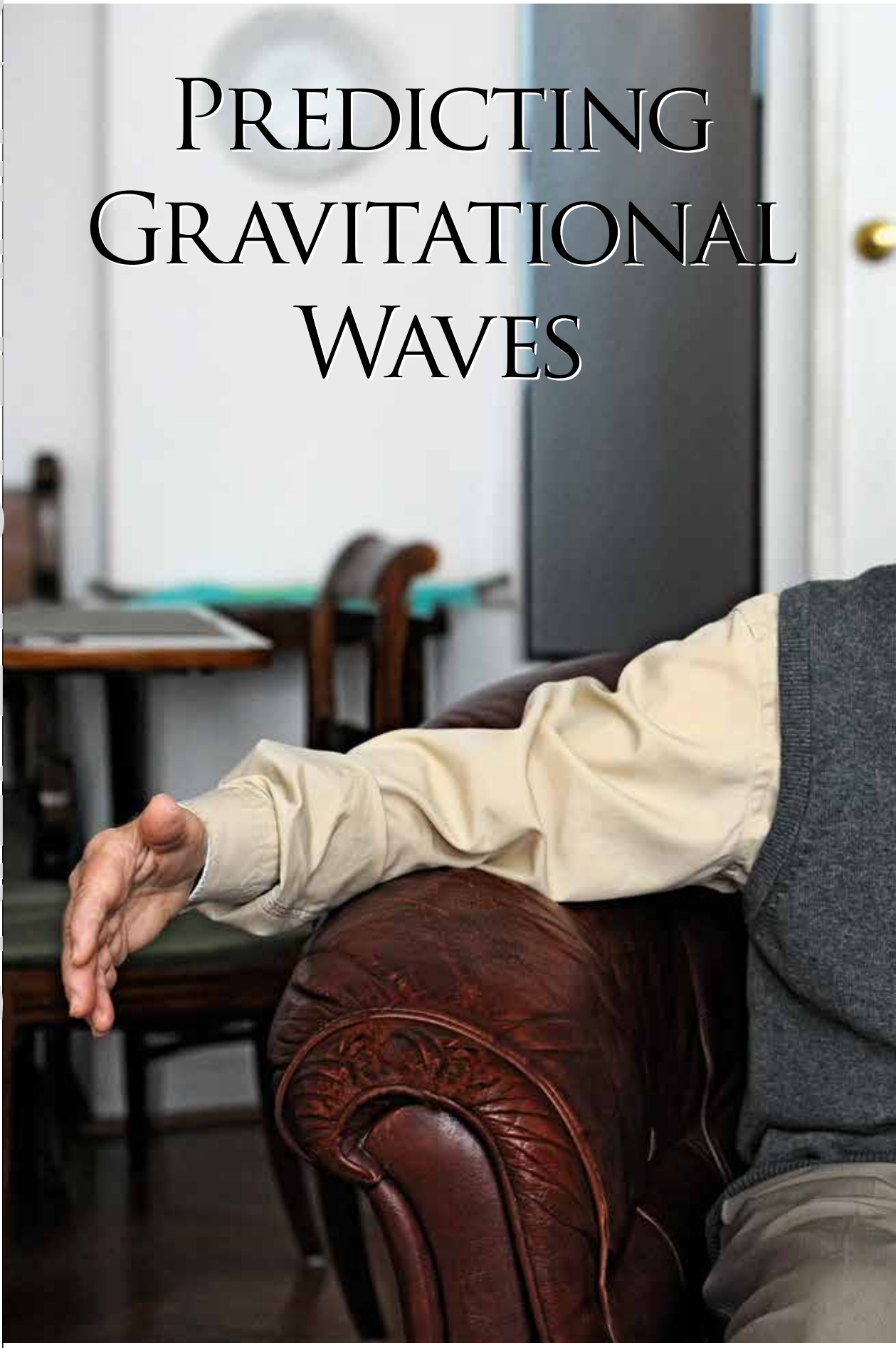
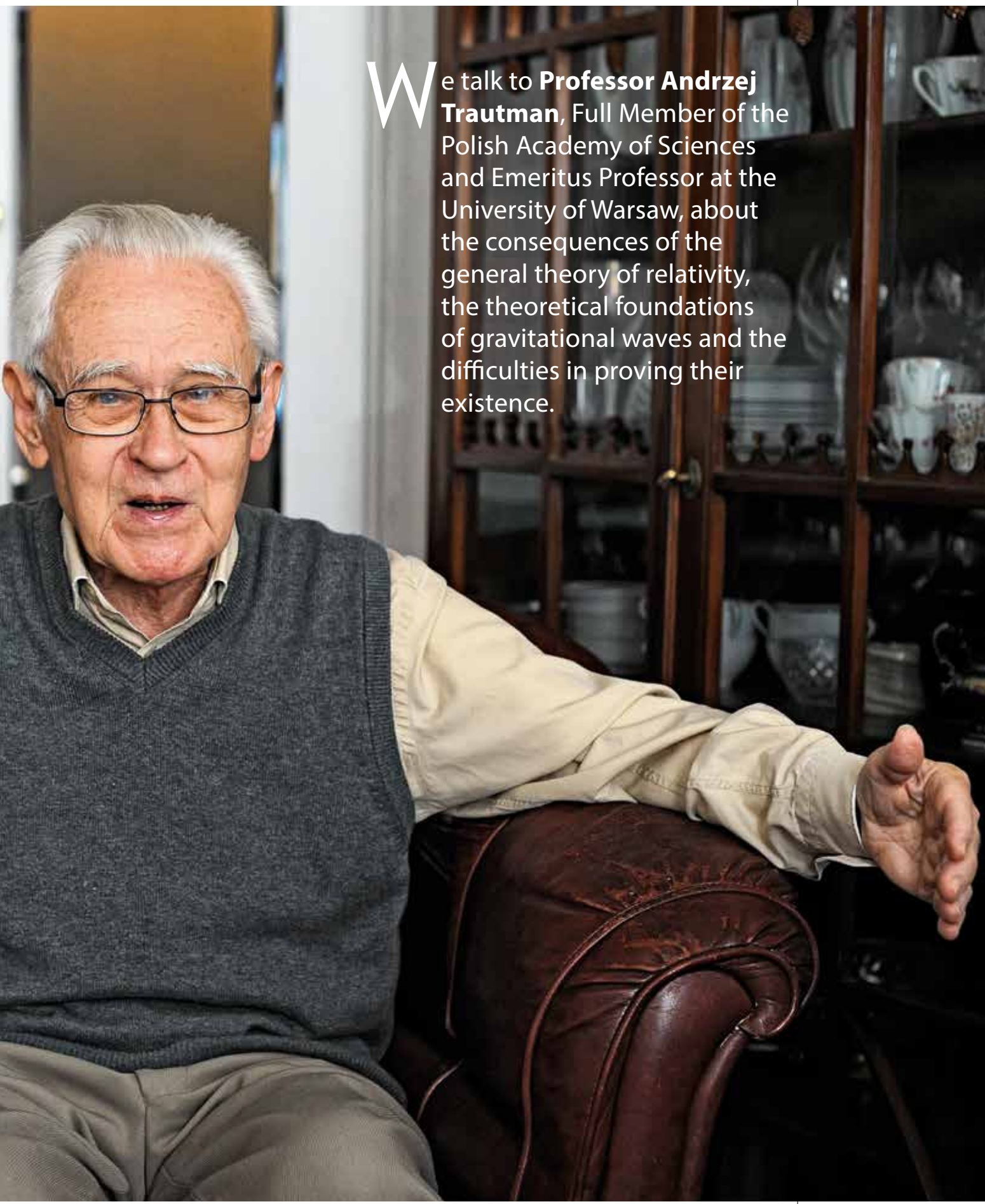
Predicting Gravitational Waves





We talk to **Professor Andrzej Trautman**, Full Member of the Polish Academy of Sciences and Emeritus Professor at the University of Warsaw, about the consequences of the general theory of relativity, the theoretical foundations of gravitational waves and the difficulties in proving their existence.

ANDRZEJ TRAUTMAN: I should start by saying that although I have worked on gravitational waves, it was only on the theory. Over fifty years ago I searched for solutions of Einstein's equations that may describe gravitational waves and studied their properties. I had always assumed that their existence would one day be confirmed, and I was right.

ACADEMIA: **Let's start by talking about what your research focuses on.**

I graduated from the Warsaw Polytechnic, so I'm actually an engineer. I first met Professor Leopold Infeld, a theoretical physicist, towards the end of my studies. I was invited to join his team and work for a PhD with him, an invitation that I was delighted to accept. This was back in 1955, and ever since then I have worked in physics, in particular on gravitational theory, general theory of relativity and gravitational waves. But my engineering background remained a considerable influence. I studied at the Faculty of Communications, and I attended there lectures on electromagnetism and radiation. It was natural for me to become involved in the study of gravitational waves. I was interested to see if any elements of the theory of electromagnetic waves could be used in gravitation.

> "You'll have a hard time – Leopold Infeld doesn't believe in gravitational radiation!" – I was told at the start of my work.

Generally speaking, future engineers don't concern themselves with theory.

When I was at high school in Paris, I asked my physics teacher whether I should study physics or math, and she really put me off. She said that at best I would become a high-school teacher, and that is not an interesting occupation. She suggested I enroll at a polytechnic rather than the university. Being then a child of 16, I listened to her advice, even though I was really drawn to physics. In fact even after I enrolled at the polytechnic, I wanted to study physics at the same time, but it was 1950 – deep, dark Stalinism and extremely rigid rules. You needed permits for absolutely everything. My friend Włodek Zych and I went to see many people of authority, imploring them to let us study at the Polytechnic and the University at the same time. But the ministry refused. It was not until the end of my work at the Polytechnic that I was able to start simultaneous studies at the University.

You were born in central Warsaw and you still live in the city now, but you spent several years after the war wandering round Europe with your mother.

During the Warsaw uprising we were deported to Germany. It was one of the worst periods of my life – filled with hunger, filth, lice. We came back to Poland, but our apartment in Warsaw was destroyed and we spent a few months in Lublin where my father's brother Stefan lived. We had nowhere to live and my mother could not find a job, so she decided to take us to Paris to join her own mother and sister. They were able to support us to some extent, and my mother found a modest job. We lived there for four years, and I went to two schools. I studied towards my final exams at three schools; I spent two years at a rather good school ran by the Goldman sisters in Warsaw. While we lived in France, my mother and I always assumed we would return to Poland, so I attended Polish schools. I started off at a school at the Polish Army base in La Courtine, and later attended the high school in Paris sponsored by the Warsaw government – and that is where I completed my high school education. In 1949 we returned to Poland, I studied at the Warsaw Polytechnic and did my PhD with Professor Infeld at the Institute of Physics of PAS. Later, I got a position in the Institute of Theoretical Physics of the University of Warsaw and I remained there for fifty years.

And that's where you wrote your papers positing the existence of gravitational waves.

That is right. At that time it was a controversial subject. To start with, when Einstein first stated that gravitational waves might exist and gave their approximate description, he was heavily criticized; opponents countered by asking how true gravitational waves would be distinguished from phenomena arising due to a change of the coordinate system. Einstein himself stressed that there is no specific system of reference; that it can be changed at will. In the general theory of relativity, gravitational fields are described with metric tensors. By changing the coordinates and using suitable functions, we obtain other forms of the metric tensor. The solution may look like a wave even though it is not a wave at all – simply due to the effect of the choice of coordinates. Einstein explained it to some extent, but not fully. His first works were based on a linear approximation in which gravitational field equations ignore everything which is not a linear function of the curvature tensor. All squares, cubes and so on are ignored for simplicity's sake. Einstein knew that this linear approximation does not work in situations such as cosmology. Descriptions of a closed universe cannot be obtained in the linear approxima-

tion, because that would result in a flat universe. All non-linear elements must be included. That is why twenty years later Einstein working with the Israeli physicist Nathan Rosen tried to find exact – rather than linearized – solutions of gravitational field equations describing plane gravitational waves. They encountered a problem: the solutions of the differential equations they had to solve had singularities: in certain places they tended towards infinity. This led them to the conclusion that gravitational waves do not, in fact, exist. Einstein and Rosen wrote a paper describing the problem, giving it the title "Do gravitational waves exist?" The paper was submitted to *Physical Review*, which – like all academic journals today – sent the paper for peer review. The reviewer was an excellent physicist who noted that the results were likely due to the selection of the system of coordinates. Rather than rejecting Einstein's paper, *Physical Review* sent him back a letter suggesting changes. This angered him, and he replied with the words that when he submitted a paper, he expected the journal to publish it, without showing it to anyone else before publication.

Whom did *Physical Review* show the paper to?

To Howard Percy Robertson, who was also at Princeton. It is likely that he didn't admit to Einstein that he was the reviewer, but did explain to him that – just as he wrote in the comments – the issue is likely to be with the coordinate system. I've looked at the relevant literature, but I can't tell whether Einstein accepted this explanation. He later published another paper on waves, but on cylindrical rather than plane waves. All this happened in 1936 and 1937 when at Einstein's invitation Leopold Infeld was also at Princeton. He didn't work with Einstein on gravitational waves, but he certainly knew of that work and probably participated in the discussions with Einstein and Rosen. It seems likely that those discussions influenced him in his later belief that gravitational waves did not exist. Infeld was lucky enough to spend the war in Toronto, and later returned to Poland. His entire family in Poland had been killed during the war. When he arrived in Poland in the early 1950s, I started working with him on the recommendation of Dr. Jerzy Plebański. In fact, Plebański suggested gravitational waves as the theme of my work, adding, "You'll have a hard time – Infeld doesn't believe in gravitational radiation!"

That certainly sounds like a challenge.

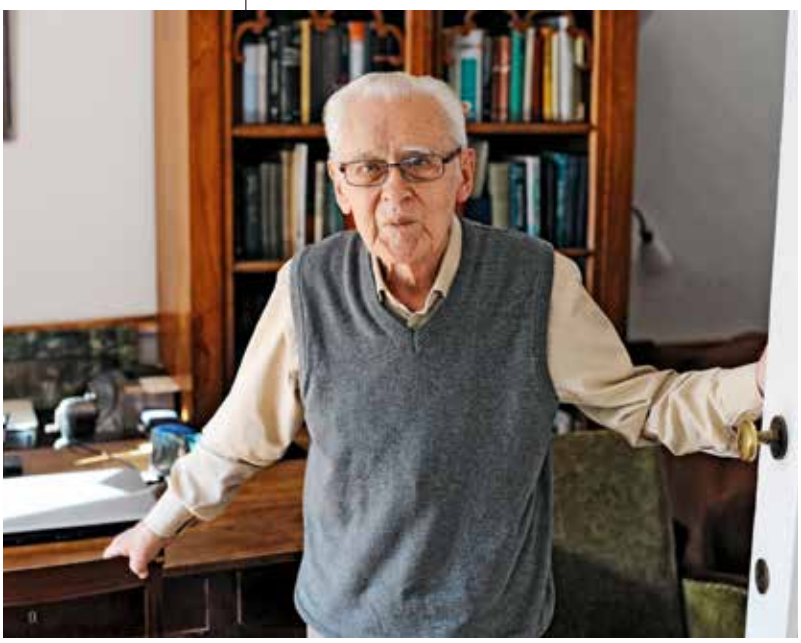
Sure, but young people don't get put off easily. I started working, studying and searching for arguments supporting the existence of gravitational waves. Eventually I obtained a few results which could be used in my PhD. I must say that even though Infeld didn't fully believe in my work, he appreciated its value. It was accepted and published by quality journals; he never opposed it and he promoted my PhD. It could be one of the few instances when someone approves a PhD even though he does not endorse its results. Infeld supported and helped me in many essential ways.

Did you fully believe in your work?

Yes, I was one hundred percent convinced, even though I only had mathematical solutions and no one even talked about actually observing or detecting gravitational waves.

MAREK HOLZMAN

Prof. Andrzej Trautman at a conference in Jabłonna in 1962. Left: Paul Dirac, right: Leopold Infeld



Andrzej Trautman

- Master's degree: 1955
- PhD: 1959
- DSc (habilitation): 1962
- Professorship: 1971

Prof. Andrzej Trautman was born in Warsaw in 1933. After the Warsaw Uprising, he was deported to Germany, returning to Poland in May 1945. In the autumn of the same year, he moved to Paris with his mother to join other members of the family. After graduating from the Polish High School in Paris, he returned to Warsaw in 1949. He studied at the Faculty of Communication at the Warsaw Polytechnic, later also taking up mathematics at the University of Warsaw. In 1961 he took up a post at the Institute of Theoretical Physics at the University of Warsaw, moving up the ranks to becoming a professor. In 1962, he completed his DSc (*habilitation*) at the Faculty of Mathematics and Physics at the University of Warsaw with a dissertation on conservation laws in the general theory of relativity.

He was invited to many research positions in Europe and the US, including at Syracuse University, College de France, University of Chicago, SUNY at Stony Brook and the University of Vienna. He has delivered many lectures at international conferences, such as the International Conferences on the General Theory of Relativity and Gravitation.

He served as deputy director and later, between 1975 and 1985, as director of the Institute of Theoretical Physics at the University of Warsaw. He also led the university's Chair of the Theory of Relativity and Gravitation.

He is an Ordinary Member of the Polish Academy of Sciences and a Full Member of the Polish Academy of Learning. He was Vice President of the Polish Academy of Sciences between 1978 and 1980, serving as President of the PAS Committee of Physics, Vice President of the Polish Physical Society, and member of the PAS Presidium and several scientific boards. He was also Editor-in-Chief of the *Journal of Geometry and Physics*.

He retired in 2003. In 2016, he was awarded the Order of Polonia Restituta. He was previously awarded the State Prize, 1st Class, and the Marian Smoluchowski Medal by the Polish Physical Society. In 2017 he was awarded the prize of the Foundation for Polish Science.

When people asked whether they will ever be observed, they were told that it was unlikely because gravitational interactions are too weak – many orders of magnitude weaker than electromagnetic interactions – making them incredibly difficult to detect. And yet we have finally made sufficient technological progress to make this incredible feat possible.

How did you react when gravitational waves were finally detected almost sixty years after your PhD?

I was pleased, but I can't say it was life-changing.

No?

Not really, because I was sure that gravitational waves exist and the moment would come sooner or later – especially given the rate at which technologies have been developing over the last half a century. Fifty years ago I met the physicist Joseph Weber who was the first to conduct observations of gravitational waves. His measuring system was an aluminum cylinder, about a meter long and with a similar diameter. At least three other groups repeated his experiment in Russia, Italy and England, but no one confirmed his results. But he was an outstanding physicist.

He certainly had imagination.

The fact that gravitational waves were detected at last is partly thanks to his initiative, perseverance and determination. Before he died, he sent me a letter asking me to use my influence in physics circles and try to convince researchers that he really saw gravitational waves…

Did Infeld ever come around to your theory?

My wife, Róża Michalska-Trautman, convinced him. They published together a paper in which they used the Einstein-Infeld-Hoffmann equations to calculate the emission of gravitational radiation.

Gravitational waves form just a part of your research – you also worked in other fields. What do you think of as your greatest achievement?

It would have to be my work on gravitational waves. I worked with the British physicist Ivor Robinson on describing new gravitational waves, waves with spherical fronts, which resemble reality more closely. Plane waves are a mathematical concept, but the gravitational waves emitted by stars, expanding and decreasing with distance, are more accurately described as spherical waves. We found such waves as exact solutions of Einstein's equations, and I regard that as my most important paper. I was also interested in other subjects, such as gauge theory. In terms of my specialization, it would be differential geometric methods in theoretical physics.

You worked with Robinson in the UK, is that right?

In 1958, I published a few papers on gravitational waves in the PAS Bulletin, which attracted the interest of the British physicist Felix Pirani. He had just published a paper on gravitational waves; when I read it, I thought I could do it better. When Infeld invited Pirani to visit Warsaw in the late 1950s, I told him about my work, and he invited me to London. Over the course of three months in 1958, I gave a cycle of lectures at King's College – they were very well attended, including by some well-known physicists. That's when I first met Robinson. I was so impressed with what he was doing that as soon as I returned I asked Infeld to invite him to Warsaw. He came over for three months, and we started working together. He told me about a whole range of projects he was involved with, and the subject of gravitational waves came up. The following year Robinson was awarded a year-long position at the University of North Carolina at Chapel Hill. That autumn I went back to London, this time to Imperial College, to spend a year working with Abdus Salam, the theoretical physicist from Pakistan who went on to receive the Nobel Prize [in 1979, together with Sheldon Lee Glashow and Steven Weinberg, for his contribution to the electroweak unification theory – ed.]. During the 1959/1960 academic year, Robinson and I continued our work by transatlantic correspondence, and we found the solutions I'd mentioned. Of course this was before the Internet so everything was sent by post, but it wasn't unusual for letters to take just two days to be delivered between London and Chapel Hill, which was incredible. We completed our work in a few months and in 1960 we published a paper in *Physical Review* Letters. In 1961 I went to Syracuse University where I met Robinson again, and we continued our work. We jointly published ten papers – more than I published with anyone else. He was a wonderful man. He married Joanna Ryteń, a younger colleague of mine from Warsaw and another of Infeld's PhD students. He eventually got an academic post in Dallas, and his wife lives there to this day. In 1962, Jabłonna hosted a major international conference on relativistic gravitational theories. Infeld was the main organizer, and he invited many outstanding researchers, including Paul Dirac from the UK, Richard Feynman from the US, Subrahmanian Chandrasekhar, the famous Indian astrophysicist, and several excellent Soviet scientists who were delighted to be able to meet colleagues from the West.

You have mentioned some of your mentors. What about your pupils?

I was extremely lucky to have had some excellent students, who became my coworkers and colleagues. many of whom are now retired themselves. Some are working abroad. My last pupil, Prof. Paweł Nurowski, is an eminent scientist working at the PAS Centre for Theoretical Physics. My first student, Prof. Marek Demiański – just six years my junior – is still scientifically active. He still regularly travels abroad, although I no longer feel up to it.

But you're still keeping up to date with the latest discoveries in physics.

I try, but this is very hard. I'm especially interested in the world of elementary particles and quantum mechanics. We already know quite a lot about those particles. We've long had a good understanding of the electrons and protons which comprise atoms, but we have also discovered many other particles. They are generated when protons are collided under high velocities. But we still don't have a good unified theory. We continue making many discoveries in the subatomic world, but we still don't fully understand them. We haven't identified a link between gravitation and quantum physics and elementary particle physics. The latter two are incredibly important and it should be possible to show links between them. There are many more fascinating, fundamental discoveries to make.

Do you see it as a challenge for theoretical physicists?

I do, but theoreticians must have experimental data to work on. They can't achieve anything alone.

Last year's Nobel Prize in physics was awarded to Barry Barish, Kip Thorne and Rainer Weiss for their work on gravitational waves.

Two experimental physicists and a theoretical physicist, who also took part in the experiments.

Do you think they should have won the prize?

The paper published in *Physical Review Letters* on the detection of gravitational waves has over a thousand authors, ten of whom are from Poland. I really don't envy the Nobel Committee, because they were faced with an almost impossible task. According to my colleagues who looked into it, Rainer Weiss and Barry Barish who conducted the experiments are highly deserving, and the theoretical support they received from Kip Thorne was very valuable. I don't see anything wrong with that. However, I question whether the Nobel Prize should be awarded at all for results where so many people have contributed. Perhaps it should reflect achievements where it is easier to describe the actual author. But of course these days there are very few such discoveries.

Interview by **Anna Zawadzka** and **Agnieszka Pollo**
Photography by **Jakub Ostałowski**