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Quantum Gravity

Melvyn Bragg : I can't resist comparing the deep fried Mars Bar to what we're going to talk about now, I'm sorry to say that it's irresistible (laughs)! Hello, early in the 20th century, physicist were alarmed at the realisation that the smallest things in the universe don't obey the laws described by Newton's theory of gravity. Ripe apples fall from trees, and the Moon orbits the Earth enthralled to its gravitational pull, and Newton had been God. But there's no such force of gravity at work in the world of very small things. It seems there's one set of rules for the realm of everyday objects and a very different set of laws for the quantum world, where tiny particles actually form the building blocks of all those larger things. It doesn't appear to make sense. Physicists decided there must be another theory, a much larger theory that unites, incorporates and finally makes sense of these two realms, and this has been the holy grail of physics ever since.

Last year we explored string theory on this programme, and one of my guests today is researching what he believes is a much stronger contender for the title of "theory of Everything" he's Lee Smolin author of "Three Roads to Quantum Gravity" and Professor of Physics at the Centre for Gravitational Physics and Geometry at Pennsylvania State University. Also with us is John Gribbin visiting fellow in astronomy at Sussex University, and Dr Janna Levin Advanced Fellow in the Department of Applied Mathematics and Theoretical Physics at the University of Cambridge.

John Gribbin, quantum theory brought us computers, genetic engineering, lasers, it's a huge achievement in science. Can you explain why Neils Bohr one of its pioneers said quote "Anyone who has not shocked by quantum physics, has not understood it", what did he mean by that?

John Gribbin : I think the key thing that he was worried about was a business of...that's called "quantum jumping" - when systems change from one state to another without passing through any in between state, and the classic analogy we have is when you think of an atom, what we learn at school is an atom has a central nucleus , we think of electrons going round it like planets going round the sun, which sounds nice and cosy, but then you find that electrons can jump to one part of the atom to another as if Mars disappeared from its orbit and reappeared in the Earth's orbit, literally instantaneously with nothing happening in between, and this runs completely counter to the ideas of Newton that came earlier and at the same time what was puzzling was what you mentioned, that physics seemed to have split in two at the beginning of the 20th century. Instead of one set of laws to explain everything you had the General Theory of Relativity - Einstein's description of gravity and the universe at large, and Quantum Theory explaining the world of the very small, and at that time seemingly no overlap between them. So it was truly shocking to people brought up on classical physics.

Melvyn Bragg : Was the shock restricted to physics or did...was there a feeling that this uncovery - discovery would lead to a shake up of the way we looked at things outside physics, the way we looked at the world in a larger sense including even let's say, at the further edges as it were - a moral sense?

John Gribbin : There certainly was, I mean this was a period when there was a lot going on in the world in general, I mean in the world of the arts, there were artistic movements doing strange things, I mean cubism and Picasso's work and stuff like that is all part of the same culture and people *do* try to make connections, both ways or either way. There are people who claim that the artists were influenced by the science, and people who claim that the scientists were influenced by the arts. I don't buy either of those two descriptions. I think there was just a cultural ferment going on at the beginning of the 20th century and lots of new ideas were emerging together.

Melvyn Bragg : I'm told, or I read that at the heart of quantum theory is Heisenberg's Uncertainty Principle, which has very very simply, that you cannot know both the momentum and the position of any sub atomic particle at the same time. Why is it impossible to measure that?

John Gribbin : It's...

Melvyn Bragg : ..simultaneously and why is that important?

John Gribbin : Well, it's not just that it's impossible to measure, this is the big thing to get hold of. It's that the quantum entity - I don't like to use the word particle - the quantum entity doesn't *itself* know both where it is and where it's going at the same time.

Melvyn Bragg : You're going to have to just describe..decode that a little bit more.

John Gribbin : The uncertainty is not a problem with our measuring apparatus. A lot of people think it is. They think if you try to measure the position of an electron it's like trying to sort of squeeze it in your fingers and it will pop out and fly off in a different direction, so you don't know where it's going, and if you try to measure where it's going somehow that disturbs it's position, so it's in a different place, but it's not. What Heisenberg told us is that things like electrons *don't have* a precise position and a precise direction which is what momentum is at the same time. So there's an in built uncertainty in the quantum world, and that again is very different from what Newton thought.

Melvyn Bragg : Can you...can you add your comments on that Lee Smolin? Can you just talk about that uncertainty there and why it is so worrying...why it *was* so worrying to people when they discovered it?

Lee Smolin : Well, it's still worrying, and I think that we don't understand Quantum Mechanics. Quantum Mechanics is a provisional theory . It works very well. If your impression is that it doesn't make sense, that's because it doesn't make sense, and I think that the question you were talking about, about the electron jumping from place to place is a question because it is a provisional theory that lends a classical view where space is continuous and you see things moving continuously, and some information about the quantum world where things come in discrete bits information can either be in one place or another. But quantum mechanics is like trying to rap to classical music. It's inherently contradictory, and what we have to do now is deepen it and understand it.

Melvyn Bragg : When you're dealing with something that doesn't make sense, you said calmly "Well it *doesn't* make sense", what sort of sense does it not make that leads you to keep on trying to make sense of it?

Lee Smolin : Well, it is a mathematical formalism, which illustrates the principles you've been talking about - uncertainty, discreteness, and we can use this in order to make predictions. For example that the energy levels of an atom do come in discrete units, an atom can have only one energy, another energy and not energies in between.

So it's this amazing thing and it's a lesson, it's a very good intellectual lesson for anybody to realise that that there's something that you can use, but not understand, a bit like most of us in a computer or radio or something...

John Gribbin : But this is the point , Lee isn't it? I mean it's not that it's weird, I mean if it was just weird people would ignore it, but it makes predictions that apply in the real world, but this kind of jumping that Lee was talking about is how a laser works, now we've all got lasers in our hi fi systems these days.
The only way we can make them is to use these weird rules of quantum mechanics. So it has practical applications, it makes predictions you can test and use in engineering, *but* it doesn't make sense, and that's the problem it's the combination of being useful in practical terms, and not making sense in scientific terms.

Melvyn Bragg : Janna can you come in on this and add your comment to what's been said?

Janna Levin : Well yeah I really do think that that's the crux of it, is that it *is* predictive. Not only is it predictive, but we can calculate things to unprecedented accuracy. We can predict things in particle accelerators, with an accuracy that really exceeds anything that we has done before. So that it is why we are forced to use a theory, even if philosophically you don't understand it , and it is in a way kind of like using your stereo, even if you don't understand how it works. , you can still use it. I think there's a big difference between that an something like Relativity, and when Einstein came up with Relativity, it was counter intuitive, it was difficult, but it's logically consistent. There isn't any point at which you would say "Those are two mutually exclusive propositions", that I cannot simultaneously hold in my mind. In that sense Relativity is understandable. Whereas Quantum Mechanics seems to say two logically opposing ideas have to be held at the same moment.

Melvyn Bragg : Is it..why is it..why shouldn't it be...why is it so difficult to hold these two opposing ideas at the same moment, and why is it so worrying? Why don't you just say...?

Janna Levin : Well, not so much the one's we mention, but there are things like the wave particle duality, which propose that a bundle of light can be a wave or a particle and those are two mutually exclusive states. We like to think things are *either* waves *or* particles, *not* that they are *both*, and yet again, like the Uncertainty Principle, in a sense it depends on what questions you ask, and how you measure a particle which it will behave like.

Melvyn Bragg : That's what I was going to come onto next. In the quantum world, Lee Smolin there's an uncertain relationship of particles to waves. Whether something's a particle or a wave *seems* to depend - you'll correct me obviously - on whether it's being observed or not, can you unravel that?

Lee Smolin : Well more interestingly, it depends on *how* it's being observed. The difference..the simplest way to say the difference between working in the quantum world so far as we do, and the ordinary world is that the...what we think of as the properties of things in the quantum world, for example whether it's a wave or a particle seems to depend on what questions we ask, and it also seems very importantly to work with the quantum world we have to be self conscious about what we physically do to ask a question of an atom, or an elementary particle. That is we can't imagine abstractly, that our own existence, our activities, our measuring instruments are not there, and think about the world as if we weren't there. It seems necessary to put our own actions and our own choices about what we choose to investigate inside the science. So that whether an electron is a wave or is a particle, or better, whether it behaves in ways that make us think of a wave, or behave in ways that make us think of a particle depends on what circumstances we put it into.

Melvyn Bragg : What consequences...can you tell us about the two hole experiment Janna first, and then tell us what consequences flow from that? I know it's a tall order, but...

Janna Levin : Yeah..that's..it's been a long time since I though about the double slit experiment. If you shine a light on one slit you expect.. so that you have a barrier with one thin region where the light can pass through it. As the light passes through it it leaves a mark, let's say on a photographic plate, and it will clearly outline that one slit, and that's a particle behaving like a particle. If you open both.. the other slit, if you have two of them - you expect the same thing, a pattern of that slit appearing on the photographic plate.
If you open both - and things are behaving like particles -you expect the particle to either pass through one slit or the other, not to to interfere with each other in any way and so you get a repeated pattern of the two slits.

However, that's not what's observed, what's observed is the light acting like a wave in the sense that when it passes through the two slits it seems to interfere like water passing through a barrier. It seems to fan out and interfere with itself. So instead of getting a pattern of two slits you get an interference pattern of peaks and troughs, which look like light is behaving more like a wave, and if anyone wants to help me on that, I would be grateful, because it's been about what...several years!?

Melvyn Bragg : They're just longing to dart in, they're longing to dart in , Lee Smolin?

Lee Smolin : No, no, no, no that's, sorry....

John Gribbin : Well the really weird thing..I mean...

Melvyn Bragg : John Gribbin?

John Gribbin : ...is that you can actually sort of make the light behave like particles - photons - and you can fire them into this system one at a time, so you know you're firing one little bullet at a time at these two slits - two holes - and if you do this over a long period of time, what builds up on the other side - each photon makes a little spot of light on your photographic plate or your TV screen or whatever it is, but you do this for hundreds and hundreds of photons, and the pattern that builds up is the pattern you expect from waves going through both holes at once, and interfering with one another.

So somehow, not only does each individual particle - as we like to think of it - pass through both slits at once - but the whole system remembers which ones have gone through which slits, and how they've interfered, and you get a pattern that's just like a wave passing through it.

Melvyn Bragg : Lee Smolin is shaking his head, I'm the one who should be shaking my head! Can you just...why is this so important? And when you say you've said "decides" that implies a sort of thinking inside the particles perhaps. Why..can you give us the..can you give us some idea of the essentiality of this particle/wave duality, to the new theories?

Lee Smolin : Well let me say where it leaves us, because I think it leaves us with two very different options, and one option is a kind of mysticism - to say the problem is with our style of thinking, with our understanding, we should go off an invent a new philosophy...

Janna Levin : Or a new form of logic.

Lee Smolin : ...to encompass this..or a new form of logic, and that's what many people have tried to do. The other response is to say "Well this just doesn't make sense and there must be something left out, there must be some part of the phenomena which is unanalysed, which we're not thinking about properly", and when one takes that point of view, one is led to realise that the unanalysed part has something to do with space and with time. We're thinking about these experiments but we're treating space and time as we always have, and the hope is that by bringing space and time into the picture, and trying to think about what space and time really are, we can find a way of understanding this phenomenon which makes perfect sense to us.

Melvyn Bragg : There was the... there is a lot of resistance to the randomness of quantum theory as I understand it John Gribbin, and Einstein famously said **"God does not play dice"** and then we have the Schrodinger's Cat which you've written about. Can you say where that- because that is, that can give lay persons like myself some kind of grip on it -can you just briefly fit that into what's been said?

John Gribbin : Well, this can be seen as an example of this randomness, this probabilistic chance business in quantum physics that Einstein hated, and Schrodinger hated it as well, although he was one of the pioneers of the subject, and he invented this so-called paradox, it's not really a paradox to highlight the weirdness of the quantum world, and his idea basically was that you could imagine a situation in which as he put it "a cat is locked in a steel chamber with a radioactive device, that has a chance of decaying in accordance with the probabilistic rules" so there's an exactly 50/50 chance that the atom has or hasn't decayed, and if it does decay it triggers something which kills the cat.

Now the strict interpretation of the conventional view of quantum physics is that until somebody measures what's going on - which means until you look in the box - the whole system, including the cat doesn't decide whether the atom has decayed or not, and therefore whether the cat is dead or alive. So Schrodinger said you know "you have this half dead half alive cat, therefore quantum physics is ridiculous", and for 60 years or so, people have used this as an example, and found ways to say why it's not a paradox and why it's not a puzzle, and there are..well there are many different interpretations of what's going on. But the fact that there are many interpretations is a sign as Lee says, that we haven't actually got to the fundamental truth.

Melvyn Bragg : But it comes back to one of the ideas that's around that science in certain areas has got nothing to do with common sense, common sense would say "the cat is dead or alive".

Lee Smolin : No.

Janna Levin : No.

Melvyn Bragg : It doesn't? Lee?

Lee Smolin : No, I think science is common sense, science must be common sense. Science is just a continuation of what human beings have been doing fro tens of thousands of years since people looked up at the stars and tried to figure out what things were. Since people understood what plants were and how to use them for different medicinal purposes, science is just common sense applied to the world, and all this - I'm very sure that in a hundred years, much of these different interpretations of quantum theory, and much of what we're talking about, will be understandable only to historians of science, and not to the scientists of a hundred years from now who will have something that makes sense to talk about.

Melvyn Bragg : Sorry, you were going to say?

Janna Levin : Well I was just going to add that also on macroscopic scales, you do expect quantum mechanics to somehow to reduce to common experience , we don't experience a state of simultaneously being here and not here, sitting on a chair and not sitting on a chair, and so there is a difficulty I think that people have tried to address in going from quantum mechanics to macroscopic physics and how that transition could occur. Which is a rich area also of research, but an important area because it says, there must be a limit that common sense does hold.

Melvyn Bragg : Is there..? John Gribbin let's move on now to this..to trying look at the idea of whether theories can be unified - which has been as I said in the introduction, in a sense the holy grail - do you believe that there is a possibility of a unified physics, looming, and if so - obviously Lee Smolin's book is about this, but I'll come to him second - but can you give us the background of that?

John Gribbin : Well people, as I say, for essentially, for a hundred years now have been trying to put the pieces back together, to find a way to make Quantum Physics and Relativity Theory, which is the theory of gravity work together, or fit together in some way, and there was very little progress for a long time, up until about the 1980s, I guess, and people like Einstein tried and failed. But there is certainly a lot of progress being made now. I'm not as optimistic as Lee. I mean Lee sometimes gives the impression that the answers going to emerge next week, but perhaps within 10-20 years I think we might have something that makes as much sense as Quantum Physics did a hundred years ago, and then you have a generation of people to put the pieces together properly.

What you need is a theory that incorporates both gravity and quantum mechanics and one way of thinking of that - the way I like to think about it - is that it's a quantum theory of gravity, which is very much Lee's area, and as Janna was saying, the difference between Relativity Theory and Quantum Physics is that Relativity Theory makes sense, in the terms of everyday logic. It's a continuous theory, it's smooth - it says that space and time you know are smooth and just like we experience the surface of this table, in everyday life, and Quantum Theory tells us that things are grainy on a very small scale - and it must be true that space and time are also grainy on a very small scale, and that's the problem - is finding out how it's grainy.

Melvyn Bragg : Before we turn to Lee, because this is the area which as you say he is working most ferociously, can we just mention string theory, because on this programme Brian Green last year talked about *that* might unite the seemingly contradictory realms of physics How do you imagine string theory and what importance do you give to it?

Janna Levin : Well if I could just draw one distinction which I drew out of Lee a couple of days ago , which was that string theory is trying to be a theory of everything. It's trying to unify all of the fundamental forces into one theory. What Lee's doing is slightly different, and that's I think maybe why they might be different pieces to the same puzzle. What Lee is trying to do is *quantize* gravity. He's not necessarily trying to unify gravity with the other forces, although I'm sure he'd like to do that eventually - all good things in order.

But in the meantime he's just trying to make gravity a discrete theory, and so that's to be distinguished from string theory, which is trying to unify all the forces together. So I see them as slightly different tasks and I think that the differences are important in the sense that string theory still has an element of the continuous in it, and erm...

Melvyn Bragg : What does that..? Can you unravel that a bit please?

Janna Levin : Sure, so string theory....

Melvyn Bragg : Hard work for string really!

Janna Levin : ...string theory suggests that instead of being grainy as individual particles, when you look at these individual grains you will realise that they are loops of string and that each of string can vibrate and as it vibrates just like you would play different notes on a musical instrument, it will give rise to different particles. So the different particles are analogous to the notes, and in that way it can unify all of fundamental physics by saying the electron and the quark, these are really different notes played on a fundamental string.

So it's pulled them all together to one fundamental element but in a sense it still has the continuous in it in that it assumes a continuous background of spacetime, and the string itself looks continuous, it's a continuous loop of something fundamental.

Melvyn Bragg : Are we talking about ...sorry.. we're talking about this as the building blocks of everything. Now Lee Smolin, in your book, "Three Roads to Quantum Gravity" you mention string...you talk about string theory of course, but you , as it were, put your money on loop quantum gravity, I'm afraid you're on your own from now on, as a far as I'm concerned! (Chuckles break out)

Lee Smolin : Well, it's not that I put my money on it, it's with some friends particularly Carlo Ravelli, but dozens of other people, we've been involved in inventing and studying this approach, and so I have some responsibility for it. I actually believe that it - that is loop quantum gravity - and string theory are each quite possibly pieces of the puzzle as Janna said and that the current task is now to put them together, but..and this is very much like, you know different people before Mount Everest was climbed attempted it from different sides, and I think that there are different communities of scientists who come to this problem which is an enormous problem, with different perspectives, with different tools, and backgrounds and have approached it in different ways and broadly speaking, among the different approaches there have coalesced these two communities of coherent..more or less coherent efforts, one of which is roughly called string theory, and one of which is roughly called loop quantum gravity, and I agree with Janna 's characterisation, the driving idea behind string theory is to unify gravity with the other forces, and with the different elementary particles, but without attacking really the question of the quantum nature or the continuous versus the discrete nature of space. What we did in loop quantum gravity was put the question of unification aside, and attack directly the question of what is the quantum nature of space, and the answer we got, because we did get a clean and clear answer, is that if you unify the principles of Quantum Theory and Relativity, predictions emerge and the predictions are that at a certain scale, which is called the Planck Scale, and...well I'll say in a minute how big it is, it's very, very small, but at his scale, space looks no longer continuous, but it gets broken up into little irreducible units, much like matter gets broken up into little atoms, and this graininess or atomic structure of space, is the main prediction, and indeed it *is* a prediction to be tested by experiment and we believe actually is in the process now of being tested by experiment.

Melvyn Bragg : And so where does that take you, with your...with unifying it with the gravity from the Theory of Relativity? How does...how does that bring it together?

Lee Smolin : Well it's a consequence of insisting that the basic principles of Quantum Theory, and the basic principles of Relativity both be true, and what we did was just very stubbornly insist that both sets of principles be true, and then find consequences of them, and the shock for me was very much a shock, was that we succeeded. I thought that by stubbornly insisting on both being true, we would discover that one or the other had to be false.

Melvyn Bragg : Is it a consequence of what you've discovered, I'll ask Janna and then come back to you, you said, the shape of the universe, this 3 dimensional universe that we see, has that changed as a consequence of this? I mean people listening, and following what you've been very clear about saying, well we sort of want to ask, so if that is true, are we looking at it the wrong way? Will we...will our imaginations turn and look at this thing in a different way as the consequences of what you've done? Does it exist in a way which will be revealed to us, not in a magical...but through knowledge, these sorts of things surely?

Janna Levin : Oh I certainly hope so yeah, so as you know, one of the things I've been interested in is the shape of the universe. Whether the universe is finite or infinite, and whether there are 3 dimensions or more dimensions and certainly string theory - I wouldn't say it makes a prediction, yet because it's not a complete theory -but it does require often, in different formulations that there be extra dimensions, and that the extra dimensions have a specific shape, so that we don't live in a 3 dimensional universe, but we can live in a universe with 10 or 26 dimensions, or it depends on the specific incarnation of the theory, and so if it says something about the compact dimensions, the hope is that..or these small extra dimensions - I say they are compact, because the idea is that that they are so small we can't notice them, or so small we can't fit our hands in them in some sense, so we're not aware that they exist, it's kind of like living in a straw, you're aware of the long length of the straw, but the not the small wound up dimensions. But the hope is that when string theory is complete - and maybe also loop quantum gravity, I'm not sure- that it will say something about the large dimensions also, and so it would be one of those ironies, that by looking at the largest property of the entire cosmos, that we could understand something about its smallest constituents.

Melvyn Bragg : John Gribbin?

John Gribbin : I think the exciting thing for me in all of this, is that there seems to be some suggestion that **there are reasons why there should be 3 dimensions of space and one of time**, even though there are - at the level you're talking about - 26 or whatever it is dimensions altogether, and that understanding- the other way round from what you said - you said "look at the big universe to understand the small", to me, I hope, that understanding why things have rolled up in this way, to leave just 3 dimensions behind, would explain why there was an event like the big bang...

Janna Levin : Yeah I absolutely agree.

John Gribbin : ...which Lee, I mean you know, rather nicely calls "the big freeze" because the universe was hotter in the big bang and then it got cold which is a nice way of thinking about it, and that something happened...something happened in terms of the energy what was going on long ago and that made the universe what it is today.

And it raises other questions which are addressed in Lee's book, is that what went before? Which is the thing that I've been asked for you know, years and years and years, and have always said "Oh well that's beyond the knowledge of cosmology" and so on, and people are now starting to ask that question, "was the big bang, the big freeze, whatever you want to call it a unique event, the beginning of everything? Or was it a change from some pre existing state?", which is very exciting and suggests that there might be something much bigger than our universe that we know about and that we're some kind of bubble embedded in that, in which- for reasons that Janna will no doubt discover in a few years time - 3 dimensions have become important and the others have all got rolled up into tiny strings.

Melvyn Bragg : Would you like to take that up Lee Smolin?

Lee Smolin : Well I think the most interesting thing for me that's come out of the progress we've made is that one can't think about the questions we've been discussing without being conscious of two things, and they haven't come up before, so I think I'll stress them.
One of them is that we are in the universe, looking at it, and the kind of Newtonian fantasy that we can talk about the whole universe as if we're somehow not a part of it and examining it under a microscope and talking about "what is it's shape?", this we can't do, and when one tries to do that, with Quantum Mechanics it *really* makes no sense , and I think it may matter for Janna's question, it may matter that we have to ask the question as participants or as observers inside the universe, we have to ask the question she wants to ask about "what's the shape, what's the topology?" and the other closely related thing is that space doesn't have a fixed geometry and a fixed structure - it's dynamic. Just like the light waves, or the electric field is dynamic and changes in time, the geometry of space changes in time, there's nothing that's fixed, and so we...the geometry looks something like Euclidean space, like we learned about in school, but that's only approximately true, and at any moment a big gravitational wave could come through this room and the geometry could be distorted, and so if we put those two things together, that we're a part of the universe and that geometry and indeed everything is dynamical, **one ends up feeling very differently about this world we live in.**

Melvyn Bragg :Can we just talk about - before we move on to the impact of this - can I talk about...a little more about the loop quantum gravity, just to try to get it a bit clearer, I know it's imposing a lot on you to do it in this abbreviated form, but just to go back to it. you...the idea as I understand it that gravity's broken up into parcels or "quanta" in the way that light or energy is, can you just address that for a few moments?

Lee Smolin : The result that we got - and I want to stress that this really is the result of putting together Quantum Theory and Einstein's Theory of Relativity and demanding that they be consistent - is that when you look at very, very small distances, and the distances are about as smaller than the atom as the atom is than the orbit of the moon, so that's about how far we have to go to this so-called Planck scale, that space looks something like those models of molecules that we used to do in high school. I'm sure if people think back to chemistry class, they had those little models with struts and little balls, and you made them together and you made different molecules, but space itself has that description and the little balls are little units that have a certain amount of volume, and they can't have less than a certain tiny bit of volume, and the little struts are actually carrying little bits of areas. So that you get..if space were 2 dimensional, then what it would look like when you looked very small would be like a geodesic dome, made up of little triangles , that each have an irreducible size, and so this has consequences - first of all - and I think it's worth stressing this - and indeed even since I wrote the book, the situation has improved dramatically - light passing through this discrete structure travels just a little bit differently than we're used to thinking on the assumption that space is smooth. Just like light travelling through the air reddens, or like travelling through a crystal or a wave travelling through a crystal, they're effects, in which if you study very carefully, the light as you receive it, you can see the patterns of the space it passed through embedded so to speak, in it, and there are now observations made about some data, particularly by somebody called Giovanni Emilino Camelia in Rome, that that's actually been observed, that we've actually seen in light and in cosmic rays coming from distant galaxies, the imprint left by this discrete geometry as the light travelled through it.

Melvyn Bragg : Janna how confident are you that physics will solve this problem?

Janna Levin : It's a subtle question, I'm sure that Lee's right, we will have one day a quantum theory of gravity, and I think we'll either unify or understand why it can't be unified, and something else will take it's place. Definitely something is going to happen - something big is going to happen - but whether or not that's going to be the end of theoretical physics, that's something that I'm more sceptical about, and I think there is this attitude, that we'll solve it and that we'll all become applied physicists after that. I don't think that's so likely. But I do think that something has to give, we can't continue in this state of quantum mechanics, gravity, all the forces not somehow speaking to each other in a more eloquent way.

Melvyn Bragg : John Gribbin?

John Gribbin : I think it's important though that we shouldn't sort of run away with the idea that all the old physics is wrong. I mean people said a hundred years ago, when Einstein's theory was proved right they said - the newspaper headlines said "Newton overthrown" and things like that -which is total rubbish, I mean you still use Newtonian physics if you want to build a rocket to go to the moon, and when we have a unified theory of gravity and quantum physics, that won't mean that we stop using the general theory to describe the universe at large, or quantum theory if we're designing lasers, or whatever it might be.

When you achieve what you might call a deeper level of knowledge, you still have to explain all the things that are already explained by your existing theories, and that's what makes it so hard. It's quite easy to come up with a quantum theory of gravity, but it's hard to come up with one which actually matches the way the universe works, that's the clever bit.

Janna Levin : I actually think it was hard! (laughs) There were reasons why it was specifically hard!

Melvyn Bragg : When - Lee Smolin, let's assume that your optimism - you declare yourself to be an optimist in the book - ...

Lee Smolin : Yes.

Melvyn Bragg : ...let's be optimism...let's hope your optimism..

Lee Smolin : Well I have to face reality.

Melvyn Bragg : ...is justified. Absolutely...how big an impact d'you think such a discovery - a unified theory - would make? I mean on the scale of things, is it as big an impact as the Theory of Relativity? I mean how big an impact is it going to have on, not on the thinking...not only on the thinking in cosmology and physics, but as it were, on the rest of us, and what happens?

Lee Smolin : Of course, we don't know, but if history is any guide, huge, there will be a huge impact. One is as I was saying and there's more to say about this than we have time, but the transition to a view of the universe in which everything is dynamical, there's nothing fixed, it's a system of relations which continually evolves in time, and we're

a part of it, is a very important part of what's happening in the 20th century. What *happened*, excuse me in 20th century science. All across the board and I think that this is already having an impact in art in the thinking about social theory, in much the way that John said that at the beginning of this century. I also always find it fascinating that when people start to say something's about to happen, with apologies to Janna here, actually at that stage it's really already happened, and an example of that - for example is the internet - at the point where everybody started saying, you know two years ago "the internet is about to happen, the internet is about to happen", basically it *had* already happened, and it had already transformed our life, it was just a question of catching up, understanding what it was, understanding that it was not a store, but it's something else, and in the same sense - although there's much work to be done, I have the sense that the turning the corner and laying on the table the basic principles of a quantum theory of gravity, the basic shape of the ideas *has* happened.
There's an idea called the holographic principle we haven't discussed, but which changes completely this issue about observation and how it affects the world, and quantum theory - there are the structures that come out of string theory, these predictions of discrete space from loop quantum gravity.
I personally think we're kind of in the mopping up phase, where we have what we need on the table, and we're just putting it together.

Melvyn Bragg : Janna do you want to come in on that?

Janna Levin : Ermm, ah there's so many things. Well first one I think, Lee said it best when he said "if history is any guide", I think that's true - if history is any guide, there's going to be huge ramifications, one's that we simply can't foresee, and you have to remember Einstein himself rejected some of his most outrageous predictions.
He rejected black holes and the big bang for a long time before he finally gave way and accepted them. So there are outrageous things that can come out of a theory that we can't foresee and maybe Lee's right we're in the mopping up phase, although I'm more sceptical. I think we have a lot more work to be done. But if we are in the mopping up phase, maybe we're all too close to it to see it. Maybe there are extraordinary predictions, that we are still ourselves being to rigid..we like to see ourselves as visionary and very flexible, and very adaptable to new ideas, but I think there's a good chance that we're less so than we hope, and that things are right in front of us, we don't yet know. I know Lee's shaking his head, yes, so that's good! (laughs)

Melvyn Bragg : There's a sense in which we can almost calculate what Newton's ideas brought to the general world and Faraday's did. They brought this..and Einstein's did. What will this theory bring, do you predict John Gribbin?

John Gribbin : Well you mention Faraday, so it's an obvious opportunity to trot out the famous quote, when Faraday was asked what use electricity was by the Prime Minister of the time, he replied " I don't know, but I'm sure one day you'll tax it" (laughter)!
And I think we're probably in the same situation here, if there is a quantum theory of gravity or a unified theory, given time, it'll actually used for practical purposes, and when those practical purposes come to fruition they'll be taxed, I'm sure.

Melvyn Bragg : Is there any sense of practical purposes when you're doing this research, Lee Smolin? D'you think "Ah, this might...", d'you have any glimmerings of electricity being taxed as it were?

Lee Smolin : Not very much. It is..we are 20 orders of magnitude smaller than the atom, and we're very happy just to be talking about real experiments that are being done now to test it. So I would say pure science is as its always been. It's own motive, and there's time enough for...after all if one looks back a century ago, it's extraordinary what's happened. I mean try to imagine explaining a lap top computer to a scientist of only a century ago, and so I think there's no doubt that we'll be extraordinary consequences in the (indistinct) and we don't know what they are, which is good.

John Gribbin : In the short term of course it's got value as entertainment. I mean people listening to this programme because they're interested in what's going on, and it doesn't cost very much money to keep people like Janna and Lee in business, it's a very cost effective of stretching all our intellectual capacity and providing a lot of enjoyment for people. So that's surely a good enough motive to be going on with.

Melvyn Bragg : D'you find any analogies because you use biology and biochemistry as analogy in your book, d'you find any analogies in the way the mind works, from what you know, to the way your ideas are working out?

Lee Smolin : Well I think it is very interesting that people who study the brain - I'm not sure if this is what you're getting at...but..

Melvyn Bragg : It is yes.

Lee Smolin : ..yes, people who study the brain, end up drawing pictures in which the brain is an interconnected network of neurones, which evolves in time, and I personally believe - and this is going beyond loop quantum gravity and string theory - but I personally believe that we will discover that the same kinds of ideas and principles that will help us how a brain works, will help us understand the early stages of the evolution of the universe, and the big bang and why it is that the world grew up from something like a little network of interacting units to something so big and beautiful.

Melvyn Bragg : Do you agree with that John Gribbin?

John Gribbin : Erm I'd like to, I think it's as Lee says, it's going a little bit further than you can reasonably extrapolate at the moment, but it would be wonderful if it was true.

Janna Levin : Yeah I think I agree with Lee, I'm not sure if this is what he's getting at, but there are ideas like chaos and complexity, which again deal with everything ultimately being dynamical, being process driven, and you can use chaos as a tool to apply to systems like the brain or language or biology, or you can use it as a tool to apply to fundamental physics, but I'm wondering if the connection isn't actually deeper than that.

Melvyn Bragg : Well thank you all....I'm sorry, you're book's "The Three Roads to Quantum Gravity" Lee Smolin...

Lee Smolin : Yes.

Melvyn Bragg :..we didn't get to the third road which is a completely outside force which just might be God....

Lee Smolin : No, no, no, no..I didn't say that. You may say that. (laughter)

Melvyn Bragg : I've said that, yes.

Lee Smolin : Oh right!

Melvyn Bragg : I think it was clear that I did say it! And I did say it at this time so you haven't any time to reply! Thank you very much Lee Smolin, John Gribbin and Janna Levin and thank you very much for listening.