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Observable Universe: Future – Literature Review

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Introduction:

According to the standard model of cosmology, time, space and thus physics, began through the Big Bang. Our universe has expanded from an infinitely energetic and dense structure to the present finite but immensely large one. We are currently around 13.8 billion years from the event, and as our knowledge of the observable universe has grown, so has our curiosity regarding its fate.

The first mention of a possible fate of the universe unsurprisingly comes from religious literature, texts from ancient civilizations that showed interest in cosmology. The Hindu holy texts state that the universe is created, destroyed and rebirthed over certain periods of time, and undergoes these cycles of change after a specific amount of time. The Greeks like Plato believed in the existence of a beginning for the universe but argued that it would not end.

Modern theories entered the fray mostly towards the beginning of the twentieth century with Einstein's theory of special relativity, and Hubble's discovery of the expanding universe. This was followed by the theory of general relativity that drastically increased the interest of the scientific community in understanding our universe. Contributions and theoretical proofs for the expansion of the universe came through Willem de Sitter and Alexander Friedmann through their solutions to the Einstein's field equations and discovery of a positive cosmological constant. George Gamow predicted the existence of cosmic microwave background radiation and Fred Hoyle coined the term "Big Bang" itself.

Through the latter half of the twentieth century to the present day, we know a lot more about our universe through both theoretical explorations of cosmology through relativity, and actual observations of outer space through space exploration. Using these discoveries, various theories behind the future of our universe have been postulated.

From a present day viewpoint, the evolution of the universe and most of the possible future scenarios are irrelevant to us, it could take place billions of years into the future. However, understanding it will help us understand our current universe better and even help us understand other areas of physical cosmology better, which could have actual current applications. This review is thus a discussion of theories that have had theoretical basis built off from assumptions. Some relevant facets of general cosmology are initially presented in layman terms to provide better understanding of the theories themselves.

Theory:

Big Bang:

The event known as the Big Bang is at the foundation of the standard model of cosmology. It is a theory which states that the universe initially was a hot and dense singularity, which started expanding after an event known as the Big Bang[1]. This event took place roughly 13.7×10^9 years ago[2]. This event started off a series of inflations, expansion and cooling that continues till this date.

The theory is supported by evidence of co-moving space density of distant radio galaxies that has been established through radio interferometry. Another support for it is the present abundance of Helium in the universe, which cannot have existed unless it was formed under certain conditions that could've only existed during the Big Bang itself. The most recent and perhaps the most important proof was the measured values of the cosmic microwave background radiation. The cosmic microwave background radiation, also known as "relic radiation", is leftover radiation from a phase shortly after the Big Bang itself that permeates space. It is most dominant in the microwave region of the radio spectrum and thus named as such.

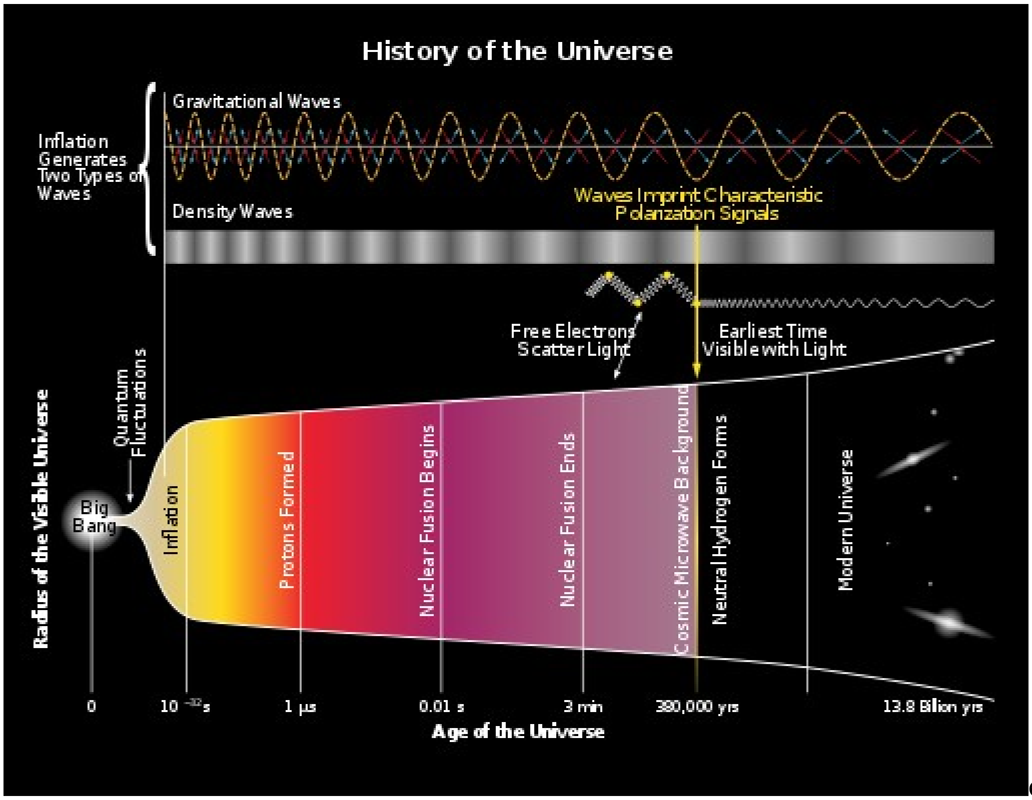

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Figure 1: History of the Universe [3]

Cosmological principle:

The Cosmological principle is a main principle in physical cosmology. It states that if viewed on a sufficiently large scale, the properties of the universe are the same for all observers. More specifically, the universe is homogeneous and isotropic in space and time. The Isotropic property means the universe must have the same properties in all directions while homogeneousness means the same property must exist at all locations.

General Theory of Relativity

The general theory of relativity is the geometric theory of the force of gravitation, first hypothesized by Albert Einstein in 1915 as a follow up to his special theory of relativity. It is a refinement of Newton's law of universal gravitation and gives a unified description of gravity as a geometric property of space-time.

Shape of the Universe:

The shape of the universe is the geometric form of the universe that can be either local or global. This feature is determined by the curvature of space as a manifold. Given the cosmological principle, it can be shown that the shape of space-time can only have three forms. With a positive curvature such as the surface of a sphere and thus finite in extent; with a negative curvature such as the surface of a saddle and infinite in extent; or no curvature at all and thus flat as the surface of a plane and infinite in extent[4].

The constituent of our universe is matter, whose average density determines the geometry of the universe for a certain horizon, which in our case is the observable universe itself. Matter is present in the universe in various forms. The most prominent of it being in the form of Dark Energy, which is 71.4% of the present mass, followed by Dark Matter at 24% and Atoms at 4.6%.

Dark Energy is a theoretical force that counteracts gravity, and thus aids with the expansion of the universe. It was hypothesized to account for the expansion rate of the universe, which is only possible if such a force exists. Dark Matter is matter that does not interact with ordinary matter or electromagnetic radiation, which is predicted to be composed of some sub-atomic particles sharing the extrinsic property in general.

This average density of the universe, if divided by the critical energy density, gives the density parameter Ω. If the value of Ω is greater than one, then the universe is open and infinite, if it is less than one, then the universe is closed and finite and if it equals one then it is flat and infinite. The figure given below demonstrated the shape of a 2D universe given the above mentioned density parameter relationships.

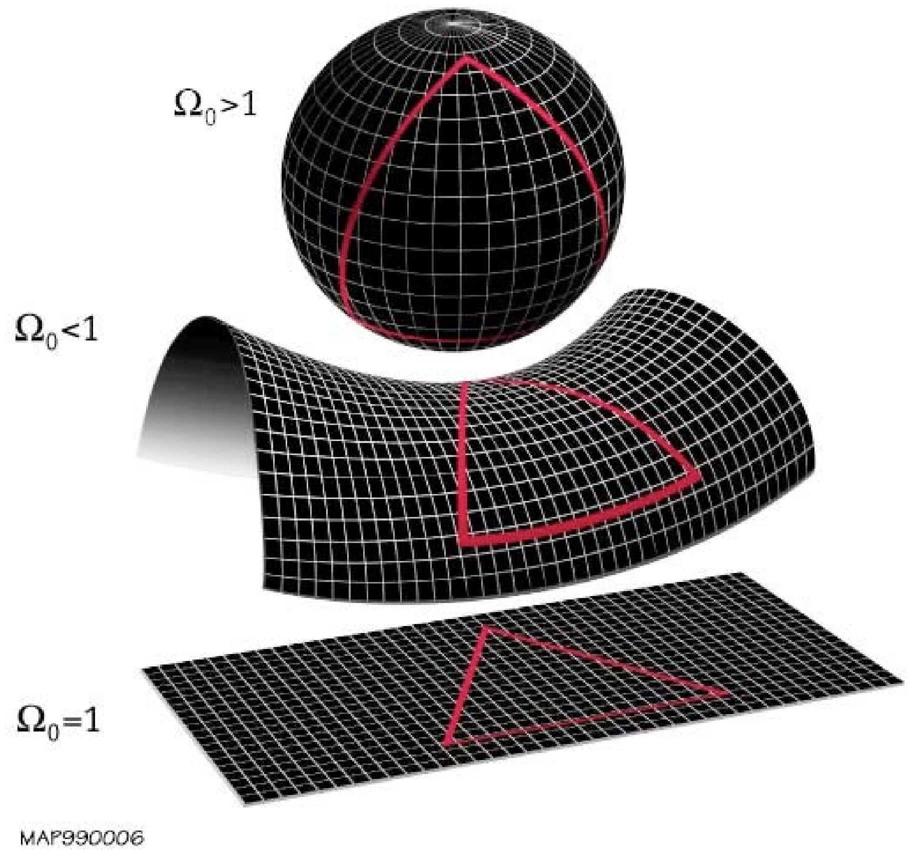

Figure 2: 2D Surface Examples for Curvature[4]

The value for the density of each type of matter has been measured experimentally by the Wilkinson Microwave Anisotropy Probe (WMAP) as well as the Planck spacecraft. The measurements for the total density parameter itself constitutes of three other densities.

$$\Omega_t = \Omega_m + \Omega_r + \Omega_\Lambda \quad (1)$$

Where Ω_t is the total density parameter, Ω_m is the mass density of ordinary mass, which includes dark matter and baryonic mass, Ω_r is the effective mass density of relativistic particles and Ω_Λ is the effective mass density of dark energy.

The actual value for the critical energy density is the density of six hydrogen atoms in a cubic meter, which is given as $\rho_{critical} = 9.47\times10^{-27}$ kg.m^{-3} The values of these according to the data collected by WMAP is listed as follows;

$\Omega_m = 0.315 \pm 0.018$

$\Omega_r = 9.24 \times 10^{-5}$

$\Omega_\Lambda = 0.6817 \pm 0.0018$

Which gives Ω_t as 1.00 ± 0.02[5, 6]. Given these values our universe is flat and infinite.

Cosmological Constant:

When Einstein postulated his general theory of gravity, he introduced a term in his field equations titled the cosmological constant. It denoted the energy density of space but was only a concept to counterbalance the effects of gravity and obtain solutions for a static universe. This value was presumed to be zero as it was soon discovered the universe was not static and was expanding. The discovery of the acceleration of the expansion however, suggested that value might actually exist, and be positive. This has since been used as an explanation for Dark Energy in the standard model of cosmology.

The equation of state for dark energy is the ratio of its pressure to its energy density.

Theories on possible fates:

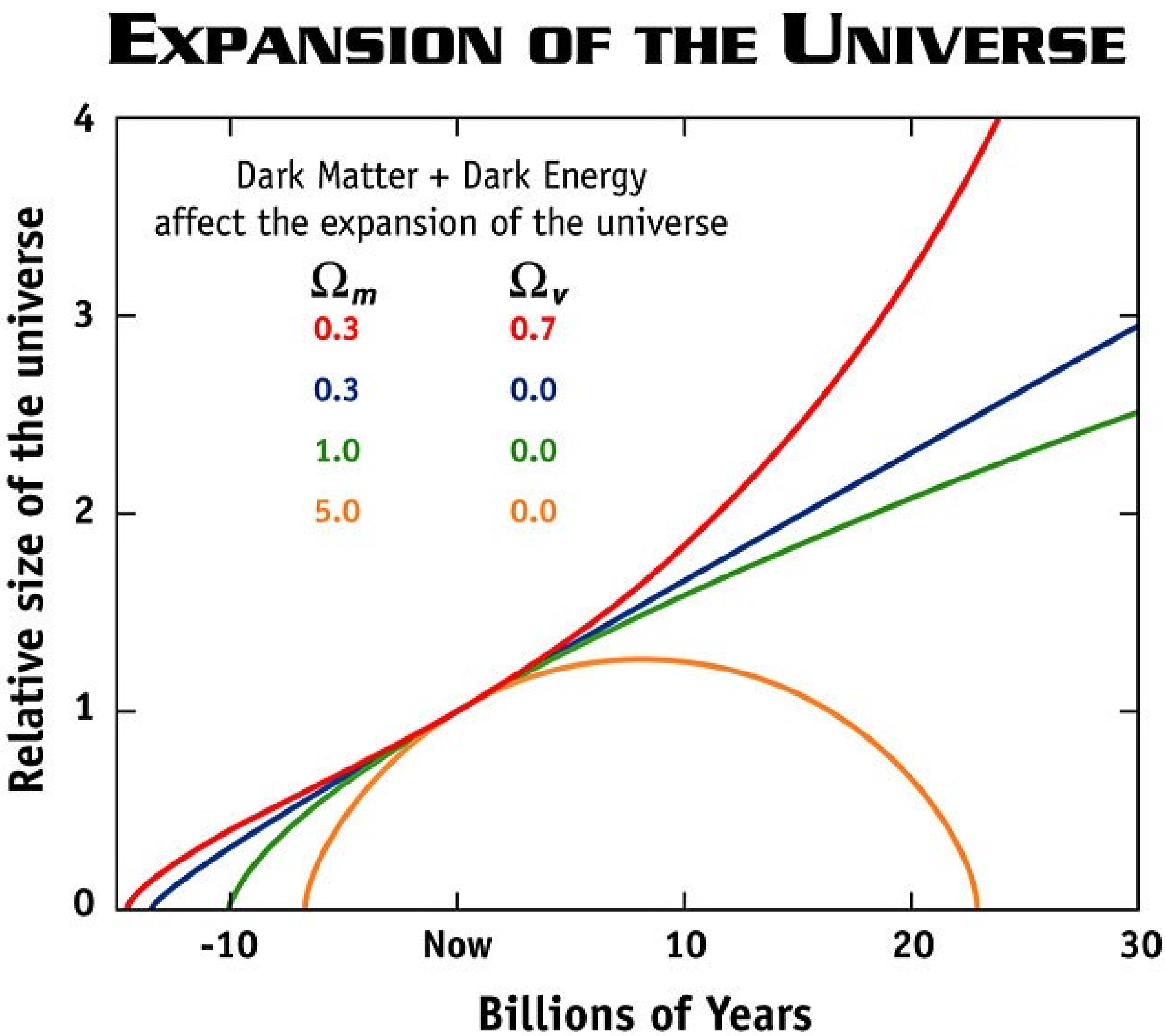

Figure 3: Expansion of the Universe. [4]

Heat Death

On his publication "On the Dynamical Theory of Heat" in 1852, Lord Kelvin wrote his opinion on the fate of the universe based mostly on the second law of thermodynamics, "the result would inevitably be a state of universal rest and death, if the universe were finite and left to obey existing laws. But it is impossible to conceive a limit to the extent of matter in the universe; and therefore science points rather to an endless progress, through an endless space, of action involving the transformation of potential energy into palpable motion and hence into heat, than to a single finite mechanism, running down like a clock, and stopping forever."

The heat death of the universe is a conjecture in which the mechanical movement of matter will run down as work is converted to heat, and all the bodies present in the universe will cool off to lead to a universe void of thermodynamic free energy. This theory does not state that the net temperature for the universe will be zero, it only requires temperature throughout to be constant, given which no processes can be exploited to perform work. The heat death is also known as the Big Chill and the Big Freeze. The addition of a verb after the word "big" in all theories for the fate of the universe is simply an attempt to complement the coinage of the beginning of the universe, the Big Bang.

The conditions for the heat death are that the geometry of the universe needs to be open, infinite and expanding. These conditions are supported by recent data as the cosmological constant is positive and the universe is assumed to be flat, making the heat death theory likely. There are however, some fallacy regarding the theory that have become significant given the recent suggested existence of dark energy and matter. The theory limits itself in terms of possible new sources of energy. If hydrogen could be regenerated from radiation, dark matter or even dark energy then the future of the universe would not be a heat death.

The Big Rip

The Big Rip is a theory for the future of the universe in which the expansion of the universe will continue at an unprecedented rate and rip all the matter, ranging from stars to molecules into their sub-atomic constituents. This theory is based on the ongoing acceleration of the expansion of the universe, and the ratio between dark energy pressure and its energy density, known as phantom energy. The assumption is that dark energy will grow so dominant overtime given the expansion, that other forces of nature such as the strong nuclear force can no longer hold atoms together.

There is a lot of uncertainty regarding current cosmological data to establish a proper value for the above mentioned phantom energy, to prove the Big Rip. There is also the assumption going into the theory that as the expansion increases, the Hubble constant will increase. The authors of the argument suggest the following formula for the calculation the time to the Big Rip[8].

$$t_{\mathrm{rip}} - t_0 \approx \frac{2}{3|1+w|H_0\sqrt{1-\Omega_{\mathrm{m}}}} \qquad (2)$$

Where t_{rip}-t_0 is the time to the Big Rip, w is the phantom energy, H_0 is the Hubble constant and Ω_{m} the density of all matter.

Big Crunch

The Big Crunch is a theory on the future of the universe in which the current expansion of the universe stops and after a certain time, the expansion reverse and the universe collapses onto itself. The underlying assumption is that the density parameter is lower than one. The WMAP data shows the density parameter being equal to, or slightly higher than one and thus suggesting that our universe is shown to be spatially flat. Given thus the Big Crunch is unlikely.

Big Bounce

The Big Bounce theory encompasses the Big Bang and the Big Crunch, hypothesizing that the evolution of the universe is a cyclic process. Once the Big Crunch has taken place, the expansion will reverse to an infinitely dense singularity and will restart from another Big Bang. The big bounce is a culminating process of an eternal universe, which is in a cyclic process of expansions and contractions. The theory remained popular throughout the latter half of the twentieth century mostly due to the aesthetics of it and its close symbolism with religious dogma. Recent interpretations of the theory in terms of loop quantum cosmology have gained some popularity as a theory for a nonsingular big bounce was constructed within Einstein's field equations for gravity[9]. Though underlying assumption of the Big Crunch, the value for critical density, remains unsupported by data, the recent developments and the unanswered questions behind the Big Bang, such as the existence of supermassive black holes soon after the event, have led to some increased support for this particular theory.

Big Slurp

The Big Slurp is a theory based on the existence of false vacuum, a state in quantum field theory that is stable, but not the most stable as there exists a state with higher stability known as true vacuum.

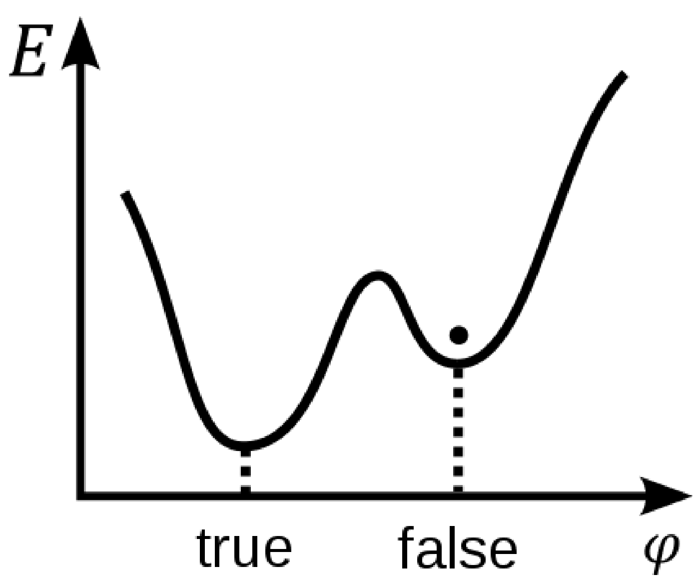

Figure 4: A scalar field with the dot representing the false vacuum.

The theory states that our observable universe is currently in the state of false vacuum, and can instantaneously move to a true vacuum by tunneling through a barrier as noticed in quantum tunneling of electrons. It is assumed that the ensuing vacuum decay could possibly destroy all life in the universe. The theory itself is not built on the cosmological model and is not further not supported by known parameters.

Conclusions:

Given the observations by WMAP, the Planck satellite, and the existing standard model of cosmology, the most likely fate of the universe seems to be either a heat death, or a Big Rip. Though both outcomes are bleak for carbon based lifeforms that currently depend on other lifeforms and existence of entropy for sustenance, we as individuals or our species for that matter might not be there to experience an end to our universe.

The theories for the fate of the universe are based on the dark energy equation of state and the parameters measured by observations of various satellites. We know very little about the physics of dark matter given its lack of interaction with electromagnetic waves and also not a lot about dark energy. The equation for dark energy itself is simple, and is derived for the current structure of the universe and is not guaranteed to be constant, given the dark energy that existed right after the big bang is not the same as it is now, and could change into the future as expansion increases. We also need better data on the cosmological parameters as the data acquired by WMAP had a three percent error. Further missions to look at different spectrums of electromagnetic radiations would confirm the density parameter with more certainty.

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