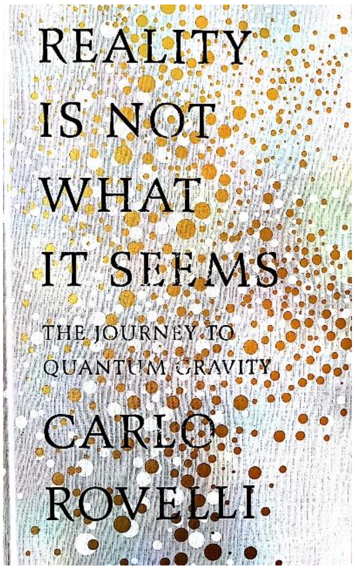
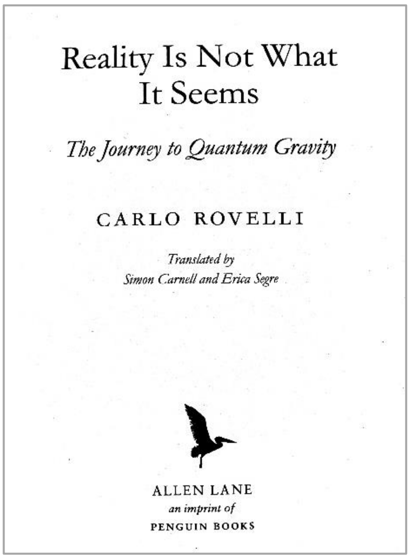
Quantum Loop Gravity

Some notes on Carlo Rovelli's book, *Reality is not what it seems.*





Reality Is Not What
It Seems

The Journey to Quantum Gravity

CARLO ROVELLI

Translated by
Simon Carnell and Erica Segre

ALLEN LANE
an imprint of
PENGUIN BOOKS

The book qualitatively describes the theory of Quantum Loop Gravity which has been developed to join up the two very successful but apparently incompatible descriptions of the Universe, General Relativity and Quantum Mechanics. It describes the earlier notions of the Universe culminating in Newton's work. It then deals with electromagnetism and the Special and General Theories of Relativity, followed by Quantum Mechanics. The synthesis offered by Quantum Loop Gravity then follows emphasising the quantisation of space itself. The final chapters describe the consequences for the big bang, black holes and the infinities contained in relativity and quantum mechanics, together with the possibilities of testing the theory experimentally.

Thanks

These notes were produced for the Keele Inquirers, a group of retired people who meet together once a month to discuss scientific and other topics. The group is organised by Alan Treherne and consists of Peter Borrell, Misbah Deene, Rick Marshall, Gordon Pearson and Eddie Slade. I am most grateful to my colleagues for their perceptive comments on, and constant encouragement for the production of these notes.

Peter Borrell, September 2017

Quantum Loop Gravity

Some notes on Carlo Rovelli's book, *Reality is not what it seems.*

Chapter — Page

Ch1 **Grains** *(First ideas of the Universe and Matter)* p8

Leucippus & Democritus: Universe is made up of boundless space in which innumerable atoms run. Atoms are indivisible. The vast variety of substances derives solely from the combining of atoms. There is no finality or purpose. The product is that of accidental combination.

Matter cannot be infinitely divisible. The universe is granular, not continuous. *The proof for atoms then awaited Brownian motion and Einstein's quantitative explanation of it in 1905.* p16 & 24

Ch2 **The Classics** *(Gravity & the Electromagnetic Field)* p27

Galileo's experiments with falling objects: they don't fall at a constant speed, they fall with a constant acceleration.

Newton's laws of motion: objects would normally move in a constant direction and a constant speed; the Moon which circles the Earth is thus being deflected towards the centre of the Earth by an acceleration. Estimation of the acceleration shows it to be the same as that determined by Galileo for falling objects. Calculations showed that the moons circulating around Jupiter and the planets circling the Sun are subject to the same quantitative acceleration. Thus acceleration due to gravity is a universal quantity.

However it is not known how gravity can act at a distance between non-touching objects.

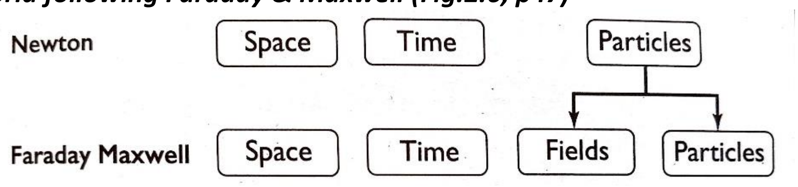
The world according to Newtonian mechanics (Fig. 2.1, p36)

In the Newtonian World, Space is a three-dimensional continuum and time is independent of motion and coordinates. (Einstein, p65 & 66)

Faraday, in order to interpret his results on electricity and magnetism, postulated the existence of an electric and magnetic fields which permeate space.

Maxwell was able to provide a mathematical background for Faraday's fields combining the whole into electromagnetism, and also discovers that light is the trembling of the field lines. The speed of oscillation of the lines provides an explanation for the differences between the colours, and that also there is a vast spectrum of electromagnetic radiation beyond the ends of the visible spectrum.

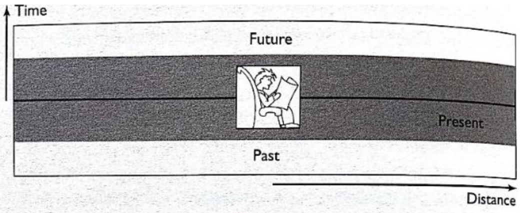
The world following Faraday & Maxwell (Fig.2.6, p47)



Ch3 **Einstein** (*the Special and General Theories of Relativity*) p51

Special Relativity: the Extended Present

Before Einstein, the future and the past are divided by an Instantaneous "present" which is the same for everyone. Thus, things in different part of the Universe enjoyed the same "time" and could be simultaneous.



p54

Figure 3.1 Space and time before Einstein.

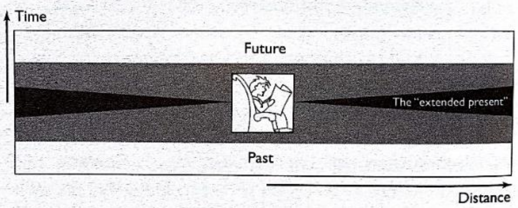


Figure 3.2 The structure of 'spacetime'. For every observer, the 'extended present' is the intermediate zone between the past and the future.

Special relativity introduces the idea of an *extended present* within the concept of spacetime. Events at a distance may be not only in the future or the past, but may take place within the extended present, an intermediate zone containing events at a space-like distance from you. This extended present can last from just a few nanoseconds in your immediate vicinity, to about 15 minutes on Mars and about two million years at the distance of the Andromeda Galaxy. The time depends on the distance from you and the speed of light. Thus there are events that may have occurred In the p57 Andromeda Galaxy which predate the appearance of your distant human ancestors; we cannot know until sufficient time has elapsed so that we can observe them. Thus the "present", like the flatness of the earth is an illusion. Rather than an invariant time interval between two events, there is an invariant spacetime interval.

Postulates of Special Relativity

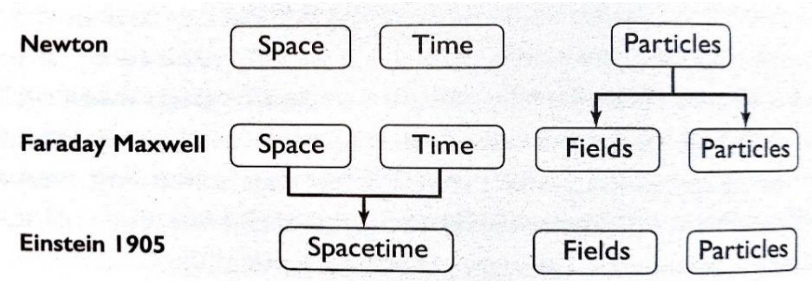
a. The speed of light is the same for all of observers and independent for all inertial frames of reference. p58
b. All observers moving at constant speed should observe the same physical laws.

Some consequences of Special Relativity

a. Merging of the concepts of space and time to give spacetime.
b. Merging of electricity and magnetism to give electromagnetism.
c. Merging of the conservation laws for mass and energy to the conservation of mass and energy ($E = mc^2$)
d. Length contraction. The length of a moving metre rod will shorten as its speed approaches the speed of light. Length/m = $(1 - v^2/c^2)^{½}$
e. Time dilation. Time measured on a moving clock (moving close to the speed of light) moves more slowly than on a clock at rest. Time/s = $(1 - v^2/c^2)^{-½}$. It is necessary to apply a correction in calculating GPS coordinates to allow for this effect.

Special relativity is special because it only deals with uniform motion

The world following Einstein, Special Relativity, 1905 (Fig. 3.4, p 60)



Spacetime is now a four-dimensional continuum. (Einstein, p66)

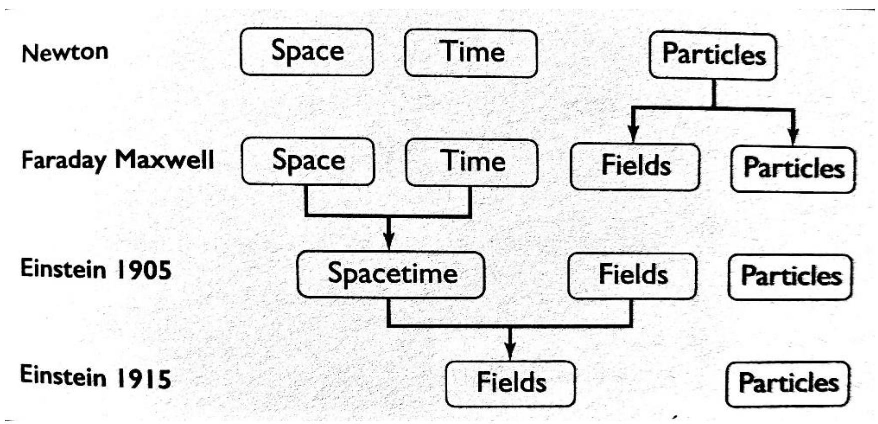
General Relativity

The problems intrinsic to the Newtonian/Special Relativity view concern gravity itself, or how can one have action at a distance, and what is "space" itself in which everything is presumed to take place.
Einstein realised that, analogous to Maxwell and Faraday's electric and magnetic field, there must be a gravitational field – and that *the gravitational field is spacetime itself – i.e.* that *spacetime is the gravitational field.* p64
The effect is that the gravitational spacetime field is a real entity which can bend, undulate, fluctuate and contort. It is unlike Newtonian space which is uniform and empty, rather like a scaffolding, a concept which had puzzled the ancients. The gravitational field is directly affected by mass, within it or near it. Furthermore, Inertial Mass and Gravitational Mass are equal.

Some of the observed effects of General Relativity p65

a. All the effects which we attribute to "gravity" – objects falling, the motion of the moon around the Earth and the planets around the sun.
b. The correction of planetary motion to allow for the effect of the sun on the field around it. The observed tiny correction to Mecury's orbit was a decisive argument for general relativity.
c. The curvature of light around the sun and distant stars leading to gravitational lensing effects.
d. The observed slowing of time near the Earth – another effect for which a GPS instrument must correct.
e. The gravitational redshift in radiation leaving a massive body.
f. The production of gravitational waves by large events in the Universe – two stars rotating around one another or the collision of a pair of black holes, recently observed by sensitive instruments on Earth.

The world following Einstein, General Relativity, 1915 (Fig. 3.5, p 65)



The Cosmos

Does the universe have a limit? An infinite universe seems absurd; but how can there be a boundary with nothing on the other side? Einstein's solution was a universe that is finite but unbounded. The surface of the Earth is finite but it does not have a boundary. In general relativity, three-dimensional space can be curved, so the universe itself can be finite but borderless. Such a three-dimensional space is a *three sphere*. p77

Reality is not what it seems. p90

a. The Earth is not flat with a moving heaven above it. but it spins on an axis and circles the Sun. The Earth is itself a planet.
b. The world is made up only of fields and particles; spacetime itself is a field.

Ch4 **Quanta and quantum mechanics** p91

The necessity of a theory of radiation appeared with the "ultraviolet catastrophe". Theory seemed to show that a "black box" will emit radiation at all frequencies, emitting more energy as the frequency increases. Experiment showed that this is not the case and that the energy emitted falls off at higher frequencies.

Plank showed that the fall in energy emitted would be observed if energy was exchanged in "quanta", units of energy with an energy content, ε, proportional to the frequency, ν: $\varepsilon = h\nu$. The proportionality constant, h, is known as Plank's constant. p92

Einstein, again in the year 1905, explained the photoelectric effect by suggesting that light (radiation) is made up of "photons" whose energy is given by the Plank relationship above. The photoelectric effect is the emission of electrons from an illuminated metal surface. Classically you would expect to get electrons emitted at any frequency; experimentally you find that there is a threshold frequency for electron emission. Einstein's suggestion explains this perfectly. p92

Bohr applied the new ideas to atoms which, when suitably excited, emit light at characteristic frequencies. Electrons which appear to circle the nucleus of an atom like the solar system of the planets, can in fact only take on particular "quantised" energies and when the electrons change energy on excitation then light is either absorbed or emitted at particular frequencies (see sodium or mercury street lights). Bohr's "old quantum theory" was able to predict the energies that the electrons could take and the frequency of the light emitted in transitions between energy states. Furthermore, the approach could also explain the structure of Mendeleev's periodic table of the chemical elements. p96

Heisenberg and Dirac and the Uncertainty Principle. Every object is defined by an abstract space (Hilbert Space). Its properties are only those which are unchanging, such as mass. Its other properties, such as position, velocity, angular momentum and electrical potential, acquire reality (a value?) only when it interacts with another object. The variables of an object are not defined between interactions. The values that the variable can take are provided by matrix mechanics or Dirac's quantum mechanics. In the case of the electrons around an atom, the values are the same as those deduced by Bohr in the old quantum theory. p99

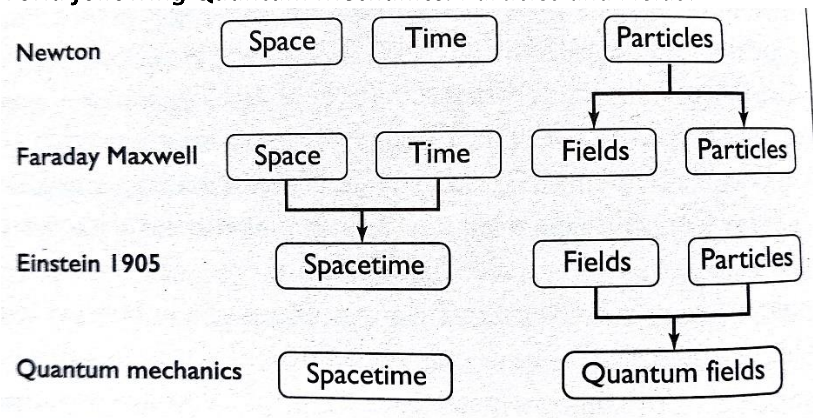
Probability. One essential difference introduced by quantum theory is the notion that while values of the properties that occur with each p104 interaction can be calculated precisely, the theory can only predict the probability that an object will present itself in a particular place. Thus while quantum mechanics provides accurate answers there is an inherent indeterminacy to the picture as the results are presented as probabilities.

The Schroedinger Wave Equation. An alternative approach was provided by the Schroedinger wave equation. The solutions provide the values of the properties of the objects, the square of the "wave function" provides the probabilities, so the results are equivalent to those from matrix mechanics. p105 footnote

Rovelli doesn't like this approach at all since he believes, probably correctly, that it appears to give to electrons and other objects a wave like character and neglects the fundamental indeterminacy of quantum mechanics.

*However the **Schroedinger equation** provides the basis for nearly all the approaches used in Theoretical Chemistry to describe, very successfully, the structure, bonding and dynamics of chemical compounds. Also the probability functions, known usually as orbitals, provide helpful visual and theoretical tools for understanding many aspects of synthetic and structural chemistry. The fact that some people carry in their heads too literal an interpretation of orbitals is probably immaterial.*

The World following Quantum Mechanics. *Particles and Fields*.



p110

Within Dirac's quantum mechanics, the notion of particles introduced by Newton and the fields introduced by Faraday merges. The electron probability cloud resembles a field. And electromagnetic fields are made up of photons. So the notion of particles and fields become "quantum fields" in the diagram above.

The way this happens is that Dirac's equation describes how the energy of the lines in a Faraday field can only take on particular values, so that the field behaves like a set of packets of energy. These are the quanta introduced by Planck and Einstein. Thus, applied to Faraday fields, the results indicate that the vibrations of the lines are also swarms of photons. When they interact with something else we see the effect of a rain of photons. p108

Electrons and other particles are made up of the quanta of a "quantum field" which, like the electromagnetic field is "granular" and subject to quantum probability.

Thus the granularity and the probabilistic nature of the field/particles emerge directly from the theory.

Quantum Mechanics, as explained by Rovelli, does not describe objects; it describes processes and events which are junction points between processes. Objects themselves, are "monotonous" processes. P116

He summarises quantum mechanics as the discovery of three features of the world.

- Granularity, limited by Planck's constant
- Indeterminacy, ultimately becoming statistical
- Relationality: events in nature are always interactions

He also points out that information is finite. The fact that energy and thus matter are quantised (have granularity) means that for example even a classical pendulum can only have particular energies. In so doing it removes the infinite number of possible values which are apparently possible classically. p120

On the understanding of quantum mechanics, Richard Feynman is quoted: "I think I can state that nobody really understands quantum mechanics" Rovelli believes that the obscurity of the theory is not the fault of quantum mechanics but the limitations of our human imaginations, like those of the men imprisoned in Plato's cave and seeing only shadows on the wall.

Ch5 **Spacetime is granular** p125

The dilemma is that there are two good theories of reality: relativity which works well for very large objects and quantum theory which works well for small objects. However, relativity describes the gravitational field (spacetime) without taking quantum fields into account; and quantum mechanics is formulated without taking into account that space/time is curved.

Matvei Bronštein pointed out that taken together, quantum mechanics and relativity are incompatible with our idea of space/time being an infinitely divisible continuum. He suggested that there is a minimum region of space defined by the "Plank Length" (about 10^{-35} meters). p129

Quantum space and quantum foam. An image of quantised space was provided by John Wheeler. Looking down on the ocean from a great height it simply looks smooth. As you move down towards it you can see the waves; descend still further can see that the surface is turbulent and frothing. On our scale, immensely larger than the Planck scale, space is smooth but, if you could move down to the Planck scale, space would be shattered and foamy. p134

The Wheeler-De Witt equation is a wave function for space or an equation of orbitals for relativity. But while it seems the right sort of equation it has weaknesses and it is also difficult to interpret. It is also odd because it does not include time.

The first solution of the Wheeler-De Witt wave equation is for "closed lines" in space – in other words – loops.

Ch6 **Quantum Loop Gravity: the Quanta of Space.** p138

The loops of space or the closed lines are the Faraday lines for the space field. Each separate line is a solution of the Wheeler-De Witt equation. We are dealing with quantum theory so everything is discrete; second we are also speaking of gravity, so we are not dealing with fields in space, but with space itself.

The solutions indicate that space Is made up of a set of points or nodes. The lines between the nodes are called links. The volume of space resides in the nodes. The lines link the volumes together. The volume of space is discrete and cannot be arbitrarily small. The nodes of the diagram represent discrete "quanta" of volume. The link is an individual quantum of a Faraday line. Two regions of space are separated by an area – areas are also quantised.

When measuring a volume, we are actually counting the grains of space. An area is a measure of the number of links or **loops**. The framework in fig 6.3 (left) represents a "spin network" with the links given by spin quantum numbers. Two nodes connected by a link are in proximity. The quanta of gravity are not "in space"; they are actually space itself. A single quantum of space is only defined by the links and the relations that these express. p141

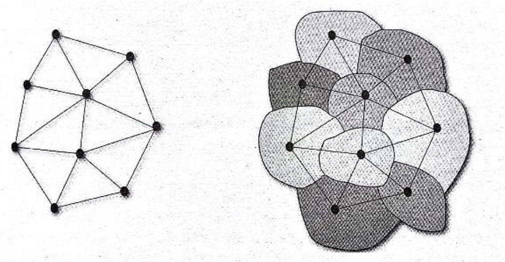


Figure 6.3 On the left, a graph formed by nodes connected by links. On the right, the grains of space which the graph represents. The links indicate the adjacent particles, separated by surfaces.

Since the granules of space are quantum phenomena the way they evolve and change is probabilistic. Also what matters is not how they are but how they interact. The networks are not space; they describe the effect of space on things. Thus space is a cloud of probabilities over the whole range of possible spin networks. Physical space is the fabric resulting from the ceaseless swarming of the web of relations. p148

Ch7 **Time does not exist** p151

Time is a useful way of comparing events happening in two different things; *e.g*. your pulse and the ticking of a watch. Time is never itself measured.

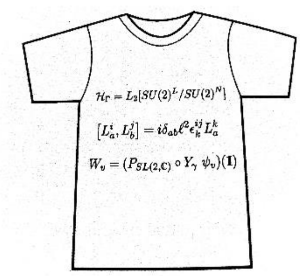
Newton realised that one cannot measure "true" time but that time is a useful assumption with which to set up an efficient description of nature. p157

In Quantum Loop Gravity, the Newtonian schema no longer works; processes occur and it is necessary to observe what actually occurs and write equations between the variables. p158

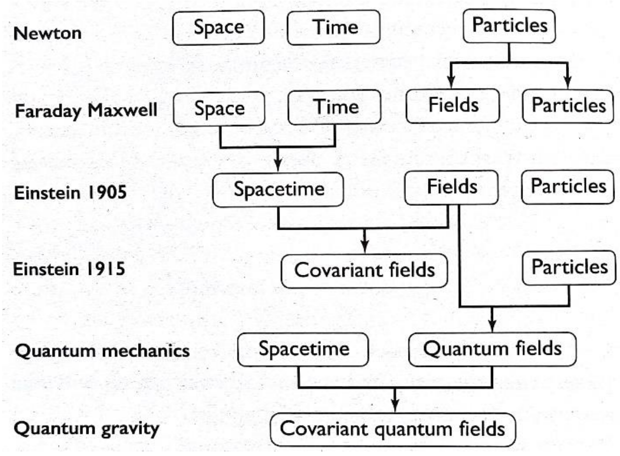
"Time does not exist"; the sense of the passage of time is a simply a useful approximation for events on normal scales. There is no longer a space which contains the world; there are elementary processes in which the quanta of space and matter continually interact with one another.

The key to understanding how quantum gravity works lies in not only considering the processes by which, say, two molecules in a box collide but by considering the whole process including the box with all that entails including the gravitational field.

Spinfoam; the Equations: written on a T-shirt***.*** p166



The World including Quantum Gravity



p168

In summary

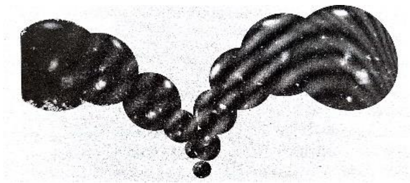
- *Particles are quanta of quantum fields.* p169
- *Light is formed by quanta of a field*
- *Space is a field, also made up of quanta*
- *Time emerges from the processes of the space field*

The conceptual price paid in adopting quantum gravity is the relinquishing of the idea of space and time as general structures with which to frame the Universe.

Ch8 **Beyond the Big Bang**

Georges Lemaître/Henrietta Leavitt & Edwin Hubble. The universe is expanding. The expansion implies a "Big Bang", the universe was originally small and compressed and started its expansion in a big explosion. Going backwards in time the universe gets smaller and smaller until it reaches the Planck limit and Einstein's equation are no longer valid. Loop Quantum Gravity provides a way through. p175

Quantum Gravity and Quantum Cosmology. A contracting Universe cannot be squashed to an infinitesimal point; it would experience quantum repulsion and would bounce back and begin to expand, as if emerging from a cosmic explosion; one would get a "Big Bounce" (see figure). p180



The change in the term "Universe".

In Cosmology, Universe nor longer means "all there is"; it now means the space/time continuum that we see around us with all the phenomena that we observe. In this sense, the universe that we observe may not be the only one. Current spin/foam calculations are attempting to describe to period before the Big Bounce. p181

Ch9 **Empirical Confirmations?**

The aims of scientific research are not just measurement and making numerical predictions. The objective is to understand how the world functions; to construct and develop an image of the world, a conceptual structure to enable us to think about it. Before being technical, science is visionary. p183

The basis on which the best research in quantum gravity is, as always, empirical knowledge. But the data is not new experiments; it is the theoretical edifices which have already structured our knowledge of the world, in forms which are only partly coherent. The "experimental data" for quantum gravity are general relativity and quantum mechanics. It is by building on these and trying to understand a world in which both quanta and curved space exist and can be made coherent, that we attempt to look towards the unknown. p185

Three signals from nature. There have been three major experimental results in recent years. p186

The first is the revelation of the Higg's Boson which confirms the validity of the ideas behind the standard model of elementary particles, based on quantum mechanics. The results from CERN, while long awaited and most exciting, were a great disappointment to those theorists who expected to find supersymmetric particles and an indication therefore that String Theory, the alternative to quantum gravity, was moving in the right direction P187

The second are the results from the Planck satellite showing the most detailed picture of the Cosmological Microwave Background, which confirm the standard cosmological model.

The third signal was obtained by the LIGO detector indicating gravitational waves from the coalescence of two black holes about 1.3 million years ago. Three such events have now been observed and provide evidence for the gravitational waves predicted by the general theory of relativity.

The thing in common with all three observations was the complete p188
absence of surprise. While each is a remarkable achievement, they do nothing other than reinforce the understanding we already had of the structure of the Universe.

In that sense, there is no "new" physics not yet described by
established theory, no supersymmetry which might support string theory, no p189
discrepancies from the standard cosmological model which support an alternative cosmology. The results seem to speak with the voice of Nature itself: "Stop dreaming about new fields and strange particles, extra dimensions, other symmetries, parallel universes strings or whatever".

Rovelli feels that many physicists are looking for new theories by guessing arbitrary hypotheses, a sort of "let's imagine" scenario, something that was never done in the formulation of the earlier pictures that we had of the Universe.

He feels the opportunity is there for Loop Quantum Gravity but as he says,
these results are just clues to what might be happening, they are not p190
experimental confirmation of the new theory.

Such confirmation might emerge if evidence is found for the Universe before p192
the big bounce, from Cosmic Microwave Background.

Ch10 **Quantum Black Holes** p195

Black holes were predicted from General Relativity. They are the result of the gravitational collapse of a massive star. The intensity of the gravitational field close to a black hole is such that essentially neither matter nor radiation can escape once it is within. The threshold surrounding the black hole, beyond which nothing can escape, is known as the event horizon.

At the event horizon the gravitational field is so intense that time stands still. If you approached but did not cross the horizon in a space ship quite a short time might pass but, on your return, several thousands if not million years might have passed!

The first problem of black holes is the Hawking prediction that some loss of p197
mass from a black hole via Hawking Radiation. Black Holes are thus essentially "hot" and are evaporating. A question arises about how the radiation is emitted.

Loop Quantum Gravity provides a possible answer: the elementary "atoms" that vibrate to produce the heat of a black hole are the individual quanta of space on the surface of the black hole. They vibrate because, in quantum mechanics, everything vibrates (*zero-point energy?*)

The second problem of black holes which Loop Quantum Gravity might p199
answer is what happens inside a black hole. At present, everything under general relativity converges to an infinitely small point of infinite density (*a singularity in mathematical terms*?). But with Loop Quantum Gravity, quantum repulsion intervenes and material will "bounce" back. This might be very quick but, from outside the event horizon everything is very, very slow so such a "bounce" may take billions of years. However, in the end, the bounce

might produce an explosion. So quantum gravity might imply that black holes might be ultimately unstable. There is a possibility that such explosions might already have been seen in the form of Fast Radio Bursts. But this suggestion requires much more study and experimental confirmation.

Ch11 The End of Infinity?

There are problems with infinities in both relativity and in quantum mechanics p202
and loop quantum gravity appears to provide a solution to both.

The singularities which appear in relativity have been mentioned chapters 8 and 10 together with their solutions. The Big Bang cannot have started from an infinitesimal point of space since space is quantised and while the minimum size is very small it is *finite*. Similarly, the interior of a black hole cannot be an infinitesimal point; the quantisation of space puts a lower limit on the size so that the size must be *finite*.

The solutions to the equations of quantum field theory developed by Dirac and Feynman include various infinite values which, to get the right results, must be subject to arbitrary re-normalisation. However, the underlying assumption of the theory is that space is continuous. Apparently the infinities disappear when space is regarded as quantised.

Thus there are two important results: taking quantum mechanics into
account resolves the infinities in relativity and, taking gravity into account p203
resolves the infinities within quantum mechanics.

There are three fundamental constants that appear to place a limit on the seemingly infinite possibilities offered by nature:

Table 11.1 Fundamental limitations discovered by theoretical physics.

Physical Quantity	Fundamental constant	Theory	Discovery
Velocity	c	Special relativity	A maximum velocity exists
Information (actions)	$\hbar$	Quantum mechanics	A minimum of information exists
Length	L_P	Quantum gravity	A minimum length exists

p204

Thus it appears that *infinity* in nature is something that we have not yet understood or counted. The only truly infinite thing is perhaps our ignorance!

Ch12 Information

This is a different chapter of which Rovelli says: the ideas here are still p209
confused and badly in need of organisation. Many physicists suspect that the concept of "information" may turn out to be a key for new advances in physics.

Shannon postulated that the quantity of information is the number of
alternatives to something. With a dice, when it falls on one face, the p210
information, N = 6. If you tell me the date of your birthday then N = 365. The
Shannon information, S, is given by S = Log_2 N. p212

Information measures the ability of one physical system to communicate with another.

The way in which the atoms of the world arrange themselves is correlated
with the way in which other atoms arrange themselves. p213

The world is not simply a network of colliding atoms, it is also a network of correlations between sets of atoms, a network of real reciprocal information between physical systems.

This approach is directly related to the second law of thermodynamics as expressed by Bolzmann: any natural process is accompanied by an increase in the number of ways of arranging the energy between the available energy state. p214

In any atomic or molecular system, the energy is distributed among the available atomic or molecular energy states of the system; in a normal gas at room temperature, such as CO_2, the energy is divided between the motion of the molecules, their rotation and their various vibrations, and as the molecules collide with one another, there is a constant exchange of energy between them. The distribution of energy between the states is determined simply by chance but among the myriad number of possible distributions, only the most common are likely to occur. Thus, although possible, the gas is never observed to move to one end of a container at constant temperature – nor do the molecules all slow down while the vibrations mop up the available energy.

Three basic ingredients are required in order to describe the natural world: not just general relativity and quantum mechanics, but also the second law of thermodynamics, which might also be described as information theory. p219

Thermal Time.

All natural processes involve the degradation of energy to heat and such natural processes provide the motive power for our lives and, as far as we can see, our universe. These natural processes provide a direction to time, a so-called arrow of time.

It is these natural processes all involving the evolution of heat which appear to provide the basis for Rovelli's Thermal Time. Time provides a way to map the progress of a natural process, but, since there are many natural processes there is no absolute measure of time.

Our own normal notion of time arises from the idiosyncrasies of our position in the solar system and we are probably fortunate that we circle a single sun which is roughly in the middle of its life. During the period of our evolution, during which we developed non-visual daylight detection, and the even shorter period that we have had some consciousness and some understanding of time, our solar system has been nearly ideal, concealing the fact that it too is gradually running down. Thus, our time, measured initially in days, months and years seems constant and perpetual. But, like so much to do with our lives and our consciousness, this is an illusion. Our solar system is decaying: the moon will drift away and the sun will turn into red giant and consume us; our fixed points will disappear but, until then, time will plod on.

Thermal Time is clearly a long way from Newton's conception of time – that time is part of the fundamental structure of the universe, a dimension independent of events in which events occur in sequence. (Wikipedia). While General Relativity apparently dispenses with absolute time, it is noticeable that Hawking (A Brief History of Time, chapter 9) discusses three arrows of time – the second law, the psychological and the cosmological. The first two are coincident; in an expanding universe, cosmological time apparently also runs in the same direction. None are absolute.

Ch13 **Mysteries**

This short chapter is reflective and philosophical and does not lend itself to being summarised. The chapter concludes with the following. p228

The world revealed by quantum gravity is a new and strange one - still full of mystery, but coherent with its simple and clear beauty. p233

It is world that does not exist in space and does not develop with time; a world made up solely of interacting quantum fields the swarming of which generates – through a dense network of reciprocal interactions – space, time, particles, waves and light:

It continues, it continues, teeming with life, and death
Tender and hostile, clear and unknowable.

And the poet, Mario Luzzi, continues:

So much the eye can see, from this watching tower.

A world without infinity, where the infinitely small does not exist, because there is a minimum scale to this teeming, beneath which there is nothing. Quanta of space mingle with the foam of spacetime, and the structure of things is born from reciprocal information which weaves the correlations between regions of the world. A world we know how to describe with a set of equations. Perhaps, to be corrected.

Rovelli: A personal note

What pleases me about Rovelli's view that time is directly related to natural processes is that it brings to the fore the importance of thermodynamics. Not only are very small things, described by quantum mechanics, and very large things, described by general relativity, important – processes at the intermediate level where we exist are also essential to the description of the universe – we are part of larger systems in which the statistics of energy distributions play an essential part both in ourselves and in our lives. And these distributions also appear to have a fundamental part to play in our understanding of the universe.

References.

Rovelli, C., *Reality is not what it seems*, Allen Lane, London, 2016
Einstein, A., *Relativity*, Crown, New York, 1931
Wikipedia, Special Relativity, 2017, https://en.wikipedia.org/wiki/Special_relativity
Wikipedia, General Relativity, 2017, https://en.wikipedia.org/wiki/General_relativity
Plus Magazine, What's so special about Special Relativity, 2005, https://plus.maths.org/content/whats-so-special-about-special-relativity

Peter Borrell
July/September 2017