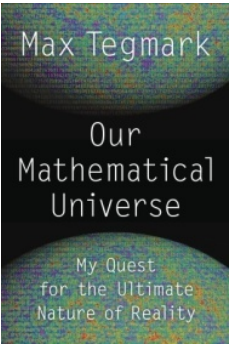**Our mathematical universe**, my quest for the ultimate nature of reality. by *Max Tegmark*. Knopf/Allen Lane, 2014, ISBN 978-0307599803/978-1846144769 (hbk), 432 pp.

Knopf (USA)   Allen Lane (UK)   Max Tegmark

As mathematicians we often defend our field by telling people that they should be aware that given our technological environment, we live in a world that breaths mathematics. However, it takes a physicist like Max Tegmark to claim that we are not surrounded by mathematics, but that everything *is* mathematics, including us, the whole universe, and all the infinitely many other universes that exist on different levels, they are all just mathematical structures. After all, if you penetrate to a sub-particle level with string or brane theory, then these are basically mathematical constructs, and if this is what all stuff is made of, including us, then everything must be just mathematics. This is a shortcut. Tegmark takes a physical road to come to his conclusion.

If anybody had claimed everything to be mathematics without further ado not many people would be inclined to take this very seriously. But Max Tegmark is a theoretical physicist teaching at MIT with a strong reputation and he takes a scientific physics approach to his claims. Because he is easily approachable by the media, his ideas are also rather visible, and his message has been reverberating for a while. With this book, he brings a passionate plea supporting his beliefs. He does that by starting with conventional views on cosmology and on the quantum mechanical approach in particle physics, but where conventional knowledge stops, he goes on and attaches his own ideas. However, he plays the game openly and clearly indicates in the introduction which chapters are conventional, mainstream, controversial, or extremely controversial.

	Chapter	Title	Focus	Status
Zooming Out *(What is reality on the largest scales?)*	1	What Is Reality?	Introduction	
	2	Our Place in Space	How big is space?	*Mainstream*
	3	Our Place in Time	History of our Universe	
	4	Our Universe by Numbers	Precision cosmology	
	5	Our Cosmic Origins	Cosmological inflation	
	6	Welcome to the Multiverse	Level I and II parallel universes	*Controversial*
Zooming In *(What is reality on the smallest scales?)*	7	Cosmic Legos	Quantum mechanics	*Mainstream*
	8	The Level III Multiverse	Quantum parallel universes	*Controversial*
Stepping Back *(Is reality math?)*	9	Internal and External Reality	The role of consciousness	
	10	Physical and Mathematical Reality	The "reality is math" idea	*Extremely Controversial*
	11	Is Time an Illusion?	Making sense of it	
	12	The Level IV Multiverse	The ultimate multiverse	
	13	Life, Our Universe and Everything	Future of Universe and humanity	*Controversial*

The book has three parts: The first part on cosmology (zooming out), the second on quantum mechanics (zooming in) and a third part (stepping back) that is more philosophical in which he explores the answers he found in *his quest for the ultimate nature of reality*. Somehow his quest is like the quest for *meaning of life* as in the comic sci-fi books of *The Hitchhiker's Guide to the Galaxy* by Douglas Adams, (in fact the *Hitchhiker's Guide* is quoted a lot) only Tegmark takes his quest more seriously. He calls his own ideas 'mind blowing' or 'crazy' and more of that kind of adjectives and he uses expressions like 'Hold on!!! Did I just go bananas???', but then he starts arguing that they are not that crazy after all. He stretches the subject to the limit in all

possible directions. Not only in space and time dimension, but also from hard mathematics, over experimental physics to philosophical world views. Although his conclusion is that everything is mathematics, there is not really mathematics present. All you need to know is that mathematical structures are "sets of entities with relations between them". The text is thus very readable and accessible for everybody. His exposition is very entertaining and fun to read. Often a number of questions are explicitly formulated (the ones that the reader already formulated in his mind) which are then answered one by one. All this is sprinkled with a sauce of autobiographical interludes. For example, he was born in Sweden. His father Harold Shapiro is a mathematics professor at KTH in Stockholm, but because Max thought Shapiro was a name too common to distinguish him from other Shapiro's in his scientific career, he decided to use his mother's name Tegmark that was much less widespread. During his career he developed a 'Dr. Jekyll/Mr. Hyde strategy' working as a 'serious scientist' but never giving up his passion for 'crazy ideas' on the side. This book is written by both Dr. Jekyll and Mr. Hyde.

Harold Shapiro   Hugh Everett   Mark Everett (E)   Schrödinger cat

Let me briefly sketch his approach and arguments. He starts with the human race exploring space. First by computing the size of the moon, the sun, the stars, the galaxies, etc. The further we can see in space, the further we see in time because it takes time for the light to travel. If we see fewer and fewer galaxies further away from us, then it is because that many light years ago, the galaxies were just starting to coagulate by gravity from the particles in the cosmic gas cloud. We see only 'baby galaxies'. Still further there is nothing to be seen, only darkness, but there is still energy coming from that far away. This is the afterglow of the very hot universe in its baby-years. It forms an opaque 'plasma wall' behind which nothing is visible anymore and it can be visualized by the cosmic microwave background (CMB) radiation. Tegmark and his first wife were strongly involved in visualizing this plasma ball using data from the WMAP project (later confirmed and improved by the Planck project). Fluctuations in the CMB spectrum gives evidence of the mysterious 'dark matter'.

So, reordering these observations forward in time, the reader is introduced to inflation theory where some 13.7 billion year ago the universe inflated very fast, hydrogen was partly transformed into helium. The hot plasma prevents looking beyond the 400,000 year young universe. Then gravity started forming galaxies while the expansion was slowed down. The 'Big Bang' is not the starting point, but was caused by the inflation. However, since the universe is still expanding at an increasing speed, the existence of dark energy is needed. Dark matter and dark energy form 95% of the material in the universe. Tegmark ends this cosmic part by introducing his so-called Level I and II multiverse. Define our universe as the region from which light has
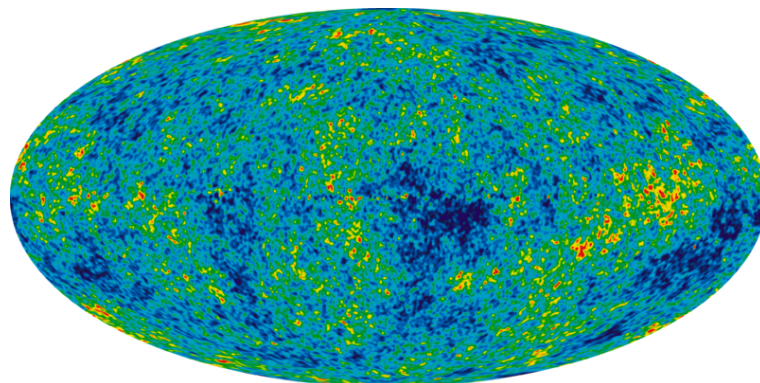

WMAP: the bright plasma wall (our baby universe)

reached us during the 14 billion years since our Big Bang, i.e., everything we can observe. Then, assuming space is infinite, it is quite reasonable that there is an infinity of parallel universes out there, beyond reach. This is the Level I multiverse. All these universes still obey the physical laws that we know, and these laws are very restrictive. Three space dimensions and 1 time dimension is the only possibility, and there are many physics constants that have to be tuned very precisely to make a universe as we know it possible. But the theory allows different solutions, so there must be universes with different effective laws of physics. A Level II multiverse exists because a Big Bang is a local phenomenon, ours happened only for that part of space that we inhabit but many other Big Bangs do take place, creating parallel universes with different physical laws like bubbles in an ever inflating space.
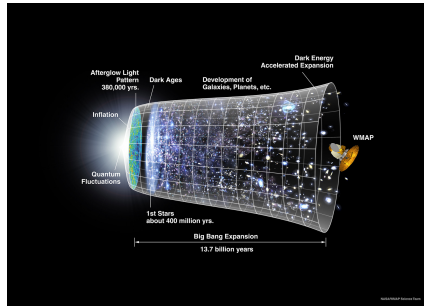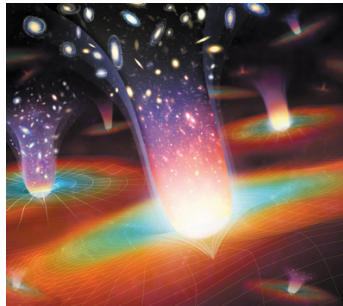

inflation theory   several Big Bangs   alternative Schrödinger cat

Let us now move to part 2 on quantum physics. Here he gives the many world interpretation of Hugh Everett as an alternative for the Copenhagen interpretation explaining the collapse of the wave function when we observe a system in quantum superposition state. Everett argued that both outcomes of the observation are possible, but that both are observed so to speak in two different worlds. This creates Level III parallel universes, not very far away beyond reach of observation, but separated from us in a Hilbert space where Schrödinger's wave functions live. Tegmark appears in a BBC documentary with Hugh Everett's son Mark who tries to understand his father's work. Mark Everett, also known as E is the front man of the rock band Eels. However, since everything is possible as outcome of an observation, Level I and II universes can be found as Level III parallel worlds.

The second half of the book goes to part 3. While the original ideas for all multiverses of previous types were initiated by others, the ultimate Level IV mathematical universe hypothesis (MUH) is Tegmark's own construction. There is the external reality, of which we only can observe a small part by what our senses allow and moreover it will we interpreted by our minds, and that can differ for individuals. If we agree upon an external physical reality (which corresponds to the intensively investigated Theory of Everything (ToE)), then it must be a mathematical structure, devoid of all baggage of possible interpretations and wordings that we humans use.

Then he deals with self-awareness, prediction, randomness (in a mathematical structure there is no randomness, but you may take averages over the infinitely many universes), and this requires the notion of a measure. Since this measure causes problems (the end of humanity, breakdown of inflation theory, instability of the universe,...), he blames this failure on infinity (the infinitely big = infinite space and the infinitely small
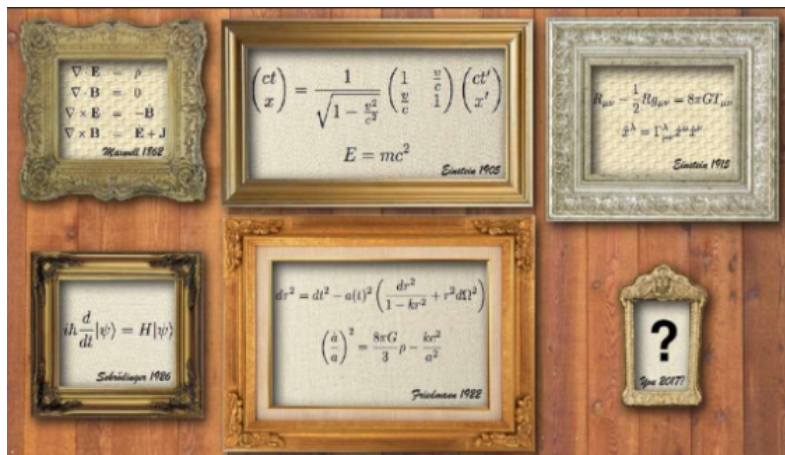
= continuity). One could do away with continuity as an approximation of reality. In the end, everything reduces to particles and the result only resembles to be continuous at a much larger scale. Reality is discrete. In any mathematical structure that contains a substructure that is self-aware will experience its world as physically real as we do. So the Level IV multiverse will contain all other multiverses. Moreover, not only universes with different effective physical laws being different solutions of the same fundamental laws may exist, but also the fundamental laws can differ. However, the structures should lead to decidable and computable conclusions, so Gödel's incompleteness and the Church-Turing uncomputability should not lead to inconsistencies. This rules out all structures containing infinity e.g., the real numbers. A strange conclusion in view of all the preceding statements.
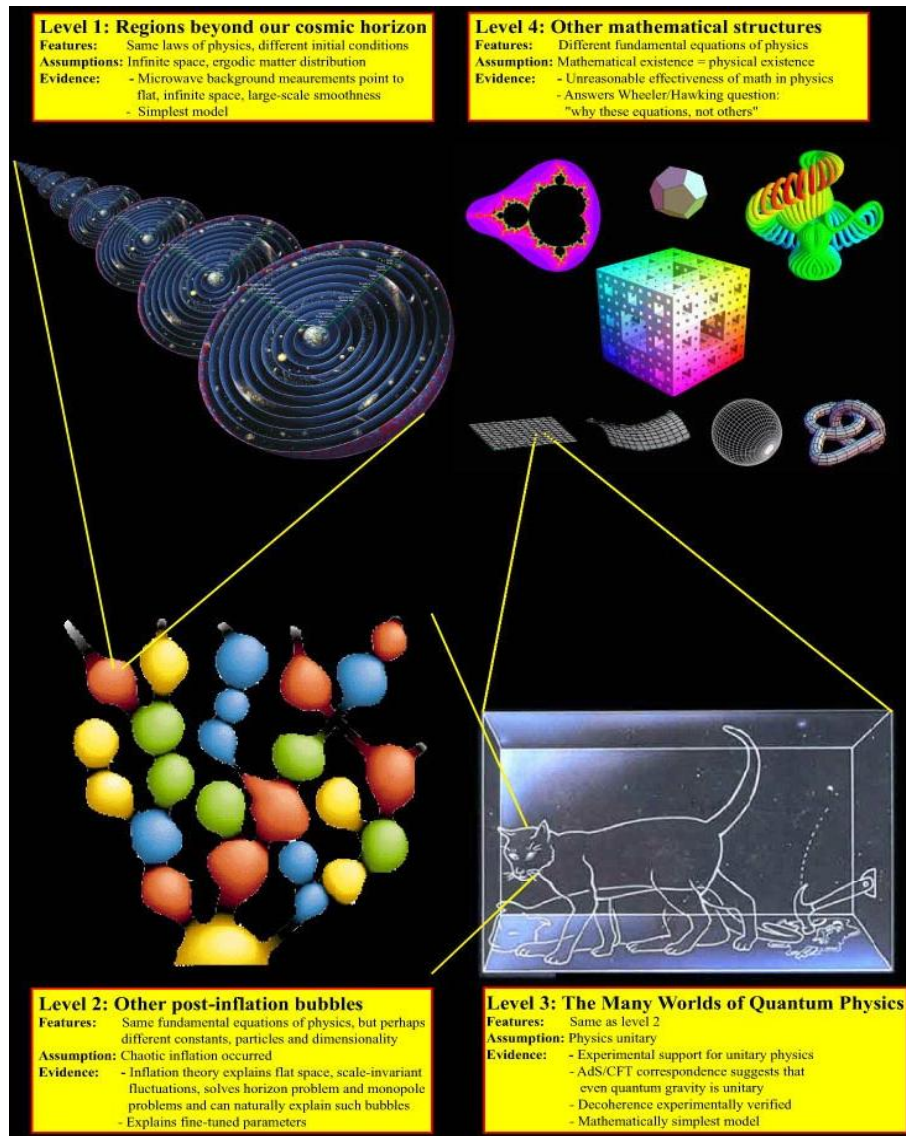
Tegmark's multiverses of Levels I-IV

If you were not pondering some of the (many) questions that Tegmark is formulating in this book, he will start you thinking about some. There are reasonable scientific answers to some of them, but other answers given by the Mr. Hyde alter ego are hard to believe and many will have problems in following his 'scientific' arguments. What starts as a very nice and elucidating explication of our cosmos, ends in speculative mystic science fiction. It might be tempting for a mathematician to believe that everything is just a mathematical structure, I doubt that many mathematicians will convert to Tegmark's faith by lack of the convincing logical steps. Tegmark has been preaching these ideas for a longer time and you may find several criticisms on the Web. Reading this book will prepare you to engage in the discussion. A. Bultheel