00:00:00 Intro

[Mira] Hi, my name is Mira

[Chris] and I am Chris

[Mira] we are associated members of ML4Q

[Chris] and you're listening to ML4Q&A – a show where members from the Matter and Light for Quantum Computing Cluster talk about their careers, their research and the future of quantum.

[Mira] Today we speak to Sebastian Hofferberth about his journey through academia and literally as he went from Heidelberg to Harvard, to Stuttgart, then Denmark and finally to Bonn where we record today.

[Chris] We talk about the challenges of this nomadic lifestyle, which almost every longtime academic faces. Of course, Sebastian also explains his work in quantum optics with Rydberg atoms and shares his passion for teaching.

[Mira] He discusses how quantum mechanics (can be) seems non-intuitive at first but can be made more approachable, especially once students would sort-of grow up with quantum computers. So without giving away much more, let's get into it.

00:01:00 Welcome Sebastian

[Chris] It is my pleasure to welcome Sebastian Hofferberth on the ML4Q&A podcast. He's a professor in Bonn and a member of ML4Q. And his career spans atoms on chip, giant atoms interacting with other atoms and light, magnetometry, non-linear optics. How do you describe yourself as a scientist?

[Sebastian] As a scientist, I am foremost an experimentalist in the sense that a large part of the research that I have done is always also driven by enjoying and experimenting with techniques that can be used exploring new directions, new limits of what can experimentally be done.

So not all questions come from what is the biggest theory question we can answer or biggest fundamental question, but really also what can actually be done, what maybe can be done with the things we are doing, a bit of motivation also for applied things. So, that is maybe the most driving thing behind many of the things I have done.

[Chris] You have been working with quantum optics, but there's also of course quantum computing, quantum mechanics. How do you balance all these different labels?

[Sebastian] Yeah, I would say that's one of the most fascinating aspects of this area. When I started quantum computing, it was already a concept and long-term motivation, but was, of course, far, far less present in day-to-day thinking. It has changed tremendously.

We have seen this transition from very vague ideas to real applications and real computers towards real computers. And that has been a lot of fun to see, but the nice thing is in all of this we have also not really moved out of the fundamental science part. We still ask ourselves questions about entanglement, about the many body quantum systems that are still as open questions fundamentally as they maybe were when I started. Maybe they have become more complex questions. We have made progress, of course, but the fundamental aspect is still there.

And to me, that is still some of the biggest fascination, trying to understand quantum mechanics, think correctly to understand quantum mechanics and develop intuition in quantum mechanics. It's a huge part of the work and that's super fun.

00:03:20 Quantum optics between fundamental and applied research

[Mira] So would you say that quantum optics is more fundamental? What is it? Can you talk a little about that?

[Sebastian] Maybe this whole distinction between fundamental and applied is sometimes a bit artificial. We have quantum mechanics as a theory since 100 years now and it works so fantastically well with very few rules and actually a relatively simple theory you can talk about how if you find the math simple or not but in principle is a very simple theory.

And then at the same time, even when we introduce it in the very first two, three postulates, it becomes non-intuitive and it becomes maybe against what you have been taught in classical physics before and so on. And this is still a discrepancy also 100 years later.

We have first not solved and we don't even know how it fundamentally can be solved. But it also has a lot of philosophical aspects. Does the physics theory need to be pleasing to humans and human intuition or not? And that's a big fun part and I think on the experimental side what I see for myself and also as a contribution maybe. Well, if the theory is like it is and it's not pleasing to humans maybe human intuition has to develop and change and by doing experiments and seeing things work in the experiment, it is a big contribution to this I think.

That's what we see every day in the labs. Also young people now working in the lab, for them maybe entanglement is just something that is intuitively more clear at least than it was to us, or to me, or still this to me, and that's cool.

[Chris] There's this Einstein quote, right, that any idiot thinks that he understands what a photon is, but they don't. But indeed, I guess Einstein had to think about photons in an abstract way, and now a student comes to the lab and he can, you know, make a router for a single photon.

[Sebastian] Exactly. I see many, many consequences of quantum optics, single photon or few photon, theory just play out in the lab. And that's a huge difference.

And again, that's not discrediting Einstein or anybody else. These guys, they came up with a new theory based on indirect evidence and so on. And they were in some sense, of course, also super lucky that they came up with a good theory. It was not clear. It only becomes clear in retrospect, but quantum optics in particular is one of the fields where experiments really shine light directly onto many of these fundamental aspects. All the Gedankenexperiments these guys came up relatively early in this complex theory. Now we just do them. That's a huge difference.

You can of course have your Gedankenexperiment and be super confused by it. But then you can see it work in the experiment and you start to think very differently about it and maybe realize, okay, maybe a lot of the confusion is more in what I would like to have happened instead of what the theory does what the nature does so i think experiment is just the best way to get intuition.

00:06:22 What are Rydberg atoms?

[Chris] Alright we're now going to talk to you a bit about your career, also with the focus on work life balance and then your research in Bonn and of course we will also discuss recent advances in Rydberg atoms which is something you have worked on for a long time already as a quantum computing platform because it's just a very timely thing.

Should we start out with briefly saying what Rydberg atoms are and then later we return to your career?

[Sebastian] Absolutely. So Rydberg atoms have become a core part of my research for over 10 years now.

A Rydberg atom is not a special atom, it's just a normal atom. Any atomic species, hydrogen, or in our lab, rubidium atoms can be brought into so-called Rydberg states. We know that in atoms there are electronic states, an electron can go into, or electrons can go into, and we call them Rydberg states, and these are relatively highly excited states with high principle quantum number and very close to where the electron actually leaves the atom and ionizes. You have an ion and an electron left. So, you go to the kind of limit of how high you can excite these atoms before they dissociate into parts.

And these are still normal atoms, but special states in the normal atoms that then have all kinds of atomic properties as normal atoms, ground state atoms have. But because you have gone so high in principle quantum number, you exaggerate a lot of the atomic properties and they become much easier and noticeable, like interaction between atoms or so, distances. And you can nicely control this in the lab and that's what we use in our experiments a lot.

[Mira] But your career started out differently. You did your PhD on coherent manipulation of Bose Einstein condensates on atom chips. So what was that about?

[Sebastian] Yes, so one of the biggest advances in atomic physics in the last, I would say, 30 years already is multiple steps toward producing so-called ultracold atoms, which are a bunch of steps from a fantastically fun experimental technique called laser cooling. You use high power lasers to make atoms as cold as you can, colder than anything we can do with any other technique we know.

And then you can even move a bit further, you can trap these atoms in vacuum and you can even further cool and turn little atoms which we normally think of as classical little balls into quantum objects into waves where you really start to see the wave nature of matter. Bose Einstein condensation is one such quantum phenomena where many atoms all of a sudden at a certain temperature jump into a collective quantum state where they all together make one big matter wave function.

That has been done in the 1990s for the first time and in 2001 Nobel Prize was given to multiple people. So when I was a student this was a cool - ultra cool - topic and very present in the physics news and attracted me and there was luckily a group in Heidelberg where I was studying. They did one specific thing and they tried to not make these Bose Einstein condensates with macroscopic setups, but with magnetic traps made by little chips, not microchips, but at least centimeter large chips, millimeter large chips with already first ideas in this quantum technology direction.

And this I just found super fascinating and that's where I ended up as a both diploma student and then as a PhD student afterwards.

00:10:25 Reflecting on the PhD project

[Mira] How was your relationship with your supervisor?

[Sebastian] I would say super fun. I hope if he hears this, he understands. He was also a charismatic, also very fun person, but also very busy. I had a lot of freedom.

[Chris] This was Jörg Schmiedmayer.

[Sebastian] Jörg Schmiedmayer was then in Heidelberg, now in Vienna. Still a very active group in Vienna. I would say super friendly in both directions. I always enjoyed working with him a lot. But it was also in the transition period when he was moving. So I finished my PhD in Heidelberg when he and most of the group had already left.

We were very free to do as we please and was also, I enjoyed being able to go in directions also a little bit on my own with this experiment and with what we were doing on the experiment.

[Chris] These chips, they have electrical engineering aspects, but you also have sort of the optics aspects of laser cooling and everything. How did you think about this? Did you get an engineering mindset there?

[Sebastian] No, I would not go that far.

Yes, these chips in particular have some microfabrication and typical chip fabrication techniques. At that time in particular, I must also admit, I personally was not so involved. There was one PhD student for the whole group, kind of coordinating and doing the fabrication together with the solid-state physics group. So not engineering, but let's say more solid-state and nanofabrication groups.

I learned a lot in these discussions and kind of in this environment also about nanofabrication and so on that I was not so aware of before. But I would consider this always a similar tool as laser cooling, as learning how to deal with lasers, how to deal with electronics. So I am by no means an electrical engineer. I could not design an interesting chip now or so.

I would say this more generally. It's also, again, the fun of this area, but maybe of many experimental areas. Whatever is useful to go on an experiment - in this case was miniaturizing these magnetic traps from huge external coils to these in-vacuum chip structures - you go into and you learn as much as you need to learn.

And then you need to learn how you actually write micrometer structures on chips and how do you, what are the limits or what are technical problems that come up. And that's a more fun part. You explore whatever is cool wherever it takes you.

[Chris] The miniaturization, for example, you can like there is now technology where you use this for magnetometry, right?

[Sebastian] So the story goes like this, these tips were built by multiple groups. And actually, one thing that was relatively quickly noticed, there was a problem.

A set of nice homogeneous atomic cloud, atomic density distribution. This was fragmented into lots of little blobs. And it then turned out this came from fabrication imperfection of these wires on the chip. This had to be understood.

And then it turns out, they turn it around, like we often do in science, actually these atoms so close to a chip being very sensitive to magnetic field perturbations turn out to be very sensitive magnetometers, which you can, for example, use to scan surfaces.

And that was kind of turning a bug into a feature story as we often have, you can even then say, these BECs, Bose Einstein Condensates, are nice surface probes, and they are still experienced to this day around the world, learning things about surfaces, about material science, using this idea the other way around. So that's a fun story.

00:14:11 Working as a postdoc with Mikhail Lukin

[Mira] And then you moved to Harvard to do a group of Mikhail Lukin. So how did you choose this group?

[Sebastian] As always, there's a lot of randomness to these decisions. So, in this work on the Einstein concept on chips, actually a theory group in Harvard, not Mikhail Lukin's group, but Eugene Demler's group at that point in Harvard.

They picked up on this topic and wrote a paper that we noticed. It was written for experiments like ours. We applied it and we started collaborating with them and then my central part of my PhD turned out to be this collaboration with them.

I think there's two publications that came out in this work and I went once or twice to Harvard to work with Eugene Demler. And then I liked the environment so much and was so impressed both by the town but also by the university and the physics being done there that I thought, wow, if I have the chance, this would be great for a post-doc and then I looked around and I found Mikhail Lukin as somebody who offers also experimental activities and I contacted him and went again and applied and ultimately ended up working in a cold atom experiment that he was just starting or was already running.

[Chris] What is Mikhail Lukin's secret? He seems like out of the currently active researchers in general quantum optics or so on, he's definitely one of the most with the highest output.

[Sebastian] Yeah, and then also in many, many different areas, right? Yeah, from Rydberg atoms now to NV centers some years ago and so on. I guess that already tells you a little bit about the secret. He is just extremely open-minded and extremely willing to take risks and go in directions. Also sometimes, again, you hear a lot of success stories, but there are also some experiments. For example, the one I worked that we stopped, that was putting ultra-cold atoms into hollow fibers that maybe didn't turn out as such a big success, but was in the maybe starting point for other activities.

So I think that's one part of the secret just being daring and trying a lot of things. And I think the rest is not so much a secret. He's just a very brilliant physicist, a very clever guy.

I would still say that's maybe important, very tough in many ways on himself and on demands what he demands from people in his group and so on. But also a nice human being is still fun to work with and I would say that's probably still the case, was definitely at that point the atmosphere in the group was super enthusiastic, super positive, also competitive and intense, but at any time also fun.

It was not a sweatshop also. I would say that's part of the secret for sure.

00:16:55 Balancing work and family

[Mira] Harvard is quite far. So how was the move for you? *D*id you have to move with family? And how was the other side of things, not the research, but the family?

[Sebastian] So at that point, actually, I was not yet married. But in a long-term relationship, I'm still in and still very happily in. So my then girlfriend, now wife, had finished a bit earlier university and had a job in Cologne and I just finished my PhD and we were debating what to do and for good or bad and maybe with some regrets 10 years later, my wife said, wow, this is a fantastic chance. I come along for two to three years. I for sure find something to do in Boston. It's a great place.

We went there for holiday first. And we both decided we want to do this without too much of it. We had no kids yet, no plans. And we actually got, in some sense, we got married because of this because it made the visa application. We were already in long-term relationship before and we got married because of this, you could argue, because it made the visa application easier.

So that was very positive from both sides. She quit her job for this and yeah maybe if we continue talking we'll see not everything is as easy or as positive as you maybe think with end of 20 and no kids and if you then follow both career paths further on but that comes at later stages.

[Chris] So during the postdoc like you had the four-year postdoc

[Sebastian] It was a bit more than three years.

[Chris] So during this time you also your first child was born. So immediately became a US citizen by birth?

[Sebastian] Yes.

[Chris] And could run for president in the future?

[Sebastian] Indeed. And sometimes looking at candidates now, very actively thinking about it. Yes, so indeed my first daughter was born there and again it was great.

I think both for my wife and me a great time. It was a wanted child if she's listening to this. Definitely planned and wanted and happy and so on.

But I think here comes the first big break in my wife's career instead of then going and finding maybe an interesting temporary job in the US like temporary post-doc for me. She turned to child support, child care. We did have a daycare at some point at high cost and difficult. It's in the US, it's even worse than in Germany.

But definitely it was the career kink for my wife and not for me. I continued working in this fantastic environment, maybe a bit reduced but almost full speed I want to say afterwards. Without thinking too much, I was also, I must admit, maybe between my wife and me, at that point, not so much a topic we discussed.

You only learn about these things later and also learn the consequences later, which then, of course, are always career difficulties for my wife, not so much for me. And this was not so transparent to us then.

So we enjoyed it, we had fun, we had time for family. It was for sure all good, but cost comes.

[Chris] Yeah, so you moved back to Germany, you immediately got an Emmy-Noether group. I suppose you applied from the US?

[Sebastian] Not immediately. It knew where I wanted to apply. I sent in the application like a few weeks after I came back and it took a bit of time. But yeah, in principle, yes.

[Chris] So essentially you moved to Stuttgart and got the Emmy-Noether group?

[Sebastian] Yes.

[Chris] So at that point you were sort of really becoming your own man scientifically.

[Sebastian] Yes, I guess that was also the moment where for me for the first time I decided okay the academic career is really what I want to pursue.

Maybe that's an important point I get also asked as a question sometimes. When did I really think about my future, honestly, at the end of this first post-doc.

When I made the decision to do my PhD, I was in Heidelberg, was fun, was in the group, was fun, life was fun. Fine, let me continue as a PhD. Then post-doc, oh wow, I can go to a board, these guys take me, I have a chance there, let's just go. If I come back, everything will be fine.

But then, of course, at this stage, I thought, no, I want to give it a try, and this immunity is the thing. I will apply, if I get it, I will try to do an academic career. It worked. I'm here. It was the first time I did this decision.

And then as a family again, we moved from Boston to Stuttgart. Very tough. The Swabians, as much as I have good friends there now. Very difficult people to get into and very difficult environment to get into. And my wife was pregnant with our second child. Again, no chance to directly start working because we waited for months and months for daycare for the first and even longer than for daycare for the second child. Also in Germany, there is no good solution. It was terrible.

[Chris] I mean, the Emmy-Noether program, it does have early career support. I guess now it probably has sort of this early career childcare.

[Sebastian] I didn't have any of this. I got it in 2012. Maybe I missed some opportunities, but it provided nothing like this.

[Chris] Because for now just to make, I mean we're on the podcast of ML4Q and ML4Q for example helps with daycare places, which is great. I'm personally profiting from this and it's really helpful.

[Sebastian] I think things have changed tremendously to the better, maybe not good, but to the better in the 12 years since then. When we moved to Stuttgart, from the Emmy-Noether program, from the DFG, they didn't offer anything at all. At least I didn't use anything at all and I would not be aware of anything at all.

I must say the group I was actually in and also the group leader, Tilman Pfau, I ended up working there with. That was a very different story, a great environment. I think that’s how it worked - maybe still works - to some extent.

It's very dependent on your direct supervisors, direct environment, how easy life work balance becomes. But institutional help is really more unusual even on that time scale, I must say.

00:23:20 Moving to Denmark for full professorship and reflecting on dual-career challenges

[Mira] So your next career step was Denmark as a full professor. So during this time, did you work completely independently, setting up a group and all? How was the process?

[Sebastian] Yes, so maybe to give some context there. I mean, the program didn't have and I think still doesn't have a tenure track option.

It's a great program in the sense of how independent, how well funded you are for five years. But it comes at the big cost that it's a DFG funded project and the universities by no means have any standardized reaction to it. On the university in Stuttgart in particular had simply zero reaction to it and didn't offer any option to stay. And then with some stress and some nervousness I started in the third year to apply for jobs. And the job market is super tough, or was tough at that point.

I applied in Germany, I was invited to some places in Germany, but ultimately I very quickly expanded my search at least to northern Europe. I decided with my wife against the US, but then I ended up having three offers from the UK, from Finland and from Denmark. And out of those three, it was a bit of a balance, I would say. My wife had a clear say in this that Finland was maybe scientifically the best option and was a clear no personally. And the UK was maybe in both anyway not the top option and Denmark was the best combination so we decided for this.

But it was also clear if I don't have to do this I wouldn't do this. It was definitely for the first time where I saw it was very hard and my wife as well. Do we really want to do this some sense yet again? Go to a new country, now with two kids, take them out of primary school, throw them into a new language, and so on. It was a very tough decision. But in the end, I felt it was the only necessary way to move forward with this academic career. And my wife, again, now already much more grudgingly agreed to join.

Oh, but you asked also about independence. No, that was fine. They gave me all the independence I wanted in Denmark. I was first associate professor, but then full professor after a year or so. It was an independent group. So that was nice and was a big change the first time really being head of my own group.

Again, I clearly say I always felt super strongly supported by Tillman Pfau in Stuttgart, giving me a lot of independence. It already felt very much like my own independent junior group, so the jump was also maybe much more gradual than maybe in other cases. But yes, finally doing everything by myself from lab design to administration was interesting.

[Chris] Did you move the group or was it more that you had to start over?

[Sebastian] No, I moved the one experiment that could be moved there. I must also say the DFG, which was super supportive and for example, letting this expensive equipment go to Denmark was super, super nice. And I moved also some people. I had, let me count, one active postdoc and one active PhD. At that time, they moved along. One other PhD we managed to graduate just on time. Then I was super lucky that two German master students also came along.

So I think a starting group of four Germans that came along with me and then slowly transitioned to Danish people and so on. That was intense and fun and very small groups, they were very nice and close-knit groups and moving all together I think made lab work and so on a lot of fun.

[Chris] And how is it the Nordic countries are really like famous for being these role models of daycare, work, life balance and so on? Was it a good experience in that sense?

[Sebastian] So I think on a national level that's true and there are many things we could learn from them. On a personal level it's also a bit more ambivalent, although again. So first thing to say, my kids were school kids, both of them at that age already. So let's say daycare for example never played a role.

I think the Danish daycare system is much better than the German daycare system but we never made use of it. So I cannot say that the school system also works in Germany more or less, but that was okay. The overall society's approach to work-life balance is just orders of magnitude, but better different.

Again, it depends a bit what you want. So to me sometimes felt even a bit in the other direction. Danish work hours are very clearly regulated. Even rules that the university imposes, for example, on public holidays, your key to the university simply doesn't work unless you are emergency personnel.

And I, as a person who is sometimes also even together with my kids, just like going to my office and spending some time there. So not even as a crazy work thing, but more like it's my office. I have books there. I have my kids had toys there and so on. So why not let's go there? We could just not go in.

So what I want to say is it's very strong, but maybe sometimes even a bit too strict, but all in all life in Denmark is super enjoyable, super nice. Again, one has to be a bit honest. What the government does, what the state also maybe even can do. For example, you get more child support money in Germany than you get in Denmark actually. It's still not much in both places, but you get more money per child in Germany than you get in Denmark.

A lot of the Danish system strongly builds again on family and friends. And Denmark is a tiny country compared to Germany. People are never far away from the family. And I think the ingrained generational contract is still much stronger than, for example, in Germany. So people spend much more time, for example, with grandkids, or so I would say, at least in my personal experience, collectively or on average. And that is also part of it. So it's not all just how it's organized.

[Chris] Is it easy to get to know the Danes?

[Sebastian] No. Now this is a good question. In my international ranking, I'm not sure where I put the Danes next to the Swabians, somewhere on the joint spot number one in not so easy to approach. Maybe a bit different.

So they are super easy to approach, kind of like the Americans in a casual way. So they are a bit of a mix of the Americans and the Australians. So they are easy to talk to, even everybody speaks perfect English and super friendly and also super interested in international people and interesting stories and so on, but really becoming friends with them. It is incredibly difficult, maybe even more difficult with the Swabians.

The whole society in Denmark is built very strongly on being a closed-off, very homogeneous in-group and coming into this. I think even for Germans; you are always an outsider. This I noticed in also my kids and my wife noticed in many, many places. I think it's a bit, maybe not so noticeable downside to this. Everybody's happy. Everybody is friendly to each other's side. This works in a small, smallish group together. And outsiders are not so welcome in some sense.

[Mira] This must have been also particularly hard for your children. So did they ever come and complain to you about things?

[Sebastian] Yes, they were 6 and 9 and as much as 6 and 9 year olds complained. I think they just suffered and maybe even without understanding suffered in many ways that even up to now strongly shapes their personality.

[Chris] I mean, this nomadic lifestyle that is sort of necessary for the academic career is really, yes, really a tough thing.

[Sebastian] Absolutely, absolutely. Again, and I think one should be as brutally honest as one can. We then say, oh, it's also taxing on us and so on. I as a person making these moves and so on, I always had something new and something to look forward to. Also always job environment. It's also always a career step upwards. So even that, I mean, now I'm a professor, now I have colleagues or whatever. Always something positive. So even if you're all by yourself, I would already say yes. It's a demanding step each time.

But for your spouses and children, It's way worse. They have to do this because somebody else demands it of them. They don't have anything normally to catch them as maybe some spouses welcome group or so, but not like, wow, you have made a big career step or so. Wow, you start again from scratch and same for your kids. Wow, new school, everything new. You have to leave behind all your friends. And what's the benefit? Not really. Your dad has a better job. That you don't notice as a six or nine-year old in any meaningful way. The cost on family is horrendous.

And I can only say this loud enough, often enough, and to anybody who hears this, take it as seriously as you can.

[Chris] Yeah, and I think, I mean, we already said like there have been steps to mitigate this, like the sort of support systems in academic institutions are slightly becoming better. And I mean let's also be honest right like it's pretty obvious that one of the reasons why we have fewer women in academia is because there's a bit more family focus especially in the sort of age range that you are when you are in this career stage. And yeah, it's really important to fix this.

[Sebastian] Yeah, I fully agree. And if anything, I want to say that's only showing that female scientists are taking important things, maybe more seriously or paying more attention to costs than male scientists. Again, also how our society works for male scientists often probably is easier because there's a female taking care of many of the things. And that this costs end up. And no, for sure. I must personally say, after a long discussion and seeing for example myself how much suffering I have caused by this, I have no absolute answer in the sense of, I think, many career paths, not even just academic ones, let's say maybe first of all career paths that take this long, but also career paths that really are building on diverse experience, international connections and so on. That is not just academic, that's also in industry or many other areas. This is relevant. I am not sure how to do them perfectly and I would also say just abolishing them is maybe not the option. Let's say that everybody become a professor in the town they were born that doesn't sound super appealing either to me. So I have no solution but I think the right way to go is to make these difficult steps significantly easier and friendlier in particular to the accompanying people. And that is possible.

In the US, I want to say, even at that stage, things were already a bit more ahead, but not fully. The universities already were a bit more geared toward accepting international scientists, for example. And so on there, Germany, I feel, is also far, far, far behind.

[Chris] Did you get support for the international school?

[Sebastian] In Denmark, no, but that was also easy. It was not super expensive. No, in general, I think employers, again, there's not only universities, but any employers should. help make these transitions and these things more attractive and there are very many ways to do this. I think most of all it is dual career support and that always goes along with good child support so that both also spouse that comes along because of one partner making this career choice does not fall into a hole. I think that is really the most important thing I would tackle.

And then again, this has to come along with, you go to a different country, you have no friends, you have no family, you need perfectly working child support. So I think employers as big as universities just need to be big investors into sensible, and not just alibi child support or university like, I don't know, Bonn or Cologne, opening a child support for 20 kids. Yeah, nice gesture, but in some sense, pointless Harvard at that point had to take care for 20 kids all full of filled by Harvard professor kids paying $2,500 in 2008 per month for this. You can put it on your nice options list, but it's pointless. So no, this has to be serious.

And again, this cannot maybe not just be the university case, not just be the university, it has to be the city, and so on. This network has to work. And it's easily said, but again, this is important.

[Mira] It's great that you spoke to us about this, because usually researchers, they only talk about the research aspect, but then I think these experiences are also very crucial in shaping the personality.

[Sebastian] I mean, for me, again, in many ways, they affect me personally, up to the point that if a relationship you invest in and you maybe care about the breaks because of these things, and it does in many cases, that's of course ideally not what you want to happen to yourself and to anybody else. And again, even if it doesn't break, you see the cost on others and imbalance.

I think in particular, the imbalance in cost is so big. I think I would say that for a family that wants ultimately as a family to end up with one or two really successful career paths that there are some costs. I think that's OK to some extent, right? If you want to have the easiest low-cost life, take a drop in your neighborhood and never move. That's OK. But that this cost is so unevenly chaired in families and in physics in particular, female sharing is completely imbalanced in the families. That is terrible and that has to change.

00:38:42 Back to Germany for the last move

[Chris] When did you start planning the move back to Germany and was it also in like a family decision or career decision?

[Sebastian] Well, a parent decision, let's say, but also a difficult one. So we had moved to Denmark and we had told our kids jointly that we even bought a house. We really had invested into staying there forever, and it was also fine. The town we lived in was a very nice place we lived in, and slowly, let's say, migration into the Danish system was coming along.

We also had noticed, I mentioned before, a lot of maybe difficulties on the personal side, going into Danish life, also limitations on the scientific life in the place I was in and so on. And then, yes, this option came and it was, again, very clear moving to Bonn would be a big step upwards in career options. Not career options, it was the last career option, but in scientific options for me.

For my wife, it was a bit more ambivalent. She had actually, as a dual career, stepped in Denmark in permanent position at the university. But that was part of the negotiation here, and then Bonn did well, and she also now has an equivalent permanent job here. So there, I must say, the University of Bonn did a good thing.

Then it was more for our kids. They had made this jump. They were happy. I mean, kids, luckily, I think, become relatively happy even in tough environments relatively quickly and feel at home. And we were putting them through the same change three or four years later. On top of Corona lockdown. So really in the worst possible situation. And I think again now my older daughter for example says she's really happy and born and after three years here I think she made a transition and missing Denmark has faded a little bit.

But first you are leaving home yet again. So even coming back to Germany and again to the kids. I think for them, language in Denmark was much less barrier than to us. And so they would also have been just as happy in Denmark or so where you always just disconnect them. And even if it's going home, it has no real meaning. It's not making it easier.

[Chris] Where are your family grandparents?

[Sebastian] In northern Germany. So actually in Denmark we lived almost, I think Denmark was actually the closest place we ever lived to both grandparents' sites ever.

[Chris] So Bonn was not an improvement.

[Sebastian] Bonn in that sense was one more hour by train. So it's not a big change. Big change, of course, and I think in the long run everybody in the family appreciates this. Everything is back in the language we speak well. We don't have to learn Danish. Cultural differences are there between Denmark and Germany, as I already mentioned. And I think in the long run, now everything's fine, but I think if I ever tell them to move again, they will simply say, no, we don't come along. Now they're old enough to just stay behind.

[Chris] But I mean, I guess the University of Bonn is happy that you are going to stay here.

[Sebastian] I might have to say, I don't know if they're happy, but I at least at the moment have absolutely no intentions. Anybody who listens, I am not going anywhere.

[Chris] Exactly. Now you're a full professor in Bonn. Indeed, your job also doesn't have an expiration date. That's all very good.

00:42:20 Discussing current research and the Rydberg blockade

[Chris] Let's maybe talk a bit about your current research. So first of all, do you more think about manipulating atoms with light or light with atoms?

[Sebastian] We are thinking more about manipulating light with atoms. So that's a bit of a transition at some point. I started on the pure atomic physics science with Bose-Einstein condensates. You manipulate them with light. And then in this jump to the project in Harvard that already made this transition and that has always remained my focus and I always found this kind of reverse - I would even say that's a bit of a defining thing of my research and the group topics - turn it around.

We really now start to not use light as a tool but use light as a thing you want to do your science, your applications with and develop things; turn things around and use the things you've manipulated now to manipulate.

[Chris] This manipulating light with Rydberg atoms has like a long history, right? Like this sort of goes back to Serge Haroche and so on.

[Sebastian] Yes, that is true so yes in some sense although I personally would not maybe see this as a direct connection so there has been very active work starting in the 1980s or so, also in Germany, in Munich, and then in Paris, using Rydberg atoms to manipulate microwave photons trapped inside microwave resonators.

So in some sense, yes, this is light, of course, and this is being manipulated really photon by photon by the atoms, culminating in the Nobel Prize for Serge Haroche Russian 2012. I personally never saw this as such a directly connected thing that makes use of similar ideas and so on, but let's say two big differences is when we talk about light we mean visible light or near infrared light so end light in free space, or at least in waveguides or in fibers, not trapped in a resonator, not cavity QED, but like being kind of transmitted somewhere else or so. So that's a bit different.

And then the properties we use, they also built on these Rydberg states, but there is a very different mechanism. So it's not really a direct one-to-one of the work we do and have started with this direction maybe has not emerged so much directly from Serge Haroche others in the cavity curie field I would say, but yes it has this long tradition.

[Mira] So you work with super-atoms, so are these just atoms with more coupling?

[Sebastian] Yes, I don't even know quite that name some years ago. So the idea is and let's say the most fundamental paradigm also when we talk about work by Serge Haroche is interaction between single photons and single atoms or now in the border context single atom like quantum systems and making experiments so pure and so nice and also, but that's one thing making a friend so nice that you really work with single atoms and single photons is already very challenging, but then ultimately there are fundamental limits to how strong a single photon can couple to a single atom.

An atom is tiny and the photon is a bit larger in wavelengths and they don't match so well together. So the solution for many decades has been to confine everything in resonators and enhance this interaction by confining the light. And the idea that we pursued and others also pursued is not do this.

Can we come up with the methods to make light interact strongly with single atoms, not in a cavity. And this was already, I started in this direction in my postdoc in Mikhail Lukens' group, by now still trapping light, but in fibers, so not longitudinally, but transversely.

[Chris] Make it 1D.

[Sebastian] Make it kind of 1D and confine the light transversely smaller than its wavelengths, or at least on the order of its wavelengths. That, as I said earlier already, was actually not such a big success. This particular system turned out to be difficult, and also I stopped working with it, but also Mikhail Lukin and others stopped working with it, although these hollow-core fibers are still very much around, and many, many different similar ideas also still are being pursued.

And then comes the super-atom idea. So the idea is can you make many atoms together behave like one atom? And there's this Rydberg, different from Serge Haroche, so-called Rydberg blockade.

Actually also a mechanism originally invented, at least by others and Mikhail Lukin. It comes into play. As I said before, you go to these very highly excited Rydberg states. And you, because now these atoms are actually large, they are still quantum mechanical objects, but the electron wave function of this Rydberg electron is so large that you can hide a coronavirus, for example, inside of it, or even larger viruses. And the consequence is that also the interaction between two such Rydberg atoms becomes very large on length scales that are huge for atomic length scales. So let's say tens of microns. Like a hair.

[Chris] The bigger you make it, the bigger the dipole moment.

[Sebastian] Exactly. The bigger the dipole moment, the longer the interaction range becomes. And that leads to this Rydberg blockade. A very fun effect. We have to think a bit the other way around. If there are two Rydberg atoms, they interact very strongly. But in quantum mechanics it works like if you make the first one, now if you want to make the second one, you have to pay this interaction cost. And this can then be blockaded. Just because the first one is already there, the second one can no longer happen.

And this can even then be extended to not just two, but to, in our case, around 10,000. If we make one of them, the Rydberg atom and all of the others cannot become a Rydberg atom. And there are two more effects. One is quantum mechanics. You have to be careful. It can be any of the 10,000. So you create a quantum state. It's in principle entangled. It has entangled these 10,000 atoms. But that's more of a side thing.

But then this one big thing interacts much, much more strongly with one photon than one before. That's what we call a super-atom. So there's 10,000 acting like one if we call a super-atom.

[Chris] How does the interaction scale with the number of atoms?

[Sebastian] With a square root of number of atoms. So not super strongly. But 100 times stronger. So 100 for 10,000, it's 100 times stronger. And that's enough for us to start seeing things like at least few photons, single super-atom, quantum optics, stuff in free space not needing a cavity.

So very similar experience. And then actually it connects to Serge Haroche and others. So things they have been looking for in cavities we are now looking for in free space, basically.

[Chris] And the way you trap the atoms, are they at that point already a Bose-Einstein condensate or something? They could be, but they don't have to.

[Sebastian] Actually, sometimes in our experiment it happens a bit accidentally. So these are bosonic atoms indeed, and if you make them too cold, they condense into this Bose-Einstein condensate. It turns out, also a bit of a research along the way, we do not want this specific quantum state for a very simple reason. They become too dense, too many atoms in one place. That makes these very large Rydberg atoms a bit unhappy because then you are not hiding a coronavirus in your Rydberg atom, but you are putting many other neutral atoms inside of your Rydberg atoms and the Rydberg atoms don't like this.

So, we put some limits so we actually do not condense, but we still cool them to this micro curve in temperatures and very dilute clouds. And that's where we work with the super-atoms.

All these things I've learned all the way back to my diploma thesis is laser cooling techniques and so on. They are still at the core of these experiments. And that again for me has always been a fun part using experimental techniques. I learned in one direction, maybe applying them a bit in a different direction and so on. That's a lot of fun.

[Mira] What kind of phenomena do you see coming out of this kind of super-atom?

[Sebastian] The whole point now is we have these atomic systems and many other experiments study all kinds of many body quantum physics between these atoms. Our specialty is we send in some light something happens of course via the atoms but then light comes back out again and basically again to your earlier question we look at the light as the physics system so we know from quantum optics what is the input quantum state of light we sent in – it's the so-called coherent state - coming out of a laser and we look at what is the interaction in the system and what is the output state in the light?

And as we love to do in physics, you can abstract this a lot and say whatever is happening with atoms and Rydberg and so on in the middle, it's just a black box. We send something in, something comes out, so we can call this an interaction between photons, an effective interaction between photons, like a scattering experiment of photons.

And then you can, again, as we also love to do in physics, use things from other scattering physics experiments, theory from this, and apply this now to photons. So you turn the photons into interacting systems. And you can then do many-body quantum mechanics with photons. That's in some sense our big goal. And what this is good for, for fun. First of all, no, it's a bit of a cheap answer.

We have a lot of understanding about light and we have great in particular great tools to measure light and characterize also multiple photons. So now if we can realize interesting quantum interaction between such photons we possibly have advantages compared to other systems where interaction on the quantum level is important because again this light comes out as photons and we can detect it and we can analyze it with a lot of tools that are maybe not as easily available in other systems, detection down to single photons, correlation measurements. This is maybe not so easy if you actually look at Bose-Einstein condensates where similar or any other matter system.

So doing this falls under the name quantum simulation if you want to. You take something you're interested in interacting many body quantum system, but now you build this out of your light. And the advantage maybe is you have new tools or other tools available for the original system to analyze what's going on. And that's a key aspect.

00:53:48 Working in the new environment of Bonn and ML4Q

[Chris] How was your arrival in Bonn? Because we already discussed the hollow-fibers. And Bonn has the fiber lab that you immediately get. Like Bonn has this big history and this big optics institute. How was it coming into this?

[Sebastian] The hollow-fibers, in that sense, in the things we bought from outside didn't play any big role. So when I came here to Bonn, for example, the fiber lab originally didn't play such a big role in the planning.

Yes, Bonn has a very strong environment in atomic physics and quantum optics. Maybe also one has to always be a bit honest, what does it mean having a super strong environment around it? You still build your own labs and do your own thing at some point. There's only so much collaboration. For example, this Fiber Lab did not play in this decision to come to Bonn or so, but then it turned out, okay, we can actually make a lot of use of it and now we are very actively using many of the capabilities that exist in Bonn and that even keep growing in Bonn and also connected to ML4Q, which is fantastic.

Whatever research you do and maybe whichever direction it takes you also again depends on many of these surrounding factors. You come and you see how colleagues can fabricate this or that and then you think about oh this we could use and then you do something new which you wouldn't have done in another place for example or without having realized this option.

[Mira] So ML4Q had a very positive impact on your research.

[Sebastian] Yes. I mean I would say in multiple ways. What are these collaborations good for?

One is, first of all, you individually get money to do your research. It's not unimportant. You can hire more students and you can buy more lasers and you can do more research.

Then two, it sets an environment of topics, and it makes you think in a certain direction. So I would say for me, for example, projects we had, but also new projects we have designed, are now maybe because of this larger environment of such a cluster going in directions, I wouldn't have necessarily gone as much before. So in this case explicitly, you have heard all kind of quantum, quantum, quantum. But let's say quantum computing maybe was not on the top agenda of our research.

And now with colleagues in ML4Q from Aachen, from Cologne, we are taking these Rydberg projects also a little bit more in this direction, which we wouldn't have done by ourselves maybe. And finally these clusters, all the, like what we are doing here, what happens a lot around the actual research, the infrastructure and the surrounding structure the cluster provides, has a huge impact on research in an indirect way, in the sense of that the students are integrated into the graduate school, that there is more connection on all levels, that we have these joint infrastructure facilities and so on. That is hugely beneficial if you find ways to make use of it.

[Chris] I mean for all the listeners ML4Q is going to end with 2025 the current incarnation and there's currently the effort to write the next next round funding which will then basically ideally start without a gap. You're also involved in this process how is this like it's like a big part of your life at the moment.

[Sebastian] Yes. So first of all, why am I involved? Because I was too slow to say no, I guess. No, a bit more seriously. This is a collaboration, a huge collaboration. The excellence clusters are the largest funding scheme, largest in the sense of most partners involved. 25 official PIs but in our case over 50 full members that will benefit and contribute to ML4Q. And somehow you have to install some structure from spokesperson to steering board and so on and so on. I came into this, it existed of course. Actually, in the first two years, I did not do any of these more administrative things. And still not, I'm not a member of the ML4Q1 steering committee, for example.

And then I think ML4Q did something very clever, made relatively early on a clear plan, how do we approach writing proposal two and how do we do this efficiently? And I think a very good choice has been made there to keep ML4Q1 fully running at speed with the team that made ML4Q1 but also kind of build not completely new team but nicely overlapping but also sometimes again the cluster also brought many new people. I didn't come as a cluster professor but others came as cluster professors. So the clever decision was made to build the ML4Q writing and concept team a bit complementary to the existing structure. And I think that has worked super well.

We have been very busy with a group of different levels, one speaker for main writers, 10 concept people or so. And now for almost a year, writing this 120 pages proposal. And it's tough work. I'm only one small part of it. But I'm impressed by the level of detail and the level of thoughts and planning and so on that has to go into all of this. And let's hope the referees are too. That's what we, of course, now all are working for, handing in a hopefully successful proposal.

00:59:48 What about Rydberg atom quantum computing?

[Mira] You said, research-wise, you're also looking into Rydberg atom quantum computing. So can we discuss a little about the history and the future? I mean, Rydberg atoms seem to have been the fastest growing quantum computing platform in the recent years. Also the proposal for the Rydberg atoms was given quite early on in around 2000s and then there was sort of not many serious growth in that field. And then now, currently, again, things are starting to move a lot. So why do you think that is the case?

[Sebastian] You already summarized this super nicely. I have to maybe first, as a disclaimer say, I am not a Rydberg quantum computing expert. My work is closely related, but I have also, for good or for bad, not been at the very forefront of this development in the last five years or so.

So, to give my take on this history, indeed, actually names show up again, Mikhail Lukin and various others had this idea of this Rydberg blockade originally in 2002 as a mechanism to make a quantum gate between two such Rydberg atoms. And then actually the work we built on the super-atom also is a follow-up paper in 2001 that goes into these larger ensembles.

And then it took until 2009, 2010 for two groups, Mark Saffman in the U.S. and Philippe Grangier and Antoine Browaeys in France, to really demonstrate the proof of principle, two atoms and a Rydberg gate between them. That seemed to be a bit all there is to this field. So these two groups picked this up and did this. Why?

First, what we were lacking for a long time. It sounds easy. Two atoms, much easier than 10,000 atoms. It's not. It's actually much harder. Another very successful platform making use of single ions. In that sense has it much easier than already it was much more advanced. Trapping single ions is much more straightforward because these are charged particles and trapping single neutral atoms and manipulating them and holding them really in place turned out to be very, very hard and took, again, just many years of maybe smaller-scale efforts to move forward.

And the scaling aspect in particular, we always ask ourselves or many similar questions in quantum computing always are: Can we make good qubits? Can we make good gates? And can we scale it? These are the three core questions. And the good qubits for neutral atoms, that was already then very clear, is very good. The gates, actually this first proof of principle experiment, that's also pretty normal, not competitive, whatever, 70% fidelity or so, but that's typical. *A*nd then you start improving. But I think mainly why there was no large-scale effort to improve from that point on was the scalability question.

The community as a whole simply had no idea how to make hundreds of these single atoms in a configuration controllable and useful. You could make thousands and tens of thousands of atoms in lattices and magnetic traps and so on, but not of this single atom control.

And then again, this is, I think, where the key breakthrough came in 2016 or so by coincidence in Mikhail Lukin's group, not by coincidence, actually. I will tell you why. Actually, a super clever postdoc, Manuel Endres and others, and also in Paris in parallel, Antoine Browaeys and others, coming up with new ideas how to not just trap two atoms, but trap hundreds of atoms in so-called optical tweezers and how to really make them move around. And this, I would say, has been the opening of the floodgates in some sense. Giving a clear step how to scale at least from two to hundreds.

And then relatively quickly, gate improvement, fidelity improvement and so on were more technical. And I think they were always some sense obvious that they could be done, but nobody was doing them because it was no big point. And so then it went very fast. People showed nice gates and so on.

[Chris] I mean, in principle, let's say you can have these atoms trapped on chips. You can have these optical lattices and you can have the tweezers and in principle you can also have combinations of all these technologies. Like the key technological advance of the tweezers to some sense has to do with the optical modulators of this.

[Sebastian] Exactly, yes. So the breakthrough was again a bit from the technical side. So there are a bunch of devices acoustic modulators or deflectors that let us steer around these beams. Also so-called spatial light modulators that really let us pattern light beams on this micrometer scale. These are not devices that were invented in 2015 or so. They were around. But just because devices are around, kind of implementing them into these complicated experiments and making them really useful and so on is tricky.

So one key aspect of this tweezer loading is an ion trap. If you can load an ion, you can verify there is an ion, and after that it's still there and it stays there for days or so. And the tweezers had the problem from the very beginning. You can load them maybe with a 50% probability or so. And then you can check, and probably in the checking you already kicked the atom out again. So, to really, and again this is okay for two, then it works in 25% of the cases or so, but not for a hundred. So this scaling was so bad.

And I think the biggest breakthrough then came in 2016-17. Was to say that it's okay to only load 50% of your tweezers if you then afterwards move them in the right place. As you try to load 1,000, only 500 are full, but you move those 500 to where you need your computer to be. And that again was this big breakthrough that came in two groups, these movable tweezers arrays.

In retrospect it sounds super obvious. But you have to implement that it has to work. It has to hold single atoms in place. Many technical challenge had to be solved and that all just came together at that point.

[Chris] I mean this is the reason why we're all now so excited because the key advantage of the platform right is that IBM makes like a hundred qubits but they all have a little bit different flavor because they are like solid state devices. Mikhail Lukin and Endres and so on can have by now more than a thousand atoms.

[Sebastian] I think even close to 10,000 now in the latest situations.

[Chris] And these atoms are all identical.

[Sebastian] Exactly, so that's one big advantage. This of course also true for the ions, right? So ions are great qubits because by nature are identical. Then the gate fidelity for the Rydberg gates, using this blockade mechanism, have become not up to standards of the ion traps.

I think the ion traps still have a digit more or so, but really at the point where we are, where the community and theoreticians get really interested because we are reaching kind of error correction thresholds.

And maybe still also there's no fundamental limit yet, so there's still technical improvement that can be done. And indeed, then these dynamically tweezer arrays, I think they have people so super excited.

You're building your computer, but you can build into your computer, moving of your information in the common, like we do in classical computers, of course, as well, which the ion people are also making huge progress on.

But it turns out then actually now moving neutral atoms with the tweezers is much easier than moving charges with the ion traps much more flexible. So, all of a sudden now these things come together and make this suddenly super competitive super interesting platform.

[Chris] What is the current limit so you have a unique good vacuum. You need good laser like I guess more atoms means more laser power and you need more of these movable traps like what will be the first limits people run into in scaling like will it be easy to go to a million atoms?

[Sebastian] I think, again, this 10,000 is super high. I'm also not an absolute expert, so there are probably better experts than me. I think the 10,000 is indeed a little bit like laser power, also a typical field of view in size of vacuum chambers; size of the lenses you make to make these tweezers.

Again, if it's 10,000 or 20,000 or so, I cannot say, or 50,000 or so. But let's say in orders of magnitude that you really make a million in such a plane, I find hard to imagine. Then at some point it's also computing, classical computing power. You need to take an image. You need to decide which spots are empty. You need to rearrange on some relatively fast time scale.

[Chris] You are saying you think about this a bit like I mean I guess catching up to the state of the art and this is very difficult because there's only 10 labs around the world that have sort of the technology?

[Sebastian] Probably less. That's a good question. Would I personally now say, wow, I missed maybe this start of the race, but now five to seven, now I have my group, I have the resources, do I jump on this?

I personally made the decision not to directly do this. In many ways, we have been using many of the same technology. We have been using these AODs and kind of tweezer traps in parallel to the single-atom traps, almost the same time as these guys developed this for our super-atoms.

And I'm very happy with this place where we are in and not working on this direct forefront of the current leading system. But that is a consequence of ML4Q. We are looking at the super-atoms now a bit more in this quantum computation context. Actually, other groups are also picking up on this and doing similar things. So I'm very happy with where we are in this bigger competition field.

No, picking up on joining this becomes harder and harder because this is really a commercial field now. A few places in the world have big investment money and have permanent staff and so on that we don't have in universities. Even in ML4Q, we don't have that.

[Mira] A lot of people also think that quantum computing may be just an engineering problem now. Do you think that's the case or do you think we still have a lot of new physics ideas coming out of it?

[Sebastian] I would definitely say we have a lot of new ideas. And again, this goes both ways, even to ourselves. If you promise things too fast and then say, oh, it's only engineering that's left, you're also maybe making things you won't be able to keep.

And to me personally, I still see this as absolute explorative science, in particular on the experimental side. Yes, maybe some core concepts of quantum information processing have been around. And some algorithms that have created a lot of the hype have now been around for a long time. But in particular on the experimental side, we still see different platforms going up in the race, falling back in the race, and this is far from over. I at least would by no means bet that now Rydberg atoms have won the race also. I would be very naive based on recent developments. I would also say ML4Q is a great place to see this, but many other places.

But even on the theory side, yes, we have a handful of very well worked out algorithms and so on. But there is so much progress on developing these error correction protocols, on coming up with more clever ideas, platform specific ideas. This is still basic science. And for good and for bad, for bad in the sense that maybe some of the *b*reakthrough applications or breakthrough impact. We are promising and maybe some investors are hoping for a further in the future than we would want them to be. But that's okay.

[Chris] At the moment the Rydberg quantum computing also has at least three super big startups coming in, right? Quantera, Pasqal and Planqc are probably among the sort of big quantum computing startups now. Do you think they will change this field and will some of it get back to your like will it also change the labs?

[Sebastian] Yes it does in good and bad ways let's say in the bad way first. They hire people we can't hire as because it does at least for near future pay better. Are they more fun to work for than in a lab or so? I don't know. And I think this is also a new thing to offer. There are also people that now make decisions to work there. So maybe we'll say in five years different things. But that's one aspect.

I think another aspect we are seeing and I think that's in some sense very good is that this forces us, again maybe we can call this a bit more, I think like engineers or so, in the sense of so far many things we have been doing, let's build this later and lock it somehow, it will be okay for our proof of principle or so. But now these companies they have to think about how does this become so stable that we can ship this to some customer or so and that it runs day and night and then you can say okay as a basic scientist I'm not really interested but as I already said I find this technical challenge is also super fun and relevant and again just saying these are just engineering challenges is also naive because this tweezer breakthrough, it became possible because optics devices had become affordable, available, technologically so fast that they made this possible.

And now laser stability is becoming solved as an issue, what was limiting gate fidelity before. Yeah, you can call this engineering, but you can also call this really fundamental laser science also. It is a bit arbitrary how you see this. And this trickles already back into our labs a lot as we learn a lot from these companies.

[Chris] And Germany in some sense, this technology is something where Germany should invest more maybe because in this laser stuff, Germany actually has several strong companies, right?

[Sebastian] Yes, so actually the strongest scientific laser company Topica is deeply invested into all of this. Now I'm not a politician and not a business person. Germany is investing in quantum computing in a big picture, relatively diverse. I think that's in general still a good idea not to be too focused.

hey are also investing a reasonable amount of money into really Rydberg quantum computing and a bunch of science ministry funded projects all over Germany. I think they are coming online. They are doing really fun stuff. And that's great. And indeed, you can see this is good or bad. One big bonus of all this money being spent is, no matter if we have a quantum computer in five years or not, we have lots of technology that goes into more research, but that also goes into many other places.

01:16:00 About EIN Quantum NRW and quantum education

[Mira] Also, the state of North Rhine-Westphalia is involved through their quantum technology ecosystem, that is the EIN Quantum NRW. So what is EIN Quantum about? And what are in particular your roles regarding this quantum ecosystem?

[Sebastian] Yes, so we were talking about German funding. The German state is a federal state organized in a bit of a funny way, in particular research universities are state institutions. North Rhine-Westphalia, as one state, as various others, has made their own quantum initiative. And here under this name, Ein quantum NRW, which stands for Education Innovation Networking.

In my part in this, I'm a member of the steering committee of this new network, and in particular I have taken responsibility for the education part of this network, which is of course also related to research, but more focused on coordinating and maybe also improving the quantum education all over North Rhine-Westphalia, which I personally can get super excited about. Again, I mentioned before this developing quantum intuition by experiment. We see this in the lab.

And now the question is, where should this start? Should this start earlier in the physics education? Should this maybe creep into other educations? Can this even and should this even be already maybe a topic at least in advanced school education?

These are super fun questions to ask and of course you can only answer them by giving good options and that's what we are trying to do. Come up with fun experiments, fun demonstrations, fun visualizations of these quantum phenomena to not only have us with this intuition, but hopefully have a larger group of people enjoy this fun stuff.

[Chris] What is your approach to teaching quantum mechanics?

[Sebastian] Experimental. I'm not teaching theoretical quantum courses. What has happened here is we have a huge range of activity in quantum research. We have very active physicists, even philosophers, historians, looking into so-called fundamentals of quantum mechanics, sometimes more with a historical view, sometimes a bit with a philosophical view, even up to the point that people are still trying to come up with better formulations. This has become a bit marginalized because the main formulation works so well.

And then we have all the experiments. I think most of all, after 100 years, we are lacking very much any attempt to put this all a bit onto a modern footing from an experimental point of view. Maybe we love to do this, oh Einstein didn't like it and Schrödinger was confused and so on. I think this is outdated a little bit.

We need a really cool way of teaching modern quantum mechanics based on experiments. That is still under development and that is what I'm trying for myself in my courses where I teach this. But I think also in this network where we are seeing more and more. The more hands-on experimental tools that are developing.

The German physics curriculum has a great thing. It has in the first years in university that they show you experiments and mechanics, thermodynamics, they really get shown to you by demonstration. And to me that is a very clever way to teach. And that is in quantum mechanics simply not the case normally. You get a theory course and you learn the basics and everything is more geared to this old thinking about sorts of experiments. And this is no longer necessary. We have the experiments. We can show them.

[Chris] I mean you can essentially make a student demonstration NV-center experiment like let's say less than a million euros.

[Sebastian] Much less. We are trying this in this EIN quantum network now for laser cooling. We are building in Bonn a Strontium magneto optical trap where you really by eye can see the laser cooled atoms. Others in the network are working with single ions, with NV centers. Building more and more of this demonstration experiment, even all the way for school experiments.

We are trying to scale some experiments, not for millions of euros, but really for hundreds or thousands of euros per experiment so that they could go into schools. And I think that's a super fun and a super important area where now also this quantum technology thing comes in. Again, the companies develop something for modern quantum computers.

But like super computers are the five inch of classical computers pocket calculators have moved into schools or so I think that's a similar story. We will not have quantum computers in schools, but we will have maybe quantum demonstration experiments in schools that will teach already much earlier intuition for this and again humans work by intuition and science works by intuition much more than maybe some of us like. But we need to do this and we need to develop quantum intuition. That's my main goal in teaching I would say.

[Mira] So do you think because quantum mechanics until now was a bit abstract that the general public doesn't really relate to it as much, you know, because there were other cases like the Higgs boson created such a big sensation all over the world?

[Sebastian] Yes, I fully agree. We are missing still a bit the key insight how to make this super active field that has also now received so much political support and financial support to really turn this into something the public cares about and also enjoys.

If you look into physics, I think we have a few areas that have done superbly well in this: astronomy. This is the key thing that brings young people to the universities but also is regularly in newspapers. That's because everybody is fascinated by the night sky. I can see the point. In some sense a bit more approachable. You made a good point.

Elementary particle physics in that sense is not everybody's business and everybody's day to day experience and so on. And these areas have also still managed to really attract by saying that we are searching for the fundamental aspects of nature.

I think this is something that we as a quantum community have to desperately work on and do. And I hope again that this bigger network play into this a lot. Unifying our efforts to do quantum outreach. There's a lot of potential. I think we are on a good track but still have a long way to go. And yes, people should read about breakthroughs and read about this and care about this somehow similarly to pictures from big telescopes or from CERN big accelerators or so.

[Mira] It's great to see Germany's efforts in the race for quantum computing and that you are playing a very significant role in it.

[Sebastian] Well, I don't know.

[Chris] Thanks a lot for doing the podcast with us.

[Sebastian]It was a lot of fun. So many topics. Thanks for having me.