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CU ON THE AIR

PODCAST

November 2019

Ana Maria Rey
Professor

Theoretical Physicist and Fellow at JILA
University of Colorado Boulder

Hosted by:
Ken McConnellogue
CU Vice President of University Communications

Ken: Today on CU on `the Air we're talking with CU Boulder Professor Ana Maria Rey. She's a theoretical physicist and a fellow at JILA. Rey has earned multiple awards for her groundbreaking research, including the coveted MacArthur Genius Fellowship and the Presidential Early Career Award for Scientists and Engineers. She earned the Alexander Cruickshank Award in 2017 and 2019, and became the first Hispanic woman to win the Blavatnik Award for Young Scientists. Professor Rey studies the interface between atomic, molecular and optical physics, condensed matter physics, and quantum informational science. Welcome to the show, Professor.

Anna Maria: Oh, thank you very much. It's a great pleasure for me to be here today.

Ken: So for someone like me, who has very little... okay, let's say no knowledge about quantum physics, how would you describe the field?

Anna Maria: Well, actually the field describes the behavior in general of the microscopic world. It happens that in the quantum world, particles can be copied, behave like sub particles, but also particular can behave as a wave. What characterize the quantum world is where particles are separated. There is something that is called a wavelength, and when the wavelength is larger comparable to the separation between particles, then that's when two mechanics start to rule. So this situation, generally we can make it happen by cooling down the particles, making them very cold, and when they are very cold then the wavelength grows. Therefore, the quantum part, the quantum behavior, it start to rule out their properties. That's what we have done here at CU for many, many years. We have learned how to cool down particles, and how to use this cool system to explore the properties of the quantum world.

Ken: I'd imagine that requires some specialized equipment.

Anna Maria: That's true. We know that we have had a few Nobel Prizes in physics. These Nobel Prizes were the manifestation of the importance of quantum physics. I mean, we are leaders in the field exploring this type of behavior. Eric Cornell, for example, Carl Wieman were awarded the Nobel Prize in 2005 for teaching us how to cool those particles. Here at CU we have very tight connections with NIST. People from NIST are the ones that pioneered this process of cooling down the particles via lasers. Another Nobel Prize, in this case Bill Phillips, William Phillips, and that was before the Nobel Prize by Eric Cornell, that tells how we can use lasers to enter the ultracold world and use that for the exploration of the quantum mechanics.

Ken: You've won several awards yourself, as we mentioned at the outset, but I'd imagine it's quite inspiring and maybe a little competitive to work with Nobel Prize winners and people like that.

Anna Maria: Yeah, this has been an inspiration. Actually, Bill Phillips, the first person, I mean he won the Nobel Prize for cooling and trapping particles with lasers. He was the person who inspired me. He was not at NIST Boulder but at NIST Gaithersburg in Maryland. I did my PhD at the University of Maryland, College Park, and it was hearing him, the story that he told us how he accomplished that, that maybe made me immediately interested in atomic physics in ultracold atoms. That's how my career started, inspired by him.

Ken: This is complex stuff, as you talked about, but your interest in it was sparked at a very early age. How did that happen?

Anna Maria: I have loved math, and I have loved the idea of using math to describe how the world behaves. I think since I was in sixth grade, I was fascinated by writing an equation, and predicting what was going to be the speed, of what ball when you throw it. This classical aspects of physics fascinated me since early stage of my career, my life. In high school I was asking my high school teacher to teach me more physics because what was taught in the school was not enough for me. This was the starting of my career. I studied physics in Colombia when at that time it was not popular at all. I mean, my mother was completely against me studying physics because, I mean, what I was going to do after finishing that work? I mean, she was concerned. There were 5 people in the class, whereas if you go to an engineering class, there were 100 people. But I use this curiosity that has always inspired me, and I have followed this curiosity all my life.

Ken: Yeah, curiosity is a wonderful trait. So through your research you developed a new understanding of atomic collisions, and it has direct applications to timekeeping and quantum stimulation. How does that happen?

Anna Maria: Yeah, so actually here at JILA, at the University of Colorado, we have the most precise atomic clock in the world. This clock, an atomic clock, is a clock that is made by atoms and light. So you think about that clock, you can think, "Well, it's just made of two things, something that that ticks, and something that calms the ticking."

Ken: I thought you were going to say something that ticks and something that tocks.

Anna Maria: So in the atomic clock what ticks is light, an electromagnetic wave, and what calms the ticking is the atoms. So JILA and the group of Jun Ye have developed the most accurate clock in the world. It's very accurate because these atoms, the type of atoms that it uses tick very fast, very, very fast. It's a very precise... Yeah. You can imagine it's a very precise ruler because it has very, very fast ticking, very precise ticks. The problem is that to prevent any systematics of the clock, it has to trap the atoms very tightly. Why? Because you know about Doppler shifts. So we do a train. If it's approaching to you, you're going to hear different frequency of it. So it's moving away from you, and the motion can completely change the frequency that you perceive.

Anna Maria: It's the same in the quantum world. If the atoms are moving, then they're not going to make a good clock. So we need to trap the atoms very tightly and frozen them. That's why we need to cool them down, to avoid their motion. The problem is that when you trap them and control them, if you trap any atoms in the same position, they start to bump into each other. This bumping into each other is bad for clocks because then the ticking of the atoms is going to also depend on how many atoms are in the clock. That is not good. You need a clock that is universally the same ticking here or in China, and these collisions were one of the most detrimental effects in the clock. So what I did was trying to model how this collision happens and try to operate in averaging where these collisions could be suppressed.

Ken: So what are some of the applications? What's the significance of the most precise clock in the world?

Anna Maria: Well, of course timekeepers are very good for navigation. So all of us are aware of the GPS, and the GPS operates with satellites, and each satellite has four atomic clocks for their operation. So, of course navigation. Timekeeping is one of the most important applications of clocks, but interestingly these clocks are becoming so precise that they're opening us to explore the quantum world itself. This is interesting because the new technologies. I mean, we know that quantum mechanics was key in current technological developments. For example, you think about the transistor or the laser. All of these were developed thanks to the understanding of the quantum mechanics, but we are reaching a point where this understanding the quantum world is not enough.

Anna Maria: At some point we need to learn more about these quantum properties. We have not explored these fascinating features of quantum mechanics, but they are very hard to understand. What the clock is going to allow is to open a window to understand this quantum behavior that is very complicated. Then if we understand it, we can use, for example, to develop new materials. I mean, we know about semiconductors, but what we want now is to develop new type of materials that have advanced properties that is beyond what nature give us by default. We can construct new computers that can overcome the capabilities of the most powerful super computer that we have so far because this is called quantum computer, and have capabilities that we have never dreamed before. So these atomic clocks are bridging what we know now to what we want to build in the future. That's why it's so fascinating.

Ken: Interesting. One of your discoveries led to tying quantum knots to an optical clock. What does that mean?

Anna Maria: The quantum world is weird. Yes, there are many things that happen that we don't understand, and one of the words that are keys that, for example, if we want to develop a quantum computer or advanced material, is the phenomenon of entanglement. Entanglement means we connect the atoms in some way. An atom cannot be described by itself. It has to be described by the presence of the other atom, even if they are far away. So what one of the things that we are trying to understand is how collisions, even though are detrimental, are very bad, can nevertheless help us if we control them to connect the atoms, and then use these connections to improve further the precision of the clock. We are trying to understand them, and one of our main goals is try to have a new generation of atomic clocks that operates using entanglement to enhance the precision. So it's coming awfully soon.

Ken: Yeah. How do you control collisions?

Anna Maria: When we have clocks, we need a two level system. The clocks measure a frequency, and a frequency is the energy difference between two levels in the atom. So the way that we have learned to control collision is that we have some atoms in the ground state, some atoms in the excited state, and the collisions actually depend... We figure out that the collision rate depends on how many atoms you are in the ground, and how many atoms you are in excited state, in a nontrivial way because in the quantum world you can have superposition. So an atom can be in the ground and excited state at the same time. Ken: Wow. So you talked about how much we don't know about this field, and your research has led in some different avenues. What are some of those?

Anna Maria: Well, one of the big mysteries that we have is that we know how the microscopic world behaves. I mean, we know that it is rule out by quantum mechanics, and we have a lot of evidence that this is the case. We know also that we live in a world... Our universe is macroscopic, and we know that there are objects like black holes. We know that Einstein told us that there is general relativity that describe the behavior of black holes, but at the moment, a connection between quantum mechanics and general relativities is missing. We don't understand how to unify these two worlds. So something that we are trying to do is trying to see how we can use, for example, these clocks to connect... These clock are so sensitive that at some point we should be able to send these clocks into space and try to feel these ripples of the space time, try to understand the importance of gravity. But because they're microscopic objects, they should allow us also to understandand appreciate the further connection between the microscopic and the macroscopic world.

Ken: Interesting. You are also interested in degenerate Fermi gases and Bose-Einstein condensates. What are those?

Anna Maria: Yeah, so it happens that when you go to the quantum world, there is something that matters that is called quantum statistics. It means if you look at electrons and protons, they have an intrinsic magnetic moment. It's called spin, and because electrons, and protons and neutrons form atoms, depending of the number of these compounds, then your atom can have even or odd spin, kind of. It happens that particles that have an odd, have a spin behavior. They behave like fermions, and the particles that have an integer spin, they behave like bosons. That means that they have very radical different behaviors. Bosons are very friendly atoms, all want to be together. They want to go to the same quantum state. At JILA we learned how to cool down bosons and form new state of matter.

Anna Maria: On the contrary, fermions are the weird guys that they don't want to be together. The two fermions cannot be in the same internal state. They really cannot by principle, so their properties when we cool down are completely different. In fact, Debbie Jin, unfortunately she died already almost three years ago, already. She was the first person who taught us how to cool down fermions, too. So they're very different objects, but now we are trying to explore the role of quantum statistics, even in clocks. So in clocks actually it happens that we need these antisocial guys. We need fermions because the fermions do not collide as often as bosons. So the new generation of atomic clocks, or the most precise generation of atomic clocks, operates with fermions. It's called quantum statistics, and rules out the behavior of the quantum world. It's so important that we take advantage of quantum statistics to make the system behave as we want.

Ken: It's good to know that the quantum world has friendly and not so friendly atoms. Sounds much like our world.

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Anna Maria: Yeah.

Ken: So we mentioned you've received a lot of awards, including the Blavatnik award. How do these awards have an effect on your work?

Anna Maria: Well, people cannot think that these awards are only given to me because that's not true. I mean, the awards are given... All what we have done here at JILA has been in the consequence of joint collaborations. I collaborate very closely with the atomic clock and Jun Ye's experimentals. Something that is important is that this type of awards recognize the importance of having synergy. I mean, it's really what we have accomplished here is just because of this tight collaboration.

Anna Maria: So that's one of the first positive outcome of this award is that to make people realize how important is this collaboration for us, and to motivate people to continue, or my students to keep these type of collaborations. My students, my postdocs have been key in all the developments that we have had in my work. I mean, they are aware that it's not only recognitions to my work. It's recognition to their work because it's thanks to them that we have done what we have. Yeah, so I think it's important because it's acknowledging people of the work, the fantastic work, that they have done.

Ken: So who are your students, and what kind of work are they doing?

Anna Maria: Well, they are CU students, and they're in the physics department, although I have one in applied math department that is great. What they do is that they're training atomic physics, there are theories, because I do theoretical work, but they learn how to interact with experimentalists. So they learn how to sit in joint meetings and not only do calculation, but do a calculation that is relevant to an experiment by sitting with experimental partner, and discussing together what are the parameters that they need to put the theory to make it relevant for experiments. So they are very smart graduate students that have learned the importance of synergy, and they are really making big advances in our understanding of the quantum world. Ken: Yes.

Anna Maria: We cannot take a piece of paper, and write, and solve. It really involves massive calculations, and they have learned how to develop very advanced numerical techniques to actually carry them out. We have a very good cluster at JILA, and they daily take advantage of all these computing capabilities.

Ken: Where do they typically go after they leave here?

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Anna Maria: Well, most of them want to continue in academia, so they do postdocs. I'm relatively new so I don't have too many people that have graduated, but most of them have started in postdocs positions to continue their research. Of course, I want them because I said also I have fantastic postdocs that help me teach and to work with the grad students. My group has kind of half component of postdocs, half component of grad students.

Ken: So tell us about the Rey Theory Group.

Anna Maria: The Rey Theory Group is fantastic. At the moment we have about 15 people. We have in general on average 5 postdocs, like 10 grad students, or 8 grad students. We have joint meetings, but also we have personal meetings. I discuss with each of my group members an hour per week. Yeah. I mean, if you go to my webpage, would you identify the names of the great people that are now, but also the great people that had been in my group before. What I say is that I'm very grateful to have such a fantastic group of students working in this topic.

Ken: What's your primary project now? What are you focusing on?

Anna Maria: Well, it's hard to say a single project because here at JILA we have a few fantastic experiments that guide my research, so maybe I can mention a few.

Well, of course the atomic clock in collaboration with Jun Ye lab is one of the priorities. There is what is called a cavity QED experiment, so atoms interacting with light in a cavity, and this experiment is by James Thompson. We are very excited on all the developments that have been in his lab. Jun also have a group working on molecules, so actually JILA has been the first group in the world that is able to cool down molecules to the quantum degenerate regime. So we are working with Jun, trying to understand the behavior of these more complex objects that are molecules. In addition, we have very tight collaboration with the NIST group.

Anna Maria: Actually, Dave Wineland is another Nobel Prize, and he got the Nobel Prize because he taught us how to control and manipulate ions. So atoms are neutral, but ions are of charge, and they have unique properties. They have shown to be ideal for creating these quantum computer, as ideal possibility or set up for creating a quantum computer. So I'm working very closely with the group of John Bollinger that is trapping... I mean, most of the trap ion experiments so far are just a few... between one of a few ions. John Bollinger has a setup that can trap like 200 or even 500 ions in a trap, so making it really many body. Actually, it's interesting. We have been thinking how we can use this ion rate to teach us about black holes. I mean, it's a dream, but-

Ken: Wow.

Anna Maria: ... this is one of the directions that we are working on. The interesting part of being at theories is that you are not in constraint to working with people at CU. I have very strong collaborations with people working at University of Toronto, and we have collaborations with people working at University of Innsbruck. We have collaboration with people working at the University of Paris, so I cannot single up a project. It's really many, many different projects that... but all of them in some way related because everything is quantum theory.

Ken: You're a busy woman.

Anna Maria: Yeah, yeah. Yes, is busy but exciting. That's-

Ken: Where do you see the field going in the next 5 or 10 years?

Anna Maria: Even though quantum mechanics has been keen developing transistors, la sers, all of these so far is what we call the first quantum revolution. I mean, it takes advantage of the quantum world, but at a very reduced level because it's like take advantage of individual particles. I mean, but what we are trying to face now is what is called the second quantum revolution, where we are learning not only to control individual atoms, but a race of atoms interacting to each other, and entanglement. Entanglement is the key. There has been a lot of interest around the world. For example, even the US government is interested in investing a lot of funding on quantum technologies. At CU, we have a new center, quantum center as they call it-

Ken: Right.

Anna Maria: CUbit center. So what I think is exciting is we can really start to take advantage of, explore these properties that are accessible, but still not understood of the quantum system for advanced technologies, including more precise sensors, more advanced materials, and ultimately the quantum computer. I think that we are on exciting... It's very exciting, the developments that will happen in the next few years.

Ken: Did you ever imagine when you were a young girl in Colombia, and interested in mathematics, and curious about the world, that you would be doing what you're doing today?

Anna Maria: Well, according to my father, he told me that I always told him that I wanted to become a nuclear physicist. Of course, I didn't have an idea of what that mean at the time, but I mean, I'm an atomic physicist. So I didn't dream, but apparently I knew in some way or not. I mean, I'm very grateful. The world has given me enormous opportunities. I mean, I'm one of the few Colombian people that are here. Of course, I work very hard, and this is always what I tell people from Colombia. I mean, you have to dream high and try to make your dreams come true, but for that you need to really invest time and work. It has been a great opportunity to come to the US and not only be exposed to great physics, but also great colleagues, and great students. Yeah, so I feel really lucky.

Ken: Are your accomplishments recognized in Colombia?

Anna Maria: Actually, yes there are. This year the president of Colombia wanted to get advice on how to plan a science and education in Colombia for the next 25 years. He created a commission, a committee he calls [foreign language 00:26:32]. In English is like Wise Committee, Wiseman Committee, trying to help him guide the future for Colombia. I am one of those people, so it's nice. I have been traveling to Colombia often, and trying to interact more with the government, and with the universities, trying to see how we can actually help Colombia invest in science and education. At the moment, it's not their priority. I mean fundamental researchThere are other priorities that more urgent, but it's very important that countries like Colombia realize that fundamental research is the key for future developments.

Ken: Yes. Well, it's quite an interesting journey from Bogota to Boulder. We're glad you're here and appreciate the work you're doing. Professor Ana Maria Rey is our guest today. Thank you so much for being with us.

Anna Maria: Thank you very much. It has been a pleasure.