QUÂNTICO

Episode 05 - COHERENCE SENDS ITS REGARDS

*"Italic":*Excerpt pseudoscience speech

[in brackets]: sound effect

OPENING ************************************

[intro - bass]

Leo - Okay, imagine a pendulum.

Lu - Do you mean a hypnotist's pendulum? Like a pocket watch dangling from a chain? [rapid ticking noise]

Leo - No, it doesn't work with this one. It has to be a pendulum with a rigid rod, the kind that passes from one side to the other in those wall clocks, you know? That we see in old movies. [slower and more low-pitched tic-tock, tolling bell]

Lu - Okay, I imagined it.

Leo - Okay, now forget the clock and just keep the pendulum. Imagine that the top part of the pendulum rod is fixed to a wall. Now, what happens when you lift the bottom and release it?

Lu - What do you mean?

Leo - What type of movement does the pendulum make?

Lu - It keeps going from one side to the other.

Leo - Forever?

Lu - No, I think that over time it will lose strength, right, until it stops completely. [pendulum swinging until it stops]

Leo - Well, when we describe this pendulum mathematically, considering the length of the rod, the force of gravity, air resistance, etc., this position in which the pendulum eventually stops, at rest, we can call it an equilibrium position. Furthermore, in this case, we say that this is a position of stable equilibrium, because every time the pendulum is in this position and we disturb it, you know, we go there and give it a flick, it oscillates, oscillates until it loses strength and returns to that same resting position again. [oscillation until it stops]

Gláucia - Yes, but there is another position, besides this one, in which the pendulum also remains still.

Lu - What do you mean?

Gláucia - If you carefully position the pendulum vertically, but upside down, as if it was doing a handstand, it will also stay there.

Lu - Hmmmm. So that's why it couldn't be a pocket watch.

Leo - That's why the rod had to be rigid. This position, pendulum in handstand, is also a position of equilibrium for the system. But in this case it is not a stable equilibrium: if there is the slightest disturbance in this pendulum, if we blow [blow], it already falls and oscillates until it stops at the bottom [oscillation until it stops].

Lu - Okay, but is this pendulum quantum?

Leo - Quantum? No, it's a normal pendulum, from a wall clock.

Lu - So why are you talking about him?

Leo - Because the big question we're going to try to answer in today's episode is: why don't we find quantum phenomena in our daily lives? And the answer is a little like this pendulum situation. The classical world, which is what we see in our daily lives, is as if it were a pendulum sitting still, down there. It's a point of stable equilibrium: whenever we leave this classic world a little bit [flick], we'll come back to it soon [oscillates until it stops]. The quantum world, where we find quantum phenomena, is like the pendulum upside down, balanced somewhat precariously. It's as if the quantum world were a point of unstable equilibrium, then any breath [blow] already makes it fall back to the classic world [oscillates until it stops]. In other words, the conditions for these weird quantum things that we have been talking about to happen are super specific and super fragile, difficult to sustain for a long period of time.

Lu - I'm Luciane Treulieb, journalist and scientific disseminator at the Federal University of Santa Maria.

Gláucia - I'm Gláucia Murta, physicist and researcher at the University of Düsseldorf in Germany.

Leo - And I'm Leonardo Guerini, mathematician and professor at UFSM. This is the podcast O Q Quântico. [bass] Today, in the first block we will talk about isolation and what Darwin's theory has to do with quantum. In the second block, we will answer whether the moon is in the sky when no one is looking. And in the third block we talk about the relationship between plant photosynthesis and bird migration with quantum theory. Come with us, as Episode 5 is starting: Coherence sends its regards.

[cat]

BLOCK 1: ISOLATION AND DECOHERENCE **

Gláucia - As we have been saying for a few episodes, quantum theory emerged when experiments began to show that unexpected things happen when we study the behavior of photons, electrons and atoms.

Leo - These quantum phenomena only began to appear at the beginning of the 20th century, partly because before that we did not have enough technology to access and manipulate such small systems. In fact, it was only around that time that we began to have evidence that matter was actually made up of atoms and the existence of the photon and electron.

Gláucia - It was important for technology to advance enough for us to be able to work with these very, very small objects, or systems, because an essential factor in being able to observe superposition and other quantum characteristics is that the systems are well isolated from everything around else. Isolation is a very important concept that will appear a lot throughout the episode, but it is basically what you imagine: leaving a system or object isolated, that is, without interacting with anything, neither another system nor even the light.

> **Barbara Amaral:** So you can have things super microscopic but, if it interacts with the environment in certain ways, its quantum characteristics are over.

Gláucia - This is Bárbara Amaral, Professor in the physics department at the University of São Paulo. As Bárbara says, there is no point in carrying out experiments with carefully prepared electrons if, during the experiment, these electrons mix with other electrons, or atoms, or photons, or anything else, in a messy way.

Leo - So working with these very small systems is useful for that reason, because we can have greater control and isolate these systems more easily. But as science and technology progressed, more sophisticated techniques were developed to protect quantum systems from this interaction with their surroundings.

> **Barbara Amaral:** And I think that is precisely why nowadays people are able to observe these quantum phenomena with molecules that are already large.

Leo - As we have already said here, the double slit experiment was initially carried out with photons, then electrons, then atoms, then molecules... so these quantum effects were confirmed for increasingly larger systems, even if still very small.

> **Barbara Amaral:** It's a stretch to say that it's a macroscopic system, right, because it's still a molecule with a few dozen atoms, but from the point of view of what was observed a few years ago, it's a big system, right, and precisely because the tools of control of these guys' interaction with the environment are much better today than they were a few years ago.

Lu - Okay, but what is the biggest thing on record that has quantum characteristics? Off the record, you had mentioned that there was a recent experiment that broke this record, right?

Leo - Well, this interview with Bárbara took place in mid-2022, and, in April 2023, an article was published in the Science journal, in which a group of researchers from ETH, which is a Federal university in Zurich, Switzerland, managed to create a superposition with the biggest physical system to date.

[pause]
Gláucia - Just remembering, in the last episode we talked a lot about superposition of trajectories, which is a kind of combination of different states that a quantum system can have. In the case of the double slit experiment, the electron may be in a superposition of passing through the left slit and passing through the right slit. But superposition doesn't just happen with trajectories, in fact we can have superposition of any property of the system.
[play]

Leo - The experiment from the ETH researchers involved a sapphire crystal connected to a superconductor circuit. We won't go into details about superconducting circuits and the experiment itself, but it was something much more sophisticated than the double slit experiment, for example, which we explained here.

Gláucia - Bringing some general information, this sapphire crystal weighed 16 micrograms, which seems almost nothing, right, but this represents a mass trillions of times greater than the mass of the largest system that had previously been placed in superposition. In fact, this crystal is visible to the naked eye, despite being very small, about the thickness of a strand of hair.

Lu - Okay, but then, unlike what Bárbara said, you can call it macroscopic, right?

Gláucia - The crystal itself is macroscopic, true, but that doesn't mean that the researchers were able to see the superposition with the naked eye, and this is the case for two reasons. Firstly because, in technical terms, what was placed in superposition were different vibration modes of the crystal structure, which we will not explain here.

Leo - But what is important for us is to know that this vibration mode of the crystalline structure is a property of the crystal that cannot be visualized directly, which is different from the position or trajectory of an object, for example.

Gláucia - And the second reason why we don't see the superposition is because, even if it were a superposition of positions, we can only see an object if our retina captures the light that was reflected by that object. It's that story, I'm only seeing this microphone in front of me because there are a bunch of photons coming out of the lamp here in the room, hitting the microphone and being reflected towards my eye. So being able to see something with the naked eye means that there are a lot of photons hitting that thing and then being detected by my eye. If we were seeing the crystal at the time of the experiment, this interaction with the photons would completely mess with its state, and that would end the superposition.

Lu - So does this mean that we will never be able to see a system in superposition with the naked eye? This is impossible?

Leo - It depends on what you call "see". In a way, when we see the interference pattern in the double slit experiment, we are witnessing that in fact the system was in superposition, now if "see" refers to directly observing, with our own eyes, the position of this object, then quantum theory, in its current form, says that this is not possible. And this could be explained as an isolation problem, since everything indicates that there is no way for a macroscopic object to remain in superposition after interacting with the environment around it, or in this case, with enough light for us to actually see it with the naked eye.

Gláucia - We talked about this with Marcelo Terra Cunha, who is a Professor in the department of applied mathematics at the state university of Campinas.

> **Marcelo Terra Cunha:** And the point is that isolated or not isolated are very different things, they are inherently different things, and then a little bit of non-isolation is enough to accumulate big differences for the isolated case.

Leo - It's as if this little bit of "non-isolation", as Terra said, somehow "dirties" the quantum characteristics of the system.

> **Marcelo Terra Cunha:** And this dirt, this noise, is what hinders us from maintaining quantum phenomena down to the macroscopic scale. But getting in the way, doesn't mean prohibiting it, right? It just means it's a lot of work.

Leo - It takes more work, because the larger the systems, the more difficult it is to protect them from interaction with their surroundings, and the faster they lose their quantum characteristics. This means that the larger the system, the smaller the time window that we have to detect and take advantage of these quantum phenomena, as Bárbara points out:

> **Barbara Amaral:** And then it is clear that scale will play a fundamental role because the larger your system, the more coupled it will be with the environment, the more it will be subject to this loss of quantum properties, so to speak.

Lu - Okay, let me see if I understand something: actually, quantum doesn't just have to do with microscopic things, right? I mean, not directly? Do we only talk about atoms and other super small things because those are the things that are easy to isolate?

Leo - Right, quantum theory is not restricted to very very small scales. What happens is that the conditions for quantum phenomena to happen are very restricted.

Gláucia - We usually think about photons and electrons when we talk about quantum, but not exactly because they are microscopic, but because these are the systems that we can isolate, that is, that we have enough technology to protect from interactions with the environment. Rafael Chaves, who is a Professor of physics at the Federal University of Rio Grande do Norte and a researcher at the International Institute of Physics, reinforces this point about the size of the systems.

> **Rafael Chaves:** Why don't I observe this if I'm going to grow this system in size? Now, instead of talking about one electron, I talk about two, three, a hundred, a thousand, maybe a million electrons or maybe a cat, or maybe a person. Well, because the larger the physical system in question, the greater its interaction with the environment that surrounds it.

Gláucia - In other words, there is no limit in size that separates the quantum world from our everyday world. We cannot make a division like [radio] "if we are talking about an atom we are in the quantum regime, if we are talking about a cat, we are in the classical regime". What does exist is an isolation problem.

> **Rafael Chaves:** And then, finally, to go into more details. We have to talk about what we call the theory of decoherence, which is what explains the transition between this exotic, weird world, which is the quantum world, and the old-fashioned world, which is the world we live in today, right.

Leo - As Rafael said, the technical name for this process of loss of quantum properties is [eco] decoherence.

> **Rafael Chaves:** So this classical-quantum transition, which is explained by this theory of decoherence, which basically tells us that the larger the physical system is, the faster its quantum properties are lost. It is what explains the fact that we do not observe quantum phenomena on the scale that we're used to.

Leo - When we talk about quantum computers, for example, an important property is the time in which the system can maintain its quantum characteristics, which is called coherence time.

Gláucia - Here, be careful not to confuse “coherence”, in the expression “the coherence time”, with “decoherence”, which is a single word.

Leo - So when we see some photos of quantum computers on the internet, like those being developed by companies like Google and IBM, most of the time what we are seeing is basically the cooling system of these computers. These very low temperatures are important to keep the system practically in a vacuum, and therefore prevent other particles from being there to “dirty” the quantum properties and disrupt the computation. In other words, to keep the system isolated and prevent the occurrence of decoherence.

Lu - And what is the coherence time of these computers?

Leo - To give a concrete example, IBM's quantum computers that are available for use in research currently have a coherence time of around 100 microseconds. Which is a thousand times shorter than the time it takes for you to blink.

Lu - Wow, there is no time for anything.

Leo - Well, it seems not, but for these computers it is enough to obtain the first results that go beyond what classical computers can do.

Gláucia - And it is also worth saying that in a quantum computer we are not interested in just leaving the system there with its quantum properties. To perform a computation, we need to interact with it, manipulate the system so that it follows a series of steps to implement a certain algorithm. And these interactions also cause decoherence.

Lu - The difficulty of building these quantum computers is starting to become clear to me….

Gláucia - Well, to explain decoherence, which is this process of losing the quantum properties of a system, a concept called [eco] quantum Darwinism was coined. As the name suggests, it is based on an analogy with the theory of natural selection. So, in a slightly simplified way, what quantum Darwinism says is that the classical world, this world that we know and interact with in our daily lives, this world is like this because when we let photons and electrons and atoms interact among themselves without any control, the states that survive this interaction are precisely those that do not present any quantum characteristics. In other words, it is that story of the "survival of the most adapted" that Darwin talks about: classical states are those most adapted to the jungle of physical interactions that happen in our daily lives, while quantum properties are only created and can only survive in very specific niches.

[cat]

BLOCK 2: DECOHERENCE AND INTERPRETATIONS ******************************

Leo - Well, once we understand that the interaction of a system with its surroundings causes decoherence, we can explain some things about quantum theory that may sound paradoxical. For example, in the last episode we saw how one of the positions we can take in relation to quantum theory and science in general is about being realist or anti-realist. We said that supporters of realism believe that quantum systems exist exactly as the theory portrays them. And the anti-realists believe, on the contrary, that the theory only presents a description created by us to talk about these phenomena, and therefore it talks more about our way of interacting with the world than about the world itself.

Gláucia - And in the last quantum bit, we told you the anecdote about Schrödinger's cat.
[pause]
In fact, if you haven't heard it yet, go there to learn the story of this very famous cat.
[play]

Schrödinger's cat appears as an argument to show that the realist interpretation of quantum theory would be absurd. According to Schrödinger, if you believe that an atom can be literally in superposition, then you must conclude that a cat can also be so. In this case, in superposition of alive and dead, which seems quite absurd indeed. But, to have an alive and dead cat, this system involving the atom and the cat needs to be isolated. In fact, that's why Schrödinger says that this whole story takes place inside a box.

> **Marcelo Terra Cunha:** So when Schrödinger describes the Schrödinger's cat experiment, he is very careful to ask for a completely isolated environment so that it is possible to somehow transmit the superposition of an atomic decay, right?

Gláucia - This again Marcelo Terra Cunha from Unicamp. So here we see that everything we discussed in the previous block, about isolation and decoherence, serves as an alternative explanation for why no one has ever seen a cat in a superposition of alive and dead: Schrödinger's conclusion that the superposition of the atom is transmitted to the cat is not so plausible because it is extremely hard, not to say impossible, to isolate a physical system as big, hot and complex as a cat. In other words, just because no one has ever encountered a zombie cat walking around doesn't necessarily mean that the realistic interpretation of quantum theory is absurd. This can be explained simply by the decoherence process.

Leo - Still in this context of philosophical discussions about quantum theory, Einstein, who was a convinced realist, brought the following question to challenge supporters of anti-realism: [radio] “Do you really believe that the moon is not in the sky when you are not looking at it?” This is because, according to anti-realists, if you are not observing the moon, you could not say anything about it.

Gláucia - But, well, I think most of us believe that the moon is there, right? In particular, bringing it to the quantum context, we do not think that the moon could be in a superposition of “being in the sky” and “not being in the sky”. But how can you argue that this doesn't actually happen? Again, decoherence explains. Here, Rafael Chaves again.

> **Rafael Chaves:** So for example, this example I think is really cool, right? Why is the moon up there in the sky when no one is looking? Because in fact someone is always looking.

Gláucia - Here, "looking" is not in the literal sense, it does not need to actually involve a person with binoculars pointing to the moon; "looking" just means that there is a record somewhere that the moon is there in the sky. And in this case, there is. In fact, there are several.

> **Rafael Chaves:** There are zillions of photons that are hitting the moon every instant of time. [...] And in this process, any, let's say, quantum superposition that the moon had, is lost because of this decoherence process.

Leo - In other words, all these interactions with photons and other particles disperse any quantum properties. The moon is never isolated enough for quantum weirdness like superposition to be demonstrated. In the words of science popularizer Phillip Ball: [radio] "the universe is always looking".

Gláucia - So we see that, before, with the cat story, Schrödinger wanted to point out that the realistic interpretation made absurd predictions. Now, with the story of the moon, Einstein tried to say that anti-realism was absurd. But in both cases, decoherence shows that these absurdities can be resolved simply by the loss of quantum properties.

Leo - In other words, decoherence explains why these arguments do not serve to discard either one point of view or the other. We cannot obtain evidence against realism or anti-realism. With this, we are convinced, once again, that this discussion is more philosophical than scientific, and does not admit easy answers.

[cat]

BLOCK 3: QUANTUM BIOLOGY ***

Gláucia - Well, it's not just philosophical questions that decoherence helps us clarify. Listen to Pablo Saldanha, Professor at the Federal University of Minas Gerais.

> **Pablo Saldanha:** So these experiments show the behavior of matter, but in an extremely restricted regime, which is dark, it has to be dark because in the same way, if the electron collides with a photon, and the photon marks the path, the interference disappears.

Gláucia - Here Pablo is referring to the double slit experiment. When we discussed this in episode 4, we said that one way to record the trajectory of the electrons after passing through the slits was to study the footprints, in quotes, that they leave through their interaction with photons. But as we saw, this goes wrong precisely because this interaction with the photons changes the state of the electrons and this ends the interference pattern.

> **Pablo Saldanha:** It has to be in the dark. It has to be in a vacuum, because if it bumps into any molecule, it's gone.

Gláucia - Just as bumping into a photon already changes the electron, bumping into any molecule, such as an air molecule, has the same effect. So there can be nothing, neither light, nor air, nor anything else, around this electron, for the experiment to proceed correctly. Therefore, vacuum is a necessary condition to isolate the system from the environment.

> **Pablo Saldanha:** So to see these quantum properties, only in state-of-the-art laboratories.

Leo - So decoherence is also useful for us to understand how improbable some ideas from quantum pseudoscience are. A few episodes ago, we told you how some people use quantum to justify, in quotation marks, "scientifically", the existence of a vibration of abundance, or a frequency of success.

[wheezing]

> *"In my quantum power mind training, I talk about all levels and how to raise the vibrational frequency and even reach the miracle frequency."*

[wheezing]

> *"The vibratory energy which is known on the scale of consciousness."*

[wheezing]

Leo - We have already told you how quantum theory describes systems through a wave-particle duality, that is, that even things that we like to think of as very solid, such as atoms and molecules, can also have wave properties. But even if there is this "vibrational" behavior of matter in the quantum regime, it is a big leap to say that there is a quantum vibration of thought, or that our organs get sick when we vibrate at the wrong frequency. This is because the human body is a terrible environment for quantum phenomena.

> **Pablo Saldanha:** For you to have this quantum superposition, you will only have it in extremely well-controlled experiments, which is not the case with

humans, right? Because they are hot, they are dense, they are subject to electromagnetic radiation.

Leo - Remember that it is necessary to have low temperatures, vacuum and isolation in general to be able to observe quantum phenomena? Everything that we do not have inside our body. And first, it's not even clear what would cause these quantum phenomena within us. But then you say…

Pablo Saldanha: …but then you say, oh no, we don't understand the brain well, let's assume that there is something inside it that creates quantum superposition. All good. If you create it, it will last for a period of time that is not enough for absolutely anything to happen.

Leo - This lack of isolation within our body would cause any quantum properties to disappear very quickly. This time window would be on the order of femtoseconds, which is a fraction of time that we obtain when we divide a second into a million equal parts and then divide each small part of these a billion times. In other words, a much shorter time than the coherence time of the quantum computers we talked about before, which were already super small.

Pablo Saldanha: Just like I said, there isn't enough time for a neuron to communicate with its neighbor, right? In fact, there is not enough time for the electrical signal to travel one thousandth of the length of a neuron. There's basically no time for anything to happen.

Lu - So can we completely rule out the possibility of quantum effects on the human body?

Gláucia - Well, throughout our discussion about decoherence, we see that the human body is a hostile environment for quantum phenomena. Which automatically collapses several pseudoscience arguments. But it's also nice to bring a counterpoint here. We mentioned in block 1 the concept of quantum Darwinism, and that this doesn't have much to do with biology, it's more of an analogy. But it turns out that there is also a field of study called [eco] quantum biology, and this one deals with the intersection between biology, chemistry and quantum physics. Here, Rafael Chaves, again.

Rafael Chaves: For example, quantum biology, which is this idea of trying to understand whether biological processes could have quantum effects present, or in another way, whether quantum effects could somehow provide evolutionary advantages, for example for different animals, in short, biological systems.

Lu - Okay, but what's the difference? Because for the same reasons you just said, that bodies are hot and don't have a vacuum or any insulation, it should also be difficult for these plants and animals to sustain quantum effects inside them, right?

Leo - True. It is worth noting that quantum biology is a relatively new area of research, so many things are still in the field of speculation. But little by little researchers have been collecting some evidence in favor of the existence of quantum effects in some very specific biological systems.

Gláucia - The most studied example is photosynthesis, in which plants and other organisms, such as bacteria, absorb light to generate energy. [pause] That's right, it's not just plants that do photosynthesis, there are bacteria that do photosynthesis too [play]. Here, it is important to say that neither Leo nor I are experts in this, but we will try to give you an idea of how this process works on a cellular scale. And well, some complicated terms will appear, but follow me because it's a really cool example.

Lu - Okay, I'm following.

Gláucia - The most studied example is, in fact, a bacteria, the green sulfur bacteria, which uses a kind of antenna in its cells to absorb photons. These photons excite electrons, more or less like the photoelectric effect, and these electrons are then transported to a place called the reaction center, to generate energy for the bacteria. The efficiency with which this process is carried out is very high: more than 99% of the excited electrons are successfully transported to the cell's reaction center. And so… this excitation of the electrons lasts a very short time, so this efficiency rate being so high is quite impressive. Too impressive. If this transport to the reaction center were carried out using classical diffusion models, a large part of these electrons would not get there, and the efficiency would be much lower. Then researchers began to suspect that some quantum process could be happening there. In 2007, researchers found evidence that this transport might be done in a [eco] quantum coherent way. In other words, the idea is that the excited electrons would be exploring a superposition of trajectories, as happens in the double slit experiment, and thus be able to find the optimal path to their destination.

Leo - These initial studies showed that these quantum effects could occur even at room temperature, and last up to 300 femtoseconds. In other words, although the superposition exists for an extremely short time, in principle this would be enough to carry out the task. In other words, what this research was suggesting is that nature has somehow evolved to the point of being able to protect, even minimally, some quantum processes from decoherence, in some way that we still don't understand.

Gláucia - However, more recent studies, carried out since 2017, estimated that this coherence time would actually be shorter, which considerably reduces the possibility of quantum effects being decisive in this process. So currently things are at this point, without a definitive answer. Maybe there won't even be time for these quantum phenomena to influence photosynthesis much. But as you can see, this is a very current research topic with several open questions.

Leo - Another problem studied by quantum biology that has attracted a lot of attention is the so-called magnetoreception. There is evidence that some birds use the Earth's magnetic field to locate themselves during periods of migration. But how do they do it? The conjecture is that these birds can detect the difference in inclination of the Earth's magnetic field.

Lu - And what does this have to do with quantum?

Gláucia - Well, although there is data that can be interpreted as evidence that this actually occurs, the question that remains is: how to explain this mechanism? One problem is that Earth's magnetic field is very small, almost insignificant compared to the thermal energy of the bird's molecules. So that's where quantum comes in: one of the hypotheses is that this variation in the magnetic field would alter the quantum state of a system called [radio] radical pairs, which can be produced in certain molecules in the presence of light. Without going into detail, the point here is that this effect can only be explained using quantum theory. So these molecules would be like a kind of quantum compass for these birds.

Leo - So in this case, we have [plim] evidence that birds navigate Earth's magnetic field, [plim] the proposal of a theory that would explain this phenomenon based on quantum effects, and, in addition, [plim] a protein has already been found in birds' eyes that is capable of generating pairs of these radicals that Gláucia mentioned, the Cryptochrome protein.

Gláucia - But you still can't hammer out and say that birds are guided by quantum phenomena. This is because there is still a lack of evidence to connect these dots and prove that these quantum mechanisms are really responsible for making birds detect the Earth's magnetic field. So while this is a really cool idea, it's still largely speculation.

Lu - It reminded me of the story of light that you told in episode two, where you had several different ideas but lacked evidence for one or the other.

Leo - Exactly. I think the final message is that research on quantum phenomena in biological systems is still in the early stages and needs to answer many questions, but there are serious studies on this being done in a responsible way.

> **Rafael Chaves:** But precisely because of this, because the people who worked in this field, they took that care, right? We have to accumulate evidence and different models, so I think it's a good example that shows that it is allowed to think outside the box as long as we do it the right way, which is using the scientific method.

[cat]

CLOSING **

Lu - The episode is coming to an end and, as we talked about several different things, I made a list of messages to take home, help me if I understood something wrong.

Gláucia - Sure.

Lu - [plim] Isolation is important for quantum processes to occur;
[plim] Quantum effects generally occur on very small scales (size and time), precisely because on this scale it is easier to isolate systems;
[plim] coherence is when systems have quantum properties and decoherence when they lose these properties;
[plim] the first quantum computers are already appearing, but they need to perform their computations in very short periods of time;
[plim] the human body, being hot, large and complex, is not a favorable environment for quantum properties, and finally

[plim] research in the area of quantum biology exists, it is serious, but we don't have precise results on this yet.

Gláucia - I think that sums it up well.

Lu - But I still have a doubt, both quantum biology and some pseudoscience talk about quantum effects in living beings. But why is one a science and the other not?

Gláucia - The two cases we mentioned about quantum biology follow the same line of reasoning, the researchers observed some phenomenon and then looked for theories and mathematical models to explain it. Some of these theories are based on quantum phenomena as the main explanation, so now researchers are looking for evidence that proves, corroborates these theories. Until then, these explanations only have the status of hypotheses.

Leo - In quantum pseudoscience, the idea disseminated in most pseudoscientific materials follows a very different line of reasoning, based mainly on a shallow extrapolation of the type [radio] “if atoms and molecules can present quantum effects and we are made of atoms and molecules, then we can also present quantum phenomena”. And that is false.

Lu - Okay, I think I understand. And precisely the discussions in today's episode show that these extrapolations don't make any sense because of decoherence, right?

Leo - Exactly. And well, we'll stop here. In the next episode, we will talk about determinism, probabilities, amateur magicians and try to answer the question: does God play dice?

[cat]

CREDITS **

[identity track - drums, then bass and piano]

Leo - On our website www.ufsm.br/oqquantico, you will find links to the scientific articles that we cited here, as well as some scientific dissemination texts about them.

In this episode you heard excerpts from interviews with Bárbara Amaral, Marcelo Terra Cunha, Pablo Saldanha and Rafael Chaves. In fact, Rafael Chaves also talks about decoherence and quantum Darwinism in his book 'Incerteza Quântica', in addition to writing an article about it for Folha de SP, which is also on our website.

We also used lines from the YouTube channel Elainne Ourives.

Gláucia - If you liked the episode, you can help by recommending the podcast to a friend who is interested in the topic. Also follow Q Quantico on Instagram @oqquantico and be sure to rate the podcast on your favorite podcast platform.

Lu - O Q Quântico is presented by me, Luciane Treulieb, Gláucia Murta and Leonardo Guerini.

In addition to the three of us, Samara Wobeto and Vitor Zuccolo complete the team of podcast producers

The script for this episode is by Leonardo Guerini, with contributions from me, Gláucia Murta, and Samara Wobeto

The project was conceived by Leonardo Guerini and Gláucia Murta

The script consultancy is carried out by the team from the Ciência Suja podcast

Sound editing is by Leonardo Guerini

The mixing is by Felipe Barbosa

The recording support is by Pablo Ruan,

The original music is by Pedro Leal David

and the visual identity and cover illustrations are by Augusto Zambonato

The person who takes care of our social media is Milene Eichelberger and

Our website was developed by Daniel Carli

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Thank you for listening and see you in the next episode!

[transition - cat]