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Fate Of The Universe

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Abstract
This paper shows the current theories that support or refute the end of the universe.Using the Friedmann equations, which are derived from Einstein's field equations, this work examines the expansion, curvature, and the roles of energy and dark matter in determining the fate of the universe. The equations were examined using the assumptions of homogeneity and isotropy in conjunction with observational data from projects such as WMAP and COBE, and the results confirmed the current dark matter and energy-dominated phase of the universe and its flat curvature with a 0.4% margin of error. With the use of simulations and adjusted equations, critical density and curvature were examined in order to comprehend potential end states, such as the Big Freeze or Big Crunch. Cosmic Microwave Background Radiation (CMBR) study provided additional confirmation of the universe's continuous expansion and energy state changes.The cyclical Big Crunch hypothesis is still speculative, but recent data points to a possible Big Freeze scenario, in which the cosmos cools and stops activity, even if dark energy drives exponential expansion and the properties of dark matter are still mostly unknown.
Keywords: *Friedmann equations, critical density, curvature of the universe, dark matter, dark energy, big freeze, big crunch.*

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I. Introduction

The paper shows how Friedmann equations are derived, it explains the symbols of the equations and deals with the two assumptions made to solve them.Curvature can be determined through additional Friedmann equation solving.It explains the many values of k and the critical density and provides observational evidence for the flatness of the universe's curvature.It then describes how much dark energy and matter is present in the universe connected to the future.Furthermore it goes through the different cosmic microwave background radiation (CMBR) values and how the current emissions can be used to predict the future.Lastly it revolves around the two main theories, the big freeze and crunch, describes the derivation of the equations and explains the future in both scenarios.

II. Results:

1.Friedmann Equations

These equations were derived from Einstein's field equation and Friedmann-Lemaitre Robertson-Walker (FLRW) metric.This equation depicts the expansion of the universe. Expansion of the universe by the scale factor, this is also proved by results obtained by various telescopes like the James Webb.Scale factor is denoted by a(t) which means the only factor it depends on is time.There are two main assumptions made while deriving the Friedmann equations was that the universe is homogeneous and isotropic.Isotropic means that the universe looks the same from all directions and one cannot specify the difference if they view the universe from the north,south,east or west side.Homogeneous means there is no preferred location in space and it looks the same from any angle.The matter content in the

universe is mainly fluids like hydrogen.Using these two assumptions and the help of Einstein's field equation the Friedmann equations come.Einstein's field equations were solved further to obtain these Friedmann equations:

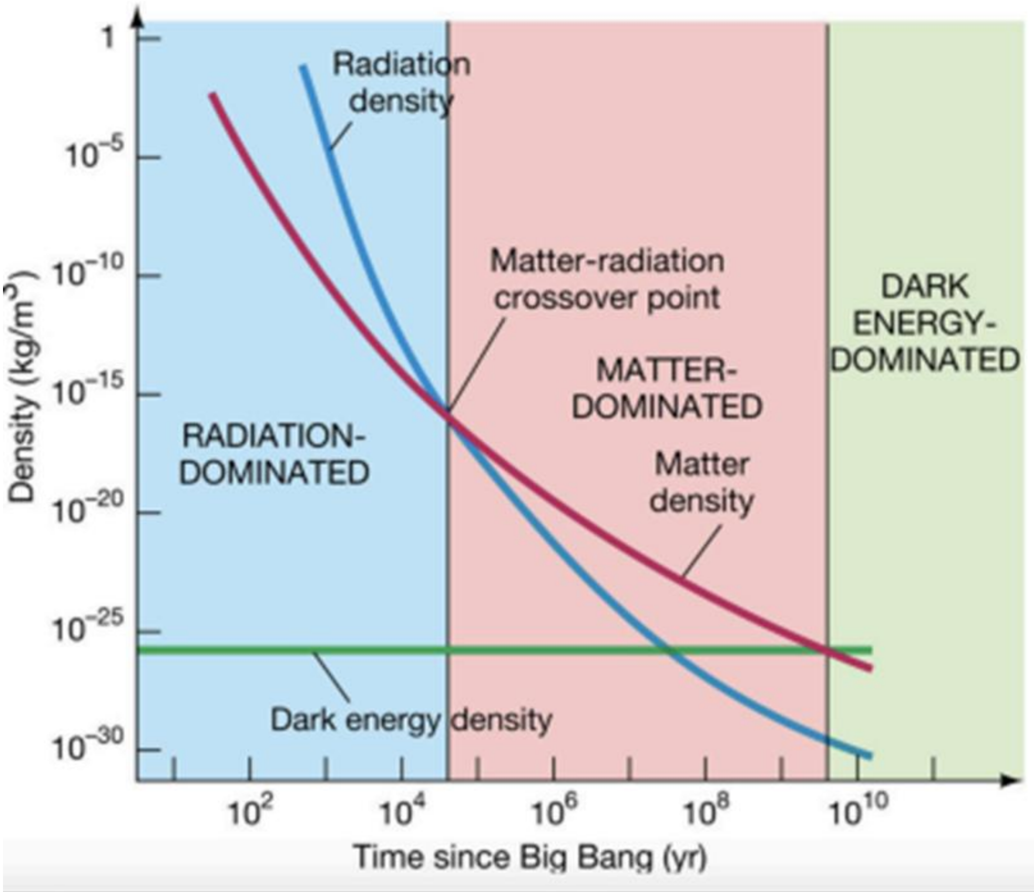
$$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p) \ ,$$

[1]

This equation shows how the evolution of the scale factor depends on the matter content of the universe.The single dot over a in the equation represents a time derivative(measures of how scale factor changes with time).The double dot over a is a second time derivative. When associating both derivatives together it stands for acceleration.Cosmological Constant, Λ, brings density into the picture by putting negative pressure in the universe.The constant k stands for the scalar curvature,outlines the basic shape of the universe(seen further is section2). ��(��) stands for pressure whereas ρ(��) stands for energy density. [2]

By solving Friedmann equations there are stages of the universe that come into discovery. Currently the universe is in the dark energy dominant era,where it is continuing to expand.



This graph shows how the era's have changed over time after the big bang.[3]

2.Curvature

In simple words curvature means the shape of the universe,there are three possible curvatures :

Positive curvature-when the value of �� = 1 and the density of the universe is greater than the critical density. Positive curvature's shapes resembles a spherical shape.eg: surface of the Earth

Negative curvature- when the value of �� = − 1 and the density of the universe is lesser than the critical density.The negative curvature looks like a hyperbolic shape.In this case the universe will never stop expanding.

Flat curvature- where the value of �� = 0 and the density is critical.The shape of the universe is just a horizontal surface.In this case the universe will stop expanding very soon.

A flat universe like ours has a mean density equal to the critical density.Critical density is the average density of matter that is necessary to stop expansion after an infinite amount of time. The critical density is given by this equation:

$$\rho_c = \frac{3H^2}{8\pi G}$$

In this equation H stands for the Hubble's constant,G stands for gravitational constant. The approximate value of critical density is 10^{-26} kg/m^3.However the exact value of critical density remains unknown but scientists are working on finding solutions through two approaches one by equations and the other geometrically. [4]

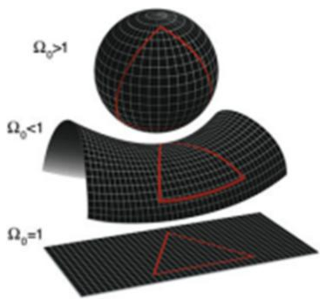
The exact value of critical density is known, it is given by a series of fundamental constants. It at most only depends on what is the Hubble constant.

The above values of k that are 1,-1 and 0 are substituted into modified Friedmann equations Equation:

$$1 = \Omega - \frac{c^2 \kappa}{a_0^2 H_0^2} \quad \Rightarrow \quad \kappa = \frac{a_0^2 H_0^2}{c^2}(\Omega - 1)$$

[5]

There is a study from Wilkinson Microwave Anisotropy Project (WMAP) that shows that the universe is flat.According to their results in 2013 it was stated the universe is flat with only 0.4% margin of error.

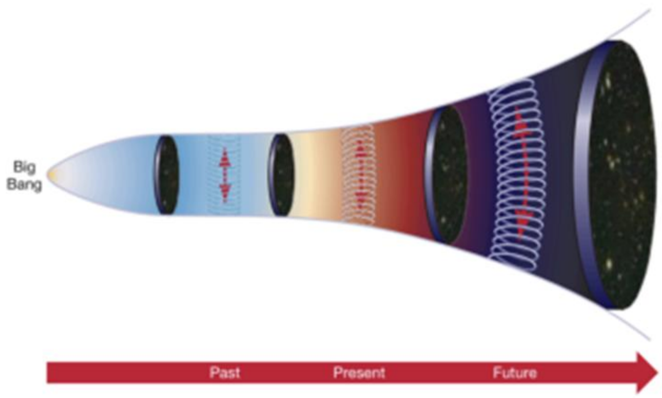


This picture from WMAP shows the different curvatures and how they look. According to their observations our universe comes under the value of Ω . �� = 1

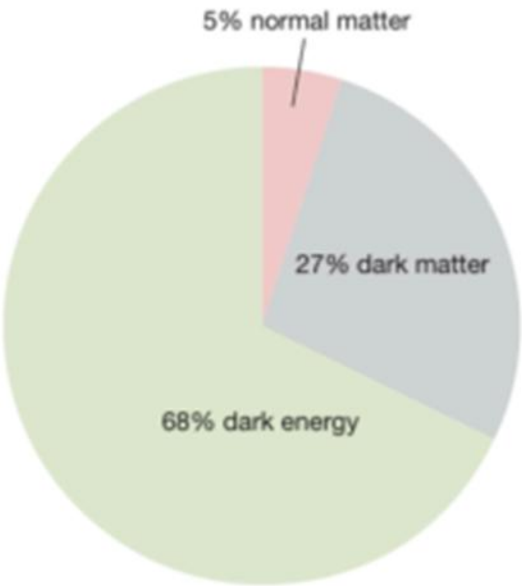
The recent study which provides observational evidence for the curvature shape is Planck's experiment. [6]

3.Dark Matter and Energy

Dark energy is a hypothetical form of energy that is proposed by physicists to explain why the universe is expanding at an accelerating rate Dark energy is known to keep expanding at an exponential rate. Why is this energy causing the universe to expand? There are two types of forces that come into play one being the attractive force of gravity and second the expansion of the universe. When these two forces are opposed the repulsion of dark energy causes the universe to expand. Dark energy initially started as a small dot but has been expanding ever since and is predicted to expand continuously at the same rate.



This picture from Astronomy: The Beginners Guide to the Universe shows the amount of dark energy in the past, present and the predicted amount in the future.

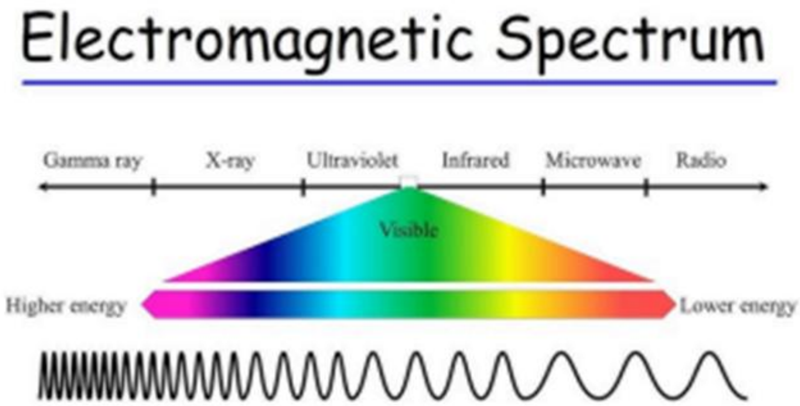


This picture from the textbook (Astronomy: A beginner's guide to the universe) shows how dark energy takes up most of the universe and is the dominant matter in the universe.At the same time scientists have not discovered 95 percent of the universe hence if the value of dark energy or matter changes drastically the prediction of the end of the Universe might change. Scientists don't know the actual source of dark matter or energy or its exact properties which could cause the predictions to change over time. [7]

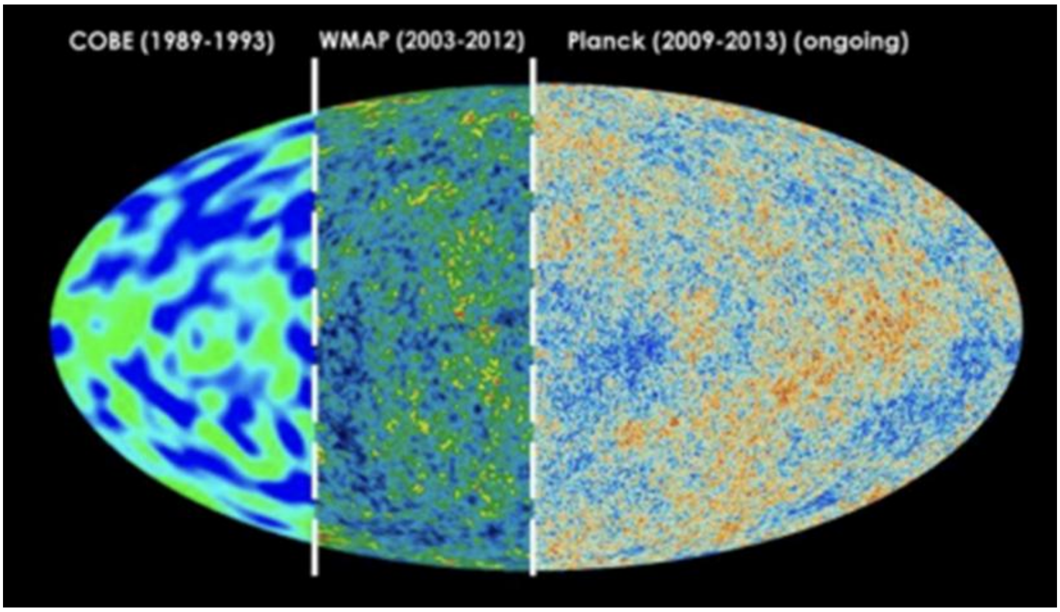
Scientists have only cracked solving half of the equation that plays a part in the end of the universe. They believe once they know the exact properties of dark matter they can comment on how it plays a role in the end of the universe. [8]

4.Cosmic Microwave Background Radiation

CMBR is the remnants after the big bang which is expected to keep decreasing as time increases.Cmbr leaves behind hints that help us predict the future.This is the following picture of the electromagnetic spectrum:



It is said that there are emissions of radio waves all around the universe,it is predicted that it will be red shifted into the microwave region very soon.This shows how the universe is moving to a higher energy state and is continuing to expand.



This image shows cmbr from COBE,WMAP and Planck.It shows how as time progresses our knowledge of the universe increases while 57% of the galaxies are unseen.At the same time this shows how the galaxies are moving away from us as time increases. [9]
tive-Distances.pdf

5.The Big Freeze and Crunch

The big crunch means that: The universe will collapse into a black hole and will be following a cycle where its believed that the end will be another big bang itself.

The big freeze means that:The universe will end with a freeze where everything will come to a stand still. In other terms its a cold freezing death of the universe This will only occur if the density of the universe is less than the critical density. When the density becomes lower it makes life in the universe impossible as there isn't enough gravitational force now to stop the expansion.This also stops any amount of heat being present in the universe anymore. This phenomenon is also called the ’heat death’.

This theory is tested by equations and observations that consider that the universe only consists of Chaplygin gas.It alters the Friedmann equations in such a manner where there are three values substituted in the equation 0,1 and -1 in the equation below from the paper Astronomical bonds on big freeze singularity:

$$w_0 < -\frac{kc^2 + H_0^2 a_0^2 (2k_0 + 1)}{3(kc^2 + H_0^2 a_0^2)}$$

Based on the values received an integral is performed which gave the result mentioned below:

$$\frac{2\sqrt{3}}{\epsilon H_0}\left(\frac{w_0}{w_0+1}\right)^{3/2\epsilon}\int \frac{(\cos\eta)^{1+3/\epsilon}(\sin\eta)^{-1+3/\epsilon}\,d\eta}{\sqrt{\mu(w_0,a_0,\epsilon)\sin^{6/\epsilon}\eta+\nu(w_0,a_0,\epsilon)\cos^{6/\epsilon}\eta+\gamma(w_0,a_0,\epsilon)\sin^{2/\epsilon}\eta\cos^{6/\epsilon}\eta}}=\int dt,$$

This further led to three possibilities which are flat spacetime,spacetime with positive spatial curvature or with negative spatial curvature.Spacetime was thought to be flat in order for the

big freeze theory to hold as observable data provided the strongest evidence for it. Upon substitution in the flat spacetime equation another equation was formulated:

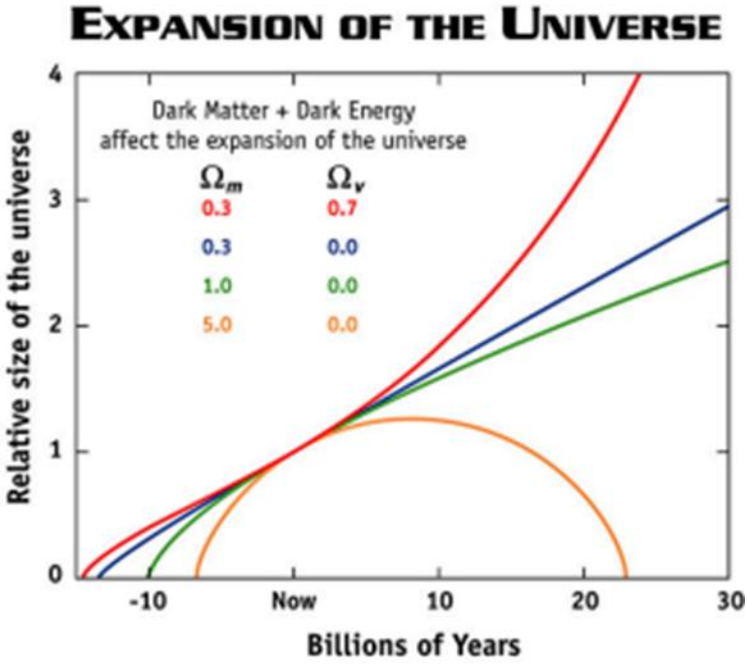
$$\hat{\psi} = -2\cos\eta + \frac{4\cos\eta}{\sin^2\eta} - 2\sin^2\eta \ln\left|\cot\frac{\eta}{2}\right|.$$

Based on chappel gas equations:

For the same values of v and lambda the universe would have started at negative infinity and kept decreasing in size until time becomes approximately 0 which would state the big bang and this cycle would keep on continuing. This is also known as the big crunch.

The second conclusion was that time starts at 0 and the universe will expand so much that it will reach a point where it won't be able to fit into astronomical data. This is known as big freeze singularity (BFS) .

The third conclusion stated that the universe itself started by the BFS and expands till it can't anymore. [10]



The above graph from(WMAP- the fate of the universe)shows the prediction of the evolution of the universe.The blue and green lines signifies the big freeze where as time increases the scale factor increases depicting the expansion of the universe constantly.The orange line signifies the big crunch where the semi circle shaped graph shows how the universe will expand till the top rim of the circle and then collapse again.0 states the big bang and where all the graphs meet is where the scale factor is 1 depicting the critical density of the universe. [11]

III. Discussion

The paper talks about some of the theories that currently exist that predict the end of the universe.Scientists have not reached a particular date or time when the universe will end but have discovered the factors that will cause the end of the universe.All of the theories are subject to change as more than half of the universe remains undiscovered and upon new finding the theories might be proven wrong.

IV. Methods

Since the Arvix database is known for astrophysics research articles, I have mostly used it to locate research publications.In addition, I utilised numerous well-known textbooks for greater understanding and simpler figures. After using a combination of these to comprehend the material, I proceeded to Google Scholar to verify the authenticity and used those sites as the foundation for my work.

References

[1] Cervantes-Cota, J. L., & Smoot, G. (2011). Cosmology Today-A Brief Review. Arxiv Preprint Arxiv:1107.1789

[2] Hirvonen, V. (N.D.-A). The Friedmann Equations Explained: A Complete Guide. Profound Physics. Https://Profoundphysics.Com/The-Friedmann-Equations-Explained-A-Complete-Guide/

[3] 1: A Brief History Of The Universe With A Focus On The Domination Of... | Download Scientific Diagram. (N.D.-B). Https://Www.Researchgate.Net/Figure/A-Brief-History-Of-The-Universe-With-A-Focus-On-The-Domi Nation-Of-Its-Different_Fig1_309730463

[4] Critical Density: Cosmos. Critical Density | COSMOS. (N.D.). Https://Astronomy.Swin.Edu.Au/Cosmos/C/Critical+Density

[5] Buchert, T., & Carfora, M. (2008). On The Curvature Of The Present-Day Universe. Classical And Quantum Gravity, 25(19), 195001.

[6] NASA. (N.D.). WMAP- Shape Of The Universe. NASA. Https://Wmap.Gsfc.Nasa.Gov/Universe/Uni_Shape.Html#:~:Text=Thus%20the%20universe%20

Was%20known,A%200.4%25%20margin%20of%20error.
[7] Chaisson, E., & Mcmillan, S. (2017). Astronomy: A Beginner's Guide To The Universe. Pearson.
[8] Telescope, L. S. S. (2020, June 4). Dark Energy And The Fate Of The Universe. Rubin Observatory. Https://Www.Lsst.Org/Science/Dark-Energy/Universe
[9] Thakur, S. N., & Frederick, P. S. O. Cosmic Microwave Background Radiation (CMB), The Observable And Non-Observable Universes, And Their Respective Distances.
[10] Yurov, A. V., Astashenok, A. V., & Gonzalez-Diaz, P. F. (2008). Astronomical Bounds On A Future Big Freeze Singularity. Gravitation And Cosmology, 14, 205-212
[11] NASA. (N.D.-A). WMAP- Fate Of The Universe. NASA. Https://Wmap.Gsfc.Nasa.Gov/Universe/Uni_Fate.Html