WEBVTT

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00:00:02.669 --> 00:00:13.590
thomas rizzo: Great. So we're very, very happy to have Andre the movie agent here today to talk to us about neutrino. So he's going to give us two electrodes on it. He's maybe a world's expert.

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00:00:14.370 --> 00:00:17.670
thomas rizzo: So take it away. Andre. Thanks.

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00:00:17.699 --> 00:00:18.720
Andre de Gouvea: Okay so uh

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00:00:19.380 --> 00:00:20.040
Andre de Gouvea: Thanks a lot.

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00:00:20.130 --> 00:00:22.320
Andre de Gouvea: And and thanks everybody for signing in.

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00:00:24.450 --> 00:00:30.810
Andre de Gouvea: Do let me know if I drop out or anything weird happens, but I will get started and I'll pretend that everything is working out fine.

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00:00:31.500 --> 00:00:47.220
Andre de Gouvea: And I will not be looking at the chat. So if something happens, you have to try to interrupt me. So let me get started. So my job is to give you a little bit of flavor of a neutrino theory and phenomenology. I have a couple of lectures and I will

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00:00:48.900 --> 00:00:57.030
Andre de Gouvea: Talk about a selection of topics that are connected. And also try to give you a sense of Neutrino Physics in general.

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00:00:57.570 --> 00:01:13.530
Andre de Gouvea: And there will be a whole bunch of other topics that we'll talk we'll mention with reno physics as well. So I think you will get a nice awfully complimentary picture of everything. So again, this is our. This is what I'll try to do in the next 110 minutes plus questions.

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00:01:14.880 --> 00:01:21.060
Andre de Gouvea: Like I said, a lot of other people will talk about neutrinos as well, including some excellent experimental is some excellent

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00:01:22.020 --> 00:01:34.140
Andre de Gouvea: cosmologists and they know a lot more than me. So whatever they say if it contradicts anything I say what they say is usually right but my goal is to tell you something about neutrino oscillations try to give you

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00:01:35.280 --> 00:01:52.980
Andre de Gouvea: A sense of where we are in terms of the questions we don't know the answers to in Neutrino Physics, then I'll spend probably the, the second two thirds of the last lecture on understanding the origin of neutrino mass is why that's a big deal. And I'll try to go over some

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00:01:54.210 --> 00:02:03.750
Andre de Gouvea: Some examples, depending on how quickly or how slowly things go. And again, this is, this is what I would like to do, and we'll see how things are going to evolve.

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00:02:06.270 --> 00:02:23.400
Andre de Gouvea: So these slides will be available. They're not available yet because my inner core competency is very limited but they will hopefully be there by certainly by by before the next lecture tomorrow. And you also get a chance to look at those. And here is a

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00:02:24.750 --> 00:02:33.690
Andre de Gouvea: A more or less up to date and incredibly biased list of references are up, you know, physics has been a very active topic in the last couple of decades.

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00:02:34.110 --> 00:02:41.880
Andre de Gouvea: And in a lot of very good people have sat down and tried to organize where we stand in terms of how we understand neutrinos.

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00:02:42.510 --> 00:02:47.670
Andre de Gouvea: On the flip side, it's kind of exciting because you know physics is also changing very quickly.

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00:02:48.510 --> 00:02:54.450
Andre de Gouvea: So if you look at some of those older reviews, which might be five, six, you know, 1012 years old.

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00:02:55.290 --> 00:03:04.140

Andre de Gouvea: You should appreciate the fact that lots of things have changed in a relatively short amount of time given you know in particle physics units.

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00:03:04.650 --> 00:03:15.150
Andre de Gouvea: Particle Physics oftentimes moves relatively slowly button Fino physics has undergone and it's still sort of in the midst of some exponential growth period.

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00:03:16.020 --> 00:03:24.990
Andre de Gouvea: One thing I want to advertise is there were lectures at Tassie this year, they all took place remotely and a whole bunch of those.

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00:03:25.530 --> 00:03:32.790
Andre de Gouvea: Were on topics related to Neutrino Physics and they're all recorded and they're all. Excellent. So I invite people to look at those.

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00:03:33.540 --> 00:03:47.580
Andre de Gouvea: And the write ups for subsets of Tassie we will hopefully start coming out in the next several months. If we can get all the lectures to actually write their stuff up, which is often a challenge.

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00:03:48.720 --> 00:03:59.610
Andre de Gouvea: Okay, so let me get started. Here's a lightning review of everything. I will assume you know about neutrinos because you're all here and you're all listening to these

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00:04:00.060 --> 00:04:08.760
Andre de Gouvea: Lectures, so I want to remind everything that you probably knew about neutrinos and even if you're not paying attention. You probably heard about this in

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00:04:09.690 --> 00:04:18.750
Andre de Gouvea: Even relatively old particle physics books. So again, what do we know about neutrinos, as far as we know, neutrinos come in three flavors.

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00:04:19.290 --> 00:04:27.600
Andre de Gouvea: And those flavors are decided by how they interact with the other charged current weekend directions. So there's a cartoon here of what that means.

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00:04:27.990 --> 00:04:39.840
Andre de Gouvea: That means when there was a week current where an electron is involved in a neutrino. It gets either produced or destroyed the neutrino that participates in that is given a name. It's called the electron Torino

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00:04:41.430 --> 00:04:49.380
Andre de Gouvea: If I'm Yuan is the charge leptons. That is showing up in your charge current process, then the neutrino. That's also

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00:04:49.920 --> 00:05:02.310
Andre de Gouvea: Participating in that interaction is called them you on retreat know. And finally, if you have a charge current process where cow leptons are involved the neutrino that comes out of that is called optometry no

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00:05:03.510 --> 00:05:07.980
Andre de Gouvea: I'm not going to spend a lot of time talking about the history of neutrinos, but

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00:05:09.330 --> 00:05:20.310
Andre de Gouvea: One obvious question that people asked a very long time ago is. So what makes all of these neutrinos different what makes them different is the same thing that defines them, which is a

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00:05:20.940 --> 00:05:28.980
Andre de Gouvea: If you have an electron neutrino that hits a detector and it produces a charge left on their charge leptin and produces is the electron

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00:05:30.090 --> 00:05:34.560
Andre de Gouvea: If I have a mule on Neutrino hitting a detector and it produces a charge left on

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00:05:35.730 --> 00:05:44.760
Andre de Gouvea: The charge left on that gets produced is the mule on and the same thing for the towel. And we've done a bunch of experiments to establish that indeed.

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00:05:45.180 --> 00:05:54.120
Andre de Gouvea: The electronic Reno is a different thing from the neutrino which is a different thing from the town between. Oh, and if you're like a particle physics. History

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00:05:55.110 --> 00:06:03.960

Andre de Gouvea: That was not a trivial statement at all. And people got Nobel Prizes for figuring out that the neutrino is not the same as the electron cream.

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00:06:05.250 --> 00:06:10.080
Andre de Gouvea: So neutrinos come in three flavors and these are what we call interaction. I can states.

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00:06:11.730 --> 00:06:20.610
Andre de Gouvea: Neutrinos only interact via the week interactions. So they talked to the w, both on and they talked to the Z bows on and that's it. If you discount gravity.

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00:06:22.410 --> 00:06:32.760
Andre de Gouvea: Another thing that was very important about neutrinos and it's still in a handful of textbooks out there is that for a very long time, we thought that neutrino masters right exactly zero

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00:06:33.270 --> 00:06:42.330
Andre de Gouvea: And of course, all of you know by now that that's not true. We have actually discovered that neutrino masses are not zero. And that's mostly about I'll talk about today.

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00:06:43.470 --> 00:06:44.190
Andre de Gouvea: Nonetheless,

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00:06:46.320 --> 00:06:57.660
Andre de Gouvea: Even if we know that the neutrino masses are not zero. I do want to highlight something that's very important and it applies to neutrinos a lot, but it's not something we normally think about

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00:06:58.410 --> 00:07:10.590
Andre de Gouvea: And it has to do with masters from aeons masses firm aeons are qualitatively different from massive firm yawns and several different ways. One easy way to

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00:07:11.760 --> 00:07:18.570
Andre de Gouvea: To appreciate that as the fact that if you're a master list for Mian you always, you know, live and die at the speed of light.

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00:07:19.200 --> 00:07:30.420
Andre de Gouvea: And one thing that's special about masters particles is that you can label them according to their felicity. So the historicity of a mass list formula and is a good quantum number. You can say, here's a left handed.

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00:07:31.290 --> 00:07:36.390
Andre de Gouvea: Firm jaan and that number doesn't change when you change reference frames. If the masses zero

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00:07:37.440 --> 00:07:44.580
Andre de Gouvea: The reason I'm talking about this is that the week interactions are famous for being maximally parody violating

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00:07:45.510 --> 00:07:53.100
Andre de Gouvea: That means that they only talk to left handed Cairo states or right handed Cairo anti states.

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00:07:53.880 --> 00:07:59.910
Andre de Gouvea: And in the case of neutrinos because they only get produced and effective via the weekend through actions. It turns out

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00:08:00.600 --> 00:08:10.920
Andre de Gouvea: That if we thought that the neutrino mass was exactly zero, the number of degrees of freedom that are required to describe everything related to neutrinos is actually two

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00:08:12.060 --> 00:08:27.450
Andre de Gouvea: And the idea is that means if the neutrino mass, where exactly zero and if it only interacted via the weekend directions, all of the neutrinos, you would ever produce in the universe ever with any physics process would be left handed. He lists city states.

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00:08:28.530 --> 00:08:40.440
Andre de Gouvea: And all of the anti neutrinos that you ever produced in the universe ever would be right handed states and we don't need to talk about the other states that you would consider having

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00:08:41.130 --> 00:08:49.560
Andre de Gouvea: Because if the neutrinos master list these states don't do anything and they don't interact. So they're as good as not existing

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00:08:50.880 --> 00:09:07.710
Andre de Gouvea: And I'll come back and I'll talk about this in the context of a distinguishing massive Mirena from to act neutrinos. Maybe at the end of the day. Today I'm finally the last property of neutrinos that I want to highlight for the same reason is that

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00:09:09.210 --> 00:09:11.880

Andre de Gouvea: Even if we ignore this business of flavor.

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00:09:13.260 --> 00:09:17.010
Andre de Gouvea: neutrino seem to carry a global charge called left on number

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00:09:18.270 --> 00:09:35.940
Andre de Gouvea: And that's an empirical fact and the empirical fact is if you assign leptin number plus to all negatively charged leptons in all neutrinos. And if you assign leptin number minus two all a positively charged leptons and all anti-neutrinos

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00:09:37.110 --> 00:09:44.070
Andre de Gouvea: The total left on number in any physics process is conserved. That means that if you start out with total left on number three.

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00:09:44.730 --> 00:09:55.380
Andre de Gouvea: And that's the evolves in time and you know particles interact and get destroyed and so on. At the end of the day, your state must have the same left. And number three, that we started with.

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00:09:56.490 --> 00:09:58.620
Andre de Gouvea: And these are all empirical facts.

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00:09:59.970 --> 00:10:10.470
Andre de Gouvea: And of course, you know, until the end of the last century, which by now it's been, you know, 20 years ago. This is all it took to understand everything that there was to understand about neutrinos.

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00:10:12.180 --> 00:10:21.330
Andre de Gouvea: Now the key point. And the reason neutrinos have gotten so popular is that this story is actually wrong. And that's what we found out at the turn of the century.

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00:10:21.810 --> 00:10:38.880
Andre de Gouvea: After quite a long time of a lot of very puzzling experimental results. And what we found out is that it turns out that in this picture. There is a caveat to this story here. And the story. Normally, is that

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00:10:40.290 --> 00:10:51.450

Andre de Gouvea: You have a charged current process you identify that an electronic Trina was detected. And then if that electronic neutrino hit something, it only knows how to produce electrons.

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00:10:52.050 --> 00:11:06.900
Andre de Gouvea: That story turns out to be not completely true. And the, the twist in the story is that if you wait long enough, it is possible to produce an electron neutrino and to detect it and some other flavor.

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00:11:08.190 --> 00:11:18.540
Andre de Gouvea: And this is the, this is what we discovered over the last many decades. And I think the picture crystallized only in the last 20 years or so.

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00:11:19.770 --> 00:11:29.400
Andre de Gouvea: Again, there will be lots of lectures that will talk about neutrinos, they will hopefully, and I'm sure they will talk about you know bits and pieces of

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00:11:29.910 --> 00:11:40.470
Andre de Gouvea: The vast number of neutrino experiments that have revealed to us that neutrinos can change flavor. Here's a very unfair description of everything.

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00:11:40.980 --> 00:11:56.370
Andre de Gouvea: And basically what we've discovered is that it is possible to be born as a meal on Neutrino but behave as 1000 Cree know when you get detected. That's what happens in accelerator experiments. That's what happens when we try to measure neutrinos produced in the atmosphere.

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00:11:57.810 --> 00:12:10.350
Andre de Gouvea: The sun as a factory of electronic neutrinos and we have discovered that some of these Nina's coming out of the sun, when they arrive, they behave like new on or thousand or create knows

72
00:12:11.130 --> 00:12:23.310
Andre de Gouvea: We've done experiments with React their anti neutrinos, which are all supposed to be electron anti neutrinos. And we also noticed that they have a probability of behaving like something that's not an electron neutrino.

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00:12:24.450 --> 00:12:36.480
Andre de Gouvea: And so there's a lot of other types of experiments and I'll show some bits and pieces of data here and there that have told us that as long as you wait long enough.

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00:12:37.590 --> 00:12:48.510
Andre de Gouvea: It is possible for the neutrinos to change flavor. So this is kind of the big deal. And this is a discovery that was solidified probably 1998 with the super K experiment.

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00:12:49.290 --> 00:12:59.130
Andre de Gouvea: They got the Nobel Prize for that, along with the snow experiment that saw the same type of phenomenon wine and atmospheric neutrinos. The other one sold them treatments.

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00:13:00.660 --> 00:13:06.810
Andre de Gouvea: Now the key point of this discovery when it comes to the physics and how we understand neutrinos is that

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00:13:07.710 --> 00:13:11.040
Andre de Gouvea: This observation which is it the neutrinos can change flavor.

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00:13:11.580 --> 00:13:21.510
Andre de Gouvea: After we take all the data and we analyze it together, it means for us, or the only interpretation that we've been able to come up with and explains everything

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00:13:21.990 --> 00:13:36.090
Andre de Gouvea: Is to postulate that the neutrinos have non zero mass. So that's what I'll talk about. So again, what the data is telling us is that if you allow the neutrinos time they can change flavor and

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00:13:37.170 --> 00:13:42.750
Andre de Gouvea: The only way that we can explain that physics is by postulating that neutrino masses are not zero.

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00:13:43.830 --> 00:13:45.330
Andre de Gouvea: So let me try to explain that.

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00:13:46.500 --> 00:14:00.810
Andre de Gouvea: In the usual way that I'm sure many of you have seen before because this is a very nice, very simple physics and it's relatively easy to grasp. If you only know ordinary quantum mechanics which everybody in this audience does very well.

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00:14:02.070 --> 00:14:08.580

Andre de Gouvea: So the idea is as follows. I told you about the electronic neutrino. The new on Neutrino in the town neutrino.

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00:14:09.480 --> 00:14:24.690
Andre de Gouvea: If we now raise the possibility that the neutrinos have mass. I can also label neutrinos according to their mass and and the label that we've devised over the years is to say that if I call my neutrino masters at 1am 2am three

85
00:14:25.980 --> 00:14:29.670
Andre de Gouvea: The neutrinos and have a well defined master called you one you too. And you three

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00:14:30.780 --> 00:14:49.320
Andre de Gouvea: So that's the name so we didn't have to invent a more weird names. So we're using 123 here. And of course, you can ask yourself. Okay, now that I know that you know neutrino number one has mass and one in Katrina. Number two, has mass him to and so on. What's the electron neutrino.

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00:14:50.910 --> 00:14:54.660
Andre de Gouvea: And the key idea is that the most general thing that you can conceive.

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00:14:55.680 --> 00:15:00.750
Andre de Gouvea: Is that the electronic neutrino is not new one new to or new tree.

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00:15:01.200 --> 00:15:10.410
Andre de Gouvea: But the most general thing is that the electron neutrino is a linear superposition, or a linear combination of material. Number one or number two in neutrino number three.

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00:15:10.980 --> 00:15:14.220
Andre de Gouvea: The same is true for the meal on between now and the town for, you know,

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00:15:15.120 --> 00:15:24.990
Andre de Gouvea: So you have a relationship that looks like this. And it says that, you know, new a new a new cow our linear super positions of new one you to a new tree.

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00:15:25.770 --> 00:15:36.930

Andre de Gouvea: And the coefficients of these different linear super positions they define a unitary matrix that's easy to understand, because again, if you have one electron neutrino.

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00:15:37.590 --> 00:15:55.110
Andre de Gouvea: The probability that that one. Electron Neutrino is an Electron keno is 100% so that tells you that the US squares add up to one. And of course, I also said that an electron neutrino is not immune to that says that if you take

94
00:15:56.400 --> 00:16:06.030
Andre de Gouvea: Combinations of these huge coefficients that correspond to different flavors. When you, when you multiply them together and you add up with the coefficients on the also add up to zero.

95
00:16:06.690 --> 00:16:13.530
Andre de Gouvea: And I'll share more about this matrix later. So that's the general idea is that if you have neutrinos well defined masses.

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00:16:14.040 --> 00:16:28.110
Andre de Gouvea: The most general thing you can decide is that the interaction. I can states are really linear super positions of the mass heightened states. Why is this important, this is important because when you calculate neutrino propagation

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00:16:29.160 --> 00:16:32.880
Andre de Gouvea: The mass eigen states they are actually just

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00:16:33.900 --> 00:16:36.240
Andre de Gouvea: I can stay to the propagation Hamiltonian

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00:16:37.590 --> 00:16:39.180
Andre de Gouvea: And this is what I wrote down here.

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00:16:40.260 --> 00:16:50.880
Andre de Gouvea: For us what it means to be a mass eigen state is that if you're produced as a mess heightened state. And I asked you, How does that state evolve in space and time.

101
00:16:51.390 --> 00:17:07.980
Andre de Gouvea: The mass eigen state is the thing that propagates like a plane wave and it's time evolution if somehow it we're sitting there at rest would be this regular short in your lifetime of evolution, you know, you're just pick up on either the minus i, et kind of evolution.

102
00:17:09.660 --> 00:17:17.610
Andre de Gouvea: And here's where it's easy to understand why neutrinos flavor neutrino flavors can change and I'll do an explicit example of that.

103
00:17:18.150 --> 00:17:24.990
Andre de Gouvea: by pretending that the town of Reno doesn't exist because that makes life easier. And it's easier to write down the equations that way.

104
00:17:25.530 --> 00:17:35.220
Andre de Gouvea: So, this equation here says that the electronic neutrino is a linear combination of new one and you too, because I'm assuming for now that the town Fino doesn't exist.

105
00:17:35.820 --> 00:17:47.310
Andre de Gouvea: The mural neutrinos also a linear combination of new one and you to these coefficients here in square have to add up to one. So it's convenient to call them sign data and cosine data.

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00:17:48.120 --> 00:17:54.750
Andre de Gouvea: The same thing goes for the new new state. But of course, because then you we and then your new states are orthogonal to one another.

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00:17:56.220 --> 00:17:57.240
Andre de Gouvea: This entire

108
00:17:58.440 --> 00:18:02.550
Andre de Gouvea: All of these linear combinations can be described in terms of one parameter called data.

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00:18:03.870 --> 00:18:12.030
Andre de Gouvea: Now what's important is that if you produce an electron neutrino and you ask, how does an electron neutrino evolve in space and time.

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00:18:12.810 --> 00:18:20.460
Andre de Gouvea: The key point is that the electron neutrinos, not an Eigen state of the Hamiltonian. That means that as this initial condition evolves.

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00:18:20.940 --> 00:18:28.560

Andre de Gouvea: These different components of the electron neutrino are eigen state to the Hamiltonian. They each pick up a different phase.

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00:18:29.100 --> 00:18:37.290
Andre de Gouvea: And the state that you're left with it and I'm writing things down in some Lorenz invariant way by assuming that the neutrinos propagate in space and time.

113
00:18:37.650 --> 00:18:43.800
Andre de Gouvea: Is that the new one component picks up a phase then you to component picks up a different phase.

114
00:18:44.310 --> 00:19:01.470
Andre de Gouvea: Which means that after the neutrino has propagated some distance, the state that you have is no longer an electron neutrino and it's not an electron neutrino time some either the I something. It's a different state and that state has a non zero overlap with them you on between

115
00:19:02.790 --> 00:19:09.510
Andre de Gouvea: This is a calculation, it's very, very easy to do. And we also like to make an extra approximation that

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00:19:10.050 --> 00:19:21.930
Andre de Gouvea: The neutrinos have an energy that's way, way bigger than the mass that's always true in any laboratory experiment, you can ever design. And if you make that approximation. You can write down

117
00:19:23.520 --> 00:19:30.390
Andre de Gouvea: The probability that you're born as an electron neutrino but are measured as a new on Neutrino as a function of the distance

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00:19:31.440 --> 00:19:37.320
Andre de Gouvea: And you end up with this very neat very, very famous expression that says that that probability

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00:19:38.640 --> 00:19:46.320
Andre de Gouvea: evolves as a sine wave in time in space in our, in our language and you have a frequency that's proportional to the fact

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00:19:46.740 --> 00:19:57.240
Andre de Gouvea: That the new one and the new two are not the same particle. I mean, they don't have exactly the same properties, which means that in our language, it means that they have different masses that the

121
00:19:58.140 --> 00:20:05.940
Andre de Gouvea: The number that you care about is the fact that or the frequency of the oscillation is proportional to the difference of the masses squared.

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00:20:07.080 --> 00:20:12.600
Andre de Gouvea: And finally, the other piece of the puzzle is the amplitude of the oscillation has to do with

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00:20:13.620 --> 00:20:24.180
Andre de Gouvea: How much of a mess. I can state the electronic Reno is not so its parameters, but this parameter theta. And of course if data had been zero

124
00:20:25.080 --> 00:20:34.020
Andre de Gouvea: You can notice that the electronic Trina would have been a mess. I can state so we wouldn't expect any flavor change. And if data had been tied over to

125
00:20:34.560 --> 00:20:48.180
Andre de Gouvea: The electronic Trina would also be a mass heightened state you also would not expect any flavor oscillations. But if data is anything which is not zero, or over to them the electronic neutrinos not American states. So, you expect these flavor or selections.

126
00:20:49.380 --> 00:20:49.740
Andre de Gouvea: And

127
00:20:51.300 --> 00:20:59.490
Andre de Gouvea: This is the idea. We can make a plot of that we expect, then that's something that's born as an electron neutrino has zero probability

128
00:20:59.940 --> 00:21:12.300
Andre de Gouvea: Of being measured as a neutrino if you wait long enough, the probability gets bigger and then it starts on moving up and down, and that's why this phenomenon is called neutrino oscillations because these probabilities oscillate.

129
00:21:13.380 --> 00:21:25.260
Andre de Gouvea: So if you stare at this. There are two things you can measure one is the amplitude of the oscillation. The other one is the wavelength of the oscillation. And these are these determine

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00:21:26.370 --> 00:21:36.510
Andre de Gouvea: And these are governed by this amplitude, which is science quarter to theta and the oscillation length is proportional to this differences of the neutrino massive square

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00:21:37.560 --> 00:21:54.300
Andre de Gouvea: Know dealt them squares and science square to data as our, our fundamental parameters. So we don't know what they are. But by doing these types of experiments we actually measure these are mixing angles and these email templates.

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00:21:56.310 --> 00:22:06.090
Andre de Gouvea: I want to pause here and let people know that this story is a very over overly simplified story. There are lots of holes in the story that I just told you.

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00:22:06.600 --> 00:22:16.470
Andre de Gouvea: If you're paying attention. You are supposed to be very confused and you and everybody else has always been very confused about this. There's a lot of literature on

134
00:22:17.130 --> 00:22:26.490
Andre de Gouvea: How exactly neutrino oscillations work. The good news are that what I told you before is correct in terms of getting the right answer.

135
00:22:27.180 --> 00:22:36.750
Andre de Gouvea: And a lot of very smart people have looked at this issue in a lot of detail. Some people have become very confused and they have confused everybody else.

136
00:22:37.320 --> 00:22:47.400
Andre de Gouvea: But there's some nice reviews. There's a rather comprehensive one by these people here and a couple of other collaborators. I think they have a couple more recent

137
00:22:47.850 --> 00:23:01.020
Andre de Gouvea: References as well and and I want to just give you a feel for what does it take for neutrino oscillations to to work and what does it take for the story that I told you to be correct. And what it takes is the following.

138
00:23:02.040 --> 00:23:07.290
Andre de Gouvea: Up. What we really need is that when you produce a neutrino.

139
00:23:08.340 --> 00:23:18.120
Andre de Gouvea: The state that you produce really has to be a coherent superposition of mass eigen states. This is the key point is that every time a neutrino gets produced

140
00:23:18.690 --> 00:23:31.320
Andre de Gouvea: If you can claim that that object is a coherent superposition of mass eigen states, then you have a necessary conditions for neutrino oscillations, that's step number one.

141
00:23:32.550 --> 00:23:39.000
Andre de Gouvea: Again, the key word is going to be coherence and then neutrino has to propagate in space and time.

142
00:23:39.780 --> 00:23:49.110
Andre de Gouvea: And that propagation process has to maintain the coherence, that means that coherence is not lost as the neutrino evolves in space and time.

143
00:23:49.740 --> 00:23:57.990
Andre de Gouvea: This is not a done deal. It's not guaranteed, but it happens to be true in all experiments we've ever done where we've seen between oscillations.

144
00:23:58.440 --> 00:24:08.040
Andre de Gouvea: But it's also something else to worry about. And finally, the last thing, which helps guarantee that these other two things are always through is that

145
00:24:08.580 --> 00:24:14.940
Andre de Gouvea: The neutrino energies are way bigger than the neutrino masses and write off a restroom is useful.

146
00:24:15.690 --> 00:24:23.370
Andre de Gouvea: Again, everything is Lorenz invariant, in the sense that you can repeat all arguments in any reference frame that you like.

147
00:24:24.090 --> 00:24:38.580
Andre de Gouvea: As is true with most cases. If you pick the an easy reference frame. It's easy to understand how things work. If you pick a weird reference frame, you should still get the same answer, but understanding how things work just gets harder.

148

00:24:39.810 --> 00:24:56.130
Andre de Gouvea: So that's that that's that that's a quick summary of what it takes to do neutrino oscillations. Now, the reason we don't spend a lot of time talking about this is that for all terrestrial types of experiments and a lot of other types of experiments that we care about.

149
00:24:57.540 --> 00:25:16.560
Andre de Gouvea: The neutrinos are a perfectly coherent linear superposition of new one, you two and three, and they don't lose that coherence, as they propagate in in space and time. So that's a question that often gets asked since I don't get to see you and you don't get to ask questions. I have to be

150
00:25:17.940 --> 00:25:32.250
Andre de Gouvea: preemptive and that's sort of what I'm trying to do. Okay. So I want to show you a little bit of data. For example, this is a atmospheric neutrino data. These are neutrinos produced in the atmosphere and detected in supercomputer kinda experiment.

151
00:25:33.330 --> 00:25:48.030
Andre de Gouvea: What's really cool about this is that they're all these different measurements. I want to concentrate on this one that has a little bit of read text in it, and the two lines. We went to look at is, there's a solid line. That's what you predict for

152
00:25:49.110 --> 00:25:59.040
Andre de Gouvea: The number of new on Aquino's you should see as a function of the direction from which they're coming so of course I'm data equals one. These are neutrinos coming from above.

153
00:25:59.670 --> 00:26:07.770
Andre de Gouvea: The are produced on average about 50 kilometers away and cosine paid equals minus one, these hundred trials that come from the ground.

154
00:26:08.280 --> 00:26:24.840
Andre de Gouvea: They're actually produced in the atmosphere, you know, more than 12,000 kilometers away on the other side of the earth, and because the neutrino interactions are so weak. We expect the flux of neutrinos to be up and down symmetric modules some weird effects that I don't want to talk about

155
00:26:26.790 --> 00:26:39.960
Andre de Gouvea: But the point is, this is what you predict and the data points are these data points with error bars and you notice how the prediction is completely wrong. And you see that the solid line does not agree with the data.

156
00:26:41.250 --> 00:26:48.930
Andre de Gouvea: On the other hand, if you assume that the neutrinos oscillate. According to the formula that I just arrived, which is a

157
00:26:49.500 --> 00:26:59.730
Andre de Gouvea: There was a non zero probability that you're a barn ism Yuan neutrino. But you're the fact that is something else which is not a new one cream. Oh, that means you don't show up on this panel here.

158
00:27:00.240 --> 00:27:18.720
Andre de Gouvea: If you take this expression here and you choose the value of science core to data to be about one and you choose the value of delta x squared to be about a few times 10 to the minus three electron volts squared, you get this dotted line and you see that that fits the data really well.

159
00:27:19.740 --> 00:27:26.400
Andre de Gouvea: So that's why we're pretty convinced that that's the phenomenon that explains what's called the atmospheric neutrino puzzle.

160
00:27:27.000 --> 00:27:31.920
Andre de Gouvea: I don't want to dwell on these very old data, but I do want to say that over the years, we've done a lot

161
00:27:32.370 --> 00:27:40.710
Andre de Gouvea: Of other experiments with new on neutrinos. We've been doing these experiments today as we speak. There was the nerve experiment that's running at Fermilab

162
00:27:41.340 --> 00:27:52.290
Andre de Gouvea: There was a teen okay experiment running in Japan and all of these experiments that have new entrepreneur beams, the travel very long distances, they see this

163
00:27:52.950 --> 00:27:59.130
Andre de Gouvea: Disappearance of new on tree knows they can all be properly explained by neutrino oscillations.

164
00:27:59.550 --> 00:28:09.210
Andre de Gouvea: And one thing which I really like to, to point out is if you look at these plots in the bottom. These are very old plots and I'm not saying I will show you what the numbers look like in a minute.

165

00:28:09.720 --> 00:28:17.100
Andre de Gouvea: But even in these very old plots. What's really impressive about these plots, is that if you take the data from atmospheric neutrinos.

166
00:28:17.670 --> 00:28:26.250
Andre de Gouvea: You get these a pink magenta color contour assess the allowed regions of the parameter space so that you can explain all of the atmospheric and cleaner data.

167
00:28:27.150 --> 00:28:33.150
Andre de Gouvea: On the flip side, if you do something like the muse experiment which stopped reading it from the lab, a few years ago.

168
00:28:33.780 --> 00:28:44.160
Andre de Gouvea: And you look at the disappearance of those neutrinos and you interpret those data in terms of neutrino oscillations D allowed region of the parameter spaces, this sort of smiley face.

169
00:28:44.760 --> 00:28:50.430
Andre de Gouvea: Regions and the thing that's most impressive. And the reason we're very short neutrino oscillations are correct.

170
00:28:50.880 --> 00:29:08.790
Andre de Gouvea: Is the fact that those two very different types of experiments, a point to the same region of parameters speaks so chances are that because those two you know contours agree with one another. Very well. It means that we know what we're doing. So neutrino oscillations are really a thing.

171
00:29:10.920 --> 00:29:19.380
Andre de Gouvea: I want to spend a little bit of time talking about more subtle phenomena that have to do neutrino oscillations, because that's important.

172
00:29:19.980 --> 00:29:36.570
Andre de Gouvea: And it is something that we're sensitive to. And it's also decisive when it comes to explaining how solar neutrinos change flavor. So I'll talk about that a little bit. It's called matter effects and the first thing that's easy to do, is that, remember I told you how

173
00:29:38.070 --> 00:29:56.670
Andre de Gouvea: These mass Sagan states evolve as a function of time. I also told you that if you assume that they're ultra relativistic I can also, I can trade off time evolution floor evolution in the laboratory frame in space and I can express that as a shorting or equation.

174
00:29:57.810 --> 00:30:05.130
Andre de Gouvea: So that means that a mass second state, which is an Oregon State of the Hamiltonian will evolve in in this

175
00:30:06.420 --> 00:30:13.020
Andre de Gouvea: Space this a baseline space, which I call L. According to something that looks exactly like a shortened great equation.

176
00:30:13.860 --> 00:30:21.510
Andre de Gouvea: And of course these are I can stay to the Hamiltonian and and of course we know how to solve this equation. If you start out as an electronic as a

177
00:30:21.900 --> 00:30:25.680
Andre de Gouvea: As a neutrino. Number one, you will just pick up an overall phase.

178
00:30:26.610 --> 00:30:39.450
Andre de Gouvea: And of course we can treat the 123 neutrinos, or the EMU town neutrinos as a basis for describing neutrinos, so we can rotate from the mass basis to the flavor basis.

179
00:30:39.930 --> 00:30:46.290
Andre de Gouvea: And we can do that here. And at the end of the day, if we express neutrinos in the electron new on basis.

180
00:30:46.770 --> 00:30:55.980
Andre de Gouvea: We can write down the time of order the baseline evolution of these States according to what what literally looks like a two level system and quantum mechanics.

181
00:30:56.580 --> 00:31:03.180
Andre de Gouvea: So for example, this a savvy this number squared is the probability that you behave like an electron Reno.

182
00:31:03.870 --> 00:31:18.450
Andre de Gouvea: And SMU that number squared is the probability that you behave like I'm you are neutrino and the time evolution of this doublet, or this neutrino state in a flavor space is governed by this very, very simple Hamiltonian

183
00:31:19.470 --> 00:31:27.930

Andre de Gouvea: If we solve this system here. And if we assume that the initial conditions are an electron neutrino which is the one zero state.

184
00:31:28.470 --> 00:31:41.250
Andre de Gouvea: And we ask, what's the probability that behaves as a mule on Neutrino which is the 01 state after a certain baseline of a certain size we would get exactly this expression that I wrote down here.

185
00:31:42.240 --> 00:31:52.140
Andre de Gouvea: Okay. And again, the reason this is a nice thing to do is because this looks exactly like a two level system and quantum mechanics. We're all experts on that even if we don't remember how to do it.

186
00:31:52.800 --> 00:32:04.380
Andre de Gouvea: And the other reason we talked about this is that when you allow for the fact that the neutrinos interact with the matter to which they propagate. You can take those effects into account very easily.

187
00:32:05.880 --> 00:32:11.490
Andre de Gouvea: So matter of facts are easy to understand. I can take the neutrino Hamiltonian

188
00:32:12.390 --> 00:32:26.610
Andre de Gouvea: And I can look at, for example, how the electronic reno interacts with the electron via W exchange and I can write that term in a funny way by having it looked like a neutral current by doing a fierce rearrangement of my Hamilton my Lagrangian

189
00:32:28.110 --> 00:32:49.530
Andre de Gouvea: So this is my Lagrangian now and now the next question I can do is let's calculate da the Iraqi equation for a neutrino taking these interactions into account but treating this electronic background as a as a gas of electrons at rest in a particular reference frame.

190
00:32:50.760 --> 00:32:59.910
Andre de Gouvea: That means that if, when I define my one between of state, I need to calculate this expectation value of this time electron neutrino operator.

191
00:33:00.540 --> 00:33:13.770
Andre de Gouvea: And that operator, if you remember it is proportional to the electron number then city, the capital and sub E, which is the electron number operators, a dagger. He if you remember

192
00:33:15.810 --> 00:33:24.840
Andre de Gouvea: Of course, I'm assuming that these electrons are rest. So the only non trivial component is the time component, the space components with the measures of

193
00:33:25.320 --> 00:33:32.070
Andre de Gouvea: Electron currents and we're assuming that these electrons are not moving around. And then for good measure, we get a factor of two.

194
00:33:32.670 --> 00:33:41.970
Andre de Gouvea: Because the neutrinos only talked to the left, to the left handed components of the electrons. So, in the presence of this electron background.

195
00:33:42.450 --> 00:33:53.610
Andre de Gouvea: My one neutrino state or base out direct equation that looks like this. This is a modified the equation, it's not the direct equation that we're familiar with, but it's pretty similar.

196
00:33:54.720 --> 00:34:06.420
Andre de Gouvea: And it turns out that this extra term that we get it looks like a potential in the classical quantum mechanics keys. So we call that the matter potential

197
00:34:07.380 --> 00:34:17.820
Andre de Gouvea: And we can solve this problem, especially in the limit where the energy is very large. And basically what we get for this direct equation here is we get a

198
00:34:18.690 --> 00:34:27.540
Andre de Gouvea: On a screen. Oh, that looks like a regular neutrino except that it's dispersion relation, instead of being e squared equals C squared minus x squared.

199
00:34:27.990 --> 00:34:37.230
Andre de Gouvea: It's something and I'm neglecting the mass here, it's something different. It becomes the energy is done momentum plus this matter potential

200
00:34:37.950 --> 00:34:43.830
Andre de Gouvea: And the other thing that's very important is that the matter potential cares about whether you have neutrinos and aunt or anti neutrinos.

201
00:34:44.310 --> 00:34:53.040
Andre de Gouvea: If it's an amino interacting the matter potential has a plus sign. If it's an anti neutrino interacting the matter potential has a minus sign.

202
00:34:53.520 --> 00:35:09.240
Andre de Gouvea: So long story short, what if scenarios are propagating through electrons. Their dispersion relation is not energy equals momentum in the limit where the masses zero but it's more like energy equals momentum, plus some other turn

203
00:35:10.350 --> 00:35:18.420
Andre de Gouvea: Now, if you're confused by this, the exact same thing happens to photons propagating and matter when I focus on propagates and matter.

204
00:35:19.500 --> 00:35:28.170
Andre de Gouvea: We like to say that the photon dispersion relation changes. If you remember, you know, classic optics we say that the photon velocity changes.

205
00:35:28.530 --> 00:35:37.830
Andre de Gouvea: Inside of the matter. And that's because the photons. Feel the electromagnetic fields generated by all of the charged particles inside of the matter.

206
00:35:38.220 --> 00:35:55.440
Andre de Gouvea: And and that interaction makes the dispersion relation of the photon change. The same is true of a neutrino as the neutrinos are propagating to matter. They feel, you know, the week field of all electrons and everything else that's in the matter and the dispersion relations change.

207
00:35:56.460 --> 00:36:01.110
Andre de Gouvea: So if you don't like any of this all that we care about is the fact that are

208
00:36:02.250 --> 00:36:07.950
Andre de Gouvea: Schrodinger equation that used to be just this first term here are Hamiltonian now gets an extra term.

209
00:36:08.520 --> 00:36:15.330
Andre de Gouvea: And this extra term big. The reason we care about that is that the extra term is special for the electronic neutrinos.

210
00:36:15.780 --> 00:36:27.840
Andre de Gouvea: And it's more of a nila for them. You and and thousand trios, and the reason is the following the electron NEW ONE AND OUR neutrinos all have neutral current interactions. So those interactions are the same for all the flavors.

211
00:36:29.250 --> 00:36:30.480
Andre de Gouvea: We don't care about

212
00:36:32.550 --> 00:36:39.150
Andre de Gouvea: Terms in our Hamiltonian which are proportional to the identity matrix. That means that these mutual current interactions. Don't do anything.

213
00:36:39.900 --> 00:36:51.150
Andre de Gouvea: But the electron neutrino has a special relationship with electrons because of the charge card interaction. That means that they get an extra potential when they're propagating through matter.

214
00:36:51.780 --> 00:37:00.690
Andre de Gouvea: And as far as we're concerned, what happens for us is that our Hamiltonian now looks like this. And this capital A. Here is the thing that we call the matter potential

215
00:37:02.340 --> 00:37:09.420
Andre de Gouvea: So now the quantum mechanics problem that we have to solve is if you're born as an electron neutrino and you're propagating through matter.

216
00:37:10.590 --> 00:37:17.040
Andre de Gouvea: You're the Hamiltonian that describes how you evolve as this one. And that turns out to make the problem much harder.

217
00:37:18.180 --> 00:37:23.850
Andre de Gouvea: Now what makes it harder, of course, is that as you're propagating through matter.

218
00:37:24.870 --> 00:37:33.270
Andre de Gouvea: This matter potential is proportional to the electron number then city. So if the electron number density changes as your propagating

219
00:37:34.260 --> 00:37:42.420

Andre de Gouvea: That's equivalent to having a time dependent Hamiltonian and we know that time dependent Hamiltonian are harder to solve.

220
00:37:43.260 --> 00:37:52.140
Andre de Gouvea: Again, this is only a two by two system. So I think we are pretty sure we could solve the two by two time dependent Hamiltonian. Sometimes the answer is very ugly.

221
00:37:52.920 --> 00:38:06.120
Andre de Gouvea: But, but that's the challenge. And that's what the matter effects will do. And the key point is that they will clearly change the oscillation. Okay, so that's the message that I think you want to take from this and

222
00:38:08.370 --> 00:38:20.880
Andre de Gouvea: Well, in some cases, the problem is very easy to solve one case when it's very easy to solve is that if this number of a or the electron number density in the medium as a function of the distance is a constant.

223
00:38:21.930 --> 00:38:28.830
Andre de Gouvea: In that case, I'm not going to go through the details, but you can solve the system. Exactly. It's a trivial problem.

224
00:38:29.310 --> 00:38:38.580
Andre de Gouvea: And what's really neat is that you can write the answer in the same way that we wrote down the vacuum oscillations. So it's some science quote have to theta.

225
00:38:38.940 --> 00:38:56.400
Andre de Gouvea: Then some science squared of l m squared L over 40 I can write the answer in exactly the same form, except that my amplitude is a little bit different, it's impacted by the matter and my oscillation frequency or oscillation link is also impacted by the matter.

226
00:38:57.690 --> 00:39:05.490
Andre de Gouvea: So this is what happens. There's another feature here that's very exciting is that and I've already said this neutrinos and anti-neutrinos behave differently.

227
00:39:06.720 --> 00:39:18.480
Andre de Gouvea: So this is what I plot here. So for example, if I had been pinos propagating and vacuum, they would have a nice oscillation probability that looks like this, and read curve in the middle.

228

00:39:19.890 --> 00:39:27.930
Andre de Gouvea: On the other hand, if the neutrinos were propagating and matter. It could be that the neutrinos will propagate like the blue curve.

229
00:39:28.470 --> 00:39:38.820
Andre de Gouvea: And the anti neutrinos will propagate like the black curve and which one is which depends a little bit on the relative signs between the matter potential

230
00:39:39.210 --> 00:39:53.400
Andre de Gouvea: Which is positive for neutrinos negative for anti neutrinos and this particular combination here of mixing parameters. And this has to do with the delta x squared and the cosine of two times the mixing angle.

231
00:39:54.630 --> 00:40:02.880
Andre de Gouvea: And what this means is that depending on whether a and delta times cosine of to data have the same plus or minus sign.

232
00:40:03.480 --> 00:40:13.260
Andre de Gouvea: Then these two things will add for an pre nose and subtract for anti neutrinos. If it's the other way around, then the anti-neutrinos will do within three knows what to do, and vice versa.

233
00:40:14.310 --> 00:40:16.830
Andre de Gouvea: This is kind of exciting because uh

234
00:40:17.880 --> 00:40:32.520
Andre de Gouvea: Yeah, I'll talk about this because it's something that people often don't talk about. So let me go back to this expression here. And if you look at this probability here it's proportionate to science part of to theta. And you can ask, what's the physics in that

235
00:40:33.540 --> 00:40:41.460
Andre de Gouvea: And the physics is in this expression for the new and the new Mew and basically the what what you want to keep in mind is that

236
00:40:41.880 --> 00:40:52.140
Andre de Gouvea: You can ask the question, you know, is the electronic reno more in your one then you to or vice versa. And that's what cosine of theta is a parameter rising

237
00:40:52.710 --> 00:41:01.350

Andre de Gouvea: So of course sign of theta is bigger than, of course, is quoted as bigger than one half. Then the new way is more new one. The new to

238
00:41:02.310 --> 00:41:07.830
Andre de Gouvea: And if science cart data is bigger than one half. Then the new mew was more new one than YouTube

239
00:41:08.490 --> 00:41:15.840
Andre de Gouvea: Of course I didn't tell you what NEW ONE AND YOU TWO ARE SO WE CAN PICK, for example, new to to be heavier and you want to be lighter

240
00:41:16.260 --> 00:41:26.250
Andre de Gouvea: So basically you know this parameter data tells you something that's physical, which is, you know, as the electronic Trina more likely to be light, or is it more likely to be heavy

241
00:41:27.300 --> 00:41:34.440
Andre de Gouvea: And if you do oscillations and vacuum. You can't answer that question, because if you exchange sine and cosine

242
00:41:35.190 --> 00:41:46.560
Andre de Gouvea: You still get the same oscillation probability. But if you're doing oscillations and matter. It turns out that the matter knows whether the electronic Reno is more present in the

243
00:41:47.100 --> 00:42:03.930
Andre de Gouvea: Heavy state or whether it's more present in the light state, so that's that's that's kind of the key point and I it's a simple point, but it's a very important point. And it's related to one of the questions we're trying to answer now and I'll hopefully get to that in a little bit.

244
00:42:05.220 --> 00:42:15.210
Andre de Gouvea: Okay. So I talked about that. If you want to try to explain solar neutrinos, you actually have to solve the problem in a time dependent Hamiltonian or in a

245
00:42:15.600 --> 00:42:25.890
Andre de Gouvea: Position the feminine Hamiltonian, because if you neutrinos are born inside of the sun and the propagate out and if you don't know about this, you're learning it now.

246
00:42:26.730 --> 00:42:34.050

Andre de Gouvea: The density of matter in the sun kind of decreases exponentially. So in the center of the sign is super dense.

247
00:42:34.620 --> 00:42:46.320
Andre de Gouvea: Outside of the sun. There's no density and the connection is exponential. So the matter potential is changing exponentially. And it turns out that we've learned how to solve this problem.

248
00:42:47.340 --> 00:43:03.330
Andre de Gouvea: And I don't want to go through how this works, unless people ask, but the the physics turns out to be. I tried to explain it in some cartoons here which will not be very useful actually lucky. Let me do this. This is way more fun than the other stuff was going to talk about

249
00:43:06.180 --> 00:43:08.760
Andre de Gouvea: Okay, so let me spend five minutes on this.

250
00:43:10.080 --> 00:43:17.610
Andre de Gouvea: So remember, this is our Hamiltonian and we want to describe how the system evolves under this Hamiltonian here.

251
00:43:18.840 --> 00:43:30.240
Andre de Gouvea: And I haven't a parameter that that's position dependent. But one thing that I can do is I can, I can certainly diagonal lines this Hamiltonian for any value of the parameter a

252
00:43:31.650 --> 00:43:38.100
Andre de Gouvea: And I can write down what the eigenvalues are as a function of this parameter eight and this is what they look like.

253
00:43:38.790 --> 00:43:51.450
Andre de Gouvea: There are two eigenvalues. There's a big one and a small one on this line here. The top line is the behavior of the largest eigenvalue as a function of the a parameter

254
00:43:51.960 --> 00:44:02.580
Andre de Gouvea: Remember the parameters, the electron number density in the lower argument value is also a function of the a parameter and it has the slower line over here.

255
00:44:03.270 --> 00:44:12.120

Andre de Gouvea: If you remember old quantum mechanics stuff. This is called the level crossing diagram because it looks like two lines that want to cross, but they don't because the

256
00:44:12.720 --> 00:44:19.260
Andre de Gouvea: The definition of heavy and light is always that the heavier, one is heavier than the lighter one so they kind of go like this.

257
00:44:20.220 --> 00:44:29.250
Andre de Gouvea: And the reason we like to talk about. This is the following. If we go back to this Hamiltonian and we ask, What are the eigenvalues of this Hamiltonian

258
00:44:29.820 --> 00:44:38.940
Andre de Gouvea: Then, the problem is harder, but if I asked you what's the Eigen value of this Hamiltonian. When the parameters, big, that means that the a parameter

259
00:44:39.390 --> 00:44:47.220
Andre de Gouvea: Is much bigger than this delta x squared over. He then the Hamiltonian is mostly this term over here, you know, the ether.

260
00:44:48.030 --> 00:44:55.980
Andre de Gouvea: And if you remember, this isn't the EMU basis. That means that the electronic neutrinos actually and I can state of the Hamiltonian. When the a parameter is very large.

261
00:44:56.880 --> 00:45:09.450
Andre de Gouvea: So with this in mind, we can talk about solar neutrinos, imagine that in the center of the sun. It's very dense. So when when the electronic Trina was born. It is born as and I can say to the Hamiltonian

262
00:45:10.800 --> 00:45:28.800
Andre de Gouvea: Now this electronic Trina has to propagate out of the sun and the way that it does that, of course, is that as it's propagating out the a parameter is getting smaller, so that the Eigen stated the Eigen value of the Hamiltonian is following these red lines.

263
00:45:30.000 --> 00:45:43.830
Andre de Gouvea: Now the key point, which is a which you have to trust me is that it turns out that the evolution of this electronic reno state for the most part, is what's called a diabetic. What this means is that

264
00:45:44.910 --> 00:45:57.390

Andre de Gouvea: The system evolves slowly enough that if you are an Oregon State of the Hamiltonian you stay an Eigen state of the Hamiltonian throughout the entire time evolution.

265
00:45:58.230 --> 00:46:06.300
Andre de Gouvea: Of course, the state changes because the I can say to the Hamiltonian are changing, but your property of being an egg and state of the Hamiltonian doesn't change.

266
00:46:06.870 --> 00:46:15.000
Andre de Gouvea: That means that if the you're born as a heavy. I can stay with the Hamiltonian, you're going to remain a heavy. I can state of the Hamiltonian through out

267
00:46:15.480 --> 00:46:22.470
Andre de Gouvea: Until you exit the sun, when a is equal to zero. And of course, you don't get to go through negative values of A, because

268
00:46:23.070 --> 00:46:30.210
Andre de Gouvea: You don't see that. But the point is you're born as an Eigen state of the Hamiltonian and you exit as an Eigen state of the Hamiltonian

269
00:46:31.200 --> 00:46:39.300
Andre de Gouvea: And the key point is we know what what's the ag instead of the Hamiltonian when you don't have any matter. These are just a mess. I can states.

270
00:46:39.660 --> 00:46:57.090
Andre de Gouvea: That means that if this process is going on the prediction that we make is that if the density is high enough, an electron neutrino born in the center of the sun will exit the sun as an Eigen state of the Hamiltonian and not just any I can state of the Hamiltonian, but the heavier one

271
00:46:58.320 --> 00:47:09.870
Andre de Gouvea: And that's what the matter effects are doing. It's a very dramatic effect because after you leave the sign as a mass eigen state you stay a mess. I can state forever until the detector eat you up.

272
00:47:10.890 --> 00:47:24.450
Andre de Gouvea: And that's kind of what happens you know you're born as an electron neutrino you exit the sun as a new to the heaviest mass side and state, the probability that you're the tech. That is an electron neutrino. She was given by saying squirt data.

273
00:47:25.620 --> 00:47:32.400
Andre de Gouvea: And people got super excited about that for lots of reasons. One reason is that this pretty much doesn't depend on the energy

274
00:47:32.940 --> 00:47:40.740
Andre de Gouvea: As long as the approximation that we made here is correct and people also got excited because this is a good way of explaining

275
00:47:41.340 --> 00:47:51.600
Andre de Gouvea: A survival probability that's less than one half. If you think about vacuum oscillations. You know, the average value of the sign squared function is about a half

276
00:47:52.230 --> 00:47:58.050
Andre de Gouvea: And if you're always doing one minus something times a half, you always get a survival probability that's bigger than a half

277
00:47:58.590 --> 00:48:05.070
Andre de Gouvea: To get a survival probability that smaller than a half is harder. So people got very excited about this.

278
00:48:05.970 --> 00:48:14.400
Andre de Gouvea: And I'm not going to talk about this detail, but the main point is that we have a prediction for how the solar neutrinos were supposed to oscillate.

279
00:48:15.270 --> 00:48:20.280
Andre de Gouvea: I just want to show this here. So basically, this says, you know, if the energy is high enough.

280
00:48:20.790 --> 00:48:27.600
Andre de Gouvea: That's when this idiomatic approximation works very well you expect that kind of flat survival probability

281
00:48:28.140 --> 00:48:35.280
Andre de Gouvea: If the energy is very small. It turns out that these matter of facts don't matter. They're kind of irrelevant. You get averaged out oscillations.

282
00:48:35.670 --> 00:48:47.550
Andre de Gouvea: So you'd expect the curve that looks like this dotted blue curve here and the points are the data points. And you see how they

explain the data very, very well. There's some details which I don't want to tell you about because they're not

283
00:48:49.110 --> 00:48:52.800
Andre de Gouvea: Important for us right now, but I want to skip that and I'm going to skip this as well.

284
00:48:53.970 --> 00:49:02.400
Andre de Gouvea: The most important thing I want to say is that we have evidence of the same phenomenon on the earth. That's the camera and experiment. It's an experiment with

285
00:49:03.270 --> 00:49:12.180
Andre de Gouvea: Reactor anti-neutrinos they block things as a function of hello very you get the super nice ocelot. Are you looking curve which is amazing.

286
00:49:12.900 --> 00:49:20.970
Andre de Gouvea: And what's even more amazing is that if you take the oscillations interpretation of the solar data and the camelon data.

287
00:49:21.690 --> 00:49:35.940
Andre de Gouvea: Completely different sources, completely different types of experiments they all point to the neutrino oscillations with the same types of parameters. So you have a you need a mass square difference and you need a mixing

288
00:49:37.590 --> 00:49:41.910
Andre de Gouvea: So the final piece of the puzzle is more recent which is a

289
00:49:43.410 --> 00:49:52.500
Andre de Gouvea: We can also do experiments with reactor anti neutrinos with our short baseline. And basically the types of experiments we can do our

290
00:49:53.340 --> 00:50:03.390
Andre de Gouvea: We have a very strong nuclear reactor we put some detectors nearby called h1 and h2 and the diabate experiment we put some detectors further way.

291
00:50:03.960 --> 00:50:13.050
Andre de Gouvea: We measure the flux of electron anti neutrinos relative to what we expect in the nearby detectors, we get pretty much all the neutrinos that we expected.

292
00:50:13.530 --> 00:50:20.760
Andre de Gouvea: In the faraway detectives. We get fewer neutrinos and we expected, we can interpret that in terms of neutrino oscillations.

293
00:50:21.720 --> 00:50:29.130
Andre de Gouvea: And we also get a very good explanation of that. Here's the equivalent of this combined plot.

294
00:50:29.880 --> 00:50:36.510
Andre de Gouvea: When you do the experiment nearby. You also get something that looks like an oscillation in this bottom panel over here.

295
00:50:37.380 --> 00:50:49.230
Andre de Gouvea: And again, because the there was a distortion of the shape of the spectrum that we can associate to the delta x squared. We can measure the Delta AMP square. And the next thing.

296
00:50:49.770 --> 00:50:50.850
thomas rizzo: Excuse me, Andre

297
00:50:51.870 --> 00:50:53.520
Andre de Gouvea: I know you've got so that's, that's good.

298
00:50:54.540 --> 00:50:54.990
Andre de Gouvea: So,

299
00:50:55.680 --> 00:51:06.210
Andre de Gouvea: Let me summarize where we are basically we have what we call the soul and Reno puzzle. We can explain that with a belt M squared and the mixing angle.

300
00:51:07.200 --> 00:51:12.720
Andre de Gouvea: We have the atmospheric puzzle. We can explain that with a different delta x squared and a different mixing angle.

301
00:51:13.440 --> 00:51:25.050
Andre de Gouvea: And finally, we have these reactor experiments that we explain without them squared, which is the same as the one that you explained the atmospheric neutrinos and mixing angle that's a third value for mixing

302
00:51:26.130 --> 00:51:37.950

Andre de Gouvea: The question we're allowed to ask is if we put it all together. And instead of just thinking about to neutrino oscillations. We think about Trina Trina oscillations does the whole thing fit. And the answer is yes.

303
00:51:38.940 --> 00:51:46.890
Andre de Gouvea: So for the last five minutes that I have, let me explain how three flavor oscillations work. And what's the stuff that we haven't measured. Yeah.

304
00:51:47.430 --> 00:51:54.000
Andre de Gouvea: So again, in that case, the mixing matrix is a three by three matrix. And now I have three mass Sagan states.

305
00:51:54.510 --> 00:52:02.970
Andre de Gouvea: One important question that we have to address is what are these mass heightened states, you know, just calling them 123 is not a is not sufficient.

306
00:52:03.390 --> 00:52:09.780
Andre de Gouvea: I have to define what these states mean and the way that we do it is we define them via their masses.

307
00:52:10.440 --> 00:52:19.410
Andre de Gouvea: And sadly, we don't know what the masses are we can only measure the differences of the masses. So in order to define them, we have to define them relative to one another in terms of mass

308
00:52:20.130 --> 00:52:29.640
Andre de Gouvea: And the way that we define things is weird. And if you're not in Reno physics, it's worthwhile listening to how we define things. The idea is that we define

309
00:52:30.420 --> 00:52:36.570
Andre de Gouvea: The mass of the two states to be bigger than the mass of the one state. So that's a reasonable definition.

310
00:52:37.290 --> 00:52:54.720
Andre de Gouvea: And then for the three state we define it to be either heavier than one and two, or lighter than one and two in such a way that you will obey this equation here that that the difference between one and two is less than the difference between, say, one in three or two and three.

311
00:52:56.040 --> 00:52:57.090

Andre de Gouvea: So that means that

312
00:52:58.170 --> 00:53:13.860
Andre de Gouvea: This delta x squared. Three one is either a positive number or a negative number. And I'll show a picture what that means. Okay. So, assuming that that was clear. Then the next point is a I have the three by three mixing matrix, I can define this using

313
00:53:15.030 --> 00:53:21.330
Andre de Gouvea: Three mixing angles. They're called Data 12323 and data one three in one phase that we call delta

314
00:53:22.290 --> 00:53:28.380
Andre de Gouvea: If we put all of this together. We say, can we explain all of the Makino data, the answer is yes, almost

315
00:53:28.740 --> 00:53:36.270
Andre de Gouvea: There's still some stuff that we don't understand which I won't have time to talk about that people can ask, but basically if we put everything together.

316
00:53:37.140 --> 00:53:47.640
Andre de Gouvea: We get a very consistent picture we can measure all of the relevant parameters at better than the 10% level and in some cases at the few percent level.

317
00:53:48.660 --> 00:53:49.380
Andre de Gouvea: Which is great.

318
00:53:50.430 --> 00:53:53.370
Andre de Gouvea: There's one wrinkle in this. So let me

319
00:53:55.230 --> 00:54:00.480
Andre de Gouvea: So for the last two minutes. I don't want to go through all these numbers. I do want to give you a sense of

320
00:54:01.590 --> 00:54:09.780
Andre de Gouvea: How well we can measure things. The one parameter that we don't measure very well as the scene called delta. That's a CPR phase, which I'll talk about tomorrow.

321
00:54:10.650 --> 00:54:25.170
Andre de Gouvea: But basically, this gives you a sense of how well we've measured the different parameters and you see that some of them are

constrained very well, but this delta parameter is not and that delta parameter is very important because it describes SCP violation in the system.

322
00:54:26.430 --> 00:54:32.280
Andre de Gouvea: So this is the last slide, which I want to show just to give you a sense of what these

323
00:54:33.450 --> 00:54:35.640
Andre de Gouvea: Numbers mean in terms of pictures.

324
00:54:36.840 --> 00:54:45.420
Andre de Gouvea: Here you have two ways in which the new cranial neutrino masses can be ordered the one on the left hand side is called a normal ordering

325
00:54:45.990 --> 00:54:52.980
Andre de Gouvea: Because the lightest neutrino can be much lighter than the second lightest neutrino which can be much lighter than the third lightest one

326
00:54:53.640 --> 00:54:58.710
Andre de Gouvea: And then the second picture is called the inverted ordering and in the Android ordering

327
00:54:59.310 --> 00:55:08.670
Andre de Gouvea: The lightest neutrino can be much lighter than the other two. But the other two are almost degenerate in mass. The reason we call that inverted ordering

328
00:55:09.330 --> 00:55:19.590
Andre de Gouvea: Is because we like to call the other one normal because the other one is very similar to how all the charge leptons and the quarks are the quark masses are also ordered

329
00:55:20.730 --> 00:55:29.040
Andre de Gouvea: So again, this is a picture of what the two possibilities are for how the neutrino masses are ordered and we don't know what the right answer is.

330
00:55:29.580 --> 00:55:39.990
Andre de Gouvea: And I will talk a little bit about how do we answer that by doing experiments. And I'll talk about that tomorrow. And then there are a few other things that we don't know the answer to. And they're listed here in

331
00:55:39.990 --> 00:55:40.740
Andre de Gouvea: The slide.

332
00:55:41.340 --> 00:55:51.300
Andre de Gouvea: And I think I have one minute, so I will give myself one minute and basically just to give you a sense of what we don't know yet as. First of all, we don't know which one of those two pictures is correct.

333
00:55:52.320 --> 00:55:58.830
Andre de Gouvea: The other question that we like to ask, which is not in this picture is whether CP is violated or not. And we'll talk about that tomorrow.

334
00:55:59.850 --> 00:56:06.780
Andre de Gouvea: And then finally, there's another funny feature of this drawing, if you stare at it is that, oh,

335
00:56:08.190 --> 00:56:19.560
Andre de Gouvea: I forgot to say this drawing has some colors in it and the colors actually means something. And this is man to indicate the new one state. The new to state and the new three state.

336
00:56:20.550 --> 00:56:33.780
Andre de Gouvea: And the colors represent the entry is of the mixing matrix squared. So for example, if you look at neutrino. Number one, the fraction of the bar that's color grad is up one squared.

337
00:56:34.890 --> 00:56:41.640
Andre de Gouvea: And so on and so forth for all of the other colors in this picture. One thing that should jump out at you in this picture is

338
00:56:42.720 --> 00:56:51.840
Andre de Gouvea: First of all, the, the red color is not in the three state, regardless of how the masses are ordered and I'll talk about that tomorrow.

339
00:56:52.470 --> 00:57:01.950
Andre de Gouvea: But the other interesting mysterious question is that if you look at all of these bars that I drew the amount of green and blue is the same in all these

340
00:57:02.580 --> 00:57:09.990

Andre de Gouvea: All these pictures and all these bars and we don't know if that's true or not, it could be true, but it doesn't have to be true.

341
00:57:10.470 --> 00:57:18.780
Andre de Gouvea: And in particular, for the number three state. One question we would like to figure out, is whether the number three state is more green than blue

342
00:57:19.290 --> 00:57:29.850
Andre de Gouvea: Or if you're talking terms of physics. If you talk about, you know, the heaviest neutrino. You can say is that more aligned with them you on Kino or is it more aligned with the town between oh

343
00:57:30.390 --> 00:57:36.360
Andre de Gouvea: And we don't know the answer to that. And I should probably stop here because I think I've gone over time, maybe backup London's

344
00:57:37.980 --> 00:57:41.310
thomas rizzo: Excellent. Andre. Let's turn this over to rich for questions.

345
00:57:43.740 --> 00:57:46.260
Richard Partridge: We've had some questions online.

346
00:57:47.850 --> 00:58:04.920
Richard Partridge: We go off to you and get your answer on this. And again, there's more questions here. Then we can deal with today, but we'll try and get answers to all them posted later.

347
00:58:06.570 --> 00:58:07.890
Richard Partridge: The first question.

348
00:58:10.410 --> 00:58:11.010
Richard Partridge: Is

349
00:58:12.510 --> 00:58:19.770
Richard Partridge: Do isolation spray generation up to number or we converting electron new to some other flavor.

350
00:58:20.790 --> 00:58:32.640
Andre de Gouvea: Yes, that's a great question. I should have said this. Absolutely. So one thing that we've discovered and the fact that this

mixing matrix is not trivial means that that flavor number for the leptons is

351
00:58:33.450 --> 00:58:43.350
Andre de Gouvea: Severely broken so so that means that the concept of electron flavor or mew on flavor or thought flavor is dramatically broken by neutrino oscillations.

352
00:58:44.310 --> 00:58:50.220
Andre de Gouvea: By the way, this is not new to our understanding of physics because quark flavors also broken

353
00:58:50.880 --> 00:58:57.510
Andre de Gouvea: And not surprisingly, it's also broken by the charge card week interactions. So it's the same phenomenon is once you allow

354
00:58:57.870 --> 00:59:03.930
Andre de Gouvea: For the charge card interactions. And once you appreciate the fact that the number of generations is more than one

355
00:59:04.740 --> 00:59:14.130
Andre de Gouvea: Then the charge card interactions allow you to violate this individual flavor numbers. And I do want to emphasize because people tend to get confused.

356
00:59:14.520 --> 00:59:32.130
Andre de Gouvea: Violating electron flavor or new on flavor is not the same as violating left on number left on numbers. The sum of all of that and and we're very sure that individual leptin flavor numbers are violated and and otherwise neutrino oscillations would not be possible.

357
00:59:33.870 --> 00:59:48.990
Richard Partridge: Okay, thank you. Next question is, is it possible to explain neutrino isolation only by matter effects with zero neutrino mass using well soon neutrino non standard interaction or new trend.

358
00:59:50.490 --> 00:59:51.660
Andre de Gouvea: That's a great question.

359
00:59:52.080 --> 00:59:52.890
Andre de Gouvea: The answer is

360
00:59:54.090 --> 01:00:04.860

Andre de Gouvea: That's how matter effects were first appreciate it is. This is done by boyfriend Stein and I forgot to mention the names of people. So both Einstein was the one that pointed out these matter effects.

361
01:00:06.240 --> 01:00:07.500
Andre de Gouvea: And he speculated

362
01:00:08.580 --> 01:00:13.500
Andre de Gouvea: That maybe if the neutrinos had some new interactions. The matter effects could be

363
01:00:14.250 --> 01:00:25.020
Andre de Gouvea: Could explain this flavor change. And again, the, the physics is not very different from oscillations in spirit, because what you really need is you need to have two different ways of talking about neutrinos.

364
01:00:25.710 --> 01:00:32.130
Andre de Gouvea: So that the charge card interactions, like the new a new a new cow. So if you invent some new interaction.

365
01:00:32.880 --> 01:00:41.700
Andre de Gouvea: That doesn't couple like a new a new a new town but it couples like linear combinations of new a new a new town, which is what the mass eigen states do

366
01:00:42.510 --> 01:00:55.440
Andre de Gouvea: You could also get get a similar effect. Now the point is we know that that's not true, because we can do experiments in all kinds of circumstances, including experiments where

367
01:00:56.160 --> 01:01:02.100
Andre de Gouvea: The neutrinos are mostly propagating through vacuum all the time and and because the

368
01:01:02.760 --> 01:01:09.960
Andre de Gouvea: The, the changes in the matter density are so dramatic from one experiment to the other. We can't really explain everything.

369
01:01:10.380 --> 01:01:15.960
Andre de Gouvea: Just by having the neutrinos have some new interaction between neutrinos and matter and that

370

01:01:16.530 --> 01:01:24.960
Andre de Gouvea: That those interactions would allow you to to explain all the data. And I think this is the key point. The key point is, because we do experiments with

371
01:01:25.440 --> 01:01:31.440
Andre de Gouvea: Different neutrino energies different neutrino sources and different neutrino environments.

372
01:01:32.430 --> 01:01:45.240
Andre de Gouvea: The handles are such that we can distinguish fewer oscillations from pure matter of fact with some new interactions and we can rule out that these new interactions are the dominant the dominant physics.

373
01:01:45.750 --> 01:01:56.190
Andre de Gouvea: They can still lead to funny changes in heaven pinos oscillate, and we look for those, but they definitely are known not to be the dominant mechanism. So the masters really have to be there.

374
01:01:57.780 --> 01:02:06.900
Richard Partridge: Okay, right. The next question is how do we know neutrinos leave the sun in the heavier. I can state instead of the lighter, I can say

375
01:02:07.560 --> 01:02:18.570
Andre de Gouvea: So that's a, that's a great question. That's the prediction. And this is where the matter potential is essential. And so if you look at this picture here.

376
01:02:19.950 --> 01:02:30.390
Andre de Gouvea: The fact that the picture looks like. This is because the eighth term is a positive number four electron neutrinos, if, if the sun was producing electron anti-neutrinos

377
01:02:31.380 --> 01:02:39.060
Andre de Gouvea: Then he would have been born, all the way down here on the clock. Those would have come out as the lightest mass and constraints. So

378
01:02:39.780 --> 01:02:47.550
Andre de Gouvea: That the prediction really is that the electronic reno comes out as the heaviest mass Sagan state in this to flavor picture that I drew here.

379

01:02:48.300 --> 01:02:56.850
Andre de Gouvea: And and that's and that's why we say that when you measure the neutrinos from the sun. You're actually measuring Science Core Data

380
01:02:57.450 --> 01:03:13.530
Andre de Gouvea: And remember, Science Core Data. Was this the find to be the mixing angle that couples to the that defines the electronic Torino as I wrote over here on this slide and then I'm defining neutrino. Number two, to be the heaviest one

381
01:03:14.940 --> 01:03:22.920
Andre de Gouvea: I don't know if this was the question, but the answer is a combination of the fact that the matter potential has a well defined sign as in plus or minus

382
01:03:23.460 --> 01:03:38.400
Andre de Gouvea: And the fact that we can define our mess eigen states in which, in any way we like. But we have to do it consistently and if we do it consistently the electronic trina's come out as the heaviest mess Agon state, which we call the cleaner. Number two.

383
01:03:39.540 --> 01:03:41.850
Andre de Gouvea: I don't know if that was done. I don't know if that's helpful but

384
01:03:45.840 --> 01:03:51.240
Richard Partridge: The next question is do chinos released from the Z Bo zone became obsolete.

385
01:03:53.550 --> 01:03:54.720
Andre de Gouvea: That's a very good question.

386
01:03:58.260 --> 01:03:59.700
Andre de Gouvea: The answer is no.

387
01:04:01.050 --> 01:04:01.470
Andre de Gouvea: And

388
01:04:02.820 --> 01:04:08.940
Andre de Gouvea: I will, I can leave that as an exercise, but basically what you really need to be thinking about is

389
01:04:10.260 --> 01:04:17.460

Andre de Gouvea: What is this neutrino. So what's the physics question that you want to ask. And again, just saying that

390
01:04:18.630 --> 01:04:26.940
Andre de Gouvea: Basically just saying that some of the peanut was produced is not a physics question the physics question has to be. I have a Z bows on which the case.

391
01:04:27.450 --> 01:04:43.860
Andre de Gouvea: And then I measure that neutrino and I I reveal the flavor of that and freedom and the statement is if I do the experiment of a Z bows on the case. And then I count electron new ones and thousand my detector that number will be a third, a third, a third

392
01:04:44.880 --> 01:04:47.820
Andre de Gouvea: And that number doesn't change as a function of the baseline.

393
01:04:48.240 --> 01:04:55.680
Andre de Gouvea: That means if I measured the neutrinos right away. A third of them will be electronic Reno's a third will be new and pre nose and the third will be down notes.

394
01:04:56.070 --> 01:05:03.240
Andre de Gouvea: If I measured you know 1000 kilometers away and God helped me because the flex will be tiny, but if I do that.

395
01:05:03.720 --> 01:05:10.560
Andre de Gouvea: The answer will still be a third of them will be electronic Reno's a third of them will be found three knows in a third of them will be new on credos

396
01:05:11.460 --> 01:05:23.460
Andre de Gouvea: And the reason this is not the same story is, I was telling you before is that you really have to sit down and think about what is the way function that describes these materials that have come out of the

397
01:05:24.990 --> 01:05:34.410
Andre de Gouvea: Of the Z DK and it's a it's a fun problem to think about. There are lots of fun things that you can do. One is, for example, there's a neutrino and an anti no treatment that comes out.

398
01:05:34.950 --> 01:05:46.170

Andre de Gouvea: So one question you can ask is, if I measure after one second that then Trina was an electron neutrino. What's the flavor of the new on. Oh no, I'm sorry, what's the flavor of the anti neutrino.

399
01:05:46.860 --> 01:05:55.410
Andre de Gouvea: And the answer is that can oscillate after you've made the electron measurement. That's kind of like a collapsing the way function of some APR there.

400
01:05:56.250 --> 01:06:04.980
Andre de Gouvea: And then asking what happens if the anti rufino propagates. It's kind of like describe the sighting. What's the flavor of the primo and then Fino side.

401
01:06:05.430 --> 01:06:15.150
Andre de Gouvea: And then asking what's the flavor of the ante and primo and once you've tagged your beam, then that will feel the anti repeater when oscillate. So it's a fun system to think about

402
01:06:16.410 --> 01:06:17.430
Richard Partridge: Okay, thank you.

403
01:06:19.980 --> 01:06:21.180
Richard Partridge: Next question is,

404
01:06:22.470 --> 01:06:26.490
Richard Partridge: How do we account for the sterling Trina in the mass isolation make

405
01:06:27.810 --> 01:06:30.510
Andre de Gouvea: So good. I didn't talk about sterile neutrinos, but

406
01:06:31.590 --> 01:06:45.990
Andre de Gouvea: The way that we would do that as the following the way that's that makes the most sense is on our show you in the picture. So basically, the way that you want to think about a sterile neutrino is of course we know about new a new a new town.

407
01:06:47.130 --> 01:07:02.430
Andre de Gouvea: And we know that there are three math science things. So if I want to add a new state. The easiest one to think about is a new mass state. So let's add a new mass state. And let's say we call it number for that will have some mass and Foursquare

408

01:07:03.510 --> 01:07:10.170
Andre de Gouvea: So it'll live somewhere like here where my little hand is moving back and forth. And then of course the

409
01:07:10.770 --> 01:07:16.290
Andre de Gouvea: This a number for state will have some probability of being detected as an electron cleaner.

410
01:07:16.710 --> 01:07:26.460
Andre de Gouvea: Or or some probability of producing an electron some probability of producing a new on some probability of producing a foul. That means that we have a little bit of this, a red, blue, green color.

411
01:07:27.300 --> 01:07:36.630
Andre de Gouvea: But, of course, the sum of all red and all blue and all green is also an a full bar. That means that I have to invent a new flavor.

412
01:07:37.020 --> 01:07:47.640
Andre de Gouvea: So it's not just a new a new a new town, there has to be a new flight. So I add a new mass state and along with the new mass state I add a new flavor. The new flavors, the sterile and feel

413
01:07:48.180 --> 01:07:57.630
Andre de Gouvea: Let's say we give it a color like yellow. So that means that now all of my mass states will be red, green, blue, and they will have a little bit of yellow as well.

414
01:07:58.170 --> 01:08:06.090
Andre de Gouvea: And now I have a more complicated picture where I have more mass states. And then I have this new flavor state. The reason I mentioned this is that

415
01:08:07.740 --> 01:08:12.840
Andre de Gouvea: This sun new flavor state is kind of useless we postulate that it doesn't interact

416
01:08:13.440 --> 01:08:15.090
Andre de Gouvea: But I still haven't you masturbate.

417
01:08:15.570 --> 01:08:24.960
Andre de Gouvea: And then you mass state has some non zero probability, hypothetically, I've been detected as outer electron new and in town knows and I know how to speak to them.

418
01:08:25.380 --> 01:08:35.040
Andre de Gouvea: So, so that's how the new mass states. And that's how we talk about the neutrino states is that we, we can add a new mass that will give me a new oscillation frequency

419
01:08:35.490 --> 01:08:43.050
Andre de Gouvea: And the reason I can see the new oscillation frequency, in spite of the fact that the new flavor state that I'm adding sterile.

420
01:08:43.410 --> 01:08:46.290
Andre de Gouvea: I can see that because it was a non zero probability

421
01:08:46.620 --> 01:08:56.610
Andre de Gouvea: That the new mass states can be detected as it as a new in town, and I can add as many states as I want. By adding as many sterile states as I want.

422
01:08:57.000 --> 01:09:08.250
Andre de Gouvea: And as long as the new mass states have some probability of interacting via the charge current interactions which is always allowed Dan, I can speak to them and I can test if the exist.

423
01:09:12.930 --> 01:09:13.650
Richard Partridge: Thank you.

424
01:09:15.480 --> 01:09:18.600
Richard Partridge: Todd. We have time for one more question. Or we finished.

425
01:09:18.840 --> 01:09:20.280
thomas rizzo: I think we have time for one more.

426
01:09:21.330 --> 01:09:30.660
Richard Partridge: Okay. Um, is there a fundamental reason for why the three most I can say similar the same amount of music and town neutrino.

427
01:09:31.620 --> 01:09:40.530
Andre de Gouvea: That's a great question, and I didn't get to talk about this, but it is a question that a lot of people worry about. So, so one thing which I won't have time to talk about is

428
01:09:41.550 --> 01:09:49.950

Andre de Gouvea: People spend a lot of research time trying to understand questions like that, you know, they try to understand, you know,

429
01:09:50.340 --> 01:10:01.080
Andre de Gouvea: Why is the electron mass so much smaller than the town mass, even though they have the same kind of numbers and then they try to understand, you know, why is a dog park so heavy. And why is the park so light.

430
01:10:01.920 --> 01:10:10.830
Andre de Gouvea: And they try to understand why is the quark Mixi matrix, almost a diagonal matrix. So an equivalent question for them trina's is exactly that question.

431
01:10:11.370 --> 01:10:17.400
Andre de Gouvea: You know, how come the amount of new one and Tao in all of these states is exactly the same, maybe

432
01:10:18.360 --> 01:10:25.710
Andre de Gouvea: And the answer is we don't know, but it could mean something very important. You know, it could be a way of nature, telling us that there's some

433
01:10:26.220 --> 01:10:37.830
Andre de Gouvea: Hidden reason and we not normally call that a cemetery, that there's some symmetry that that is a more fundamental underlying like family cemetery amongst the different generations.

434
01:10:38.280 --> 01:10:50.790
Andre de Gouvea: That renders this some new tower symmetry, to be exact, or or very similar, clearly it's not exact, because the meal on in the cow have very different masses. So there are all kinds of things story about. But yes, it's

435
01:10:51.420 --> 01:11:01.110
Andre de Gouvea: Understanding the pattern of the make the you know the patterns that could be imprinted in the mixing matrix is a question and a lot of people that work on flavor theories

436
01:11:02.010 --> 01:11:09.630
Andre de Gouvea: They spend a lot of their research time worrying about this, you know, why does the pattern of this mixing matrix and perhaps more important is

437
01:11:09.990 --> 01:11:20.460

Andre de Gouvea: And how do I learn if my solution to the pattern is is actually what nature does. So it's a question that people have been asking for a very long time. Ever since they discovered

438
01:11:21.090 --> 01:11:30.990
Andre de Gouvea: You know the cubby boy angle. And I think it's fair to say that we have not made a lot of progress in figuring out what is the physics behind

439
01:11:31.440 --> 01:11:44.580
Andre de Gouvea: This weird, you know, three generations hierarchical masses mixing angles, blah, blah, blah. But we were hoping that that there's also information encoded in the neutrinos and we're trying to figure out what that is.

440
01:11:47.070 --> 01:11:51.030
Andre de Gouvea: And I have to say it's weird to answer questions without knowing if they had any impact, but

441
01:11:51.480 --> 01:11:55.890
Andre de Gouvea: I'm happy to try later if people are there are mechanisms for the week.

442
01:11:57.180 --> 01:12:07.230
thomas rizzo: Okay, thanks a lot. Andre, we're going to get the rest of these questions to you in some form or other but thanks again for the great lecture today and we're looking forward to your talk tomorrow.

443
01:12:08.130 --> 01:12:09.420
thomas rizzo: So I'm going to end the

444
01:12:09.840 --> 01:12:10.680
thomas rizzo: Recording now.