Introduction

Martin Rees' book Just Six Numbers: The Deep Forces That Shape the Universe.
Synopsis: How could a single "genesis event" create billions of galaxies, black holes, stars and planets? The nature of our universe is remarkably sensitive to just six numbers, constant values that describe and define everything from the way atoms are held together to the amount of matter in our universe. If any of these values was "untuned," there would be no stars and life as we know it in our current universe. This realization offers a radically new perspective on our place in the universe, and on the deep forces that shape, quite simply, everything.

Credit: http://www.dontow.com/2010/01/review-of-martin-rees-book--just-six-numbers-the-deep-forces-that-shape-the-universe/

About the book author: Martin Rees is a famous astrophysicist and cosmologist from England. He is currently Professor of Cosmology and Astrophysics at Cambridge University; he is also the President of the Royal Society in England. The book is published by Basic Books in 2000.

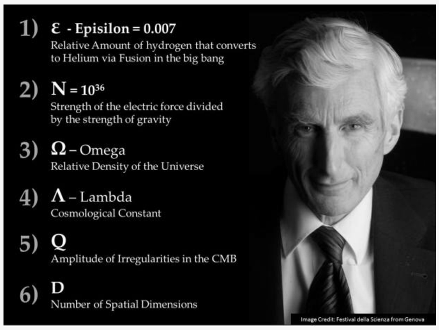
1. N = Relative strength of electrical force

N = Relative strength of electrical force over gravitational force (e.g., electrical force between 2 protons/gravitational force between 2 protons) = (approximately) 1036, i.e. the gravitational force is extremely weak compared with the electrical force.
Matter is made up of atoms and molecules which in general are neutral because they are made up of equal numbers of protons (positively charge) and electrons (negatively charge), and some neutrons (neutrally charge). Therefore, even though the electrical force is so much larger than the gravitational force, the aggregate force governing the macroscopic structure of matter is the gravitational force, and not the electrical force. This self gravitational force will pull the matter inward into smaller and smaller spheres. When they get smaller and smaller, its temperature gets hotter and hotter, because temperature is due to the collision of atoms with each other within the matter, and there will be more collisions if the spheres are smaller. When the interior temperature gets hot enough, nuclear fusion reactions can occur as in our sun. These nuclear fusion reactions release energy and therefore outward pressure which can counteract the inward pressure from gravitation.

1. N = Relative strength of electrical force (cont)

That keeps the matter from continuous collapse and allows stars like our sun to shine from the released energy.. However, If the gravitational force were larger, e.g., a million times larger, i.e., if N=1030, then the matter spheres would collapse much faster into smaller spheres when they reach the temperature which can generate the nuclear fusion reactions and stabilize the matter. Under these circumstances, galaxies would form much more quickly and would be much smaller in size (due to less time for the universe to expand). Instead of the stars being widely dispersed, they would be so densely packed that close encounters would be frequent, thus precluding stable planetary systems, which are a prerequisite for life. Furthermore, when gravity is so strong (relatively speaking), no animals could get much larger than very tiny insects, because gravity would cause any larger living organism to collapse.. We can conclude that instead of having 36 zeros after 1 in the value of N, if there were only 30 zeros after 1, then the universe would be very much different from the current universe, and life as we know it would not be able to exist. Note: On the other hand, if the gravitational force were even weaker, i.e., if N is even larger (having more than 36 zeros after 1), then it would take longer to form galactic structure, and galactic structures would be less densely populated, and larger and perhaps more complex life organisms, different from current life organisms, could exist..

Just Six Numbers



2. € = nuclear efficiency

€ = nuclear efficiency, defined as the % of the mass of the nuclear constituents that is converted to heat when the nuclear constituents react via nuclear fusion to form a heavier nuclei = 0.007.
The force governing nuclear fusion is called the strong force, and is one of four forces known in nature, with the other three being the electromagnetic force, the weak force (a repulsive short-range force governing radioactive decay), and the gravitational force.

2. € = nuclear efficiency (cont)

The strong force is the strongest of the four forces and is about 100 times stronger than the electromagnetic force. However, its force is very short range, i.e., the force falls off very rapidly with distance. The number € is a measure of the strength of the strong force; a larger € means a stronger strong force.. As explained below, if € were smaller than 0.006 or larger than 0.008, then the universe and life as we know it would not exist.

When two protons and two neutrons react to form a helium nucleus, the reaction does not go in one step. Instead, it occurs in two steps. The first step is that one proton and one neutron would react to form a deuterium nucleus, i.e., an isotope of hydrogen consisting of one proton and one neutron. Similarly, the other proton and the other neutron would react to form another deuterium nucleus. Then the two deuterium nuclei would react to form a helium nucleus consisting of two protons and two neutrons.. If € = 0.006 or smaller, the strong force is not strong enough to fuse a proton and a neutron into a stable deuterium. Without stable deuterium, helium cannot be formed. Then our universe would be composed of hydrogen only, and no heavier elements could be formed to make rocky planets and carbon-based living things. This means no chemistry and therefore no life organisms as we know it can be formed.

In our actual universe with € = 0.007, the strong force is not strong enough for two protons to overcome their electrical repulsion to fuse together. It requires one or more neutrons which provide additional strong force but no additional electrical repulsion to fuse together into a heavier element.

If € = 0.008 or greater, then the strong force is strong enough to overcome the electrical repulsion of two protons, and two protons can fuse together. This would have happened early in the life of the universe, so that all the hydrogen (i.e., protons) would have been used up very early on, and there is no hydrogen remaining to continue to provide the fuel to produce light in ordinary stars as in our sun. Furthermore, water, H_2O, could never have existed, and therefore no life as we know it.

Any universe with complex chemistry and life would require € to be in the range of 0.006 – 0.008.

3. Ω and dark matter

When a rocket, is launched upward from the surface of a galactic object, e.g., the earth, whether it will escape from that galactic object, or whether it will be pulled back by gravity to the surface of that galactic object, depends on the velocity of the launch and the strength of gravity for that galactic object. The critical velocity that is required to cause that rocket to escape from that galactic object is known as the “escape velocity”. In the case of the earth with its known gravitational field, the “escape velocity” is 11.2 kilometers per second, or about 25,000 miles per hour.. In an expanding universe, galactic matters are moving apart from each other. Will this expansion continue forever, or will these motions eventually reverse, so that the universe will eventually re-collapse to a “Big Crunch”? Since we know the expansion speed of our expanding universe, the answer to the above question depends on whether there is enough matter in the universe so that gravity from all these matters is strong enough to slow down the expansion and then cause the collapse to a “Big Crunch”. The matter density in the universe that is necessary to cause this reversal is called the galactic “critical density”. Knowing the expansion speed, we can calculate and determine this critical density to be approximately five atoms [4] per cubic meter.. If we calculate the masses of all known matter in our universe, we can determine the average mass density of all known matter in our universe, which turns out to be about 0.2 atoms per cubic meter, or about 25 times smaller than the critical density.Ω = ratio of actual density in galactic matter to the galactic critical density = 0.2/5 = 0.04. We see that the known matter in the universe is only about 4% of the critical mass (i.e., about 25 times smaller) than the amount of matter needed to keep the universe from expanding forever.. Is there any other indication for the existence of dark matter? By observing the motions of various stars and galaxies, it seems that their motions cannot be completely explained by the gravitational pulls of other stars and galaxies that are known to exist today. It seems that there are other matters in the universe, called dark matter (because we cannot see/detect their electromagnetic radiation), that are nevertheless affecting the motions of stars and galaxies. The assumption of the existence of dark matter is actually not so ad hoc or unreasonable.

3. Ω and dark matter (cont)

Such inference is actually the same line of reasoning used to explain the unexpected motion of some stars by assuming that these stars must be orbiting around a “black hole” that does not emit any radiation and therefore cannot be directly seen or detected. It is also similar to the reasoning used in the 19th century to infer the existence of the planet Neptune in order to explain the observed motion of the planet Uranus.. Even with generous account of the possibility of such dark matter, based on current information the value of Ω can at most be raised to approximately 0.3, not quite the critical value of 1, but not extremely far from it. At first sight, such large abundance of dark matter may seem strange, but why most of the matter in the universe must emit radiation so that they can be seen or directly detectable? There are various theories for what constitutes dark matter, but it remains as one of the most important unsolved questions in astrophysics and cosmology.. What is the significance of the value of Ω with respect to the existence of our universe and life as we know it? If Ω were significantly smaller than 1, then not only that the universe would expand forever, the gravitational pull would be so small that expansion would occur so rapidly that galactic matters would be so far apart and galaxies would not be able to be formed, with a corollary that planets and life as we know it would not be able to exist. On the other hand, if Ω were significantly larger than 1, then the universe would quickly collapse before there was time for any interesting evolution of galaxies, planets, and life as we know it..

4. λ: cosmological constant

λ: When Einstein first formulated his field equation in general relativity in 1916 to describe the universe, he found that the solutions of his field equation would lead to a non-static universe, i.e., the universe would either contract or expand. Since the general thinking at that time (in the latter part of the 1910 decade or the early part of the 1920 decade) was that the universe should be static (remember that this period was before Hubble’s observations that the universe was expanding), Einstein introduced an extra term in his equation, called the cosmological constant term containing the cosmological constant λ. By adding this term and with the proper choice of the value of λ, his equation could lead to a static universe.. However, in 1922, the Russian mathematician Alexander Friedman showed that Einstein’s fix is unstable, like balancing a pencil on its point, and therefore really doesn’t lead to a static universe.

4. λ: cosmological constant (cont)

When in 1929 Hubble discovered Hubble’s Law that the universe is expanding, Einstein regretted that he ever introduced the cosmological constant term and called that action the “biggest blunder” of his life. [Note: Since without the lamda term, Einstein’s equation can also lead to an expanding universe, so why do we need to introduce the lamda term in an ad hoc way. That was why Einstein thought that doing that was a big blunder.]
The common belief in the 1970s and 1980s was that the expansion of the universe should slow down with time due to the continued pull of gravitation from all the matter in the universe. In the decades of the 1990s and 2000s, a series of observations of very bright stars called supernova was carried out to try to show that. [One of the leaders of this research was a physicist from the Lawrence Berkeley Laboratory of the University of California at Berkeley.] It was a great surprise that these observations found that not only that the universe is expanding, but its expansion is accelerating, i.e., the expansion speed is increasing instead of decreasing with time. The magazine Science rated this as the number-one scientific discovery of 1998 in any field of research. This led to a revival of the need for the cosmological constant term, with this term representing perhaps a new form of matter or energy that is gravitationally repulsive, unlike the dark matter of the previous section. Adding such a term could lead to an accelerating expanding universe. Such explanation is very tentative and much more work remains to elucidate this mystery!. From other astronomical observations, the current estimated value for λ is around 0.7, which is also consistent with the supernova observations of an accelerating expanding universe. A much larger value for λ would mean that the universe would have expanded rapidly even in its early stages. Therefore, there would not be sufficient time for stars, galaxies, planets to form, and therefore would have precluded life as we know it. On the other hand, a much smaller value for λ would not lead to catastrophic consequences in terms of the formation of stars, galaxies, planets, and life; it only means that the expansion of the universe will slow down..

5. Q:

Q: After the Big Bang as the universe expanded, matter was randomly distributed in space, which means that there were areas which were more densely populated and areas which were less densely populated. In the more densely populated areas, there would be stronger gravitational attractions between various matters. So over time, these clusterings of matter would become bigger and bigger and would eventually form stars, galaxies, and clusters of galaxies, all are held together by gravity.
How tightly these structures are bound together is tied to the physical and biological evolution of the universe. If they were very tightly bound, i.e., it would take a lot of energy to break them up and disperse them (or Q as defined two paragraphs later is very large), then clustering would occur earlier and more likely to stay together. This would mean that it would take less time for the universe to evolve to the current structure. Stars and galaxies would be more closely packed, and they would more likely collide with each other, thus decreasing the chance to retain stable planetary systems and therefore less likely for life as we know it to exist.. On the other hand, if they were very loosely bound, i.e., it would not take a lot of energy to break them up and disperse them (or Q as defined in the next paragraph is very small), then clustering would be less likely to occur or to stay together. This would mean that it would take more time for the universe to evolve to the current structure. There would not be sufficient time for stars, galaxies, and planets to form, and then for life as we know it to develop and evolve.
The measure of the strength of these bonds among galactic matter to form clusters (stars, galaxies, and clusters of galaxies) is called Q = the amount of energy, as a proportion to their rest mass energy, needed to break up and disperse the clusters.

For our universe, Q is estimated to be 10-5. As explained in the two previous paragraphs, if Q were much larger or smaller than 10-5, then life as we know it would not exist.

6. D: the number of dimensions in our universe

D = the number of dimensions in our universe = the number of physical dimensions plus the dimension of time.
We are used to thinking that we live in a world of four dimensions, with three spatial directions and one time dimension with an arrow. But why are there only three spatial dimensions?
One consequence of a three-dimensional spatial world is that forces like gravity and electricity obey an inverse-square law, such that the force from a mass or charge is four times weaker if you go twice as far away.

6. D: the number of dimensions in our universe (cont)

This can be illustrated by a graphical method (first pointed out by Michael Faraday, a pioneer in the study of electricity). If you envisage lines of (electrical or gravitational) force emanating from every charge or mass and the strength of the force is proportional to the concentration of the force lines. At a distance r, the force lines are spread over an area of (π x r2). At a distance 2r, the force lines are spread over an area of [π x (2r)2] = 4πr2. Since in both cases, the number of force lines is identical, the force at a distance of 2r is thus four times weaker than the force at a distance of r. However, in a four-dimensional spatial world, the force lines would now be spread over the volume of a sphere (instead of the area of a circle) which is proportional to r3, thus the force at 2r would be eight times weaker than at r, and not consistent with the physical electrical and gravitational forces we observe in nature.. The author Rees provides another reason for a three-dimensional world: “Another reason for a three-dimensional spatial world is the stability of orbits in our solar system, in the sense that a slight change in a planet’s speed would only nudge its orbit slightly. But this stability would be lost if gravity followed an inverse-cube (or steeper) law rather than one based on inverse squares. An orbiting planet that was slowed down – even slightly – would then plunge ever faster into the sun, rather than merely shift into a slightly smaller orbit, because an inverse-cube force strengthens so steeply towards the center; conversely, an orbiting planet that was slightly speeded up would quickly spiral outwards into darkness.. ”Are there arguments against a world with fewer than three spatial dimensions? In a two-dimensional spatial world, it is impossible to have a complicated network without the wires crossing. This would make it essentially impossible to create communication networks or physiological circulatory networks. Similarly, you cannot have a channel through an organ (e.g., a digestive tract) without dividing the organ into two. The restrictions are even more severe in a one-dimensional spatial world.
Can we live in a universe where the fundamental physical laws at the time of the Big Bang have more dimensions than four, and then these physical laws “simplify” to our current four-dimensional world shortly after the Big Bang? To address this question, we will first discuss the grand unification of the forces of nature. Almost 150 years ago, Maxwell was able to provide a unified description of the electric force and the magnetic force into a single set of equations that describe both forces, now called the electromagnetic force.

6. D: the number of dimensions in our universe (cont)

The introduction of quantum mechanics and especially the advances in the last 60 years seem to have led first to a quantum mechanical unified field theory of the electromagnetic force, called Quantum Electrodynamics. Then it led to a quantum mechanical unified field theory of the electromagnetic force and the weak force, called the Standard Electroweak Theory. Similar type of field theory may also have the potential to provide a quantum mechanical field theory of the strong force, called Quantum Chromodynamics, thus leading to the hope that such field theories may be able to provide a unified description of the electromagnetic force, the weak force, the strong force, and perhaps also the gravitational force..