THE PHILOSOPHER OF THE BIG BOUNCE

Humankind has always been fascinated by the mythical concept of a cyclic universe that ends in a cosmic conflagration and is then reborn. Modern Big Bang theory that suggests an infinitely expanding universe rules out this possibility. But has the final word been spoken on the issue? Anna Ijjas investigates this fundamental question at the Max Planck Institute for Gravitational Physics in Hannover.

TEXT: THOMAS BÜHRKE

More than 1,600 years ago, the famous theologian Augustine posed the question of what God may have been up to before creating the world. His answer was both simple and surprising: "Before God made heaven and earth, He did nothing." This actually agrees pretty well with the Big Bang theory that cosmologists use to describe the beginning of the universe. Before the Big Bang, nothing existed, neither space nor time. Our current knowledge of physics enables us to describe all the processes that started within the hot fireball about one billionth of a second after the Big Bang. Whatever happened before that is beyond our knowledge. And the actual Big Bang? It's a "singularity" that both pillars of modern physics – the theory of relativity and quantum physics – fail to explain.

But what if there never was a Big Bang? Could our universe have originated from a precursor? Anna Ijjas at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute) in Hannover, Germany is breathing new life into this age-old cosmological model.

You have to be a fast walker to keep up with the lively researcher as you follow her along the corridors of the Institute to her office. The office itself is still sparsely furnished with little more than a laptop on the desk. The janitor stops by briefly to check on something. Anna Ijjas has only been in Hannover since early September 2019. She is one of the first nine group leaders of the Lise Meitner Excellence Program recently established by the Max Planck Society. She was selected out of nearly 300 candidates from 42 countries.

With the Lise Meitner Excellence Program, the Max Planck Society intends to increase the number of female scientists in leadership positions with the goal of identifying future female Directors for the Society. Within five years, Lise Meitner Excellence Group Leaders are guaranteed participation in a tenure procedure for an associate professorship (W2). Upon positive evaluation, they will be permanently granted the W2 position with group resources. The selection process was tough, and the final decision for Anna Ijjas offers insights into the current situation in basic research. The scientist had previously spent several years at Princeton University. "Research in the U.S. is very conservative," she says. "Junior scientists there often follow well-trodden paths." Ijjas credits the selection committee of the Lise Meitner Excellence Program for having consciously chosen a candidate who embraces a more unconventional approach.

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VISIT TO

ANNA IJJAS

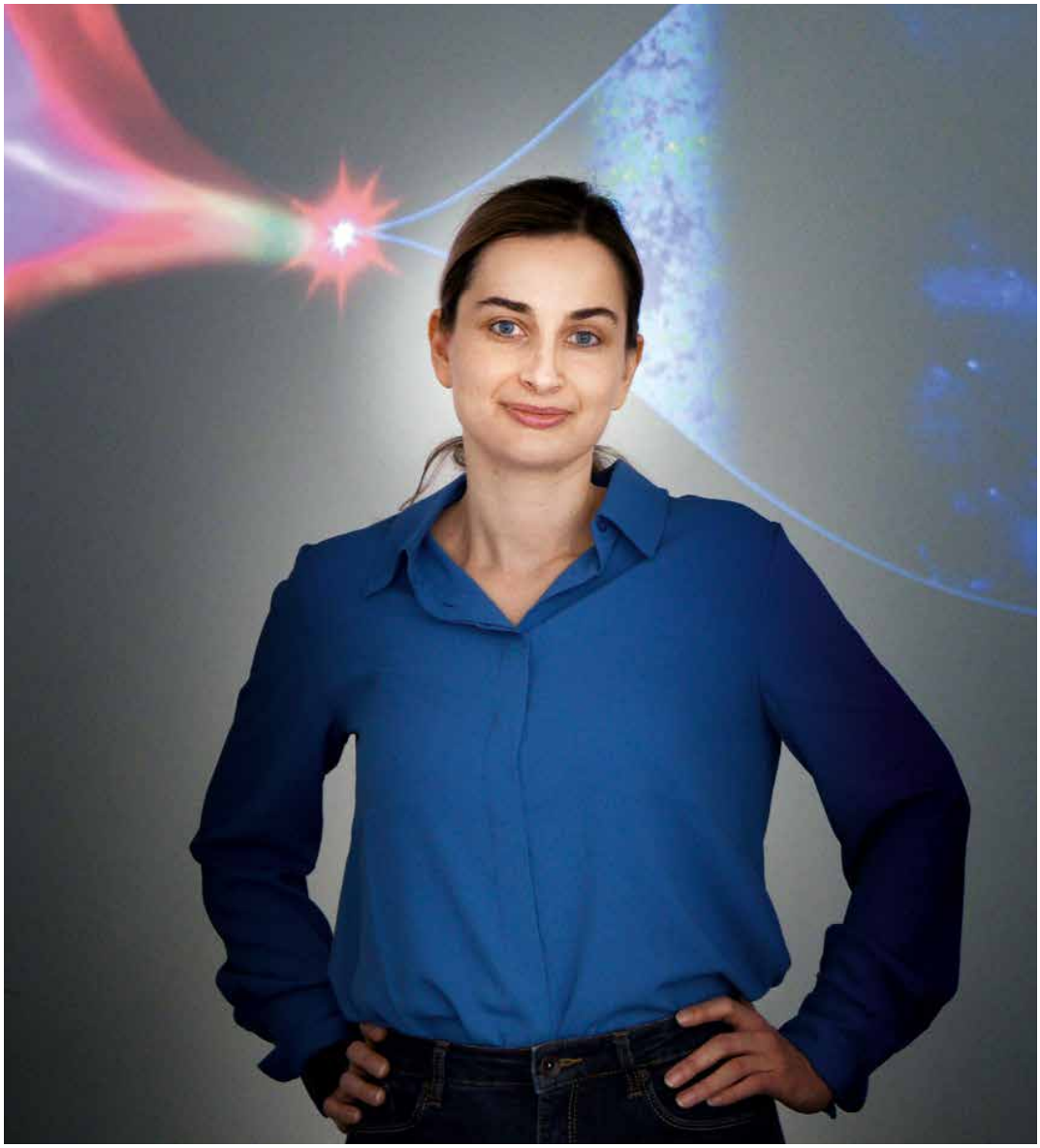

PHOTO: FRANK VINKEN

Unconventional: Anna Ijjas is taking an unorthodox approach to investigating the origins of the universe at the Max Planck Institute for Gravitational Physics.

However, in the field of cosmology – the study of the origin and evolution of the universe – it seemed that much of the science had already been settled. "Theorists made great strides from the 1970s to the 1990s," says Anna Ijjas. With string theory, a comprehensive description of all forces of nature appeared to be found. And the hypothesis of an inflationary universe promised to solve all the problems associated with the Big Bang cosmology.

Inflation is an integral part of today's Big Bang cosmological model. It describes a rapidly accelerating expansion of the universe beginning right after its birth. Subsequently, the universe continued to expand at a decelerating rate. "Today many theorists are convinced that we have come very close to the big answers and that we only need to clarify a few more details," says Ijjas. However, she has a completely different take on the situation. First, we know next to nothing about 95 percent of the universe: dark matter and dark energy remain great mysteries. String theory is still unable to provide any concrete predictions that can be tested by astronomical observations or physical experiments. And the theory of inflation has so many flexible parameters that it can be adjusted to fit nearly any observations. "Andrei Linde, one of the founders of the theory, likes to say that there will never be an observation that could be used to refute inflation," says Ijjas. "It would be pure arrogance to claim we have already figured out nearly everything. Quite the opposite – we need new ideas."

The path to this insight was long and by no means a straight one for the researcher. However, she never lost sight of her goals. Anna Ijjas was born in a small town in Hungary in 1985. Her father was a physician and knew a German who gave private lessons. So Anna began to learn German at the age of five. Later, while at high school in Budapest, she went to Bavaria for two months as part of a student exchange. After graduating, it was clear to her that she wanted to study abroad. But she did not agree with her parents' wish for her to become a lawyer. Instead, she enrolled at Ludwig-Maximilians-Universität to study mathematics and the philosophy of religion in Munich, with the goal of eventually becoming a high-school teacher. Later, she also added physics to her curriculum.

Upon completing her undergraduate degrees, Ijjas concentrated her efforts on the natural sciences and obtained a doctorate in philosophy. The title of her thesis was inspired by an aphorism credited to Einstein: "The Old One with the Dice: On the Metaphysics of Quantum Mechanics." There, she maintained that an interdisciplinary dialog between science and religion is both possible and fruitful. At first, she tried to unite both fields, especially in conversations with friends. Now she regards them as two realms that have little to do with one another: "Science and religion can coexist," she says.

At the time, she was unsure whether she was good enough to become a researcher. But then she was encouraged by her mentor, Harald Lesch. Armed with a scholarship, she went to the U.S. and sought out two particular scientists as mentors who are known for their creative ideas. One of them, Paul Steinhardt, had made a significant

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Probing the heavens: the Simons Observatory, a project in which Anna Ijjas participates, is under construction in the Atacama Desert in Chile. These telescopes could answer the question of whether or not we live in a cyclic universe.

PHOTOS: DEBRA KELLNER / SIMONS OBSERVATORY

contribution to the development of the inflationary paradigm. In 2002, though, Steinhardt surprised his colleagues with an alternative hypothesis that assumes a cyclic universe. This ekpyrotic universe forgoes a Big Bang out of nothing and without space and time. With the term "ekpyrosis" or "conflagration," Steinhardt revived old myths of the world ending in a fiery catastrophe and being reborn from the ashes.

Inflation requires very special initial conditions

Since then, Anna Ijjas has had increasing doubts about inflation theory. In her opinion, the theory has two critical weaknesses: on the one hand, it necessitates very special initial conditions, and on the other, the theory leads to the claim that an infinite number of universes are created, each with different properties. One of these is our universe.

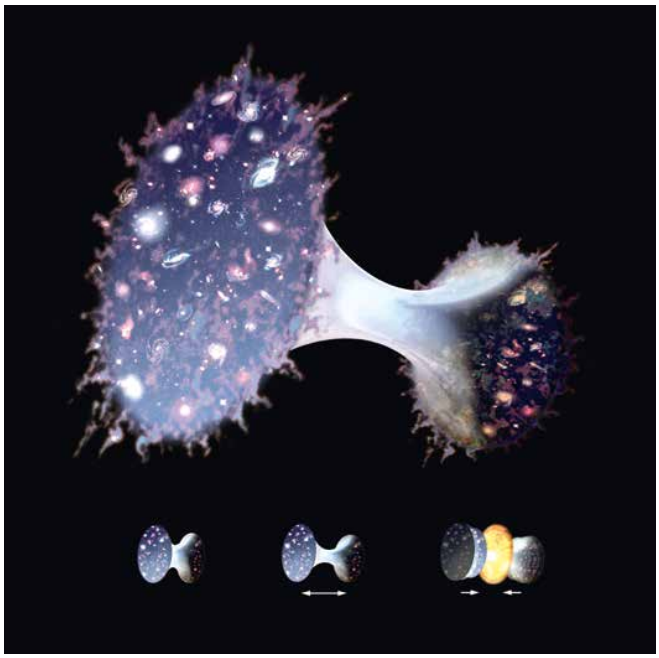
"What bothers me about this is that we cannot go on to explain the origin of these properties," says the Max Planck researcher. Everything is possible, and physics can't even predict what is probable. Ijjas refuses to accept this arbitrariness. She demands that physics meets a different standard: "I want to know why the world is the way it is." In this, she pursues Albert Einstein's enigmatic question: did God have any choice when He created the world?

Ijjas addressed problems of the inflationary paradigm in her second dissertation, which she concluded by examining a new class of cyclic models. "These don't need as much fine tuning," she summarizes in her thesis. And she circumvents yet another unsolved problem of the Big Bang theory, namely the Big Bang itself. There is no explanation for how the universe could have originated from a quantum fluctuation based on the laws of physics as currently known to science. Both relativity theory and quantum physics fail under these circumstances. Most theorists try to get around this dilemma by seeking a unification of the two theories: quantum gravity. Thus far, however, all attempts in this 40-year-long endeavor, including string theory, have failed. As a result, researchers are now trying out various other models.. "Although quantum gravity is essential for some problems in physics," Anna Ijjas says, "our cyclic universe approach does not need it."

In all the cyclic models, our world passed through a transitional phase: a previous universe had slowly contracted and expanded again. According to this picture, the Big Bang was actually a Big Bounce. "In that moment, space and time were in a state that can still be described by the laws as we know them," says Ijjas. "To describe the Big Bounce, we only have to introduce a new type of interaction between matter and spacetime."

The cosmologist has produced key new results over the past three years. In one of her calculations, the previous universe contracted down to a size of 10–25 centimeters before it underwent the Big Bounce. This is only one trillionth of the diameter of a proton, yet it can still be described with today's physical laws. This model also explains all the issues associated with the original Big Bang theory which inflation failed to resolve. The Big Bounce scenario put forward by Anna Ijjas and her colleagues manages entirely without inflation. It also accounts for dark energy, which otherwise has been difficult to accommodate, especially within string theory. Seen in this way, the cyclic universe has many advantages. But does it describe reality? And how can we find out if it does?

In her first doctoral thesis, Ijjas had come to the conclusion that many physicists follow their personal preferences and world view more often than they would care to admit. Intuition as already invoked by Einstein plays a major role. "This applies to me as well," she admits. "However, in the end, we have to be able to make an empirical decision as to whether a theory is right or wrong." The scientist follows Karl Popper's approach here. Strictly speaking, according to his philosophy of knowledge, theories cannot be proven experimentally, they can at best be falsified. Those theories which survive empirical tests prevail in a selection process. "Dissatisfaction with the theory of cosmic inflation in this regard has led me to conceive of the alternative," says Anna Ijjas.



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End and beginning: according to the Big Bounce model, the present universe developed from a predecessor. At the end of its existence, this predecessor contracted to a tiny volume that then rebounded to create our cosmos.

She needs a strategy to be taken seriously at conferences

It's not always easy for her at conferences with this unconventional cosmology – especially not as a woman who looks younger than she is. She was often not taken seriously. "People thought I was simply a student who had nothing to offer," she recalls. She has no issues with objective criticism but had to develop a strategy to even be noticed. "I don't want to give others the feeling that they are wrong; I just want to present my own standpoint without claiming to be the sole purveyor of truth."

Anna Ijjas enjoys fact-based discussions and respects differing opinions. She lives for science and hardly has any time for hobbies. Running every day, an occasional evening at the opera or a hike in the mountains, is about all she has time for. She has learned to play the violin, but she has no opportunity to practise. She doesn't own a TV, and after work, she often continues her calculations on the cyclic universe at home. And this model does actually offer the possibility of falsification as stipulated by Popper. If an event as violent as inflation occurred, gravitational waves would have to have formed. By contrast, the reversal in the cyclic universe was gentler, without severe shocks in spacetime. Traces of this primordial phase should still be detectable in the cosmic background radiation.

This background radiation, which can be observed everywhere in the sky, is considered to be the oldest information in the universe. It formed about 380,000 years after the current expansion started and exhibits subtle fluctuations that serve as seeds for the subsequent evolution of galaxies and galaxy clusters. Gravitational waves must produce a polarization pattern – a partial alignment of the waves in the background radiation. In the spring of 2014, a report went around

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PHOTO: FRANK VINKEN

Lively debate: Anna Ijjas in discussion with cosmologist Paul Steinhardt (center) from Princeton University and Roman Kolevatov, who is a PhD student there.

the world in which researchers claimed to have measured exactly this polarization with the BICEP2 telescope. The proof for the inflationary universe appeared to be at hand. However, this claim was later refuted by more detailed analyses using data collected with ESA's Planck space telescope: the measured polarization of the background radiation was caused by dust in the Milky Way galaxy. Since then, the search for this Holy Grail of cosmology has continued to gain momentum.

Anna Ijjas will be working with one of the new telescopes at the Simons Observatory in the Atacama Desert in Chile. The project is financed by U.S. billionaire Jim Simons. With her latest results mathematically modeling the Big Bounce, Ijjas recently convinced him to continue supporting her research even after her move to the Max Planck Institute for Gravitational Physics. This constitutes a unique exception, as the Simons Foundation only supports projects in the U.S. "Jim prefers the theory of a cyclic universe for philosophical reasons," says Ijjas.

The Simons Observatory could solve the question of polarization within the next five to ten years. What if it were actually found, refuting the prediction of the cyclic universe? "According to Popper, this would be an ideal situation, because we would at least know what the universe is not like, and that alone would teach us a lot," says Ijjas. In that case, she would have to turn to new ideas – something she has no problem doing.

Incidentally, on the tricky question of what God was doing before creating the world, the theologian Augustine quotes a colleague who had facetiously answered: "He was preparing Hell for those who pry too deeply into such great secrets." Anna Ijjas will just have to hope that this anonymous philosopher was mistaken....

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