Newsletter No. 1

- for the Indiegogo crowdfunding campaign

A THEORY OF EVERYTHING

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Dear all,

welcome to my first newsletter.

I wish to begin this newsletter by thanking you all for participating in and contributing to our crowdfunding campaign and our work. I know that most of you do not understand the details of our work - it is highly specialised and it requires a solid background in both theoretical physics and mathematics to read it - and hence I would like to thank you for your trust. I can assure you that we will do our best to honor it.

I will write these newsletters roughly every six month - with irregularities to be expected! - and I will write both about modern theoretical physics in general and about my research with Johannes Aastrup in particular. I will attempt to provide the background information necessary for you to understand all this without having any prior knowledge in mathematical physics (I hope I will succeed in this).

But before I get to our research I would like to first update you on what has been going on since the end of the crowdfunding campaign:

- **Publications, semi-popular:**

In connection to our recent publication in **Classical and Quantum Gravity** I was asked to write a so-called insight piece for CQG+. This piece, which has the title "The possible emptiness of a final theory", is written for a broad audience and is a brief outline of my views on our research, what makes it interesting an what we hope to achieve. The topics covered here are very similar to what I am writing about in the popular book, that I am currently working on and which many of you have ordered. It is my hope that this piece will be of interest also to people with little knowledge of theoretical physics.

- **Publications, scientific:**

When we started the crowdfunding campaign we had a backlog of two papers pending in the review process and a new one. These have now all been published:

1. Quantum Holonomy Theory. This paper, in which we first propose what we call quantum holonomy theory, was stuck in the review process for a long time (almost two years). Its

quite technical and long and it has therefore taken a while to get it published. It has now been published in *Fortschritte Der Physik.*

2. *On a Lattice-independent Formulation of Quantum Holonomy Theory.* In this paper we propose a formulation of our theory that does not rely on lattices. It has now been published in *Classical and Quantum Gravity.*

3. *Quantum Holonomy Theory and Hilbert Space Representations.* This is our latest paper, where we propose an alternative formulation of our theory. It has now been published in *Fortschritte Der Physik.* The paper includes an acknowledgement of all the backers of the Indiegogo crowdfunding campaign (see front page and page 908, attached)

- **Media:**

For those of you who speak danish I was recently interviewed by the paper *Kristeligt Dagblad*.

- **My book:**

At the end of the crowdfunding campaign, when hundreds of people had ordered the book, which I had promised to write (again: thank you for your trust!), I felt somewhat of a pressure to actually produce this book. After all, I've never written a book before and I was a little nervous whether I could actually do this. So I ended up spending most of the summer writing. At the moment I have finished a first draft and expect to have it published within a year. I might postpone this somewhat as I wish to include material, which we are currently working on. But you can be certain that the book will be in your hands (or in your computer) much sooner than the five years that I put as a deadline in the campaign (By the way! If any of you know a good editor and/or publisher then please let me know - I'm looking for options).

Our Research

I will now describe to you where Johannes and I are with our research project at the moment. To do this I will first briefly provide some background material.

- ***What is a quantum theory?***

I would like to start with a very concrete question, which is absolutely central to our work and to most of modern theoretical physics: *"what is a quantum theory?"* And I would like to approach this question from a mathematical perspective - that is, what does a quantum theory look like as a *mathematical* object.

Quantum mechanics - or in general: quantum theory - can be a very confusing subject. If you check wikipedia you'll find close to 20 *different* interpretations of quantum mechanics! It is an incredible fact that 100 odd years after its discovery quantum mechanics is still clouded in controversy with respect to its interpretation. On the other side, we understand precisely what quantum mechanics is as a mathematical object and we have known this for a very long time. The confusion arises when we try to convert this mathematics into the *language* of our everyday lives.

This is one of the reasons why I think it is best to completely avoid the question of interpretation of quantum mechanics. After all, this story is not finished, we don't know where the quantum theory - *the standard model of particle physics* -, which we now know describes reality to a very high precision, originates from. Until we know this we may be better served by not putting too much emphasis on interpretation and instead focus on what we know, which is the mathematical formulation.

In classical physics - and we call anything prior to quantum mechanics for classical - everything is described by *numbers*. Velocity, position, energy, - its all given by numbers. A car drives 50 miles per hours - a *number* - your garden troll has a precise location - given by a *number* (if you chart your garden with a coordinate system), a piano falling from 10th floor of your building has an impact given by a *number*. Everything is described by numbers.

This changes in quantum mechanics. It is a fact that when you measure something - say the position of your coffee cup - there is a smallest interaction, which cannot be avoided. That is, when you measure the position of your cup you will always have to interact with it - say, by shining a beam of light on the cup - and that this interaction cannot be made arbitrarily small. This smallest interaction is given by what is called *Planck's constant* and lies at the very heart of quantum mechanics.

The existence of this smallest interaction has enormous implications for the mathematical description of reality. It means that a measurement will always change the state of the object being measured and that this interaction is not just a question of precision of your laboratory apparatus but a key aspect of reality. It enforces a shift of focus from position, velocity and energy etc. to the *measurement* of position, the *measurement* of velocity and *measurement* of energy. The mathematics no longer deals with numbers but with the *operation* of obtaining these numbers. This shift has enormous implications.

Now, mathematicians and physicists have spend the past century investigating what the mathematics of operations - or *operators*, as they are called - looks like. Let's take a look.

So, instead of talking about the position and velocity of an object we talk about the *operators* corresponding to its position and its velocity - and of any other physical quantity. But what is the main difference between numbers and operators? Well, here it is: numbers don't care in which order you multiply them. 2 times 3 equals 6, as does 3 times 2. We say that numbers *commute*. Operators, on the other hand, in general do not commute. Why? Well, here is an example that explains this: say you're in your lovers apartment at 7th floor and her husband suddenly comes home. You rush to the window and climb down a rope. Now, there are two critical *operations* in this example: 1. tying the rope to the huge wooden bed and 2. climbing out the window and down the rope. It makes a big difference in which order you execute these actions: if you tie the rope *first* and then climb, you live, if you do it in the reverse order you'll die.

So an operation changes the physical system at hand - in this example the state of the rope - and thus it matters in which order you perform them. Operators do not always commute - this is the very essence of quantum theory, this is what it is all about.

Operators form what is called an algebra - which is a mathematical playground where you can *add* and *multiply* elements - just like ordinary numbers form an algebra. When you add and multiply numbers you get new numbers and likewise, when you add and multiply operators you get new operators.

But an algebra of operators does not give you a quantum theory. It is merely the first half of the story. The second half is what is called a *Hilbert space*. A Hilbert space is the mathematical stage on which the operators *act* in order to produce the numbers, which we eventually need in order to compare our theory to experiments. The Hilbert space contains all the possible *states*, which the system can be in. When an operator act on one of these states it may change it into another state, which is also contained in the Hilbert space.

So this is the basics of quantum theory: An algebra of operators and a Hilbert space, in which they act. From this basic machinery springs all the marvels of the quantum world, which is so utterly different from the everyday world in which we spend our time.

- Our work on Quantum Holonomy Theory

When you wish to formulate a quantum theory of gravity your first task is to choose which algebra of operators should form the basis of your theory. This is where Johannes and myself have a new take on the problem.

The algebra, which we propose, is called the *Quantum Holonomy-diffeomorphism* (QHD) algebra and is, despite its complicated name, very simple. It is generated by two basic type of operators:

- operators, which move *stuff* around in 3-dimensional space. These are called holonomy-diffeomorphisms and essential tell you how diffeomorphisms (*moving stuff around*) act on *spinors,* i.e. matter (for instance an electron).

- operators, which change the way these holonomy-diffeomorphisms act.

There are two reasons why this algebra is interesting to consider as a foundation of a unified theory of quantum gravity:

- it automatically encodes what is called the *canonical commutation relations* of general relativity. This means that this algebra automatically encodes the key prerequisite for a quantum theory of gravity.

- in a certain limit this algebra produces a particular mathematical structure, that bridges to a completely different part of modern theoretical physics, namely the standard model of particle physics - i.e. *matter*. The mathematical structure, that the QHD algebra produces plays into a formulation of the standard model that uses a framework known as *non-commutative geometry*.

Non-commutative geometry is a branch of modern mathematics pioneered by the mathematician and Field medalist Alain Connes. The fact that the QHD algebra provides a possible link to the work of Connes and co-workers tells us that a theory based on this algebra could involve an element of *unification* of the fundamental forces of Nature. This is precisely what we are looking for.

So to summarise: the QHD algebra naturally brings together two essential elements: 1) quantum gravity and 2) an element of unification of fundamental forces.

So this is all very well, but if we wish to formulate a quantum theory based on the QHD algebra, then we need to find a Hilbert space in which it can act. This is what we have been working on for the past 2-3 years.

In our first two papers on quantum holonomy theory we have devised what we believe is a viable strategy to accomplish this. This strategy involves a certain modification of the QHD algebra as we in our initial analysis almost immediately encountered a significant obstacle in finding a Hilbert space for the QHD algebra itself.

This seems to work and we appear to have a candidate for a quantum theory, but Johannes and I have over the past months been increasingly suspicious about this initial strategy. We have come to suspect that we might have missed something important by working with a modification of QHD algebra instead of the original version. As a consequence of this we have in our most recent paper laid out an alternative strategy, that involves a Hilbert space for the unmodified QHD algebra. We now believe that this is the correct approach to this problem.

- Locality

This new approach has an interesting and very attractive feature, which I would like to explain here.

A key ingredient in what is called *quantum field theory*, which is the general framework for quantum theories that involve fields (such as electro-magnetism and their generalisations known as Yang-Mills theories, which describe the interactions found in the standard model of particle physics), is *locality.*

Locality implies that you can localise everything to, essentially, single points. The fields, which you work with, are local and their interactions are local.

There are, however, reasons to believe that a quantum theory of gravity must somehow break with locality. Simple arguments, that combine general relativity with quantum mechanics, indicate that distances shorter than what is known as the Planck length, are operational meaningless as they cannot be measured, which suggest that a theory, that reconcile Einsteins theory of relativity with quantum theory, cannot be local. There have been several attempts to rigorously formulate such a non-locality but so far - in my opinion - not in a satisfactory manner.

Let me here add a technical comment: It is an old idea that a theory of quantum gravity should provide a natural regularisation for the divergencies, which you encounter in quantum field theory and which are dealt with in the process known as renormalisation, where divergencies, which emerge in the process of quantization, are systematically removed. This idea is motivated precisely by the arguments I mentioned above - the Planck length should provide an ultra-violet (short distance) cut-off - but so far no one has been able to realise this idea in a satisfactory manner (for the very good reason that we do not have a theory of quantum gravity).

Now, it turns out that in order to construct a Hilbert space for the QHD algebra you will have to give up locality. In fact, this observation was what in the first place made us introduce a modification of our algebra, because locality is such a key feature of modern physics that it simply didn't occur to us that we should give it up.

But once you accept that you might have to do precisely that, several interesting avenues open up. First of all, as explained in the above, there are good reasons why a quantum theory of gravity should involve precisely such a non-locality and thus it is encouraging to see this feature emerge. Secondly, it provides a possible link to renormalisation theory as the non-locality, which we suspect that the QHD algebra generates, seems to be of a form, which resembles the way renormalisation theory shifts between physics at different scales. If there really is a connection to renormalisation theory it would be a very interesting development - and it would be very close to the old idea I mentioned above, where a theory of quantum gravity is expected to provide a natural regularisation for quantum field theory.

These are the questions that we are currently working on. We are at the moment not able to provide definite answers - it is too soon for that - but we are moderately optimistic that we will be able to do so in the foreseeable future, say, within a year.

- Merry Christmas!

With this I end this newsletter. I expect to write the next newsletter in the late spring or early summer of 2017.

If you have questions or a particular topic, which you would like to hear more about (preferable about physics), then you are welcome to ask me and I will try to include it in a future newsletter.

I wish you all a merry christmas and a happy new year. Take good care and see you in 2017.

With the best wishes,

Jesper

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