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The Astrophysical Processes of Cosmological Hydrogen that Generate the Chemical Elements that Make up the Universe

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ABSTRACT

The objective of the present article is to explain how all the chemical elements were formed from the big bang generated element: hydrogen. The methodology used was to analyze the main cosmological and astrophysical processes in order to explain the origin of all the known chemical elements. The main results are: Hydrogen cannot be formed in any part of the actual universe; it must come from the Big Bang. Helium and a little bit of lithium can have a cosmological origin associated to the Big Bang nucleosynthesis and the recombination process. The elements with an atomic number between 3 and 26 were, and continue to be, synthetized by nuclear fusion reactions inside the core of massive stars and liberated by explosion when the stars go supernovae, at the end of their lives. In the process of going supernova, elements with a medium atomic number, between 27 and 40, are created. All the elements with an atomic number larger than 40 were generated by neutron star collisions. When Mendeleev and Lothar Meyer designed an ordered arrangement of chemical elements, their tables included the 63 chemical elements known in 1869. A century and a half later, the known elements are 118. By studying different topics related to the elements, it was possible to uncover fundamental particles, such as quarks and leptons, and the strong and weak nuclear forces that form the baryonic part of the universe. The Sun was formed 6000 million years ago and its planets, including earth, were formed 4600 million years ago when and where there were debris of different stars that went supernova, in particular 1A type, and also debris, of at least one of a binary neutron star collision, so to attain, all the elements

that have been identified in the solar system, and especially in earth. In addition, the current "periodic table" includes 26 synthetic elements that were produced in neutron star collisions but, because of their short lifetimes, they are not found, on earth. The vast quantities of the elements, produced during the aforementioned astrophysical processes, clustered into planets, stars and galaxies; and at least in one planet, our earth, some chemical elements organized themselves into living creatures.

1. INTRODUCTION

By the 1800's, the chemical elements were thought to constitute everything that exists in nature [1]. Even though at that time, still there were three main questions to be answered. The first one was: Are the chemical elements, the indivisible particles, or atoms, postulated by Democritus of Abdera (c. 460-370BC) 2200 years earlier [2], or even these so-called atoms were composed of something more fundamental? It took almost two hundred years, to the scientific world, to give a step by step answer to this question. In 1897, J. J. Thomson announced the discovery and subsequent identification of the first subatomic and negatively charged particle [3], now called electron, present in all the atoms. Ernest Rutherford, in 1911, formulated a model of the atom with a very small positively charged nucleus [4], which contains much of the atom's mass and is orbited by low-mass electrons; and in 1920, he identified and named the proton, in the hydrogen nucleus and as a part of other nuclei. In 1932, James Chadwick discovered the neutron [5], a particle with no electric charge and a mass slightly greater than that of a proton. At the end of 1960's and in the 1970's, several researches (Murray Gell-Mann, George Zweig, Makoto Kobayashi, ToshihideMaskawa, Leon Lederman, etc.) explained why protons and neutrons are not fundamental particles [6]. Inside each proton and neutron, there are three smaller and fundamental particles now called the *up* and *down* quarks.

The second question was related with the total number of elements existing in nature and a possible arrangement of all of them. The number of known elements increased from 13 that were known in antiquity and middle ages up to 45 through the discoveries of the 17th and 18th centuries. A big achievement was made in 1869 when, the Russian chemist Dmitri Ivanovich Mendeleev and German chemist Julius Lothar Meyer, separately proposed closely identical versions on how to group the 63 elements known at that time, based on recurring cyclic characteristics shown by them [7]. Both scientists proposed the periodic law which states that the properties of elements are periodic functions of their atomic masses. For that reason, it was possible to write the list of elements as a table, with columns of elements that share similar attributes. Between 1893 and 1898, Sir William Ramsay, Lord Rayleigh and Morris Travers discovered the inert gases of our terrestrial atmosphere: helium, neon, argon, krypton and xenon. In 1900, Ramsey suggested to add a new group to the periodic table, the group 0, now called the noble gasses group. At the beginning of the 20th century, there were 83 recognized chemical elements. One of the most important advances, concerning the classification of the elements, came up in 1913, due to the English physicist Henry Moseley, based on his experiments on X-ray emission spectra. He observed that the frequencies of X-ray emitted from elements were correlated with the values of their nuclear charges [8], *i.e.* their atomic number [9]. In April 2009, after the successful synthesis of element 117 Tennessine, penultimate element of the 7th period of the periodic table, the number of known elements reached 118. Of these, 26 elements are not found on earth, because of their short half-life, but they were synthesized in nuclear colliders.

The third question is related to the origin of the elements in the periodic table: when and how did they begin to exist? This is the topic of the present publication. The answer did not come from experiments made on any chemical or nuclear laboratory, but from thought experiments, mathematical models solved in the newest supercomputers and specially, from the careful and smart interpretation of the data obtained by observations made with the newest and larger telescopes, some of them based on earth, and others, in orbit around the earth. The most famous of this is the Hubble Space Telescope, HST. It was necessary a series of astrophysical transformations during several billions of years, based on nuclear reactions, of the cosmologically produced light elements, hydrogen and helium, to generate all the chemical elements that are described in the Periodic Table and also conform all the known universe.

2. SYNOPSIS

With the purpose of explaining: the creation or origin of the chemical elements we shall deal with the next 8 issues. The light elements had their origin not in a point or in different places, but in the hole universe, study which is the subject of Cosmology, then in part 1, there will be described the fundamental aspects of cosmology. In part 2, it will be described how the light elements hydrogen, H, and helium, He, had their origin at a very precise moment known as the recombination epoch. In part 3, it will be explained how the elements heavier than helium have their own way to be created. Since these heavy elements have three different astrophysical phenomena that generates three groups of elements; in part 4, it will be explained, how during the hole life of stars, the first group of elements is generated; in part 5, it will be explained how the second group of elements is generated during the short period that marks the dead of a star, referred to, as the time when they go supernovae; and in part 6, it will be explained how the heavier element groups are generated during certain special phenomena that take place at the end of the life cycle of certain binary stars and during the collision of neutron stars. In part 7, it will be explored the relation of the so-called synthetic elements and the astrophysical phenomena. In the last part 8, it is exposed how the vast quantities of some of the elements, produced during the aforementioned processes, clustered and acquired an order, to form planets, stars and galaxies; and at least in one planet, our earth, some chemical elements acquired a surprisingly arrangement to form living beings.

2.1. The Fundamental Aspects of Cosmology

In the nowadays universe, it is not possible to create or manufacture the basic element H, so it must come from the beginning of the universe, from a primordial explosion, also called big bang, that occurred around 13,800 million of years ago. To explain the origin of H and some fraction of He, the lightest elements of the periodic table, it is necessary to use the theoretical explanations and observational facts accumulated by Cosmology. This science is based on the next 2 assumptions:

2.1.1. The Universal Applicability of the Laws of Nature

In order to describe the entire universe, not only from the cosmological, but also from the astronomical point of view, it is made the first assumption, by which it is accepted that the laws of nature, that we know and apply today inside and around the Earth, are universally applied. All previous astronomical observations also point to a general validity of the laws of nature.

2.1.2. The Isotropic Principle

It is assumed that the universe in all locations looks the same in all directions for long distances. This is called the cosmological principle, or spatial homogeneity principle, or the second cosmological assumption, or the isotropy principle, which states that for long distances, the universe, at the same time, looks the same in all points of space and also in all directions. The concept of long distance in Cosmology needs to be clearly defined. When somebody looks at the starry sky with the naked eye, immediately, it can be confirmed that the Universe near the Earth is not homogeneous or isotropic, because there are irregularly distributed stars. On a larger scale, it can be seen that the stars form galaxies. The Milky Way is a medium size spiral galaxy, with an average diameter of 48 Kiloparsecs, equivalent to 1.5×10^{18} Km. Now it is known that the average distance between galaxies is closed to 1 Megaparsec, equivalent to 3.08×10^{19} Km. Most of the galaxies are forming clusters of galaxies. These clusters of galaxies are distributed in a structure similar to a honeycomb consisting of the so-called filaments and holes. When it is used an observational scale of the order of 100 times the distance between galaxies, then no structure can be recognized. This observational scale is the cosmological long distance, of at least 100 Megaparsecs, and it is equivalent to 3.08×10^{21} km or more.

When the Universe homogeneity, at a scale larger than 100 Megaparsecs, is accepted at the same time than, the observed high degree of isotropy of the cosmic background radiation, then it is justified the description of the universe as a whole, by the spatial homogeneity principle, or cosmological principle. As a point of comparison, it is given the radius of the observable Universe, which is equal to, the distance the light has traveled since the big bang = (13.8×10^9 years) (9.4607×10^{12} km/year) = 130.56×10^{21} km = 1.3×10^{23} km (Equivalent to 4220 Megaparsecs). And now it is raised the next question: how is the universe outside the sphere we can observe? Since the universe is very homogeneous and isotropic in the observed sphere, it is reasonable to suppose that it remains so for at least a few orders of magnitude further [10]. And we do not have any idea of what there is after that.

2.2. The Observational Evidence that Explains How the Light Elements H and He of the Universe, Began to Exist

Under the prevailing cosmological description for the development of the Universe, known as the Big Bang, time, space and energy emerged together 13,800 million years ago [11]. This theory describes how the universe expanded from a high-density and high-temperature state, to the now observable Universe. At its earlier proposed periods, the Universe was extremely hot and dense and began to expand and cool down. In less than 10^{-32} seconds, the four fundamental forces (Electromagnetic, strong nuclear, weak nuclear and gravity) were separated from a unified fundamental force, and various types of subatomic particles (mainly the quarks and leptons) were able to form [11]. Everything that we can observe in the baryonic part of the Universe is made of only 4 fundamental particles: up quark, down quark, electron and neutrino. It is probable than only these particles were generated in order to interact with the fundamental forces [12]. During the next milli-second, stable protons and neutrons were formed. In no more than 1 second, the process known as Big Bang Nucleosynthesis took place. About 25% of the protons and all the neutrons were converted to helium nuclei, with traces of lithium nuclei. The other 75% of the protons remained as hydrogen nuclei. After nucleosynthesis ended, the universe was at a temperature of about 10^{13} K and it entered into a period known as the photon epoch. During this epoch the universe contained a plasma of positively charged nuclei, electrons and high energy photons and it went into a process of expansion and cooling down. After 380,000 years from the Big Bang the universe temperature descended to about 3000 K. At this temperature the electrons and nuclei were able to combine and form stable atoms. These atoms were hydrogen, helium and a little bit of lithium.

To explain the observable universe scientists have proposed, and continue to work in the development of some other theories like: 1). The string theory, which is a theoretical framework in which the point-like particles of particle physics can also be modeled as one-dimensional objects called strings, 2). The brane Cosmology, that explains that the visible, three-dimensional universe is restricted to a brane inside a higher-dimensional space, called the "hyperspace" and 3). The M-Theory, which is a theory in physics that unifies all consistent versions of superstring theory. For the moment there is not enough observable evidence to validate any one of them.

On the other hand, the Big Bang theory makes several predictions about the actual state of the universe, and from them, there is observational evidence. Each of these evidences offers a partial proof of the Big Bang theory. The most important predictions are: 1) The Universe expansion, 2) The elements distribution, 3) The cosmic microwave background radiation and 4) The large-scale structure.

2.2.1. The Universe Expansion

By expansion of the universe it is understood the increase of the distance between two macro objects, mainly galaxies or galaxies clusters, with time. Edwin Hubble discovered in 1929 that the distance of galaxies to the Milky Way galaxy is proportional to the recession velocity as measured by their redshifts [13]. Since 1912 Vesto Slipher reported that the spiral galaxies, at distances bigger than 10 Mpc from the Milky

Way galaxy, have considerable red shifts, which was interpreted as a recessional velocity [14]. Slipher's and Hubble's observations are a corroboration of the theoretical work developed by Alexander Friedman in 1922 and George Lemaitre in 1927 [15] that is known as the Friedmann-Lemaître-Robertson-Walker, FLRW, metric. This metric is an exact solution of Einstein's field equations of general relativity and it describes a homogeneous, isotropic and expanding universe [16]. The expansion of the universe confirms the Big Bang theory when it is considered backwards the expansion in time, until a time when the universe should have been at a point where the density of matter and energy tend to infinity.

2.2.2. The Elements Distribution

Observations with measurements on the frequency of the elements shows that 99% of the baryonic mass of the universe has the distribution of, about 3/4 of the universe atoms are hydrogen atoms, and the remaining 1/4 arehelium atoms. This relative abundance was correctly explained by the Alpher-Bethe-Gamow theory [17] about the formation of hydrogen and helium in the nucleosynthesis that took place during the first second after the big bang.

2.2.3. The Cosmic Microwave Background Radiation

In 1964 Arno Penzias and Robert Wilson discovered by accident the cosmic microwave background, CMB, radiation, when they were experimenting with a supersensitive, 6-meter horn antenna originally built to detect radio waves bounced off Echo balloon satellites. By the joint work with theoretical Astrophysicists at Princeton University: Robert H. Dicke, Jim Peebles, and David Wilkinson, it was possible to confirm the existence of the oldest electromagnetic radiation in the universe, dating to the epoch of recombination. Penzias and Wilson earned the 1978 Nobel Prize in Physics.

The CMB is considered an electromagnetic radiation, remnant from an early stage of the universe, before the formation of stars and planets. It was formed after 380,000 years from the Big Bang, when the universe temperature descended up to about 3000 K, and the protons and helium nuclei could combine with electrons to form neutral hydrogen and helium atoms [18]. This period of time is referred as **the recombination epoch** and the event shortly afterwards when photons started to travel freely through space rather than constantly being scattered by electrons, protons and helium nuclei, as in the previously existent plasma, is referred to as **photon decoupling**. By this time universe became transparent instead of being an opaque fog.

Jim Peebles, who continued working not only in the CMB, but also in the description of Cosmological concepts like the black mater and energy, was also awarded the 2019 Nobel Prize in Physics, "for theoretical discoveries in physical cosmology".

2.2.4. The Large-Scale Structure

After the decoupling of radiation, the matter of the Universe was more strongly influenced by gravity. After 1 million years of the Big Bang, large-scale structures were formed in the cosmos, with a honeycomb shape of holes and filaments and smaller structures, such as galaxies. It is calculated that dark matter also participated in these formations, although it is currently unknown what type of particle(s) forms the dark matter. Collapsed gas clouds became into much more massive stars than our sun. In the nucleus of these stars, heavy elements such as carbon, oxygen and iron were soon produced by nuclear fusion. To exceed the nuclear repulsive forces for fusion the relation between kinetic energy and temperature $1/2mv^2 = 3/2k_bT$, given by the equipartition theorem, was fulfilled. The lifespan of these stars was relatively short, only 3 to 10 million years, and then exploded as supernovae. The clouds of gas enriched with metal cooled faster, and under the explosion pressure, they condensed the adjacent gas clouds to form new stars, with a lower luminosity, but a longer useful life. Subsequently, the first globular clusters of these stars were formed, then the first galaxies of their precursors. The galaxies formed clusters which are distributed in a structure similar to a honeycomb consisting of the so-called filaments and holes, that constitute the universe structure at a large scale.

From the concepts exposed in this issue about the light elements of the universe, it may be concluded that everything started from the Big Bang where the temperature was higher than the so-called Plank temperature of 1.4×10^{32} K, and immediately the Universe began to cool down till, after 380,000 years, it reached a temperature of about 3000 K, when the universe formed elemental atoms. Hydrogen, helium and lithium are the three elements now recognized as the only ones that have a cosmological origin. From the practical point of view, it is possible to assure that all the hydrogen atoms, that now exists in the Universe, were formed during the recombination epoch. Helium and lithium have not only a cosmological origin, but also an astrophysical origin as will be explained in what follows.

2.3. How and When Did the Chemical Elements, with Atomic Number Larger than 2, Began to form by Astrophysical Processes

Before decoupling, the entire universe consisted of a plasma of protons, helium nuclei, electrons and radiation in the form of ultra-high frequency light, with a high interaction with the first three components of the plasma. After decoupling, the electrons were confined to their corresponding space around their respective nuclei to form atoms. Instead, the high-energy electromagnetic radiation stayed there, traveling freely through space.

This electromagnetic radiation can still be measured today as cosmic microwave background radiation, CMB. However, due to the expansion of the universe it is now a radiation of much longer wavelength, and corresponds to a temperature of 2.73 K. **Figure 1** has a representation in time of the CMB radiation.

A lot of information can be extracted from the study of the CMB radiation. Three satellites have been used for this study: 1) The Cosmic Background Explorer, COBE, which operated from 1989 to 1993. From its measurements were obtained two key pieces of evidence that supported the Big Bang theory of the universe: a). that the CMB has a near-perfect black-body spectrum, and b). that it has very faint anisotropies, 2) The Wilkinson Microwave Anisotropy Probe, WMAP, which was launched by NASA with the mission of measuring the temperature differences observed in the CMB, the remnants of the Big Bang. It operated from 2001 to 2010, and 3) The Planck spacecraft that was a space observatory operated by the European Space Agency, ESA, from 2009 to 2013, which mapped the anisotropies of the CMB, at microwave and infra-red frequencies, with high sensitivity and small angular resolution.

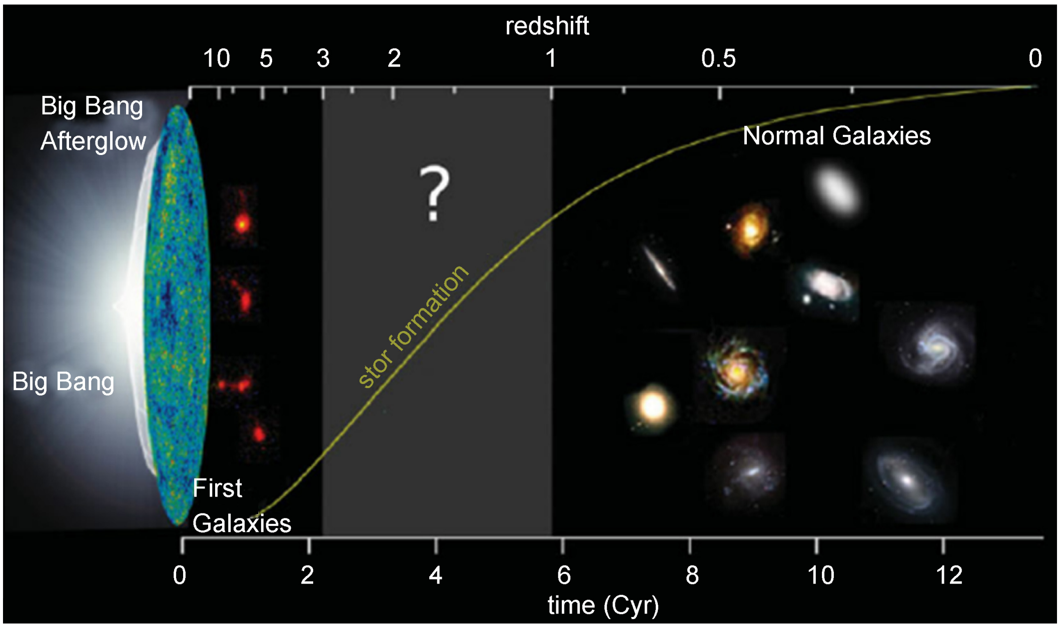

Figure 1. A summary of the evolution of the universe with the cosmic microwave background.

From the expansion rate of the universe it is possible to calculate the elapsed time, already mentioned above, in which the photon decoupling occurred. If it is assumed that the scale factor of the universe, *a*, is proportional to the universe temperature, *t*, and the temperature since the decoupling time has fallen down from 3000 K to 2.73 K. This means that the universe scale factor must have increased by a factor of 1098.9. For the matter dominated universe, that exists after the decoupling time, it is possible to deduce [19], from the FLRW equation, that the scale factor *a* can be expressed as:

$$a = ct^{2/3} \tag{1}$$

where *c* is a constant and *t* is the time. From them it is established the next equation:

$$1098.9 = \left(ct_t^{2/3}\right) / \left(ct_i^{2/3}\right) \tag{2}$$

where t_t is the time of today, equal to 1.38 × 10^{10} years.

And t_i is the time when the ionization occurred, to be calculated as:

$$t_i = t_t / 1098.9^{3/2} \tag{3}$$

$$t_i = 1.38 \times 10^{10} / 36428 = 3.788 \times 10^5 \approx 380000 \text{ years} \left(\text{After the big bang}\right) \tag{4}$$

After 1 million years of the Big Bang, collapsed gas clouds condensed to form the first stars. These were fundamentally much more massive than our sun, so they became very hot and generated high pressures [20]. Inside those stars, by nuclear reactions, heavier elements such as carbon, oxygen and iron ware produced. Due to their great mass, the lifespan of these stars was relatively short, in the range of 3 - 10 million years, and after that lifespan, they exploded as a supernova. During the explosion, the capture of neutrons produced heavier elements than iron, mainly of atomic number in the range of 27 to 40, and reached the interstellar space. Explosion pressure condensed adjacent gas clouds, which could produce new stars faster. As clouds of gas enriched with metal cooled faster, stars with less mass formed, with a lower luminosity, but with a longer lifespan. The first globular clusters of these stars were formed, and finally the first galaxies of their precursors.

2.4. When and How Did the Stars Clustered into Galaxies?

In the earliest stages of the universe, tiny fluctuations within the Universe's density led to concentrations of dark matter that was gradually forming. The existing atoms were attracted to them by gravity, producing large gas clouds and eventually, stars and galaxies. After around 100 - 300 million years, the first stars formed [21]. These were probably very massive, luminous, nonmetallic and short-lived. They were responsible for seeding the universe with elements heavier than helium, through stellar nucleosynthesis. As remnants of these massive, short lived stars, black holes were formed. By the merging of two or more of them huge black holes were formed, that in turn, through gravity pulled together several clusters of stars to form each of the new galaxies.

2.5. What Is the Cycle of the Nuclear Reaction Process that Is Happening Inside the Stars?

From Particle Physics we can say that nature only makes use of four fundamental particles: Up quark, **u**, down quark, **d**, electron, **e-**, and neutrino, **ν**. Even though to configure matter these particles must interact with the fundamental particles called bosons, they are the next six:

γ	Photon
g	Gluon (eight different types)
Z	Neutral weak boson
$W^{+/-}$	Charged weak bosons
H	Higgs boson
G	Graviton. A hypothetical force-carrier of quantum gravity.

When an amount of mass accumulates, composed mainly of nuclei of H and He, with a magnitude in the range of 0.2 and 50 or more solar masses, $M_\odot$, is accumulated, a star is formed. Through gravity the temperature, density and pressure of the star center increases up to a high enough degree that a series of nuclear reactions starts. In the case of the Sun, its core has a temperature of 15 million K, a density of 150 g/cm^3, and a pressure of 2.65×10^{11} atmospheres [22].

Each **H** nucleus, or proton, **P**, contains 2 **up** quarks and 1 **down** quark. At a star conditions of temperature and pressure it is possible to convert one of its **up** quarks to a **down** quark, see **Figure 2**, and a neutron, **N**, is formed.

At the core of a star there are happening several nuclear reactions, but during most of the star life, with the newly formed neutrons, **N**, the principal nuclear reaction is the formation of helium nuclei:

$$2\text{P} + 2\text{N} \rightarrow \text{He nucleus} + \text{Energy} \tag{5}$$

The difference in mass for each He nucleus formed, in Equation (5), between the reactants ($2 \times 1.6726 + 2 \times 1.6749 = 6.6950) \times 10^{-27}$ kg, and the mass of the product, the He nucleus (6.6463×10^{-27} kg), that is equal to (0.0487×10^{-27} kg), is converted into energy, in accordance with the famous Einstein equation:

$$\begin{aligned} E = mc^2 &= 0.0487 \times 10^{-27}\,\text{kg} \times \left(3 \times 10^8\,\text{m/s}\right)^2 \\ &= 4.383 \times 10^{-12}\,\text{kg} \cdot \text{m}^2/\text{s}^2\,[=]\,\text{Joules} \end{aligned} \tag{6}$$

Based on the Sun luminosity, $L_\odot$, of 3.90×10^{26} Watts [=] Joules/s, that Freedman *et al.* [9] reports, it is possible to calculate the amount of He nuclei that are formed in each second:

$$\left(3.862 \times 10^{26}\,\text{Joules/s}\right) / \left(4.383 \times 10^{-12}\,\text{Joules/He nucleus}\right) = 8.898 \times 10^{37}\,\text{He nuclei/s} \tag{7}$$

The mass of the Sun that is converted to helium nuclei is:

$$\begin{aligned} &\left(8.889 \times 10^{37}\,\text{He atoms/s}\right)\left(4\,\text{g/mole}\right) / \left(6.022 \times 10^{23}\,\text{atoms/mole}\right) \\ &= 5.910 \times 10^{14}\,\text{g/s} = 5.91 \times 10^{11}\,\text{kg/s} = 5.91 \times 10^{8}\,\text{Ton/s} \end{aligned} \tag{8}$$

From Equation (8) it is possible to say that in the Sun core, each second, around 600 million tons of H nuclei are being converted into He nuclei. It is also calculated that when about 10% of the star hydrogen

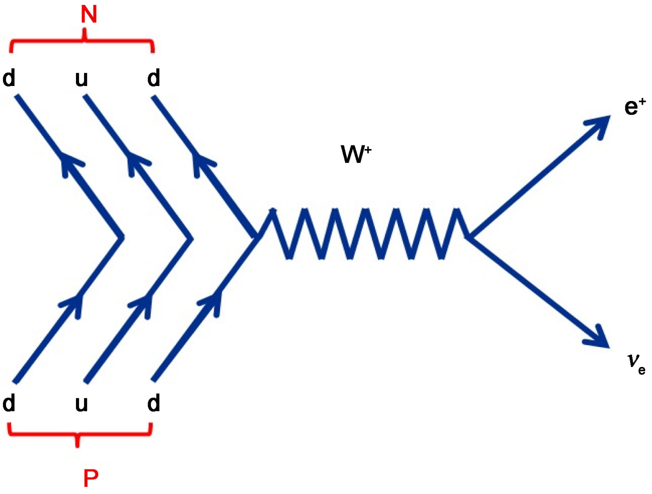

Figure 2. A Feynman diagram to show how a proton, P, is converted to a neutron, N, with the emission of a W^+ boson, which immediately decomposes into a positron e^+ and a neutrino electron, ν_e.

atoms, precisely those located at the core, are converted into helium atoms, then the star begins to contract, and several other changes occur, that conducts rapidly the star to its dying. In the case of the Sun, with a mass of 2×10^{30} kg, it is possible to calculate what is the time needed to burn 10% of its mass, based on the rate of helium formation.

$$(0.1)\left(2\times10^{30}\,\text{kg}\right)/\left(5.91\times10^{11}\,\text{kg/s}\right)=3.384\times10^{17}\,\text{s} \tag{9}$$

Since the seconds in one year are:

$$(365.25\,\text{day/year})(24\,\text{hour/day})(3600\,\text{s/hour})=3.156\times10^{7}\,\text{s/year} \tag{10}$$

Then the life span of the Sun is calculated as:

$$\left(3.384\times10^{17}\,\text{s}\right)/\left(3.156\times10^{7}\,\text{s/year}\right)=1.072\times10^{10}\,\text{years}\approx10000\,\text{million years} \tag{11}$$

The Sun has been shining for about 5000 million years, it will stop shining in about 5000 million years more. In Table 1 it is shown some of the typical nuclear reactions that occur in the core of a 10 $M_\odot$star. Note that for a star ten times bigger than the Sun the time periods are relatively smaller than those for the Sun. For example, the stage of helium formation in a 10 $M_\odot$ star is of only 10 million years vs the 10,000 million years of the Sun.

As more massive the star is, the speed of the nuclear reactions is faster, but the life, or nuclear reactions cycle time, is smaller. Table 2 shows the lifetime of stars as a function of its mass, in solar masses, $M_\odot$.

A medium size star, like the Sun spends about 10,000 million years converting, protons into helium nuclei at its core, at a nuclear reaction temperature of 15 million K. When the protons at the star core are finished the star collapses to increase the temperature, in order to make possible the nuclear reactions of helium nuclei to produce carbon, oxygen, nitrogen and other elements nuclei up to atomic weight of the iron, ^{26}Fe. When the helium nuclei are finished the star expands and become a red giant and expels the outer layers in order to become a white dwarf, which after several million years of being cooling down it becomes a black dwarf.

For stars heavier than the Sun, up to 3 $M_\odot$ when the hydrogen nuclei have been depleted, it continues making all the elements from helium to iron nuclei. When the helium nuclei are depleted the star collapses, but then it bounces off. It results in the most cataclysmic of all the explosions. The star in this process is called supernova. During this explosion elements with atomic number from 14 up to 40 are generated. The elements formed go off as dust with hydrogen, that later on can form a new star and its planets.

Table 1. Nuclear reaction process for a star with a mass of 10 $M_\odot$.

Fuel	Main products	Secondary products	Core Temperature (1000 K)	Duration (years)
Hydrogen	He	N	30	10,000,000
Helium	C, O	O, Ne	200	1,000,000
Carbon	Ne, Mg	Na	800	1000
Neon	O, Mg	Al, P	1500	3
Oxygen	Si, S	Cl, Ar, K, Ca	2000	8 months
Silicon	Fe	Ti, V, Cr, Mn, Cu, Ni	3500	1 week

$M_\odot$ = Mass of the sun = 1.9891×10^{30} kg (About 2×10^{30} kg = $2 \times (10^6)^5$ kg).

Table 2. **Mass vs life (Nuclear reactions cycle time) of stars.**

Classification	Type	$M_\odot$	Life, Millions of years
O	O5	40	1
B	B0	17	10
B	B5	7	100
A	A5	2.2	1000
G	G0	1.2	10,000
G	G2	1	12,000
K	K0	0.8	20,000
M	MO	0.5	75,000
M	M5	0.2	200,000

2.6. How Many More Elements Are Formed at the End of the Life Cycle of Certain Binary Stars and in a Collision of Neutron Stars?

It is very common for the stars, to form binary systems (two stars orbiting each other). Here, two of the most important end-of-life processes for stars are described. One of them gives rise to what is called the 1A supernova explosion and the other is the neutron stars collision.

When a star with 3 to 7 $M_\odot$ ends its life, goes supernova, forms a planetary nebula and by drifting away the outer nebula layers, what is left is a white dwarf, with a mass comparable to that of the Sun, while its volume is comparable to that of Earth. If the white dwarf occurs in a binary system it can accrete mass from the binary companion. When this star reaches the so-called Chandrasekhar limit of 1.44 $M_\odot$, it explodes [23]. During this explosion, elements with atomic number from 14 up to rubidium, ^{37}Rb are generated.

When the binary system stars have a size between 8 to 20 $M_\odot$ they will have a lifespan of 80 to 8 million years, and then they will go supernova, liberating the elements they have formed, from helium up to iron, and since the explosion is a highly exothermic process, they also synthesize new elements up to rubidium, ^{37}Rb. A neutron star is left from each star, with masses between 1.1 and 1.6 $M_\odot$, and a diameter of about 10 km. They continue to orbit each around the other. After a few million years, they collapse to form a black hole, liberating a huge amount of energy, and expelling about 3% of their mass as heavy elements, with atomic number between 38 and may be 118 or bigger. This is exactly what was detected on August 17, 2017, and it was reported by the researches from the Laser Interferometer Gravitational-wave Observatory, LIGO, by detecting the ripple of gravitational waves passing through the Earth [24]. In a fraction of a second the mass of the Earth in precious elements was generated. Just the amount of gold in there, was equivalent to the mass of the Moon.

Even though the above described processes with binary systems are the most important for generating and liberating all the natural elements of the periodic table, most of the single stars, independent from their mass, when they go to the highly exothermic process called supernova, they liberate the elements that have been formed during their lives and also generate different, even though small amounts of, heavy elements. See the yellow marked elements of **Figure 3**. Along many years of observations there exist in the literature a number of quantitative astronomical reports that indicate the formation of elements in Supernova events (e.g. McCaray 1993, Fesen & Well 2020).

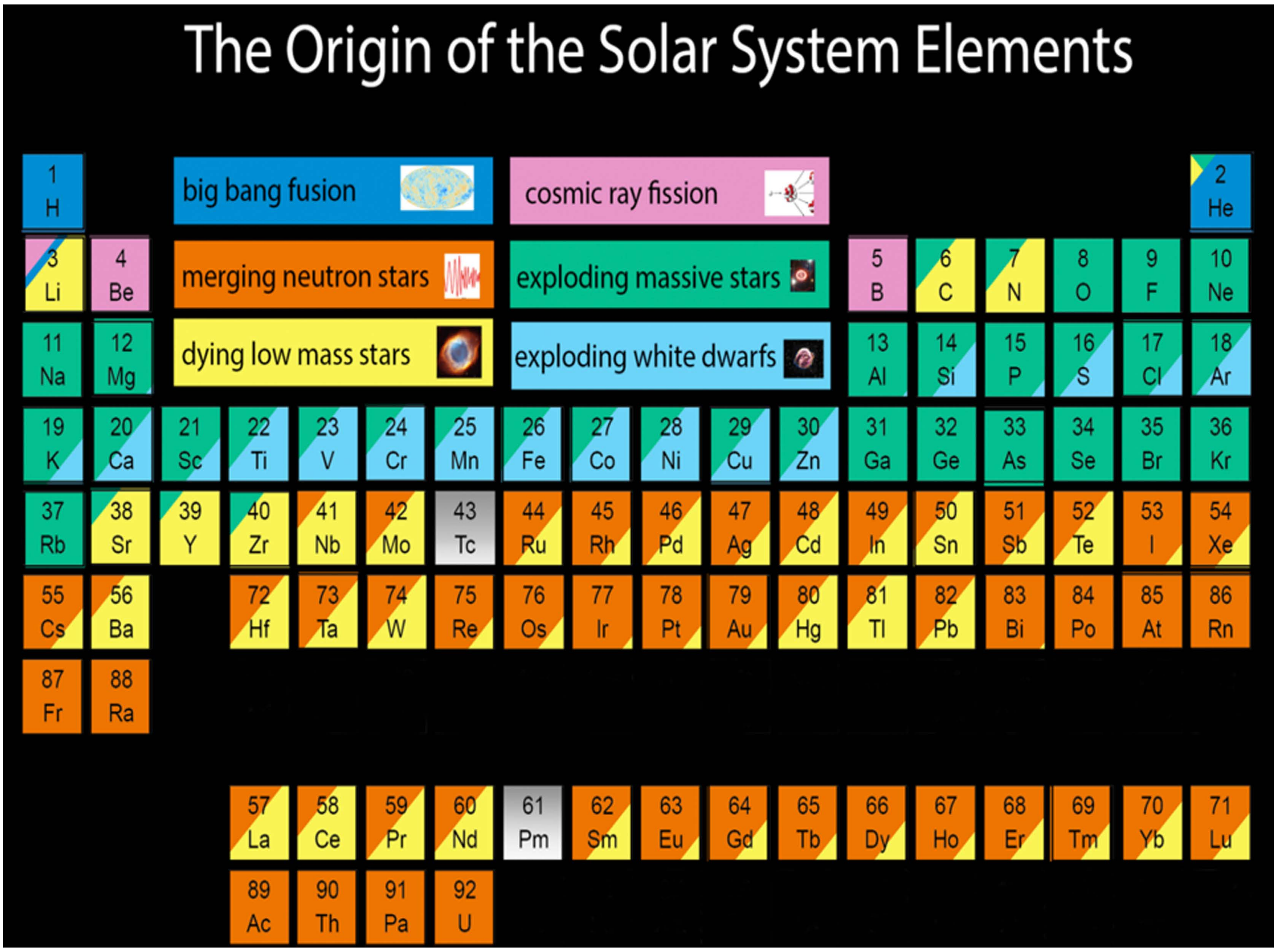

Figure 3. It is shown the origin of the 90 chemical elements, found in earth [25].

2.7. The Synthetic Elements and the Astrophysical Phenomena

The actual periodic table shows 26 synthetic elements that do not occur naturally on Earth. These are the elements with atomic numbers 95 - 118, along with technetium, Tc, and promethium, Pm, with atomic numbers 43 and 61 [26]. They all are now produced by nuclear fusion in particle accelerators, or by decay of other radioactive elements isotopes. In the case of Tc and Pm, it has been demonstrated that the elements are and were produced by the normal nuclear reactions of stars, but since, their most stable isotopes have a relatively short half-life of 4.21 million years and 17.7 years [27] [28] respectively, by the time scientist are trying to detect them on the earth, there are almost no traces left. After the detection of the neutron star crash it is accepted that all the now called synthetic elements were also produced in that event, but they are not detectable on the earth because of their short half-lives [29].

Scientists have been trying to synthetize heavier elements to study their periodicity and other properties. The next element to be synthetized, the number 119, should be like the elements of the 1st. group (Li, Na, …). But it seems that, due to relativistic effects the "periodic" table is no longer periodic, its periodicity is lost from element 116 and above [30]. For example, element 118 would no longer be a noble gas but a solid. It would be interesting to know what comes next in the field of heavy element research.

2.8. The Arrangement of Chemical Elements into Planets, Stars and Galaxies and the Chemical Arrangement of Them into Living Creatures

It took to the Universe 0.00038 billion years to build all the hydrogen and helium that is possible to detect in the observable Universe, whose composition is shown in the first column of Table 3. During the next 7.8 billion years stars appeared, and produced heavy elements by nuclear reactions, which ended, partially as clouds on non-reacted hydrogen and, as black dwarfs, neutron stars or black holes. The black holes became, or were located at, the center of the primary arrangement or unit of the Universe, the so-called galaxies. The newly formed clouds of hydrogen and heavy elements formed new stars, that in the presence of heavy elements formed their own planetary system. As a part of the Milky Way galaxy, 6 billion years ago it was formed the star called Sun: Sometime later, 4.6 billion years ago, the planet Earth formed, which is composed mainly of iron, oxygen, silicon and magnesium, see the second column of Table 3. It has a composition completely different than the surrounding Universe.

Table 3. **Chemical composition of the Universe, the earth and the human body.**

The Universe, Wt. %	Bulk Earth, Wt. %	Human body, Wt. %
H, 73%	Fe, 32.1	O, 65.0
He, 25%	O, 30.1	C, 18.5
O, 0.80%	Si, 15.1	H, 9.5
C, 0.36%	Mg, 13.9	N, 3.2
Fe, 0.16%	S, 2.9	Ca, 1.5
Ne, 0.12%	Ni, 1.8	P, 1.0
N, 0.09%	Ca, 1.5	K, 0.4
Si, 0.07%	Al, 1.4	S, 0.3
Mg, 0.05%		Na, 0.2
S, 0.04%	H, 0.01	Cl, 0.2
o.c., 0.04	o.c., 1.2	o.c., 1.0

o.c. = Others combined.

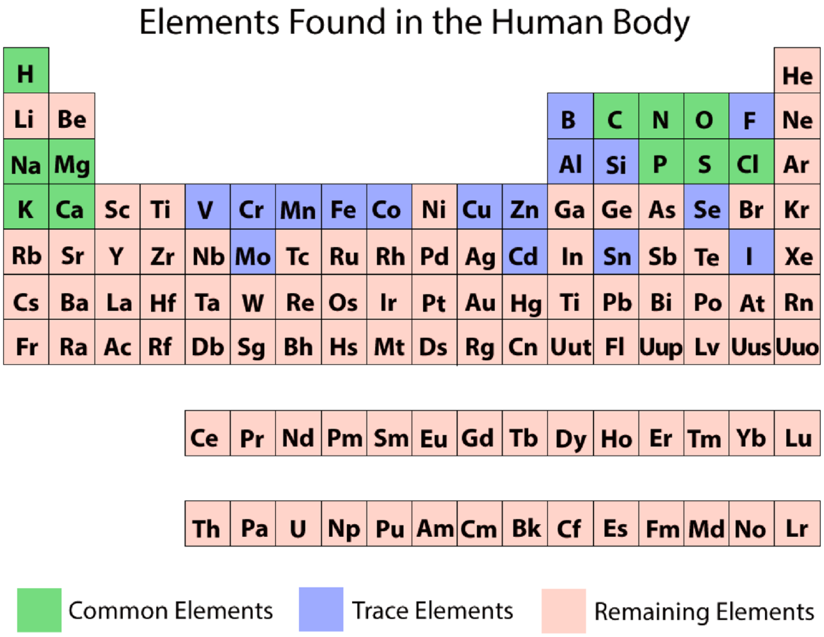

Figure 4. **Elements found in the Human Body.**

The most astonishing and marvelous fact, around the chemical elements, is the transformation and/or arrangement of a few of them in the Earth. In the last 4.6 billion years the elements carbon, hydrogen, oxygen, nitrogen, and a small percentage of some others participated in a transformation in order to produce and/or generate the so-called living beings. See in the third column of **Table 3** the list of those special elements. It seems that there was an evolution in time of the simplest or elementary of the living beings, into the most sophisticated of them, and all the way up until the last 0.0001 of a billion years that a perfected and especially self-conscious being appeared *i.e.* ourselves, the human beings. In **Figure 4** are shown in green color the few elements that were used to form the living beings.

3. DISCUSSION

The Milky Way began as one or several small over densities in the mass distribution in the Universe, shortly after the Big Bang. There have been at least two or three generations of stars. The Sun may be a third-generation star that was formed 6000 million years ago [31], and its planet Earth 1400 million years later, when and where there were debris of different stars that went supernova, specially of the type 1A, and also debris of at least one of a binary neutron star collision, in order to have all the elements, including the heavy ones, needed to form the so called terrestrial planets. Planet Earth is composed mainly of Fe, Si, Ni, O, S, Mg, Ca and Al, but it contains another 82 chemical elements in concentrations smaller to 1%, or even in such a small amount that it is described as traces. All the 90 elements that have been identified in the chemical laboratories come from the primarily and secondary stars that left their debris to be allocated as part of something else in a new star and its planetary system. During the 4600 million years that the earth has existed there has been an astonishing arrangement or evolution of some inert elements into ordered living structures, and especially conscious beings, *i.e.* the humans.

4. CONCLUSIONS

The cosmological building blocks are the galaxies, made of stars whirling around a black hole. Stars are made of hydrogen and helium produced at the big bang. The earth and the living beings are stars debris, or stars dust, organized in an incredibly good and delicate order.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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