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Introductory Chapter: Standard Model of Cosmology

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1. Introduction

The current Standard Model of Cosmology (SMC), also called the "Concordance Cosmological Model" or the "ΛCDM Model," assumes that the universe was created in the "Big Bang" from pure energy, and is now composed of about 5% ordinary matter, 27% dark matter, and 68% dark energy [1].

While the SMC is based primarily upon two theoretical models: (1) the Standard Model of Particle Physics (SMPP) [2], which describes the physics of the very small in terms of quantum mechanics and (2) the General Theory of Relativity (GTR) [3], which describes the physics of the very large in terms of classical mechanics; it also depends upon several additional assumptions.

The main additional assumptions of the SMC are: (1) the universe was created in the Big Bang from pure energy; (2) the mass energy content of the universe is given by 5% ordinary matter, 27% dark matter, and 68% dark energy; (3) the gravitational interactions between the above three components of the mass energy content of the universe are described by the GTR; and (4) the universe is homogeneous and isotropic on sufficiently large (cosmic) scales.

Unfortunately, both the SMPP and the GTR are considered to be *incomplete* in the sense that they do not provide any understanding of several empirical observations. The SMPP does not provide any understanding of the existence of three families or generations of leptons and quarks, the mass hierarchy of these elementary particles, the nature of gravity, the nature of dark matter, etc. [4]. The GTR does not provide any understanding of the Big Bang cosmology, inflation, the matter-antimatter asymmetry in the universe, the nature of dark energy, etc.

Furthermore, the latest version of the SMC, the ΛCDM Model is essentially a parameterization of the Big Bang cosmological model in which the GTR contains a cosmological constant, Λ, which is associated with dark energy, and the universe contains sufficiently massive dark matter particles, i.e., "cold dark matter." However, both dark energy and dark matter are simply names describing unknown entities.

The main aim of this Cosmology Book is to discuss the above serious problems that threaten to undermine the foundations of the current SMC.

2. Dubious assumptions of SMC

The current SMC has numerous dubious assumptions that will be discussed in the following. It will be indicated that many of the problems associated with the SMC arise from the dubious assumption that the GTR is valid for all distances

within the expanding universe and not just for the very small distances of the Solar System.

In 1916, Einstein published his GTR, which today is still regarded as the best theory of gravity. The GTR, representing gravitational interactions in terms of the geometry of space-time [3], is equivalent to Newtonian gravity provided that the concentration of mass energy is not too great. However, the GTR is clearly superior to Newtonian gravity since it is consistent with special relativity and in addition provides an understanding of several observations unexplained by the Newtonian theory, e.g., the anomalous perihelion advance of the planet Mercury and the deflection of starlight by the Sun during a total eclipse is twice that predicted by the Newtonian theory.

The GTR describes space-time by a metric that determines the distances separating nearby points (stars, galaxies, etc.). The assumption that the metric should be homogeneous and isotropic on large scales uniquely requires that the metric be the Friedmann-Lemaître-Robertson-Walker metric (FLRW metric). Historically, Friedmann in 1922 [5] simplified the field equations of GRT by assuming that the universe is homogeneous and isotropic. In 1927, Lemaître [6] obtained similar results to Friedmann. The majority of the solutions of the Friedmann field equations predict an expanding or a contracting universe, depending upon initial parameters such as the mass-energy of the universe. Both Robertson [7] and Walker [8] considered the theory further and proved that the FLRW metric is the only one that is spatially homogeneous and isotropic.

The use of the FLRW metric assumes that the universe is spatially both homogeneous and isotropic on each reasonably large scale, e.g., on galactic scales. This is a dubious assumption, since recent astronomical observations have shown that the distribution of galaxies is definitely not smooth, displaying filamentary structures separated by regions containing very few galaxies.

In 1929, Hubble [9] discovered that light from remote galaxies was redshifted, implying that these galaxies were receding from the Earth. Hubble observed that there is a linear relationship between the radial speed with which a galaxy recedes from the Earth and its distance from the Earth. The constant of proportionality is known as the Hubble constant. Recently, the International Astronomical Union resolved that from now on, the expansion of the universe be referred to as the Hubble-Lemaître law. If the universe is expanding, this implies that (i) only the expanding solutions of the Friedmann equations are allowed as solutions for the universe and (ii) the universe must have had a very dense and hot beginning. It should be noted that the expanding solutions of Friedmann consider that it is space itself that is expanding and that the galaxies are at rest within the expanding space. Thus, the redshift for each galaxy is a consequence of the wavelength of the light being stretched by the expansion of space and is *not* a normal Doppler redshift.

In 1927, Lemaître noted that an expanding universe could be extrapolated back in time to an originating singular point that has become associated with the notion of the Big Bang. Lemaître called this original very small and compact hot dense universe the "primordial atom" and considered that the present universe arose as a result of the observed expansion.

The prevailing model of the Big Bang is based upon the GTR. According to this theory, extrapolation of the expansion of the universe backward in time yields an infinite mass-energy density and temperature at a finite time, approximately 13.8 billion years ago. Thus the "birth" of the universe appears to be associated with a *singularity*, which describes not only a breakdown of the GTR, but also all the laws of physics. This suggests a dubious assumption associated with the Big Bang hypothesis, indicating that the GTR with the FLRW metric is *not valid* for extremely small regions of space.

On the other hand, the Big Bang scenario has had some success. In 1948, Gamow [10] suggested that the present features of the universe could be understood as a result of the evolutionary development of the universe via expansion from the Big Bang phase. In particular, he suggested that the elements could have been made during the early hot matter-energy phase associated with the Big Bang. It has since been shown that as the initial hot dense mass-energy phase of the universe cooled during the expansion that only several light elements were formed, including hydrogen ($\approx$75%), helium ($\approx$25%), and small amounts of deuterium, lithium, etc.

As the hot dense phase continued to cool down during the expansion, the atomic nuclei of hydrogen, helium, etc. captured electrons, thereby, generating *neutral* atoms. This is estimated to have occurred about 400,000 years after the Big Bang, when photons ceased interacting significantly with matter, leading to the occurrence of the so-called *Cosmic Microwave Background* (CMB) radiation. In 1948, Alpher and Herman [11] calculated the present temperature of this CMB to be about 5 K, remarkably close to the modern value of about 2.73 K, determined by the COBE satellite [12]. In addition, the COBE results showed an extremely isotropic and homogeneous CMB. This led to the need for an *inflationary* phase [13] of strongly accelerated expansion prior to the decoupling of photons from ordinary matter.

In the 1960s, the interpretation of the CMB as the remnant from an early stage of the universe following the Big Bang was challenged by some proponents [14] of the Steady-State Model [15, 16] of the universe. They argued that the microwave background was the result of scattered starlight from distant galaxies. However, the discovery of the CMB radiation in 1964 by Penzias and Wilson [17], especially with the later results from the COBE satellite, which indicated that the CMB spectrum was a thermal black body spectrum, strongly supported the fact that the CMB is a remnant of the Big Bang.

The SMC has two additional major dubious assumptions: the existence of both *dark matter* and *dark energy*, which the SMC claims constitute about 27% and 68%, respectively, of the mass-energy content of the universe.

The notion of "dark matter" arose from observations of large astronomical objects such as galaxies and clusters of galaxies, which displayed gravitational effects that could not be accounted for by the visible matter: stars, hydrogen gas, etc., assuming the validity of Newton's universal law of gravitation. In particular, the observations of Rubin et al. [18], who measured the rotation curves for the luminous matter of many spiral galaxies together with the observations of Bosma [19], who compiled 21 cm rotation curves for neutral hydrogen gas that extended far beyond the luminous matter of each galaxy, showed that the composite rotation curves were essentially "flat" out to the edge of the 21 cm data. This implied that if Newton's law of gravity was approximately valid, as in the Solar System, considerably more mass was required to be present in each galaxy. This invisible matter was called *dark matter*.

This led to the introduction of the "dark matter hypothesis" by Ostriker et al. [20], who concluded that the rotation curves of spiral galaxies could most plausibly be understood if the spiral galaxy was embedded in a giant spherical halo of invisible "dark matter" that provided a large contribution to the gravitational field at large distances from the center of the galaxy.

This dark matter hypothesis is very dubious, since to date no dark matter has been definitely *detected* and the nature of dark matter remains *unknown* [21].

The notion of "dark energy" arose from two sets of observations [22, 23] that suggested that the expansion of the universe is *accelerating*. These observations were very surprising and unexpected, since it was generally considered that the spatial expansion of the universe should be slowing down due to the gravitational attraction of the galaxies.

Both sets of observations were based upon the analysis of supernovae of Type Ia, which are considered to be excellent standard candles across cosmological distances, and allow the expansion history of the universe to be measured by considering the relationship between the distance to an object and its redshift, which indicates how fast the supernova is receding from us. Both teams found that the supernovae observed about halfway across the observable universe (6–7 billion light-years away) were dimmer than expected and concluded that the expansion of the universe was accelerating rather than slowing down as expected.

The conclusion from this observation was that the universe had to contain enough energy to overcome gravity. This energy was named "dark energy." The amount of dark energy in the universe, assuming the validity of the SMC, is estimated to be about 68% of the total mass-energy existing in the universe.

According to Peebles and Ratra [24], dark energy is a hypothetical form of energy that pervades the whole of space and causes the expansion of the universe to accelerate at large cosmological distances. Currently there exists no accepted physical theory of dark energy, suggesting that the existence of such energy is a dubious assumption of the SMC.

3. Discussion and conclusion

This book is divided into two main sections. Section 2 is devoted primarily to alternatives to the Big Bang scenario of the SMC based upon modifications of the Steady-State Models that were popular prior to 1965. Section 3 contains chapters that discuss modifications to the GTR.

Chapter 2 considers the "Tired Light" hypothesis introduced by Zwicky in 1929, in which the redshift is assumed to occur by the photons loosing energy due to interactions with material particles as they travel through cosmological space. The authors indicate that this assumption satisfies many of the observations and overcomes some of the problems of the Big Bang hypothesis.

Chapter 3 presents a different Steady-State Model as another alternative to the Big Bang hypothesis. The author discusses the possible existence of repulsive electromagnetic force fields emanating from galactic super-massive black hole cores that cause the expansion of the universe, although purely gravitational dynamics is maintained within each galaxy. The author indicates the implication of these electromagnetic fields upon the SMC.

Chapter 4 describes the effects of the large scale magnetic fields observed in galaxies and clusters of galaxies upon the Big Bang scenario and the CMB. The authors discuss the origin of such large scale magnetic fields and in particular, analyze their effects upon the CMB anisotropies.

Chapter 5 discusses alternative models for gravitational interactions that provide a generalization of the field equations of the GTR. In particular, it reviews cosmological models based upon a "polynomial affine gravity" scenario and discusses in some detail several cosmological solutions, especially those in the relativistic limit, in which the torsion vanishes.

Chapter 6 proposes a generalization of the Equivalence Principle for quantum gravity to reconcile quantum mechanics and general relativity. It defines the "Equivalence Principle of quantum gravity" to be "The laws of physics must be of such a nature that they apply to systems of reference in any kind of motion, both classical and quantum."

In conclusion, I believe that the dubious assumptions of the SMC will only be overcome when both the incompatible SMPP and the GTR are replaced by a quantum gravitational field, especially one based upon a particle physics model that has the appropriate properties to provide an understanding of both dark matter and dark energy [25].

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