INTERVIEWER: Today is April 15, 2011. And I'm Barbara Moran. And today we are in the MIT studio and speaking with Frank Wilczek as part of the MIT 150 Infinite History Project. Dr. Wilczek, considered one of the world's most eminent theoretical physicists, is the Herman Feshbach professor of physics at MIT. Professor Wilczek received his Bachelor's degree from the University of Chicago and his PhD from Princeton University. When only 21 years old and a graduate student at Princeton in work with David Gross, he defined the properties of color gluons, which hold atomic nuclei together. He has received numerous awards for his work, including in 2004, the Nobel Prize in Physics for the discovery of asymptotic freedom in the theory of the strong interaction. He is also a distinguished science writer and poet.

Welcome, Dr. Wilczek. Did I pronounce "asymptotic" correctly?

WILCZEK: It's "asymptotic" actually. But you approached it closely, which is appropriate because it means "close approach."

INTERVIEWER: Okay. Great. Sorry about that. I even spelled it out for myself.

I wanted to start by asking you about winning the Nobel Prize. And I know you've told the story many times before. But I'm wondering if you could tell me where you were when you got the call for the Nobel Prize? And tell us that story?

WILCZEK: I was-- well, that's the punch line. I'll build up to it. For several years I have been anticipating that that could happen. So much so that knowing the announcement was going to be made, the night before I would be very restless and couldn't sleep. And 2004 was no different. I was tossing and turning and not sleeping. And we had a little digital clock by the side of the bed with the red numbers. So every once in a while I would look at it and see what time it was. And it got to be 5 o'clock. And the announcement was going to be made at 6 o'clock. So I said well, look Frank, you're not sleeping. Why don't you just get up and take a shower. And just in case, you'll be ready.

And so I got up and went into the shower. I thought that they didn't call people up until after the announcement. But that turned us be wrong because 10 minutes into my shower, my wife came in, holding the phone. I didn't hear any ring or anything. She was holding the phone and said, "There's a woman on the phone for you with a beautiful accent. Sounds Swedish." I think you should talk to her. And so I did. And that was it. And the other thing I didn't know--

INTERVIEWER: Did you stay in the shower?

WILCZEK: No. I got out of the shower. But that's all. I didn't dry myself off or anything. And I thought-- I think maybe actually I left one foot in the shower. I was kind of half in. Anyway-- I turned off the water for sure.

And the other thing I didn't realize until it happened was that I thought the phone call would be of the nature of congratulations, you've won the Nobel Prize. Goodbye. But it wasn't that way at all. They wanted to give me advice on how to handle the press, tell me to shut up until six o'clock. But that was just the beginning. There were people from the Academy who wanted to congratulate me. Some of my friends in Sweden wanted to have little conversations, tell me that they were responsible for it. And so on--

INTERVIEWER: How long was the conversation?

WILCZEK: It was 20 minutes, half an hour, or something like that. And the whole time of course I was dripping wet and cold. But it was really only afterwards that I realized I was very cold because I was all goose bumps. But at the time I didn't feel it at all.

INTERVIEWER: I'm sure.

So what did you do afterwards? Who did you call first?

WILCZEK: I called my parents right away. And then--

INTERVIEWER: What did they say?

WILCZEK: They were very pleased. I don't remember their exact words. But especially from my father, I think it was tremendously meaningful because he-- both of them grew up in the Depression and really struggled and sacrificed on my behalf. And they were extremely supportive for many years. And my father was kind of a technical person. He worked in radio and television repair kind of things. And electronics. And so to him, it was especially meaningful because of science. This was kind of the pinnacle of being. If he had learned that I'd somehow made a billion dollars or something, that wouldn't carry nearly the weight of winning this prize.

INTERVIEWER: That's wonderful.

WILCZEK: Yeah.

INTERVIEWER: That's nice.

So-- okay, so after you call your parents-- which is good. That's a lousy answer. I wanted you to call your mother. Then what do you do? What do you do when you win the Nobel Prize? Just go to work?

WILCZEK: No, you get ready for the press. Because at six o'clock the announcement was going to come. And I knew that there would be press conferences, and people storming the door, and lots of telephone calls. So I dried off finally. I got dressed. And kind of gathered my-- I thought a little bit about the next thing.

MIT called also. Before the announcement I believe, if I remember correctly. They had also been informed. And they had scheduled a press conference for that morning. So I decided it would be nice to walk in. I walked in. The press conference was quite early. So that was the first concrete thing. But in between, a guy from AP-- a photographer from AP arrived about 6:15. He happened to be in the neighborhood. Lived in the neighborhood. Based in the neighborhood. And so we had to host this photographer. Couldn't really tell him not to come. And the phone just rang continuously, starting immediately-- from all over the world. So we just-- after a few--

INTERVIEWER: Took it off?

WILCZEK: Yeah. There's just no way to deal with it.

INTERVIEWER: Yes.

Do you remember what was your primary emotion at the time? Was it that you're just ecstatic? Or was it relief?

WILCZEK: It was relief really. It was relief.

INTERVIEWER: And why? I've heard you mention before that you had been thinking the call might come for several years. And why was that on your mind?

WILCZEK: I'd done very great work. And several people had told me that they had nominated me. They weren't doing any favors really of telling me this. But got-- and that speculating on you know, trying to be nice, saying how much I deserved and all. So it just built a lot of--

INTERVIEWER: I can imagine.

WILCZEK: --tension. You know it's like being pregnant for five years or something.

INTERVIEWER: That's very funny.

So I noticed that-- can you explain to a non-physicist the work for which you won the Nobel Prize? And then do you have a--

WILCZEK: There are different levels of explanation.

INTERVIEWER: Yes.

WILCZEK: But I can first tell you sort of in quasi-historical terms. There are four basic forces of nature: gravity and electromagnetism. And then two forces that were only really discovered in the 20th century because their effects in most accessible circumstances are only on subatomic scales. And these are called the strong and weak force-- very unappealing names. But you had to name them something. And one is strong-- the strong force is much more powerful. It's the strongest force in nature. It holds atomic nuclei together. So not atoms, but their inner core. It holds them together. In fact as we understand it more deeply, it holds protons and neutrons-- protons themselves together, made of the basic things-- quarks and gluons.

Anyway that wasn't known at the time that I did my work. What we did, David Gross and I, was figure out what the equations of the strong force are and how to demonstrate that those are the right equations experimentally. It's not so easy when you're looking at forces there really.

INTERVIEWER: Yes.

WILCZEK: And that's had all kinds of consequences for physics. For instance, knowing how those forces work allows you to talk sensibly about what happened in the very early universe where things were really squeezed together. It also has allowed us to make more progress in fundamental particle physics at accelerators because most of what happens is due to this strong force. So if you want to see subtle new effects that haven't been anticipated, you have to be very, very confident that you can sort of subtract off accurately what usually happens. So the interesting events might be one in a million or one in a trillion and at a place like the Large Hadron Collider. So you really have to understand the background extremely well.

INTERVIEWER: When you were doing the work-- you talk a lot in your writings about beautiful equations and all equations. When you were doing that work, was there a moment when the equation just clicked? And it was beautiful? And you said, "this is it?"

WILCZEK: There was a definite moment when the equations gave a beautiful surprise, let's put it that way-- the equations we were studying. And this pointed to a very interesting area of investigation. It took a few weeks, which sounds like a short time. But if you actually lived through it and are working 15 hours a day on this, it's actually quite a long time. It took a few weeks to get from that breakthrough-- which was kind of a mathematical breakthrough-- to a theory of this force. We sort of-- it was really-- it was very much almost unimaginable a realization of this idea that you look for beauty in equations. And then if you find beautiful equations, you look for places to use them. But it was a stunning gift from nature that this phenomenon-- this asymptotic freedom-- really pointed very uniquely to a complete theory of the strong force.

INTERVIEWER: Yeah. It must have been-- I can only imagine. Once you finished the equation, it must have been kind of stunning to realize--

WILCZEK: It was. But this was at the very beginning of my career. I thought this was the way it was. This was always going to be this way. Okay, so this week we solve the strong interaction. Next week, we'll do the weak interaction. Then we'll do gravity. And then we'll unify them all.

I wouldn't say it's been a letdown ever since. But was not-- I didn't realize how rare and extraordinary it was to make that kind of progress.

INTERVIEWER: That's very interesting. At what point did you begin to think that that work was Nobel worthy? Was it at that point?

WILCZEK: Right away. I should-- with a "if". Or a big "but", I should say.

The experimental evidence at first was very thin. And in fact some of it was contradictory. If we really had supplied the equations for the strong force, that definitely was huge. But nature gets her say-- gets really the last word. And it wasn't clear for quite awhile actually that these equations were actually the right ones.

INTERVIEWER: And is that because the experiments didn't exist? Like you didn't have the--

WILCZEK: They didn't penetrate the high-- We could only really draw out the consequences of these equations in a convincing way for behavior at high energy, where high means really high. Higher than was then accessible. So although in principle the theory describes everything about the strong interaction, how nuclei work, and so forth, in practice we can only solve it accurately and make numerical, quantitative comparisons with experiments at high energy. So it had to rely on more powerful accelerators, also getting experimentalists to organize their data in a certain way so that we could really compare the predictions of our questions to the reality.

INTERVIEWER: Now, you already alluded to this a little bit. But in several talks you gave around winning the Nobel Prize, you thanked Mother Nature.

WILCZEK: Yes.

INTERVIEWER: Are you thanking Mother Nature for just creating this world for you to explore or for creating these beautiful equations and giving them to you somehow?

WILCZEK: Both. It's a wonderful world. But even on top of that miracle, the fact that finding this one phenomenon opened up the whole subject. And really, people have been struggling with this strong attraction for decades. Decades of intense labor by many, many smart people. And then it turned out just by focusing on this one fact and trying to make it consistent with everything else and have beautiful equations for it, we solved the problem in a few weeks. That didn't have to be that way. It's usually not that way. People struggle to get more or less approximate theories for this or that. There are only a handful of incidents like that in the whole history of physics I think.

So that was very lucky. It's even more than that. It was a gift. These equations had consequences that I certainly didn't anticipate at first. I mentioned that the predictions are clearest and the behavior is simplest at high energies. That as I mentioned, opens up new vistas in accelerator physics because you can calculate things. And in the early universe, because you can calculate, if you have a speculation, you can actually calculate what it implies, which you couldn't do before. But also the particular equations that govern the strong force turn out to be deeply similar-- although of course different. But they have a kind of family resemblance to the equations for electromagnetism and to the weak force. So it's allowed us to think about unifying all these forces, and gravity too for that matter. And so that-- people have always dreamed of unified field theories. But now it's real.

INTERVIEWER: I want to get more to that in the end and about how you're going to figure out how to get gravity in there.

After winning the prize, did it change your research or change your life in any way? Did it allow you to-- what did it do for you for your career and your life?

WILCZEK: It opens a lot of doors. And it's also kind of overwhelming. I mean, it's overwhelming if you let it be, which I did.

INTERVIEWER: How so?

WILCZEK: There are many opportunities to talk to the public, to write books. Publishers are very interested all of a sudden. Instead of you approaching them, they approach you. And sort of within the physics and academic world, there are many opportunities to give public lectures and represent the community, represent high energy physics within the broader scientific world. And so I've taken that pretty seriously.

INTERVIEWER: Right. You could pretty much leave your work and just go become a representative of physics if you wanted to.

WILCZEK: Right. And I sort of did that for a couple years. I didn't completely leave my work. But it really was pretty consuming. I wrote a book in that time. And kept up some level of research. I was thinking. And I built up a backlog of ideas. But as to writing them up, that just didn't happen. And I'm still sort of gradually getting past that stage. But for the first couple of years, it was really overwhelming. But then-- you know, I really made a very conscious decision that I wanted to be a researcher and not a full-time scientific statesman or whatever. And so I've really cut back. That means saying no to a lot of thing.

INTERVIEWER: Right. Right. Like cool stuff, too.

WILCZEK: A lot of it is very cool. That's right. Exactly. It's not easy.

INTERVIEWER: Are there any downsides to winning the Nobel Prize?

WILCZEK: That's it.

INTERVIEWER: That's it?

WILCZEK: I would say. You have to really make choices and say no to people you like sometimes, and things like that.

INTERVIEWER: One other Nobel Prize winner once said that if you win the Nobel Prize, people think you're an expert on everything. And they're always asking him like medical questions.

WILCZEK: They think that briefly. Then you open your mouth. Anyway, I've tried also to be careful about not--

INTERVIEWER: I imagine it's a big responsibility. Because a Noble Prize winner says anything--

WILCZEK: It's taken maybe more seriously than it should be. Although you know on the other hand, if I look around-- people who make pronouncements and decisions for our country and civilization are not necessarily qualified either, you know.

INTERVIEWER: Yes.

WILCZEK: Who elected-- I don't know-- Tom Friedman or these guys.

INTERVIEWER: Along that note-- that's a really interesting-- has it allowed you-- given you a certain cachet or power or something like that to push a cause or promote something?

WILCZEK: It might have if I--

INTERVIEWER: If you let it.

WILCZEK: If I had really worked at it. It's not automatic, at least in my experience. You have to work at it because there are lots of people grabbing the microphone.

INTERVIEWER: Yeah. Yeah. Huh. That's interesting.

So I wanted to talk to you a little bit about your upbringing. I have read a bit about it. But I wanted to just ask you in person. And I think it's also interesting when someone wins a Nobel Prize, people want to know like, what did their parents do? How would I raise a child that wins a Nobel Prize? So I want to look at some of the secrets of your childhood that led to you winning the Nobel Prize. But can you just tell me a little bit about where you grew up, what your upbringing was like, your parents?

WILCZEK: Yes? So I'm a second generation-- well, third generation-- like how you count. My grandparents immigrated from Europe, all of them-- my mother's side from Italy, my father's side from Poland.

INTERVIEWER: After the First World War?

WILCZEK: First World War-- thereabouts. And they really struggled in the Depression-- which was sort of their prime-- the adulthood to my grandparents.

INTERVIEWER: And they came from New York-- living in New York?

WILCZEK: New York-- Long Island.

INTERVIEWER: Okay.

WILCZEK: So some of it was just barely in New York and some barely outside.

INTERVIEWER: When you say they struggled, they didn't have any--

WILCZEK: Money. I've learned about some of this history. My father's family had saved up some money in the bank by doing kind of odd jobs. And my grandfather was a sand engineer-- a stoker. The sand that underlies Manhattan and the skyscrapers came from Long Island and these big ditches. And he was involved in excavating that. And my grandmother had been a schoolteacher in Poland. But of course wasn't licensed here. And just did housekeeping and things like this. On my mother's side, my grandfather was a Mason. So they didn't-- they were quite modest. And also got wiped out. Their bank went poof. There was no insurance.

INTERVIEWER: Horrible.

WILCZEK: No nothing. So it was really tough going. And my father quit high school to help the family work. But kept up his education in night school and got eventually-- Actually when I was growing up, he was studying calculus and things like this. And the books were around the house. That was one of the things I picked up on. Because I thought it was really cool to compete with my father by learning calculus.

Because of this experience in part I think, they were very concerned that I do-- get a secure living. And also the time I grew up with sort of the Cold War. And competition and science was extremely-- it was also-- the atom bomb was a relatively recent memory for-- So science had enormous prestige. And not only among my parents, but also with the other kids and my teachers. I went to excellent public schools in New York. We didn't have a lot of money. But fortunately the schools were really good. And so I was blessed, I feel.

INTERVIEWER: So you always had this early aptitude for science and math--

WILCZEK: Yes.

INTERVIEWER: --or do you feel like there might have been a--

WILCZEK: I could have done something else probably. But no. But I always was very interested in sort of abstract reasoning and big numbers and little numbers. My earliest memories are of-- which I think are even preverbal was sort of-- we had a percolator-- one of these coffee things that has different parts-- six or seven different parts. And I remember-- I have this vision of myself sitting on the kitchen floor and just taking this apart and putting it together, and taking it apart and putting it together until I really understood it. It was really preverbal. So I probably was less than one year old. That's what I remember.

And then I kept little notebooks. I invented ways of making big numbers, I remember. It was sort of--

INTERVIEWER: What does that mean, invented ways of making big numbers?

WILCZEK: You'd multiply-- so you'd start with two. And then you multiply two by itself twice. Then you multiply that by itself-- the number of times that you had before. So it was that kind of way of doing it. So the idea is iterating things to make really huge-- I loved that idea. I memorized the powers of two to very high orders. I didn't know what I was doing. I didn't know the proper description of that.

INTERVIEWER: That didn't seem like fun.

WILCZEK: But that's what I was doing. And another project I remember because this one is really fun. I learned about money-- coins-- and you know like a quarter is worth five nickels. So I thought about changing money from one kind into another. And then seeing if you could come out ahead. So if you could have this--

INTERVIEWER: Did you figure it out?

WILCZEK: Yeah. I had some things that worked. But unfortunately when I checked, it didn't work. And what one time I came out with less. But I realized that's okay. Because all you have to do is do it backwards. But anyway. My father kind of put a damper on that. He said, "better check."

INTERVIEWER: Right. You had it all figured out. That's very funny.

Do you feel like your parents had-- you talk with their experience through the Depression. And that they wanted you to have a secure living. Were there other kind of values or beliefs in your household that you feel like shaped you?

WILCZEK: I'll mention a couple of things. One is-- my parents did a very smart thing. A very unusual and smart thing that I think really changed my live or molded it. Once a week they took me to a toy store. There was a toy store not far away. And I could pick out something-- not too expensive.

INTERVIEWER: One toy?

WILCZEK: Yeah. It was actually I could pick out something. And then several weeks later I'd save up. I had an allowance. So I could pick it. So that really was I think a big deal for me because I had to think about which things I wanted and how much. So how long I'd have to save up to get this. And refrain from getting one thing and get another. But also it was just really stimulating to the imagination to think that at least you could get these things. Right. The other thing is I would--

INTERVIEWER: Before you go on, are there any toys that stood out in your memory as the most influential--

WILCZEK: I like the toys where you could do things. So there was there was a kind of-- one thing I liked-- there was a kind of Cape Canaveral thing with models of the different rockets that they had. And they had stages and little space men. And maybe you could do that.

INTERVIEWER: You're all about taking things apart and putting them back together.

WILCZEK: At that time I was, yeah. A lot of the things I got in fact were models of-- model airplanes, model rockets, and things like that. I remember there was a very elaborate battleship I got at one point. And that it took a long time to assemble. There was a kind of truck that was a missile launcher. It had a light you could turn on and off. And yeah, I really liked that too.

INTERVIEWER: It was good to take Cold War toys.

WILCZEK: Right. Exactly. I had several different kinds of missiles. But the coolest thing-- it had a spotlight that you could project different images with. And a telescope thing. And you could look at.

INTERVIEWER: That is cool.

WILCZEK: Yeah, it was really cool.

INTERVIEWER: That's worth saving up for a couple weeks for. Not just for a--

WILCZEK: Yeah. I had to save up for quite awhile for that one. I think maybe a couple of months.

INTERVIEWER: So you were going to say something else about your parents?

WILCZEK: The other thing is I-- it wasn't actually in terms of time-- or in terms of my parents really-- that big a fraction. But it had enormous influence on me-- was I grew up in the Catholic kind of environment. I went to the catechism class once a week. I didn't go to Catholic school but just this class once a week. And that really also caught my imagination. Just the idea that there was a secret history to the universe. Right. That there was more than everyday life. That there were bigger forces in play. Bigger pictures. Different things that weren't obvious about the world that really were its meaning and deep structure.

INTERVIEWER: And maybe order-- an order?

WILCZEK: Order. Right. Right.

INTERVIEWER: That there's an order out there.

WILCZEK: Right. So I took that very seriously. Once I did take it seriously-- and at the same time as learning about science in my early teenage years. There's something called confirmation, which occurs when you're 12 or 13. And we went on a retreat and got really intense training. And at that point I realized that the stories really didn't agree very well with the science I was learning. And I had a crisis after that.

INTERVIEWER: Did you get confirmed? Did that make your parents happy anyway?

WILCZEK: Oh, no. I definitely got confirmed. It was really only a few weeks later that things really came to a head. But I'm grateful for that because the sort of having to wrestle with those questions and that concept that there are real issues about what the universe means, somehow really drove me.

INTERVIEWER: From your early education-- you said you went to really good schools and had a good science education. Were there any early teachers that encouraged you or helped you out?

WILCZEK: They all did. It was really very fortunate.

INTERVIEWER: Were you pointed out early on that you really had an aptitude for--

WILCZEK: Yes. I might get some people in trouble. But at that time they gave IQ tests and so forth. The teacher told my parents, which they weren't supposed to. And my parents told me, which they weren't supposed to. Anyway, it was a very--

INTERVIEWER: So they told you your IQ?

WILCZEK: Yes. Very, very--

INTERVIEWER: Are you going to tell us?

WILCZEK: No.

INTERVIEWER: Is it above normal?

WILCZEK: It's way above normal. But anyway, the point is that all my teachers knew about this.

INTERVIEWER: I see.

WILCZEK: So I didn't realize it entirely at the time. But it's clear to me now that they really were very interested in this kind of--

INTERVIEWER: Boy genius?

WILCZEK: --strange character that they had. And they were kind of forgiving if you did something that didn't seem to make sense. Maybe it was because you had--

INTERVIEWER: So what age did that happen? Is that-- how old? Like 10? What are you 14? When does that all happen? Age 7? At some point you became, aha-- here's the--

WILCZEK: Well, I think it was very early. The test I think was in second grade. And I skipped several grades. I only learned about it though considerably later than sixth grade because there was an issue about whether to send me to a different-- to a special school, which we didn't do.

INTERVIEWER: Can you tell me about that? What was the--

WILCZEK: There were special schools-- out further on the Island that weren't public schools-- that were supposed to be places that they took precocious things. I'm very, very glad that we dodged that bullet actually.

INTERVIEWER: Why?

WILCZEK: Because the public school worked very well.

INTERVIEWER: Interesting

WILCZEK: And let me stay home.

INTERVIEWER: And do you have any siblings?

WILCZEK: Yeah, I have a brother.

INTERVIEWER: And is your brother also--

WILCZEK: He's a computer technician. And he works at University of Florida now.

INTERVIEWER: Interestingly. Huh. All right.

So okay. So your teachers encourage you. And did you go to-- you graduated from high school a little bit early and--

WILCZEK: Yes. Yes.

INTERVIEWER: Why University of Chicago? Why did you go there?

WILCZEK: They offered us money, which was very nice. And they had a special program called University Scholars at that time which allowed a lot of freedom. So that was quite appealing.

INTERVIEWER: So at that point in your life were you are already aimed toward physics?

WILCZEK: No.

INTERVIEWER: Okay. So tell me about how that evolved.

WILCZEK: I want to do something mathematical clearly. I actually was torn between philosophy, which for me meant mathematical logic; neuroscience-- I guess you'd call it-- anyway, trying to figure out how minds work; and physics. I couldn't decide what I really wanted to do. All these were appealing as an undergraduate. I guess I mostly-- I thought probably figuring out the mind-- how the mind works-- was the thing I really wanted to do. But once I learned the state of the subject and that it really required experimental work-- and when I tried to do some experimental work I decided that that wasn't the way to go so for me. I just don't have the patience for it.

INTERVIEWER: Really. It seems like-- because the equation you could just do. You don't have to set up an experiment?

WILCZEK: Right.

INTERVIEWER: I see. I see. Did you have a-- was there a particular instance where you actually--

WILCZEK: It was a graduate-- I just couldn't get things to work. I think it wasn't an elevating experience. The cathode ray tube didn't work the way it was supposed-- I didn't understand it. I didn't hook it up correctly or something. Nothing ever worked. Gradually I got to be able to fix things. But it took so long to do anything interesting. It was just a very, very slow process.

INTERVIEWER: Very interesting.

WILCZEK: And also, if you're actually working with brains they're this kind of jelly like stuff. And it didn't resonate. I was spending time in a lab trying to fix things that didn't work. And I could have been-- I always thought to myself-- I could have been learning some beautiful mathematics. So instead of learning something, I was-- I was learning something. But what I was learning it wasn't as intense by a lot.

So anyway, the more theoretical part just wasn't right at that time. Even I could perceive-- as an undergraduate, I could perceive that it really wasn't ready for mathematical treatment.

INTERVIEWER: The theoretical part of neuroscience?

WILCZEK: There just wasn't enough structure. No. It was like physics in the 16th century or something. But I didn't really know what I wanted to do except that I wanted to graduate and go into-- I don't know-- the next step. I was always in a hurry in those days. And so I majored in mathematics because that didn't involve any lab work. I could graduate quickly. And keep my options open. So I majored in mathematics.

INTERVIEWER: And in a hurry to do what?

WILCZEK: Something big. And I was looking for opportunities. That was my philosophy. Okay. I was like a hammer in search of a nail. I was going to build up this kind of mathematical sophistication. But I didn't want to do pure mathematics. I wanted to do something else. I wasn't sure what exactly. But I was going to go to Princeton and look for openings.

INTERVIEWER: I see. And so how old are you?

WILCZEK: And that's what happened.

INTERVIEWER: So at this point you're like 20, 19-- 20?

WILCZEK: I graduated when I was 19.

INTERVIEWER: Okay. And what year is it?

WILCZEK: That was 1970.

INTERVIEWER: Okay. So at this point you're 19 years old. You know you want to do something big with math. You're not sure what. You're looking for opportunities. What were the big questions or problems at the time that drew you?

WILCZEK: That's what I went to Princeton to find out.

INTERVIEWER: I see. Okay.

WILCZEK: Why did I go to Princeton-- because I don't know-- Einstein was there. I had gotten advice from professors at Chicago about what to do. And Princeton was certainly--

INTERVIEWER: Princeton was the epicenter of theoretical physics.

WILCZEK: At that time, yeah-- definitely. And mathematics. Especially mathematics actually at that time. So, yeah. So I went there. And I actually struggled for a couple of years because this-- I was in the math department. And this philosophy of just hanging loose and not really committing is not the way graduate schools usually function. But fortunately for me the math building and physics building are actually connected at Princeton. It was very easy to walk over to the physics building and see what was going on. And go to seminars. And I very quickly realized that this was a great time in theoretical physics. There were new ideas. Powerful ideas that used mathematics were blossoming.

INTERVIEWER: Yes. Yes.

WILCZEK: And so I jumped in.

INTERVIEWER: As you are kind of in this period of searching, were there any particular professors that stand out, or you went to one lecture and it was like "ah ha!"

WILCZEK: David Gross. I went to this course by David Gross. At the time I thought it was a very senior guy. But he was 30 or something. But he is extremely dynamic. You know, very forceful and brilliant. And we just hit it off. And we started working together right away, even though he knew a lot more than I did, of course. But I was pretty quick in picking up on things.

INTERVIEWER: And what was the class he was teaching?

WILCZEK: Quantum field theory.

INTERVIEWER: Quantum field theory.

WILCZEK: That was just the thing.

INTERVIEWER: Yeah. And so it was there you went to such--

WILCZEK: It was really neat because he-- I guess in a formal way it was maybe not a highly polished course. But he really gave a sense of the excitement and the dynamic of the subject. Because it was absolutely oriented to research. That's what he was interested in.

INTERVIEWER: Yes. So that kind of light bulb went off with you in a way

WILCZEK: Yeah. I said this is an opportunity-- this is the sort of thing you've been looking for. Okay. So time to commit. So I did.

INTERVIEWER: You said you hit it off. Did you just go up to him after class. And did you just say, this is--

WILCZEK: Not right away. I was a little intimidated. But I worked very hard on the homework. So I did beautiful homework. And then once I'd done that and I got his attention, then I told him about my situation. And we started talking.

INTERVIEWER: And he'd already been working on the strong force?

WILCZEK: Not as such. He's been working on the strong force. But he had built up a lot of the machinery that we subsequently used.

INTERVIEWER: Interesting.

WILCZEK: In fact, the way I thought about this project at first was not really in terms of trying to solve the strong force. I was trying to solve a much more abstract problem, actually about the weak force. How did the weak force behave at high energies? But it turns out that in the process of investigating that, we came across this phenomenon of asymptotic freedom, which we realized would be a very good thing to have for the strong force.

INTERVIEWER: When you say that this time-- like 1970-- this is a really good time for theoretical physics, why? Was it just a lot of things coming together or was some experimental thing catching up with some theoretical thing? Or were a bunch of ideas converging? Or what were the big questions that were emerging?

WILCZEK: There were new ideas. So an analog would be in the period just before the '20s. And then in the early '20s itself, there was a great new idea-- quantum mechanics. And that opened up many, many new kinds of investigations and understanding of the nature of solids and understanding the fundamentals of chemistry, and many, many things.

In the late '60s and early '70s, there were new ideas that go by the names of Gauge Theory on the one hand and the normalization group on the other hand that in retrospect were extremely powerful. What we did was basically put those together and crack the nut of the strong interaction. But these were just great mathematical ideas. So I could recognize that even without knowing much physics or seeing where it was going to head exactly, that there were these mathematical ideas that very much were in the spirit of the mathematics I found most beautiful and could run with it.

Of course, all this was based on accumulated-- the fact that we could make such rapid progress in an application to reality was based on the fact that there was this enormous accumulation of poorly understood experimental results that were forming-- unexpected simplicities and regularities that posed sharp challenges to theory. In fact, the key one for us was the work on the structure of the proton that Professor Friedman here and Kendall and Taylor won their Nobel Prize for.

INTERVIEWER: Interesting. When you there at Princeton, were there other-- did you have like a cohort of other young sort of physicists your age that were all just--

WILCZEK: Yeah.

INTERVIEWER: --churning around together.

WILCZEK: Right. At that time high energy theory wasn't a popular subject at that time. I don't know why. I guess the news hadn't really spread. There's a delay in kind of the awareness at the graduate student level in general. But there were only three of us really in high energy-- or-- yeah, three of us that year and one from a previous year. Just a handful of people. But we talked and hung around at all hours. My office mate Bill Caswell especially was important to me at that time.

INTERVIEWER: How so?

WILCZEK: He was just a smart guy that I could exchange ideas with.

INTERVIEWER: What was exciting to you about the work. Or what-- what made you want to do the work? Was it just this idea of being able to do something big? Or was just you felt like this was the place to be? You know what I mean-- like big things were happening here? Or something about--

WILCZEK: There were external causes. But I think the most important thing-- the most important influence was actually the inner structure of the work. That it was just a beautiful thing. I liked doing for instance puzzles-- crossword puzzles-- especially these cryptic crossword puzzles. And just all kinds of puzzles-- elaborate Sudoku puzzles or programming things. I just liked solving problems. And was doing that. But I didn't have to feel so guilty about wasting time because this was a recognized, socially valuable activity somehow.

INTERVIEWER: As opposed to puzzles?

WILCZEK: Yes. Because it goes somewhere. You can publish it and you get tenure and so on. So there was that inner appeal-- just beautiful ideas. And not too easy-- play with them. So that's really where I was coming from. And to some extent that's still where I'm coming from. But later the kind of possibilities that these discoveries opened up for applications to the early universe-- to what happens in other extreme conditions-- they really caught my imagination. And I worked out that those made new puzzles-- and applying the equations. Unification is probably the nicest puzzle of all.

INTERVIEWER: The big dog.

WILCZEK: And it really is almost literally like a puzzle because we have this scattered knowledge and you have to try and put it together.

INTERVIEWER: Right. And I imagine if you push one piece and that sort of--

WILCZEK: That's when you know something is not working. But actually I think there's a way to do it that things actually do fit together.

INTERVIEWER: Yes.

WILCZEK: And it's an exciting time right now because we're finding-- we're going to find out whether this vision that I've been pushing for unification is correct or not at the Large Hadron Collider. We should find out pretty soon.

INTERVIEWER: So I wanted to talk to you a little bit about coming to MIT. So you came here in 2000, I believe? And could you just tell me how that all came about?

WILCZEK: I came here from the Institute for Advanced Study at Princeton where I'd been for about 10 years, which is a very attractive place.

INTERVIEWER: Yes.

WILCZEK: And I was kind of surprised that MIT or anybody would make me an offer because who would move from Princeton? But MIT just got me at the right time somehow. And they made a very attractive offer. And we went through a process of weighing pluses and minuses. And I came here. Part of it was family reasons. My wife's family is based in New England. And our daughters were going to school at Harvard and MIT. But also scientifically it sort of appealed to me to look for new horizons. The Institute for Advanced Study is a wonderful place. But it's a small place. It's very kind of ivory tower insular. And I still had dreams about understanding how the mind works or doing something more exploratory. And I thought that would be more feasible.

INTERVIEWER: I think you're saying that the Institute for Advanced Study is like cloistered? Is that the word?

WILCZEK: Yeah.

INTERVIEWER: And here at MIT there's a lot more interplay among disciplines.

WILCZEK: Right. Right.

INTERVIEWER: Interesting. And was bringing you here part of a larger plan to bolster their theoretical physics?

WILCZEK: Yeah. That was part of the idea was that it's going to be an opportunity to mold things somewhat.

INTERVIEWER: Yes. That's a nice opportunity I would think-- a nice feeling.

WILCZEK: Yeah. Although I mostly work in very small groups.

INTERVIEWER: Coming here, was that your first experience with MIT? You hadn't done any previous work here?

WILCZEK: Not really. No.

INTERVIEWER: And have you been struck by any differences of MIT than other places that you've been.

WILCZEK: It's very different. It's very intense. Very dynamic terms of people doing things-- lots of students and a kind of engineering attitude in many ways of getting to the practice-- getting things underway as opposed to dreaming. I have a tendency to kind of dream and play.

INTERVIEWER: So that's something you like about MIT or that's not a good fit with you?

WILCZEK: I don't like it. But it's good for me I'm sure.

INTERVIEWER: That's interesting. When you think about MIT or describing MIT, is there a specific example or anecdote or something in your mind that sort of captures what is MIT to you or what?

WILCZEK: I should be prepared for questions like that, but I'm not. For instance I really like the whimsicality sometimes of the pranks. And the Stata Center. And now these installations all over campus. I just like it that people can do real things and yet also have imagination. So I think this kind of disciplined imagination is really extremely appealing.

INTERVIEWER: What is it about the Stata Center? I'm just saying it because you're not the first person who has said that to me. There's something deeply appealing to a lot of mathematicians and scientists about the Stata Center. And I'm just wondering what it is?

WILCZEK: It shows that buildings can be different somehow. And it's just interesting to look at and yet never exhaust it. You look from different angles and different perspectives.

INTERVIEWER: It's kind of like an analogy of your work.

WILCZEK: Yeah. And our CTP-- our Center of Theoretical Physics, since it's been renovated is also kind of a work of art. It's a big open space with Sol LeWitt mosaics on the floor. It's kind of like an art gallery. It's really terrific.

INTERVIEWER: Just while we're on this, you mention in your first book-- I believe it's your first book-- about the harmonies that I've been reading-- this interesting connection between music and physics. And you're talking about art and your work. I do see that in a lot of mathematicians and physicists. There's some kind of connection between the two. Can you just talk a little bit about that within you or how--

WILCZEK: For me, it's not so much a technical connection. It's possible to study the physics of music. But I don't. But the idea that different worlds correspond to each other-- it's not even an idea-- just the reality that different worlds correspond to each other. It's like when you're playing the piano-- which is what I do mostly musically-- you're looking at these black marks on paper. You're translating that into motions. You're thinking about the structure. And you're also hearing something. And all these things are sort of an integrated whole, and yet they belong to a completely different domains really.

And that's the sort of thing also in physics that's so magical. On the one hand, you have equations and the concepts they represent. And then you have experiments, which look nothing like the equations. This struck me very much in my graduate student career when I first-- or just after, when I first visited the laboratory-- the Brookhaven Laboratory where some of the relevant experiments are actually going to be done. And you know, I scribble things on paper-- little calculations and things. And then there was this gigantic machine where they're going to collide particles-- and detectors, and people crawling all over it to do this. And it just hit me that their activities are the same activity as writing equations. And you know that's how the world works. It was like almost a religious experience to think that there's this harmony between different worlds.

INTERVIEWER: Yes. That's good. It was a good experience and not a disappointing experience?

WILCZEK: It was a wonderful experience. No. It's like Plato's Cave where you suddenly realize that you're seeing a projection of something where the ideas correspond to the deeper reality.

INTERVIEWER: So do you play the piano often?

WILCZEK: Oh, yeah. Practically every day.

INTERVIEWER: Does it help you with your work, do you think? Or is it a separate thing than your work? Is it a relief from your work or a part of your work?

WILCZEK: It's more a relief than a part I would say. I can't say that I've derived any concrete ideas of technical use from playing the piano. But it's a mood elevator. And it also-- I often in the middle of the calculation, I'll just wander down and play the piano for awhile if I'm stuck. Or just tired or just looking for something-- And it doesn't break the chain so much that I can't after playing for half an hour or something go right back to the calculation, refreshed. So it really works that way. Because somehow the same areas of the brain are still churning away when you need different kinds of activities usually.

INTERVIEWER: Very interesting.

WILCZEK: Whereas if I-- and the same thing if I take a walk. That's fine. I can keep thinking. But if I have to go pay the bills or do something like that, then it's hopeless. You can't really pick up where you left off.

INTERVIEWER: Interesting. And when did you sort of discover that about the piano. Is that something you've been doing since you were 20 or is that--

WILCZEK: No. No. Piano-- I used to play the accordion when I was a kid. And I still have the accordion. Because we couldn't have a piano in our little apartment, with neighbors all over the place. So I played the accordion. Although I haven't practiced for many years, when I was playing the accordion I reached a higher level than I've ever reached with the piano I think.

INTERVIEWER: I wish I had known that. I would have made you bring it in. Have you done any recent performances?

WILCZEK: No. No. No. I would have to do a lot of renovations. I took up the piano only as an adult when I was 30 or so.

INTERVIEWER: Interesting.

WILCZEK: So has been a lot of fun. Really, classical music has been one of the joys of my adult life because I didn't do it when I was younger. I was in a rock band. And I played the keyboards and accordion and drums-- all these things, but not any really complicated music.

INTERVIEWER: Interesting. Huh. Why were you in a rock band?

WILCZEK: Why not? Everybody was, right?

INTERVIEWER: Because you wanted to play music. Or because you thought it would like be cool and help you get girls? Or like that?

WILCZEK: Yeah, like that.

INTERVIEWER: So did it work?

WILCZEK: Not so much.

INTERVIEWER: So when you play the piano is this classical music mostly?

WILCZEK: Yeah. I'll play whatever is on the rack.

INTERVIEWER: Whatever somebody left on the sheet?

WILCZEK: Yeah. But mostly classical. And mostly sight reading until recently. Just the last couple of years I've decided that I should memorize things. So I've learned quite a few things by heart.

INTERVIEWER: That's interesting. I was just wanted-- this is along these lines. But I was just wondering if you could tell me like what a typical working day is like for you? Or how do you work? Do you work at night or during the day? Do you work for a half hour then play the piano?

WILCZEK: It's very unstructured. I'm blessed in that I have-- I can work any time. And I do. Yeah.

INTERVIEWER: You mean you can-- when you say you can, you mean like your job allows you or your constitution allows you to?

WILCZEK: Both. So I don't have to have any elaborate equipment. And also there's lots of different kinds of activities. There's reading books or papers, there's going to seminars, there's talking to colleagues and students, as well as just thinking and calculating. So all those things count as work at some level. And they all work together. It's a spontaneous activity. It's just something I derive pleasure from-- playing with ideas and trying to see how they fit together. And I really get annoyed if things aren't fitting-- that's another thing. And this has to do with also solving puzzles. It's really irritating if you don't have the solution. I just can't let go. It just annoys the heck out of me in fact. Some loose end that I failed to think that-- you know, it should be better. But I can't see quite how. So that drives me a lot.

INTERVIEWER: Yeah. So if you're stuck there on this problem and trying to get the loose end to fit, are you the kind of the person who stays up for like three nights in a row working on it?

WILCZEK: I used to. Not so much any more. When I was a graduate student and had a almost empty calendar, I pulled all nighters regularly. And that was sort my style. And for days at a time I would hardly sleep. You know three or four hours a night. And then crash.

INTERVIEWER: You mean crash at the end of it?

WILCZEK: Yeah. And then just sleep for a long time. But when you're an adult and have a regular life, it's not so practical. Although I do tend to revert to that sometimes during the summer.

INTERVIEWER: When it's less structured.

WILCZEK: Yeah when it's less structured.

INTERVIEWER: So does like coffee play a large role in your life?

WILCZEK: Yeah. I drink a lot of coffee. A lot of coffee.

INTERVIEWER: What's a lot of coffee?

WILCZEK: How much coffee do you think a person could drink in a day?

INTERVIEWER: Is it a continuing IV drip?

WILCZEK: Probably 10 cups.

INTERVIEWER: So 10 cups.

WILCZEK: Something like that. Four or five in the morning and then through the day.

INTERVIEWER: God. Four or five at once in the morning? Like-- welcome back.

WILCZEK: It's four or five normal cups-- which means two of my mugs full, really.

INTERVIEWER: Yeah, got you. Yeah. Huh.

WILCZEK: I make I make a pot of coffee in the morning. And then I basically drink it all.

INTERVIEWER: All right. So. Wow. So does that cause like other problems in your life?

WILCZEK: No.

INTERVIEWER: No. That's just you get to your normal state?

WILCZEK: Yes.

INTERVIEWER: Yeah. And what happens--

WILCZEK: If I don't get it, I start to get headaches and things like this. So I have to have it.

INTERVIEWER: Interesting. Wow. And is that something that's common among physicists?

WILCZEK: It's not rare.

INTERVIEWER: Probably non-caffeinated is rare, I would guess.

WILCZEK: Probably.

INTERVIEWER: Yeah. Okay. And now what about--

WILCZEK: I tried to--

INTERVIEWER: You tried to quit.

WILCZEK: I tried to wean myself of-- but I went back.

INTERVIEWER: Other than if you tried to wean yourself-- other than the headaches, do you find that it affects your work or-- you don't think?

WILCZEK: Yeah. I was kind of a wreck at first. Although after a couple of weeks, I was functioning fine then. And I guess I probably could learn to do without it but I just found myself you know-- Okay. Okay. So I weaned myself down to a couple cups a day. And then I said well, why not have another one, and have another one. Like an alcoholic.

INTERVIEWER: Yeah. Yeah.

WILCZEK: But they don't have CA.

INTERVIEWER: CA?

WILCZEK: Coffee Anonymous.

INTERVIEWER: What would they serve? They'd serve vodka?

WILCZEK: That's right. Serve sangria.

INTERVIEWER: That's pretty funny. Okay. So what do you think you'd be doing if you weren't a physicist? Have you ever imagined an alternate life for yourself?

WILCZEK: Yeah, I have. Probably something that involves math somehow. But it could have been almost anything.

INTERVIEWER: Yeah.

WILCZEK: It could have been even economics, for instance, which has become very mathematical.

INTERVIEWER: Yes. See that doesn't seem very far off from where you are now. There's no other sort of-- you really wanted to be a vet or something?

WILCZEK: The thing I really loved, but I never really thought about taking up as a profession, is history. Just the facts and thinking about what they mean. So I could imagine some quantitative form of history.

INTERVIEWER: Yes. If you like--

WILCZEK: But history is also great stories. So it doesn't have to be quantitative. So that's a different direction.

INTERVIEWER: Yeah. And you get to do a bit of that in your writing, I would think.

WILCZEK: Yeah. In fact, I've been working on a novel in recent months.

INTERVIEWER: Yeah.

WILCZEK: Yeah.

INTERVIEWER: I remember reading something about it. It involves physicists-- oh, right. Something-- there's a murder.

WILCZEK: Right.

INTERVIEWER: Yeah.

WILCZEK: Maybe a murder. Maybe a suicide.

INTERVIEWER: Do you want to tell me about it or do you want to keep it a secret?

WILCZEK: I can tell you just a little bit. I can tell you the main thread that holds it together. I hung a lot of stuff around this thread. The idea is that there are four physicists who make a great discovery. They discover what the dark matter of the universe is.

INTERVIEWER: That's big.

WILCZEK: And it's of course verifying one of my pet theories. So if it's not true reality, at least can be true in this novel. So it's clear that they should get the Nobel Prize for this. However, according to the rules for the prize at most three people can share it. So somebody's got to go. And then one of them dies in kind of suspicious circumstance.

INTERVIEWER: Interesting. I'm sure it's not a suicide, if he's going to win the Nobel Prize. Oh, all right. Okay. We'll have to find out.

So why do you write? You're quite prolific as a writer too. And very accomplished--

WILCZEK: I like it. And I get a lot of positive feedback. Also it's different but it's a related activity of solving problems. You solve different kind of problems. Not mathematical problems, but structural problems of how you fit doing things together, how you find the right words, how you vary. So I like that kind of activity. It's different. But also it allows one to loosen up and explore ideas in a more--

INTERVIEWER: Yeah. Creative way-- not "creative."

WILCZEK: I'm not sure "creative" is the right word.

INTERVIEWER: Relaxed?

WILCZEK: Somehow-- Looser.

INTERVIEWER: There aren't as many rules. In fact, the rules can be not good.

WILCZEK: Yeah. It doesn't scream back at you that you're wrong. If your equations don't agree with experiment of if they are internally inconsistent, then you get this immediate feedback. You're wrong. And that's in fact mostly what happens in theoretical physics. If you're trying to do exploratory or speculative work, most ideas don't pan out. But in writing-- sometimes structures don't work and so-- but its never so unambiguous that you're wrong, so you're allowed to continue it. It's a different kind of thing. It's very different.

The other thing that's different just at a technical level is in science, you want to write concisely and unambiguously. And it's kind of very disciplined, very constrained. In a way it's much more straightforward to write this. Although not many people do it well. But writing fiction or writing for the public is quite different. It's almost the opposite. You want to be expansive. In fiction you don't want to be clear and unambiguous.

INTERVIEWER: Right. Boring. So it looks like you're using all parts of your brain for different-- all your different pursuits.

WILCZEK: Yeah. That's one of my aspirations-- there are these books about 1,000 places you need to visit before you die. And I want to do everything.

INTERVIEWER: Yes. Yes. Visit all those places.

WILCZEK: Have different experiences.

INTERVIEWER: Yes. Yes. So I wonder if you could just tell me a little bit about what the big questions are today in physics that you're grappling with?

WILCZEK: Right.

INTERVIEWER: And talk a little bit about the standard model and what's going on with it? What's the big picture there?

WILCZEK: So the standard model is this remarkable synthesis of the theories of the forces that was achieved, mainly in a period around the 1970s. That at the time I certainly thought-- and I think everybody involved probably thought-- was going to be a very provisional structure that we modify. Parts of it are kind of ramshackle actually. But it's turned out to be just uncannily accurate and powerful. And even though experimenters would surely win Nobel Prizes for finding deviations from the standard model-- they work very hard to do it-- it's only been proved more and more accurate as time goes on. So it's pretty economical, extremely powerful. Even parts of it are very beautiful.

INTERVIEWER: Yes. It should be like wow, we got it right.

WILCZEK: Yesh. We got it right. And so it's close to nature's last word. It really describes an enormous range of phenomena pretty economically. And nice equations. That you can't change. Very hard to change in a consistent way. But it's not as beautiful as it should be given that status. It has lots of moving parts and it's kind of lopsided. So it's kind of begging to be embedded in some framework where all the parts make sense. I like to say it's--

INTERVIEWER: Lopsided meaning some parts are better figured out than other parts?

WILCZEK: The analogy I like to use is we have-- a dodecahedron is a perfect solid. It has 12 sides. All pentagons that come together in a regular way. Suppose some evil spirit took some of the parts away and unfolded it. If you knew about perfect solids you would know they were pentagons and they came together three on a side. Even if you only saw part of it, you might be able to reconstruct that it was meant to be a dodecahedron. Just some evil spirit has wiped away parts of it or hidden parts. And it's like that. The standard model has a lot of symmetry. But it has parts that-- it looks like something is missing. Right. And if you fill it in the right way, then it makes more sense. The different parts are lopsided in just the way they need to be fit into a larger symmetrical structure.

INTERVIEWER: Interesting. Interesting.

WILCZEK: So that's the vision of unification.

INTERVIEWER: Yes.

WILCZEK: And actually if you build on it-- if you try to implement that idea, a lot of things work beautifully actually. It really does fit into a compact structure. And we know how to hide the pieces, so to speak We know how that could happen. But to really make it work in detail and quantitatively-- this is what I discovered-- you need extra particles of a certain kind. This is called low energy supersymmetry. So it kind of doubles the number of particles in the world in a very symmetrical way. And that's something that's going to be tested now. That's what we've been waiting for a long time now. Because those ideas kind of jelled in the early '80s. And we haven't had the experimental power until now to really see.

INTERVIEWER: I always get the impression that there is a lot of people like you just waiting for the LHC to be--

WILCZEK: I have to find other things to do. But this particular work really has just been sitting there. A lot of people have been trying to extend it, but it gets more and more speculative because you're building castles in the air. And you can build in different directions. And at most one of them is right.

INTERVIEWER: Yes.

WILCZEK: And so we really need experimental guidance. There were hopes that just by pure thought you'd be able to figure everything out. But I think we've had pretty convincing evidence over 30 years that that's not going to work. And we really need some more guidance from experiment to progress.

So that's one thing. And another in the same spirit, but really quite distinct is that within our theory of the strong interaction-- which is called QCD or quantum chromodynamics-- there's also kind of something that doesn't look right. There's a possibility that the theory allows for effects that break the symmetry between the forward direction of time and the backward direction of time that don't appear to be realized in nature. So there's this possibility that the theory would allow-- it doesn't have to have it-- but would allow. And I find that-- all my colleagues find it-- extremely annoying that there's this possibility. Why doesn't nature use it?

So there's a theory of why it doesn't and leads to the existence of another new kind of particle call axions. And they are very interesting, not yet discovered, but could very well be the dark matter of the universe. And so that's another big idea that's out there that I'm hoping for.

INTERVIEWER: It's interesting-- it seems-- I could be wrong about this too-- but it seems to me that maybe 30 years ago that particle physics and cosmology were quite distant and didn't--

WILCZEK: Yes. Right.

INTERVIEWER: --interact with each other quite as much. And now they seem to be converging to some extent. Is there a reason why that's happening?

WILCZEK: The big reason is that fundamental physics came of age. Asymptotic freedom had a big part to do with this. We learned how matter behaves in very extreme conditions. And so it became feasible to think sensibly about the very early universe. So that's what really changed. And then the other thing that's happened is that some very good ideas arose, especially the idea of inflation that Professor Guth here came up with. That's turned out to be extremely fruitful. So good things came out of this opening.

And on the experimental side, the technology has really broken through-- that people have been able to take advantage of new techniques for observing very subtle effects. It's called the microwave background radiation. It gives a really, really rich portal into the early universe. You can sort of see the early universe and what its structure was like. And this is a relatively recent development. And it's turned out that the early universe seems to have been pretty simple. That is, the first guesses about what it might have been turn out to be pretty near to the truth.

INTERVIEWER: It's interesting. It seems like a lot of the solutions end up being simple. Not to me-- but simple-- elegant or beautiful in that way. Do you think that there's any-- I don't know what the word is-- but once unification comes, do you expect to be another elegant--

WILCZEK: It is elegant. Yeah. We have candidates. We have a candidate theory for it that is extremely-- it's better than the standard model. So it's really nice. It has other loose ends, but definitely it would be a huge step forward.

INTERVIEWER: What would happen if--

WILCZEK: And axions too. Even better because-- in a sense-- because they are more unique-- a uniquely defined theory.

INTERVIEWER: What would happen if five years from now you or someone else-- it was all proven and done. And your theory proved true. And the loose ends are tied up.

WILCZEK: Yeah.

INTERVIEWER: And then you're like, oh--

WILCZEK: The basic is nothing would happen. First of all, I don't think it's a realistic possibility. But--

INTERVIEWER: Because?

WILCZEK: There are just are just too many loose-- there's too much unknown-- too many loose ends that don't look to be close to being tied up. There are some things that look very right. But there are many things that don't look right at all.

Then okay-- but you could imagine a world in which we knew the equations. And there would be a period of experiments to test them and so forth. But eventually if they passed all the tests, people would get tired of wasting their time testing the theory. You just decide that it's right. And then okay. So then you work on neurobiology or--

INTERVIEWER: I see.

WILCZEK: --something else more practical you-- I don't know-- you set up websites. You do something else that doesn't-- the idea that you have to find better and better fundamental laws of nature and pursue the reductionist program indefinitely is not necessarily the case. It could go out with a bang if we actually achieve a complete theory. Or could go out with a whimper if people decided it's too expensive to build these accelerators. And the loose ends are just so esoteric, who cares. Okay.

But another thing that's conceivable is that-- and has often happened in the past-- is that when you find the equations, they're smarter than you were-- that they contain more than you put in it. So that you get extra effects that you didn't realize. You know like Maxwell put together electricity and magnetism. That when he put together the laws, he discovered they also described light and new forms of light which hadn't been discovered-- ultraviolet, infrared, and so forth-- radio.

INTERVIEWER: Yes. Yes.

WILCZEK: And when Dirac put together relativity and quantum mechanics, he found that you had to have antiparticles.

INTERVIEWER: So new doors.

WILCZEK: There are new doors that could open. I don't know what they'd be. I don't know. People speculate different things. Within physics also I should say just knowing the equations is not the end of the story by any means. Sometimes when physicists succeed in getting their basic equations that part of physics is ruled no longer to be physics. Like atomic physics-- figuring out how atoms work-- used to be physics. Now it's chemistry. It's called chemistry. Other parts of physics-- Newton-- Newtonian mechanics used to be the frontier of physics. Now it's engineering. So we might call it something else. But it would be coming from physics.

And right now within physics for instance, another wonderful surprise from my own work has been I took some of the concepts that we use to describe fundamental particles and fields and it turns out the same equations also govern how matter behaves at low temperature. So you have exotic quantum mechanical phenomenon-- these are called "anyons"-- that people have been exploring for possible use in quantum computers and other kind of very exotic, futuristic engineering.

INTERVIEWER: Yes. It must be really gratifying to see this-- this little-- your baby from--

WILCZEK: It's the greatest thing in the world. It really is. Right. Exactly. It's like seeing your baby grow up.

INTERVIEWER: Yeah. And do all these wonderful things.

WILCZEK: Surprising you.

INTERVIEWER: It's like-- you know, it's your immortality I suppose to be able to have that-- an influence so far beyond your personal self in a way.

WILCZEK: It's really nice.

INTERVIEWER: You have two daughters?

WILCZEK: Yes.

INTERVIEWER: They both went into science?

WILCZEK: Yes-- with a broad definition.

INTERVIEWER: Did you encourage them to go into science or did you let them--

WILCZEK: I didn't discourage-- they could see that I really admired science. I think that had some influence. They were embedded in that environment. But they haven't gone into physics. It's quite different what they're doing. I was going to support them no matter what they did. If they decided to become beachcombers or Republicans I might have raised an eyebrow. But was happy to help with almost anything they did. But certainly I'm very, very pleased with what they've actually chosen to do. My older daughter is a professor of biology.

INTERVIEWER: Nice.

WILCZEK: And my younger daughter, who went to MIT and the Sloan School, is doing kind of technological business-- bringing high tech ideas into practice.

INTERVIEWER: Oh, that's great. And so your daughter was at MIT when you were at Princeton and then you came here.

WILCZEK: Right. Just one year. She was one year in when I came.

INTERVIEWER: Oh, that's nice. And she said, oh god, I thought I got away and now --

WILCZEK: Yeah. I think she had some reservations about this. But it worked out well.

INTERVIEWER: Interesting. MIT has this idea of its role in the world as bringing ideas into practices, as we discussed. And how does your work fit into that? I'm just wondering if the people here are looking at your work for ways to make it practical. You talked a little bit about it.

WILCZEK: Not really. Not in any five or 10 year horizon I would say, which is usually what people are interested in who will invest money or-- The closest thing are these anyons I would say that could be important in the long run for new forms of computing or electronics.

INTERVIEWER: Yes.

WILCZEK: Through that kind of thing I've gotten interested in the behavior of matter at low temperatures and things like this that might someday be something practical maybe. But that's not what I think about. And MIT has certainly not in any way pressured me to try to think on a shorter--

INTERVIEWER: On a short term.

WILCZEK: --horizon.

By the way before leaving the subject of my daughters, I think it's appropriate to mention that my younger daughter has met and married another MIT student who was also an undergraduate at MIT and went to the Sloan School as well. And is also kind of in bringing technology to practice.

INTERVIEWER: That's great. That's great. An accomplished family.

WILCZEK: I'm very gratified. Actually. Yeah.

INTERVIEWER: Did you do similar things with them that your parents did with you? Do you used to take them to the toy store once a week?

WILCZEK: Yeah. I didn't regularly. No, it wasn't so regular. But I certainly encouraged--

INTERVIEWER: And were they equally into taking things apart and doing puzzles as you? Did you see that reflected in your--

WILCZEK: Not quite as much. No, I would say. They didn't seem to quite as obsessed as I was actually.

INTERVIEWER: No percolator taken apart.

Do you have any sort of principles that have guided you through your career? I guess I'm wondering is do you find yourself-- how do you choose what problems to work on it? Are they obvious or do you often have to choose? Do you try to choose what's more interesting or what's more-- I don't know.

WILCZEK: It's sort of all the above. It's a very spontaneous activity. Actually one it one of the things that's-- to call it a principle would be giving it too much dignity I think. My principle such as it is, is just to stay curious and try different things and see. And I work on things at all different levels. So some are grandiose-- trying to unify the forces or think about how maybe quantum mechanics could be modified or making prettier equations of this or that. But I also just like playing around.

And the other thing that people on the outside probably don't realize is that most ideas don't work. I have a saying which is that if you don't have failures that means you're not working on hard enough problems. If you know where you're going so to speak, then you're not exploring new ground. I like to work on both ideas that are big but may not pan out and also at the same time, projects that I know I can finish in a finite amount of time that will give some tangible results.

INTERVIEWER: Sure. Sure. Sure. That makes sense. That's a good mix.

WILCZEK: And I spend a lot of time exploring-- learning things that won't necessarily lead to any tangible work on my part. But I have to decide what I want to do. I was very gratified actually when I learned Einstein's favorite joke, which is very much along these lines. I'll just give a short version. So there's a guy whose car won't work. So he takes it to different garages. He's very frustrated. Nobody can give him a straight story. And he's spending a lot of money. So finally he's in desperation and he goes to the local garage, which is a kind of ramshackle place. But the mechanic looks at his car, opens the hood, takes out a wrench and tightens a screw. And then the car runs perfectly. So the guy is very happy until he gets the bill. The bill is $200, which at that time was a lot of money-- $200. And he's extremely annoyed. And he storms back to the garage and says, "how dare you give me a bill for $200? All you did was tighten a screw. I want an itemized account of why it cost $200." So the guy pulls out his pen and he writes down-- "labor, tightening screw, $2.00. Knowing which screw to tighten, $198." So-- I like that.

INTERVIEWER: Yes. It's interesting-- how do you go about sort of staying curious and engaging yourself in these different areas?

WILCZEK: Oh, I don't have a problem with that. My problem with anything is--

INTERVIEWER: How do you actually physically do it?

WILCZEK: --converging.

INTERVIEWER: Do you try to go to different talks?

WILCZEK: Yeah. Go to talks. I read books, talk to people, all those things. And in recent years, poking around on the internet and things like that. Although that's dangerous actually because--

INTERVIEWER: Because it could just suck you in forever?

WILCZEK: Yeah. And away from science too. There's lots of interesting stuff there that I don't want to get interested in, like politics. Once you when you're exposed to it, it's hard to get pulled.

INTERVIEWER: Yeah. Sure. I believe your wife is kind of active politically.

WILCZEK: Yeah. She does a lot of work-- I don't know how much I should talk about. But she does a lot of work maintaining the standards of Wikipedia, for instance. She does a lot of editing--

INTERVIEWER: Huh. That's very interesting.

WILCZEK: --and making sure the articles are accurate and conform to the standards and so forth.

INTERVIEWER: That's very interesting.

WILCZEK: I think that's important work.

INTERVIEWER: Right. Because there is somebody doing that. You wonder about Wikipedia.

WILCZEK: And some of it has a political component, but it's political not in an advocacy sense but just in terms of keeping things honest. But she also does scientific things.

INTERVIEWER: Have you ever felt this pull to be drawn into politics? Do you feel like you avoid it?

WILCZEK: It is a pull, but I avoid it. No, I can't-- it's not--

INTERVIEWER: Not appropriate or just it will draw you away from your work or both? Or why do you avoid it?

WILCZEK: It's clear to me that I can still accomplish things in science. It's not clear to me that could accomplish anything in politics. It can be very unpleasant-- so much arguing. And so much of it is dopey. It's really annoying to me when people can set out rational arguments and make a case for a certain policy and then just get blown away or ignored.

INTERVIEWER: Yes. Yes. A lot more emotional levels.

WILCZEK: Opposed with emotional--

INTERVIEWER: Fear mongering or whatever.

WILCZEK: Arguments that aren't rational-- that don't really stick to the point.

INTERVIEWER: If it didn't make any sense for you, you'd go nuts.

WILCZEK: Right. I really admire-- there is a scientist who went into politics who I really admire, Rush Holt, who was our representative in Princeton. So he did it. But his family was political. And I guess he had planned for a long time.

INTERVIEWER: I see. He was sort of used to it.

Do you feel like there's certain keys to a successful career in science?

WILCZEK: Yeah. It helps.

INTERVIEWER: Obviously, being the genius.

WILCZEK: It helps to be very clever.

INTERVIEWER: Yes.

WILCZEK: But not everyone who's successful in science is very clever and not everyone who is very clever and decides to do science, is successful. There's more to it. You have to be prepared to fail. You have to be willing to take risks. And I guess the thing is first of all to recognize that something is not working. And secondly, to move on if it's not working. So it takes persistence. It takes a certain kind of character and not getting discouraged too easily.

INTERVIEWER: Are there particular failures that you've had in your career that have been--

WILCZEK: Oh, many.

INTERVIEWER: Is there any that stand out as particularly helpful to you that got you off a path or that taught you something about your work or yourself or something?

WILCZEK: The ones that really stick in my mind are more missed opportunities than anything else. Things I could have done, I really was in a great position to do, but somehow I was doing something else or I wasn't smart enough. I just didn't do it. I could have discovered the inflationary universe. I was perfectly positioned to do that. I knew everything that was required. I just didn't think of it. And there are many lesser examples. There are lots of things I could have done that I didn't.

INTERVIEWER: And why do you think you didn't? Were you just too--

WILCZEK: I was thinking about other things. And how should I say, it's a-- there's a lot of luck involved too. It's like water going down a mountain and there are many paths. But one of them become the mainstream. One of them breaks through and happens to find-- And it might take a long meander. If you take the wrong choice, you don't get there.

INTERVIEWER: Do you ever sort of wake up and think you have an answer and write it down and then it's--

WILCZEK: That's happened.

INTERVIEWER: Is often like right or wrong? Like half and half.

WILCZEK: I've had both. It's more often right than wrong. Sometimes it's just ridiculous. The most exciting instances were just silly. This has only happened a couple of times. But I think I really made some grand piece of progress that was very paradoxical. And how can you-- And the most spectacular ideas in science are sort of paradoxical. Things that you think can't possibly make sense at first. But then you see it from a higher point of view that somehow reconciles the irreconcilable. But dreams also will reconcile the irreconcilable. They just don't really do it. So I've had dreams like that where I think I've--

INTERVIEWER: Put it all together.

WILCZEK: I'll have a new theory of gravity or something like this. And there just doesn't--

INTERVIEWER: And you wake up--

WILCZEK: I wake up and there's just nothing there.

INTERVIEWER: Bummer.

So I just want to ask you one more question about gravity. And then I want to ask you about a sonnet, if you might be up for it.

So can you just tell me a little bit about the problem or the issue of gravity within physics today?

WILCZEK: The problem with gravity-- there are a couple of problems with gravity. One is understanding why empty space weighs just a little bit. There are some ideas about that. They're not compelling, but okay so that it may be right-- kind of ugly ideas actually. But another profound problem is how gravity behaves in extreme-- really extreme conditions where quantum mechanics becomes important. These conditions are very rare in the universe. And they may have occurred in the earliest moments of the big bang or in the interior of black holes-- things like this. So they're not practical problems, but they're conceptual problems. How do you reconcile these two big theories of physics in detail?

We had an experience like that already with special relativity and quantum mechanics. Special relativity tries to treat space and time on the same footing. But in quantum mechanics, the way it's formulated, it doesn't work that way at all. Time is treated very different from space. And so you have to work very hard in order to make theories that are consistent with both special relativity and quantum mechanics. And really doing that is what led to the standard-- the ideas-- the deep ideas that enabled the standard model. And so it's been extremely fruitful to make that synthesis. It's not that either one is wrong. But putting them together is very difficult.

And general relativity is even harder because time becomes even more mixed up with space and less rigid. So there are many different times you could have chosen. Quantum mechanics says you have to choose one time and work with it. And then you have to show-- okay, if you build up this elaborate structure based on time. Then okay, if you chose a different time-- a different way of defining time-- you'd get a very different structure. You have to show somehow that they define the same world. They don't look like it at all. And no one has succeeded in really doing that. I don't know where it will lead if you do solve it, but so far no one has really solved that.

INTERVIEWER: I understand you've written a number of sonnets.

WILCZEK: Yeah.

INTERVIEWER: And why? What is it-- I guess if I can see you have this sort of sense of order. And so a sonnet would be appealing to you.

WILCZEK: It's fun. It's short.

INTERVIEWER: And would you-- I know you said you had at least one memorized.

WILCZEK: I think I have it.

INTERVIEWER: If you wouldn't mind, can you tell me what if it's about or why you--

WILCZEK: Yeah. This is a sonnet entitled "Virtual Particles". And it's about virtual particles. Virtual particles are particles that come to be-- that really are in our equations but not in our apparatus--

INTERVIEWER: Got you.

WILCZEK: --visible things. But they play an important role in formulating the theory, they mediate forces, and so forth. So here's the poem.

Beware of thinking nothing's there. Remove all you can, despite your care. Behind remains an endless seething. Of mindless clones beyond conceiving.

They come in a wink, and dance about. Whatever they touch is touched by doubt: What am I doing here? What should I weigh? Those thoughts often lead to rapid decay.

Fear not! The terminology's misleading. Decay is virtual particles breeding. And seething, no mindless, oft serve noble ends: This clone exchanged, makes a bond between friends.

To be or not? The choice seems clear enough. But Hamlet vacillated. And so does this stuff.

INTERVIEWER: Bravo. Was there an occasion that you wrote that for or did you--

WILCZEK: I wrote it for my book, for *Longing for the Harmonies.* Virtual particles was part of it. And I just somehow-- it was so strange to write about. How should I say-- it's one of those cases where it's much easier to write down equations than to articulate in English what they mean.

INTERVIEWER: Very interesting.

WILCZEK: So to sort of make that bridge, ordinary prose somehow wasn't adequate.

INTERVIEWER: I think it's nice. You did a good job with that.

I think that's about all the time we have. Thank you very much for sitting with us today.

WILCZEK: Oh, it's been a joy.