



## #204: Particles of doubt: What if it wasn't the Higgs boson?

VOICEOVER

Welcome to Up Close, the research talk show from University of Melbourne, Australia.

SHANE HUNTINGTON

I'm Shane Huntington. Thanks for joining us. The Higgs boson has been surrounded by both mystery and hype since Peter Higgs and fellow theorists first predicted its existence in the 1960s. It has been dubbed the god particle for its ability to explain our observations of the universe, and physicists have been searching for ways to prove its existence for decades. And now, historically, the search for the Higgs may be over. The latest in our endeavour to detect the Higgs boson has recently produced some extraordinary results. Experiments of this size fall into the category of big science. Not only do these programs combine the efforts of numerous countries, but they can involve thousands of individual scientists. The Large Hadron Collider, or LHC as it's known, where the Higgs experiments were done, made its mark long before it was even turned on in 2008. Some predicted these experiments would even end the world. Happily, we are all still here, and with a better understanding of how the universe works. To discuss these exciting experiments in particle physics we are joined by Dr Serguei Ganjour from the French Alternative Energies and Atomic Energy Commission, and Dr Martin White, Research Fellow in the experimental particle physics group here at the University of Melbourne. Welcome to Up Close, Serguei and Martin.

MARTIN WHITE

Thanks.

SERGUEI GANJOUR

Good morning.

SHANE HUNTINGTON

Martin, I might start with you. Many of our listeners would be familiar with the periodic table of the elements; so this is a chart that, essentially, places the elements according to their various properties. What is the equivalent in particle physics?

MARTIN WHITE

So we, indeed, have a similar table which just contains the fundamental particles that we're made of. I mean everyone, I guess, has played with LEGO at some point in their lives, and the universe is just the biggest LEGO set that there is by definition. And in LEGO you have lots of different types of block, and there's only one way of sticking them together. In nature there's lots of different types of block, like the quark and the electron and the muon and things, but there's four ways of sticking them together. So our sub-periodic table, periodic table of particle physics, is really the matter in the universe and the different types of glue that can stick that matter together.

SHANE HUNTINGTON

Can you give us some examples of bosons? We're here to talk about the possible discovery of the Higgs boson, but it's not the only boson that we know about. What are some of the others and what are their properties?

MARTIN WHITE

First of all, I guess I should explain what a boson is. And it's not that complicated. So everyone's aware that particles have a charge. The electron has a charge and our atoms are stuck together, essentially, because the electron has a minus charge and our nucleus has a positive charge. That's how it works. Particles also have other properties, like a spin. Particles have something called a spin, and it's related to their intrinsic angular momentum. But it's just another property that they have and it affects how they interact. So everything that has a spin which is a fraction, like a half or three halves, we call that a fermion. Everything that has a spin which is a whole number we called a boson. So the bosons are, generally, the glue in nature and the matter is fermionic; it all has this half-integer spin. So the other bosons that we know of are the glue particles, the particles that stick things together; so things like the W and Z boson - there's a force called the weak force, which causes radioactive decay, and those are the other bosons that we know of. The Higgs is different because it has a spin of zero. These all have a spin of one. The Higgs has a spin of zero, so it's really slightly different to a glue particle, but it's, nevertheless, a boson because it isn't a particle of matter.

SHANE HUNTINGTON

Talk us through how this glue aspect of these particles works. I mean when you have a group of other non-bosons that are accumulated or stuck together what are these bosons doing to actually keep them together? Are these bosons continuously around? Are they just being exchanged momentarily? How does that work?

MARTIN WHITE

My only way of visualising this is just some weird quantum mechanical stew. Right? In a proton, for example, you have this continuous flux of gluons which is binding this together. You shouldn't think of this as a small, round bag full of quark stuck together with gluons that you can shake and hear something inside. It's this weird quantum mechanical glue thing and, suddenly, you get this emergent thing which is an object which is bound together. I don't know if Serguei can put it any better than that.

SERGUEI GANJOUR

It's actually not so easy to explain. So, in fact, the fundamental difference between bosons and fermion - fermions is this constituent of our matter and the bosons is a carrier of the interaction or fundamental interactions of the nature. In fact, bosons are, basically, a field; so we know there are four fundamental interactions in nature: electromagnetic interaction, weak interaction, strong interaction and gravity. And there are four bosons we know at this moment. Now we know a fifth one is a Higgs boson and that the W boson, Z boson, which were discovered in the early '80s. And there is one important boson for us is a very well known photon which has mass zero and has a spin one. So this has fundamental meaning for the science, what we call in our theory, which was greatly tested for the past 50 years - it's a standard model. So we observed [the] effect which was predicted by theorists - what we call electroweak symmetry breaking. It simply explain us why photon has mass zero and gauge bosons, like W and Z, has non-zero mass.

SHANE HUNTINGTON

Serguei, let's talk about the standard model for a minute. What are the main components of this model and what is it used to predict?

SERGUEI GANJOUR

So the standard model has, in fact, 36 unique types of particles, 24 fermions, which is 12 fermions, six quarks and six leptons and antiparticles, and it has 12 bosons which are responsible for interaction between those particles. So many physicists believe in the standard model. However, it is incomplete. It does not explain several things, so that's why many physicists believe the existence so-called new physics. The standard model does not explain three fundamental things. One is what we call Hierarchy problem. Hierarchy problem means why the mass of bosons ? W, Z bosons and, now, we know the Higgs boson - is so small with respect to the Planck scale. The Planck scale is an energy - a typical energy when we believed all forces had the same strength. And the second one - we know that our universe composed from the baryons. The baryons, for example, protons or neutrons which are constituents of the nuclear, it's only four per cent of our universe, so the rest we don't know what it is. The standard model, explicitly, does not say what it is. And the third one - which is also very important - that in our universe we know that the amount of antimatter is very small. This standard model does not explain why. So that's why we believe there should be something else - there should be new physics which we definitely hope to observe at some point because the standard model is incomplete.

SHANE HUNTINGTON

Martin, let's talk about the Higgs a bit further. With regards to the idea that this bestows upon everything mass - can you explain how this works and why it's necessary to have this particle for other particles and even the particle of the Higgs itself to have mass?

MARTIN WHITE

Yes. I'm going to try and avoid innuendo when I talk about the Higgs interacting with itself but, essentially, the physicists of the 1960s - when they were playing around when the Beatles were releasing their best works - well, their only works, I guess. They knew most of the details about this theory, but if you tried to add mass it was obvious that these gauge bosons, for example, the force carriers, had a large mass. If you try to just stick mass when you write the equation it just breaks. It's embarrassing. You get infinities every time you calculate anything. So it obviously just didn't work. So about six different physicists - and Peter Higgs became the most prominent person associated with the idea. Peter Higgs is now retired but, really, still affiliated to the University of Edinburgh in the way that no physicist ever really retires. They just come in and have more expensive coffee. He came up with this idea that maybe there's a field that particles interact with to get their mass. So you don't have to stick in an intrinsic mass for the particles, which breaks your equation. You can just stick it in the field and they interact to get their mass. It's not a particularly whacky or complex idea. Imagine a tiny bug which is, basically, massless, and it's walking through some treacle. It feels this immense inertia, essentially, because it's interacting with the treacle. So the idea is that our particles are getting that mass by interaction with this kind of cosmic treacle, which is a field for filling space.

SHANE HUNTINGTON

Martin, when we look around the world and the universe that we exist in how many Higgs bosons are around? Are these things still common?

MARTIN WHITE

Well, I mean the idea of the Higgs, really, is that it is this field, essentially, which fills space. So excitations of that field would be known as the Higgs boson.

SHANE HUNTINGTON

How would you answer this question?

SERGUEI GANJOUR

None of Higgs exist in nature anymore. They lived about a little bit more than  $10^{-21}$  seconds after the big bang, so they are all decayed. However, the Higgs field is everywhere. The Higgs field is responsible for mass. It's responsible for my mass, for your mass, [unclear] mass.

SHANE HUNTINGTON

This is Up Close, coming to you from the University of Melbourne, Australia. I'm Shane Huntington. In this episode we're talking about the actual work on looking for the Higgs boson with Dr Serguei Ganjour and Dr Martin White. Serguei, the Large Hadron Collider was built with the research for the Higgs boson as one of its main aims. How big is the accelerator physically? Can you describe what it looks like?

SERGUEI GANJOUR

Yes. The Large Hadron Collider is placed in the tunnel with the perimeter about 27 kilometres next to Geneva. This is set of magnets which comprise, if I'm not mistaken, approximately 7000 magnets.

SHANE HUNTINGTON

Martin, how long did it take to build the Large Hadron Collider and, approximately, how much do they cost?

MARTIN WHITE

Well, the first meeting on the LHC was in 1982 I think, so decades. There's people like me - their entire career's been spent working on the LHC. I mean I was there before it was running, so it's a long time to construct. The actual tunnel that this thing is in existed before because there was a previous accelerator in that tunnel. So it was, literally, a case of rip the bits out, stick the new bits in. That's a very, very long and complicated process. Total costs, Serguei, I can't remember which currency.

SERGUEI GANJOUR

It's ten billion dollars.

MARTIN WHITE

Ten billion dollars?

SERGUEI GANJOUR

Yes, approximately.

MARTIN WHITE

Again, think of 10 billion over 30 years and something like 30 countries, roughly.

SERGUEI GANJOUR

Yes.

MARTIN WHITE

So each country contributes a rather small amount. Yet you managed to do this amazing science.

SERGUEI GANJOUR

The biggest fraction of this money is the price of the machine.

SHANE HUNTINGTON

And what actually makes the particles speed up? What's the drive for these particles to get to such high speeds?

SERGUEI GANJOUR

So electrical field accelerate particles to the certain energy, and the magnetic field allows us to keep the particles within the certain orbit.

SHANE HUNTINGTON

Serguei, if we knew the maximum energy these accelerators could produce and we knew the energy where the Higgs should be found was actually below that accelerator value, why did we bother even looking for the Higgs in these older experiments?

SERGUEI GANJOUR

In fact, it's not so trivial because there are two different types of machine. One is a Hadron Collider - you have LHC - and there are electron colliders - plus or minus colliders. So the previous CERN machine - which was a large electron-positron collider - had an energy significantly smaller. But the old energy of leptons was, basically, used to produce a new particle. So in the Hadron Colliders this is not the case. It's only part of protons - the constituents. The quarks are interacted. It's a probability that all energy of proton will be accumulated to produce a new particle is very small. So that's why the energy of Hadron Colliders is significantly higher than the energy of electron-positron colliders. So this cannot be directly compared.

SHANE HUNTINGTON

When we consider something like the Higgs - you mentioned earlier that with some of the quarks in particular we had a very specific understanding of what the energy of the quark would be so we knew where to look and what we had to produce to get those experiments to be successful. With the Higgs did we have the same kind of certainty?

SERGUEI GANJOUR

In fact, in each particular interaction we don't know exactly energy of interacting quarks. We know some probability of each certain energies the quark absorbs from the energy of the proton. So the Higgs - this is a particle which is short lived, but it has a certain mass. This helps a lot. So if this particle is produced in the detector we obviously don't detect the Higgs because it has a very short lifetime. We detect the products of its disintegration of this particle and, by reconstructing the properties of these particles - photons or electrons or muons - we precisely reconstruct the mass of the Higgs. So that, basically, helps a lot because if the real Higgs was produced we should see what we say, the peak on top of continuous background. This is some known physics processes of the standard model.

MARTIN WHITE

We didn't know the mass of the Higgs in advance, so unlike the top quark, where you pretty much knew where it had to be, it wasn't possible to calculate the mass of the Higgs. You know, these equations of the model let you have slightly enough room to manoeuvre that you couldn't pin down exactly with the Higgs mass. The one thing we did know is that something like the Higgs had to appear at LHC energies, because the theory breaks completely. I mean there's this relationship between the Higgs and interactions of W boson. So if you look at the LHC, if there wasn't something like the Higgs you would have pairs of W bosons that scatter off each other, and you start getting more out than you put in. So your probability equations break. We call that, in our posh words, the violation of unitarity, but what it really means is something for nothing. It's a free lunch - going back to the Nobel Prize winners. So you have this situation where you suddenly get more out than you put, and it's broken. Either your theory is fundamentally broken, or there's something like the Higgs there. And indeed, it's actually come out fairly early. So that's why the LAC was significant. It was the only experiment where you could say we're going to rule this out if we don't see it because something has to appear at this energy.

SHANE HUNTINGTON

Now, Martin, the Large Hadron Collider, the LHC as you guys call it, has two main detectors; one called CMS and the other being ATLAS. Can you tell us about these two detectors; why we have both of them and how they're different from one another?

MARTIN WHITE

So there reason we have two is straightforward. It's simply that you want to see something like this in two different places before you really start to believe it. This has been the basic philosophy of particle accelerators now for 40 years or so. You always have two similar experiments. What you do is when you're at the design phase of these things you form two independent teams and you say right, build your detectors. This is the goal of our experiment. We want to be able to see something like the Higgs. We want to be able to see things like dark matter, if we happen to produce that. You have a totally free rein. Pick your own technology. Pick your own strategy. So the detectors function in a similar manner. They're the same sorts of machine. If an alien came in he'd probably look at these and say oh well, that's a particle detector, circa Earth 2000 and something. The inside measures momentum. The outside measures energy. Then you have some kind of magnet system, but they use different technologies and different designs for some components of this machine.

SHANE HUNTINGTON

Now, these detectors don't directly measure the Higgs itself. Why is that? Why can't they detect that particle; whereas they can detect many of the products from its decay?

MARTIN WHITE

It's simply the fact that it decays very, very quickly. We collide the protons hundreds of millions of times a second, so we're reading this thing out every 25 nanoseconds, but this thing decays in a time scale shorter than that. So you simply don't make it for long enough to see. There are particles that decay in nature that do live long enough to fly to the detector, like the muon. So the muon is a heavier version of the electron. If you make a muon - which could happen through a Higgs boson decay - that thing actually flies out to the detector and we have a special muon catcher to exploit this around the outside. Yes, the Higgs is just too short lived, unfortunately.

SHANE HUNTINGTON

Now, anyone who has seen an image of some of these simulations of the decay that occurs here - and the collision that occurs - will see there's just an incredible mess of particles going all different directions. How much of the work that you guys do at this point is actually just a computationally intensive way of sorting out what all these products are?

MARTIN WHITE

It's about 99.9 per cent of the work, I would say. You're right. You look at these pictures and people will look at them, and it's just a psychedelic load of crap. There's no other way to explain this. It's a huge mess. So let's say the Higgs decay to Z bosons and the Z bosons then decay extremely quickly to electrons and muons. So these are charged particles. They fly out to the detector. We have an array of digital cameras in the middle of this which, basically, every time a charged particle goes through a piece of silicon it leaves a current. So you, essentially, put loads of pieces of silicon there. I'm waving my hands a lot to explain this. Your listeners won't see this. Just imagine four pieces of silicon all going up in the air. As a charged particle goes through it leaves a dot in each of them. So you can, essentially, see where it went by joining the dots. Then you look at these pictures and you realise there's so many charged particles flying through that the whole thing - it's like my dandruff is covering the table. By eye you simply aren't able to

see where these particles went, but we have very, very sophisticated algorithms and computer programs that have to run extremely quickly. We're doing this hundreds of millions of times a second and we're able to resolve these tracks quite well. You spend the early years - the first year I'm sure Serguei had the same experience on CMS. You spend the first year just calibrating the machine, making sure this is all working. There was a phenomenal amount of work, even before we turned it on, to make sure that we were reconstructing tracks properly. Our resolution on tracks is crazy. We can measure the momentum to some absurd position. We know the Higgs mass now. That's simply because this is so precise.

SHANE HUNTINGTON

Serguei, how do you go about this calibration? How do you make sure that the detectors are set up correctly?

SERGUEI GANJOUR

Yeah. The calibration is one of the most important stages of experiment to make sure that everything works properly; that the calibration is done on the known physics processes, which is very well measured before, very well established. We know the parameters of these processes. These are normal standard model processes, and we use them to calibrator the detector to make sure that what we see in the detector is consistent with our previous knowledge. So this is an easily explained procedure, but very complicated technically because the detector has a few million electronic [unclear]. Everything has to be calibrated.

SHANE HUNTINGTON

I'm Shane Huntington. My guests today are Dr Martin White and Dr Serguei Ganjour. We're talking about the Higgs boson and whether or not we've really found it, here on Up Close, coming to you from the University of Melbourne, Australia. Serguei, how sure are we that we've actually detected a new particle?

SERGUEI GANJOUR

We are quite sure we have detected a new particle; so that the probability that this is a statistical fluctuation of background processes, which are most of the known standard model processes, is very small; so it's one chance per million or something like this. However, the particle we detect cannot be treated in ambiguous ways, that this is a Higgs particle. What we can say now is that the observation we did is consistent, with a given experimental on certainty, there is a standard model Higgs boson. However, we need more data. That's what we're going to do next year, to understand what is the origin of this particle and what is the type of electroweak symmetry of a breaking mechanism.

SHANE HUNTINGTON

Serguei, how many actual Higgs particles or decay products from Higgs particles have we detected?

SERGUEI GANJOUR

We detected about 200 of Higgs particle. The problem that counting of this particle cannot be treated in an ambiguous way because it decayed in different processes. The two main observation channels of the Higgs is one with a two photon in the final stage and another with four lepton[s]. The performance of these channels are very different. In the Higgs to gamma-gamma decay channel we have a huge background. So, basically, detecting of 200 Higgs particles on top of 30,000 background processes is a big challenge. However, in [the] four-lepton channel we detected in the order of five or six Higgs particles but, basically, with a zero background.

SHANE HUNTINGTON

Serguei, what specifically are gamma particles?

SERGUEI GANJOUR

Gamma particles with the photon particles - in physics we use a Greek notation: gamma.

SHANE HUNTINGTON

When we talk about the lifetime of the Higgs and its ability to actually get to the detector, how far does it actually travel in the time it's in existence?

SERGUEI GANJOUR

Oh, this is a very short distance. This is a distance which is 100 times less than the distance between two neighbour atoms. This is very short.

SHANE HUNTINGTON

Now, the mainstream media, Serguei, has been very quick to jump on this and state that it's the Higgs particle. Throughout this interview we've been talking about the uncertainty relating to what this new boson actually is. Why don't we know for sure that it's the Higgs, and how will we go about determining that?

SERGUEI GANJOUR

We don't know for sure whether it's a Higgs boson predicted by the standard model because we need to measure the properties of this particle. We need more data for this. We need to measure the spin - what explained before - we have to confirm this is a zero-spin particle. We have to measure how this particle couples with the other particles; with the fermions and with the bosons. So the standard model predict us very precisely how this Higgs boson has to couple with fermions and bosons. So there are different models which also predict the Higgs particle, but the couplings with the non-particles is different. This is what we are going to investigate.

SHANE HUNTINGTON

So in terms of doing that what's the next stage for the LHC in terms of determining the properties of the particle? We've inferred its existence - or a boson's existence. How do we go about determining the actual properties themselves?

SERGUEI GANJOUR

So to determine the properties of the Higgs we need to factorise different production mechanisms of this particle. In the standard model we have four different production mechanisms. At current statistics we mostly measure just inclusive yield of this. Once we have more data we will be able to disentangle different productions mechanisms, and this would give us the direct information on the couplings of this particle with the fermions or bosons.

SHANE HUNTINGTON

Martin, let's say, for example, we find out that it's not the Higgs boson. What would that mean for the standard model?

MARTIN WHITE

The answer has to be qualified, as usual. But it really depends on exactly what we find it isn't. I mean Serguei mentioned earlier that we think that the standard model is not the final answer in nature. The last missing piece of the puzzle is the Higgs boson within that model, but there's lots of things that the standard model doesn't explain. Ninety six per cent of the universe is not what we're made of. There's some weird dark matter that's a chunk of that and there's some weird dark energy. That's probably the biggest thing. There are various other things about the standard model that make you ask serious questions. These

new theories, generally, predict much more complicated Higgs' sectors, if you like. Supersymmetry is a popular alternative, and we're looking for that directly. That would have five Higgs bosons. So we'd have seen one of them, but there are four more there. We might not be able to see all of them at the LHC, but we could still - legitimately, of course - claim - if we discovered that was, in fact, the correct explanation - well, we have seen a Higgs boson. It's just one of five. So I think that most people would say that what we've seen - it's so far consistent with the standard model Higgs boson, but with quite a large error on that consistency. It's like if someone went missing, it's really the second after the universe was born, and they've reappeared and they have the same colour eyes and they have the same colour hair and everything, but we have to run a lot more checks to see if it's the same person. You might want to get a DNA test or something. So that's the position we're in. It's consistent, but there's a large error. If we do this more detailed work I think we'll find that it is a type of Higgs boson, but it might be a Higgs boson coming from a more exotic theory.

SHANE HUNTINGTON

Now, our listeners would be hearing these numbers like 96 per cent of the universe not explained by the standard model and would, rightly, I think, be a bit concerned about its validity, but...

MARTIN WHITE

What have we been doing for all these years? I wonder what they're thinking?

SHANE HUNTINGTON

The standard model, of course, explains everything important to us for life on earth. Is it looking like we will have a complete refresh of the model, similar to some of the paradigm shifts in physics hundreds of years ago? Or is this going to be an add on to the standard model that includes things like dark matter and dark energy?

MARTIN WHITE

I think that what's going to happen here is that we will discover a theory which, in a certain energy limit, it looks like the standard model and, as you go higher in energy - there are extra things in nature, but they're just not important at the energy scales we've probed so far. I think the language of particle physics - this theory is a particular type of theory called a quantum field theory. I think that's safe. I think the discovery of the Higgs really shows us that this particular way of writing our theories and doing our maths and, really, our picture of the world is staggeringly correct. It was thought to be a great intellectual achievement. It's now a giant intellectual achievement. The discovery of the Higgs confirms that. So I think that language will stay the same and I think we'll be looking at theories which, maybe, have extra particle content, extra symmetries in nature or else; but the basic framework is intact.

SHANE HUNTINGTON

About three minutes after the announcement that the new boson had been confirmed the mainstream media turned to the battle over the Nobel Prize. This is something that will be particularly interesting for the world of particle physics because there are just literally so many people involved in these experiments. The Nobel's only given to three people. How do you see this playing out? Should it be provided to those involved in the Higgs work, in terms of who would actually end up getting that?

MARTIN WHITE

Well, I think we should say here and now that Serguei and I are willing to receive it, should it be given [laughs]. No, it's very complicated. I mean the problem here is that not only do you have these giant experiments that have 6000 people between them - and if you look at the contributions made by people

over the 20 years they've been running it's a much larger number. There's actually six theorists who could share this prize legitimately. I honestly don't know how this is going to go. I mean people are suggesting, maybe, you can't give a prize for this now. Whatever you do is going to, fundamentally, annoy half the community. I would hope that people would think look, the field deserves recognition for this. We must be able to come to some way of doing this. Given the age of Peter Higgs, I think the decision would have to be made fairly quickly. This thing can't be done posthumously.

SHANE HUNTINGTON

Serguei, what's going to happen next with the Large Hadron Collider? I can imagine a few people would have the idea that it's done its job, move on. There's a lot of work still to be done. What's going to come up in the next few years?

SERGUEI GANJOUR

For the next three years we would like, first, to understand - or at least maximise our knowledge about the nature of the new particle we discovered. So we would like to understand whether it's really Higgs boson predicted by the standard model or if it's something else. For most of physics, as I said, the standard model is quite incomplete. We wish to find a new physics. This is the most important. However, within the next three years I don't think this would be really possible because, currently, we plan to have a shutdown of the machine in 2013 and 2014 for two years to prepare the machine running for the twice larger energy. This is a significant technical step for us in order to move towards a search of the new physics.

SHANE HUNTINGTON

Serguei, it sounds like it would be more exciting if it turns out that this is not the Higgs boson.

SERGUEI GANJOUR

I think so. I agree with you. That will be much more exciting if this is not Higgs boson or, at least, it's not a standard model Higgs boson. This will give us additional momentum to move toward new discoveries.

SHANE HUNTINGTON

Dr Serguei Ganjour from the French Alternative Energies and Atomic Energies Commission and Dr Martin White, research fellow in the experimental particle physics group here at the University of Melbourne, thank you for being our guests today on Up Close and talking to us about the Higgs boson.

SERGUEI GANJOUR

Thank you.

MARTIN WHITE

Yes, thank you.

SHANE HUNTINGTON

Relevant links, a full transcript and more info on this episode can be found at our website at [www.upclose.unimelb.edu.au](http://www.upclose.unimelb.edu.au). Up Close is a production of the University of Melbourne, Australia. This episode was recorded on 12 July 2012. Our producers for this episode were Kelvin Param and Eric van Bommel; associate producer, Dyani Lewis; audio engineer, Gavin Nebauer. Up Close is created by Eric van Bommel and Kelvin Param. I'm Shane Huntington. Until next time, goodbye.

VOICEOVER

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