BOOKS AND IDEAS PODCAST

with Ginger Campbell, MD

Episode #23:

Nobel Physicist Frank Wilczek

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Frank Wilczek: We're constantly discovering new aspects of the grid but I think the basic concept is here to stay- that really space is a medium with a variety of properties that make it not only an important component of reality but really the primary component of reality.

Frank Wilczek: I find it awesome that that's what our eyes would see if they were capable of resolving small enough distances and small enough times.

[music]

This is episode 23 of *Books and Ideas*. Today my guest is Dr. Frank Wilczek from MIT. In 2004, Dr. Wilczek and his mentor Dr. David Gross were awarded the Nobel Prize in Physics for the discovery of asymptotic freedom in the theory of strong interaction. Dr. Wilczek recently published a wonderful new book called *The Lightness of Being: Mass, Ether, and the Unification of Forces*. This is an excellent review of our current state of knowledge of the nature of matter, energy, and space. In this interview Dr. Wilczek helps us to get a handle on some of these ideas. He also helps us to understand the importance of the Large Hadron Collider, which was recently completed near Geneva, Switzerland, and which physicists hope will go into full-scale operation in the spring of 2009.

I hope this is going to be the first of several conversations that I have with Dr. Wilczek, so feel free to send me e-mail suggesting questions and topics for future conversations.

Let's get on in to the interview.

[music]

Ginger Campbell: Frank, it really is an honor to have you on *Books and Ideas*. I thought maybe we might start out by letting you tell us just a little bit about your background and maybe a little bit about why you became a physicist.

Frank Wilczek: Yes, well, I'm an American immigrant story. My grandparents came from Europe- my father's side from Poland, my mother's side from Italy. I grew up in New York City, went to public schools. I've always been interested in big things- numbers, patterns. My earliest memories have to do with taking apart and putting together an old coffee percolator we had. So I think I was destined to do something quantitative, something scientific. I grew up in the time of Sputnik. I did very well in school, majored in Mathematics at Chicago. I didn't really know what I wanted to do with the Mathematics.

Eventually went to graduate school at Princeton in Mathematics, but still didn't know what I wanted to do exactly. And fortunately the mathematics building was right next to the Physics building and I wandered over to Physics and a lot of exciting things were happening at time. Big ideas were in the play that used the kind of mathematics I knew about, so I just jumped in with both feet and that was my calling. I found that I could do things easily and make progress and it was very exciting. Some of my earliest work when I was just getting into physics- I was 21 years old when I was just becoming a professional, so to speak. That's what eventually got the Nobel Prize.

Ginger Campbell: What's it like getting a Nobel Prize for something you did when you were so young. I guess that's not all that unusual.

Frank Wilczek: Well the whole process of getting a Nobel Prize is an amazing process. For me it started in the shower. I had thought for several years that it was a possibility and so I had a hard time sleeping when I knew that the announcement was going to be made. October 8th, I believe it was, of 2004 was no different- I wasn't able to sleep. And eventually after tossing and turning, at 5:00 I decided to get up and take a shower. I knew the announcement was going to be at 6 and I thought that if they called it would be after the announcement. But it turns out that they call before the announcement. So at 10 after 5 my wife came in with the telephone- and I was in the shower- and said, "There's a lady with a beautiful Swedish accent who says she wants to talk to you." And that was it.

I got out of the shower and took the call, and that was it. It was announcement of the Nobel Prize. But another thing I didn't realize about it is that it's not just, "Congratulations you won the Nobel Prize. Goodbye." Not at all. [laughs] They wanted to discuss with me some of the practical arrangements- how to deal with the press, and then there was congratulations from various official people- the head of the Academy and then from friends in Sweden. The whole thing took twenty minutes of half an hour, and there I was still dripping wet and naked. And then the press descends.

But it was a wonderful experience and I called my parents right away. And then, you know, a whirlwind of activity culminating in this magical week of parties at Stockholm. It's like a fairy tale. People get all dressed up in 19th century kind of tails and gowns and there's dancing and the Royal Family is involved. It's extraordinary. And then at a deeper level it's very very gratifying to see your work sort of certified as a permanent notable contribution to science, to human culture. And it was a real outpouring of, I could only call it love, from the community of people who knew about the work, even people I thought of as rivals, and so they just were very happy to see our subject honored. You know it really is a community and we appreciate each other and are very happy when our work gets the attention it deserves.

Ginger Campbell: So I guess you're pretty excited about this year's Nobel Prize.

Frank Wilczek: Yes- this year's was very very gratifying to me, something I had hoped for for quite a while.

Ginger Campbell: I was reading the text of your Nobel lecture and I noticed that you mentioned one of the people who got the-

Frank Wilczek: Nambu

Ginger Campbell: Yes- Nambu. I'm going to put a link to your lecture in the show notes for my listeners [Nobel Prize lecture] and we'll, hopefully, get to come back to that. Your background reminds me of what I read about in Richard Feynman's autobiography about growing up in Brooklyn and he...

Frank Wilczek: Well he grew up in Queens as I did. Don't confuse Queens with Brooklyn- we're very sensitive about that.

Ginger Campbell: He grew up in the Depression making money putting things back together for people.

Frank Wilczek: Right, that's right. Repairing radios, right. My father also did that sort of thing. He repaired radios and was sort of an electrical engineer technician, and we had a lot of old radios and primitive televisions, you know like with 1 and 2 inch screens, around the house. Yeah I got to play with those too.

Ginger Campbell: And I guess starting out as a mathematician must have been a big advantage, because I think for most of us now we look at physics and we go, "That math is impenetrable."

Frank Wilczek: Yeah. So doing work in theoretical physics, I think it's important to get the basic mathematics really into your bones as early as possible. So when students ask me what to do if they want to become a physicist, I tell them to learn the mathematics as early as possible and to do a lot of problems so that it's really in your bones so you just don't have to think about it. It's, I think, perhaps related to Mozart's relationship with music. He started so early and got the technique so deeply into his being that he could write enormous amounts very easily and then bring enormous depth to it as well, sort of work on a higher level, because all that matters with technique was done automatically.

Ginger Campbell: I really appreciate that there are people like you that are willing to take the effort to try to sort of translate what you do into the kind of English the rest of us can understand. I actually got interested in your work when I heard you interviewed by Steve Mirsky on the *Scientific American* podcast, and so I decided to buy your book *The Lightness of Being* because I realized that I didn't even have a clue what the Large Hadron Collider was for.

Frank Wilczek: [laughs]

Ginger Campbell: So I was hoping that today you might talk us through some of the key ideas of your book, and I have four questions that I kind of want to work toward.

Frank Wilczek: Alright

Ginger Campbell: And I'm going to tell you those up front so you can kind of help me make sure that I don't get off track with the wrong questions. The first question that I want to ask you is, basically what I just said- what is the Large Hadron Collider and why is it important?

The second question is to talk a little bit about this year's Nobel Prize. The third one has to do with what is dark matter and dark energy. And the fourth, if we have time, is- do we need string theory? And I picked these four questions because they're subjects that non-physicists hear about and kind of don't really know what they are. The only physics I've done on my show so far is I did a review of Lee Smolin's book [*The Trouble with Physics].*

Frank Wilczek: Uh huh. So that's why you're questioning string theory. [laughs]

Ginger Campbell: Yes, exactly. I have read *The Elegant Universe* also, so I've read both sides of that, but as a non-mathematician I came down on Smolin's side because I like testable theories. [laughs]

Frank Wilczek: Yeah, yeah. I think that's a healthy attitude.

Ginger Campbell: I'm a big fan of Popper- Karl Popper. And I've had an astronomer on the show, a woman, Pamela Gay, who has an excellent podcast called Astronomy Cast and...

Frank Wilczek: Uh huh.

Ginger Campbell: I think she's probably explained some of these issues. She does a lot of physics on her show. At any rate you're one of the few physicists we've had on. So my idea was to help those of us who aren't physicists have a better idea about some of these basic questions.

Frank Wilczek: Okay. Yeah we can go with those.

Ginger Campbell: And I guess then, does that bring us back to some of the more fundamental questions about the nature of matter and the nature of space?

Frank Wilczek: Well yes, I mean those are the kinds of questions that are in play and, well, we've learned tremendous amounts about that in the past century and in particular in the last few decades. That's really surprising that very few people know about my impression on the general public but they could really enrich their experience of the world if they open their minds to the things we're discovering about physical reality.

Ginger Campbell: Well that's the great thing about your book, is that it makes some of those things begin to make sense. You started out in the book just talking about Newton's Laws of Motion and how they're rooted in the basic assumption that matter can't be either created or destroyed.

Frank Wilczek: Yes.

Ginger Campbell: For those of us who grew up in the last fifty years or so, the fact that that's wrong seems almost obvious. We grew up with $E=mc^2$ and we at least have the concept that mass could be turned into energy.

Frank Wilczek: Yes.

Ginger Campbell: So I thought maybe we might start by asking you, why is that assumption- even though it was wrong- why was that assumption so important?

Frank Wilczek: In the book I make a distinction that Niels Bohr made between an ordinary truth and a profound truth. An ordinary truth is something whose opposite is false. A profound truth is a truth whose opposite is also a profound truth. And the principle of conservation of mass- it was a profound truth. It is not accurate in the end, so it's not literally true, however it's a very very good approximation under a wide variety of circumstances that are encountered in everyday life and even in astronomy. So it's an extremely useful principle to use, and was thought to be true for centuries, and used very very fruitfully.

However in the 20th century its limitations became clear and stark. So we've had to go beyond it. But we use the principles of Newtonian mechanics and classical physics in everyday life to build bridges, to plot the trajectories of space satellites, to plan voyages into space, and lots of other things. But we've now come to a stage where we realize that fundamentally, the conservation of mass is just totally wrong. So if we want to dig deeper we have to unlearn and start all over again. And it really couldn't be more dramatic.

As I emphasized in the book, the modern understanding of the origin of mass starts from building blocks that essentially have zero mass. So we've taken it to the other extreme. You know, if mass was conserved so that it couldn't be created or destroyed, there would be no hope of explaining the origin of mass because it's just always what it is. But we don't have that anymore. We can't think that energy is a deeper concept than mass, and we can explain the energy not just in principle of some kind of exotic matter, but actually the matter we are, the matter we've been studying in biology and chemistry and stellar astrophysics, and thought that this is all there is for us for centuries. We've learned that the mass of that kind of matter is almost entirely due to the motion of massless building blocks rattling around inside.

Ginger Campbell: And that is a weird idea, isn't it?

Frank Wilczek: Well it's the ultimate fruition, the ultimate realization, of the potential of that equation you mentioned, $E=mc^2$. I jokingly say that the more important law is Einstein's Second Law, $m=E/c^2$, which is just a rearrangement, of course, of $E=mc^2$ but suggests the idea that really what we should be doing is not explaining energy in terms of mass but explaining mass in terms of energy. And that's actually the way Einstein thought of it. His original paper is called "Does the Inertia of a Body Depend Upon Its Energy Content?" That is, does the mass of an object depend on the energy of things inside? And so out of my work it's emerged that the answer is a resounding yes, I think beyond what Einstein even had in mind. Not only is the mass of ordinary matter depending on the energy of things inside, it *is* the energy of things inside to a very good approximation.

Ginger Campbell: So knowing that... this means that you ask a whole lot of different questions than you would've in Newton's day, I guess.

Frank Wilczek: That's right. Or even at the beginning of the 20th century. Physics is a completely different subject now in its fundamental aspects than it was 30 or certainly 50 years ago. Just completely different. The textbooks have to be junked.

Ginger Campbell: Yeah.

Frank Wilczek: We start all over again, really, and have gone much deeper. In particular, for instance, the ancient contrast- maybe the most basic contrast we've encountered once we start to think about the physical world- is the contrast between light and matter. Light is something that moves very very fast and apparent infinite. It can come to be and pass away, gets absorbed and emitted, whereas matter is this stuff that's hard to move, that persists, that can be associated with mass that's always conserved- the starting mass is the same as the ending mass.

All these things seem to be terrible contrasts, so much so that they're used in metaphors in our experience. Light is thought of as spiritual, matter is mundane. Light is celestial, matter is earthy. But in modern physics we've learned really that there's only one thing, and it's much more like the traditional concept of light than the traditional concept of matter. I find that quite wonderful, so it makes us spiritual and celestial and all the things we like to associate with light- that's our deepest understanding of what matter is.

[music]

Ginger Campbell: Are we ready to tackle hadrons?

Frank Wilczek: Yeah, very much. Hadrons fit into this framework very well. We understand that the building blocks of protons and neutrons, which are examples of hadrons, the ones that we encounter in everyday life and that you can think of as making up our atomic nuclei- we understand those as being certain kinds of stable arrangements of quarks and gluons, more basic particles in stable equilibrium. But there are many other kinds of equilibria of those same basic objects that are not as stable but have an interest of their own. We create them in accelerators and study them and some of them even have an important influence on how protons and neutrons combine into nuclei. These are hadrons in general. So properly understanding what protons and neutrons [are] makes them appear as members of a much much larger family and those are the hadrons.

It's been a marvelous endeavor to see what the possibilities of these quarks and gluons are- the different possible ways they can arrange themselves in stable and meta-stable states. This has been an endeavor that's taxed the creativity and the technology of gigantic computers. But I think it's one of the great triumphs of science that starting from very rigid, very precise, and, I must say, beautiful equations, you go through hard computations to figure out the consequences and it matches this whole world of hadrons.

Ginger Campbell: So this is math that can be experimentally tested.

Frank Wilczek: Oh yes. You can feed the equations to a computer. The computer works very very hard and calculates that certain particles with certain kinds of mass should exist and then you'd better find them and not find other ones. [laughs] Yeah it couldn't be more concrete.

Ginger Campbell: So one of the things you said in your book was that- I'm going to quote from page 33- you said, "Quarks and gluons are not just another layer." Could you sort of say something about that, because it gets a little confusing to a non-physicist. It seems like there's too many of these.

Frank Wilczek: Right. It's like the Emperor Joseph who said to Mozart, "Too many notes." It's just as many notes as are necessary to make the patterns, the mathematical patterns of symmetry that these concepts demand. So the thing that's special about quarks and gluons is that they're not just another kind of particle.

The things that make them special is that their behavior is kind of ideally simple. That is, we have very precise equations that, as far as we can tell, say exactly what quarks and gluons are. That is exactly how the patterns of energy and motion that we like to associate with quarks and gluons will behave under all circumstances. These are equations that you can write down on a couple of lines, though there's an enormous compression, an enormous amount of information, that's captured in these very beautiful and precise concepts that wouldn't work, for instance, if you tried to write equations for protons and neutrons, more complicated objects. Or wouldn't work if you tried to write equations directly for atoms or molecules without first breaking them up into electrons and photons and those kinds of objects which obey simpler equations.

I guess the right way to think about it is, the thing that's special about quarks and gluons and also photons and electrons is that they represent, as far as we can tell, at least for very many purposes, they represent the rock bottom. They obey simple equations. We can't change those equations without making them worse or inconsistent. And from those objects, from those concepts, we can build up a description of the world that does justice to many many phenomena.

Ginger Campbell: So a question I think might come up for the average person who has only a vague understanding of modern physics but knows about the Heisenberg Uncertainty Principle, how can you predict what these guys are going to do and take into account that?

Frank Wilczek: Well, we learn over and over again in science, but particularly dramatically in the 20th century, that there's some things that we can predict and other things we can't predict, even in principle.

So back in the roots of science in the 16th and 17th centuries, for instance, Kepler hoped to predict how many planets there are in the solar system and how far each one is from the sun. As science developed over the next century or so it became clear that those were the wrong sorts of things to try to predict. You couldn't predict how far the different planets are going to be from the sun or how many planets there are, and now we know, in fact, that there are many solar systems in the universe with different numbers of planets at different distances from their stars. But that was nevertheless part of the great advance in science, because it was a by-product- that is, this ignorance was a by-product of much greater insight. We realized what could be predicted about planetary motions- you know, what the force of gravity was, what the laws of motion were. You couldn't calculate what the distances of the planets are from the sun, but if you knew the distances and velocities at one time, you could predict what they would be later with great precision.

It's a similar process in modern quantum physics. Heisenberg tells us we can't hope to predict or even measure the position and momentum of a particle accurately at the same time. As far as we can tell that is in the nature of things. That's a fundamental aspect of understanding what position and momentum in quantum mechanics mean. I won't attempt to do justice to the mathematics here, but it's a mathematical result that position and momentum kind of interfere with each other so you can't measure both of them at once.

So we learn there are certain kinds of things we can't predict, but that's a by-product of learning a framework in which many many many other things *can* be predicted accurately and have been. So we give up on measuring precisely position and momentum simultaneously but at the same time we learn techniques that allow us to calculate successfully the masses of particles, the probabilities of different kinds of reactions, the foundation of chemistry and so forth. So you win some, you lose some, I guess. But as you get deeper insights you learn that some things are amenable to precise mathematical treatment and other ones are just the wrong question to ask or they're questions that the theory is not going to be able to address.

Ginger Campbell: Even though your area is not specifically quantum mechanics, does it drive you crazy when you see people using quantum mechanics to justify all kinds of weird, magical thinking?

Frank Wilczek: It doesn't drive me crazy, but it makes me sad in a way. Well I guess it does drive me crazy too, but it also makes me sad or sort of inspires me to action because I think that quantum mechanics *should* fundamentally change the way people think about basic questions of the nature of reality, what the world is, even what logic is- those philosophical and even theological questions I believe you can't think sensibly about unless you know something about quantum mechanics, because quantum mechanics really changes what the world is when you properly understand it. And so I think if people *want* to think about philosophy or want to think even about questions that are usually called theology about the basic nature of reality, existence, where it comes from, what it is- I think you *have* to know about quantum mechanics. Otherwise you can't possibly address those questions accurately.

So I think quantum mechanics has a lot to say about that stuff and so when people bring in quantum mechanics to discussions of those issues I get excited. I say, "Oh boy, finally someone's going to do it right." But very few people get it right, that's the problem. You have to have enough patience and tenacity to open up your mind and encourage, really, to open up your mind to new ideas and absorb them properly, and only then go back to try to apply them to those big questions. You know, out in the popular culture there's a lot of loose talk about quantum mechanics that's very ill-informed and almost comical. But I sympathize with the desire and, well I think we need more quantum mechanics in those discussions, not less. It has to be used properly.

Ginger Campbell: I guess we could have a whole conversation on that.

Frank Wilczek: Yeah, definitely. Several. And that's one thing I was trying to address in my book too, is really open up the idea that the world as revealed by quantum mechanics is a much much bigger place than appears to the naked eye and really obeys different rules, not just different in detail but different in kind, and are familiar in everyday experience.

Ginger Campbell: And I liked the fact that you talked specifically about astrology and said that just because, you know, we know that- because you know the spin of one thing, it has to be different at another place- it doesn't mean astrology works.

Frank Wilczek: That's right. There's also the phenomenon that a little knowledge can be a dangerous thing. So if people know isolated facts that come up out of quantum mechanics and kind of pluck them out of context, it can lead to very strange errors.

Ginger Campbell: Yeah well I have to admit that I was a victim of *The Tao of Physics*, which I read back in the 80s and...

Frank Wilczek: Uh huh.

Ginger Campbell: Which I think led me to spend about ten years lost in New Age thinking.

Frank Wilczek: Yeah. Well, yeah I sympathize in a sense. There really is a bigger world and a richer world than appears to the naked eye, so I think that kind of quest is very valid. But I think you have to bring the same kind of rigor and carefulness to that kind of thinking. If you want to do justice to the world you really have to bring rigor and care to thinking about it and only then, if you're willing talk to talk nature's language, then she'll have a very nice, inspiring conversation with you. Otherwise you wind up talking to other people and talking gibberish. [laughs]

Ginger Campbell: So let's go back to where we were and I'm going to ask you sort of a- this is sort of my review- see if I've got this right or you can set me straight. I have to admit that even as I was reading your book I remained a little confused about hadrons.

Frank Wilczek: Right.

Ginger Campbell: For a while I wasn't sure that protons were hadrons. I thought hadrons were something that happened to protons.

Frank Wilczek: No no. Protons are examples of hadrons.

Ginger Campbell: I finally managed to get that straight by reading the…

Frank Wilczek: Glossary. That's why the glossary is there, because it is a lot to ingest all at once, so that's why I was led to make a glossary- so people wouldn't get tripped up by things that are just a matter of definition, really.

Ginger Campbell: But quarks are hadrons. They come together to make hadrons.

Frank Wilczek: That's right.

Ginger Campbell: Okay.

Frank Wilczek: Hadrons are observable particles that are made out of quarks and gluons, but quarks in isolation have never been observed and according to theory, never will. They are used as building blocks and have various indirect signatures, we call them. There's various indirect ways of reconstructing their existence from experiments, but they should never be observed as isolated particles according to theory, and they haven't been. So we don't bless them with the name of *hadrons*. *Hadrons* is used just for observable particles.

Ginger Campbell: Was is Murray Gell-Mann that came up with that theory? When he came up with it he didn't really think quarks were anything real, did he? I mean…

Frank Wilczek: Well there was a long period of confusion. I mean, quarks were inferred from indirect clues, and the first ideas about them were, in retrospect, a little confused and certainly very crude. So I think in the early days people *were* hoping that quarks would be observed as isolated particles, and experimenters looked very very hard for particles that had the properties of quarks, such as electric charges that are fractions of the charge and then electrons.

But after many many very energetic experiments didn't turn up any evidence for those things, it became more and more paradoxical, in a sense, that there were these objects that were used in the theory as a concept, sort of seemed to be very fruitful, but didn't actually exist. So it became one of the goals of theoretical physics to make a proper theory of quarks that would explain why they were so hard to produce. And that's basically what I did. That was an outcome of the Nobel Prize work that we had a proper theory of quarks with actual equations that tell you how they behave.

Ginger Campbell: And explain why we can't isolate them.

Frank Wilczek: And explains why you can't isolate them, right.

Ginger Campbell: But the way we can be sure that they exist even though they can't be isolated is now the theory predicts other things they do that you could then measure.

Frank Wilczek: Yes- they predict other things. So we can use the theory also to predict the masses of hadrons, that is, of particles that do exist, and of course compare those with what's measured. Also, very dramatically, you'll see in the book there are actually pictures of quarks, which sounds paradoxical because they don't exist. They don't exist as single isolated particles, but they do manifest themselves pretty directly in experiments as what are called jets.

That is, in situations where the equations tell you you produce a rapidly moving quark, what you actually see is not a rapidly moving single particle but a bunch of hadrons, in fact, moving in the same direction as what the equations told you the quark would be moving. And if you add up the total energy of all those hadrons and the total momentum of all those hadrons, it matches the energy and momentum of what the quark was supposed to have. If you sort of squint and pretend all those particles are actually one particle and add up the energy and momentum, then it reproduces the quark. So if you go with the flow you can actually see the quark.

Ginger Campbell: Yeah and that picture that's in your book, I think, is also on the nobel.org website [the correct address is nobelprize.org] on the page.

Frank Wilczek: Yes, yes, that's right. I know that the... that's a coincidence or else they took it from me, I don't know. [laughs]

Ginger Campbell: And there's also an animation on there that's pretty cool.

Frank Wilczek: Yeah there's a beautiful animation produced by Professor Derek Leinweber of the University of Adelaide, sort of as a by-product of the calculations that tell you what a proton is and what its mass is, and you analyze how quarks and gluons behave to make stable configurations like protons. You can look inside the computer, so to speak, and see what's going on, what is happening at the very small distances and times that are crucial to making the quarks and gluons balance. It looks kind of like a lava lamp of gluon fields fluctuating and their energy distributing themselves in different ways in space and time. I find it awesome that that's what our eyes would see if they were capable of resolving small enough distances and small enough times.

Ginger Campbell: Yeah I really enjoyed that point you made in the book, we can't see at that level of resolution, either in time or space.

Frank Wilczek: Right, but it's there. But we, using our noodle, we can by now be quite certain that that's what we would see if we had more precise senses. Just as a microscope allows you to expand your knowledge of the very small using light, the super-duper microscopes that we call accelerators tell us what space itself looks like when you look at really really really small distances and really really small times. You have to do a lot of image processing to make an image out of it, but you can and in that way we've tremendously enhanced our senses and can actually make pretty pictures of what it looks like.

Ginger Campbell: People don't have any problems with looking at MRI pictures.

Frank Wilczek: That's right. A lot of image processing goes into that. So yes, if you want to enhance your sense you really have to, well, you really have to work. But actually if you think about it, we take of course our sophisticated sense of vision for granted, but it's a result of enormous image processing too. The beginning of it is photons coming through a little dot in your iris- a little hole there.

Ginger Campbell: And we don't see what actually hit our retina either, so.

Frank Wilczek: Right. And you get these electrical impulses. Photons get absorbed that changes the shape of molecules and then you get electrical signals that go through many many stages of processing, get fed through your brain. And it's an awesome process that's in many ways only vaguely understood now. Looking out and seeing things, we do it so effortlessly that we take it for granted, but it's actually an extremely complex process. And the point is if we want to extend that to other realms we also have to use complex image processing.

[music]

Ginger Campbell: Well I can already tell that we're not going to be getting- I thought four questions wasn't very many, but I think we're going to be doing good to get to the first one. I think before we can talk about the Large Hadron Collider we need to talk about space. We've talked about matter now. We need to talk about the fact that space is not really empty. That's the other really surprising idea in your book. At least it was to me because I kind of had the misunderstanding that Einstein had disproved the existence of the ether. That shows you how backwards I am.

Frank Wilczek: Well he thought briefly that he had, but he soon recanted. And really from a deeper point-of-view he elevated the ether to what it is to this day, which is the primary building block of our fundamental understanding of nature. That is, we think understanding space itself properly, even what seems to be empty- once you understand that properly then understanding matter just falls out, and what we perceive as material in the ordinary sense is just little ripples on the activity of space that's going on all the time everywhere.

Ginger Campbell: And you call in your book, space- you call it the *grid*.

Frank Wilczek: I call it the *grid* because the ether has a lot of bad connotations and the early models which were overthrown by Einstein's Relativity didn't use adequate concepts and deservedly got a bad name. That's why people thought the ether is gone. I think the modern incarnation is quite different and much richer, but it shares the idea that space is full and a material but nothing else, so I thought it should have a new name. I thought about using *the matrix*. The first Matrix movie actually had this kind of idea that there's an overlying reality, but the sequels were terrible and so I gave up on the matrix. So *grid* is a nice one-syllable word that has connotations of activity and something you tap into. I also thought about *borg* but that's kind of evil so... [laughs] and also has connotations of mind that I think are, at the very least, premature as applied to the grid. So *grid* is it. Yeah, *grid* is the winner.

Ginger Campbell: And I'm going to quote again from your book where you said on page 73, you said the grid is "a powerful dynamic medium whose activity molds the world." That's a pretty big claim.

Frank Wilczek: Oh yes, but I have lots of proof. I and my colleagues construct very very accurate, precise, complete theories of the behavior of matter that have held up to extremely rigorous experimental investigations. I don't apologize for making big claims, for I can back them up.

Ginger Campbell: Would you say that we've already proven this, or is this something that...

Frank Wilczek: Yeah, yeah. Well it's subject to refinement and we're constantly discovering new aspects of the grid, but I think the basic concept is here to stay- that really space is a medium with a variety of properties that make it not only an important component of reality but really the primary component of reality.

Ginger Campbell: So can you talk a little bit about the grid?

Frank Wilczek: Yeah. Okay. The simplest property that empty space has that already shows that something is going on is that it weighs something. This is sometimes called the cosmological term 24or dark energy. What it means is that everywhere, and also at every moment of time as far as has been measured, what appears to be empty space- the space between objects- has a non-zero density- non-zero density of mass. That's its first property. You ordinarily associate having mass or having density with material, and space has density.

Another property is what we talked about earlier- the spontaneous activity of gluon fields that looks like a lava lamp- what are called quantum fluctuations or virtual particles. These are responsible, for instance, for quarks never existing as isolated particles. If they're isolated they produce too much of a disturbance in the gluon fields that would cost an infinite amount of energy, so that's not allowed. And the way we understand it is, starting with the fluctuations- starting with that- and seeing how those are impacted by putting different things in. So really that's a good example of how the primary reality is this spontaneous activity in space and what we ordinarily call matter like protons is little disturbances in that space set up when you plunk down quarks in different ways.

If you add another aspect is- what's a big target for the LHC [Large Hadron Collider] project that's now coming to fruition near Geneva- is what's called the Higgs condensate. I like to explain that with a metaphor. Suppose there were suddenly a new degree of intelligence among fish or, say, dolphins, that they were beginning to learn about physics and suddenly they realize that the world they'd taken for granted for millennia or for millions of years and so regarded it as just emptiness, that there was actually this material called water that was affecting the way they moved. That the real laws of motion wouldn't make you stop if you stopped swimming. There are better laws of motion that are more flexible and more accurate that you could have if you realized that you're living in a medium that's complicating things.

Well that's us. We've realized as we're progressed in physics that we can get better equations that explain motion more profoundly if we postulate that we're living in a medium that's distorting the simpler motion that we *should* have in the absence of a medium. That medium is called the Higgs field or the Higgs condensate. We don't know what it is, what it's made out of. It's as if these fish didn't know yet about molecules of water. They just have an idea that there was a material around them. And that's what the LHC is going to allow us to determine- what this Higgs material is. It's definitely not any of the forms of matter we know about- none of it has the right properties. So it's got to be something new.

So those are some of the aspects of the grid.

Ginger Campbell: So is what's going to happen in the Large Hadron Collider is by having this much higher level- higher energy level of collisions, you hope to actually perturb the grid enough to be able to detect?

Frank Wilczek: Exactly. Right. You'll take some of these fluctuations that are happening all the time and amplify them enough so they can sort of break free, so they don't come to be and pass away but can actually break free if you amplify them enough. It's like if you have magma under the surface boiling away and then you puncture a little hole and make a volcano and it comes out and it's lava- that's what the LHC is doing. It's going to supply enough oomph or events for that spontaneous activity to emerge into something we can sense and measure.

Ginger Campbell: In your book you talked about the accelerator that's already built in that same...

Frank Wilczek: In the same tunnel, right.

Ginger Campbell: So this Large Hadron Collider is going to be ten times as powerful as that? Or...

Frank Wilczek: Well the previous machine that occupied the same tunnel was called the LEP- the Large Electron Positron Collider. And it was based on colliding electrons and positrons. The LHC is going to be colliding just two beams of protons moving in opposite directions. The advantage of using protons is that it's feasible to accelerate them to considerably higher energies than you could electrons and positrons. And so the energies that will be probed at the LHC are roughly 100 times higher. It's higher energy. There's a price, in that protons are somewhat complicated objects and so the results are harder to analyze than you have for electrons and positrons and for electrons and anti-electrons.

Ginger Campbell: So there's lots of computers required too.

Frank Wilczek: Oh yeah. In fact there's a project called the Grid also [laughs], which is a new computer architecture that's going to allow thousands and thousands of computers all over the world to function as one giant brain roughly. So they'll be able to access each other's memories and trade programs and so forth. It's kind of like the internet on steroids, with tremendously communication links and very flexible so you can not only trade text files or video but actually really function as one computer. That's what's necessary to deal with the gush of information that's going to come out of these collisions.

There will be trillions of collisions per second now. Many of them won't even be looked at because very early stages of analysis within the detectors themselves will censor, if you like, or screen out events that are obviously not interesting- the way the protons almost missed each other so not much energy was exchanged, things like that. Even after that there will be perhaps a million events per second that you want to analyze and these events are very complicated. We sometimes call them little bangs, where you concentrate in a very small volume, kinds of energy that were last seen in the universe when it was about a ten thousandth of a second old at the origin of the Big Bang.

So it makes a little fireball that then expands and produces many particles of different kinds, and to figure out what happens- this is the kind of sophisticated image processing we were talking about- you have to figure out what the particles are, how fast they're moving, who decays into who. It's far beyond human capabilities. So it's fed out to the Grid to analyze these, make pictures, and then after many layers of processing eventually, it gets compared with theoretical expectations or perhaps expanded theories, different alternatives, and we see which does the best justice to reality.

Ginger Campbell: So since they're saying, last thing I read was eight months it's going to be before actually, because of the leak or whatever.

Frank Wilczek: Yeah. It's a gigantic engineering project. I like to say it's our civilizations answer to the pyramids. And it will be amazing if it works at all. I mean, I think it will work, but it's an awesome awesome achievement. I would say significantly more difficult than achieving putting a man on the moon. Anyway the pieces are all in place. There were test runs I guess a little over a month ago now, and during the test run there was an electrical failure and that set things back a bit. But the program is set to resume next April.

Ginger Campbell: Are you going to do experiments that are related to the...

Frank Wilczek: No. I don't do experiments.

Ginger Campbell: You're a theoretical guy.

Frank Wilczek: Yes. There's a division of labor because there's so much to know that no one person can really... takes so much time that no one person can really master it all or have time to do it all.

Ginger Campbell: Absolutely. What are the guys who are planning the experiments when there's a downtime...

Frank Wilczek: Well some of them get involved in repairs, of course. The detectors are also enormously complicated, so they're constantly tweaking the detectors and testing them in different ways. The people who work on the detectors are not altogether unhappy to have this little extra time so they can get ready and test things.

Ginger Campbell: And the computer guys have plenty of work to do.

Frank Wilczek: And the computer guys also- they have plenty of work to do, right. When it gets turned on in April it won't be up to full power with all these different components working hand-in-hand amicably right away. It's going to be a process. The fact that it's going to be delayed means that some of that later process can be worked out better in advance.

Ginger Campbell: So most everybody has something to do.

Frank Wilczek: Oh yeah. [laughs] Yeah I think that kind of problem actually kind of generates *more* work. It doesn't lead to idleness because the repairs have to be made, of course. The reason for the failure has to be thoroughly understood so that it doesn't happen again. And, well, in fact the nature of the failure was certain- links between the different magnets hadn't been properly insulated basically, and so you have to go around the ring and install insulation on all those things.

Ginger Campbell: Well I think we're almost out of time. I would love to have you come back and talk about the other topics if you want to.

Frank Wilczek: Sure- we could do that.

Ginger Campbell: Is there anything else that you would like to share with my listeners before we end for today?

Frank Wilczek: Well if you want to learn more, go to www.frankwilczek.com. There are lots of links there to elaborations and extensions of the things we've talked about, and of course there's a great book that you can now get where these things are explained with clarity and wit [laughs] and that's *The Lightness of Being*.

Ginger Campbell: Does itsfrombits.com go...

Frank Wilczek: That goes to the same place, right. There are several different names that go to the same place.

Ginger Campbell: Your book is really good. Do you have any opinions about other books on physics that you think are worthwhile?

Frank Wilczek: Well all Feynman's books are very good. Some of the most recent ones after he died, they are kind of scraping a little, so I would avoid those. But certainly his book about QED [entitled *QED: The Strange Theory of Light and Matter*], *The Feynman Lectures*- those are kind of high level things. But also his *Surely You're Joking* [full title: *Surely You're Joking, Mr. Feynman!*] and *What Do You Care What Other People Think?* Those are great.

Ginger Campbell: I've read those. In fact I've read *QED* years ago, but obviously nothing in it stuck to my brain.

Frank Wilczek: *The First Three Minutes*, Weinberg's popular cosmology book, is very good [full title: *The First Three Minutes: A Modern View of the Origin of the Universe*]. Allen Guth's book about the inflational universe [entitled *The Inflationary Universe*], that's very good.

Ginger Campbell: I enjoyed *Origins*. I didn't like the TV show, but I thought the book was good.

Frank Wilczek: I'm not so familiar with that one.

Ginger Campbell: It was a companion book to Neil Degrasse's *Nova* show and it's actually much better than the TV show, which has got much too much special effects but not enough meat in it, but the actual book is very good at explaining things like how they know that the universe is 14 billion years old.

Frank Wilczek: Very good. Okay well I should look at that one. I didn't know it.

Ginger Campbell: Do you know of any physics podcasts? Because I have a website for science podcasts- I'm trying to recruit science podcasts. I don't know of any physics podcasts other than Astronomy Cast.

Frank Wilczek: I don't know of any that's specifically devoted to physics. I've done quite a few interviews. [laughs] I guess I haven't followed exactly what they were for. You know, of course, Steve Mirsky as you mentioned.

Ginger Campbell: Yeah that's a great show.

Frank Wilczek: But it's not just physics.

Ginger Campbell: They do everything.

Frank Wilczek: That's right. No I don't know of any just devoted to physics. I kind of doubt that there is one, because that would be a tough sell.

Ginger Campbell: Actually Astronomy Cast- she does a lot of physics on there. In fact my husband was telling me, because he actually listens to her show, that she had dealt with some of this stuff. I think some of my listeners are already hooked on her because I interviewed her about a year ago.

Frank Wilczek: Uh huh.

Ginger Campbell: I want to say about your book- I have probably a stack of books that I've bought from Mirsky's podcast and I think yours is the only one I've actually read the whole thing of.

Frank Wilczek: Oh great. Thank you very much.

Ginger Campbell: I spend most of my time doing the *Brain Science Podcast*, which takes up a lot of time reading neuroscience books, and it's hard to find time to...

Frank Wilczek: I'm very interested in neuroscience also actually. So what do you recommend there?

Ginger Campbell: Uh you have to listen to my podcast. [laughs]

Frank Wilczek: [laughs] Oh alright. I just read this one called *Big Brain* [full *title: Big Brain: The Origins and Future of Human Intelligence*].

Ginger Campbell: Yeah I just interviewed that guy in my most recent episode.

Frank Wilczek: But I was a little bit disappointed because I looked up- I did a Google search on this Boskop.

Ginger Campbell: Yeah.

Frank Wilczek: And I'm kind of- it's not, well, to say the least, it's not widely accepted.

Ginger Campbell: Absolutely. Actually I think Boskop is something they put in there to flesh out the book because when I interviewed him we didn't even... I didn't even bring up Boskop. We talked about the rest of the stuff.

Frank Wilczek: It does seem kind of tacked on.

Ginger Campbell: I determined the same thing before I interviewed him. I did the same thing you did- I Googled and realized Boskop- there's nothing there so we concentrated on the real ideas, and he never even brought it up during the interview either. I have a feeling that was one of those- the publisher said, "You need to spice this up with something more attention-getting."

Frank Wilczek: Yes.

Ginger Campbell: And if you take that out, the material is a lot more, is a lot solid.

Frank Wilczek: Is a lot tighter, yeah.

Ginger Campbell: You can find my interview of Dr. Gary Lynch, the author of *Big Brain* at brainsciencepodcast.com. It's episode 48.

Frank Wilczek: Alright great. Well I look forward to listening to that.

Ginger Campbell: So your show is probably going to come out about the first of November.

Frank Wilczek: Alright. And if you want to do a follow-up, I'm perfectly open to that. We didn't touch any of the questions really that you...

Ginger Campbell: I know, I know! I was a little bit intimidated. I thought, "Well I think I might be in over my head." And I thought, "Well what is the basic stuff I really want to know?" And that's where I got those four and then I... but we only barely touched number 1.

Frank Wilczek: But I think we've laid the foundation.

Ginger Campbell: Yes. We laid the foundations.

Frank Wilczek: Alright. Well it's been a pleasure and we'll keep in touch.

Ginger Campbell: Thanks a lot.

Frank Wilczek: Alright.

Ginger Campbell: Bye.

Frank Wilczek: Bye now.

[music]

It was a great honor to have Dr. Wilczek on *Books and Ideas*. His book *The Lightness of Being* is one that everyone can enjoy. You will find links to his website and his Nobel lecture at booksandideas.com. You can leave feedback at the website and at our discussion forum, which is located inside brainscienceforum.com. Or you can send me e-mail at docartemis@gmail.com. Since Dr. Wilczek has graciously offered to return in the future, I would love to hear what questions you would like me to ask him the next time he comes on the podcast.

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Thanks again for listening. I look forward to talking to you again real soon.

[music]

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[music]

-transcribed by Jenine John