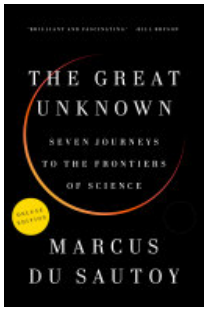
**What we cannot know**, *Marcus du Sautoy*, Harper Collins (UK), (2016) ISBN 978-00075-7666-1 (hbk), 320 p. ≡ **The Great Unknown**, Viking (US) (2017) ISBN 978-07352-2180-2.




UK edition (2016)

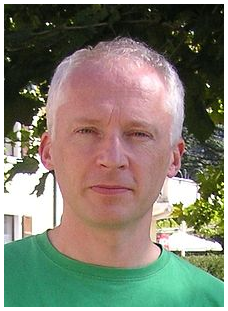



US edition (2017)









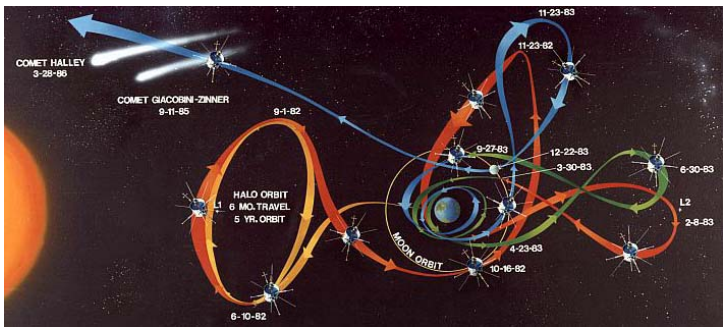
Marcus du Sautoy (2007)

Marcus du Sautoy is a mathematics professor from Oxford. He did excellent mathematical work mainly on group theory and number theory, but for a broader public he is well known because he appears regularly in the media and he wrote several books to popularize mathematics. Since 2009 he holds the chair of the *Simonyi Professorship for the Public Understanding of Science*. That was established in 1995 and 'the holder is expected to make important contributions to the public understanding of some scientific field', which du Sautoy rightfully does.

At the time of writing, the book under review is his most recent one. The original is from 2016 but in 2017 it was published under a different title for the US and also the Dutch (Uitg. Nieuwezijds) and French (Ed. Héloïse d'Ormesson) translations came out. As explained in a chapter zero, the idea is to explore where the boundaries of science are for the moment and whether we will ever be able to answer all the questions that are still open.

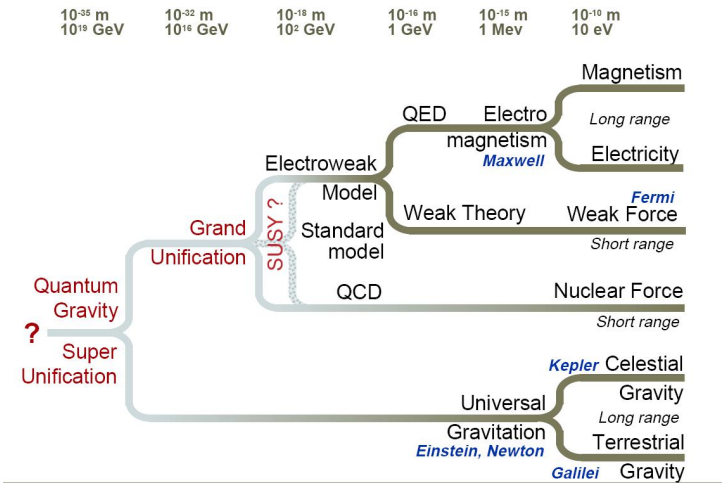
There are seven parts, each one consisting of two chapters. Du Sautoy calls these parts 'Edges' since they lead you to the boundary of where science meets its present limitations beyond which is the abyss of the 'great unknown'. Of course there is confidence that with further research these boundaries will be shifted forward in the future. However the main objective is to also discuss what will be attainable in the distant future and du Sautoy comes to the conclusion that there are certain targets for which we have to give up all hope to ever reach them.

Because of this Simonyi chair du Sautoy is supposed to know everything about science and du Sautoy is regularly involved in discussions about religion. Ever since humans have explored the laws of the world surrounding them, there were phenomena that could not be explained with the limited knowledge of the moment. Where knowledge ended was often where religion began. God was an explanation of things that could not be explained. So one could define God as that what cannot be explained or known: the God of the gaps. Du Sautoy is a convinced atheist and in this book, when he arrives at those phenomena that we probably will never know, he spends some time on whether or not this could be a definition of God or a proof of his existence.



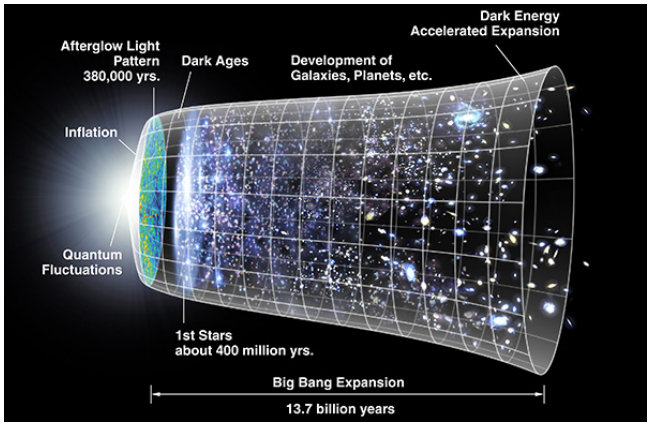

The distinction between the subjects populating the different edges is not very strict but every edge has its main focus. The first edge is about the theory of everything as it was conceived by Newton. Things happened according to strict physical laws, and everything was predictable. Our world and the planetary system was arranged like a clockwork. Sometimes, when the system is too complex to compute we have to recourse to statistics to predict the outcome of throwing a die, or to apply statistical mechanics to explain the behaviour of a gas. Until Poincaré threw the bat in the hen house and declared that actually our planetary system was not

a clockwork but behaved in a very chaotic way. The tiniest change at one moment may give a completely different state of the system after a while. Long time weather forecasting is made impossible because of the nonlinear dynamics of the climate system. And as mathematics show, very simple laws can result in very complex fractal results. But even chaos is deterministic. But since every particle in the universe can influence every other particle, it is just too much information to deal with. Does it mean that free will is impossible? God doesn't play dice, so he must be the one who knows everything at every instance, or he must have conceived everything from the beginning.




Edge number two is about the infinitely small. In mathematics, that has led us to the irrational numbers. Although there are infinitely many digits, we can still prove things about them. When physicists were looking for smaller and smaller particles that make up the physical world they ended up with an unmanageable zoo of quarks and leptons. Some order could be brought by introducing symmetry and SU(3) was the mathematical tool that saved them from chaos. Experiments at this scale are seemingly impossible, but we conceived indirect ways of making observations that tell us something about the properties of these particles that are not directly observable. Whether we will ever be able to reach a time scale of $10^{-22}$ is unlikely, but it cannot be proved impossible.

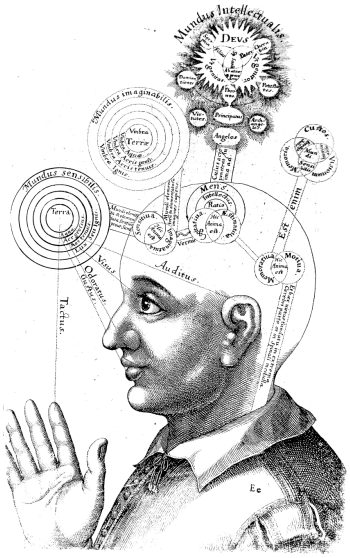
The next edge is about quantum physics which comes with the intrinsic limit of the Heisenberg uncertainty relation putting a theoretical restriction on what we can ever know about the state of a quantum object. Moreover, our observation is an act of creation because by Bell's theorem, it changes the properties of what we observe and our very observation may create a random outcome. But is this really random? Is this where God can interact with our world? The Planck length ($10^{-35}$m) seems to be the absolute limit. Points at a smaller distance are indistinguishable. That is where quantum physics and general relativity do not match and where we have to enter the abstract mathematical fantasy world of strings and quantum gravity.




Stopped at the infinitely small, the next edge switches to the infinitely large and tackles cosmology. Several theories were proposed looking for the origin of the universe. All of them based on observations. This has given us the Big Bang theory of Lemaître. But the standard model can only explain 4.9% of matter-energy. The remaining 95.1% is dark matter and dark energy. There are theoretical horizons for what we can observe, both in time and in space. We cannot see further in time than we do because light could not make it through the plasma some 378.000 years after the Big Bang but we can observe the neutrinos that could. In multiverse theories it is conjectured that just like the bubble of our universe inflated in $10^{-36}$ seconds to $10^{78}$ times its size, similarly other universes may have been created with different physical constants and by definition there is no way we can interact with them. True of not, this is definitely something we shall never know.

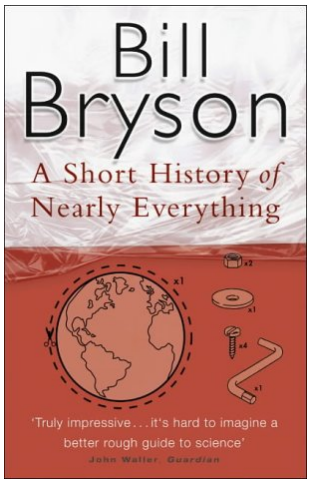
Edge number five is introducing relativity theory and explains how space and time are related and how gravity can deform the space-time configuration. In extreme cases gravity creates a

black hole singularity preventing even light to escape beyond an event horizon. However Hawking conjectured that some radiation is still possible. That is related to information that is leaking because the entropy inside does not really represent perfect order. Recall that the increase of entropy defines time. According to Penrose, our universe is just a sequence of big bangs each one seamlessly starting a new aeon. Is God something like mathematics that exists outside of our universe of time and space and is this the reason for the 'unreasonable effectiveness of mathematics'? According to du Sautoy this may well be, but he does not go as far as Tegmark to define our physical universe as a finite discrete mathematical abstraction.



Then du Sautoy engages in the problem of defining consciousness. Traditionally a less mathematical subject, although it is close to the study of (artificial) intelligence. After all, the problem of knowing what we cannot know, only exists because we humans are conscious. This requires an exploration of the brain, and a discussion of the mind-body problem. And yet there is the neuroscientist Tononi who defined a mathematical quantity $\Phi$ that can be assigned to any network, thus also to the neural network of our brain, to define the amount of its consciousness. The philosopher John Searle is strongly opposing this idea. It is not because a machine can follow the rules defining how a conscious entity would act that it would be conscious itself. And yet statements are uttered about the Internet being alive and when you ask Google about 'conscious networks' you get a several organizations and companies using it as part of their brand name.

And that brings us to the last edge of what we can ever know in mathematics. While (physical) science is constantly evolving depending on the observations, one might hope that mathematics is fairly static. However, new geometries are possible when the axioms change. We can prove things about things that can never be verified experimentally because it would need an infinite amount of time like for example Fermat's Last Theorem. On the other hand ample experimental evidence like for the Riemann Hypothesis for example does not prove it. And then there are Cantor's uncountable infinities and Gödel's incompleteness theorems to definitely limit the mathematical possibilities to prove everything. But at least we know and we can prove that we shall never know whether a certain theorem will be true or false.




Du Sautoy brings here a survey that is almost as broad as the 2003 Bill Bryson's classic *A Short History of Nearly Everything*, but more focused on the edges mentioned above. Knowing the unknown is a popular subject and several scientists have written so-called popularizing books about their domain of expertise, which are often circling the ideas of the infinite small, the infinite large or the functioning of our brain. Some examples are listed below. They were mostly theoretical physicists or one on the edge of mathematics, and it is not always easy reading, even for a mathematician that is not expert in the material. Du Sautoy is more of a mathematical outsider and his view on these topics is closer to how an average mathematician looks at this stuff.

He has quite some experience with science communication and so he brings his account in an entertaining way. The dice he has on his desk are a recurring gadget he uses throughout the book and also playing the trumpet and the cello is used to illustrate discrete versus continuous.

It is also clear that he went though a lot of research. He did several interviews for example with Bob May (nonlinear dynamics), Melissa Franklin (particle physics), John Polkinghorne (theoretical

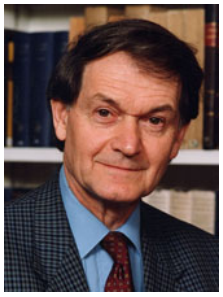
physics and theology), John Barrow (cosmology), Roger Penrose (mathematical physics; his office in Oxford is just downstairs of du Sautoy's), and Christof Koch (neuroscience). The interviews are not really formal and written down in the book in a casual way as part of the meandering of du Sautoy's account.


R. May


M. Franklin


J. Polkinghorne


J. Barrow

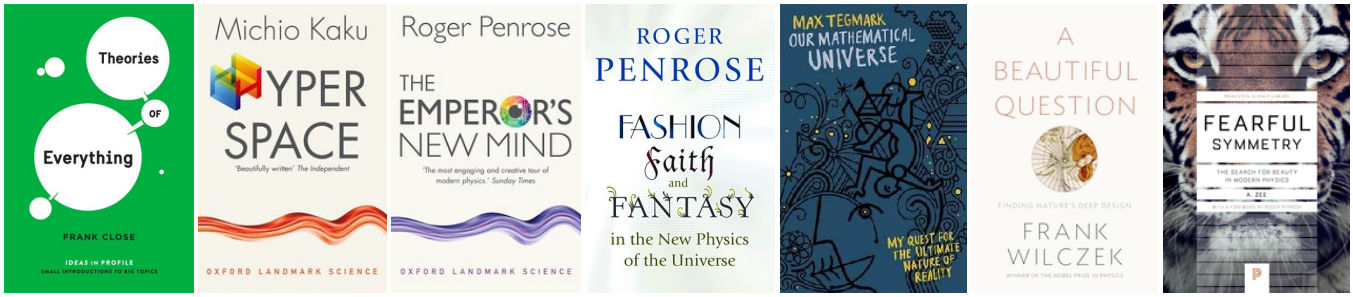

R. Penrose


C. Koch

He even has put himself through experiments such as fMRI scans. In the first case he was being anaesthetised with propofol (the drug that probably killed Michael Jackson). In a second fMRI experiment he was given two buttons that he could push randomly at will. It was shown that one could see by his brain activity which one of two buttons he was going to push 6 seconds before he actually pushed it. So if a computer can predict what you will do before you actually do it, what does this say about free will?

The story is brought to us in an entertaining way. I cannot say that du Sautoy is particularly funny, but neither is he boring. The views are those of a mathematician, but formal mathematics are never used. So for example the reader can understand that symmetry is important to solve equations and to get some order in the quark zoo, and that SU(3) is very helpful, but it is not really explained what SU(3) actually is. The symmetry of a die cube is used to explain S4, but SU(3) is described as 'the object that can describe the symmetries of a range of different geometrical objects in different dimensions'. But the reader should have caught the idea that it is some sort of generalization of what S4 does for the cube.

Some related or similar books:




- Frank Close, Theories of Everything Ideas in Profile, (2017)
- Michio Kaku, Hyperspace A Scientific Odyssey through Parallel Universes, Time Warps, and the Tenth Dimension (1994)
- Roger Penrose, The Emperor's New Mind. Concerning Computers, Minds, and the Laws of Physics (1989)
- Roger Penrose, Fashion, Faith, and Fantasy in the New Physics of the Universe. (2016)
- Ian Stewart, Calculating the Cosmos. How Mathematics Unveils the Universe (2016)
- Max Tegmark, Our mathematical universe. My quest for the ultimate nature of reality (2014).
- Frank Wilczek, A Beautiful Question. Finding Nature's Deep Design (2015).
- Anthony Zee, Fearful Symmetry. The Search for Beauty in Modern Physics (1986).

Adhemar Bultheel