Structure Formation, Evolution and Fate of the Expanding Universe

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Abstract – The cosmological principle predicts that the universe could have begun from a dense sea of black holes which decayed into matter which lead to formation of structure in the universe and radiation which expanded space and created the conditions for the observable universe. What are these early objects of matter formed and how were they formed? What gave rise to the structure of universe in the form of stars, galaxies and clusters of galaxies? What constitutes the invisible matter and how can the existence of this dark matter be confirmed? What is this dark energy and how can its existence be confirmed? While the radiation filled universe is expanding what is the effect of dark matter and dark energy on the expansion of universe? Will the universe expand forever? What could be the fate of the universe? This research paper attempts to present answers to these questions.

Keywords: Black holes, Dark Matter, Dark Energy, Gravity, Cosmic Microwave Background, Big Bang Nucleosynthesis, Cosmological Constant, Stellar evolution, Fragmenting Universe scenario, Big Crunch.

I. INTRODUCTION

Primordial black holes decayed into large number of photons and radiation which filled the universe. As the universe expanded matter began to form in the low density regions and small quantum fluctuations in the matter gave rise to formation of early objects in these regions. The early objects formed gave rise to gradual increase in the matter density in these regions [7][8][9].

The geometry and course of expansion of universe is determined by the fractional density of the different types of matter in the universe. Cosmologists classify types of matter by the relationship between its pressure and energy density into visible matter or baryonic matter, dark matter or non-baryonic matter, dark energy and radiation [4][5].

II. DARK MATTER AND DARK ENERGY

Observable universe consists of about 70% of dark energy, 25% of dark matter and 5% of visible matter [5]. The dark energy is distributed evenly in the universe and leads to a repulsive force which accelerates the expansion of universe as confirmed by the observations based on the Hubble Law. The measurements from these observations give the rate of expansion of the universe and its acceleration and provide the estimate of how much of this mysterious dark energy is present in the universe [5][14].

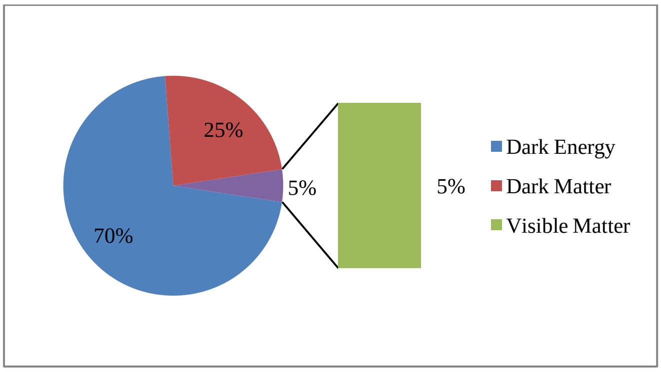

Figure-1: Composition of Universe.

The dark matter does not absorb, reflect or emit light, making it invisible. The existence of dark matter is confirmed only from the gravitational effect it seems to have on visible matter. Galaxies in our universe are rotating with speeds that the gravity generated by their visible matter could not possibly hold them together which explains that something invisible is giving these galaxies additional mass, generating the gravity they need to hold them together. This invisible matter is what is called as dark matter. The visible matter also referred as baryonic matter is ordinary matter composed primarily of protons, neutrons and electrons. While radiation, is composed of massless or nearly massless particles, such as photons and neutrinos that move at the speed of light.[5] [11]

III. PRIMORDIAL BLACK HOLE PARTICLES

The smaller black holes formed by the density fluctuations of the early universe being at higher temperature would radiate more than they absorb. They would eventually decrease in mass, get hotter and radiate faster. The quantum mechanical effects cause black holes to create and emit particles. As the temperature will rise more than the rest mass of the particles, it causes the black holes emits those particles. When the temperature got up to 10^{12} ^{o}K or when the mass of the black hole got down to 10^{14} grams the number of different species of particles emitted will be very high that cause the black hole to radiate away all its rest mass on a strong interaction time scale of 10^{-23} seconds. This emission would produce an explosion with energy of 10^{35} ergs. Even if the number of species of particles emitted is did not increase very much the black hole would radiate away all its mass of the order of 10^{-28} M^3s. [1]

The larger black holes will decay in lesser rate. The gravitational field of the black holes causes the black holes to create and emit particles to infinity at the rate that one would expect if the black hole was an ordinary body with temperature in geometric units of $k/2\pi$, were k is the surface gravity of the black hole. In ordinary units, this temperature is of the order 10^{26} M^{-1} ^{o}K, were M is the mass, in grams, of the black hole. For black holes of solar mass this temperature is much less than 3 ^{o}K temperature of the cosmic microwave background. Thus, the black holes of this size will absorb radiation much faster than it can emit and would increase in mass. [1]

According to the first law of thermodynamics, classically, two neighboring black hole equilibrium states are related by the equation:

$$dM = k/8\pi \, dA + \Omega \, dJ \qquad (1)$$

where M, Ω and J are the mass, angular velocity and angular momentum of the black hole, A is area of event horizon. [1]

According to the second law of thermodynamics, classically, the area of the event horizon can never decrease and that when two black holes collide and merge together the area of the final event horizon is greater than the sum of the event horizons of the original black holes. [1]

As the mass of the black hole decreases, the area of the event horizon would have to go down violating the second law of thermodynamics. This violation must presumably be caused by a flux of negative energy across the event horizon which balances the positive energy flux emitted to infinity. Thus, outside the event horizon there will be virtual pairs of particles, one with positive energy and one with negative energy. The negative particle is in the region which is classically forbidden but can tunnel through the event horizon to the region inside the black hole where it can exist as a real particle though with negative energy. The other particle of the virtual pair having positive energy can escape to infinity where it constitutes a part of thermal emission described above as the radiation from black hole. [1]

IV. STRUCTURE FORMATION IN UNIVERSE

The early universe was hot and dense as a cosmic nuclear reactor expanding and cooling very rapidly as a result the universe was filled with a sea of neutrons, protons, electrons, positrons, photons and neutrinos. As the universe cooled, the neutrons either decayed into protons and electrons or combined with protons to make deuterium, most of the deuterium combined to make helium. Trace amounts of lithium were also produced within about 3 minutes of the Big Bang. This process of light element formation in the early universe is called "Big Bang nucleosynthesis", BBN. [2][3]

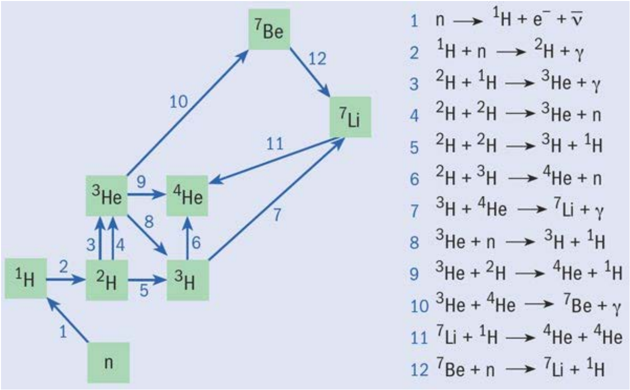

Figure-2: Nuclear Reactions – www.physicsworld.com

The primordial yields of light elements are determined by the competition between the expansion rate of the Universe (the Hubble parameter H) and the rates of the weak and nuclear reactions. It is the weak interaction, inter-converting neutrons and protons, that largely determines the amount of ^{4}He which may be synthesized, while detailed nuclear reaction rates regulate the production (and destruction) of the other light elements. The ^{4}He abundance is very sensitive to the early expansion rate while the abundances of the other light nuclides depend mainly on the nuclear reaction rates which scale with the nucleon (baryon) density. [2]

In the standard model of cosmology the early expansion rate is fixed by the total energy density ρ,

$$H^2 = 8\pi G\rho/3 \qquad (2)$$

where G is Newton's gravitational constant. In the standard model of particle physics the early energy density is dominated by the lightest relativistic particles,

$$\rho = \rho_\gamma + \rho_e + N_\nu \, \rho_\nu \qquad (3)$$

where, ρ_γ, ρ_e, and ρ_ν are energy densities in photons, electrons and positrons respectively, N_ν is the number of massless neutrino species. [2]

"In Standard model BBN (i.e., N = 3) the abundances of the light nuclides synthesized primordially depend on only one free parameter, η. SBBN is thus 'overconstrained' once one value (or, a narrow range of values set by the observational and theoretical reaction rate uncertainties) of η must account consistently for the primordial abundances of D, ^{3}He, ^{4}He and ^{7}Li. At the same time this value/range of η must be consistent with current estimates of (or, bounds to) the present baryon density. For these reasons BBN is one of the key pillars supporting the edifice of the standard model of cosmology and, is the only one which offers a glimpse of the earliest evolution of the Universe”. [2]

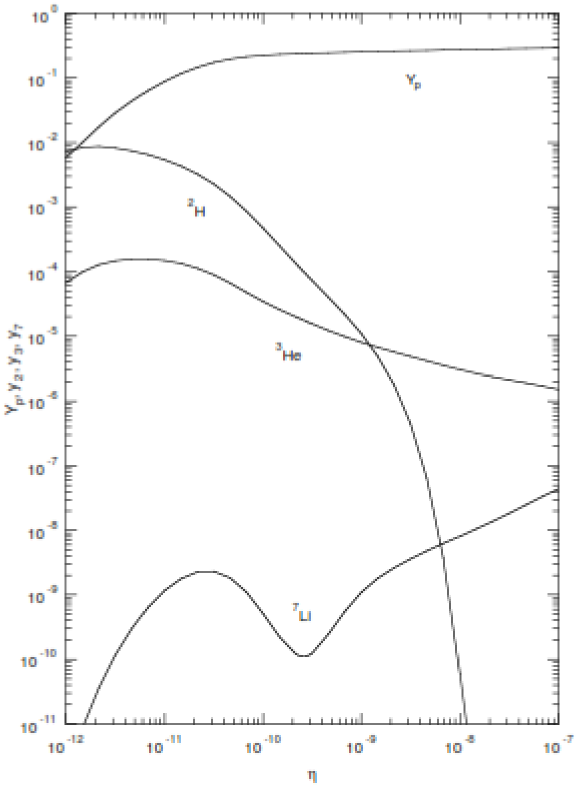

Figure-3: The predicted primordial abundances as a function of η. Y_P is the ^{4}He mass fraction while y_{2P}, y_{3P}, and y_{7P} are the number density ratios to hydrogen of D, ^{3}He, and ^{4}He respectively. [2]

The light elements synthesised from the sea of particles as the temperature of the universe cooled result in interstellar gas further undergo chemical evolution leading to stellar structure formation. Further nucleosynthesis in the star cores result in stellar explosions and star reminants. Elements heavier than lithium are all synthesized in stars. Carbon-based life is composed of stardust. During the late stages of stellar evolution, massive stars burn helium to carbon, oxygen, silicon, sulphur, and iron. Elements heavier than iron are produced in the outer envelopes of super-giant stars and in the explosion of supernovae. [3]

Most cosmologists believe that the galaxies that we observe today grew from the gravitational pull of small fluctuations in the nearly-uniform density of the early universe. These fluctuations leave an imprint in the cosmic microwave background radiation in the form of temperature fluctuations from point to point across the sky. Astronomers observe considerable structure in the universe, from stars to galaxies to clusters and super clusters of galaxies. [12]

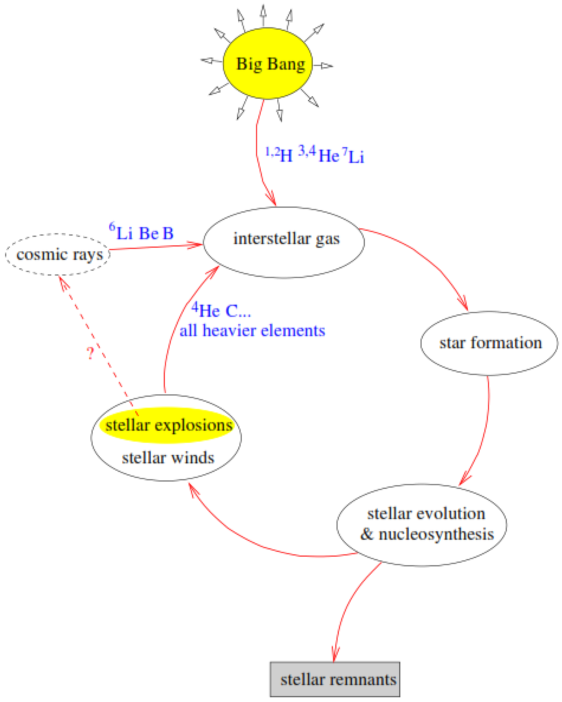

Figure-4: Schematic depiction of cosmic chemical evolution and recycling of elements. [3]

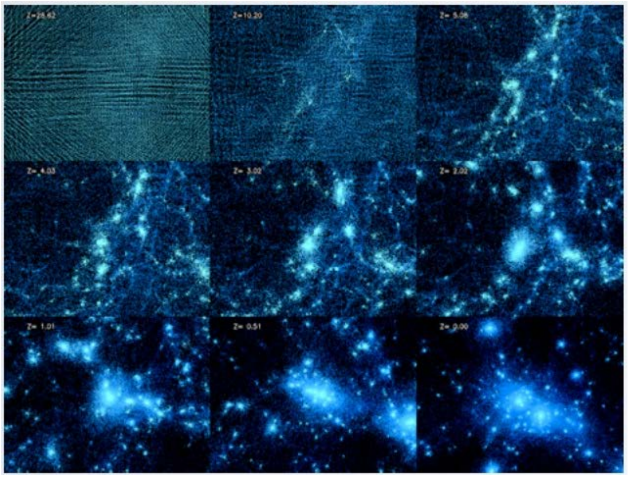

Figure-5: The observed structures of the universe forming from the growth and collapse of initial small density fluctuations. – www.physicsworld.com

While the Big Bang theory accounts for the existence of the cosmic microwave background radiation and explain the origin of the light elements, it does not explain the existence of galaxies and large-scale structure. [3]

V. EFFECT OF DARK MATTER AND DARK ENERGY ON EXPANSION OF UNIVERSE

The fate of the universe is determined by a struggle between the momentum of expansion and the pull of gravity. The rate of expansion is expressed by the Hubble Constant, H, while the strength of gravity depends on the density and pressure of the matter in the universe. If the pressure of the matter is low, as is the case with most forms of matter which are known, then the fate of the universe is governed by the density. If the density of the universe is less than the 'critical density', which is proportional to the square of the Hubble constant, then the universe will expand forever due to lack of enough gravity. If the density of the universe is greater than the 'critical density', then gravity will eventually win and the universe will collapse back on itself, which is called as the 'Big Crunch'. In this universe, there is sufficient mass in the universe to slow the expansion to a stop, and then eventually reverse it. So the cosmologists present two possible fates of the universe: Endless expansion and Big Crunch. [15]

However, the astronomical observations of distant supernova have suggested that the expansion of the universe is actually accelerating, which implies the existence of a form of matter with a strong negative pressure, such as the cosmological constant. This mysterious form of matter is referred to as 'dark energy' which plays a significant role in the evolution and expansion of the universe. Then in all possibility the universe will continue to expand forever since the fate of the universe is governed by the pressure of 'dark energy'. [15]

VI. FATE OF UNIVERSE

There is a growing consensus among cosmologists that the total density of matter is equal to the critical density, so that the universe is spatially flat. And as the universe is expanding with the rate of expansion expressed by the Hubble Constant, its volume is increasing while the total mass is constant so its density is decreasing. When the density of the universe becomes less than the 'critical density', which is proportional to the square of the Hubble constant, then the universe, will expand forever. [15]

According to a scenario of fragmenting universe presented by Lauris Baum and Paul Frampton, the universe is expanding faster and faster diluting matter and radiation, eventually moving each patch of the universe containing matter away from other regions resulting in 'Big Rip'. In this scenario each patch is cut off from the others and become smaller universes. At this point each of these small universes begin at the inflationary phase, and with low entropy as the entropy produced is divided among each of the several new universes spawned from the fragmentation of the old universe. [13]

Considering this scenario, each of these several small universes will have the matter and radiation distributed and the evolution of these universes is determined by a struggle between their momentum of expansion and the gravity. This struggle will give rise to the two possible fates of either 'endless expansion' or 'big crunch' and due to the presence of 'dark energy' the whole process will repeat itself, resulting in innumerable expanding small universes from the wreckage of ours. Hence this model states that our universe may have been one among such universes ripped from mother universe and that the number of universes is, has been and will be infinite. [13][15]

VII. FUTURE SCOPE

Large scale experimental research is in progress with particle accelerators in action to create black holes and discover particle emissions from black holes. Discoveries of the new particles from these accelerators will further explain structural symmetries in the universe. Astrophysical Research is in progress on dark matter constituents in connection with the particle emissions, gravitational properties of antimatter and dark energy which may bring new light on the evolution and expansion of the universe. [14][16]

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