Yuan-Ming Lu Describes the Sur...s' Thanos and Condensed Matter

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SPEAKERS

Eva Dale, David Staley, Lu Yuan-Ming

E Eva Dale 00:00

From the heart of the Ohio State University on the Oval, this is Voices of Excellence from the College of Arts and Sciences with your host, David Staley. Voices focuses on the innovative work being done by faculty and staff in the College of Arts and Sciences at The Ohio State University. From departments as wide ranging as art, astronomy, chemistry and biochemistry, physics, emergent materials, mathematics and languages, among many others, the college always has something great happening. Join us to find out what's new now.

D David Staley 00:31

Lu Yuan-ming is an Assistant Professor in the Department of Physics at The Ohio State University. He earned his PhD at Boston College in 2011, and joined the faculty of Ohio State in 2015. He was awarded a National Science Foundation Career Grant in 2017, a five year and nearly half million dollar grant to develop new ways to detect and design topological orders. Professor Lu is a condensed matter theorist, and we'll learn what that means very soon. Welcome to Voices from the Arts and Sciences, Dr. Lu.

L Lu Yuan-Ming 01:05

Hi.

D David Staley 01:07

Let's start with some basics. What is condensed matter in simple terms?

Lu Yuan-Ming 01:12

Yeah, that's a good question. So, the older name for condensed matter is actually solid state physics.

David Staley 01:17

Solid state.

Lu Yuan-Ming 01:18

That sounds more familiar, right?

David Staley 01:19

Yes.

Lu Yuan-Ming 01:19

Let's start in just some material with a solid form, such as table, chair, all kinds of material you have in a word. And I think later people try to expand this area a little bit, expanded into also incorporate liquid into solid. So we call this condensed matter as contrast to you know, air is like uncondensed matter.

David Staley 01:38

So what does it mean, then for a physicist to study solid objects or even liquid objects?

Lu Yuan-Ming 01:42

Yeah, that's a great question. So, in a solid, typically, there is a huge amount of electrons and atoms, which form this whole material. So our goal is to understand the behavior of the huge number of atoms and electrons based on certain tools, such as quantum mechanics, and also statistical mechanics.

David Staley 02:00

Yeah.

Lu Yuan-Ming 02:00

So, this is actually when the number of particles is huge, as huge as 10 to the power of 23rd

So, this is actually when the number of particles is huge, as huge as 10 to the power of 23rd.

David Staley 02:08

10 to the power 23rd. That's 10 with 23 zeros. That's, that's an awful lot, right?

Lu Yuan-Ming 02:13

Yeah, that's awful lot. Yeah. So I guess all you need to know is when the number of particles is larger than a certain number, the behavior may be completely different than what you expect from a single particle. You know, I guess recently, people all watched Avengers Infinity War.

David Staley 02:28

Of course.

Lu Yuan-Ming 02:29

You know, as Thanos gathers seven Infinity Stones, it's already much more powerful than he has one, right? So imagine he has a huge number of them, then the behavior are completely different. Even a change of his mind would actually make things very different.

David Staley 02:43

So what sorts of objects, solid or liquid, are you interested in? What sorts of things do you study?

Lu Yuan-Ming 02:48

Yeah, so we study certain materials, and those materials, our goal is to make those materials applicable to our everyday life. For example, one of the things we pursue is superconductivity. You know, typically when we have conductors, they transport electricity, but in the process of transporting electricity has a huge amount of dissipation, you know, like heating, problem like that. But if you have a superconductor, the resistance of the transport is going to be reduced to a very small amount. So that means-

David Staley 03:18

Not zero, but near zero.

Lu Yuan-Ming 03:20

Yeah, ideally, it will be zero, but in reality is never zero. Yeah, so as long as we can significantly

Yeah, ideally, it will be zero, but in reality is never zero. Yeah, so as long as we can significantly reduce this dissipation, we can significantly also increase the efficiency of the transport and so on. So this would do a lot of good to humans.

D David Staley 03:33

And are there superconducting materials or is it still theoretical?

L Lu Yuan-Ming 03:36

Yeah, there has been superconductor materials. The first one was actually discovered last century, in 19th century. But our real goal is to find a superconductor at room temperature, because currently, the superconductors only exist at very low temperature. Yeah, so that's not very practical. So we want we're looking for room temperature superconductor. So that's one possible thing that we can do. So the other possible thing we can do is to, for example, look for new materials that can store information, and can also operate information. For example, we all know hard drives, right? Drives, which we know everyday in computers, those are based on certain condensed matter phenomena, which people call giant magnetoresistance. This is also what was awarded for a Nobel Prize in 2007, giant magnetoresistance. So using giant magnetoresistance is why you're able to store information in your hard drive and to write and read information on our hard drive. So our goal is to look for some new materials, which also have lower dissipation, allows us to better do this job.

D David Staley 04:34

So right now it's silicon, silicon chips. That's the sort of thing.

L Lu Yuan-Ming 04:36

Yes. Yes.

D David Staley 04:37

And you're looking for the next material beyond silicon.

L Lu Yuan-Ming 04:40

Yes, exactly.

D David Staley 04:41

What, are there any candidate materials that we could be looking at?

L Lu Yuan-Ming 04:44

Yeah, I think one of the very hot topics in our area is something people call spintronics.

D David Staley 04:47

Spintronics?

L Lu Yuan-Ming 04:49

Yeah. So you know, previously we were based most of our technology on electronics, electronics. Basically, we use the electronic current to control things, but right now we want to use property of spins to control properties.

D David Staley 05:00

Spins, actual like, like electrons and things spinning?

L Lu Yuan-Ming 05:04

Yes, yes, exactly. So spinning is the microscopic property of electrons. You know, typically what, you know if you'll see a ballet dancer, if it's spinning, so there is a direction with respect, which is spinning, right, there's some axes of spinning. So he could either spin clockwise with respect to the axis or counterclockwise. So, you know, microscopic objects such as the electron, there's also similar phenomena as spin. So this spin is an intrinsic quantum mechanical property of these microscopic particles, and they can be used to store information and to help us operate on these information.

D David Staley 05:36

Well I want to get back to that in a minute, cause you used the word quantum and it sounds like we're talking about computing, and I want to explore that. But I'm also interested in the other part of your work, topological orders, what what does that refer to? What do we mean by that?

L Lu Yuan-Ming 05:49

Yeah, so topological order is described in contrast to some traditional phenomena, which we know very well, traditionally, when we say a material is ordered, it typically means the material has some property at low temperature, which does not exist that high temperature. For example, if you have a magnet, if you heat up the magnet, a very high temperature, it's not magnetic.

D David Staley 06:10
Oh, I didn't know that.

L Lu Yuan-Ming 06:11
It's just that that temperature is extremely high, yeah. Much higher than our root computer.

D David Staley 06:15
Oh.

L Lu Yuan-Ming 06:16
That's why it's not-

D David Staley 06:16
Really high temperature. Okay.

L Lu Yuan-Ming 06:17
A doughnut, and you have an ant which is sitting on a donut, and he's actually moving on a donut. And you want to ask the ant, can you tell whether you are moving on a donut, or are you moving on actually the surface of an orange or apple? If the ant is only moving within a very tiny area, he's not able to tell whether it's a donut or an apple or something. You imagine they have the same shape. Yeah, really high temperature, yes. But when you lower it down to a certain temperature, you can see the magnet, magnetic moment point to certain direction, right? That's what makes them magnet, material magnetic, right. So that's something we call traditional order. So these traditional orders, they, they have very sharp features that can be detected, for example, the direction or the moment of these magnetic material, right. But in some certain materials are more subtle properties in low temperature, which is not as obvious as the directional moment. So, those properties typically cannot be detected locally. You see, if you have anything more to, if you probe it locally, and just look at one part of it, you can already see where there's a magnetic moment, point to, but in some material, if you locally probe it, you cannot really see it. I guess one example is the following. Imagine you have a doughnut.

D David Staley 07:27
Yes.

L

Lu Yuan-Ming 07:28

Yeah. But-

D

David Staley 07:29

The curve, the curve, you're suggesting. Right. It's called a torus. A torus is a mathematical object that has a hole in it.

L

Lu Yuan-Ming 07:30

Exactly, exactly. But with a donut, to completely explore the whole torus, to be able to see the torus is actually- I'm sorry, the donut is actually different than the apple because there's a hole in the doughnut, right? In the apple- Exactly, yeah, that's something we call topological property. So these topological,they're just like these topological property of donut versus apple, you need some global measure, not a local measure, you'll be able to tell them

D

David Staley 07:57

So, topology refers to the shape of an object or the different properties that the shapes represent?

L

Lu Yuan-Ming 08:02

Yes.

D

David Staley 08:03

Is that fair to say?

L

Lu Yuan-Ming 08:04

Yeah, that's fair to say. Actually in condensed matter physics a topological order, more precisely, they are described as the property of the electron, how the electron behaving in a solid state material. Yeah.

D

David Staley 08:16

Are there particular materials that you look at in this in this area? Are,

L

Lu Yuan-Ming 08:20

Yes, yes. So, I'm currently we are in close collaboration with experimentalists. Although in the physics department, we have a Center for Emergent Materials. Emergent, as I said, will have a huge number of particles, there are some new phenomena which does not exist, we have small number of particles. So, with these experimentalists we are working on certain material, which have interesting topological property. I think one of the most famous example of topological property, which is also a hot topic recently is something people call topological insulator. So yeah.

D David Staley 08:51

Insulator?

L Lu Yuan-Ming 08:52

Yeah, so let me tell you what roughly that means. So typically, we have a piece of material right, it is a conductor or not a conductor, if it does conduct we call it conductor. If it does not conduct we call it insulator, right. But there are certain material which have very strange behavior, where the bulk of the material does not conduct. So the bulk can look like an insulator, but only the surface conducts. So these are what people call topological insulator. And these are some interesting thing we're exploring right now with these experimentalists.

D David Staley 09:19

What are some of the applications or are you concerned about applications? As a theoretical physicist, is it the theory, that basic science that's of interest to you or is it the applications?

L Lu Yuan-Ming 09:30

Good question. So I, myself, is mostly driven by curiosity, but there is indeed very exciting application for this study. For example, togological insulator, as I said, the surface state and the surface state is conducting, the bulk is insulating. And somehow the surface data very, real fast conductors, you know, you can throw in dirt, you can actually hammer the material, but the surface still conduct, no matter what you do. It's very robust behavior. So that's what makes these materials special, make these material, what we call topological, yeah. Just like when you have a doughnut and an apple, you cannot make an apple become a doughnut. Unless you punch a hole, you have to do something really, really dramatic. So here the surface data, also robust properties.

D David Staley 10:11

I said I wanted to get back to the question of quantum, quantum states and computing, the implications of this. So you're working toward the goal of enabling quantum computing?

L Lu Yuan-Ming 10:24

L Lu Yuan-Ming 10:24

Yeah, I guess-

D David Staley 10:26

Maybe we should start with what do you mean by quantum? When we say a quantum, what makes a quantum computer different from the kind of computer in my desktop let's say?

L Lu Yuan-Ming 10:33

That's a great question. So currently, the classical computer, we use something we call bit, right?

D David Staley 10:39

A bit, sure.

L Lu Yuan-Ming 10:39

A bit to store a message. So the bit, it reads either a zero or one, right, just the two possibilities. But you know, quantum bit, which is something we call qbit -

D David Staley 10:50

Qbit.

L Lu Yuan-Ming 10:50

Quantum bit, qbit. Even with just one qbit, there's much more information you can store than just 0, 1. It can be partially zero, partially one.

D David Staley 10:58

Partially zero, partially one?

L Lu Yuan-Ming 11:00

It's just like something you probably have, many people have heard it's Schrodinger's cat. Dead, alive at the same time. Yeah. So, that's much more possibilities. So basically, using a quantum computer, you can store much more information. And sometimes because of the ability to store much more information and to operate on this much more information, you can also do something that is much faster than the classical computer. I think the best known example so far is the factorization of an integer. Like eight is two times two times two, that's yes, yeah. So generally, when the number becomes larger and larger, it's much harder and harder to do factorization, if you write a code on classical computer, and typically that grows exponentially with the number, or the number of unilateral I just say, 1 million. I say, if the number grows from 500 to 1000, you expect the number of time it take for the classical computer solve the problems increase exponentially. And the other half is quantum computer, it only grows polynomially. So that's the power of-

David Staley 11:55

1, 2, 3, 4, as opposed to exponentially.

Lu Yuan-Ming 11:58

Exponentially. Yeah, exactly.

David Staley 11:59

And so the idea that you can do more computing or more calculation in the same area, or you can even get, what, computers that are smaller and smaller and smaller - is that the goal of quantum computing?

Lu Yuan-Ming 12:10

Yeah, that's the goal.

David Staley 12:10

Small or more or both?

Lu Yuan-Ming 12:11

Yeah. Yeah, I guess smaller, smaller and more, exactly, yeah. But I would have to say that I think quantum computer right now is still at a very early age. And, to be honest, we don't know, we're still exploring, this is largely the unexplored area. That's what exactly make this exciting. I think many agencies in US and all over the world are putting a lot of money for the research in quantum computer, is because we don't know, for example, a much more examples where quantum computer is actually better than classical computer. Like the factorization example is one of the few example where we know that quantum computer is definitively better than classical computer. But we don't know too much about it.

David Staley 12:50

David Staley 12:50

And my understanding is, at quantum levels, we still have lots of uncertainties, there's a lot of things we don't understand what happens at that sort of quantum levels. Does that happen here? When we start working about quantum computing that we're just going to reach a level, a stage, we're just not going to have an understanding of the computing that's occurring?

Lu Yuan-Ming 13:06

Yeah. So that's a really good question. Indeed, even internal quantum mechanics are many phenomena which we do not understand before. For example, the topological insulator is something which was only proposed 10 years ago, we didn't notice before.

David Staley 13:18

Oh, wow.

Lu Yuan-Ming 13:19

It's pure quantum mechanical phenomena. So, and, the discovery of topological insulators also allows people to propose a new way to do quantum computing. You know, previously, part of quantum computing, were mostly based on something for example, as superconducting qbit, we use superconductor to build these qbits. But right now, people have proposed new ways to build a computer based on say, topological insulators, and some other more topological ordered system. So these quantum computing, are what people call topological quantum computer, so they are different from the usual quantum computer in the sense that they are immune to the decoherence.

David Staley 13:54

Decoherence, meaning?

Lu Yuan-Ming 13:56

Very good question, so decoherence, meaning, usually if ever qbit, the qbit, will have to come up with the environment, right? Yeah, electrons will talk to the light, and so on, they have interaction with light, so that light will decohere the qbit. So if you store some information, after a long time, you're gonna lose that information. Because the information is going to be entangled in the environment. However, in a topological quantum computer, the information stored is very robust. They don't actually decay easily with the environment. So that's the power of these topological quantum computers.

David Staley 14:26

But it, it sounds like it's still some time before I'm gonna have a quantum computer on my desktop or on my, my phone or something,

Lu Yuan-Ming 14:32

I guess, yeah. Fair enough, yeah.

David Staley 14:35

So we've been having an interesting, complex theoretical conversation about qbits and about condensed matter. But I also understand that you work with students at Innis Elementary through the Center for Emergent Materials.

Lu Yuan-Ming 14:49

Yes.

David Staley 14:49

Their Scientific Thinkers program. So you work with elementary kids?

Lu Yuan-Ming 14:53

Yes.

David Staley 14:54

Tell us about that experience.

Lu Yuan-Ming 14:56

Yeah. So the Center for Emergent Materials is an NSF funded agency so we do both science and outreach. So on the outreach activity, many of it is conducted together with Innis elementary school. So Innis elementary school has many underrepresented kids. So what do we want to do is to teach them science at an early age. So we start from doing certain things, regular things. For example, every week, some students have gone to come there, they will do certain demonstration with the kids. And the kids is gonna learn some kind of basic physics from the demonstration and so on. So we also have an annual Science Day, and the Science Day, lots of people volunteer and go there. And then, also do these demonstrations, spend half a day or the whole day with the kids, and so on. So, for example, I was there last year on the Science Day and spent half a day with the kids. I have to say, it's very exhausting behavior.

David Staley 15:46

D David Staley 15:46

Exhausting. Exhausting, I can imagine kindergarteners.

L Lu Yuan-Ming 15:49

Kids is always so energetic compared to us, I have to say, they're so energetic. They just have so many questions, yeah. And really, is the testing of your expression ability when you talk to kids. Yeah, it's a huge challenge. But it's also a lot of fun, yeah. So I think my goal there is to try to do some new demonstration for the kids, something related, for example, to topology, yeah, tell them difference between donut and apple, things like that.

D David Staley 16:16

And do kids get this do you find? I mean, do they, do they understand topology, do they understand condensed matter?

L Lu Yuan-Ming 16:24

Well, we're still trying.

D David Staley 16:27

And do you work at all, do you discuss qbits or quantum mechanics with them?

L Lu Yuan-Ming 16:32

Not yet. But, we were actually thinking about some new project that we can perform in the future.

D David Staley 16:37

That's fantastic. The idea, again, is to, is to get young kids interested in science, get them thinking about about science. Usually, the interviews that I have done with your colleagues in the sciences, they usually work as part of a lab or they, they run a lab, they have postdocs, and graduate students. But you're a theoretical physicist, do you have a lab?

L Lu Yuan-Ming 16:59

Not really.

D David Staley 17:00

You don't really have a lab? So how do you work then, if not through a lab?

Lu Yuan-Ming 17:05

Yeah, so I actually have the office. So you may call my office my lab, and so on. I think the most useful and most inspiring way for me to work is to talk to people, discuss with people on various kinds of things.

David Staley 17:20

Kind of like what we're doing!

Lu Yuan-Ming 17:21

Yeah. For example, we have collaboration with both people from chemistry department and from mathematics department, as you can see, if, if we are talking about topological order, mathematics is definitely very useful.

David Staley 17:32

That's right.

Lu Yuan-Ming 17:32

So that's why I'm also collaborating with some other mathematicians, you know, and also chemists, they can discover new materials, we can realize these topological order things we propose. So we also work in collaboration closely with the chemists. And I also have like regular discussion with my students. It can either be scheduled or spontaneous. Through this discussion, we have some new spark of ingenuity during the discussion that shows off, we have some new idea. And then we can start to work on separately, and then we can discuss again, and so on.

David Staley 18:04

I assume that working through the Center for Emergent Materials, you must work with engineers as well, mechanical engineers- Those who have an interest in the properties of materials.

Lu Yuan-Ming 18:09

Yes. Yes, yes. So when working with these engineers, what we do is that we propose some kind of concept, that then may be interesting. And we can perform some calculations, they sometimes perform some calculations, and then we can talk about how those calculations can help us materialize what our concept and so on. Yeah, so this is actually a very successful pattern of collaboration in the Eenter of Emergent Materials. We have chemists, physicists, we also have engineers from the material engineering department. So we carry around various different kinds of things and new ideas emerge. Yeah, new material has been discovered.

D David Staley 18:49

Well, I was really struck by something you said earlier, that you're driven as much by curiosity as by, by application. And do you find that in your work? Are you driven more by what we might call basic science versus applied science? And are there pressures on you to, to work more in the area of applied science?

L Lu Yuan-Ming 19:09

That is a fantastic question. I should say, right now, I don't feel too much propelled to do things that I don't, I'm not willing to do. In fact, I really enjoy the collaboration with people with more applicable dealers. But I have to say deep down, I think I'm driven more by curiosity. Yeah, what I believe to be really interesting phenomena, new phenomena, that inspires me to work on it. For example, last year, a Nobel Prize was given to physicists working on topological orders generally. So for all these, recipients of the Nobel Prize, their work, I don't think directly impacts the industry or human work, human life so far, but they really enjoy what they do. And they are driven purely by curiosity. I will think about that as a successful pattern for scientist to contribute to the society.

D David Staley 20:00

Well I think if you're working at a quantum level, you must be at the absolute forefront of sciences, you must be. So what's next? What are your next research ideas or research goals?

L Lu Yuan-Ming 20:11

Yeah, my, my next idea is to I guess, generally there are two parts. One part is to understand new topological phenomena in condensed matter physics, which are robust against, you know, like impurities and other stuff in the material, some robust properties, which we call topological properties. That's one thing. The other thing is we try to understand the entanglement in quantum systems.

D David Staley 20:33

Entanglement?

L Lu Yuan-Ming 20:33

Yes.

D

David Staley 20:34

I understand the word. What's entangled, for a physicist?

L

Lu Yuan-Ming 20:38

Yeah, for example, earlier I was talk about qbit. Like I said, the single qbit is entangled with light, because they interact with light and together they form a whole new quantum matter. So they start to entangle, so entanglment is actually everywhere, you know, we're talking we start to entangle. So, in quantum mechanics, I think that one of the current front is how do understanding entanglement mainly by the system, we have a huge number of particles, how do they really entangle with each other? For example, even measure part of the system? Can you get some information from other part, and this information, this knowledge, I think, also greatly helps us to understand quantum computer and so on and to propose new quantum computing protocols and so on.

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David Staley 21:19

Lu Yuan-Ming, thank you.

L

Lu Yuan-Ming 21:21

Thank you.

E

Eva Dale 21:22

Voices is produced and recorded at the Ohio State University College of Arts and Sciences Technology Services Studio. Sound engineering by Paul Kotheimer, produced by Doug Dangler.