'. If he is proved correct, the consequences for our understanding of the universe and its origins will be far-reaching.  In 2011, he received the Spinoza prize (the Dutch *Nobel Prize)* from the Netherlands Organisation for Scientific Research.

Robbert Dijkgraaf, UvA University Professor and current director of the Institute for Advanced Study in Princeton (where scientists including Turing, Oppenheimer and Einstein have worked) went so far as to say: 'Everyone who is working on theoretical physics is trying to improve on Einstein. In my opinion, Erik Verlinde has found an important key for the next step forward.'

So, what are Verlinde's views on the future of Physics and our understanding of the origins of the universe?

**For many people, Theoretical Physics is an abstract concept. How would you describe it to a layman, who is not scientifically minded?**

Well, we try to understand how nature works and how all the matter we see in the universe works including the forces in between. We do this in Theoretical Physics by thinking about the equations that describe matter, space and time. We then try to find laws that we can use to make predictions, and test these with experiments. In this way, we make progress in our understanding of nature.

**String theory is quite a 'hip', modern concept in physics. Can you explain what string theory involves?**

Quantum mechanics is needed to able to describe what is going on with particles at the smallest scales, and we know quantum theory works very well. We can also look at things involving gravity, space and time, and General Relativity. It has been a long-standing puzzle to combine quantum mechanics and General Relativity into one framework. String theory does this in quite an elegant way. It has a very precise mathematical structure that you can build on. It then allows you to do calculations that bring these two aspects – quantum mechanics and General Relativity – together.

**You're famous for developing this new theory, or idea, on gravity in which you say that gravity is an illusion. Can you explain what you mean by that?**

Well, of course gravity is not an illusion in the sense that we know that things fall. Most people, certainly in physics, think we can describe gravity perfectly adequately using Einstein's General Relativity. But it now seems that we can also start from a microscopic formulation where there is no gravity to begin with, but you can derive it. This is called 'emergence'.

We have other phenomena in Physics like this. Take a concept like 'temperature', for instance. We experience it every day. We can feel temperature. But, if you really think about the microscopic molecules, there's no notion of temperature there. It's something that has to do with the property of all molecules together; it's like the average energy per molecule.

Gravity is similar. It's really something that only appears when you put many things together at a microscopic scale and then you suddenly see that certain equations arise.

**What's the practical importance of having this new manner of considering gravity?**

As scientists, we first want to understand nature and our universe. In doing so, we have observed things that are deeply puzzling, such as phenomena related to dark matter. We see things happening that we don't understand. There must be more matter out there that we don't see. There's also something called 'dark energy'. And then there's the whole puzzle of the beginning of the universe. We now have what is called the 'Big Bang' theory.

I think the ideas I have will shed a totally new light on and resolve some of these puzzles.

A better understanding of what gravity is will teach us more about the universe around us. The practical implications will only be revealed in the future and are not something of immediate interest to me as a scientist. I'm more interested in finding out how nature works.

**Can you explain the concept of 'dark matter' and 'dark energy' and why they're important in relation to gravity?**

We think we understand gravity in most situations, but when we look at galaxies and, on much larger scales, at galaxy clusters, we see things happening that we don't understand using our familiar equations, like Newton's equation of gravity or even Einstein's gravity. So we have to assume there's this mysterious form of matter, which we call dark matter, which we cannot see. Now dark energy is even weirder, in the sense that we don't even know what it consists of. It's something we can put in our equations to make things work, but there's really a big puzzle to be solved in terms of why it's there and what it's made of. At present, we have not really found the right equations to describe it.

There's clearly progress to be made in terms of finding a better theory of gravity, and understanding what's happening in our universe.

**A *New York Times* article stated that 'some of the best physicists in the world say they don't understand Dr Verlinde's paper, and many are outright sceptical'. How do you feel about that?**

I had a new idea, which I thought was exciting. Some people I talked to understood this immediately. I explained it to Robbert Dijkgraaf and he said 'something is happening here and this is going to have an impact.' I wrote it down in a very pure form. Robbert advised me to do so, because there's a very simple argument. I think people who read it may have been surprised that I didn't use any heavy mathematics. It was also very intuitive and if you don't spend time trying to understand that intuition, you may have some trouble understanding it. But I've worked things out and given many talks at Princeton and Harvard, and people now take this idea very seriously. Later, people thanked me and said 'Now we understand what you meant'. It took some time. This is not surprising, because if you change the way people think, it creates some resistance.

**Is it true that the origin of your 'big idea' came to you when you were on holiday?**

I had to remain on holiday for a week because my car keys had been stolen. I decided I was going to use the time to think about an important question I'd already been busy with for a while. Suddenly, an idea came to me. It was a 'eureka' moment, where I thought I really understood something fundamental about gravity, inertia and the laws of Newton in a surprising way. For weeks, I woke up with a feeling of wonder. I felt that what I was doing was spectacular. I wasn't totally surprised when the paper got a lot of attention. It was one of those moments that only happen once in a lifetime.

**The way you talk about inspiration and that 'eureka' moment sounds like there may be some parallels between Theoretical Physics and a creative process more related to the humanities.**

It's true that theoretical physics also involves a lot of inspiration. It's not always just calculating, which is what a lot of people think. You have to think of new ideas. It's much more important for a theoretical physicist to challenge existing ideas.

**Is there a link between Theoretical Physics and Philosophy?**

Well, there is actually. Because of the work I've done, I've been more exposed to this link. There are philosophers who think about the way we conduct science, things like 'what is a paradigm?' In science, we usually start with some basic rules, but sometimes it's necessary to throw away some of those rules. This is closely related to the philosophical way of thinking about nature. Not many physicists do this. They think about the mathematics and stick to the same rules. Changing the rules is not something that's easily done. You need some intuition to do this. You also need some philosophical ideas about what to keep and what principles we should start from.

**How close do you feel to fleshing out your theory so that it will be accepted as scientific fact?**

I'm now working on dark matter in particular, and I've made quite a lot of progress in explaining some of those phenomena. There are some small gaps in my reasoning and things that I still do based on intuition. I'm trying to fill in those gaps.

**Do you think you will fill in those gaps in your lifetime?**

I think I have enough years left to fill in those gaps. Quantum mechanics took approximately 26 years to develop. We've had string theory for 40 years and nothing yet has come out of that which can be directly tested with observations or experiments. I think my idea has a greater chance of being tested with observations, which is an exciting thing. I think it will take no more than 10 or 15 years.

**Would the end result lead to a paradigm shift in how people think that the universe was created?**

Yes, but also in terms of what forces are and what matter is, and how all these things come together. I use a lot of ideas from string theory, but I find it to be too mathematically complex and too involved. I feel one should try to extract the essence of it and start from certain principles. String theory makes some *ad hoc* assumptions. I think the principles will be more important. My paper was about a principle. I think people were not ready to grasp it, but I think eventually they will.

**You've talked about the flaws of string theory. Could this lead to the creation of a new field or theory?**

String theory has many correct elements, but I think we need to rethink the starting point. We have all kinds of elements, but we don't really know how they hang together. Eventually, we can create a starting point that makes it totally clear and we will understand what gravity and the other forces are and answer the questions about dark energy. We have to find this new starting point. I want to change the direction we take instead of taking string theory as a given and using those equations.

**You have stated that not everything needs to be explained or quantified. What do you mean?**

You often see papers where everything is written down using very precise mathematical equations, but sometimes you need to make a jump. This takes intuition. You then combine things in a less precise way, enabling you to make a conceptual point. You change the way people think. In my opinion, these types of papers are generally more important, because they influence how physics progresses more than technical papers do that just deal with one small, technical issue.

**You've talked about how popular science, referring specifically to Stephen Hawking, attempts to explain everything, and that there are perhaps some delusions of grandeur. What do you mean?**

Quite often in popular science books, people give the impression that we already know everything about the universe. And they tell the audience 'this is how it is'. It's true that we understand a lot. But there's this idea that if we work out our equations, we will be able to predict everything. I think this idea is wrong. I think as human beings we are able describe a lot, but there are also many thing we don't understand. Sometimes it's better to accept this fact. I think this is a more fruitful way of thinking about physics. And we have to accept that, as human beings, we have finite capabilities in terms of understanding our universe. The universe is much more complicated than we think.

**Were you involved in the recent developments at CERN relating to the Higgs particle?**

I followed it very closely and discussed it with scientists. You get a sense of their excitement, but also that they are puzzled, because they still have to figure out if this particle really is the Higgs particle. There are still some questions there. For me it's very interesting. It would also be very interesting if they found something that is not exactly the Higgs particle as predicted by the Standard Model, but something slightly different.

**You've talked about the Big Bang theory and how it's illogical to think there was nothing and then it exploded. Can you explain this?**

What I find illogical about the Big Bang theory is the idea that at a particular moment things suddenly started exploding and growing, and that our universe got bigger. I find it very illogical to think it came from this one moment. We use concepts like time and space, but we don't really understand what this means microscopically. That might change. The Big Bang has to do with our understanding of what time should be, and I think we will have a much better understanding of this in the future. I think we will figure out that what we thought was the Big Bang was actually a different kind of event. Or maybe that we should not think that the universe really began at a particular moment and that there's another way to describe that.

**What would be the alternative to the Big Bang theory?**

In my view, the information we have today and the equations we now use only describe a very small part of what is actually going on. If you think that something grows, like our universe, than something else must become smaller. I think there's something we haven't found yet and this will help us discover the origins of our universe. In short, the universe originated from something, not from nothing. There was something there and we have to find the equations. It has something to do with dark energy and how that is related to dark matter. If we understand the equations for those components of our universe, I think we'll also have a better understanding of how the universe began. I think it's all about the interplay between these different forms of energy and matter.

**Is the Big Bang theory just a fallacy then?**

Well, it works well in the sense that it gives us some understanding of how particular elements in our universe came about and there are other things that we can observe, like the radiation that came from the Big Bang. But the whole idea of an expanding universe that started with a big explosion… I think that idea will change. You need to think about the equations in a bigger setting. You need to describe more than just the matter particles. You need to know more about what space/time is. All these things have to come together in order to be able to explain the Big Bang.

**Robbert Dijkgraaf said in an interview that he formed a rebellious club with you and your brother at university. To what extent do you feel you are still rebelling against the establishment or the norms?**

I am someone who challenges ideas, but that doesn't mean I'm rebellious. I generally use a lot of well-known theories and build on these theories. I have also done work which is close to mathematical physics, but I think it contains some element of surprise or something new. I think it has more to do with being original and not repeating the things that other people have been doing.

**How much is that valued in the scientific community?**

I think it's essential. I have a number of equations or formulae that have carried my name. Originality is quite important and brings excitement to the field, because Theoretical Physics is quite an exciting topic

**What area of physics excites you the most? Are there new fields?**

There are things happening in condensed matter that are quite exciting and also in quantum computers. In relation to my work, I think cosmology is where things are really happening.

**What differentiates the UvA from other universities? What's the added benefit of coming here for (international) students?**

We do exciting physics. Theoretical Physics is strong here, but we also have colleagues doing high-energy particle physics and astrophysics and condensed matter and quantum computing. We have state-of-the-art facilities and people are immediately brought into contact with cutting-edge research.

**Which courses do you teach?**

This year, I'll be teaching courses in classical mechanics and special relativity at Bachelor's level.