TJ Higgins:	00:00:00	Hello. My name is TJ Higgins. I'm interviewing Professor Hans Bachor for Conversations with Australian Scientists. We're doing this at the Australian Academy of Science at the Shine Dome. Today's date is October the 27th, 2021. Hello, Hans.
Hans-Albert Bac...:	00:00:24	Good morning, TJ. I'm glad you're interviewing not me.
TJ Higgins:	00:00:27	I'm interviewing you today. I would like to start off by asking you a few questions about your early days in Germany. Can you tell me in which city you were born?
Hans-Albert Bac...:	00:00:42	Good. My passport says Wolfenbüttel, but that's just where my mother went. It was actually near Wolfsburg and that's of some interest because it's the town where the VW factory was already established and was growing at the time. The home of the famous [VW] beetle and my father had a job as an engineer, he was planning factories. I guess that shaped my outlook on life.
TJ Higgins:	00:01:11	So that got you interested in technical matters and how things work?
Hans-Albert Bac...:	00:01:15	Yeah, so my, one of my first memories is when we moved from Wolfsburg to a new place called Hannover and they were planning the factory that was later making all the VW Kombi's. They came from the factory that was just appearing outside the windows of where I lived as a small child and that was very impressive. So, you know, I got seriously interested in machinery, in anything engineering.
TJ Higgins:	00:01:44	I seem to recall that you used to have a Kombi in Australia?
Hans-Albert Bac...:	00:01:49	Oh Yes. We brought a Kombi to Australia partially because we had converted that into a camper van, and we explored parts of Europe from Scotland to Spain. We had converted it ourselves. I wanted to sell it; nobody offered a decent price, so I decided to put it onto a boat. It ended up in Australia, it had the steering on the wrong side, but I found a way of fixing that myself and then got it through rego. That was a neat project and we drove it for another 12 or 14 years.

TJ Higgins:	00:02:23	We're getting ahead of ourselves here, but this is a very interesting little sideline. So, the school that you went to, how big was the school? The primary school? What we would call a primary school here?
Hans-Albert Bac...:	00:02:37	It was a small school in a small country village, and we had two age groups in one class. So 1, 2....3, 4, were one class. There might've been about eight or nine of us in one age group in a small village. One thing that stood out for me was the head teacher. I think there were three teachers all together. He was of the conviction that none of us was bright enough to ever make it to the gymnasium, the highest level. That meant that none of us would ever go to university, and he believed that. So I'm pleased that I proved him wrong, yes.
TJ Higgins:	00:03:19	So you were already showing signs of becoming more nerdy than he thought?
Hans-Albert Bac...:	00:03:25	Absolutely. I mean, looking at old pictures, I probably was pretty much a nerd. I wasn't any good in any sport, but fortunately in German schools, that's not so important. If you don't stand out, it doesn't matter, we don't have representative sport in Germany. It was more about physical activity. I broke my arm in high jump and that was it for athletics. I could do whatever I wanted in terms of science, felt supported and as long as I help the others in the class with their homework and occasionally in the exams, or during the exams, not going there to the details you know, we were a happy bunch of people.
TJ Higgins:	00:04:14	It sounds like it. Your early days were very much like your more mature days, very interested in other people and their ability with science?
Hans-Albert Bac...:	00:04:27	Yeah, I think you're right TJ. I always paid attention to others in some regard to their needs. I was a little baffled that they couldn't understand the simple math. So, you become a tutor for others and then you realise that yes -you know, I somehow had the ability to see structures or see things in maths and physics that they just simply couldn't without major help. So tutoring, or explaining both of that, became part of my life.
TJ Higgins:	00:05:01	Yes. It seems very prophetic really for what you ended up, well, [with] what you have been devoting your life to in Australia as

well. Is the gymnasium the equivalent of a high school or college?

Hans-Albert Bac...: 00:05:14 Well, Germany, Germany has streaming. So there were three levels and at the time when I went to school, about half of the students would have been in the lowest level. You go to year nine or ten and you learn a trade. Then there was a middle school maybe a quarter, and then there was the highest level in terms of streaming and that's a gymnasium. At the end of that, you get a certificate called the Abitur, and that's basically the entrance to university.

TJ Higgins: 00:05:48 Right. Okay. Like higher school certificate or college. So, you proved the teacher wrong? You did make it into the gymnasium?

Hans-Albert Bac...: 00:05:58 I did make it into the gymnasium and I was almost thrown out from the gymnasium because of my poor English marks. If you think about it at that stage, I lived in Germany, everything I saw on television, on film, in theatre, everything was in German. Why on earth would you want to learn a foreign language? Since I didn't have an answer to that, I just wasn't very good at it. Learning vocabularies or anything by heart wasn't really my strength.

TJ Higgins: 00:06:31 So when you left, you were able to enter the university then? And you studied - what did you study at university?

Hans-Albert Bac...: 00:06:39 Well, there was a difficult decision to make. I had a choice. You could study anything you want, but personally, for me, there was a choice to either study engineering or physics. When I had to make that choice, I was actually in the compulsory military service, which is another interesting side chapter because it made me realize how other people think, very differently to just the top line at the gymnasium. I decided on physics in the end because I was more interested in how things were working, than just perfecting them. It looked like engineering, like my father, was about building the best factories, but he hardly ever had the time for his curiosity as much as he wanted. So, I opted for the curiosity path, which was physics.

TJ Higgins: 00:07:34 So you got a degree in physics?

Hans-Albert Bac...:	00:07:37	Correct. In Germany we have a diploma, there is no time limit. You can repeat any classes as much as you want, and I surely had to do that. Quantum physics I had to repeat twice, which [was] because I just didn't get it. Only the third teacher sort of came up with something that I could really accept. The other interesting thing...possibly because it comes back to my time here, was that a bunch of young physics educators just at that time decided to abolish all exams in that particular university in physics, apart from oral exams. So, there was no way I knew how good I was, but there were four exams after year two. Four exams after year five, and nothing else. They were all oral exams. I took that later to Australia and had I think great success with it, but nobody really understood that the ANU really deeply. What is the difference between an oral exam and the written exam?
TJ Higgins:	00:08:54	So you didn't know how well you were doing, but other people knew how well you were doing?
Hans-Albert Bac...:	00:08:57	Yeah, but only after they saw me for half an hour.
TJ Higgins:	00:09:01	Yes, that's what I mean, after the oral exam. They were aware that you were very knowledgeable and capable?
Hans-Albert Bac...:	00:09:09	Yeah, and oral exams are little bit like...I lead you to a new lake in the mountains, you jump in and you go to the other side and you solve anything in-between. Right. You don't know where you are, but you have to use your wits to get out at the other end, swimming through whatever it might be. That's how you set up an oral exam and you see how clever they are in using their knowledge.
TJ Higgins:	00:09:32	Yes. How important was mathematics?
Hans-Albert Bac...:	00:09:36	About 50% of our training would have been mathematics of various forms.
TJ Higgins:	00:09:42	So that was something that would have served you very well later as well?
Hans-Albert Bac...:	00:09:46	Absolutely. Yeah, I think, and I still think up to now in some cases, I think in German. That's one of the few areas where I never really learned all the lingo because that's sort of the basic knowledge I have. I would probably come back to German

terms occasionally. I can tell you about [speaks German], but I wouldn't do that in English.

TJ Higgins: 00:10:13 Yes. Very, really, very interesting. When you finished your first degree, was that when you went to the UK?

Hans-Albert Bac...: 00:10:21 Yeah. Everybody wanted to study fast. I got this idea, together with a friend, that I really wanted to see other cultures, and there was an opportunity to get a scholarship for one year fully paid by the German government. You could choose your university. I chose Imperial College by going to London and actually just knocking on doors and asking what they would do with me if I could come for one year fully paid. One of the deciding factors was the Lady Anne Pery Thorne who became my first supervisor in any way. I had not chosen any specific type of physics. She was in plasma physics and needed to build lasers, and I just felt at home with her. So my first supervisor was Anne Pery Thorne and then anything else sort of developed from there?

TJ Higgins: 00:11:24 So, she was like a kind of a mentor?

Hans-Albert Bac...: 00:11:27 Yes. This was [where] Imperial College mimicked, in a way, Oxford and Cambridge. There were pairs of students with a tutor. We had our weekly meeting, something completely novel to me when I came from Germany. You never saw your professor personally in Germany, but they had the tutoring system. So that was impressive, and so she became a personal mentor.

TJ Higgins: 00:11:51 And got you interested in lasers?

Hans-Albert Bac...: 00:11:55 In lasers, and you couldn't buy them. We built them. Nobody would allow us to build these lasers now in the way we did, but the safety regulations were either not there or not applied to the basement in Imperial College. No accidents happened. I have never damaged my eye, but in terms of electrical safety, it was pretty marginal.

TJ Higgins: 00:12:20 Yes, probably. It wouldn't be easy to do it today.

Hans-Albert Bac...: 00:12:23 No

	00:12:23	These were pulse lasers, big capacitors, high voltages, the whole lot. And we just with great confidence moved in there, built it. I think they kept an eye on us...
TJ Higgins:	00:12:33	I'm sure they did.
Hans-Albert Bac...:	00:12:33	It was probably safe, but we felt that we were explorers.
TJ Higgins:	00:12:38	At the end of that year at Imperial College...that was a brave decision for you to make, considering you weren't all that interested in English earlier and suddenly you were dropped right into it.
Hans-Albert Bac...:	00:12:52	Yes. It would have been interesting to have a recording of me in the first month or two in London. Probably terrible, but I learned a word per day. I wrote it down. My vocabulary expanded and after a few months I just learned the language directly without a teacher and that was very effective. I felt that I could, at the end of the year, really contribute, communicate, go to conferences. So suddenly English wasn't a barrier. It was just a way of communicating.
TJ Higgins:	00:13:32	Yes. That's really fascinating that you did that and that you made such progress in a very short time. Did you experience any difficulty in...at this time it would still be interesting having Germans visit the UK? Did you observe anything?
Hans-Albert Bac...:	00:13:54	Oh, sure. I mean, you know old war movies galore. A very stereotypical idea of Germans after World War II, but as Germans, we were acutely aware, I mean, educated in Germany at the time, that's what I should say. We were all carrying a high guilt for World War II, for the Nazis. We were very sensitive that Germany was the country that started it all. So in a way, if anybody was critical about Germany during the Nazi time, we expected that and wouldn't discuss it in any...wouldn't defend any things that happened.
Hans-Albert Bachor:	00:14:38	No. What was, it was more in the other direction. Britain is such a country full of traditions. I didn't mention my supervisor Anne Pery Thorne was actually a lady squared. She had inherited a title. She was in the House of Lords, and she had married the Usher of the Black Rod who opens the parliament. Now all of that, I only learned in the last two weeks of the whole year because she never mentioned it, but you could imagine that this

was an immediate exposure to all the tradition of Royal Britain, and that was so strange coming from Germany. So it was a big awakening, how different the culture only a few hundred kilometres away could be.

TJ Higgins: 00:15:26 Yes, and probably had...was quite important in you developing your interest in cultures, which I know you have done subsequently. That would have been huge. I would think, a huge culture shock.

Hans-Albert Bac...: 00:15:43 Yeah, that's true. I think it was a big investment, but it was also...allowed me to think that I could work in other countries. Maybe jumping ahead, we didn't come to Australia because we wanted to migrate. It wasn't that we wanted to get from Australia...from Germany, but when we arrived here Australia convinced us that we should stay.

TJ Higgins: 00:16:10 Yes, you were culturally adapted really, but just going back to when you returned to Germany from Imperial College. Then you started your real post-graduate studies, presumably?

Hans-Albert Bac...: 00:16:23 I was only two years down the five-year track. I had another three years to go. I got a few credit points for having worked in Imperial College. So I went through all my senior classwork, like you would do it here in year three and year four. Then I embarked on a diploma project, which was more or less an extension. I had brought ideas from Imperial College to Hannover, and we realised that that's exactly what they needed in plasma physics there. So my diploma was pretty rapid. During the diploma, I wrote a research proposal and said what I wanted to do as a PhD, so that seamlessly led to the PhD. Then I got into a competition with a colleague who could do his PhD faster. I don't know whether it's a record, but it was only two and a half years for the PhD. It's a shocking thesis when I look at it now in terms of the quality of the writing, but it's good science, we published it and that was it. I had done what I wanted and now was the time to think and look outside.

TJ Higgins: 00:17:37 Ah-huh. So even when you look at it now, when you look at your thesis…now it was in German, presumably?

Hans-Albert Bac...: 00:17:45 Yes, in German. Since we're sitting in a library, you had to produce and pay for one copy for every university in Germany, that has German as a language. That was about 90 copies. Then

you had to go to the library, gives them one and it's supposed to be stored in the archives, deep down in every German speaking university.

TJ Higgins: 00:18:09 And you had to pay for the production of each of those copies?

Hans-Albert Bac...: 00:18:13 Yeah, sure. That's why the print quality we went for [was] the lowest cost reproduction, so it doesn't look anything like an ANU thesis or an Australia thesis. No hard cover. None of that. It's A5 and a soft cover and it was...I had handwritten it. That was the time a lady typed it; she made the one systematic mistake I had made in the spelling. So I learned what copy and paste is because you type out the correct word 45 times, you cut it out, you paste it on and that's in the thesis before it got photocopied. So, you know...

TJ Higgins: 00:18:58 The original copy and pasting?

Hans-Albert Bac...: 00:18:58 The original copy has a cut and paste. Yes. So one couldn't think that this is high quality looking from where we are now.

TJ Higgins: 00:19:08 So when did you move to Australia? Was it immediately after you finished your post graduate degree?

Hans-Albert Bac...: 00:19:16 Yes. I finished my degree, and we could apply to a German scholarship that did not...Fellowship, let's say. That did not specify where...which country. It was for one year only, fully paid. I had met during my PhD one person from Australia, Professor John Sandeman from the ANU and we had discussed what we were doing and [that] I had made a good contribution to what he was doing here at the ANU, at the time, and so that was it. One year, two people having great fun.

TJ Higgins: 00:20:01 Yes again, pointing to how important it is in the scientific community for people to be able to move around internationally. Here are you meeting somebody who is likely to be quite influential in your future direction, but it was important that he was able to travel as well.

Hans-Albert Bac...: 00:20:24 Yes, absolutely. At the time he had spent a fairly substantial part, more like a sabbatical - a couple of months in Zurich with another colleague. That's where I met him as a sort of sideline of a conference. Yes, and we got really intrigued by the opportunities that were suddenly opened. He had not used the

lasers in the way that I had in Hanover. He was working on other projects here, which were more about supersonic vehicles, because ANU was one of the leading places in having shock tubes and piston compressors. They were really testing re-entry vehicles. That was very fashionable at the time to understand the physics of how you slow down a satellite or an Apollo capsule or something like that when it comes back from the moon, and there's a lot of physics that needs to go into the models. How you would actually do that when you re-enter, and ANU at the time was one of the very few, if not the only place, that could simulate that in real experiments.

TJ Higgins: 00:21:42 So you had one year of funding when you arrived?

Hans-Albert Bac...: 00:21:48 Yes. I got there and suddenly I saw something that I had never seen in Germany. Germany was very hierarchical. There is a big professor and my next step in Germany would have been to study for my Habilitation, which would take five years, and you basically do what the professor tells you. That's the tradition and you might have a job afterwards, or you might not. I think at the time about 50% of the people with Habilitation would get a job in universities. The other half went to industry, some of their own choosing. In ANU, the situation was quite different. They said - well here's a lab, we have some equipment, you have some good ideas. Why don't you do that? By the way, we've got some honours students here and you might have some ideas what they should do in the next year. So I had immediately three collaborators who were doing honours, very bright students. And by the way, if you need some new equipment, we still have a little bit of money in the kitty and you tell us what we need. I mean, wow!

TJ Higgins: 00:23:03 What an opportunity this was?

Hans-Albert Bac...: 00:23:05 Fantastic. Right? And then I complained about the state of their second-year laboratory and said, well, you know, they're pretty dull experiments, you could do better. The response was, well, if you think so, why don't you improve it? And so suddenly I was building demonstration experiments and laboratories and things like that. I was flat out enjoying myself.

TJ Higgins: 00:23:34 Given your head, you are being, given your head, which might've been more difficult in the German system?

Hans-Albert Bac...:	00:23:40	Absolutely. So that was, you know…combine that with the beautiful weather of Canberra. We arrived in a drought. There was no rain fall for the first three months, we thought that was terrific. And the openness of the people. So, when they actually said you could become a lecturer here, we would offer you a position. And this was the good old fashioned proper lectureship, not a time position, just start your career. We said, yes!
TJ Higgins:	00:24:12	Wonderful. So, you were offered a job as a lecturer how soon after you arrived here?
Hans-Albert Bac...:	00:24:21	Well, at the end of that postdoc.
TJ Higgins:	00:24:23	So one year?
Hans-Albert Bac...:	00:24:25	They tested me for one year. They offered me a lectureship.
TJ Higgins:	00:24:28	Wow. That was fantastic, you must have done really well during that one year?
Hans-Albert Bac...:	00:24:34	Well, maybe I was good and notorious or something. Right, so anyhow, they made a move, and then actually, I have [had] only one working contract in my entire life. That was the ANU contract from 1982 to 2011, never changed employer.
TJ Higgins:	00:24:55	This is a wonderful story. So in about 1985, I think you went to a conference in Hawaii that was quite influential?
Hans-Albert Bac...:	00:25:04	Yes. We were on our path. We were doing our physics and we had much better lasers. It gets a little technical here. We can talk about the resolution. You know, when you look at a spectrum, what is the finest detail you can measure? And for a long time, because the light that you are looking at would come from a lamp, from a discharged lamp, like a fluorescent. That would be what we know is Doppler broadening. So, you know, the atoms would move in that gives it a Doppler shift, and so you can't see the fine details. Now, just at the time when I arrived in Australia, or was just a few years earlier? People had found ways of making lasers about a thousand times narrower in the line width. So suddenly you could explore all of these fine details that were in the textbooks that came from the theory, but which you could not measure.

	00:26:06	So, globally there was a big rush. In Stanford, Ted Hänsch was working there later [and] got the Nobel prize at NIST [National Institute of Standards and Technology]. Other people I worked with were working there on making better lasers. We were able to do that. Suddenly we could ask completely different questions, but after four years of doing that, having brilliant PhDs, publishing, and becoming part of this worldwide network of high-resolution spectroscopy, I was too. Because there were situations where I had a bright idea, I thought for about two or three days that this was really revolutionary and then I discovered that people had done exactly that, but they had done that with microwave because microwave's already had that resolution. So three days of jubilation, realising, okay, we are just repeating another microwave experiment and went on and on, and on.
TJ Higgins:	00:27:13	It sounds like science.
Hans-Albert Bac...:	00:27:13	Exactly, but I was thinking maybe that's something optics can do that microwave can't, so that went through my head. I went to this laser spectroscopy conference that was all about this topic in Hawaii. There was a new topic where people were not measuring the line width for fine details or quantum physical predictions, but they were actually measuring the signal to noise ratio, you know, can I modulate it? What is the noise? And the noise turned out to be a pure quantum effect.
TJ Higgins:	00:27:53	So this is the start of your interest in quantum optics?
Hans-Albert Bac...:	00:27:58	Exactly, and then very quickly you could see that with radio waves, this noise level was not observable because it was masked by all sorts of thermal noise so microwave had no chance. Other various parts of the spectrum had no chance. And so, optics was at that time in the mid-eighties, the only area where you could actually test all of these predictions of where does the noise, the randomness of the light, actually comes from. That fascinated me, and I learned about it at the conference. I sort of decided this is how it ought to be, how should we do that?
TJ Higgins:	00:28:42	This challenge that you solved, which occupied you for 10 years?

Hans-Albert Bac...:	00:28:49	It must have impressed somehow, yeah. We insisted that after the conference, we flew to California and also to Colorado to the leading laboratories because we thought, well, if we go, as far as Hawaii, we might as well go further. We knocked on the door. Hardly anybody knew us. Yes. I've seen you on the conference. Two of us, my PhD student and myself, we just insisted that we wanted to learn this. They were a bit surprised.
TJ Higgins:	00:29:28	So these were people who had techniques that you could see were going to be useful?
Hans-Albert Bac...:	00:29:33	Yes, they were the world leaders, right. One of them a couple of months later said, would you be interested to become a research fellow at IBM in California?
TJ Higgins:	00:29:48	So who was that person? Can you remember?
Hans-Albert Bac...:	00:29:51	Yeah. His name is Mark Levinson. At the time one of the five leading people. So there was a competition who could be there first. Mark Levenson invited me, I got a warning that he wasn't an easy person to work with. Ignored that. Spent three months at IBM. Learnt all the tricks. He came to ANU, wanted to know what we had. I went back two years later to do another stint at three months.
TJ Higgins:	00:30:20	So this is a wonderful collaboration. Clearly they saw that you had things to offer as well? Yes, very much so, really.
Hans-Albert Bac...:	00:30:30	And that became the nucleus of the group at ANU. I had a fantastic freedom to just learn all the tricks, go into all the labs in the US, and it was largely a US game at the time. There we were: the first experiment took four years and had only marginal success in Australia. We had just picked the wrong material, the wrong idea. I went back to Europe and learned more about how to do it in crystals. The second experiment at ANU took another four years and it got us the world record in a way. We were the best noise suppression. Just by being very clear and very pedantic at what we wanted to do. So that was Ping Koy Lamb and his generation. Then we were on the map.
TJ Higgins:	00:31:29	So I have a question for you. You are regarded as the father of squeezed light in Australia.
Hans-Albert Bac...:	00:31:38	Yes

TJ Higgins: 00:31:38 Now I'm just wondering what squeezed light is?

Hans-Albert Bac...: 00:31:44 Okay. So, this is all going back to this idea of noise.

TJ Higgins: 00:31:48 Can you get rid of the noise?

Hans-Albert Bac...: 00:31:51 Yes. When you modulate a light beam. Let's say you want to send a signal from here to the moon. So you would put some sort of modulation on your light beam and with light, because it's the wave, you have two ways of doing that. You could either make an amplitude modulation, we call that FM, or you could actually change the phase of the wave. Forward and backwards, right? And in radio technology, we call that FM. So, you have AM and FM are the waves on the radio. That exists for light. What you encounter is that because of the quantum physical origin of the light, of the photons, there will always be a noise background on the laser. The best possible signal to noise ratio is your signal and the quantum noise. Right? And so squeezed light means is that you have a choice.

00:32:57 You could actually make the noise, let's say, in the amplitude smaller. So, if you have an AM transmitter, actually, your quality goes up. But at the same time, because of the Heisenberg uncertainty principle, the noise in the other component, we call it, the other quadrature, in the phase would go up. So, you don't win overall, but you win in one particular way of modulating. And that was the famous squeezed light. So, by 1985, [inaudible] Hawaii [inaudible] demonstrated that, but there were four groups in the US at four different locations doing four different...using four different techniques. And by...in about 1986, 1987, two or three of them had succeed, right. So, we came too late to be the first.

TJ Higgins: 00:34:02 But made a huge contribution, as well.

Hans-Albert Bac...: 00:34:03 We made contribution, we learned. Nobody took us serious, that was great. Nobody expected much, that was great. And by 1996, we published the best or the deepest squeezing of any of them. So, we had overtaken them in a technical sense. And then it was time to think what you could do with that.

TJ Higgins: 00:34:28 I'm sure people did make use of that knowledge and they...I have a feeling that that was also important in LIGO [Laser

Interferometer Gravitational-wave Observatory] and the detection of the gravitational waves.

Hans-Albert Bac...: 00:34:40 It will be. That's an interesting one, TJ. We wrote publications. We estimated how much better we could do with squeezed light in a gravitational wave detector. But first of all, you have to note that the detectors only good when it works 24 hours per day for weeks, because you never know when it comes. And so, it has to be amazingly reliable.

TJ Higgins: 00:35:06 And very robust...

Hans-Albert Bac...: 00:35:08 Very robust, and it's quite complicated. It's a full table of stuff. And the reality is that none of the gravitational wave detectors as of two or three years ago, when they made the first big discoveries - 2015 was the first one - uses squeezed light. However, the people who have since then first demonstrated squeezed light on a tabletop. Not three kilometres, but that big, some of that was at ANU. You [know] the person who then did it for the German team.

00:35:45 He was a postdoc with me, a Humboldt Feodor Lynen Fellow. The other person is a PhD and still here. David McClelland, who pushed very hard joined my team. He didn't come as a postdoc. He came as another lecturer, but deliberately into my team that was just emerging. So, you know, if I wanted to be super bold, we were the nucleus of how to turn squeezed light and make it useful for gravitational wave detectors. And the fruits of that will only come in the next few years when they have switched...they had to improve about six other things before squeezing is the ultimate factor of two at the end of the whole saga. The other things already led them to detecting gravitational waves and now it's going to be so much better with squeezed light. So, the origin can be traced back to...

TJ Higgins: 00:36:49 To those days..

Hans-Albert Bac...: 00:36:50 To here. Obviously other people had proposed it. It wasn't our idea, but we made it work.

TJ Higgins: 00:36:58 Fantastic. You had a Centre of Excellence; you're I think Director of that Centre of Excellence. An ARC [Australian Research Council] Center of Excellence. Tell me a little bit about that centre?

Hans-Albert Bac...: 00:37:07 Well, it had sort of two missions. At the time I had been on ARC selection committees, you know, grant committees. I was around when the government decided that they wanted to set new priorities. We had a little bit to say [about] what exactly the priorities should be. We steered it towards…photon science and technology was I think the title at the time. We had Vicki Sara, who was heading the new type of ARC, which got administratively quite a different direction. And so, quantum optics and related things were a topic, and really my mission. I had just become a [ARC] Federation Fellow. So that was an independent decision, and you were supposed to think big as a Federation Fellow. Good. And so, I felt that what was worth demonstrating to the ARC and to maybe the government was that if you lifted the game from a local competition...ARC is like the national football league, right. You have all the local clubs playing against each other.

00:38:31 If you had a Centre of Excellence and you could combine the best in the whole country, you get a national team and then suddenly your competitors were in Europe and the US or possibly in Asia. So that would be a new level of playing field. I was actually very keen as a Director to demonstrate that this could be done. What you had to do is to take people who were used to playing against each other, and that means they were not very perfectly open with their ideas. They didn't trust each other because every year they had to compete for another ARC grant. After about three years we could demonstrate that we trusted each other and had new, bigger ideas, which we did on a global scene. So that was one of the reasons for the Centre of Excellence. I think we documented that well. And so, the fact that we still have Centers of Excellence rests on the fourth, maybe let's say four examples at the time where this concept was really demonstrated

TJ Higgins: 00:39:41 This takes real leadership in science. Getting competing groups together to realise that it's much better to collaborate and that the advances would be much greater if you're collaborating rather than competing.

Hans-Albert Bac...: 00:39:56 Exactly, TJ. So that was one of my missions and I'm very pleased we pulled that off. You know, an alternative would have been just to have a single centre or a single person type of research. That wasn't what it was all about. The second mission was that at that time, we were sort of already on top of the game in

quantum optics. We knew and understood that, but it was also the time when there were big ideas about forming Bose-Einstein condensates. That scientifically meant that you could actually make a group of atoms behave as one entity from a quantum point of view. You could see a pathway how the effects, which we had done with squeezing and entanglement and so on, in the optical world could be repeated in Bose-Einstein condensates. There was also a topic called the atom laser, which was a narrow beam of atoms, but it had almost all the quality of a laser beam.

00:41:08 Neither the BEC nor the atom laser were things that we did first. There were people in the top 10 laboratories in France, in Germany, and the US and Japan that could do that, but what was unique about us was the vision that we would combine that. That's why the word for the Centre, the title is Atom-Quantum Optics. It has a hyphen between atom and optics. A friend of mine, [Bill] Phillips the Nobel Laureate from NIST, at the opening said, the hyphen is important as the other full words. This is about linking, and what I like about the centre, why I'm on the advisory board is that you are trying to bring these two worlds together. So, it was about bringing people together and bringing ideas together.

TJ Higgins: 00:42:14 I think you took quantum optical techniques into biology as well?

Hans-Albert Bac...: 00:42:19 Yes. that's an interesting story. I call myself a quantum mechanic. I'm a gadget builder. I'm a person who needs real machines and I could see that the improvement of squeezed light made better machines, which allows us to understand biology better, make faster measurements, more precise measurements. And we did a demonstration together with my ex-PhD student who was at Queensland, or still is at Queensland. We published one of the first papers on measuring biological effects. At the time there was, and there still is a school of thinking that quantum mechanics plays a role in biology. There are people who think that you could only understand photosynthesis being so fast in the reaction if there was some entanglement in different parts of the molecules of the living body. I must say that I was always a very big critic of that.

	00:43:34	I couldn't see how that would actually work for scientific reasons. It became a really big field in Europe and parts of the US, and to the best of my knowledge, nothing much came out of it in terms of demonstrated experimental evidence, but it's a big field. So in a way, we did our demonstration both to show what squeezed light can do for biology, and I coined the word quantum inspired science. That was controversial a bit for a time now, people are using it. It basically says look, in order to do quantum physics, you need the best instruments you could build. If you use the same instruments, forget for the moment about the quantum, you can make really big improvements and other things. In communication, in understanding the brain, in understanding biological processes, by producing better data, faster data, more reliable data. Now that's quantum inspired because you learn these tricks only when you wanted to do something as measurement entanglement or teleportation. But please don't claim that what you are now measuring is quantum physics. You're using the tricks, but you're not using the quantum. That became...I became an outsider because that statement is too critical, but never mind, I think from my perspective, it's reality.
TJ Higgins:	00:45:17	It's part of advancing the science. Just going back a little bit in time. I'm thinking now, not just of your scientific discoveries and advances, but also your ability to convince, say, senior ministers, that they should be supporting science. That's something that we would love to see happening today as, as you might imagine. I'm thinking of some of your interactions with Brendan Nelson, who was then the Minister.
Hans-Albert Bac...:	00:45:46	Well, Brendon Nelson was the Minister when I was awarded the Federation Fellowship. So that, that was obviously, I mean, that's clearly one of the highlights. To be elected for that, that was great. As you might recall we were sort of the little elite troop where the government experimented, *if you give really good money to people, what can they do?* And we promise teleportation. Now that was a bit cheeky because everybody knew teleportation from various science fiction movies. I even had a centre, no, a grant called Scotty. Where we had, you know, you put the words together up to [when] you get an acronym, and we manage to do teleportation of information with lasers. We were not the first, but again, we were probably at the time the best.

TJ Higgins: 00:46:40 And certainly convinced the minister

Hans-Albert Bac...: 00:46:42 And that convinced the minister because then suddenly you can rave about the future of teleportation. I had a radio interview from Sydney, which was actually about the terrible traffic situation. The only reason they brought me in was to say, would teleportation help with the traffic jams in Sydney. And you do that. I don't mind doing that. I like to go in front of audiences, so...and I knew it was correct. This wasn't hype, this was real, as long as you choose your words carefully, we were teleporting information, right. We were showing that there was a loophole in the answers that you couldn't teleport something physical. We showed with an experiment that there were more options for teleporting things like rebuilding things out of atoms than the simple-minded estimate had shown. So that was a breakthrough, but it didn't mean that we could teleport things.

TJ Higgins: 00:47:55 No.

Hans-Albert Bac...: 00:47:56 Right. So carefully crafted, and I think Vicki Sara also saw an opportunity and she said, look, let's go out there, make a big spiel. And we did. And it helped to argue that Australia was able to do this sort of frontier big science that impressed Nelson, and maybe these were some of the examples, and there were others, [as to] why you should spend more on science.

TJ Higgins: 00:48:24 Yes, absolutely critical being able to do that sort of thing, providing policy advice...

Hans-Albert Bac...: 00:48:30 I never saw him in his office. I never lobbied it. I just provided the material that others could use for lobbying.

TJ Higgins: 00:48:37 Well, you're providing policy advice. You also wrote a book on....a Guide to [Experiments in] Quantum Optics.

Hans-Albert Bac...: 00:48:46 Yes. So being this quantum mechanic I try to do things as simple as possible. The books that I read were all correct, but they were very mathematical. That's not me. So I try to push together...I tried to push the limit. What was the simplest way I could explain squeezing and all of that? The first edition was sort of fine, but it had quite a few technical errors and also some typos. I'm very prone to typos. It wasn't such a good book, but I got together with one of my PhD students. It became a two-author paper, a book, the second edition which... and he's

a theoretician. We really had a beautiful collaboration of he critiquing me and I critique him. I pushed him further than he wanted to go. He pulled me back because it was over simplified. So, the second edition was really good. The third edition, which we published only a few years ago in 2018, 2019 is sort of still state-of-the-art. It lasted 10, 12 years, and then we had to rewrite it almost completely because in that area, technology determines the progress and so much good has happened that the old book needed a revamp. It's still being read. It's still being quoted. I think it's about 1200 citations, which isn't that bad for something that is basically a textbook.

TJ Higgins: 00:50:22 Yes, that's wonderful. I know that it's part of your ability to explain things well, and simply. The ABC was interested in you and the New Inventors, and you had to explain entanglement?

Hans-Albert Bac...: 00:50:38 Yeah, that's a nice little story in itself. So basically, the ABC had run the New Inventors for quite a while, and it was very popular. I mean, we watched it all the time. You might've seen it; Noreen Potters, right. It was about all sorts of interesting little gadgets. They approached us with about a week's notice and said, look, we have an idea. We want to try where we can have actual a scientist, or some new science, in the series just to see how far we can push it. And I said, yes, that's an interesting idea. What would it take? Well, you're going to make a video clip in the next three days. You're going to come to the studio. We are going to prerecord it and then it will be shown later. So, you've got a week to do this. Curiously. The big hurdle was to convince my PhD students.

00:51:33 They said, no, no, no, we are not inventors. We are serious scientists. We make innovation maybe, but no inventing no way. After some heavy arm-twisting I got them included. We made the video clip on campus, and [when] we appeared one of them, she said, no, I'm not going on stage. This is too frightening, ABC studio live audience, no way. So, it was just one other, but she is in the video. Then I had to build some props and there's the big ropes still in my home. We went on stage. We convinced the judges. One of them is actually Veena Sahajwalla from New South Wales Uni.

TJ Higgins: 00:52:24 And a Fellow of the Academy

Hans-Albert Bac...: 00:52:26 That's right. We won the judges prize, but we were in competition with a Fox light. That's a blinking light that deters foxes, and most importantly, an automated kebabs slicer that goes on the big meat stick and prevents people from burning their fingers because it was slicing. The Kebab slicer was the popular choice. So, you know, can't beat that, but we had great fun trying to convey something as abstract as entanglement to a television audience. I proudly have that trophy at home.

TJ Higgins: 00:53:05 Yes, you should have. And it's a great introduction, introducing your collaborators and students to conveying science to the public.

Hans-Albert Bac...: 00:53:15 Yeah, I think in the end, they were all proud and convinced, but not in the beginning.

TJ Higgins: 00:53:19 Yes, I remember meeting you, and you wouldn't remember this at all, but the first I came across you was at the National Science Youth Forum. I think a long time ago. And they're very…it wasn't even called that then I think but I remember you.

Hans-Albert Bac...: 00:53:35 It was the National Science Summer School.

TJ Higgins: 00:53:36 Yes, Summer School. You have always been interested and very active in telling people about science much more broadly than just the academic community. You're very interested in making people aware of science and its importance.

Hans-Albert Bac...: 00:53:55 That's true. Yeah. I mean, I had that right from the beginning. Maybe it started with my classmates and there is a bit of urge to inform others about science and make it as simple, but as correct as possible. I think there is a bit of an art to it. How far can you simplify and still be correct in an academic sense? Now, many of my colleagues don't want to go there. It looks too...either too simple or too dangerous to oversimplify. I love that. I love to be pulled back and said, well, you know, you went a bit too far and it's not quite as simple that's to me, these are really deep discussions actually. Yeah, so I always was on the lookout for an audience. I got that at the University with first year, second year, you know, all the undergraduate teaching. And then I expended to NYSF [National Science Summer School]. I did that for five years as the Chair of the Board. Then I came up with public shows, which got me to Questacon and

nowadays it's at the Academy and it's all these attempts to what we say, engage the unengaged.

TJ Higgins: 00:55:11 **S**o you've been heavily involved in the Academy for quite a long time. I think maybe originally through the National Committees?

Hans-Albert Bac...: 00:55:18 Yeah, so the National Committees. [I] didn't actually think much of the Academy, in a way. It looked sort of stale. But I had very positive encounters with Jim Peacock, and also I had always a high respect for Sue Serjeantson and who was a Director of the National Institutes in the ANU and Jim Peacock had this idea of bringing scientists into schools. But apart from that, I knew the physicist who were in the Academy, but it really didn't interest me that much. It looked a little bit wooden, a bit old fashioned and then Joe had nominated me, and it didn't go anywhere for six years. So fine. I mean, that's it, but what brought me back was my passion for the National Committee for Physics, for a decadal plan for demonstrating how important physics was to this, to the community. Then there was an opportunity to actually do a systematic study with economists. Could we quantify the role of physical sciences? Ian Chubb was the...

TJ Higgins: 00:56:38 Chief Scientist?

Hans-Albert Bac...: 00:56:39 Chief Scientist at the time, the National Chief Scientist. He found the money. He found me and we went ahead, and we engaged a proper economic research team and got reliable numbers. And I'm very pleased basically they're still quoted. These are the numbers that the politicians are quoting.

TJ Higgins: 00:57:01 Highly influential.

Hans-Albert Bac...: 00:57:03 Ian Chubb had just the right nose to say, these numbers we need, but who can do that? I was the one who brought the scientists together and the economists did all the mathematics and the methodology. So that worked and it was great fun. And through that, and being Chair of the National Committee for Physics, I then realized that there was another very interesting, fascinating, and important side to the Academy.

TJ Higgins: 00:57:32 ...and the role of the Academy. Now you're the Secretary for Education [and Public Awareness] and on the Executive

Committee, highly interested in the video system [Video Project].

Hans-Albert Bac...: 00:57:42 Yeah. Highly interested in engaging very different audiences. The videos, well you know, one of our best videos is only five minutes long. It was designed for a single person and that was the Minister for Education at the time, and it got us the grant. So that was at one end, an audience of one and I think it was very effective. So video is the language and in the other audience....[at the] other end of the spectrum, we have our Facebook pages or things on YouTube, which are designed to be attractive to many different people who don't actually look for us, don't search for us, but we get them to listen to material from the Academy and through that they get to really reliable and true material. That's an attempt to do something constructive in the age of misinformation.

TJ Higgins: 00:58:42 I think one other area that I know that you've been involved in, and it's interesting to me to think about you doing this. That is making contact with Germany again, through Falling Walls?

Hans-Albert Bac...: 00:58:55 Yes. I had this link with Germany. I continued the link. I was a...I got a Humboldt Prize. Through that, I got people joining me in Australia for the Humboldt scheme. We got people into Germany, so it became an active exchange. Through that, I learned about Falling Walls and realized that was an emerging global stage for the ideas of young people. It was an opportunity for Australians to get a global audience. Well, that's fantastic, right. If you have an idea and you can actually speak to decision makers, not just on the radio randomly, but the audience is what made Falling Walls always so great. I use the past tense because it's important as a live event. A little bit more questionable now in the moment, but it will be live again, after COVID. There was an opportunity to send some really sparkly, bright people, and you know some of them TJ, who got selected here, and then they had the opportunity to speak in front of a powerful audience. The style is a bit like TED, but the audience is completely different, much smaller, but much more influential.

TJ Higgins: 01:00:12 And a wonderful opportunity for these young people to talk to Nobel laureates. I think some of them have done very well.

Hans-Albert Bac...: 01:00:21 Exactly right. So, the parallel program is Lindau [Nobel Laureate Meetings], where we are allowed to send 10 people to Lindau. I'm actively involved in showing them more of how science is done in Germany, because there's such a big contrast to how it's done here. Max Planck Institute, [?] Hofer, you know, it's a different way of dealing with it. More integration of industry, far more in Germany than here. So that became another passion, of opening doors.

TJ Higgins: 01:00:52 We've talked a lot about your science and the contribution, the fantastic contributions that you've made over your lifetime, but you also have a life outside science. I know. Just tell me a little bit about your interests and Connie's interests, especially in the Australian environment that you find yourself in and have found yourself in. Really.

Hans-Albert Bac...: 01:01:14 So it's important that I bring family in there. I came with my wife, Connie. She was a teacher. She had trained as a teacher in German and English. She taught here for a while and her other passion is horses, training, horses, training people to ride, judging competitions and so on. We were simultaneously looking for a place where we could have horses and that's so easy in Canberra. You know, you can drive within 20 minutes. There were not that many traffic lights in those days in 1980s. We picked a place in the country after about five years in Canberra, which we enjoyed. We moved out there and I always wanted to build a solar house, but you couldn't get Australian builders to build you a solar house. I mean, they all looked a bit ugly, and they were all a bit experimental and the builders just didn't want to do what you asked them.

01:02:19 So, you know, when it comes to insulation and double glazing, and so the only choice was to do it more or less yourself. We have done that ever since, but then at the same time, once we moved into the country and you observe nature, you realize how fragile it can be in a drought, fire, but also that you could have possibly too many plants of one type. So, we call them weeds. We are presently eradicating a native plant as a weed because it started to dominate after the rain came back. So, you know, we got all involved in this whole question, how can you actually live in nature? And can you do something actively to keep nature in balance?

TJ Higgins: 01:03:09 So you're interested in sustainability?

Hans-Albert Bac...:	01:03:11	Sustainability, all of it...yeah, and we try to set up practical examples. And so, we have been doing that for the last three decades and we really enjoy it. And it's a beautiful compliment to this sort of academic work, right? When you got stuck with the latest squeezing experiment, you go there and build a horse yard, or you do something big, and it gets you away from the minute little detail of quantum optics. It has always been a great compliment.
TJ Higgins:	01:03:43	I think you've been interested in the history of architecture as well?
Hans-Albert Bac...:	01:03:45	Yeah, particularly modern architecture. You know, we visit cathedrals, we learn about...and I'm amazed about cathedrals because how do you actually manage to build something let's say for 300 years? When every craftsman only has a life in his job of about 30? So that would be at least 10 generations, you know, how do you communicate the idea over 10 generation of craftsmen? That's sort of one thing that fascinates me, but I'm particularly interested in post-World War II architecture. Germany is a poor place for that because it was…my hometown of Hannover was 90% destroyed. It was rebuilt very quickly and not much thought went into architecture. Very few buildings. Canberra is a fascinating place to me, and here at the Shine Dome I'm sitting in, you know, to see the vision of the people and they had the opportunity to actually shape something.
	01:04:51	I think we have some brilliant architecture here in Canberra, in Sydney, to a lesser degree in Melbourne, of the 1950s, 60s, 70s. I've now become a fan and a supporter, and I like to argue about maintaining that. I think Australia - one of the criticisms I have is we are very poor in creating history. We are pulling things down after 30 years. You think about Sydney CBD. In my counting, that's the seventh generation of buildings since 1788. We pulled six generations of building away and just destroyed them, and there's very few examples left. So, you know, we continue to do that. It's a fascinating country in comparison to Europe. I have this opinion about; we need to preserve some of the really hallmarks of architecture.
TJ Higgins:	01:05:47	Speaking of hallmarks and the future. I'm thinking now about the future of science, how do you see science for the future and young people, what their role will be?

Hans-Albert Bac...:	01:06:01	Well, it's a mixture. I'm optimistic. I think the last two years are a brilliant example that have shown how much we need science. We wouldn't be in this good shape with the pandemic, with vaccinations and all of that without the biology, the medicine, and also the modelling that we have done. I think that's a great example, what science can do when hard-pressed. Much better than World War II, where it was about making better weapons, anyway that was also a boom time for science. Sure. The role of young people is of utmost importance because we need their creativity. We need, you know, some of the things I did when I was a young person look pretty foolish now, but they were creative, they were pushing the limits. I think young people are great and pushing the limits. So that's good. Now, as a young person, you would be much more concerned about your future, your security, where's the job coming from? I don't think the career that I had, straight into a lecturer, never changed employer, is probably not feasible. I'm a bit concerned that we don't give them the security that they deserve, and that needs us the older generation to be vocal and active, to create more security. But on the whole, I have an optimistic outlook.
TJ Higgins:	01:07:30	What about concepts and physics for the future?
Hans-Albert Bac...:	01:07:33	That's always very hard to predict. Lord Kelvin predicted there was nothing new and he was utterly wrong. People in 2000 at the turn of the thousand years. Forget the word in the moment, predicted there was no new physics. People did serious thinking about when you go into a new millennium, that's the word, in the new millennium, knew that there would be nothing new. That's probably wrong. Where the novelty from comes from, I'm not sure. I think in the moment, the greatest innovation is to take the best of all sciences in each field, and to see what happens, if you bring the ideas together.
TJ Higgins:	01:08:27	Interdisciplinary approaches?
Hans-Albert Bac...:	01:08:28	Interdisciplinary, multidisciplinary, transdisciplinary, people argue about which pronoun for that. But making sure that the minds work together, that minds provoke each other. From that point of view, I see the Academy as a fascinating place because we're all...you come from different backgrounds to me, but we can come up with new things, new important things, maybe even new concepts that we borrow from each other. And so, I think that's for the moment, where the future is. People say,

and they want to just be a little bit provocative that physics always changes. I would always say, no, it always expands. There are very few situations we had where we actually made a change. Yes. Newton made a change, and the way we understand the solar system changed, I give you that. There were ideas that revolutionized what optics was and radio physics and radio activity.

01:09:34 Yes. But in regard to the possible new concepts of physics, some people make the case that there is new physics, and I would rather argue that physics is always expanding. There are examples of physics can be new. We had that with optics. We had that with the planetary system. We had examples where we sort of corrected and changed the physics, but for the moment that doesn't look as important as bringing physics together with other disciplines. I see it as an ongoing expansion of physics into the future, unpredictable as it is, but I don't see that we are going to revolutionise and actually declare that we have things in our present concepts which are actually wrong.

TJ Higgins: 01:10:29 That's a good point on which to finish and I would like to thank you Hans, for a wonderful exposition. I know that you're going to continue to make huge contributions into the future.

Hans-Albert Bac...: 01:10:41 And thank you, TJ for being patient. I was a bit raving, but I enjoyed it.