The Universe is So Fine-Tuned

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Robert Marks:

Welcome to the Mind Matters News podcast. I'm your appreciative host Robert J. Marks, appreciative of the quality of the guests that we are able to have on Mind Matters News. So let's talk. Why is the speed of light, the speed of light? Why isn't it slower or faster? Why is the universal gravitational constant what it is? It turns out these and other constants of the cosmos are what they are so that the universe is habitable so that you and I can live on planet earth. There is very little controversy that the universe is fine-tuned. Astronomer Robert Jastrow was head of NASA's theoretical division and the founding director of the Goddard Institute for Space Studies.

Robert Marks:

He said "it is my view that the universe was created for men to live in." And it's because it's very, very finely tuned by some of these constants that we're talking about, and we talk about fine-tuning of the cosmos today on Mind Matters News. We have two great guests who have published extensively in the literature about fine-tuning. Dr. Daniel Diaz is a research assistant professor of biostatistics at the University of Miami. Daniel, welcome.

Daniel Diaz:

Thank you Rob, it's a pleasure to be here again.

Robert Marks:

Okay. And Dr. Ola Hössjer is a professor of mathematical studies at Stockholm University and joins us today, directly from Sweden. Ola, welcome to you too.

Ola Hössjer:

Oh, thanks a lot Rob, and it's a pleasure for me too, to be part of this.

Robert Marks:

That's great. We're handling a three continent podcast today because Daniel is in his home country of Columbia, he teaches at University of Miami, and Ola is in Sweden so this is really amazing. Ola, Daniel, I'm an engineer. When I design something, I want robustness. If I use a resistor of 10 ohms and some sort of circuit, and the resistant changes to say, I don't know, 10 and a half ohms, I want my circuit to still work. But there has to be some wiggle room for small changes in parameters, such as the ohmage. But eventually the circle will break, if the resistance changes to something like a million ohms, my circuit might no longer work.

Robert Marks:

Now the universe... My example of a resistor in the universe isn't applicable because I don't think we're talking about resistance here, but there's lots of other parameters in the universe as it exists. And that's what we want to talk about. They are fine tuned, just like my 10 ohm resistor to work well. And there isn't, in some cases, a lot of wiggle room. So Daniel, let's start with you. What are some of the constants in cosmology we can look for, for fine tuning and what would the impact be on the universe if these constants vary too much?

Daniel Diaz:

Yeah. Thank you, Rob again. So just let me first mention that that's a very interesting case that I had not considered before, the one that you were mentioning for the resistor for fine tuning. It's a very cool example. Basically I think a way to define news, also a fine tuning, you can look at fine tuning for any system to work.

Robert Marks:

Yes.

Daniel Diaz:

For any system to produce the desired outcome you can use to measure the permeability, and then you say if it is fine-tune or closely tuned, whatever it is. So that's a very nice example. In particular, for your question on the cosmological fine tuning, we look at different things when we are considering cosmological fine tuning. We look first at the laws of nature, lots of nature like the most well-known case, the gravitational law. So gravitation has to be in some very small interval, so the life can be produced.

Daniel Diaz:

Now it is really a kind of shooting like a rocket life. This is more appropriate even to the consequence would be that life exists or does not exist, it's more appropriate even to say that if there is a big fluctuation of gravity stars will not exist. For instance...

Robert Marks:

Let me ask you, what is the gravitational constant?

Daniel Diaz:

The gravitational constant is just a number that is attached to Newton's gravitational law. Now, that constant was more formally developed after Einstein's general theory of relativity. But it is a nice way used to think about it in terms of what Newton did that is more familiar to all our minds, to all that we know. The basic idea is that there is a constant attached to the gravitational law. And in that gravitational law, that constant is producing some effect. That is the effect that if the constant... Were the constant too small, then stars could not be formed.

Daniel Diaz:

And as it happens, it is in the stars that carbon is also formed. So if stars are not formed, carbon does not come into existence. And if carbon does not come into existence, we living beings, we in biology are based on carbon in order to exist, then could have not existed. So that very small number in the gravitational constant would have produced that stars could not be formed, and therefore we would not be here. On the other side were the constant too large, then everything would have collapsed. Basically the gravitational force would be too strong and then everything would be collapsing into one single thing. Let's put it like that, I mean, in the most extreme case. So in that scenario also life, as we know it, could have not existed because it's task would have not existed either. So that's one example in the laws of nature.

Robert Marks:

Okay. Here's an important question. If the gravitational constant increased and I went to my scales, would I weigh more? I think so, right?

Daniel Diaz:

That will be given by the gravitational constant.

Robert Marks:

If we increase the gravitational constant the stars would collapse into a singularity, but right now my immediate thing is whether I would weigh more or not.

Daniel Diaz:

That's a real...preoccupation. You're right. And there are other examples, it is not only fine tuning in the laws of nature, it also happens in the boundary conditions. For instance, it is assumed that entropy would have to be at a very low value at the beginning of the universe so that again, life could exist as we know it right now. That is something that belongs to a category that is called boundary conditions. And there is another set also of constants to look as fine tuned, and it is the parameters to look at fine tuned, those are the parameters that come in the standard models in physics. So there is a cosmological and there is a particle, the standard model in physics and those models, as any mathematical model, have constants parameters, three parameters as they call it in physics. Then those parameters also in general, have to br finely tuned in order for life to exist.

Robert Marks:

What are some of the other examples of universal constants that we can have interest in?

Daniel Diaz:

Okay. So other examples for instance, are the cosmological constant that Einstein developed with his general theory of relativity.

Robert Marks:

Let me ask you about the cosmological constant. I know enough to know a little bit about the history that Einstein fudged the cosmological constant to get the results that he want and later regretted doing so. Do we have a way of measuring the cosmological constant a lot more accurately today?

Daniel Diaz:

Yeah. I mean, there was some discrepancy actually between what we are observing and it's a big discrepancy actually between what we're observing, but it was theoretically predicted. And that's why one of the biggest questions in physics right now, one of the most interesting question in physics right now depends on that cosmological constant, but it is very interesting. And some people have pointed this out that even though that cosmological constant was introduced by Einstein in order to, quotation marks, "correct" the theory that he was developing, because it was implying a beginning. And when he realized that his theory of relativity was implying a beginning, he tried to correct that because the worldview at the time was that the universe has existed for an infinite time. Then actually he interviewed this constant and he called it the biggest blunder in his life.

Robert Marks:

Yes.

Daniel Diaz:

Some people have pointed out even Einstein's mistakes ended up being useful. So that cosmological constant right now is a central topic of cosmology, and a lot of research is happening, trying to justify some discrepancies, big discrepancies actually that are observed in the cosmological constant.

Robert Marks:

Okay. So some other constants that we have to pay attention to.

Daniel Diaz:

Yeah. There is also the primordial fluctuations, this is basically a quantum event. That is something very interesting actually about it, it has usually been mentioned that these primordial fluctuations are finely tuned. One of the things that we found in our paper is that for this particular example, the probability is very large. So it may be that subject to a different set of conditions and restrictions. It could end up being fine tuned. But as we measured, it is not as fine tuned as it was thought before. That's another example at least of tuning, even if it is not fine, but close, according to our findings.

Robert Marks:

So in truth, there's a lot of fundamental constants, I have heard, for example, the electric charge of an electron, for example the weak force, the strong force. There looks to be tens, maybe hundreds of different constants that we can look at, and we have to ask the question like the speed of light, why is this constant equal to this constant? And look at the consequences of what would happen if it varied. Is it a fine tuned thing or if there a lot of wiggle room there?

Daniel Diaz:

Yeah, you're right. When you were mentioning before there are basically four fundamental forces, the electromagnetic force, the gravitational force, the weak, and the strong force. Those are the four big forces, and the unification of all those four forces is that what is called a theory of everything in physics. That theory does not exist yet, basically because gravitation is very stubborn and it refuses to be placed in the same category as the others or in the same model, let's say, as the others in terms of unification.

Robert Marks:

In fact, I think it was Stephen Hawking that gave up pursuing the theory of everything. He didn't do it because of the unification of the different forces, but he appealed to girdle. And the fact that no matter what you did, there were going to be stuff that was true in the universe that you still needed to prove.

Daniel Diaz:

That's very interesting, Hawking appealing to girdle, that's interesting. So what we need in order to discover that the university is saying to, we don't even need that to measure and to see that all the constants are finely tuned. If only one of those is finely tuned, then we can simply say that the universe is fine tuned. That's very interesting because actually what is happening is that if those constants are independent of each other, and that's what is happening in the models, reigning physical models right now, is that they have to be assumed as independent. If they are not then one could be reduced to the other and they could be discarded from the model. So if only one of those is finely tuned, then we can say that the universe is finely tuned too.

Robert Marks:

So are there numerous constants that are finely tuned?

Daniel Diaz:

That's our quest actually, and that's what we want to observe. So what follows in our project is just now that we develop the theoretical way to measure those qualities is go and measuring those qualities for the cosmological and particle model.

Robert Marks:

Excellent, excellent.

Daniel Diaz:

What we expect is to find that some of them, maybe most of them are going to be finely tuned. But again, if there is only one that is finely tuned, then that would be enough to say that the universe is finely tuned too.

Robert Marks:

That's interesting. But again, Stephen Hawking, I think speaking of Stephen Hawking also said that nothing has ever proved in physics, you just accumulate evidence. So if you have one that is not finely tuned, that's evidence, but boy, if you have a bunch of them that are required to be finely tuned, that's really a lot of evidence that something is going on. And as Fred Hoyle said, somebody has been monkeying with the universe, so very interesting. Ola, we talk about fine tuning and these cosmological constants and one of the terms that you use in your papers is an LPI. What's an LPI? What does it mean? And how do we measure it?

Ola Hössjer:

Yes. And we talked about this during the episodes one and two and LPI, that's a life permitting interval for a certain constant of nature or certain cosmological constant. And it could also be a life permitting interval for a ratio between two constants of nature. And that means that this constant or this Ray, or the ratio of these two constants, needs to fall within it's life permitting interval in order for the universe to harbour life. And in episodes one and two, we talked about the universe being fine tuned, it requires two things. First of all, we need to find this life permitting interval, and that is physicists have done that. And that is an independent specification, that life permitting interval. And then we need to find what would be the probability if the universe was generated by chance, according to some distribution, what would be the probability that these constants of nature or the ratio between two constants of nature ended up within its life permitting intervals?

Ola Hössjer:

And if that probability is small, then we say that that constant of nature or the ratio between these two constants of nature is fine tuned. And as Daniel said, it's enough to find one constant of nature that is fine tuned in order for the universe to be fine tuned, because then it's also very unlikely that the universe was generated by chance, one that harvests life.

Robert Marks:

We talked before about the difference between just looking at the intervals and looking at the probability an event was in that interval. Can you give me some examples of some of the constants of nature and the probability that the event as we see it lies within the life permitting interval?

Ola Hössjer:

Yes. And in this joint paper of ours is cosmological tuning final course in the journal of cosmology and astro particle physics, then we give a couple of examples. And the first example, that's really a ratio or two constants of nature. It's the ratio of the constant of gravity that Daniel talked about and Hubble's constant square, and Hubble's constants is related to the constant that explains how fast the universe is expanding.

Robert Marks:

Let me ask you this, why don't you take the ratio of constants as opposed to the constants? I mean, couldn't you kind of cook the books by looking at different ratios and seeing that they were fine tuned? What's the reason behind taking these ratios?

Ola Hössjer:

Well, sometimes it could be the case that the ratio is more fine tuned than each of the two constants themselves. It could be that they have to have a certain ratio in order for life to exist in that universe. We can think of it as a balance between different forces, the balance is more important than the actual strength of the two forces, so to speak.

Robert Marks:

I see. So maybe the life permitting interval for one of these constants would not be as meaningful as with another one, because there's an interplay between those two constants.

Ola Hössjer:

Yeah, exactly. So sometimes the life permitting interval of the ratio could be smaller than the life permitting intervals of each constants by themselves. And in this case, theoretical physicists have come up with an equation that relates the ratio between the constants of gravity and Hobble's constant square with the critical density of the universe inverse when the universe was very young. So it's actually the case that that critical density is highly fine tuned. And then there are some other constants as well, but this is sort of the important constant that comes up in that equation that says that the critical density of the universe is closely related to the ratio between the constant of gravity and Hubble's Constant Square.

Robert Marks:

I just thought of an example of this in my field of electrical engineering, there's something called a voltage divider where the percent of a voltage that is bled off is just a function of the ratio between the two resistors. And so therefore talking about the sensitivity of a single resistor doesn't make sense, you do have to talk about the ratio of two. So in talking with you, I just realized that these are problems in circuit design also, and I'm sure in other designs. Okay, continue with your example because we want some numbers.

Ola Hössjer:

Yeah. And that example, which relates the ratio between the constant of gravity and the Square Hubble Constant, it relates that to the inverse of the critical density of the universe, that's called the Friedman equation. And Paul Davis, he has actually estimated, one well-known physicist, he has estimated that the life permitting interval of that ratio between these two constants of nature has a relative size of 10 to minus 60. And that means this is the length of the interval divided by its midpoint. And it's more meaningful to talk about the relative size because it's dimension-less, it's not dependent on the unit we use to measure the constant of gravity or the Hubble's Constant Squared. So the relative size of the life permitting interval is 10 to minus 60. We can think of 1% as 10 to minus two or one perilla to as 10 to minus three. So it's extremely small.

Robert Marks:

Now that's the probability, is that right?

Ola Hössjer:

Oh no, it's actually the size of the [inaudible 00:19:49]. Yeah, it's the size. And then we have a general way, and we talked about that during episode one and two, that then the important thing is not the size per se, and not even the relative size per se, even though it's dementia less, it's actually the probability that we sign to this life permitting interval. And then we have, and actually that probability depends a little bit on how we choose the normal distribution, the distribution of the ratio between these two constants of nature. And it can be done in a few slightly different ways, but they all end up with probabilities that are like 74% of this relative size. So if this relative size was a 10 to minus 60, the probability is 0.74 times 10 to minus 60. And another approach is 50% instead of 74%. But the take home messages that the probability is very close, it's all the same order as the relative size of the life permitting interval.

Robert Marks:

So the probability, you're saying, is about one in a million if I remember your...

Announcer:

Well, it's one to 10 to 60, so it's much smaller than, yeah.

Robert Marks:

Oh my goodness, 10 to the 60th. Now, putting that into perspective, I think I've heard that there are 10 to the 80th atoms in the universe. And so 10 to the 60th is really, really big. What is that? It's a million, you say a million, 10 times you get 10 to the 60th. So it's a million, million, million, million, million, million, million, million, million, million, becomes a tongue twister after a while. So it's a really, really humongous number.

Ola Hössjer:

Yeah, it is. It's really amazingly large. And then we have another closely related example that also gives a highly fine tuned ratio. And then we still have the constant of gravity in the numerator of that ratio, but then we have something called [inaudible 00:22:01], that is a contribution from vacuum energy to the cosmological constant that Daniel talked about. And then physicists have come up with very small number for the relative size of the life permitting interval of that ratio as well. The constant of gravity divided by [inaudible 00:22:22]. And then the relative size, depending on the theory used, some authors come up with a relative size of that life permitting interval that is 10 to minus 50, or even 10 to minus 100.

Robert Marks:

Now that's the interval, not the probability.

Ola Hössjer:

Yeah, and then the probability is of the same order as the relative size of the interval. So, it's like a half of the relative size, the probability, or is 75% of the relative size of the life permitting interval depending what approach we use for computing, the probability. We talked about this during episode one and two that we use maximum entropy for the... We chose the prior distribution or the ratio of these two constants, according to the maximum mentor principal, but we could do it in different ways. Either we could choose to apply the prior to the ratio itself between these two constants of nature, or we can apply prior to the numerator and denominator specifically.

Ola Hössjer:

But at the end of the day, we come up with very similar numbers for the probability of ending up within this life permitting interval, which is of the same order as the relative size of this life permitting interval. Which is, like in the second example, the constant of gravity divided by [inaudible 00:23:43], which was the contribution vacant energy to the cosmological constant and its relative size was 10 to minus 50 or 10 to minus 100. And that the probability of ending up in that interval is of the same order, regardless of which maximum entropy approach we use for calculating the prior.

Robert Marks:

That's fascinating stuff. You've pointed out, Ola, some things, some parameters that are very finely tuned. Daniel, are there constants of the cosmos that are not finely tuned?

Daniel Diaz:

Well, yes. In our paper we find two cases, one of those very typical, I think this was something that Ola was mentioned in one of the previous podcasts. Once we're measuring the ratio of two constants, it is possible for some settings to obtain that the ratio is not going to be that finely tuned. That particularly is going to happen when the average is inside the life permitting interval. But then if we take into account that life permitting interval is more, we can find prior distribution for that parameter, the average, the expected value being inside that life permitting interval.

Robert Marks:

Yes.

Daniel Diaz:

And then depending on that, it's possible, even though atypical, to find that in some cases that average is going to inside that life permitting interval. If it is happening then particularly when the two constants in question are living in the whole real line so it's not taking only for instance, positive values, but it could be positive values, negative values, and zero. Then in that scenario, it is possible not to have a fine tuning.

Robert Marks:

Do you have a specific example?

Daniel Diaz:

Yeah. So for the situations that Ola was mentioning, then it is possible just not to think of those constants are living in the positive interval, in the positive real line. When we're considering the whole real line, then we could obtain those things. For instance, let me just mention something, because this is a theoretical example, or this is a theoretical consideration, a mathematical consideration, again, as we mentioned before. So gravity is assumed to be positive so that it is an attraction force, but theoretically if we are allowing for the constant of gravity to move outside the life permitting interval, then it is also possible to think of a universe in which there's no attraction force, in which case the gravitation would be the gravitational constant will be zero.

Robert Marks:

So if I went and weighed myself, I would really lose weight, right?

Daniel Diaz:

Oh yeah. Your weight would be zero.

Robert Marks:

I'm obsessed with my weight.

Daniel Diaz:

And it is even theoretically possible once we are moving the value of that constant, which is again the essence of the fine tuning argument. It is also theoretically possible to think of gravity as being negative. In which case it would not be an attraction force, but it will be a repulsion force. So in that case, then the gravitational constant will be living throughout the whole reel line. It could take values throughout the whole real line. And then in that scenario, if again the expected value, the average is living inside the life permitting interval, is found inside the life permitting interval, is going to be very difficult to determine if there is fine tuning. So the tuning would be chorus in that case.

Robert Marks:

Excellent.

Daniel Diaz:

There's also another possible scenario that we studied. These are part of the two examples that we consider in the paper, we were looking at the gravitational constant and the ratio to other constants in nature, but we also consider the amplitude of the primordial filtration. As I mentioned in the previous answer with these amplitude for the primordial fluctuations, we did not find that it was finely tuned. Actually, what we found is it is coarsely tuned.

Robert Marks:

What was that example again? Could you be specific about the contants involved?

Daniel Diaz:

Yeah. The amplitude of the primordial filtration. So we are taking this constant as standing alone, no ratio or anything, it's just we are looking at it.

Robert Marks:

I see, okay.

Daniel Diaz:

And what we found is that actually the probability of its life permitting interval is very large. If I remember well, it's something like 0.3, but Ola can correct me if...

Robert Marks:

So that was 30%. That was the probability that that constant would be created by chance, right?

Daniel Diaz:

Yeah. It's actually not 0.3, it's actually close to 0.7. So it's very high. I'm looking here at the paper and I correct myself. So the point is that actually, what is happening with this primordial fluctuations is that the life permitting interval is spreading through several orders of magnitude. And that is producing that when we're looking at probabilities in the way we measure them, then the probability is high, so it's not going to be that finely tuned. That being said, it is important to notice that in our method, what we're finding is a maximum for that probability. So to put it in some formal terms, whenever we are finding that one constant is finely tuned, then we can be sure that it is finely tuned, but because the actual priority is going to be either that maximum or smaller.

Robert Marks:

So the probabilities are the worst case, that's the worst possible case that it could be.

Daniel Diaz:

Yes. That's because we have been highly conservative in order to avoid false positives.

Robert Marks:

Understood.

Daniel Diaz:

So we are avoiding false positives, but the method is not that good in avoiding false negatives because it is a maximum again. So from that perspective, whenever we are finding a high probability with our method, it does not mean that it is not finely tuned, it means that the method cannot say anything definite in the end.

Robert Marks:

I see. So it could be that the things that you found that were not fine tuned could be fine tuned, but from what we know and in accordance to the model you're using, they're not fine tuned.

Daniel Diaz:

Yes, exactly because as I said again, this is a maximum. So if the maximum is very small, then we know that the probability should be smaller than the maximum, and then it is finely tuned. But if the maximum is to high, then we don't know what is the statistics.

Robert Marks:

Okay. Well, excellent. This has been a fun chat. We've been talking with Dr. Ola Hössjer from Stockholm university, and he's in Sweden right now. And Dr. Daniel Diaz from the university of Miami, who is in Columbia. We've been talking about different ways to measure fine tuning. Thus far, we have talked about fine tuning, but we haven't talked about the cause of fine tuning. We'll continue to talk about that in the next podcast on Mind Matters News. Until then be of good cheer.

Announcer:

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