The Quantum and Cosmic Codes of the Universe

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PREFACE

Physics is one of the most fundamental sciences. Therefore, virtually everyone is interested in it or everyone somehow faces most of the implications of physics in their lives. Physics with its laws, principles, hypotheses, and theories involves a wide range of areas such as astronomy, cosmology, mathematics, biology, chemistry, engineering, agriculture, geology, geography, computation, philosophy, and many more, including its own specific subjects. However, to the general public it is thought to be a very difficult to understand and comprehend sophisticated concept. For this reason, I decided to write this book in such a way that everyone could discover the central theories of physics and realise how the universe is coded and how it works, giving unique examples and explanations. Of course, quantum and cosmic phenomena contemplate and govern nature. Therefore, the book is grounded in these issues, delivering the fundamental concepts of modern physics from the creation of the universe to the present. The appearances of basic principles, laws, and theories such as Heisenberg's uncertainty principle and Einstein's relativity theories are presented in relation to some of the initial events that happened with the inception of the universe. It is intended that the principia are justified using the basic laws of thermodynamics and quantum physics.

The book is written using conceptual concerns, which give an account of ideas rather than complicating matters with facts and numbers. In this sense, I foresee that this book will be a reference and textbook suitable for all levels of physics, astronomy, cosmology, philosophy, and modern sciences from A level to postgraduate level, as well as a book of popular science, assisting readers to embrace these universal ideas.

Over the years of writing this book, I have been helped by my family Ayça, Mert, and Mevsim. I am very grateful to them. My special thanks to Dr. Ö. Çoban who designed some of the figures as well as my son Cemal Mert Tüzemen who created the intelligent charcoal drawings and designs in the book.

S. TÜZEMEN
Erzurum, April 2019

CHAPTER ONE

INCEPTION OF THE UNIVERSE

"God played dice with the universe and created it from nothing."[1]

The photograph above shows Edwin Hubble (1889–1953) making his famous inspections of space. Hubble is undoubtedly one of the most important astronomers of the twentieth century, whose findings were interpreted as the theory of the expansion of the universe after his death. The Hubble Space Telescope was named in his honour. (Photo by Margaret Bourke-White)

[1] The quotation was transcribed from one of Einstein's famous expressions.

Ever since the dawn of humankind, there has been curiosity about the kind of environment we live in and how the universe was created. This curiosity has probably provided the main source for our present knowledge and science. Today, the combination of Einstein's ideas of the extent of that "heat as substance" with Hubble's observations on the "expanding universe" has led physicists and astronomers to focus on the Big Bang theory, which has been accepted as a scientific consensus in modern cosmology.

The huge heat released by the Big Bang and the various kinds of transformations of that heat from energy to particles or matter during the particular stages of the creation defined the main principles and laws of nature and physics; humans have been trying to understand what it is all about, and will continue to do so for as long as the world remains.

This chapter will begin with present theories on the inception of the universe, underlining the findings of modern astronomy. Together with a chronology, it will explain the seven steps after the Big Bang, the stages of the creation of elementary and sub-atomic particles, and the foundation of today's known baryonic particles and materials that constitute the planets, stars, and galaxies of the whole universe. Furthermore, the origin of universal constants such as the speed of light in a vacuum (c), Planck's constant (h), Planck length (L), and gravitational constant (G) will be explained, to encourage readers to have an opinion on the formation of the present cosmos. It will introduce reasons for why the non-deterministic quantum and cosmic features of the universe, such as the uncertainty principle, occurred. The expansion of the universe with the Hubble parameter will be explained with a simplified model. Finally, possible scenarios about the end of the universe will be delineated, using the possible relations of the second law of thermodynamics and entropy.

Creation

The Big Bang—from the explosion of an ultra-hot and massless point to the condensation of an ultra-cold and ultra-massive point (black hole)—initiated the miraculous expansion of the universe, which took nearly 14 billion years to constitute the present form of the cosmos (see figure 1.1 for the observable universe).[2] The expansion still continues as discovered by Edwin Hubble's observations in 1929 on red-shifted radiation from some of

[2] The initiation of the universe with the Big Bang is a scientific consensus; standard cosmology emerges from the entire series of consensuses.

the galaxies. Since then, data are still collected by the satellite telescope named after him, among others.

Figure 1.1. A logarithmic illustration of the observable universe containing many super-clusters ("clustered" towards the edge of the figure due to the logarithmic image) each containing thousands of galaxies; our Milky Way is included in the centre, with a total ordinary baryonic mass of 10^{53} kg, a diameter of nearly 10^{27} m, and an average temperature of 2.7 K.[3]

The observable universe is a sphere space within the cosmic horizon, centred by the observer on Earth[4] at present, covering all the ordinary matter that emits or reflects the electromagnetic radiation sensed by presently available instruments. It appears as the electromagnetic signals and images from these species, which have taken time to reach Earth since the beginning of the expanding universe. Observatories located in different parts of the universe would certainly provide different formations of the observable universe, which would probably match the one centred on Earth only in some aspects.

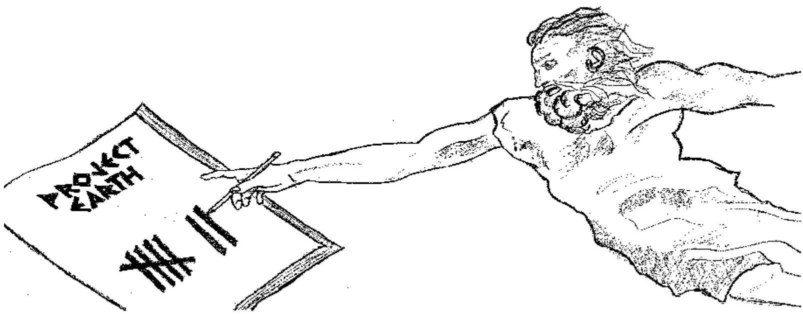
Interestingly, it is thought that the total observable mass (baryonic matter or normal matter) of the universe is even less than 5% of the entire

[3] This file is licensed under a Creative Commons license, created by Pablo Carlos Budassi.

[4] Probably it has the same etymological roots as the word *ard* in Arabic.

universe, and that the remaining 95% is missing and remains a mystery. This will presently be theorised as *dark matter* and *dark energy*, in order to explain certain unexpected behaviours such as the strange activities of galaxies and the accelerating expansion of the universe observed especially since the 1990s, which advanced and modified the basic principles of modern astronomy and cosmology.

Before we look at the details of these unexpected behaviours, let us discuss why we believe that the universe was created in an unexpected, sudden inception and the sequential evolution of a tremendous energy (heat): the Big Bang. Ontologically, heat[5] is considered as a substance[6] like a massless gas, which can move in and out of matter. Although this is a classical concept, it is quite a useful tool in terms of understanding how energy is converted to matter, which constituted the present forms of the universe—planets, stars, solar systems, galaxies, galaxy clusters, black holes, and so on—from the thermodynamics point of view. However, further understanding of the creation, of course, requires quantum mechanical concepts and some sophisticated theories such as "gauge theory" and "quantum field theory" (which will be explained in Chapters 5 and 6); pedagogically, the explanations of classical thermodynamics in the next section are more successful in aiding understanding of the creation.



An artist's imagination of creation, visualising the steps of the creation.[7]

[5] In ancient history, heat as fire was considered to be one of the four basic elements.
[6] Albert Einstein and Leopold Infeld, *The Evolution of Physics from Early Concepts to Relativity and Quanta*, edited by Walter Isaacson (Simon & Schuster, 2007), 35.
[7] Sketched by Cemal Mert Tüzemen and courtesy of him created for this book.

Several consequently instigated initial events and conditions have coded and structured the present form of the universe. As the noted Turkish composer Fazıl Say[8] describes in his famous "Universe" Symphony, "the dark matter is the evidence of the creation of the universe which creates itself out of nothing." The melody progresses with seven notes, probably pointing out the following seven stages[9] of the creation:

(1) The initial expansion caused by the Big Bang lasted only 10^{-36} seconds, called the Planck epoch.
(2) A sudden exponential expansion called the cosmic inflation[10] occurred within the duration of the inflationary epoch from the end of the Planck epoch to at most 10^{-32} seconds.
(3) Scale invariant[11] quantum fluctuations, which are considered to be due to the cosmic inflation. These fluctuations were like a "butterfly effect," which structured the present universe, growing from tiny temperature (heat) ripples to, probably, the infinite cosmos.
(4) Reheating started just after the super-cooling of the universe due to cosmic inflation, populating the universe with a dense and hot mixture of subatomic elementary particles such as quarks, anti-quarks, and gluons constituting the hadrons (protons and neutrons) through electroweak interaction because of the Higgs field, which is explained in Chapter 5.
(5) Cooling down to average temperatures of 3,000 K due to the normal expansion of the universe.
(6) Recombination producing small atoms such as helium,[12] hydrogen, deuteron, and lithium.
(7) Photon decoupling allowing the present observation of red-shifted thermal radiation called *cosmic microwave background radiation* (CMBR).

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[8] Successful globally known composer and pianist.
[9] Some Asian theologians also indicate the seven-step creation of the universe.
[10] Some sets of very important radio-astronomical observation results by NASA show that the initial phases of the universe are built up with a sudden inflation that happened only 10^{-36} second after the big bang.
[11] The fluctuations are scale invariant and brought to the present time with no change, consolidating some of the constants, such as Planck's, to be constant no matter how big the universe gets.
[12] Helium was somehow produced earlier due to the higher binding energy standing on the higher temperature thermal energies.

Had one of these seven processes happened or occurred in a different way or in a different sequence, then everything in the universe would have been completely different than it is in the present. The universe is so "finely tuned" that the scale of creatures and matter are appropriate to and match each other to constitute the concordance and harmony of everything that conducts an "intelligent system and life."

Predictions of thermodynamics

In fact, the simple thermodynamic evaluations of the first two of the above-mentioned processes result in an extraordinary understanding of the basic principles and codes of the universe during the creation stages. From the thermodynamical point of view, when the constant Q_i[13] amount of heat was created in the Big Bang, because there was no matter at the beginning of the universe, pressure- (p) and volume- (V) dependent mechanical work ($p\Delta V$) was zero, and therefore, the potential[14] energy of the universe is given by

$$U = Q \equiv T_i S_i \tag{1.1}$$

where T_i and S_i are respectively the initial absolute temperature and the entropy of the universe at the time t=0. When the universe cooled as it expanded, the entropy had to increase (ΔS>0) in order to keep the product constant in equation (1.1). This is the second law of thermodynamics, or, as I like to call it, "the first law of the universe."

Because of cosmic inflation, although the entropy adds up at the macroscopic scale with respect to the second law of thermodynamics, there is a probability of $\pm\delta S$ fluctuations in the entropy at a microscopic scale in a given point of space, when the universe was still microscopic at the beginning of the inflationary epoch. The fluctuations in the entropy were recently confirmed by the fluctuation theorem.[15] These entropy fluctuations resulted in the scale-invariant energy fluctuations of ΔE in Δt amount of time, corresponding to the heat fluctuations according to equation (1.1).

From the quantum mechanical point of view, entropy means the logarithmic number of the quantum (energy) states of a system. Therefore, the fluctuations in the entropy correspond to fluctuations in the number of quantum states. This situation would cause a Gaussian-like distribution of the density of states as $\rho_E = \rho_E(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}, \boldsymbol{t})$, resulting in an uncertainty in

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[13] Coincidentally, in mystical theology it is believed that the universe was created by God issuing the order *Qun* (Q), meaning "be."

[14] It is considered that all the energy of the universe started with potential energy, converting itself gradually to other types, such as heat, mechanical, and so on.

[15] D. J. Evans, E. G. D. Cohen, and G. P. Morriss, "Probability of Second Law Violations in Shearing Steady States," *Phys Rev Lett* 71, no. 15 (1993): 2401.

energy at a given point $(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}, \boldsymbol{t})$ in space. Later, this will be explained through Heisenberg's uncertainty principle (HUP), which predicts that these energy fluctuations per unit time are quantised[16] with the intervals of the reduced Planck constant, $\hbar$ and given by

$$\Delta E = n\hbar/\Delta t\ ,\ n = 1,2,3, \dots \infty \tag{1.2a}$$

or

$$\Delta E \geq \hbar/\Delta t \tag{1.2b}$$

which I would like to call "the first principle of the universe." It was shown that this principle allows an extraordinary effect, so-called quantum fluctuations[17] in quantum field theory (QFT), which explains the fundamental force fields of mediating particles due to the HUP. Quantum fluctuations caused a sort of butterfly effect, which structured the huge universe from small ripples in the entropy and consequently in the energy.

The decrease in entropy arising from the fluctuations seems to work against the second law of thermodynamics at a microscopic scale. This is to say that the Planck epoch caused a continuous increase in entropy; on the other hand, the latter inflationary epoch caused reductions in entropy, violating the second law of thermodynamics. We can also interpret that the two subsequent events opposed to each other cause an uncertainty in the energy/time or equivalently in the position/momentum couples at a microscopic scale. The violation of the second law of thermodynamics means the violation of the first (conservation of energy)[18] at the microscopic scale, confirming the HUP that bases the standard model of the universe and the QFT, suggesting mediating virtual particles[19] in free space. These unusual extraordinary effects appear only at a microscopic scale and can be ignored at a macroscopic scale, allowing the classic mechanical predictions to be valid for the macroscopic limits of quantum mechanics.

Due to the inflation accompanied by a sudden and huge expansion, the universe was brought to a macroscopic scale (the cosmic scale) from microscopic dimensions. Therefore, T is drastically dropped to a temperature of T_f, more than several orders of magnitudes, resulting in the super cooling of the universe. This decrease in temperature was much higher

[16] Nature gives us quantities (such as energy, charge, and particles) with certain packages of quanta; likewise, an apple tree gives you apples in integer numbers.

[17] The fluctuations appear also in the cosmic microwave background radiation spectrum as a fine structure.

[18] The first law of thermodynamics explains the conservation of energy.

[19] The mediating virtual particles named gauge bosons constitute the fundamental forces.

than the increase in entropy,[20] S_f, so that multiplication of the two could not provide the conservation of energy. Therefore, this huge drop in temperature had an earthquake-like effect, compulsorily producing other types of energies (mechanical work and Einstein's equivalent mass energy) in order to compensate for the level of the sudden drop in heat. This caused the creation of elementary particles such as quarks, anti-quarks, and gluons that are the basic constituents of the matter, having pressure (mechanical work) and mass energy. This is the necessity of equation (1.1) with a constant amount of heat incepted in the Big Bang. Therefore, equation (1.1) converts to

$$Q_i = T_i S = T_f S_f + p\Delta V + Mc^2 \tag{1.3}$$

after the creation of the elementary particles with pressure, p, and a total mass[21] of M (massless ones are not included). In other words, when the heat dropped suddenly, there needed to be mechanical energy (a kinetic term in energy) with pressure and an equivalent mass energy due to the creation of matter, compensating the sudden drop in the amount of heat. This dissipation of heat during the inflationary epoch caused a decrease in the potential energy of the universe as

$$\Delta U = -(p\Delta V + Mc^2) \tag{1.4}$$

Following the cosmic inflation with the super cooling of the universe, the predictions point to a reheating period that further reduced the potential energy, converting to the kinetic energy of the created elementary particles during the inflation as explained in the previous paragraph. Highly energetic particles of the plasma caused super collisions of these elementary particles created during the inflationary epoch, composing (symmetry breaking)[22] into the heavy hadrons (protons and neutrons) due to reheating. Due to the ongoing further expansion, this event eventually constituted the small atoms (He, H, and Li) by cooling to appropriate average temperatures of around 3,200 K at which the electronic bonds of the atoms cannot be broken. Since then, it has been possible to convert matter to energy and vice versa either naturally or artificially through nuclear reactions.

There exist some other alternative theories other than the Big Bang within non-standard cosmology. However, the term *non-standard* may change over time by general scientific consensus including a theory or term within standard cosmology. For instance, Einstein's cosmological constant-

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[20] The increase in entropy is so slow during these stages of the universe that most of the processes can approximately be considered as isentropic ($\Delta S \approx 0$).

[21] At the beginning just after the Big Bang, the Higgs Field probably didn't exist. As the universe cooled, the Higgs Field existed and gave mass to the particles with whom it interfered. The mechanism is going to be explained later.

[22] The term will be further explained in detail in Chapter 5.

Λ was not accepted as standard up to very recent times in the last decade. However, it is now within standard cosmology and has been a backbone of the modern cosmology constituting the *lambda-cold dark matter* (Λ-CDM)[23] model of the universe. After recognition of dark matter and dark energy, the term *hot dark matter* has been removed to outside the standard. Standard cosmology presently recognises that the initiation began with the Big Bang, and that the universe is governed by general relativity, which is explained in Chapter 2.

Understanding the expansion

The most important question arises when we think of an explosion-type of accelerating expansion, which has taken place since the beginning of the universe. The question is, Wouldn't the objects go faster than the speed of light as the acceleration goes on for 14 billion years? Even the relatively small gravitational acceleration of the Earth ($g=9.81$ m/s^2) takes a bit less than one year to accelerate a particle to the "pseudo" speed of light.

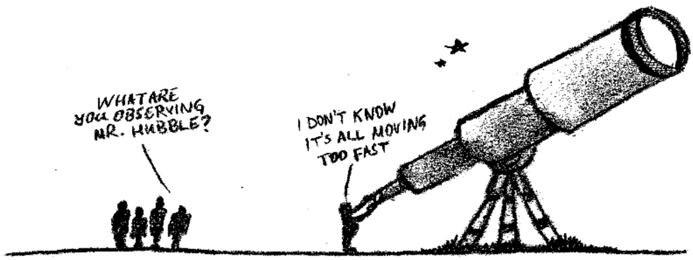
Conveying the objects to the speed of light is impossible from the relativistic point of view and because we could not have observed the present observable universe since the objects near the edge of the cosmos would go further away from us faster than the speed of light, and, therefore, the cosmic signals could never reach us. For instance, if the galaxies flew apart faster than the speed of light, we could not observe them at the present time.

If we take the expansion as an explosion-type of expansion, we cannot understand the metric growth or metric enlargement of the universe. We should think of spacetime expansion according to general relativity, rather than as only a spatial expansion in a classical explosion-type of expansion. The metric expansion is something that can take place in large-scale species, as at the scale of galaxies. In physics, some anomalies appear when the objects are too small or too big. The quantum phenomena appear at microscopic scales while the metric expansion[24] appears at macroscopic scales.

We should think of the metric expansion as the scale growth of the universe rather than the spatial enlargement of the universe. For instance, let us imagine that we wake up to a "Black Monday" situation where the value of money has gone down a million times. The money itself didn't

[23] The standard model of Big Bang cosmology.
[24] See for example, A. B. Whiting, "The Expansion of Space: Free Particle Motion and the Cosmological Redshift," *Observatory* 124 (2004).

change, but the scale has changed so that it would cost a million pounds to buy bread or 100 billion pounds to buy a house. We would call this big "inflation," wouldn't we? In the inflationary epoch, it is estimated that the universe suddenly expanded nearly 10^{26} times in length in less than 10^{-32} of a second, which is equivalent to an enlargement of a nano-metric distance to about 10^{17} m, and which requires a much higher speed than the speed of light in Newtonian phenomena. An expansion of this kind cannot be explained in terms of classical, ordinary spatial expansion estimations. Although the general expansion of the universe is not that sharp, it is still too big, taking billions and billions of years to reach the speed of light in classical thinking, which is nonsense in modern terms.



The cartoonish imagination of the artist, caricaturing the expansion.[25]

We can probably understand the expansion with the simplified Minkowski diagram of a light triangle[26] shown in figure 1.2. For simplicity, the y and z coordinates are omitted, and the x–t configuration is drawn as a spacetime diagram, only. O represents the observer at reference time t_0, positioned at the origin, observing the two galaxies situated at points A and B. When the observer measures the distance d_0 between the two galaxies, time for the galaxies will be at the time of t_1 in the past until the light reaches the observer, travelling the green arms of the triangle (AOB). The observer shuts down everything for, let's say, 10 years and comes back for a new measurement. Time for the observer O' has gone a bit further (10 years) and is now at time t at the bottom of the triangle $(A'O'B')$. In this latter case, light travels the longer red arms, observing the situation of the two galaxies at the time t_2, since the light travelled the longer length than for the first

[25] Sketched by Cemal Mert Tüzemen.
[26] For the two dimensions of space, it would be called a "light cone." It is impossible to demonstrate the three dimensions on a piece of paper.

time. The difference between t_1 and t_2 will be even greater than 10 years, because 10 years is already past for the second measurement and plus the light travelled the longer distances (red lines). This also explains the accelerating expansion because the delay wouldn't be linear if we made a third measurement after 10 more years.

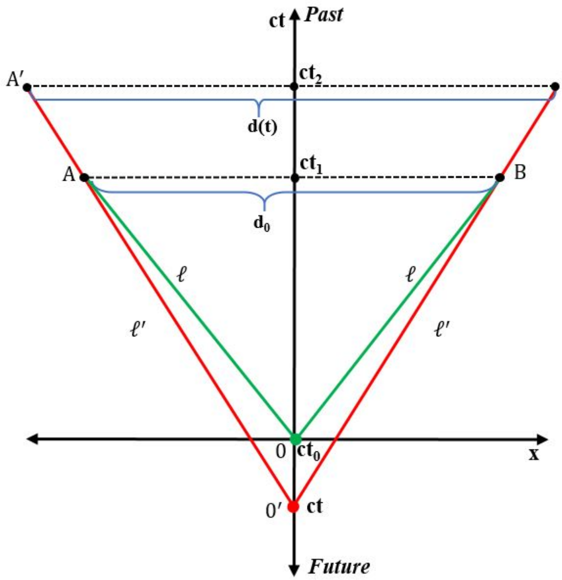


Figure 1.2. A simplified Minkowski diagram imagining a measurement of the distance between the two galaxies (*A* and *B*) from the observational point of *O*.[27]

In the second measurement, the observer would see the galaxies at positions $A^{'}$ and $B^{'}$ and measure the distance between the galaxies as *d(t),* which is greater than d_0 due to the light delay. This effect cannot be observed for the objects close to the observer because the light trajectories would be the same between the two subsequent measurements. In fact, the real positions of the galaxies didn't change according to the ones who live in them; instead, we detected the positions of the galaxies much more back in the past, as we went ahead in time. This is really an illusion of spacetime playing a game with us. These illusions are what we have to accept as a reality of the universe at larger scales, which appear according to the spacetime network of general relativity (see Chapter 2). Einstein must have

[27] This diagram is exaggeratedly drawn for pedagogical reasons. It cannot be applied to the real situation.

said one of his famous expressions, “Reality is merely an illusion, albeit a very persistent one,” on the basis of these considerations.

The expansion is evaluated by a dimensionless parameter called the scale factor $a(t)$, defined as the ratio of the proper distances between the two specific objects at a given time, t and at a reference time, t_0;

$$a(t) \equiv d(t)/d_0 \tag{1.5}$$

Equation (1.5) means that the larger the expansion, the larger the scale factor. The ratio is always ≥1, starting from the reference time as the expansion of the universe continues. It also describes Hubble’s Law, defining the Hubble constant, H given as

$$H \equiv [\partial a(t)/\partial t]/a(t) \tag{1.6}$$

or equivalently as

$$H \equiv [\partial d(t)/\partial t]/d(t) \tag{1.7}$$

This expansion consequently results in the Doppler shift, called the “redshift” in this case, because the observed species goes further away from the observer. The Doppler effect is just like when you hear an ambulance have a sharpening sound as it travels towards you yet have a broadening sound while it travels away from you. The broadening entails the enlargement of the wavelength corresponding to the redshift.

The scale factor can also be defined in terms of the redshift of the observed light wavelength, which is given by

$$a(t) = \lambda_o/\lambda_e \tag{1.8}$$

where λ_o and λ_e are respectively the observed and emitted light wavelengths coming from the observed specimen. Because of the redshift, the ratio is always >1 due to the broadening of the observed light wavelength, as long as the universe expands.

Signatures of the Big Bang

Cosmic Microwave Background Radiation (CMBR) is one of the first signatures of the Big Bang. CMBR is the earliest cosmic code of the universe: it is like the DNA of the cosmos or the fingerprint of the Big Bang left at the “crime scene.” On the other hand, quantum fluctuations are like the “gens” of the universe because they characterised and structured the present universe.

Just as nothing is left secret even if the incident has been over for 14 billion years, a very important hint left from the Big Bang was found by the accidental detection of a parasitic radio frequency (a sort of “cosmic noise”) when the radio astronomers Arno Penzias and Robert Wilson were carrying out a completely different experiment in radio astronomy in 1964. I am not sure whether they were trying to explore the first ever ancient universe radiation at that time, but they didn't disregard their important observation. The observations eventually resulted in the great discovery of Cosmic Microwave Background Radiation, which is now considered a remnant radiation, emitted from an early form of the universe in Big Bang cosmology. This is probably the most ancient signature of the universe. The CMBR together with the redshift of the cosmic spectra are the fundamental evidence of both the Big Bang and the expansion of the universe.

The scenario is as follows; just after the Big Bang in ultra-hot times, the universe was opaque to photons because all the photons were scattered by plasma. As the expansion took place, the cooling from very high plasmatic temperatures to around 3,000 K gave rise to the coupling of protons (p) and electrons (e) constituting the hydrogen (H) atom. This epoch of the universe is called the recombination era, when the thermal kT energy of around 0.26 eV for T=3000 K is not enough to break the p-e bonds of the H atom, which is around 13.6 eV. However, the environment was still hot, and very energetic electrons prefer to drop onto protons emitting the highest possible spectrum of the H atom. This allowed photons to propagate in space rather than being scattered by the plasma, starting an epoch of photon decoupling. However, most of these photons were still absorbed by the matter acting like a black body.

What presently was produced from the thermal radiation of the black body was Cosmic Microwave Background Radiation, which experiences a decrease in energy due to the redshift of the spectrum as the expansion of the universe continues. At the present time, this situation appears to reach us as low microwave energy. Figure 1.3 shows the precise measurement of the spectral distribution of Cosmic Microwave Background Radiation (CMBR) measured by the Cosmic Background Explorer (COBE) telescope of the National Aeronautics and Space Administration (NASA), matching exactly Planck's radiation law at a temperature of 2.7 K.

This is purely black-body thermal radiation of the matter at a colour temperature of around 2.7 K, as described by Planck's Law (see figure 1.3). The colour temperature of the hot gas has dropped from 3,000 to 2.7 K by a factor of roughly a kilo that still increases since the expansion continues.

The simulations from tiny nuanced details of this spectrum show nearly exact resemblances to the Planck radiation of a hot gas that has enlarged to the current size of the universe, despite some fluctuations. These simulations and measurements are unique to the location of Earth where the observations are being made. The results might have been completely different if Earth had been situated in a different galaxy instead of the Milky Way or in a different part of this galaxy.

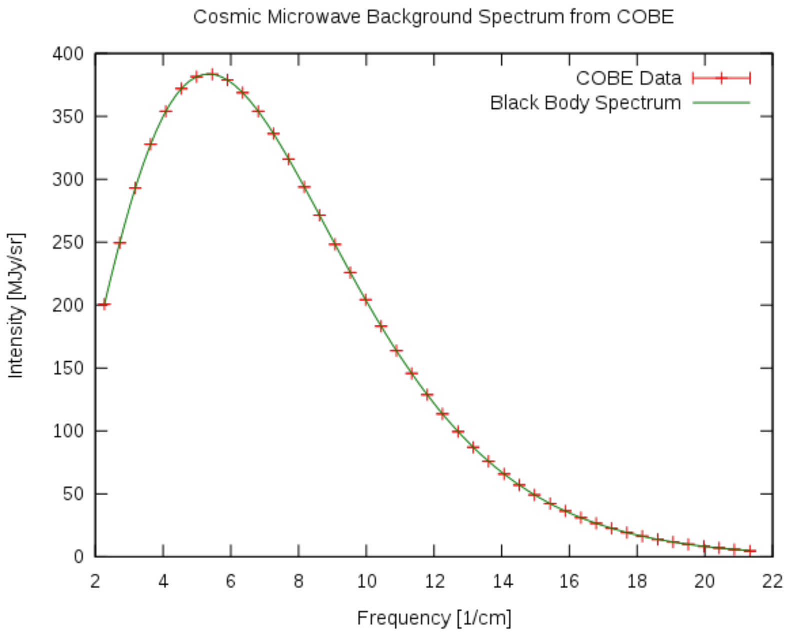


Figure 1.3. Precise measurement of spectral distribution of cosmic microwave background radiation (CMBR) by the Cosmic Background Explorer (COBE) telescope of NASA, matching exactly Planck's radiation law at a temperature of 2.7 K.[28]

Quantum fluctuations are also one of the signatures of the Big Bang, which eventually resulted in energy-time or position-momentum uncertainties at a given point in space, and that constituted the fundamental forces and consequently the universe as explained in the creation section. In fact, the entire universe is constituted by two important principia: uncertainty and relativity, which both refuse certainty. In this respect, I would like to point out, paraphrasing Einstein, that these uncertainties are probably a message from the creator, reminding the creatures of the fact that the exact certainty only belongs to Himself and how incapable we creatures are. As Einstein says also, "I want to know God's thoughts—the rest are mere details."[29]

[28] Courtesy of NASA, available at https://lambda.gsfc.nasa.gov/product/cobe.
[29] See http://www.bbc.co.uk/sn/tvradio/programmes/horizon/einstein_symphony_prog_summary.shtml.

Another important signature of the universe is certainly gravitational waves, which were detected recently in 2015, and which should not be mixed up with CMBR. Poincaré predicted gravitational waves in 1905, and Einstein used them in 1916 on the basis of his general relativity theory, presuming that spacetime curvature fluctuates and therefore propagates these waves at the speed of light due to rotation or any kind of motion of the gravitating source. They were only hypothetical until it was directly detected after a century by the US' Laser Interferometer Gravitational-Wave Observatory (LIGO) and the EU's Virgo Collaboration teams observing gravitational waves from a pair of black holes using the advanced detectors of the LIGO and Virgo Interferometers.[30] The proof of such waves earned the discoverers the 2017 Nobel Prize. This is also important evidence in terms of differentiating the modern gravitational effect from classical Newtonian gravitation, which predicts instantaneous propagation of physical effects with an infinite speed rather than the speed of light.

The period of these waves is supposed to range from the age of the universe to the orders of milliseconds, depending on whether the source is initiated by certain quantum fluctuations in the early universe or by a rotating supernova. They are not electromagnetic radiation like CMBR but they carry a radiant energy called gravitational radiation. It is also predicted that a background gravitational radiation left from the inflationary epoch ought to exist. However, the predicted energy is so low due also to the redshift that it is under the sensitivity limit of detectors such as the LIGO. Therefore, the background radiation related to the gravitational waves has not yet been detected. The idea of mapping the gravitational waves throughout the observable universe has opened a new gateway to modern astronomy, named gravitational-wave astronomy.

Other significant indicators of the universe appear as physical constants[31] or universal constants, such as the speed of light in a vacuum (c), Planck's constant (h), Planck length (L), elementary charge (e), electric constant (ε_0—permittivity of free space), magnetic constant (μ_0-permeability of free space), and gravitational constant (G). All are thought to be signified by the initial conditions of the universe during the Big Bang and thereafter. These scale invariant constants are time independent. This situation eventually constituted a natural mind in the universe extracting a self-governance to have a "fine-tuned" universe, allowing for intelligent life. It is predicted that if these fundamental constants had been slightly different

[30] LIGO Scientific Collaboration and Virgo Collaboration, *Physical Review Letters* 116, no. 6 (2016).

[31] See the table of fundamental constants on the final page of the book.

than they were, this intelligent system of the universe probably would not have existed.

All the other important parameters, such as the fine structure constant (α), the Boltzmann constant (k), the Bohr radius (a_0) or the Rydberg constant (R), are the combinational multiplication and division of the physical constants, which govern the principia and laws of nature. For instance, the Avogadro number (N_A) is an indicator of how much material can be packed in space and is roughly given by the division of a_0 by L. If they were slightly different, N_A would be different and everything in nature would be smaller or larger in size. In fact, the cosmos is a concordance and harmony of matter and energy in the spacetime fabric, which is like a digital art "coded" throughout the universe.

Big anomalies: dark matter and dark energy

First of all, observation of galaxies shows an extraordinary behaviour, which does not even fit the classical Kepler's Law[32] with respect to their visible sizes. According to this law of astrophysics, galaxies with visible sizes should circle a larger orbit if they are flying apart rather than rotating around their centre, as illustrated in figure 1.4. This was a great anomaly, and the explanation of it is rather theoretical, invoking an invisible part called *dark matter*. It means that these galaxies are in fact "obese" even though we observe them as "slim."

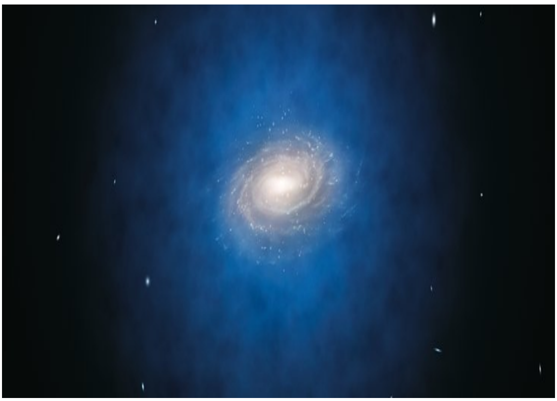
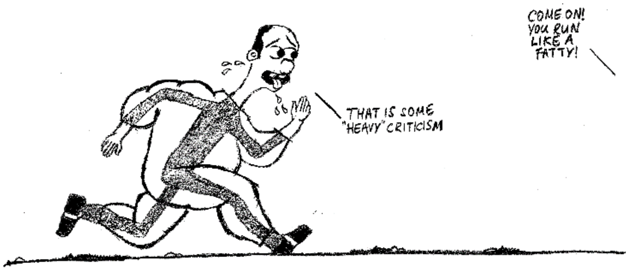


Figure 1.4. An illustration of the dark matter around the rotating Milky Way galaxy. The blue area is the artist's imagination of the dark matter.[33]

[32] The law defines the motion of rotating objects in the universe.
[33] Courtesy of the European Southern Observatory (ESO) for press release.



A cartoonish impression of the artist, caricaturing the dark mass.[34]

It is like watching your favourite athlete, supporting him/her with your cheers, "Run! Run! Run!" but he/she cannot, because he/she is surrounded by some unseen masses that weighs 85% more than he/she normally weighs. This is shown in the artistic charcoal drawing above.

The constituents of the dark matter are presently unknown except that we know what it is not. Anyway, it is not known baryonic or normal matter, because it cannot be detected with presently invented detectors. Modern science predicts and hopes that it can probably be detected through its gravitational effect, such as "gravitational lensing,"[35] using presently available techniques.

The total content of the universe consists of nearly 5% ordinary and nearly 27% dark matter, which is 32% of the total. According to the standard model of cosmology, the missing 68% of the total content is another mystery, hypothesised as "dark energy." The most important evidence that indicates its existence is the accelerating expansion of the universe. It is thought that the universe is a tremendous accelerator. Therefore, a huge force is required[36] for such acceleration, corresponding to a massive energy beyond known forms, which is dark energy. Dark energy is so homogeneously distributed across the universe that its density is very low.

Einstein termed the first-known form of dark energy with a constant called *cosmological constant-Λ*, in his general relativity theory, which eventually constituted *ΛCDM (lambda cold dark matter)* or the *lambda-CDM* model of the universe. This was a theoretical requirement in the

[34] Sketched by Cemal Mert Tüzemen.
[35] According to general relativity, light curves when it crosses a massive object from which emerges gravitational lensing.
[36] Some physicists believe it is an unusual form of force other than the four fundamental forces called *the fifth force*.

equations, filling the missing part of the energy. However, after the discovery of expansion it was realised that Λ shouldn't be constant since the observable volume changes over time. Therefore, a dynamic time-dependent scalar field called *quintessence-Q*[37] was introduced, although it is very difficult to feel the dynamism of Q to distinguish the difference between Λ and Q in the normal lifetime of the world, since the change is so slow.

Apart from hypothetical predictions such as Λ and Q for dark energy, a more concrete candidate for dark energy is the energy propagated by the "virtual particles"[38] that appear due to the HUP in the standard model (see Chapters 5 and 6). However, the calculations of this energy propagated from the annihilation of the virtual particles work out to be extremely high to fit with dark energy; thus, I would rather consider it to be "virtual," leaving the dark energy still as a mystery.

The ratio of the dark energy content of the universe is very high in comparison to the rest. Therefore, the present time of the universe is recognised as the *dark-energy dominated era*.

Chronology

The chronological order of the universe from the Big Bang to the present is given in various different ways such as the cosmic calendar,[39] the chronology of epochs or eras, and so on. The cosmic calendar is probably the most famous such chronology in terms of the popularisation of modern astronomy. However, here it is probably better to give it in terms of the eras, since I mention several epochs in this chapter from time to time.

The chronology of the eras during the universe's 14-billion-year adventure can be given as follows (the following is much more comprehensive than the epochs, but still covers the epochs):

1. The very early universe: This era includes the important epochs such as the Planck and the inflationary epochs defining the initial

[37] P. Ratra and L. Peebles, "Cosmological Consequences of a Rolling Homogeneous Scalar Field," *Physical Review* D. 37, no. 12 (1988): 3406; R. R. Caldwell, R. Dave, and P. J. Steinhardt, "Cosmological Imprint of an Energy Component with General Equation-of-State," *Phys. Rev. Lett.* 80, no. 8 (1998): 1582–85.
[38] Further details of the production of virtual particles will be given in Chapter 5.
[39] In this chronology invented by popular astronomer Carl Edward Sagan, a nearly 14-billion-year span of the chronology of the universe is packed into one year from 1 January to 31 December, explaining the events day to day, hour to hour, minute to minute, and second to second. Of this year, we humans came into existence only in the last couple of seconds of the last day of the year.

conditions in the first picosecond of cosmic time. Although some specific laws of physics do not appear in this very early stage, important principles such as Heisenberg's and the tendency of increasing entropy initiated the formation of the large-scale universe.

2. The early universe: Starting from the creation of subatomic particles to the formation of early atoms, it lasted around 377,000 years. Initially, the universe was cold enough to constitute the small nucleuses; the protons and neutrons are composed of without breaking the bonds. However, it was not cold enough to keep the atoms neutral, and opaque plasma didn't release photons to travel long distances. Eventually it was cooled to form neutral atoms and decouple photons to produce the CMBR in the next era.
3. The dark age: This is a very long era lasting from 377,000 years to about 1 billion years. Because recombination and photon decoupling occurred, the photons travelled. However, since there were no stars as light sources, this period is called the dark age of the universe. The only radiation moving around was photons that were released from the H atoms constituting the CMBR that even today is observed as the microwave-radio frequency range. Eventually supernovas, galaxies, and galaxy clusters were formed with the stars in their present forms up to the end of this stage.
4. The present universe: One billion years after the creation, the universe briefly looked as it appears to us today. It will continue to appear very similar for many billions of years into the future. The solar system appeared after about 9.2 billion years and the earliest stages of life on Earth emerged after about 10.3 billion years, around 3.5 billion years ago. The dark energy ratio is so high in this period that it is called the dark energy–dominated era.

Possible futures and the end

The density parameter Ω, representing matter and dark matter densities with M and Λ indexes, respectively, is considered to be an important parameter from which the scale factor in equation (1.5) can be calculated according to Friedmann equations; the distances between galaxies can be estimated according to this parameter, as shown in figure 1.5. If $\Omega>1$, then the universe is called the *closed universe*, or, the other way around, it is called the *open universe*.

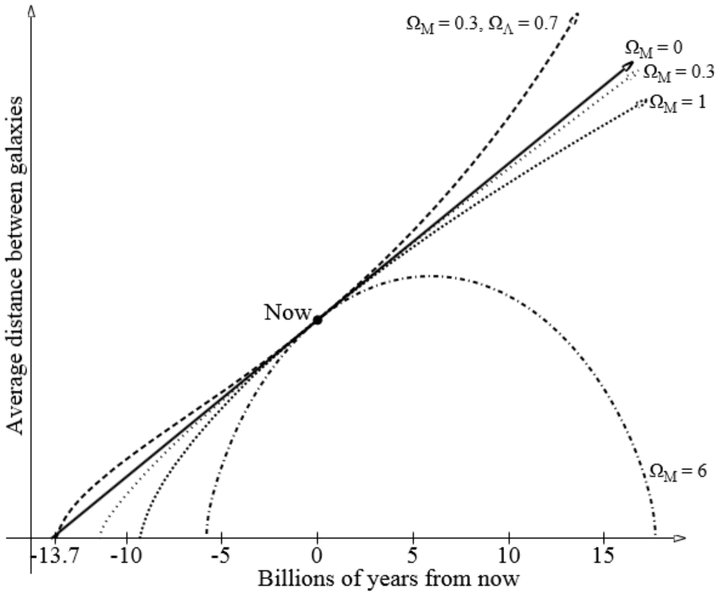


Figure 1.5. Estimated average distance plots as functions of time. The dashed line at the top shows the present expansion of the universe.[40]

Theories estimating the possible ultimate fate of the universe are based on the density parameter being either too low or too high. It is predicted that, from the perspectives of modern cosmology, the present form of the universe will continue for many more billions of years, about 100 billion years from the beginning and about 86 billion years from now. Beyond that all predictions indicate an ultimate destiny, depicting various “doomsday” scenarios.

The “heat death” is a possible scenario: As the expansion of the universe continues, the universe will become consequently colder and less dense. Therefore, eventually everything would collapse into a black hole ending with very slow evaporation due to *Hawking radiation*—the black body radiation emitted from black holes. In other words, the universe would be shutting itself down into “Davy Jones’s locker”[41] forever.

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[40] This work is licensed under a Creative Commons license, which is free to copy, distribute, and transmit.
[41] This phrase means deep down at the bottom of the ocean in sailor’s jargon.

In the “big rip” scenario, as the dark energy content is highly dominated, the acceleration of the universe would rapidly increase to enormous values that the fundamental forces would not overcome; thus there is nothing to keep the masses, atoms, and molecules, and eventually even the nucleuses, together, pulling everything apart, turning everything into their elementary particles. Eventually, even the spacetime fabric would be torn apart.

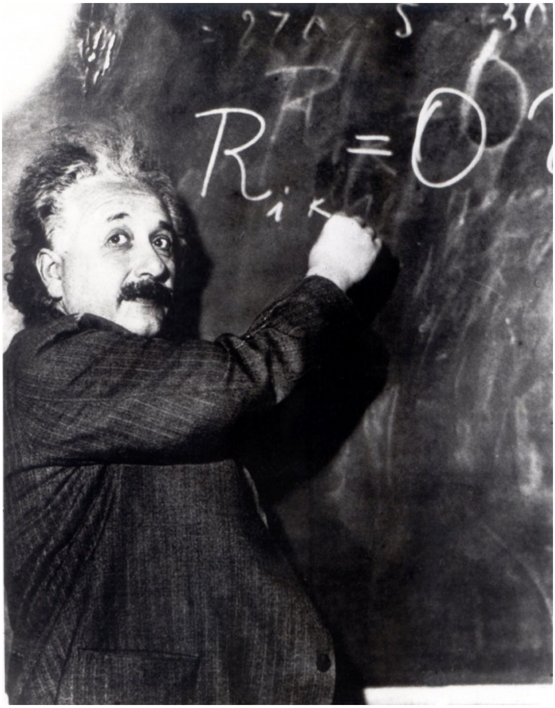
Although the “big crunch”—proposing the contraction after some point of expansion like a spring—is also another possibility, current observations show that this is unlikely. However, in this scenario, metric expansion of the universe would be reversed into a metric contraction, converting the universe into a hot and dense state at the microscopic scale, returning to the situation at the beginning of the Big Bang.

There are many other scenarios but we shall finish the discussion by indicating that the end of the universe is a requirement in terms of the second law of thermodynamics, proposing an endless increase of entropy. Entropy means “disambiguation”: the increase in this disambiguation, according to the second law of thermodynamics, would bring about the end. It also stems from the ideas of Lord Kelvin, formulated as early as the 1850s.

CHAPTER TWO

"GENERALLY" RELATIVITY

"Time is an illusion."
—Albert Einstein



A 1931 photo of Albert Einstein, taken at the Mt. Wilson Observatory Headquarters of the Carnegie Institute in Pasadena, CA, explaining the density of the Milky Way.[1]

[1] Supplied by WENN, an internet photograph portal.