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The Relic Neutrino Contribution to the Universe Energy Density

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Summary

The existence of the cosmic neutrino background $(C\upsilon B)$ is predicted by The Big Bang Theory. Its properties are closely related to the ones of the cosmic microwave background (CMB), which is measured with amazing accuracy. According to the Big Bang Model (BBM), the universe is filled with neutrinos and antineutrinos. When the universe was about one second old, these particles decoupled. Since that moment, their wavelengths have been expanding in proportion to the size of the universe.

The shape 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 parameter "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 the matter we know of, then the density governs the fate of the universe. If the density of the universe is less than the "critical density" which is proportional to the square of the Hubble parameter, then the universe will expand forever. 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 in what is known as the "Big Crunch".

This work will show the role of the relic neutrinos in the universe density constant. The calculations will show that the relic neutrino density constant is $\Omega_{relic} = 6.26\times10^{-5}$ and this means that the relic neutrinos will make the pull in the universe a little bigger than the push within it, and therefore the universe cannot expand indefinitely and its expansion rate will decelerate with time due to these relic neutrinos. This work will also show that the contribution of the light relativistic particles with mass equivalent to the electromagnetic energy density parameter to be $\Omega_{light} = 1.98\times10^{-5}$.

Keywords: Relic neutrinos, big bang, big crunch, Hubble parameter, critical density, relic neutrino density constant.

Introduction

Neutrino physics took in recent years its share of interest among many scientists and researchers. Many Nobel Prize in physics were awarded to physicists in the field of neutrino research. In 2002, the American Raymothd Davis and the Japanese Masatosha Koshiba were awarded the prize for their work that revealed some of the secrets that surround the neutrino since its discovery after Wolfgang Pauli predicted its existence in 1930 [1]. John C. Mather of NASA and George F. Smoot of the University of California at Berkeley were awarded the Nobel Prize in Physics in 2006 for their distinctive work in cosmic neutrino radiation based on data from the Cosmic Background Explorer probe (COBE) which was sent into space in 1989. Their work contributed to the enrichment of our knowledge about the Big Bang theory and deepened our understanding of the process of evolution of the galaxies, stars and the evolution of the universe as a whole.

Relic neutrinos are neutrinos that have emerged after about a second of the start of the Big Bang (BB) and are still swimming in space until the present time [2]. The current Temperature of each of these neutrinos is $T_{relic} = 1.95K = 1.68\times10^{-4} eV$ with a mass of around $\sim 10^{-3} eV$. The hope is that the study of these relic neutrinos will help us understand the universe and give us a clear picture of those early times at the start of the Big Bang until the present time and contribute to the knowledge of the future of the universe in terms of its expansion, shrinking, or some state of in-between.

Neutrinos tend to interact with electrons. In 1973, the first such interaction was observed inside the giant bubble chamber detector the Gargamelle at CERN [3]. The interaction was of the type:

$$\upsilon_i\,(\overline{\upsilon}_i)\; e^- \rightarrow \upsilon_i\,(\overline{\upsilon}_i)\; e^- \quad i = e, \mu, \tau \; .$$

In 1976, a team of researchers observed the first reference to the interaction $\overline{\upsilon}_e\, e^- \rightarrow \overline{\upsilon}_e\, e^-$, which is part of the former interaction, using electronic anti-neutrinos $\overline{\upsilon}_e$ coming from the nuclear reactor program [4]. Soon after that, many experiments and research studies on determining the neutrino mass and its magnetic moment were undertaken as they are the two major factors influencing the interactions mentioned above. “In spite of the progress of research in the field of neutrino physics, more surprises still await us from these ghostly particles”, says Carlo Rubbia; winner of the Nobel Prize in Physics in 1984 and former director of the European Laboratory for Particle Physics (CERN). Since then, competition has been taking place among the fields of neutrino physics and cosmology. Many papers have appeared on the use of neutrino properties to remove some ambiguities on many issues regarding the universe that were unresolved at that time. Neutrino has been able to find a place for itself in shaping the structure of the universe Large Scale Structure (LSS), in the Big Bang Nucleosynthesis (BBN), and in demonstrating the irradiative properties of the Cosmic Microwave Background Radiation (CMBR) as well as some other cosmic phenomena. Scientists are hoping that neutrino research will answer many cosmological questions, in particular the question of the fate of the universe: Is it is expanding and if it is, how long does it last? Is it shrinking and if it is, when will it collapse on itself?

At the big initial blast, the standard Big Bang model (SBB) predicts the cosmic background relic neutrinos having an average density approximately equal to $339.3 neutrino/cm^3$ for each flavor [5]. This research aims to find the contribution of relic neutrino mass in the density of matter of the universe and to identify ways it contributes by using the newly followed methods in recent years, particularly the one used in calculating the universe matter density without the relic neutrino contribution. The density of matter in the universe is still not known with precision. There are different models that give different results. The calculation performed by scientists of the quantity of matter in the universe is limited to the quantities that they can be seen and measured using optical and radio equipments and consequently, there are enormous amount of matter that is left out and not taken into account, such as the Cosmological Dark Matter (CDM). Today, the known value of choice for the critical mass density in the universe is: $\rho_c = 5X10^{-30} gram/cm^3$ [7,6] or on average about 3 to 4 hydrogen atoms per cubic meter.

Account of the energy density of the relic Neutrinos

Throughout this work, we will use the natural system of units $c, \hbar, k = 1$ [8] and assume the cosmological models to be symmetrical and homogenous and depend on the theory of general relativity. For that, we choose the Friedman-Lemaitre-Robertson-Walker metric in our calculations [9].

The cosmological constant known as Ω-density is defined by the relation: $\Omega = \rho/\rho_c$ where ρ represents the density of the actual matter in the universe and ρ_c the critical density of the Friedman universe which is equal $\rho_c = 3H^2/8\pi G$, where G is Newton's gravitational constant equal to $1.221\times10^{19} GeV$ and H is the Hubble parameter reflecting the expansion rate of the universe. The Wilkinson Microwave Anisotropy Probe (WMAP) provides us with the total value of the cosmological density constant [10,11]:

$$\Omega_{total} = \Omega_M + \Omega_{rel} + \Omega_\Lambda \cong 1$$

Where:

Ω_{total} The total density of the universe and is equal to: (1.02 ± 0.02),

Ω_M The density of ordinary matter (baryonic and dark matter) and is equal to: (0.27 ± 0.04),

Ω_{rel} The effective density of matter of the relativistic particles (light particles and neutrinos) and is equal to: (8.24×10^{-5}) and

Ω_Λ The density of dark matter related to the cosmological constant Λ, and is equal to: (0.73 ± 0.04).

It is worth mentioning that previous theoretical studies also predicted the value of Ω_{total} to be equal to one, within a precision equal to 10^{-4} as shown in the references [12-14].

Starting with the equation of the relic neutrino energy density [15]:

$\rho_{relic} = (7/2)\ N_\upsilon\ \sigma_{SB}\ T^4_{relic}$

Where: $N_\upsilon = 3$ is the number of effective neutrino flavors, and T_{relic} represents the absolute temperature of the relic neutrino equal to $1.95K \approx 1.68\times10^{-4}eV$, while $\sigma_{SB} = (\pi^2/60)k^4/\hbar^3c^2$ represents the fixed Stefan - Boltzmann Constant which becomes equal to $\sigma_{SB} = (\pi^2/60)$ in our natural system of units, we find:

$$\rho_{relic} = (7/2)N_\upsilon\sigma_{SB}T^4_{relic} = (7/2)(3)(\pi^2/60)(1.95K)^4 \cong 3.132\times10^{-34}\,g/cm^3$$

Cosmological density constant

The share of the cosmological density constant (Ω_{relic}) comes from relic neutrino contribution. By using the relations: $\Omega_{relic} = (\rho_{relic}/\rho_c)$ and $\rho_c = 3H^2/8\pi G$ we find Ω_{rel} to be $\Omega_{relic} = 6.26\times10^{-5}$.

This result is quite small and it is of the same order as Ω_{light} of the relativistic light particles obtained from the WMAP probe. We can now, on the basis of the WMAP probe data mentioned earlier, calculate the cosmological density constant of the relativistic light particles and find it to be: $\Omega_{light} = 1.98\times10^{-5}$.

After adding these new parameters $\Omega_{relic} = 6.26\times10^{-5}$ and $\Omega_{light} = 1.98\times10^{-5}$ to Ω_{total}, we find that the cosmological density constant of matter is still almost equal to one: $\Omega_{total} \cong 1$. We conclude that the relic neutrinos contribute to the mass density of the universe making the pull in the universe a little bit bigger than the push, but outside the limit of accuracy 10^{-4} of the data provided by the WMAP satellite and this means that the universe will remain close to the critical case. We also conclude that the absence of the relic neutrino contribution to the earlier calculated cosmological density constant distribution of the cosmic matter is due to one of the two following options: either because this contribution is beyond the limits of the precision 10^{-4} which is the framework of this paper, or because the earlier calculations did not take it into consideration, at least in this way. We turn now to discussing the role of neutrinos in determining the fate of the universe by making the following statements:

The cosmic predictions of the total various neutrino masses provided by the reference [16] and represented by the relation: $\Omega_\upsilon \rangle 1 \rightarrow \sum_i m_i \leq 25\ eV$ lead to a total of neutrino masses equal only $25\ eV$ to close the universe. While the reference [17] calls for the total of neutrino masses smaller than $46eV$ for the universe to remain in constant expansion as represented by the relation: $\Omega_\upsilon \langle\ 1 \rightarrow \sum_i m_i \langle\ 46\ eV$. We conclude that the mass difference $21\,eV$ is what separates the two cases of the closure and expansion of the universe. In the near future, this mass difference will be overcome and the fate of the universe will be known through the dark matter neutrino which is the most likely candidate representing the cornerstone of the universe structure.

Conclusion and Results

We summarize the results reached in this research as follow:
First: The relic neutrinos contribute to the mass density of the universe and this contribution is equal to:

$$\rho_{relic} = 3.132\times10^{-34}\,g/cm^3 .$$

Second: The absence of the relic neutrino contribution in the distribution of the cosmic matter Ω_{total} is either because it is too small, beyond the limits of the precision 10^{-4} or that it has not been calculated before. This density constant is equal $\Omega_{relic} = 6.26\times10^{-5}$.

Third: We found based on the experimental data provided by the WMAP satellite that the relative contribution of other light relativistic particles is $\Omega_{light} = 1.98\times10^{-5}$.
Fourth: The contribution in the measurement of the critical cosmic density that can close the universe and led eventually to its re-collapse put conditions on the sum of the masses of the three flavors of neutrino that make the dark matter. The cosmic prediction of $25eV$ neutrino mass contributes to the closure of the universe, meanwhile the mean value $46eV$ of the total various neutrino mass of dark matter contributes in its expansion. This means that only $21eV$ of the mass of dark matter neutrino can determine the fate of the universe between expansion and contraction. Finally, astronomers attribute the expansion of the universe or its slowdown mainly to this subtle phantom energy and the composition candidate of its fundamental building blocks to neutrinos.

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