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Expansion of the universe and Hubble's law

The research

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Dedication:

This research project is the work of one academic year. It is dedicated to:

- My beloved family
- To all my teachers, who taught me throughout my life, especially assistant professor Dr. Mohammed Azeez Saeed who supervised this research work.

Acknowledgments:

I would like to send my warm and endless thanks and gratitude to my family who supported me during all the years of the study without which I was not able to continue my education. Also my special thanks is extended to Assistant Professor Dr. Mohammed AzeezSaeed for supervision of the study. Appreciations are due to the Department of General Science and the College of Basic Education for their support during the four years of the study.

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Abstract/Summary:

The Hubble constant is an important cosmological parameter that describes the expansion rate of the universe. It is not regarded as a fundamental parameter in standard cosmological models; it can be measured by various independent methods and enables the researchers to exploit the wealth of observational data to advance the theoretical understanding in cosmology.

In this research work, theoretical background of the origin of the universe and the theories governed the status of the universe were carefully reviewed and outlined.

The derivation of the Hubble law for the expansion of the universe is discussed. Furthermore, we discuss the application of the Hubble constant to predict the age of the universe and to validate our understanding on the underlying cosmology of the universe. Based on the Hubble law, various distance methods have been devised to determine the Hubble constant via distance measurements on different types of galactic objects.

Data of velocity, distances of some 10 supernova host galaxies have been collected in the literature and plotted on excel sheet using linear regression analysis, least square method. The empirical formula of Hubble law was obtained. The value of the constant obtained is 71.47 KmS^{-1}/MPc. The correlation coefficient was 0,99 with percentage error of 1.1%

Keywords: Universe, Cosmology, Big Bang, Hubble's law, Hubble constant

Chapter One

1.1 Introduction:

The **expansion of the universe** is the increase in distance between any two given gravitationally unbound parts of the observable universe with time.[1] It is an intrinsic expansion whereby the scale of space itself changes. The universe does not expand "into" anything and does not require space to exist "outside" it. Technically, neither space nor objects in space move. Instead it is the metric (which governing the size and geometry of space time itself) that changes in scale. As the spatial part of the universe's space time metric increases in scale, objects become more distant from one another at ever-increasing speeds. To any observer in the universe, it appears that all of space is expanding, and that all but the nearest galaxies (which are bound by gravity) recede at speeds that are proportional to their distance from the observer. While objects within space cannot travel faster than light, this limitation does not apply to changes in the metric itself. Therefore at great enough distances the speeds of distant objects exceed even the speed of light, and they become unable to be observed, limiting the size of our observable universe [2].

As an effect of general relativity, the expansion of the universe is different from the expansions and explosions seen in daily life. It is a property of the universe as a whole and occurs throughout the universe, rather than happening just to one part of the universe. Therefore, unlike other expansions and explosions, it cannot be observed from "outside" of it; it is believed that there is no "outside" to observe from.

Metric expansion is a key feature of Big Bang cosmology, is modeled mathematically with the Friedmann–Lemaître–Robertson–Walker metric and is a generic property of the universe we inhabit. However, the model is valid only on large scales (roughly the scale of galaxy clusters and above), because gravity binds matter together strongly enough that metric expansion cannot be observed on a smaller scale at this time. As such, the only galaxies receding from one another as a result of metric expansion are those separated by cosmologically relevant scales larger than the length scales associated with the gravitational collapse that are possible in the age of the universe given the matter density and average expansion rate. It is believed that in the very far future, the metric will gradually outpace the gravity that bodies require to remain bound together, meaning that for any observer in space, all but the closest of galaxies and other objects will increasingly recede and in time become unobservable [3].

According to inflation theory, during the inflationary epoch about 10^{-32} of a second after the Big Bang, the universe suddenly expanded, and its volume increased by a factor of at least 10^{78} (an expansion of distance by a factor of at least 10^{26} in each of the three dimensions), equivalent to expanding an object 1 nanometer (10^{-9} m, about half the width of a molecule of DNA) in length to one approximately 10.6 light years (about 10^{17} m or 62 trillion miles) long. A much slower and gradual expansion of space continued after this, until at around 9.8 billion years after the Big Bang (4 billion years ago) it began to gradually expand more quickly, and is still doing so. Physicists have postulated the existence of dark energy, appearing as a cosmological constant in the simplest gravitational models, as a way to explain this late-time acceleration. According to the simplest extrapolation of the currently favored cosmological model, the Lambda-CDM model, this acceleration becomes more dominant into the future[4]. In June 2016, NASA and ESA scientists reported that the universe was found to be expanding 5% to 9% faster than thought earlier, based on studies using the Hubble Space Telescope.

1.2 Origin of the Universe:

During the course of the history, scientists have put forward many theories of the origin of the universe, among these[4]:

1- Aristotalies Universe
2- Einstein – de Sitter Theory
3- Big Bang Theory
4- Steady State Theory

1- Aristotelian theory: This theory put forward in 4th AD. It states that the earth is fixed and represent the centre of the universe. The universe has three relative motions, linear, circular and mixed. The stars are in circular shapes made of Ether.
2- Einestein-de Sitter Theory: This theory assumes that the speed of light is constant in whole universe. Relayed on cosmological principle; namely, isotropic directional properties and uniform in space and time. General relativity theory has been used in the explanation of the gravity.

The gravity is a space-time curvature

- The Universe is stationary

- Introducing cosmological constant into Field Equation
- de-Sitter: Field Equation can be Solved for non-stationary universe.
- General Relativity theory coincide with expanding universe i.e., Cosmological constant not needed. Biggest mistake

3- Steady State theory: Put forward by Sir Fred Koyle, Bondi and Gold at university College, Cardiff, Wales-UK in 1948.The universe is expanding forever. Galaxies recede in all directions; matter is created in the form of Hydrogen atoms to fill the space galaxies. Creation of one hydrogen atom occurs in each cm^3 every 10^{13} years. This theory was overthrown by the Big bang theory in 1965.

4- The Big bang Theory: The Big Bang hypothesis is the most widely accepted theory of the origin of the universe. The Big bang states that the universe began when primordial mass exploded in titanic holocaust. This fireball gradually cooled as it expanded outward, and giant clouds of swirling gas formed the celestial bodies.

- Entire galaxies took shape as they were propelled outward by the initial cataclysm.
- The universe created by the Big Bang may expand forever or it may gradually slow and eventually collapse in on itself.
- The Big Bang theory does not explain *why* the bang occurred, but predicts what the consequences of such an event would be.
- Several key pieces of evidence have been assembled that support the Big Bang theory and have laid to rest many of the competing theories.
- It is now generally agreed among both astronomers and physicists alike that the Universe was created some 10 to 20 billion years ago in a leviathan explosion dubbed the "Big Bang".
- The exact nature of the initial event is still cause for much speculation, and we know little about the first instant of creation.
- Nevertheless we do know that the Universe used to be incredibly hotter and more dense than it is today.
- Expansion and cooling after this cataclysm of the Big Bang, resulted in the production of all of the physical contents of the Universe which we see today.

The expansion of the universe proceeds in all directions as determined by the Hubble constant. However, the Hubble constant can change in the past and in the future, dependent on the observed value of density parameters (Ω). Before the discovery of dark energy , it was believed that the universe was matter-dominated, and so Ω on this graph corresponds to the ratio of the mat ter density to the critical density (Ω_m). See figure (1) below.

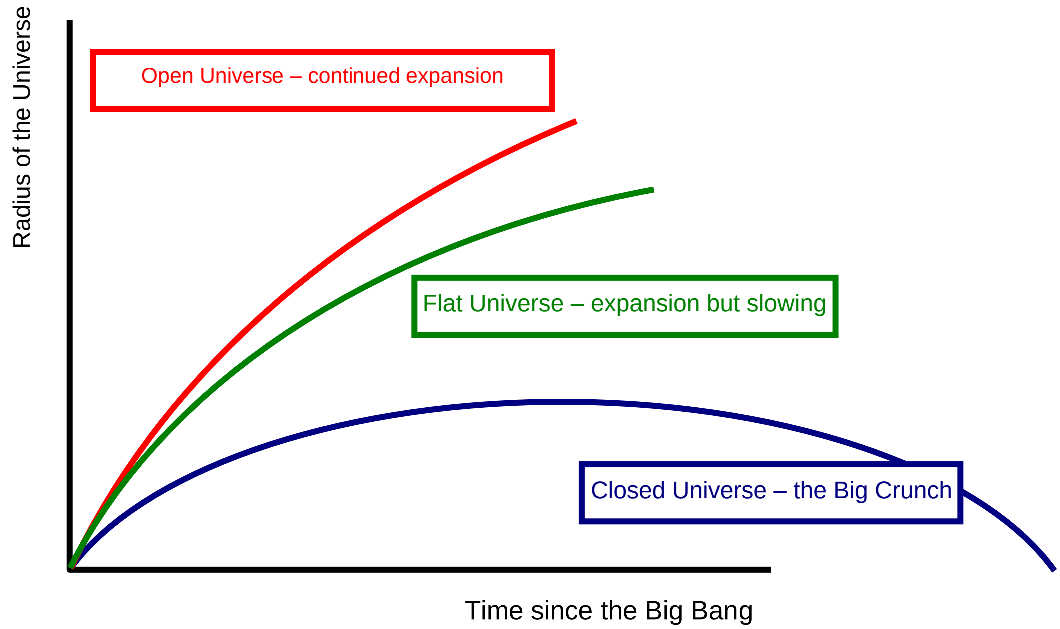

Figure (1): Types of the Universe. Open, Flat and Closed Universe

If there is enough mass in the Universe then its gravitational attraction will eventually overcome the expansion. The Universe will stop expanding and then collapse to an eventual big crunch (cf. throwing an object upwards with less than the escape velocity). This is called a *closed universe*.

If the quantity of mass is just right then the expansion slows to zero 'at infinity'. This is called a *flat universe.*

If there is not enough mass for its gravitation effect to overcome the expansion, the Universe will continue to expand forever. This is called an *open universe*[5].

A closed universe might rebound forever – a big bang eventually resulting in a big crunch which rebounds into a big bang and so on. The whole Universe may be a gigantic oscillator!

The critical density is the demarcation between an open and closed Universe.

Chapter Two:

2.1 Hubble's law:

Edwin Hubble (1889-1953)[6] gives me great faith in humanity, because he started out as a lawyer and then became an astronomer. Hubble made a significant breakthrough in 1925 with the new Mount Wilson 100-inch Hooker telescope. With the telescopes available, astronomers were able to discern fuzzy images of objects that were not simple stars in our galaxy. They called these nebulae, which is basically Latin for 'fuzzy thing' (actually 'cloud'). They also debated whether these objects were in our galaxy or outside of it. Since the prevailing view of the universe at the time was that our galaxy was all that there was, most astronomers fell in the 'in our galaxy' camp, led by the famous astronomer Harlow Shapley at Harvard. In seminal work he demonstrated that the Milky Way was much larger than previously thought and that the Sun was not at its center but simply in a remote, uninteresting corner. He was a formidable force in astronomy and therefore his views on the nature of nebulae held considerable sway.

On New Year's Day 1925[6], Hubble published the results of his two-year study of so-called spiral nebulae, where he was able to identify a certain type of variable star, called a Cepheid variable star, in these nebulae, including the nebula now known as Andromeda. First observed in 1784, Cepheid variable stars are stars whose brightness varies over some regular period. Therefore, if one could determine the distance to a single Cepheid of a known period (subsequently determined in 1913), then measuring the brightness of other Cepheids of the same period would allow one to determine the distance to these other stars!

Since the observed brightness of stars goes down inversely with the square of the distance to the star (the light spreads out uniformly over a sphere whose area increases as the square of the distance, and thus since the light is spread out over a bigger sphere, the intensity of the light observed at any point decreases inversely with the area of the sphere), determining the distance to faraway stars has always been the major challenge in astronomy.

Hubble was able to use his measurement of Cepheids period-luminosity relation to prove definitively that the Cepheids in Andromeda and several other nebulae were much too distant to be inside the Milky Way. Andromeda was discovered to be another island universe, another spiral galaxy almost identical to our one, and one of the more than 100 billion other galaxies that, we now know, exist in our observable universe. Hubble’s result was sufficiently unambiguous that the astronomical community – quickly accepted the fact that the Milky Way is not all there is around us. Suddenly the size of the known universe had expanded in a single leap by a greater amount than it had in centuries! Its character had changed, too, as had almost everything else.

After this dramatic discovery, Hubble was after bigger galaxies. By measuring ever fainter Cepheids in ever more distant galaxies, he was able to map the universe out to ever-larger scales. When he did, however, he discovered something else that was even more remarkable: the universe is expanding!

Hubble achieved his result by comparing the distances for the galaxies he measured with a different set of measurements from another American astronomer, VestoSlipher[7], who had measured the spectra of light coming from these galaxies. Understanding the existence and nature of such spectra is beginning of modern astronomy.

When Hubble first presented his remarkable result – that almost all galaxies are moving away from us, and those that are twice as far away are moving twice as fast, those that are three times away three times as fast, etc. – it seems obvious what this implies: *We are the center of the universe!* and it was consistent the relationship that Hubble had predicted. Our universe is indeed expanding.

Hubble’s law is consistent with a universe that is expanding. Now, when Hubble and Humason first reported their analysis in 1929[8], they not only reported a linear relationship between distance and recession velocity, but also gave a quantitative estimate of the expansion rate itself. The number for the expansion rate they obtained, derived for the plot, suggested that a galaxy a million parsecs away (3 million light-years) – the average separation between galaxies – is moving away from us with a speed of 500km/sec.

Such an estimate is clearly an upper limit on the age of the universe, because, if the galaxies were once moving faster, they would have gotten where they are today in less time than this estimate would suggest. From this estimate based on Hubble’s analysis, the Big Bang happened approximately 1.5 billion years ago. Even in 1929, however, the evidence was already clear that the Earth was older than 3 billion years old.

A supernova, is one of the brightest fireworks displays in the universe. When a star explodes, it over the course of about a month or so shines in visible light with a brightness of 10 billion stars. Over this range, observations and theoretical predictions agree. This is one of the most famous, significant, and successful predictions telling that the Big Bang really happened. *Only a hot Big Bang can maintain consistency with the current observed expansion of the universe*.

This too is in complete agreement with independent estimates of the age of the oldest stars in our galaxy. For four hundred years of modern science have produced a remarkable and consistent picture of the expanding universe. Everything holds together. The Big Bang picture is in good shape.

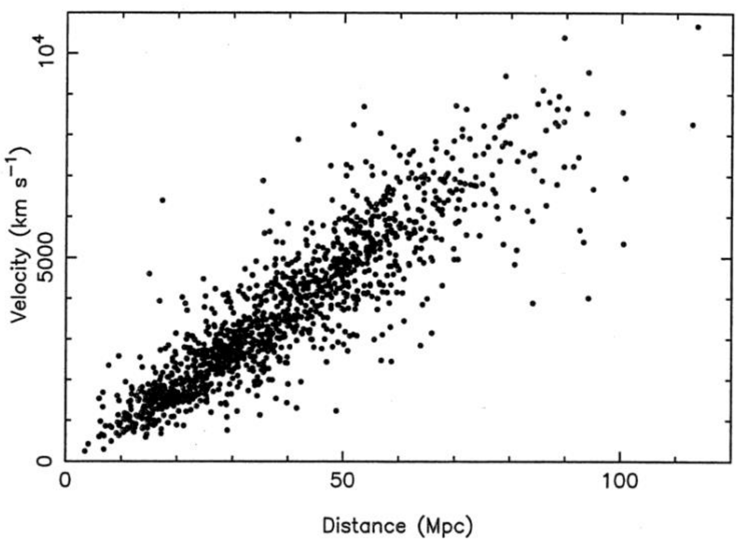

Figure (2): A plot of velocity versus estimated distance for a set of 1355 galaxies. A straight line relation implies Hubble's Law. The scatter of the data is due to observational uncertainties and random galaxy motions, but the best fit accurately gives Hubble's law.

2.2 Theory:

"A relation between distance and radial velocity among extra-galactic nebulae"[10] , that led to a turning point in understanding of the universe. In his short paper, Hubble presented the observational evidence for one of science's greatest discoveries—the expanding universe. Hubble showed that galaxies are receding away from us with a velocity that is proportional to their distance from us: more distant galaxies recede faster than nearby galaxies. Hubble's classic graph of the observed velocity

vs. distance for nearby galaxies is presented in Fig. 1; this graph has become a scientific landmark that is regularly reproduced
in astronomy textbooks. The graph reveals a linear relation between galaxy velocity (V) and its distance (d)

$$V = Ho \times d \qquad (1)$$

This relation is the well-known Hubble Law (and its graphic representation is the Hubble Diagram). It indicates a constant expansion of the cosmos where, like in an expanding raisin cake that swells in size, galaxies, like the raisins, recede from each other at a constant speed per unit distance; thus, more distant objects move faster than nearby ones. The slope of the relation, Ho, is the Hubble Constant; it represents the constant rate of cosmic expansion caused by the
stretching of space-time itself.
1 Mpc = 10^6 parsec = 3.26×10^6 light year.
The inverse of the Hubble Constant is the Hubble Time,

$$t_H = d/V = 1/Ho \qquad (2)$$

It reflects the time since a linear cosmic expansion has begun (extrapolating a linear Hubble Law back to time t = 0); it is thus related to the age of the Universe from the Big-Bang to today. For the above value of Ho,
$t_H = 1/Ho \sim 14$ billion years.

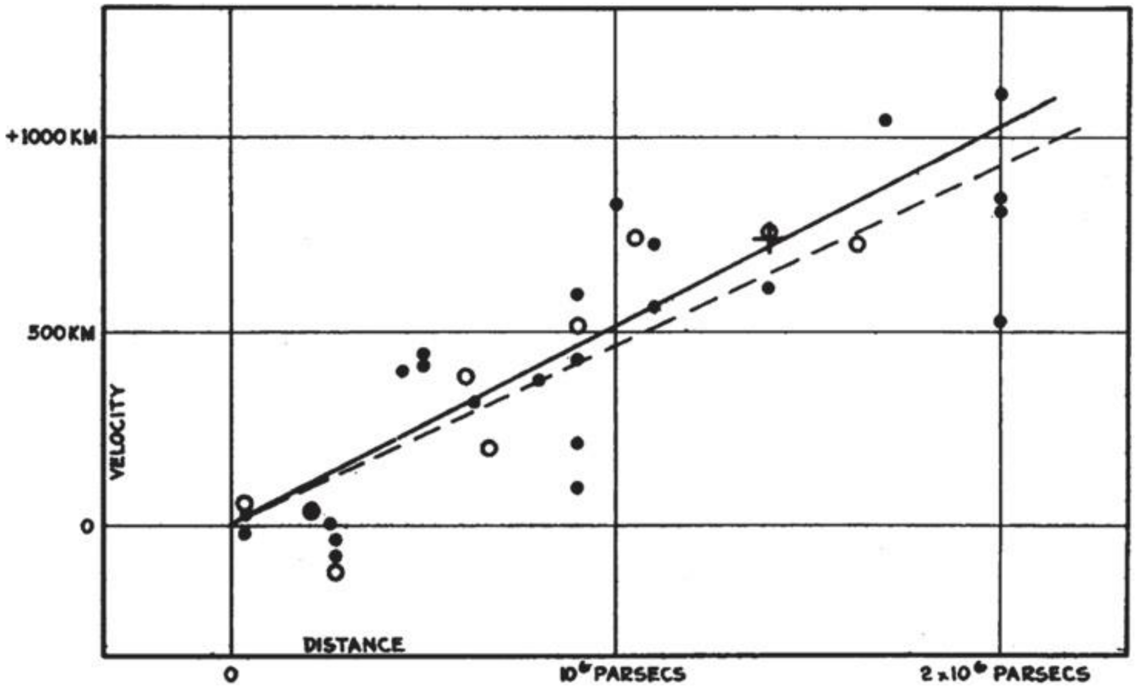

Fig. 3. Velocity–distance relation among extragalactic nebulae. “Radial velocities, corrected for solar motion, are plotted against distances estimated from involved stars and mean luminosities of nebulae in a cluster. The black discs and full line represent the solution for solar motion using the nebulae individually; the circles and broken line represent the solution combining the nebulae into groups; the cross represents the mean velocity corresponding to the mean distance of 22 nebulae whose distances could not be estimated individually”. (Note: Velocity units should be in kilometers per second.)[10]

Chapter Three:

3.1 Data and Methods:

In this paper, the values of the velocity and distances of 10 supernova galaxies have been collected in the literature and published papers (from references 11 to 20). The values together with complete information of the data are listed in table (1) below.

Table (1): Distance in MPc, velocity in Km/sec, Ho values and source of the data.

Distance MPc	Velocity Km/Sec	Supernova	Host galaxy	Estimated Ho, Km.S^{-1} MPc^{-1}	Reference
6	500	SN2000cx	NGC524	71.60	Tonry et al 2001
8	650	SN1994D	NGC4626	73.24	Cantiello et al 2018b
10	800	SN2007 on	NGC1404	70.50	Blakslee et al 2009
17	1300	SN2012cg	NGC1316	69.18	Cantiello et al 2013
20	1700	SN1980N	NGC 7619	72.84	Mie et al 2003
26	2000	SN2003hv	NGC1201	71.51	Ajhar et al 2001
33	2300	SN2008Q	NGC7619	67.80	Cantiello et al 2007
31	2100	SN1983G	NGC4753	70.03	Brout&Scolnic 2020
52	3600	SN2014bv	NGC4258	70.10	Riess et al 2016
25	1750	SN2015bp	NGC4258	70.14	Hoffman et al 2016
Average				70.69	

3.2 Results and Discussion:

Using excel sheet, a plot of the graph of the velocity of the galaxies as coordinate against their distances as abscissa has been carried out. A straight line has been fitted into the plotted data by least square method (linear regression) . The result of the fitting is shown in figure (4) below.

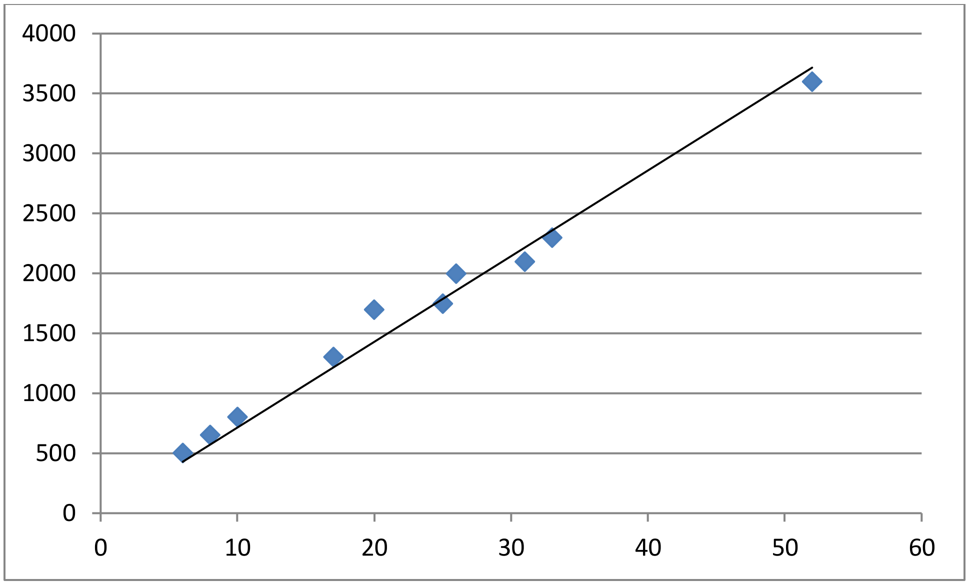

Figure (4): Graph of Velocity in Km./Sec on Y-axis against Distance in MPc on X-axis.

From the fitted straight line has a formula in the form of equation (1) above:

$V=H_o d$ (3) Hubble's Law

The slope of the graph is = H_o = 71.47 KmS^{-1} MPc^{-1}

Thus the formula becomes

V= 71.47 d (4) Hubble's Law

Having the correlation coefficient of R= 0.99. This indicates the degree dependence of the velocity of the moving galaxies on their distances. It can bee seen that the value of Ho obtained in this work (71.47 KmS-1MPc-1 is in a very good approximation of the results obtained by other authers in the past.

The percentage error was also calculated using the equation:

Percentage error=100x (Approximate value-Exact value)/Exact value (5)

The calculation gave the result:

Percentage error = 100x (71.47-70.69)/70.69

= 1.1%

The error is law and the outcome is promising, and can be used to know the velocity of other galaxies by using equation (4) , which was obtained in this research work.

Chapter four:

4.1 Conclusions:

From the results and analysis carried out in this research work, the following conclusions can be made:

1. Regression analysis, least square method is a very good statistical method for the calibration and determination of Hubble constant
2. Hubble's law is an accurate formula which can be used for the proof of the expansion of the universe.
3. Hubble constant Ho is a suitable value for the estimation of the age of the universe.

4.2 Suggestions for future work:

1. Collection of more data of velocity and distances of galaxies will strength the results and reduces the percentage error.
2. Use of other software such as SPASS for the analysis and determination of Hubble constant and age of the universe.

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