Penrose's Cyclic Universe

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Sir Roger Penrose is an English 92 years old mathematician, mathematical physicist and philosopher of science. Apart from receiving the Nobel prize in physics in 2020, Penrose has received a lot of prizes and to mention them all would be an article in itself. Among others, in 1985 he was awarded the Royal Society Royal Medal and along with Stephen Hawking, he was awarded the prestigious Wolf Foundation Prize for Physics in 1988.

Besides his cosmological model which is known as Conformal Cyclic Cosmology or for short CCC, he has worked on consciousness, ways to map geometric objects in Minkowski space into the 4-dimensional complex space known as twistor theory and discovering the Penrose tiling, just to mention some of Penrose's research.

This article is based on an interview that I made with Sir Roger Penrose on February 6th, 2024, on the internet.

Usually, we do not bring English articles in KVANT, but when a Nobel prize winner, Sir Roger Penrose, agreed to be interviewed by KVANT we made an exception. His research is covering a lot of different topics in mathematics, physics, and cosmology. We will mostly be interested in his ideas for an alternative to the standard cosmological model.

Figur 1. Roger Penrose with the Nobel Prize for physics medal.

What are you working on in cosmology now? And what is the state of cosmology today in your opinion?

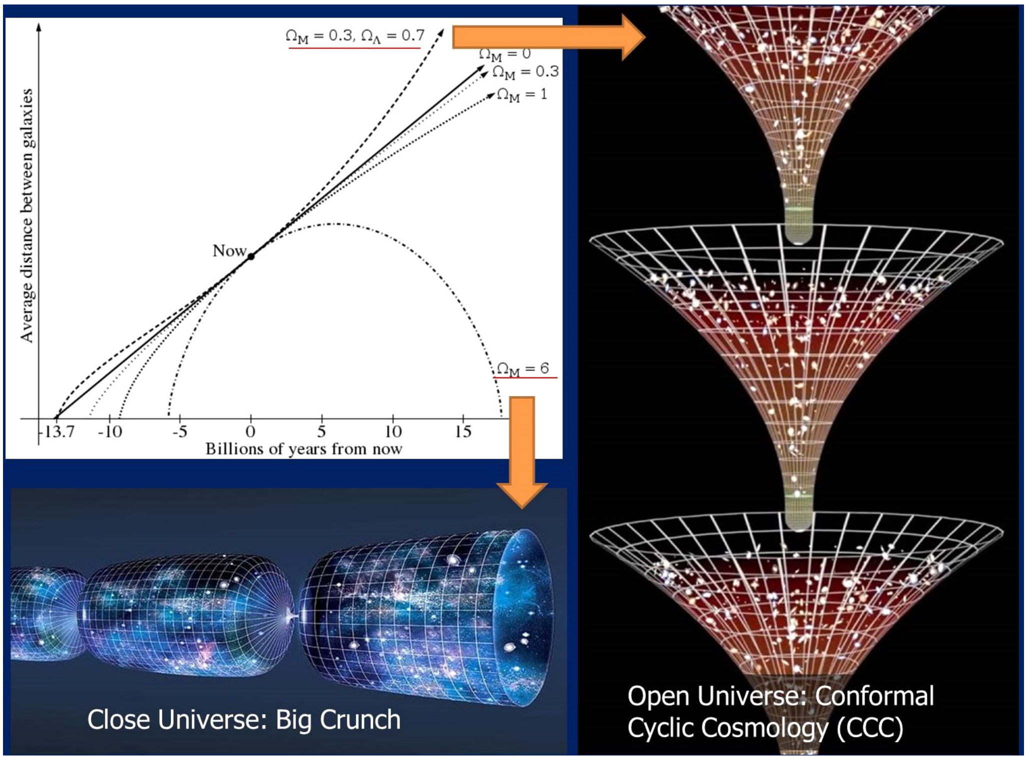
I'm trying to finish writing a paper with a Polish colleague, Krzysztof Meissner, on the scheme which I actually introduced ages ago. I think round about 2005 or slightly earlier, which is a scheme which I may say people having rather difficulty picking up on it, even though we have good evidence for it. That is what I call conformal cyclic cosmology.

The Big Bang is normally considered to be the beginning of the universe, but I was actually driven to this new view for many, many years. The second law of thermodynamics says it's got to be very special because the entropy goes up. That means the initial state must have been very special and the earliest direct observations of the universe we see are the microwave background. Well, I mean that's apart from some other things which I can mention, but the microwave background is noteworthy. Particularly, because it has such a perfect Planck spectrum which means the entropy in the radiation is at a maximum and for some reason, people didn't puzzle about that. It seemed to me extraordinarily remarkable that it starts off at a maximum. Where's it got to go? It's already at the top piece.

The point is that what you're looking at is matter and radiation which is more or less at this early stage at the maximum entropy state. But what is at a low entropy is gravitation and the thing is it works in the opposite way for most things. For most things when you have an irregular state and the entropy goes up, it gets more and more regular, and the high entropy is very uniform. If you have some gas in a box, it spreads out and fills the little box uniformly. Whereas if you imagine a system with a lot of stars and they start to clump by gravity and they produce black holes, the entropy goes shooting up. Its entropy goes up but the irregularities in the system also go up and so the uniform state as far as gravity is concerned has very low entropy, whereas with regard to matter, it has very high entropy, which is a very strange situation. You've got gravity singled out as being very peculiar.

For some reason, people never picked up on that. I don't know why. It seems almost obvious but for some reason it's not stressed by people normally. That I had the view later on, partly stimulated by one of my former graduate students Paul Tod who had a nice way of stating the way in which the universe was special by saying that you conformally stretch it. I used to do a lot of work on looking at infinity by squashing it down and looking at how fields behave. The asymptotic behaviors of fields, gravitational waves, or electromagnetic fields and so on. It's very convenient trick to squash it down by conformal squashing and you can then look at infinity. It's a nice finite looking place, and because particularly electromagnetism is conformally invariant, it doesn't know infinity is anything special. In the future you can squash it down and the Big Bang can stretch it out. I was struck by the fact that if you do those two things, in the remote future you squash down and the Big Bang stretches it out. They look awfully similar.

You might say they look very different because one is very hot and dense and the other is very cold and rarefied but if you squash down cold and rarefied, it gets

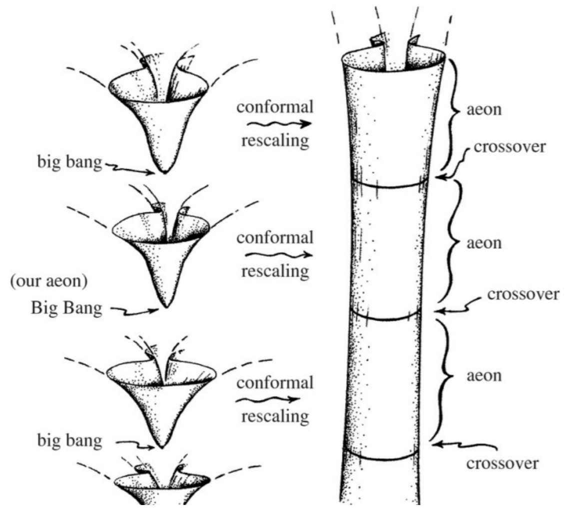


Figur 2. The two cyclic models of the universe, the closed model in standard cosmology has a density parameter Ω_M larger than 1 and the universe will collapse in a Big Crunch. The open model of the CCC has density parameter slightly smaller than 1 which means it will continue to expand.

hotter and denser. If you stretch out hot and dense, it becomes colder and more rarefied. They really look very much the same from a conformal point of view. So that's conformal. What that means is you're looking at shapes, small shapes and you're not interested in the size, so big and small are equivalent.

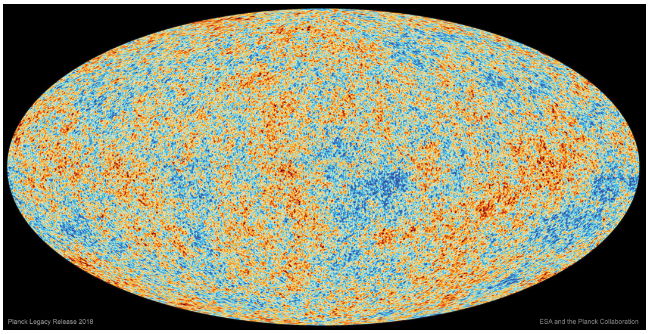
The only thing that distinguishes big from small is mass, basically. These are the two most famous equations of 20th century physics, $E = mc^2$ and $E = hf$. The last equation is the Planck formula which tells you that energy and frequency are equivalent. If you put the two together, you see that mass and frequency are equivalent. Mass basically determines frequency or it determines clocks and therefore it determines the scale. If you don't have mass, you don't have the scale. The argument is, that in the remote future you could say as simplification it's dominated mainly by photons and they don't have any mass. They wouldn't know big from small. In the early state of the universe, it's so hot that the energy and particles are dominated by their motion and not by the mass and the mass becomes irrelevant the closer you get to the Big Bang. The argument is now that if you can ignore the mass in the Big Bang and in the remote future, then the Big Bang and the remote future aren't so different from each other.

The conformal cyclic model is to say that our remote future will continue as the Big Bang or what I call the next Aeon. Our Aeon started with the Big Bang and that Big Bang was the continuation of the remote future of a previous Aeon. You have this picture of Aeons, one after the other, each with their Big Bang in their remote future. For a long time, I didn't know any way to test this and then eventually I persuaded an Armenian friend of mine, Vahe Gurzadyan, and some Polish people quite independently looked at signals which I claimed might be able to come through from the previous Aeon.



Figur 3. The Conformal Cyclic Cosmology. One Big Bang follows another from one Aeon to another. There is a crossover from one Aeon to another, where a conformal rescaling takes place. This means that the universe has expanded so much that size can be rescaled.

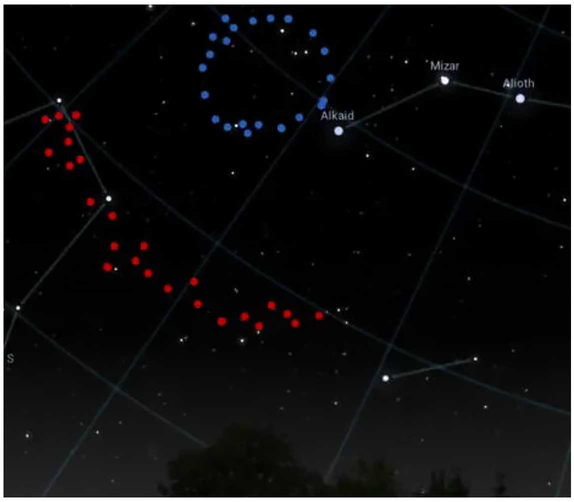
You have colliding supermassive black holes which is going to happen from time to time. As we know now, our Galaxy has a black hole in its center, and we are on a collision course with the Andromeda Galaxy which has a much bigger black hole in its center. When we collide, these black holes will search each other out and then finally spiral in towards each other. As the Andromeda is much bigger than our galaxy, it more or less swallows ours up. But that will be the remote future of a galactic cluster and will be dominated by a black hole which is the result of various other black holes running into each other. As they do, they will emit enormous signals of gravitational waves. This will happen in the Aeon prior to ours. The gravitational waves can get through from one Aeon to the next, and so you might see the effects of these gravitational wave signals. You don't directly see the gravitational waves. Well, that might be an interesting test with gravitational wave detectors you might just be able to see the gravitational waves directly, but what you can see apparently is the residual effect that is hitting the dark matter and producing rings in the sky, which are detected and seen by both the Polish group and by our group. We wrote papers on this but nobody paid any attention.



Figur 4. Planck satellite mapping of the Cosmic Microwave Background Radiation (NASA). Penrose used this mapping to find the Hawking spots with a high confidence.

Somewhat later, we had a different test which involves evaporation of black holes in galactic clusters. They'll sit around for ages, and then they will start to radiate by Hawking evaporation and eventually, this radiation, since it happened so late, will be concentrated in the single point which comes through what I refer to as Hawking points. These Hawking points describe spots in the sky of raised temperature. The Hawking points are seen, and we have a paper in the Monthly Notices of the Royal Astronomical Society about three years ago now. I don't think that I've seen any comment on the paper. I've seen comments on the archives which we had to take down as a condition for the paper being published. We saw these points with a confidence level of 99.98% confidence. Does anybody pay any attention to these signals? No. I don't think so. Very curiously. Some people claim not to see them and then you look at the paper and they do see them. Very strange. They seem to be there, and these points are evidence for this particular model.

Even recently there was a curious signal. People noticed rings of galaxies. There was a little bit of a noise about that just the last few weeks (see press release from January 11th 2024 [1]). That could be a possible signal I hadn't thought of it before. You might find that these rings of disturbance, which are gravitational wave signals, could be seeds of galaxies and the fact that they're in circular rings where this is one particular circular ring. I think there's an arc outside the ring and they have pretty well the same center. This is the sort of thing you might see, because if these events happen several times, you might expect, they will produce rings with the same center. That's what Vahe Gurzadyan was looking for and now he seemed to find them.



Figur 5. A newly discovered giant ring of galaxies (blue dots) and the earlier discovered arc of a ring (red) [1].

That's my answer to the state of cosmology. How well do they have it right? Well in a certain sense, a lot of the things they've done are very impressive. They don't seem to have got the big picture right. That's what I claim, although not many people agree with me.

Research has worked according to some kind of fashion. Hasn't it?

Yes, well there is a lot of fashion involved. I wrote this book called Fashion, Faith and Fantasy [2]. I mean, there's got to be evidence. There's certainly good evidence that the Big Bang was there, so I agree with that. In my very, very early days, I was a grand young graduate student, and I went to Cambridge, and I made friends with Dennis Sciama. I'd heard the lectures given by Fred Hoyle and this was on the steady state model. I was quite keen on the steady state model because it seemed to be sort of philosophically rather nice and it had a good thing in its favor, which unfortunately was a mistake. It depended on mixing up one kind of Cepheid variables with another kind. In those days, the universe was estimated to be younger than some of its contents. The Big Bang was estimated on the basis of these Cepheid variables to be younger than these very, very old globular clusters. The globular clusters seemed to be older than the universe and that didn't make any sense. The steady state model was born out of this. That was a mistake. They mixed up two different kinds of globular clusters. When they got that right then there wasn't this conflict. Then the microwave background was discovered, and I had a great respect for my very great colleague Dennis Sciama who taught me an awful lot of physics. I did pure mathematics as a graduate student and I learned an awful lot from him, including the steady state model. When the microwave background was confirmed, he changed his mind. He would go and give a big lecture where he would say, "I was wrong" at the beginning. I had a great respect for him.

I understand that inflation is not really necessary in CCC. Have I understood this right?

That's right. You see the inflation is needed in a standard picture for various things but in my scheme, you don't need it. In fact, it would cause trouble with my CCC model, but you see the thing is that inflation seems to indicate that there was evidence for an exponential expansion in the very early universe. I'm saying that this is evidence for the exponential expansion of the previous Aeon which didn't happen after the Big Bang, but it happened before the Big Bang because you're looking back into this exponential expanding phase of the previous Aeon. In many respects that looks rather like inflation. The picture of inflation comes about from kind of not having the view that there was a previous Aeon. This previous Aeon explains the things that you would otherwise might need inflation for.

It gets rid of inflation, which is a good thing as far as I'm concerned. It's such an artificial theory. You have to put in this inflaton field which doesn't do anything else apart from inflation. It doesn't even work because if inflation works to smooth out the Big Bang, which seemed to be the argument, why doesn't it happen again in the remote future? It doesn't really hang together. The remote future doesn't add itself up. You get black holes colliding and they produce a great mess. The singularities in black holes are a great mess. They're nothing like the Big Bang which is a singular state. I had this theorem which eventually seems to have won me a Nobel Prize which is flattering. This theorem was to show that in generic situations of gravitational collapse, you will get these singular states which are very peculiar and these singular states in the remote future are extremely different. They're high entropy singularities, whereas the Big Bang is very low entropy. It's got to be for the 2nd law of thermodynamics to work.

It's rather one of these things, I regard it's sort of obvious which for some reason you want a state in the beginning, which is at very, very low entropy and in low entropy in the gravitational field. If you put inflation in, it doesn't do it. You have to start it off with something that's already very uniform. Inflation doesn't even work without it being already very uniform. That doesn't solve that problem at all. Still most people still go down that line, so if you ask me what I think about current thinking in cosmology; it is seriously wrong. The conformal cyclic cosmology does other things. It produces dark matter. Another question you wanted to ask me about is dark matter and dark energy. People talk about dark energy to me. It is one of the worst names I know in physics and there are a lot of pretty bad ones. That's even worse because it's neither dark nor energy. It's not dark, it's invisible, which is quite different from dark. Look at the Galaxy edge on, and you see a dark line across the middle, which is dust, that's dark. The dark energy is invisible. It's not energy. That's the other thing energy attracts. This push. It's the other way around. It's not even the other right, it's just different. It's not energy. It doesn't behave like energy at all. It's an atrocious name just like the Big Bang. Fred Hoyle introduced the name Big Bang as a joke, trying to make fun of it. That was the idea and now it's stuck. That's quite funny.

I assume that time is infinite or do you view it different in CCC?

It would be infinite, yes. Well, you see, I mean maybe there are only 73 Aeons. Who knows? The easiest scheme is to say an infinite number of Aeons and they continue indefinitely in both directions, in which case your timeline continues indefinitely in both directions. In the future, you have to worry about what you mean by time.

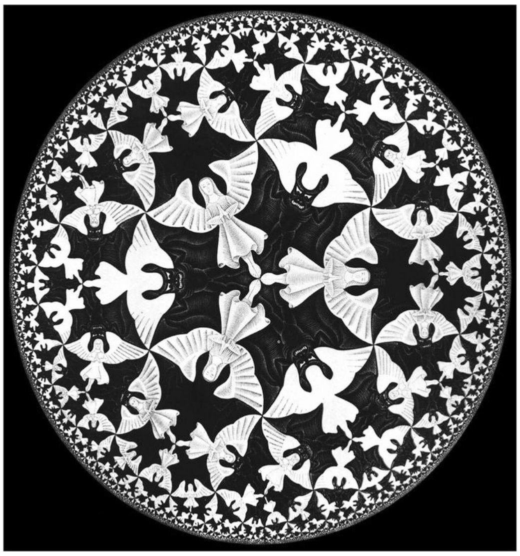
What do you mean by time normally? It depends on frequencies and these ultimately depend on mass. If you've got atomic and nuclear clocks, they really do depend on mass levels being slightly different. You have very precise clocks, and they depend on the matter having mass. The mass gives you a definite frequency and ultimately that's what gives you clocks. Now if the mass fades away and becomes a massless photon then you lose the concept of time, which is in a sense what you need to do in CCC because the timescale altogether comes somehow to an end. Even though, you might lose the concept of the clock because maybe the mass will fade out in the remote future. If this is a sort of hypothesis, I don't know whether you need to have it, but I think you do need something like that in order for the model to make sense. As long as you have massive particles and the ratio between the masses is fixed then you have a definite notion of time but if over a very, very long time scales the masses phase out then you don't have a universal notion of time. You may say, well, there isn't a universal notion of time which is really what I need for CCC because somehow you have to have a conformal time which enables you to continue into the next Aeon.

There are lots of things about the scheme which need to do be done in trying to complete a paper with the Polish colleague Krzysztof Meissner. We have a new idea about how the CCC thing works, and we keep running into snags. He wants to finish the paper within a few months because he's got a grant which he wants to be able to renew. He gets this grant for working with me and so he wants to be able to say we've got this paper which we've got accepted for publication. That would enable him to continue his work, which would be a good thing. That means finishing this paper, which is running into all sorts of snags. It's peculiar snags which need to be understood. Our view has changed slightly. I wrote a book which was called cycles of time [3]. That book presented my view about CCC but the view has changed a bit from what I described in that book. That's what Krzysztof and I are trying to explain – what determines the crossover? You should have a crossover from one Aeon to the next. That makes sense but to make it work in detail is more tricky.

When I asked if he wanted to elaborate more on the new idea, Penrose declined since they have not published about the idea yet.

Does it make a difference for your model what the curvature of the Universe is?

The curvature actually makes a difference. Curvature of space is almost flat. The calculations we do in our paper assume it's flat. If these Aeons have to continue and continue in order for this to work, the universe especially has to be slightly negative which is a curious but not a very popular idea. It should not be very negative. In fact, the observations are that any curvature is very, very tiny, but it you have to have a slightly negative curvature with the scheme to work.



Figur 6. M.C. Escher, Circle Limit IV, woodcut, 1960. This illustrates a negative curved universe, but Penrose also uses it as inspiration for his Conformal Cyclic Cosmology.

The negative curvature is the saddle form. You present this in the picture of Escher's angels and devils.

Yes, that's not what our paper is about, but it's one of the implications. Not even of our paper. It's independent actually. It is one of the implications of this CCC scheme, curiously enough, I never realized this until only very recently. That it really has to have very, very slightly negative curvature, and there might be other ways around it. The ordinary picture comes to this conclusion.

Does CCC not end up as another version of the multiverse theories?

I don't call it multiverse at all. You see the multiverse kind of picture is more or less sort of stacked up beside each other, so to speak, rather than temporarily on top of each other. I don't see the need for a multiverse. You see multiverses are partly trying to get around the idea that they regard the universe as very unusual. I don't know. It's all tied up with string theory and things like that, which I have lots more trouble with. I don't see any need for a multiverse. That's sort of universes that are going parallel to each other in some sense. I think some people argue that in order to have life in the universe, you have to have a very special universe. There may be all these dead universes around. The reason, we get away with having a second law of thermodynamics which is congenial to us, is that we just happen to live in the universe and that we can't live in these other ones, I don't think that the argument works. It doesn't make sense to me, but I think it's the kind of view that people have in the backs of their minds that in order to allow the universe to be peculiar enough to have life in it, you've got to have lots of tries at the universe. Only the lucky ones with people in them are the ones which we have to be in because we're living things. I see that argument, but I don't think it makes any sense really. There are other reasons for why the universe has the specialty. It's nothing to do with multiverses but there may be string theory views. You see, people like string theory and multiverses, and I don't like string theory.

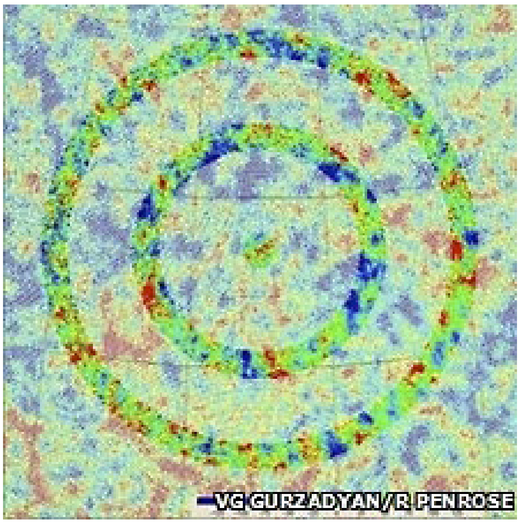
What's going to happen with the Higgs field at the end of the Aeons?

Well, you see, that was one of the things I kept worrying about in the book [2], but the new scheme avoids all those problems. You see the crossover occurs a little earlier. It depends on what physics is involved in the scheme, which I was trying to plug in that book. It did involve particle physics having some rather peculiar properties and maybe it doesn't have those peculiar properties. It depended on particle physics, and I certainly talked about the Higgs field without knowing much about it. This new proposal, we have, seems to sidestep that problem. It's not particle physics at all. It's another part of physics which is important. It does depend on the new scheme, so that part of the book is superseded at the moment, but I'm afraid we still haven't quite handed out all our problems.

You say that we can test for the gravitational waves from one Aeon to another, but will it not create a scenario with larger and larger fluctuations for each Aeon in the CCC-model?

I hope not.

My colleague is working on things called epochs. You have these different stages in the universe, where the main physics dominates what's going on. It changes from one state to another and it's a question of which physics is dominating different stages. You have matter dominated and radiation dominated, and these are different phases in the universe's behavior. Actually, there's a curious irony that the paper that we are writing arose partly from the discussion that I had with Alan Guth, one of the originators of inflation theory and he was trying to convince me that my theory had to be wrong, and inflation had to be right. He came up with an argument, if what you say is correct and this was the paper in the Monthly Notices of the Royal Astronomical Society [5]. We look at these spots in the sky which we call Hawking points and the diameter of these spots comes out to be a very definite amount and within cosmology this has to do with how much expansion there is from a certain stage to another stage. Alan Guth had worked this out. He had put himself in my shoes. I gave him all the credit. He said from your perspective, you should come out with spots which are only half the diameter than the ones you see. He says there's something wrong, so I get hold of Krzysztof and I said that Alan Guth told me that there's something wrong and the spots should be half the size that we see. Krzysztof has done a recalculation and then eventually says he's right. The spots are the wrong size, so this has led us to this new view that we're holding, and this is the paper which I'm trying to write with Krzysztof.



Figur 7. This is a close-up of a Hawking ring as seen in figure 4. The Guth anomaly found that these spots should have a diameter half of their observed size. Penrose and Krzysztof are working on a solution to this problem.

There is something different. We put it like this that there's another era (not to be confused with Aeon). You have these different stages in the universe where different features dominate. There's a certain stage where radiation dominated but before the radiation dominated era, there was something else which happened that gave an expansion phase and that's needed in order to explain the Guth anomaly. Apparently, according to Krzysztof, Guth was right. It depends on all sorts of particle physics, which I don't understand at all. I never know whether he was right or not but Krzysztof is an expert on these things, so I trust him when he says Guth is right on this. The trouble involves renormalizations of things and why do you only get a factor of 2 when you're subtracting one infinity from another infinity.

Well, you are skeptical about string theory. Why is that so?

You see, when I first heard about string theory, I quite liked the idea but then it very rapidly drifted off into having to have all these extra dimensions. Initially, they needed to have 26 dimensional and then they got it down to 10, which I suppose was an improvement. Now it's a mixture of being 26 and 10 or 11 dimensions at the same time.

I think 11 dimensions in M-theory?

I have a very strong objection to these arguments which I've made many times but again nobody pays any attention. The argument is that people is trying to tuck these extra dimensions into very tiny volumes. They're trying to say you don't disturb those tiny volumes. If the dimension of space-time is more than four then you have too many degrees of freedom and it would just swamp everything else. You don't see them. People would say you tuck them up into these little, tiny balls, but then why don't they leak into the universe – all those degrees of freedom? The degrees of freedom are enormously bigger. It's not like adding a few degrees of freedom.

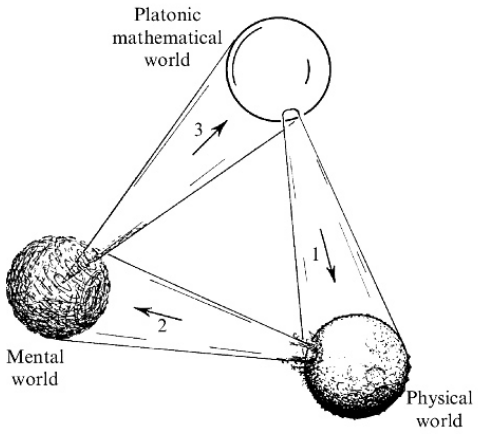
It's a complete change when you're changing the number of dimensions of the space from 3 to 9 or whatever. It's a very, very drastic thing to do. All your fields are of a completely different character. They would completely swamp everything else. Now they say, well, we don't swamp them because it needs too much energy to excite them, but that energy is not all that big. This is huge but compared with the Earth going around the Sun, it's extremely small. It's huge only if you think of it as a local energy but this is the energy for the whole universe and for the whole universe it's tiny. It's a little tiny bit of energy for the entire universe. Why can't you activate that little, tiny amount of it? The amount of energy per particle is tiny. It's a big energy because it's taking the whole energy, but you don't need the whole energy in the whole universe. Why can't you just use the energy locally?

I've talked about these things many times, and again nobody pays any attention. I even write books on it, and people buy the books but they still don't pay any attention to the arguments as far as I can see. I have an opportunity to comment again on the new edition of Fashion, Faith and Fantasy, which I do have to think about in a serious way. The trouble with that is I don't really know where string theory has gone. I've just paid no attention to it. I don't think it's done anything. They haven't got the dimensions down. It's still just as bad as it was. It's got all these extra dimensions and it has not found of any way of getting rid of them, as far as I can see. I can't see that any progress has been made in that direction. I just think the dimensionality argument is wrong. You can't have more space dimensions without them having a huge effect on our physics.

While I was preparing for this interview, I read a book by Sabine Hossenfelder [6] where she thinks that physics is misled by mathematics. As you are a mathematician, I would like to hear your opinion about this.

Well, mathematics is what controls physics. Certainly, we can't get away from it. I think there's another thing where I might agree with her. Some people are carried away by things which they regard as very beautiful mathematics and I think this is one of the troubles with string theory. People regard mathematics as too beautiful to be false. That is absolutely a dangerous point of view, especially when you get the wrong number of dimensions of space. It could be as beautiful as it likes, but if it's got the wrong number of space dimensions then it's wrong.

I have this cartoon which I drew in various books of mine with the three worlds. I have the physical world, the mental world and the mathematical world. This is sort of a triangle and a small part of each world seems to control the entire other world. It's a very small part of the mathematical world, which seems to be relevant to physics. There's an enormous amount of mathematics hanging around. How much of that is to do with physics just the teeny-weeny little bit but if you get it right, it seems to produce physics in some sense. Then again, there's only a small part of the physical world which seems to produce conscious beings and there's only a small part of the conscious thinking that involves thinking about mathematics. So this was some sort of slight joke in a way, but that was the way I had of representing this impossible structure of a small part of each world controlling the next one as you go around. That was a sort of jokey philosophical picture but I'm not saying that just because mathematics is beautiful, it needs to have anything to do with physics. We just seem to find that when you get it right with regard to physics, it has an enormous power and beauty of its own, which sometimes seem to transcend what you get in other areas.



Figur 8. The three "worlds", the platonic mathematic, the physical and the mental world. According to Penrose, we only use an extremely small part of each world to describe the other worlds.

Should we be careful judging physics on how beautiful it is?

I mean we now have a beautiful explanation for the periodic table as you get it right down to the way that nuclear charge, nuclei and electrons behave and it's beautiful. It's not just that it's beautiful. It seems to be a correct description and there are corrections to it.

General relativity has an extraordinary precision. I mean now people know it's right to many decimal places. It's about the same with quantum mechanics. They both have a precision of a corresponding order to each other which is extraordinary. However, we know they can't be quite right. Quantum mechanics can't be quite right, because it doesn't explain the collapse of the wave function.

I have this slightly unconventional view combining general relativity with quantum mechanics. People say the Holy Grail is quantum gravity. You have to quantize gravity, bring it into the scope of quantum mechanics, pull it in to be covered by quantum mechanics. That's not what we really need. What we really need is the other way around, how gravity fixes the problems of quantum mechanics. Quantum mechanics has the problem that you have the reduction of the state. It doesn't follow the Schrödinger equation. It doesn't follow unitary evolution which is an idealization. People have arguments like von Neumann[1] and it's a good argument, but it's not an answer when your assistant gets involved with the complicated environment. It's useful to change your perspective to one of those referred to as a density matrix, in order that you can handle it. But it's what I call a double ontology shift. It's not an answer to the problem. It's just a way of handling the problem you say. We'll use a density matrix and then we reinterpret the density matrix as probabilities of different kinds of states, and that's why you get the state reduction. It's not an answer. It's just a way of doing it I suppose. It's not a resolution of the problem of state reduction, collapse of the wave function, but it's a way of measuring how much is going to be there. It doesn't replace the theory by an improved theory in which the reduction of the state is part of theory. That in my view has to be a gravitational contribution bringing gravity and quantum mechanics together. That's a very important thing to do but it's not quantizing gravity. It's gravity using quantum mechanics. That's my unconventional view on that subject.

We ended the interview and the author thanked Penrose for his time and effort to present his ideas. I would also like to thank Penrose's personal assistant, Helen McGregor, for the technical support. The figure captions are solely the responsibility of the author.

Litteratur

[1] A Big Cosmological Mystery: Discovery of a second ultra-large structure in distant space further challenges what we understand about the universe. Press Release University of Central Lancashire, 11 January 2024. https://www.uclan.ac.uk/news/big-ring-in-the-sky.

[2] R. Penrose (2016) "Fashion, Faith and Fantasy in the New Physics of the Universe", Princeton University Press.

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John Rosendal Nielsen er medlem af Kvants redaktion. Han beskæftiger sig hovedsageligt med videnskabshistorie, fundamental fysik og kosmologi.

[1]The von Neumann–Wigner interpretation is an interpretation of quantum mechanics in which consciousness is postulated to be necessary for the completion of the process of quantum measurement. It is known as *'the consciousness causes collapse"*.