Global Scientific JOURNALS

GSJ: Volume 13, Issue 3, March 2025, Online: ISSN 2320-9186
www.globalscientificjournal.com

A CRITICAL REVIEW OF THE PROBLEM OF MISSING MASS

(Astrophysics Section)

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ABSTRACT

The present communication proposes to undertake a review of the problem dark matter with a purpose to investigate and understand the mysteries connected with origin, evolution, formation, nature, content and ultimate fate of the entire universe at large and the composition of matter in the universe in particular. Both the observational evidences and the experimental findings have confirmed that dark matter is broadly composed of Baryonic Matter (i.e. ordinary matter) and Non-Baryonic Matter, which is further divide into Hot Dark Matter (HDM) and Cold Dark Matter (CDM). The present communication attempts to underline the details of these contents of dark matter including the implications connected with the concepts of dark energy, responsible for the accelerating pace of the universe's ongoing expansion and flat geometry. The importance of the cosmological constant in reference to dark energy has also been brought home.

Keywords: Dark Matter, Dark Energy and Cosmological Constant

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1. Introduction :-

Astronomers like to call all materials including distant stars made up of protons, neutrons and electrons " Baryonic Matter", ordinary atoms. Observations of the current abundances of light elements such as hydrogen, helium, lithium and other light elements which were created in the Big Bang and the Big Bang Nucleosynthesis (BBN) resulting into the formation of the elements in the early universe, within the three minutes of the Big Bang, all indicate that the density of baryons (protons + neutrons) in the universe can be no more than about 5% of the critical density. Further, the measurement of the gravitational force holding galactic clusters, galaxies and solar system together has led to conclude that only 5% of it consists of ordinary matter. In other words, if we pile up all the known matter in the universe – all the stars, planets, cosmic dust and gases and measure the gravitational effect their combined mass exerts, it would be only about 5% of the force necessary to hold things together. Where is the remaining 95% of the "missing mass", which has been real puzzle and is being searched by scientists and is of fundamental interest to astronomers, astrophysicists, cosmologists and nuclear and particle physicists. It's as if more than 90% of the universe consists of something other than atoms and photons, the bedrock of ordinary matter and energy.

The unseen force holding things together, scientists conclude, must be produced by other things – which, for the lack of better terms, are classified as "dark matter" and "dark energy" ("dark" meaning objects emit no radiation directly perceptible to us, whether visible light or otherwise). Dark matter, scientists believe, coexists with normal matter, but the candidates for dark matter are still under debate and search. Even stranger than dark matter is dark energy, for it appears to work across larger distances and is an opposite way to gravity. This antigravity force seems responsible for the accelerating pace of universe's ongoing expansion. The existence of dark matter appears to have been substantiated recently when astronomers observed two large clusters of galaxies passing through each other. Dark matter and normal matter seem to have been wrenched apart by the tremendous collision of two galactic clusters. The discovery, NASA's Chandra X-ray observatory and other telescopes, provide supporting evidence for dark matter. Its presence is inferred indirectly from the motion of astronomical objects, specifically stellar, galactic and galaxy cluster/ super clusters. It is also required in order to enable "gravity" to amplify the small fluctuations in the Cosmic Microwave Background (CMB) enough to form the large- scale structures that we see in the universe today.

In astrophysics and cosmology, "dark matter" is a hypothetical form of matter that does not emit or reflect enough electromagnetic radiation to be observed directly, but whose presence can be inferred from the gravitational effects on the visible matter. According to present observations of structures larger than galaxies, as well as Big Bang cosmology, dark matter component has vastly more mass than the "visible" component of the universe [1], which of course interacts with electromagnetic radiation. Therefore, it can be rightly remarked that dark matter plays a central role in structure formation and galaxy evolution and has measurable effect on the anisotrophy of Cosmic Microwave Background (CMB). The observed phenomena consistent with the dark matter observations include the :

(a) rotational speed of galaxies
(b) orbital velocities of galaxies in clusters
(c) gravitational lensing of background objects by galaxy clusters such as Bullet Cluster
(d) temperature distribution of hot gases in galaxies and cluster of galaxies

The Big Bang model is based on the cosmological principle which assumes that matter in the universe is uniformly distributed on all scales – large and small. This is very useful approximation that allows one to develop the basic Big Bang scenario, but a more complete understanding of our universe requires going beyond the cosmological principle to search the answers of the puzzles of the standard Big Bang model such as:

(!) Structures in the universe – The Big Bang theory makes no attempt to explain how structures like stars and galaxies came to exist in the universe.
(!!) Fluctuations in the Cosmic Microwave Background (CMB) radiation – The temperature of the CMB is observed to vary slightly across the sky. What produced these fluctuations and how do they relate to stars and galaxies?

The Big Bang model does not account for the needed fluctuations to produce the structures like stars, galaxies, cluster of galaxies and super clusters. Most of the cosmologists believe that the galaxies that we observe today grew from the gravitational pull of small fluctuations in the nearly uniform density of the early universe. These fluctuations leave an imprint in the Cosmic Microwave Background (CMB) radiation in the form of temperature fluctuations from point to point across the sky. The tiny temperature variations or fluctuations offer great insight into the origin, evolution and content of the universe. The Cosmic Background Explorer (COBE) satellite in 1992 and Wilkinson Microwave Anisotrophy Probe (WAMP) satellite in 2001 detected cosmological fluctuations in the microwave background temperature and confirmed by the Far Infra Red Survey (FIRS) balloon – bore experiment. It is worth to mention that WAMP detected much finer features than are visible in the COBE maps in the sky (Fig. 1).

2. WMAP and Dark Matter/ Dark Energy:-

By making accurate measurements of the Cosmic Microwave Background (CMB) fluctuations by WMAP (Wilkinson Microwave Anisotrophy Probe) which is a satellite mission to survey the sky and measure the temperature of the radiant heat left over from the Big Bang and was launched by a Delta II rocket on June 30, 2001 which is joint project between NASA Goddard Space Flight Center and Princeton University led by Professor Charles L. Bennett [2] of Jons Hopkins University and named after Dr. David Wilkinson, a pioneer in the study of Cosmic Microwave Background (CMB) radiation, who died in September 2002. WMAP is able to measure the basic parameters of the Big Bang model including the density and composition of the universe. WMAP measures the relative density of "Baryonic" and "Non-Baryonic" matter to an accuracy of better than a few percent of overall density. It is also able to determine some of the properties of the non-baryonic matter, the interaction of the non-baryonic matter with itself, its mass and its interaction with ordinary matter – all affect the details of the Cosmic Microwave Background fluctuation spectrum.

WMAP determined that the universe is "flat", from which it follows that the mean energy density in the universe is equal to the "critical density" i.e., the total Omega is 1. This is equivalent to 9.9×10^{-30} g/cm^3, which is equivalent to only 5.9 protons per cubic meter. The observation that Omega is fairly close to 1 today, means that it must have been even closure to 1 in the past. It is much more appealing to consider that we do not live at a special epoch, so that Omega is still close to 1. But then we need to explain why Omega started out very close to 1 in the early universe. The theory of inflation provides just such a justification – most versions of inflation predict that the early universe was driven extremely close to flat and it is still very close to flat. If this is so, then at least 90% energy density of the universe is dark. Although the universe is flat, that does not mean that matter makes up the critical density. IN addition to "dark matter", there is "dark energy", e.g. a "Cosmological Constant", that perhaps needs to be included in accounting and Physically equivalent to "vacuum energy". As the expansion of the universe continues, matter diluted even further and the cosmological constant becomes dominant, leading to an acceleration in the universe's expansion. Dark energy causes expansion of the universe at an "accelerating rate" because it has strong "negative pressure", which in turn causes "gravitational repulsion". One hypothesis is that "dark energy" is the energy of "virtual particles", which mathematically must exist in vacuum due to uncertainty principle.

The breakup of the total density of the universe (Fig. 2) is now clear and the universe is made up of:

(!) 4.6% Atoms i.e., Visible ordinary baryonic matter. More than 95% of the energy density in the universe is in a form that has never been directly detected in the laboratory. The actual density of atoms is equivalent to roughly 1 proton per 4 cubic meters.

(!!) 23% non-baryonic dark matter. Dark Matter [3] is likely to be composed of one or more species of sub-atomic particles that interact very weakly with ordinary matter. The gravitational effects of dark matter are well understood, as it behaves like cold, non-radiative dust which forms halos around galaxies. Dark matter has never been detected in the laboratory and the particle physics nature of the dark matter is completely unknown and still under investigation. However, there are a number of candidates such as a stable super symmetric particle, a weakly interacting massive particle, an axion and a massive compact halo object.

(!!!) 72% Dark Energy – which is distributed diffusely in space and the term "dark energy" was coined by Michael Turner in 1998 [4]. The first observational hints of dark energy in the universe date back to the 1980's when astronomers were trying to understand how clusters of galaxies were formed. In the 1990's observations of supernova were used to trace the expansion history of the universe and the big surprise was that the expansion appeared to be speeding up, rather than slowing down. In 1998, observations of type 1a supernovae ("one-A") by the Supernova Cosmology Project at Lawrence Berkeley Laboratory and the High-z Supernova Search Team suggested that the expansion of the universe is "accelerating" came as a first direct evidence from Riess et al [5] and later confirmed by Perlmutter et al [6]. Supernovae are the best-known standard candles across the cosmological distance and allow the expansion history of the universe to be measured by looking at the relationship between the distance to an object and its red shift, which gives how fast it is receding from us. Measurements of the cosmic microwave background radiation, gravitational lensing and large scale structure of the cosmos as well as improved measurements of supernovae have been found to be consistent with the Lambda-CDM model [7] which has been referred to as the "standard model" of cosmology because of its precise agreement with observations. The results of this model are consistent with cosmological observations and the latest being the 2005 Supernova Legacy Survey (SNLS). The results from SNLS reveal that the average behaviour (i.e. equation of state) of the dark energy behaves like Einstein's cosmological constant to a precision of 10% as indicated by Pierre Astier et al [8]. Recent results from the Hubble Space Telescope Higher-z Team indicate that dark energy has been present for at least 9 billion years and during the period preceding cosmic acceleration.

According to the Lambda-CDM model of the universe, WMAP data shows that the age of the observable universe is 13.73 ± 0.12 billion years old, with a Hubble Constant of 70.1±1.3 Kms^{-1} Mpc^{-1}. It also shows that the universe is composed of 4.6% of ordinary baryonic matter, 23% of non-baryonic dark matter, which does not emit or absorb light, 72% 0f a mysterious dark energy, which acts to accelerate expansion and <1%neutrinos. The data is consistent with flat geometry, with the ratio of energy density to the critical density i.e. Omega (Ω) = 1.02 ± 0.02. WMAP results support Lambda- CDM model, as well as the cosmological scenarios of cosmic inflation and provide independent evidence for cosmic neutrino background radiation [9].

3. Observational evidence of dark matter:-

The first to provide evidence and infer the existence of a phenomena that has come to be called "dark matter" was Swiss astrophysicist Fritz Zwicky, of the California Institute of Technology (Caltech) in 1938 [10]. Zwicky applied the virial theorem to study a small group of seven galaxies in the coma cluster in order to obtain evidence of unseen mass, because much of the evidence for dark mass comes from the study of the motions of galaxies. Zwicky estimated the cluster's total mass by studying the dispersion speeds of these seven galaxies near their edges. By using Newton's law, he calculated its mass known as "dynamic mass", then compared it with the "luminous mass", which is the mass calculated from the quantity of light emitted (i.e. by measuring their brightness) by the cluster by using the assumption of a reasonable distribution of star population in the galaxies.

Zwicky was surprised to note that the speeds observed in the coma cluster were very high. The "dynamic mass" which is normally considered the only "true mass", as it is a measurement of the mass deduced from its gravitational influence, was found to be 400 times larger than the "luminous mass". This discrepancy in the observed (luminous) and computed (dynamic) masses is now known as the "missing mass problem" [11]. Actually, "missing matter" may be misleading- it's really the light that is missing [12]. Alternatively, the gravity of the visible galaxies in the cluster would be far too small for such fast orbits, so something extra was required as per Zwicky, which he considered must be some non-visible form of matter, which would provide enough of the mass and gravity to hold the cluster together.

For 40 years after Zwicky initial observations, no other corroborating observations indicated that mass to light ratio was anything other rhan unity (a high mass-to-light ratio indicates the presence of dark matter). In 1970s, the American astronomer Vera Rubin studied the rotation of spiral galaxies to know the difference between the dynamic and luminous mass of the galaxy clusters. By analyzing the spiral galaxies spectrum such as the "Andromeda" galaxy, it is possible to calculate curve from its rotation.

The "curve of rotation", is a direct measurement of the total distribution of matter in the galaxy and as well as a good measure of the "dynamic mass". The curve of rotation, after a maximum, start to go decrease again. However, Vera Rubin observed that the stars located in the periphery of "Andromeda" galaxy – as far the other spiral galaxies - appeared to rotate too fast such that speed remained almost "constant" when the distance to the center increased i.e., most stars in the spiral galaxies orbit at roughly the same speed, which implied that their mass densities were uniform well beyond the location with most of the stars.

Hence, the galactic rotation curves, which illustrate the velocity of rotation versus the distance from the galactic center, cannot be explained by only the "visible matter". A possible explanation was to think of the existence of a "huge non-visible matter halo" surrounding the galaxies; a halo contains up to 90% of the galaxies total mass. Eventually, when other astronomers began to corroborate the work of Vera Rubin and it soon became well established that most galaxies were in fact dominated by "dark matter" [13] ; exceptions appeared to be the galaxies with mass-to-light ratio close to stars. Measurements of velocity curves in spiral galaxies were soon followed up with velocity dispersions of elliptical galaxies. While sometimes appearing with lower mass-to-light ratios, the measurements of elliptical galaxies still indicate a relatively high dark matter content [14]. Likewise measurements of the diffuse interstellar gas found at the edge of galaxies indicate not only dark matter distributions that extend beyond the visible limit of the galaxies are virilized up to ten times their visible radii. Therefore, the "conclusion" is – galaxies show signs of being composed largely of a roughly spherically symmetric, centrally concentrated " halo of dark matter" with the visible matter concentrated in a disc at the center. Indeed, astronomers consider that galaxies which contain "non-luminous stars" such as – dwarf brown, dwarf white, black holes, neutron stars also form good candidates for "dark matter" and represent a large part of the total mass of the galaxy, but not visible by optical instruments.

Gravitational lensing [15] (which occurs when a brown dwarf or a black hole passes between a light source, such as star or a galaxy and an observer on the earth. The dark matter acts as a lens on account of gravity bending light rays as per Einstein) can be used to directly map the total distribution of mass including both the dark matter and visible matter, by determining distances and the duration of the lens effect. In most regions of the universe, dark matter and visible material are found together [16], as expected because of their mutual gravitational attraction. However, the different forms of matter were separated by the violent collision of the clusters of galaxies about 150 million years ago, a system known as the Bullet cluster [17]. Researchers mapped the distribution of mass using measurements of gravitational lensing and compared it to X-ray maps showing hot gases, thought to constitute the large majority of ordinary matter in the clusters.

In 2005, astronomers from Cardiff University claimed to discover a galaxy made "almost entirely of dark matter", 50 million light years away in the Virgo cluster, which was named VIRGOHI 21 [18] and was seen with radio frequency observations of hydrogen. The Milky Way Galaxy is believed to have roughly 10 times as much dark matter as ordinary matter. However, there are places where "dark matter" seems to be a small component or totally absent. Globular clusters show no evidence of dark matter, though their orbital interactions with galaxies do show evidence for galactic dark matter. There are also a small number of galaxies, like NGC 3379 whose measured orbital velocity of its gas clouds, show that it contains almost "no dark matter" at all [19].

4, **Missing mass in clusters of galaxies:-**

Dark matter affects galaxy clusters as well. X-ray measurements of hot inter cluster gas corresponds closely to Zwicky's observations of mass-to-light ratios for large clusters of nearly 10 to 1.

The galaxy cluster Abell 2029 is composed of galaxies enveloped in a cloud of hot gas and an amount of dark matter equivalent to more than 10^{14} Suns has been observed. At the center of this cluster is an enormous, elliptically shaped galaxy that is thought to have been formed from the mergers of many small galaxies [20]. The measured orbital velocities of galaxies within galactic clusters have been found to be consistent with dark matter observations. By measuring how the background galaxies are distorted by the foreground clusters, astronomers can measure the mass in the cluster. The mass in the cluster is more than five times larger than the inferred mass in the visible stars, gas and dust.

Gravitational "strong" lensing, which looks for the observed distortions of the background galaxies into arcs when the light passes through a gravitational lens, has been observed around a few distant clusters including Abell 1689. By measuring the distortion geometry, the mass of the cluster causing the phenomena can be obtained and the estimates of the mass-to-light ratios correspond to the dynamical dark matter measurements of clusters.

Gravitational "weak" lensing, which looks at "minute distortions" of galaxies observed in the vast galaxy surveys due to foreground objects through "statistical analysis". By measuring the "shear deformation" of the adjacent background galaxies, astrophysicists can characterize the mean distortion of "dark matter" by "statistical means" and have found mass-to-light ratios that correspond to dark matter densities predicted by other large-scale structure measurements.

5. Contents of the dark matter:-

Dark Matter (DM) can neither be seen nor can be touched, but its existence is implied by observations, investigations, measurements and experimental techniques. Possibilities for dark matter range from tiny subatomic particles weighing 100,000 times less than an electron to black holes with masses million of times that of the Sun [21]. Dark matter (DM) candidates are usually split into two broad categories, with second category being further sub-divided:

5.1 Ordinary Matter or Baryonic Matter
5.2 Non-Baryonic Matter
5.2.1 Hot Dark Matter (HDM)
5.2.2 Cold Dark Matter (CDM)

depending on their respective masses and speeds. HDM candidates move rapidly with speeds close to light (hence "hot") such as neutrino, while CDM candidates travel at slow speed (hence "cold"). The two important candidates for cold dark matter (CDM) are ;

5.2.2 (a) MACHOs (Massive Astrophysical Compact Halo Objects) are the big strong dark matter objects ranging in size from small stars, gas clouds to super massive black holes and are made of ordinary or baryonic matter.

5.2.2 (b) WIMPs (Weakly Interacting Massive Particles) are little weak subatomic dark matter candidates, which are thought to be made of stuff other than ordinary matter, called non-baryonic matter.

Astronomers search for MACHOs [22] and particle physicists look for WIMPs [23]. It can rightly be remarked that in later decades the search for dark matter has shifted from Heavens to Earth. In fact, the search for dark matter went underground. Today there are experiments searching for dark matter hundred and thousand of meters below ground in mines, road tunnels and other subterranean locations. These experiments are becoming more sensitive every year and are beginning to test new models and theories in particle physics and cosmology.

6. Dark Matter Composition:

6.1 Hot Dark Matter (HDM) and Cold Dark Matter (CDM) :-

Understanding the formation and evolution of the largest and earliest structures (i.e., quasars, galaxies, clusters and super clusters) is one of the major efforts in cosmology. Two main theories clash when they try to describe the nature of this "dark matter" [24]. These theories rely on the mass and speed of the particles composing the dark matter. In case of the dark matter known as "hot", the particles have speeds close to light, while the particles of dark matter known as "cold" are more massive and slower.

The speed of these particles is crucial to the Big Bang model and the order of formation of the universe's great structures. If the universe composition is primarily made of "hot dark matter", the very high speed of particles would initially prevent the formation of a structure smaller than the super cluster of galaxies dividing up in a galaxy cluster then in galaxies, then in smaller structures. It is the scenario known as "up bottom", since the largest structures are formed initially, for then dividing. The best candidate to constitute the hot dark matter is "neutrino", which is considered to have a very "small mass" and do not interact via either the electromagnetic or the strong nuclear fore, so difficult to detect.

On the other hand, if the "cold dark matter", is the main component of the universe, the particles will go on a smaller distance and thus will erase the density's fluctuations on extents smaller than in case of hot dark matter. Observations suggest that structure formation in the universe proceeds "hierarchically" with smaller objects forming first, while the largest objects, such as super clusters, are still assembling. This implies that ordinary matter would then gather to form galaxies (starting from gas clouds and smaller structures), which themselves will gather in clusters, then super clusters. It is the scenario, known as "bottom up". In the "bottom up" model of structure formation, as the structures collapse (with the smallest structures collapsing first and followed by galaxies and then cluster of galaxies) in the evolving universe, they began to "light up" as the baryonic matter heats up through gravitational contraction and the objects approaches hydrostatic pressure balance. Ordinary baryonic matter had too high a temperature and too much pressure left over from the Big Bang to collapse and form smaller structures as stars. Thus, dark matter acts as a "compactor" of structure. The candidates for "cold dark matter" [25] are WIMPs (Non-Baryonoc Matter) and MACHOs (Baryonic Matter).

These two theories were defended by Y.B.Zeldovitch for the hot dark matter and James Peebles for the cold dark matter. Currently, it is the cold dark matter (CDM) which seems to be more consistent. Indeed, the galaxies are in dynamic balance, which shows that they were created before the clusters. However, the current theory introduces a little bit of hot dark matter (HDM) as it is necessary to explain the formation of galaxy clusters.

6.2 Ordinary or Baryonic Matter:- MACHOs ;

Massive Astrophysical Compact Halo Objects which have been dubbed as MACHOs are "non-luminous" that make up the halos around the galaxies and are detected by means of advance refined telescopes such as HST (Hubble Space Telescope), gravitational lensing and the gravitational effect of circling stars that they have on objects around them. MACHOs are thought to be primarily gas clouds, dead or unborn stars, brown dwarf stars and black holes and all contribute to gravitational field. Like many astronomical objects, their existence had been predicted by theory long before there was any proof. The existence of brown dwarfs was predicted by theory that describe star formation [26]. Black holes were predicted by Albert Einstein's General Theory of Relativity [27].

6.2.1 Gas Clouds:

In the 1990s, precise Cartographies of the universe X-ray emission sources highlighted the presence of gigantic ionized gas clouds (Thanks to Rose Satellite) within galactic clusters; clouds of several million degrees non-emitting in the visible field. Astronomers consider that these clouds contain ten times more matter than the galaxies of these clusters and are the proof of the presence of "dark matter" around the galaxies. Indeed, to reach high temperatures, the particles constituting the clouds must be accelerated at very high speeds (approximately 300 Km /s) and this acceleration comes from the force of gravitation. However, the quantity of gas is insufficient to generate such a gravitational field. Also, the stars alone cannot prevent the gas cloud from escaping. The gravitational influence of the "dark matter" is then necessary to explain the containment of these clouds near the galaxies.

6.2.2 Brown Dwarf:

Brown dwarf are made out of hydrogen – the same as our Sun but they are typically much smaller. Stars like our Sun form when a mass of hydrogen collapses under its own gravity and the intense pressure initiates a nuclear reaction, emitting light and energy. Brown dwarfs are different from normal stars. Because of their relatively low mass, brown dwarfs do not have enough gravity to ignite when they form. Thus, a brown dwarf is not a "real" star; it is an accumulation of hydrogen gas held together by gravity. Brown dwarfs give off some heat and a small amount of light. DDO 240 is a gas and dark matter rich dwarf galaxies [28].

6.2.3 Black Holes:

Black holes, unlike brown dwarfs, have an over abundance of matter. All that matter "collapses" under its own enormous gravity into relatively small area. The black hole is so dense that anything that comes too close to it, even light, cannot escape the pull of its gravitational field. Black holes emit no light; they are truly black.

Black holes [29] are really just the evolutionary end point of massive stars. As a star ends its life, much of its mass is thrown out in a supernova expansion or in a planetary nebula and what remains after the process is called a fairly massive burned out stellar remnant. The stellar remnant formation takes place in three possible ways depending on the initial masses of the star. Some stars may end life as white dwarfs, while others collapse to neutron stars and still others are doomed crunch all the way down as a black hole, a point of zero volume and infinite density, creating what is known as a singularity.

Cygnus X-1 is longest known of the black hole candidates. It is highly variable and irregular source with X-ray emission that flickers in hundredths of a second, because the random variations in the emitted x-rays indicates sign of the presence of a black hole. Cyg X-1 have a mass of about 7 solar masses. Another massive black hole is M33 X-7 and is found to have 16 times the Suns mass. Astronomers like Jeffery Silverman and Alexei Filippenko at the University of California, Berkeley, USA have confirmed the existence of the heaviest known black hole in the universe, known as IC 10X –1 discovered in 2007, is between 24 and 33 times the Suns mass. It is considered 18 billion times bigger than our Sun and 3.5 billion light years away. The mass of a black hole is determined either by gravitational lensing or by measuring the rotational velocities from the Doppler shifts of circling stars. Some astronomers speculate that there may be copious number of black holes comprising dark matter and super massive black holes are thought to power distant k quasers.

6.3 Non-Baryonic Matter;- WIMPs ;

Cosmologists speculate that the dark matter may be made of particles produced shortly after Big Bang and are very different from ordinary "baryonic matter". Cosmologists call these hypothetical particles WIMPs (Weakly Interacting Massive Particles) or "non-baryonic matter". One of the primary motivations for building "supercolliders" is to try to produce this matter in the laboratory. Since the universe was dense and hot in the early moments following the Big Bang, the universe itself was a "wonderful particle accelerator". Smaller than atoms, WIMPs are thought to have mass, but usually interact with baryonic matter gravitationally- they pass right through ordinary matter. Since each WIMP has only a small mass, there needs to be a large number of them to make up the bulk of the missing matter. That means that millions of WIMPs are passing through ordinary matter- the Earth and you and me- every few seconds. Although some particle physicists claim that WIMPs were proposed only because they provide a "quick fix" to the "missing mass problem", but most physicists believe that WIMPs do exist. But the problem with searching for WIMPs is that they rarely interact with matter, which makes them difficult to detect.

High particle physicists have proposed various candidates for non-baryonic matter, all of which may indicate new physics beyond the well tested Standard Model of particle physics. In the Standard Model, matter is made from quarks and leptons and there are four forces- gravity plus the strong, weak and electromagnetic forces- that can act between matter particles. The forces are carried by particles such as photons, which is responsible for electromagnetism and the W and Z bosons, which carry the unified electroweak forces. The Standard Model is completed by the three families of neutrinos corresponding to three families of leptons.

6.3.1 The Neutrino:

It is a particle introduced first time in 1930 by W. Pauli, before the discovery of neutron and which was detected in 1956 by F. Reines and C.L. Cowan. Currently, scientists believe that only six leptons exist : the electron, the muon and the tau and a neutrino associates with each such as (e^-, ν_e), (μ^-, ν_μ) and (τ^-,ν_τ). Each of these six leptons has an antiparticle. The tau lepton, discovered in 1975, has a mass equal to about twice that of the proton and the tau neutrino was discovered in July, 2000 at Fermi Lab. The neutrino- insensitive to electromagnetic forces and strong nuclear force- is emitted during a beta disintegration, along with an electron. The neutrino does not interact much with other particles, which makes it a good candidate for "dark matter".

Although the neutrino has "zero mass" in the Standard Model, but the various extensions of the model do allow it to have a mass. Moreover, with the "problem of missing mass" of the universe, the physicists wondered if the neutrino would have a "non-zero mass", especially as the neutrino is the most abundant particle in the universe, after the photon. In recent years, observations of solar and atmospheric neutrinos have indicated that one flavour (muon neutrino) can change into another (tau neutrino) on their journey through earth, which can only happen if the neutrino has mass [30]. The search for dark matter has indicated that the neutrino had a mass in the range 10 – 15 ev c^{-2} (the electron, in comparison, has a mass of 500,000 ev c^{-2}).

The best evidence for neutrino mass comes from SuperKamiokande experiment, which is situated 1000 meters below ground in a lead and zinc mine in Japan (Refer "Neutrino mass discovered" by Lincoln Wolfenstein, Physics World, July 1998 pp 17-18). The results of this experiment indicate a mass difference of –0.05 ev c^{-2} between the muon neutrino and the tau neutrino and such a small mass difference suggests that the neutrino masses themselves lie below 1ev c^{-2}, which is cosmologically not significant, but contributes to the non-baryonic dark matter in the universe. The SNO (Sudbury Neutrino Observatory) experiment also speculates too small a mass to neutrino. The neutrinos, at best represent 18% of the universe's total mass.

6.3.2 Supersymmetric (SUSY) extension of the Standard Model :- The Neutralino :

Another candidate for non-baryonic dark matter is the family of heavy neutral particles. The leading candidate in this class is the neutralino [31], a particle predicted by supersymmetric (SUSY) extension of the standard model.

Supersymmetry is the most convincing theory that explains the particle-mass hierarchy and can unify the strong and electroweak forces. In supersymmetry, all the particles in the standard model have superpartners. The idea of supersymmetry is to associate "each boson to a fermion" and vice versa. Each particle is then given a superpartner, having identical properties (mass, load), but with a spin which differs by ½.. Thus, the number of particles is doubled. For example, the photon is accompanied by a photino, the graviton by a gravitino, the electron by a selectron, etc. Following the impossibility to detect 511 Kev boson (the electron partner), the physicists had to re-examine the idea of an exact symmetry. Symmetry is "broken" and superpartners have a very important mass.

In many SUSY models, the lightest supersymmetric particle (LSP) is a "neutralino" with a mass between 20 Gev c^{-2} and 1000 Gev c^{-2} (that is 20 to 1000 times that of the proton mass). In most of the supersymmetric theories (without violation of the R- parity), the LSP is a stable particle because it cannot disintegrate in a lighter particle. It is of neutral color and electric charge and is only sensitive to weak interaction.

Neutralino is catch all name for the lightest neutral SUSY particle. It is likely to be a quantum superposition of the superpartners of the two neutral Higgs boson, the Z- boson and B- boson (which is a neutral superposition of the W and Z bosons). Accelerators can be used to recreate the conditions that existed shortly after the Big Bang and in which "neutralinos" might have been formed and the latest results from the LEP accelerator at CERN (European Center for Nuclear Research) Laboratory in Geneva place a lower limit of 34Gev c^{-2} on the "neutralino mass".

6.3.3 The Axions:-

Another theoretical particle, the axion – a very light particle with masses in the range 10^{-4} to 10^{-6} ev c^{-2} have been predicted to exist by several theories [32]. Although an extra light, stable particle but practically undetectable presently – make another good candidate for dark matter. It is speculated that this particle would solve problems arising from the antimatter (why matter won over antimatter). Various programs were launched since 1996 to try to detect axions.

6.4 Detection of WIMPs:-

Several groups around the world are carrying out "non-accelerator" experiments to search for WIMPs that have been left over after the Big Bang. Unfortunately, for WIMP interaction there are millions of background events. These events arise from cosmic rays bombarding the surface of the earth and from radioactivity in both the surroundings and the material of the detector itself. To escape the cosmic radiation, most dark matter searches are performed deep underground. These groups include the authors and colleagues at Imperial College, Rutherford Appleton Laboratory and Sheffield University in the UK Dark Matter Collaboration (UKDMC), the Italian / Chinese DAMA Collaboration and the Cryogenic Dark Matter Search (CDMS) in the US.

The UKDMC experiments comprise several NaI crystals (Due to low mass of Sodiun and high mass of Iodine, NaI scintillation detectors give good sensitivity over a wide range of WIMP masses) ranging from 1 to 10 Kg and is located 1100 meters below the ground in the Boulby salt mine in North Yorkshire, while the DAMA experiments (using a 100 Kg NaI array to look for a different signature of the WIMP interaction) is located at Gran Sasso National Laboratory in Italy. The Gran Sasso lab was built 1400 meters below ground alongside a tunnel through a mountain on the road from Rome to L' Aquila. However, the use of a cosmic –ray veto means that the CDMS experiments is located just 10 meters underground at Stanford University in California and uses both Cryogenic Germanium and Silicon Detectors. The experiments such as DAMA / NaI, DAMA /LIBRA (uses NaI detector of 250 Kg) and EGRET claiming positive evidence for dark matter are confronted with the negative results of other experiments. Several searches for "dark matter" are currently underway, including Cryogenic Dark Matter Search (CDMS) in the Soudan mine in Minnesota (using Germanium / Silicon targets of 10 Kg which when struck by a WIMP generates heat), the XENON detector (in which nuclear recoil produces both an ionization and a scintillation signal) uses Xenon to measure the flash of light that occurs on those rare occasions when a WIMP strikes a Xenon nucleus, CRESST experiments (uses low temperature detectors based on calcium tungstate) at Gran Sasso and the ZEPLIN project at Boulby underground Laboratory (UK), DRIFT detector (which uses a low pressure Xenon gas target are in developing stage to be operational).

Experiments with the LHC (Large Hadron Collider) at CERN Laboratory in Geneva may be able to detect WIMPs. The GLAST space telescope, planned for launch in October 2008, searching gamma wave events, may also detect WIMPS.

The fact is scientists are tossing theories back and forth. Some are skeptical of WIMPs; whereas particle physicists say MACHOs will never account for 90% of the universe.

6.5 Alternative Explanations:-

6.5.1 Modification of gravity: -

A proposed alternative to physical dark matter particles has been to suppose that the observed inconsistencies are due to incomplete understanding of gravitation. To explain the observations, the gravitational force has to become stronger than the Newtonian approximation at great distances or in weak fields. One of the proposed models is Modified Newtonian Dynamics (MOND), which corrects Newton's law at small acceleration. The leading relativistic MOND theory, proposed by Jacob Bekenstein in 2004 is called TeVeS for Tensor-Vector- Scalar and solves many of the problems of earlier attempts. However, a study in August 2006 reported an observation of a pair of colliding galaxy clusters whose behaviour was found not compatible with any current modified gravity theories [33]. But, in 2007 astronomer John W. Moffatt proposed a theory of modified gravity (MOG) based on the Non-symmetric Gravitational Theory (NGT) that accounts for the behaviour of colliding galaxies.

6.5.2 Quantum mechanical explanations:-

In another class of theories one attempts to reconcile gravitation with quantum mechanics and obtains corrections to the conventional gravitational interaction. In Scalar-tensor theories, scalar fields like the "Higgs field" couple to the curvature given through the Riemann tensor. In many of such theories, the scalar field equals the inflation field, which is needed to explain the inflation of the universe after the Big Bang, as the dominating factor of the quintessence or dark energy. According to Reuter and Weyer [34] that the Newton's constant and the cosmological constant can be considered as scalar functions on space time if one associate renormalization scales to the points of space time.

6.5.3 Recent findings:-

In May 2008, astronomers have found some matter that had been "missing" in deep space and claimed that it is "strung along web-like filaments" that form the "backbone" of the universe (Fig. 3). This study has recently been published by Mike Shull of the University of Colorado in the Astrophysical Journal. The ethereal strands of hydrogen and oxygen atoms could account for up to half the matter that scientists knew must be there but simply could not see, the researchers reported. The team of Mike Shull has now claimed that about half of the missing baryonic matter has turned up, seen by the orbiting Hubble Space Telescope (HST) and Nasa's Far Ultraviolet Spectroscopic Explorer (FUSE). The matter is spread as superheated oxygen and hydrogen in what looked like vast empty spaces between galaxies.

However, observations of a quasar- a bright object far off in space- show its light is diffused much as a lighthouse can reflect on a thin fog that was invisible in the dark. According to Shull – "It is kind of like a spider web. The gravity of the spider web is what produced what we see. It is very thin. Some of it is very hot gas, almost a million degree." This is where the "dark matter" comes in. This dark matter is heating up the gas and has gravity. Its pull the gas in and causes what is called as "sonic booms" – shock waves as per Shull. This shock heats up the gas to a million degree and makes it even harder to see. The atoms of oxygen are in a stripped –down, ionized form. Five of the eight electrons are gone, emitting an ultraviolet spectrum of light that instruments aboard FUSE and Hubble Space Telescope (HST) can spot.

Shull has claimed that these web-like filaments of matter are the structure upon which the galaxies form and so when we look at the distribution of galaxies on a very large scale, we see they are not uniform.

7. Dark Energy:-

In physical cosmology, dark energy is a hypothetical form of energy that permeates all of space and tends to increase the rate of expansion of the universe [35]. Assuming the existence of dark energy is the most popular way to explain recent observations that the universe appears to be "expanding at an accelerating rate roughly 5 billion years ago" (Fig 4). If the universe is to be "flat "as per WMAP measurements, then there must be an additional component making up 72% of the energy density of the universe, which is referred as "dark energy". Thus, in the standard model of cosmology because of its precise agreement with observations and referred as "Lambda-CDM model" [obtained by adding the cosmological constant to Friedmann-Lemaitree-Robertson- Walker (FLRW) metric], dark energy currently accounts for almost three quarters of the total mass energy of the universe. The "exact nature" of this "dark energy" is a matter of speculation. It is known to be very homogenous, not very dense and is not known to interact through any of the fundamental forces other than gravity. Since it is not very dense- roughly 10^{-29} grams per cubic centimeter- it is hard to imagine experiments to detect it in the laboratory. Dark energy can only have such a profound impact on the universe, making up 72% of all energy, because it uniformly fills otherwise empty space.

However, apart from its density and its clustering properties, nothing is known about dark energy. However, two proposed models for dark energy are:

7.1 Cosmological constant:-

A constant energy density filling space homogenously [36] and physically equivalent to vacuum energy. Quantum field theory predicts a cosmological constant much like dark energy, but 120 orders of magnitude too large [37]. Steven Weinberg and a number of string theorists have used this as evidence for the anthropic principle [38], which suggest that the cosmological constant is "so small" because life cannot exist in a universe with "large" cosmological constant, but some cosmologists find this an "unsatisfying" explanation.

7.1 (a) Historical View:-

In 1917, Albert Einstein tried to use his newly developed theory of general relativity to describe the shape and evolution of the universe. The prevailing idea at that time was that the universe was static and unchanging. Einstein had fully expected general relativity to support this view but surprisingly, it did not. The inexorable force of gravity pulling on every species of matter demanded that the universe collapse under its own weight.

His remedy for this dilemma was to add a new "antigravity term" to his original equations to balance the attraction force of gravity. It enables his mathematical universe to appear as permanent and invariable as the real one. The term, usually written as Greek symbol lambda λ, is called the "cosmological constant". It has exactly the 'same value" everywhere in the universe, delicately chosen to offset the tendency towards gravitational collapse at every point in space.

A simple thought experiment may help illustrate the nature of lambda. Let us consider a cubic meter of space and remove all matter and radiation from it. Most of us would agree that this is a perfect vacuum. But, like a ghost in the night the cosmological constant would still be there. So, empty space is not really empty at all – Lambda gives it a peculiar "latent energy". In other words, even Nothing is Something! Thus, the cosmological constant is an extra term in Einstein's equation of general relativity which physically represents that there is a density and pressure associated with "empty space". The inclusion of this vacuum energy term can greatly affect cosmological theories.

In fact, the cosmological constant was first proposed by Einstein as a mechanism to obtain a stable solution of gravitational field equation that would lead to a static universe, effectively using dark energy to balance gravity. Not only was the mechanism an inelegant example of fine tuning, it was soon realized that Einstein's static universe would actually be "unstable" because local inhomogeneities would ultimately lead to either the runaway expansion or contraction of the universe. The equilibrium is unstable: if the universe expands slightly, then expansion releases "vacuum energy", which causes yet more expansion. Likewise, a universe contracts slightly will continue contracting. These sort of disturbances are inevitable, due to uneven distribution of matter throughout the universe. Einstein's fudged solution remained unchallenged until 1922 when Friedmann, a Russian mathematician realized that this was an unstable fix; like balancing a pencil on its point and proposed an expanding universe model but without the extra quantity, now called the Big Bang theory. When Hubble's study of nearby galaxies showed that the universe was in fact expanding, Einstein regretted modifying his elegant theory, which prohibited him to predict the idea of dynamic universe, in contrast to static universe and viewed the cosmological constant term as his "greatest blunder". Admitting his blunder, Einstein retracted Lambda in 1932. At first this seemed to end the debate about its existence yet decades later, despite the great physicist's disavowal, Lambda keeps turning up the cosmologist's discussions about the origin, evolution and fate of the universe.

7.1 (b) Present View:-

The simplest explanation for "dark energy" is that it is simply the "cost of having space": that is, a volume of space has some intrinsic, fundamental energy. This is called cosmological constant. Since energy and mass are related by $E=mc^2$, Einstein's theory of general relativity predicts that it will have a gravitational effect. It is sometimes called a "vacuum energy" because it is the energy density of empty vacuum and supported by the existence of the "zero point energy" [39] predicted by quantum mechanics. In fact, most theories of particle physics predict vacuum fluctuations that would give vacuum exactly this sort of energy. This is related to "Cosimir Effect" [40] given by Dutch physicist

Hendrik B G Cosimir in 1948, where two uncharged conducting plates attract each other due to quantum fluctuations because a small force can be measured between the plates, which is directly ascribable to a change of the zero point energy of the electromagnetic field between the plates and is directly observable in "nanoscale device". The cosmological constant is estimated by cosmologists to be on the order of 10^{-29} g/cm^3 or about 10^{-120} in reduced Planck units. Particle physics predicts a natural value of 1 in reduced Planck units, quite a bit off.

The cosmological constant has "negative pressure" equal to its energy density and so causes the expansion of the universe to "accelerate". The conclusion can be arrived by considering one of the field equations corresponding to Newtonian equation for the gravitational potential Φ, with an extra ingredient.

$$\nabla^2\Phi = 4\pi G\,(\rho + 3P/\,c^2)$$

the added ingredient is that besides density, pressure also contributes to gravitational potential. This is a purely general relativistic effect. It is the fact that pressure also contributes to gravity that makes the inclusion of cosmological constant interesting and is related with vacuum energy density as

$$\lambda = 8\pi G\rho_{VAC}$$

Because the cosmological constant term is proportional to the metric (In general relativity, the shape of the space-time is described by a "metric" equation and is considered to satisfy the condition of homogeneity and isotropy in the universe), the pressure associated with vacuum is then given by

$$P_{VAC} = -\,\rho_{VAC}\,c^2$$

so the "cosmological constant" behaves gravitationally like "matter and energy" except that it has "negative pressure". The net effect of a positive cosmological constant is then to create a "repulsive" gravitational force. This repulsion acts to expand the universe.

The vacuum energy density behaves "differently" from matter and energy density in another regard. As the universe expands, matter and energy are spread out over more physical space and thus their gravitational attraction is diminished. For the vacuum energy, however, the Pdv work done by vacuum during adiabatic expansions provides exactly the amount of energy to fill the new volume to the same density. Therefore, the "cosmological constant" remains "truly constant" and its gravitational repulsion (or attraction) never changes during the universe's evolution.

7.1 (c) Nothing and Everything:-

In order to understand how universe came into existence and how its various ingredients have evolved, we must delve deeply into the fundamental constituents of matter and the forces that dictate how it will interact. Soon after the Big Bang, the universe was at such a high temperature and density that only the details of matter's composition (quarks, electrons etc.) and how they interact via the "four fundamental forces" of nature were important. They represented the most complex collections of matter in existence, long before atoms, planets, stars and galaxies had arrived on the scene.

For four decades now, physicists have been attempting o unify the forces and particles that make up our world to find a common mathematical description that encompasses them all. Some think that such a "Theory of Everything (TOE)" is just within the reach. It would account not only for the known forms of matter, but also for the fundamental interactions among them: gravity, electromagnetism and the strong and weak nuclear forces. These unification theories are known by a variety of names: grand unification theory, super symmetric theory and superstring theory. The basic claim is that nature operates according to a small set of simple rules called "symmetries". Among other things, "symmetries of nature", dictate the strengths and ranges of the natural forces and the properties of the particles they act upon. Although nature's symmetries are hidden in today's cold world, they reveal themselves at very high temperatures and can be studies in modern particle accelerators. The real goal in unification theory is actually two fold: not only to uncover and describe the underlying symmetries of the world, but to find physical mechanisms for "breaking" them at low energy.

Theoreticians working on this problem are often forced to add terms to their equations that represent entirely "new fields" in nature. The concept of a field was invented by mathematicians to express how a particular quantity may vary from point to point in space. The interactions of these fields with quarks, electrons and other particles cause "symmetries to break down". These fields are usually very different than those we already know. The much sought after "Higgs boson field", for example, was introduced by Sheldon Glashow, Abdus Salem and Steven Weinberg in 1979 and were awarded Nobel Prize for their unified theory of the electromagnetic and weak nuclear forces. the most spectacular prediction of the theory is about the masses of the intermediate vector bosons $W^{\pm}$ and Z^{o} at about 82 Gev/c^2 and 93 Gev/c^2 respectively and in tune with experimental findings. The "Higgs field" makes these forces act differently at low temperature/energy. But at temperature above 1000 trillion degree, the weak and electromagnetic forces become virtually identical in the way that they affect matter.

There is, however a price that must be paid for introducing new fields into the mathematical machinery. Not only do they "break symmetries", but they can also give the "vacuum state", an enormous latent energy that, curiously behave just like Lambda in cosmological models.

The embarrassment of having to resurrect the "obsolete quantity Lambda" is compounded when unification theories are used to predict its values. Instead of being at best a vanishing minor ingredient to the universe, the predicted values are in some instances 10 to power of 120 times greater [37] than even the most generous astronomical upper limits. It is an unpleasant fact of life for physicists that the best candidates for the Theory of Everything (TOE) always have to be fine tuned to get rid of their undesirable cosmological consequences. Without proper adjustments, these candidates may give correct predictions in the microscopic world of particle physics, but predict a universe which on its largest scales look very different from the one we inhabit.

According to Stephen Hawking [41], unlike the electron acted upon by protons, our universe is completely "self contained". It requires "no outside conditions or fields" to help define its probability. The likelihood that our universe looks the way it does depend only on the strengths of fields within it. Among these internal fields, there may even be ones that we haven't yet discovered. Could the "Cosmological constant" be the "fingerprint" in our universe of a new "hidden field" in nature? This new field could affect the likelihood of our universe just as a kettle of soup contains "unknown ingredients" although we can still precisely determine the kettle's mass.

A series of mathematical considerations led Hawking to deduce that the "weaker" the hidden field becomes, the "smaller" will be the value we observe for the "cosmological constant" and surprisingly, the more likely will be the current geometry of the universe. This in turn, implies that if Lambda were big enough to measure by astronomers in the first place, our universe would be an improbable one. Philosophically, this may not trouble who see our cosmos as absolutely unique, but in a world seemingly ruled by probability, a counter view is also possible. There may, in fact, exist an infinite number of universes, but only a minority of them has the correct blend of physical laws and conditions resembling our life – nurturing one.

According to Hawking, at the so called Planck scale of length of 10^{-35} m ($l_p=\sqrt{(\hbar G/c^3)}$), the cosmos could be thought of as an "effervescent landscape or space-time foam", then perhaps a natural mechanism could exist for eliminating the cosmological constant for good. One of the curiosities of combining the speed of light (c) and Newton's constant of gravitation (G) from general relativity, with Plank's constant from quantum mechanics, is that they can be made to define unique values for length, time and energy like;

Planck length $l_p=\sqrt{(\hbar G/c^3)} = 2.55 * 10^{-35}$ m

Planck time $t_p = \sqrt{(\hbar G/c^5)} = 5.4 * 10^{-44}$ s

Planck energy $E_p = \sqrt{(\hbar c^5/G)} = 1.23 * 10^{19}$ Gev

Physicists believe that at these Planck's scales – general relativity and quantum mechanics blend together to become a single comprehensive theory of physical world : The Theory of everything (TOE). The universe itself, soon after the Big Bang, must also have passed through such scales of space, time and energy during its first instants of existence. Cosmologists refer to this period as the "Plank Era". It marks the earliest times that physicists are able to explore the universe's physical state without having a complete "Theory of Everything" to guide them.

The Planck energy (at 10^{19} Gev) is thought to be the energy where the conventional physical theories break down and a new theory of quantum gravity is required. If we impose this energy as the cut off, we obtain;

$$\rho_{VAC} \approx 10^{92} \text{ ergs/cm}^3 \approx 10^{91} \text{ J/m}^3$$

$$\Omega_{\Lambda o} \approx 10^{120}$$

Such a high value for the cosmological constant is surely absurd. One might argue that we have chosen too high a value of energy, but in order to satisfy the observational constraints we would have to use a cut off energy ~ 10^{-2} ev, which is surely unrealistic.

Such high theoretical calculations of $\Omega_{\Lambda o}$ are a real limit to the plausibility of a non-zero cosmological constant. The above was only examples for a single field and it is possible that contributions of all different fields associated with the particles of the standard model conspire to produce a cosmological constant that is small. This argument, however leads to the belief that the cosmological constant is exactly zero, for how could the fields conspire to cancel out all but 1 part of 120?

Even though theoretical calculations of cosmological constant are not fully understood, the fact remains that the vacuum energy does exist. Since gravity couples all forms of energy, the cosmological constant remains as a physically plausible part of another cosmology. Like a messenger from the depths of time, the largeness/smallness or absence of the cosmological constant today is telling us something important about how to craft a correct Theory of

Everything (TOE). It is a signpost of the way nature's symmetries is broken at low energy and a nagging reminder that our understanding of the physical world is still incomplete in some fundamental way.

7.1 (c) Conclusions:-

There are reasons to believe that the cosmological constant may still be a viable part of cosmology. Today's paradigm is that the universe went through a period of rapid expansion, called "inflation" [42], early in its history. This inflation could have acted to smooth out the universe and made it geometrically flat. This flatness is one of the motivations behind considering the cosmological constant in present day cosmology. Mathematically, it makes $\Omega_{total,\,p}$ to be very close to one (1) today. This causes problems that the cosmological constant may remedy when astronomers measure the amount of matter and energy in the universe today; they only come up with 30% of what is needed to make the universe flat. The "cosmological constant" can pick up the "slack" and make the universe flat. Even if inflation is wrong and there is no reason to believe the universe is spatially flat, there is still an apparent problem with the "age of the universe".

Astronomers estimate the age of the universe in two ways: (i) by looking for the oldest stars and (ii) by measuring the rate of expansion of the universe using Hubble's constant and extrapolating back to the Big Bang, just as the crime detectives can trace the origin of a bullet from the holes in a wall.

Astronomers have tried to place a lower limit to the age of the universe by studying oldest stars, known as "Globular Clusters". They are considered to be a dense collection of roughly a million stars with stellar densities near the center are enormous. All the stars in a globular cluster formed at roughly the same time, thus they can serve as "cosmic clocks". The life cycle of a star depends upon its "mass". High mass stars are much brighter than low mass stars, so their fuel supply burns more quickly. A star like the Sun has enough fuel in its core to burn at its current brightness for approximately 9 Billion years. The oldest globular cluster contains only stars less massive than 0.7 solar masses. These low mass stars are much dimmer than the Sun. This observation suggests that the oldest globular clusters are between 12 and 18 Billion years old.

The age for an open universe with matter (ordinary or dark) at the level (30%) we observe and with no cosmological constant is given by

$$t_0 = 2/\,(3H_0)$$

Taking the best fit for the value of Hubble's constant as 72 Km/sec/Megaparasec, the value of

$$t_0 = 9 \text{ billion years}$$

which is shorter than the age of the oldest stars.

If the universe has a very low density of matter, then its extrapolated age is larger i.e

$$t_0 = 1/ H_0$$

However, a flat universe with both matter at the level (30%) we observe and a cosmological constant refers to a much older universe and is indeed as old as the oldest stars.

The above contradiction as regards the age of the universe implies that either (i) our measurements of the Hubble constant is incorrect (ii) the Big Bang theory is incorrect or (iii) that we need a form of matter like a cosmological constant that implies an older age for a given observed expansion rate.

Some astronomers believe that this crisis will pass as soon as measurements improve. If the astronomers who have measured the smaller values of the Hubble constant are correct and if the smaller estimates of globular cluster ages are also correct; then all is well for the Big Bang theory, even without a cosmological constant. But the main attraction of the cosmological constant term is that it significantly improves the agreement between theory and observations supported by the facts such as accelerating pace of the universe's on going expansion can be explained on the basis that universe contains a bizarre form of energy, called dark energy i.e., a cosmological constant, which is in effect gravitationally repulsive and providing solution to the age crisis of the universe. There are a number of other observations that are suggestive of the need for a cosmological constant. A cosmological constant term added to the standard model Big Bang theory leads to a model that appears to be consistent with the observed large-scale distribution of galaxies and clusters, with WMAP'S measurements of cosmic microwave background fluctuations and with the observed properties of X-rays clusters.

Measurements by the WMAP satellite estimate the age of the universe to about 1%: 13.7±0.13 billion years! The expansion age measured by WMAP is larger than the oldest globular clusters, so the Big Bang theory has passed an important test. If the expansion age measured by WMAP has been smaller than the oldest globular clusters, then these would have been something fundamentally wrong about either the Big Bang theory or the theory of stellar evolution. Either way, astronomers would have needed to rethink many of their cherished ideas. But our current estimates of age fit well with what we know from other kinds of measurements.

Another reason to expect a cosmological constant is the existence of "quantum mechanical vacuum energy". Quantum mechanics theory predicts that the vacuum is not really empty but has amount of energy associated with it. Since general relativity states that all forms of energy and matter should gravitate, including the energy of the vacuum hence the cosmological constant and therefore the cosmological constant can rightly be associated with the energy of the vacuum. The coupling of the vacuum energy and gravity is not unprecedented because inflationary theory relies on the gravitational influence of a vacuum energy. Actually, inflation proposes a period of extremely rapid (exponential) expansion of the universe prior to the more gradual Big Bang expansion, during which time the linear size of the universe increased by more than 60"e-folds" or a factor of 10^{26} in only a small fraction of a second and the energy density of the universe was dominated by a cosmological constant – type of vacuum energy that later decayed to produce matter and radiation that fill the universe today. Moreover, inflation theory links important ideas in modern physics, such as – symmetry breaking and phase transitions, to cosmology.

It is for these reasons that the interest in the cosmological constant is still alive today and why it is worth bothering to think about the cosmological constant in present day cosmology. The fact that the cosmological constant is still debated today, almost a century after it was introduced by Einstein and that it lies at the crossroads of quantum mechanics and gravity, makes one think that it was probably not Einstein's biggest blunder, but perhaps his greatest legacy. In spite of its problems [39], the cosmological constant is in many respects the most economical solution to the problem of cosmic acceleration. One number successfully explains a multitude of observations. Thus, the current standard model of cosmology, the Lambda –CDM model, includes the cosmological constant as an essential feature.

7.2 Quintessence:-

The other possible explanations for dark energy include quintessence or modification of gravity on the largest scales. It refers to scalar fields – dynamic quantities whose energy density can vary in space and time. Contributions from scalar fields that are constant in space are usually also included in cosmological constant. Scalar fields which do change in space can be difficult to distinguish from a cosmological constant, because the change may be extremely slow[43-45]

In quintessence models of dark energy, the observed acceleration of the scale factor is caused by the potential energy of a dynamic field, referred to as quintessence field. Quintessence differs from the cosmological constant; that it can vary in space and time. Although no evidence of quintessence is yet available, but it has not been ruled out either. It generally predicts a slightly slower acceleration of the expansion of the universe than the cosmological constant.

Some special cases of quintessence are "**phantom energy**", in which the energy density of quintessence actually increases with time and K-essence (i.e. Kinetic quintessence) which has a non standard form of Kinetic energy and have unusual properties. The phantom energy causes divergent expansion, which would imply that the effective force of dark energy continues growing until it dominates all other forces in the universe, leading to a Big Rip.

The effect on cosmology of the dark energy that these models describe is given by the dark energy's **equation of state**, which varies depending upon the theory. The investigation of the nature of dark energy is one of the most challenging problems in cosmology. High precision measurements of the expansion of the universe are required to understand how the expansion rate changes overtime. In general relativity, the evolution of this expansion rate is parameterized by the cosmological equation of state. Measuring the equation of state of dark energy is one of the biggest efforts in observational cosmology today.

A better understanding of dark energy is likely to solve the problem of the ultimate fate of the universe. In the recent cosmological epoch, the accelerated expansion due to dark energy is preventing structures larger than super clusters from forming. It is not known whether the acceleration will continue indefinitely, perhaps even increasing until a "Big Rip" (i.e. tearing apart all gravitationally bound structures and eventually overcome the electrical and nuclear forces to tear apart atoms themselves) or whether it will eventually reverse in a Big Crunch (i.e. a universe that contracts in on itself due to dissipation of dark energy with time or even becoming attractive).

References

[1] L. Krauss, The fifth essence (New York, Basic Book 1989) The story of dark matter; some theories win, some lose. NASA, using the WMAP dataset.
V Trimble, Ann. Rev. Astron. Astrophysics. **25**, 425 (1987)

[2] C. L. Bennelt et al (2003) "The **microwave** Anisotropy Probe (MAP) Mission" Astrophysical journal, **583,** 1–23, (2003); Astrophysical Journal Supplement **148**, 97-117, (2003).

[3] Kim Griest, "The search for the Dark Matter: WMAPs and MACH0s" Annals of the New York Academy of Sciences, vol. **688**, 390-407, (June 1993).
James Trefil, "Dark Matter", Smithsonian, June 1993: 27-35
James R. Asker, "Missing Mass Enigma Deepens", Aviation week and Space Technology, **21,** 31, (Nov, 1994).

[4] Dragan Huterer and Michael Turner (August 1998) "Prospects for probing Dark Energy via Supernova Distance Measurements", Phys..Rev. D **60**, 081301 (1999)

[5] Adam G Riess et al (supernova Search team 1998) "Observational evidence from supernova for an accelerating universe and a cosmological constant", Astronomical Journal **116**, 1009-38.

[6] S Perlmutter et al (The supernova Cosmology Project, 1999) "Measurements of Omega and Lambda from 42 high redshift supernova", Astrophysical Journal **517**,
565-86
Mano Mateu, " Searching for dark Matter", sky and Telescope Jan 1994: 20-24

[7] D. N. Speryel et al (WMAP Collaboration, March 2006) three years results; Implications for cosmology.
Astrophysical Journal Supplement (2003) **148**, 175-198
Astrophysical Journal supplement (2007) **170**, 377-408

[8] Pierre Astier et al (supernova Legacy Survey 2006) Astronomy and Astrophysics **447**, 31-48

[9] G Hinshaw et al (2008)" Five year WMAP observations; Data processing, Sky Maps and Basic Results". Astrophysical Journal Supplement, arXiV: 0803.0732

[10] F Zwicky, Physica Acta **6**, 110-127 (1933)

[11] John Gribben, The Omega Point: The search for the missing mass, the ultimate fate of the universe. New York, Bantam 1988

[12] Kim A Mcdonald, "New findings deepen the mystery of the Universe's Missing Mass. Chronicle of Higher Education 23 Nov, 1994: A8-A13

[13] Scott I Chase, "what is Dark Matter" Physics – faq /part 2 Sci. physics Newsgroup,
5 Dec 1994

[14] H Awaki, T Mimara et al 1994 PASJ **46**, 65 ASCA.

[15] Falco, Emilio and Nathaniel Cohen "Gravity Lenses: A Focus on the Cosmic Twins". Astronomy July 1981: 18-22

[16] R Massey et al, " Dark Matter maps reveal Cosmic Scaffolding", Nature **445**, 286-90 (18 Jan, 2007).

[17] D Clowe and M Bradac et al, "A direct empirical proof for the existence of Dark Matter" Astrophysical Journal Letters **648**, 109-113 (Sept 2006)
Dark Matter Observed. SLAC Today

[18] Astronomers claim first dark galaxy (http://www.newscientist.com/article.ns?id=dn7056) New scientist 2005-02-23
Wikinews: Dark matter galaxy discovered.

[19] New Scientist (2008)' " Cosmic Enlightenment" (March 8, 2008) No. **2646** p 29

[20] Abell 2029: Hot news for cold Dark Matter. Chandra X-ray observatory collaboration (11 June 2003).
N Bahcall, L M Lubin and V Dorman, Astrophysical Journal **447**, L81 (1995)

[21] Proceedings of the Second International Conference on Dark Matter in Astro and Particle Physics held in Heidelberg, Germany, 20-25 July 1998, ed H V Klapdor-Kleingrothaus and L Baudis

[22] C Alcock et al. Astrophysical Journal **445**, 133 (1995)

[23] K Buckland, M J Lehner, g E Masek and M Mojaver, Phys Rev Lett. **73**, 1067 (1994)
G D Starkman and D N Spergel Phys.Rev.Lett **74**, 2623, 1995.

[24] J L Rosner, " Dark Matter in Many Forms", Presented at 2005 ALCPG & ILC Workshops Snowmass Co. 14-27 August 2005

[25] S Ahlen et al, Phys.Lett **B195** 603 (1987)
M W Goodman and E Witten, Phys.Rev **D31**, 3059 (1985)
P F Smith and J D Lewin, Phys.Rep **187**, 203 (1990). A nice review of cold dark matter detection.
G Jungman, M Kamionkowski and K Griest, Physics Report of 1995. This is an excellent up to date review of cold dark matter detection.

[26] Michael, Zeilik and John Gaustad, Astronomy: The Cosmic perspective, Newyork: John Wiley & Sons, Inc.1990.

[27] Matt McIrvin, " Some frequently asked questions about black holes" physics-faq/part 2. Sci.physics Newsgroup. 5 Dec 1994.

[28] C Carrignan and K C Freeman Astrophysical Journal **332**, L33 (1988)

[29] John Noble Wilford, " New galactic evidence of black holes", Newyork Times 12 Jan 1995: **B9**.
Makoto Miyoshi et al. "Evidence for a Black hole from High rotation velocities in a sub par sec Region of NGC 458". Nature 12 Jan 1995 127-129.

[30] D N Spergel and J N Bahcall, Phys Lett. **B200**, 366 (1988).

[31] J Ellis et al. Nuclear Physics, **B238**, 453 (1984)
M Kamionkowski, K Griest, G Jungman and B Sadonlat, Phys. Rev Lett. **74**, 5174 (1995).

[32] R. L. Davis, Phys. Lett. **B180**, 225 (1986)
R. L. Davis an E.P.S. Shellard, Nuclear Physics **B234**, 167 (1989)
M. Dine, W. fischler and M. Srednicki, Phys. Lett., **B104**,1955 (1981)
M. A. Shifman, A.I. Vainshtein and V. I. Zakharou, Nuclear Physics **B166**, 493 (1989)
S. Weinberg, Phys. rev. Lett. 40, 223 (1978); F Wilczek, Phys.Rev.Lett. **40**, 279 (1978). these papers describe how the axion can solve CP problem.
G. Raffelt (1995) and S. Matsuki et al (1995). Proceedings of the XVth Moriond workshop: Dark Matter in cosmology, An excellent introduction to axion dark matter physics and detection scheme for axions that uses Rydberg atoms.

[33] NASA (2006-08-21) "NASA finds direct proof of dark matter". Press Release.

[34] M Reuter and H Weyer, "Running Newton constant, Improved gravitational actions and galaxy rotation curves". Phys Rev. **D70,** doi: 10, 1103/Phys. Rev. D70, 12 4028 (2004)

[35] P J E Peebles and Bharat Ratra, "The cosmological constant and dark energy". Reviews of Modern Physics **75**, 559-606 (2003).
Robert P Krishner, "Throwing light in dark energy". Science, Vol. **300**. No. 5627 pp. 1914-1918 (20 June 2003)

[36] Sean Carroll, "Article on the cosmological constant". Living reviews in Relativity. Retrieved on 2006-09-28.

[37] Jenny Hogan, "Unseen Universe: Welcome to the dark side". Nature **448** (7151): 140-245 (2007)

[38] Steven Weinberg, "Anthropic bound on the cosmological constant". Phys. Rev. Lett **59** (22): 2607 – 2610 (1987).

[39] introduction to Zero Point Energy – Caltech Physics Institute. Nick cook (2001) The hunt for zero point energy. London Century.
Philip Yam, "Exploiting Zero Point Energy". Scientific American Magazine December 1977 pp 82-85.

[40] S K Lamoreaux, "Demonstration of the Cosimir Force in the 0.6 to 6 Micrometer Range". Phys Rev Lett **78** (No. 1) pp 5-8 (6 Jan 1997).

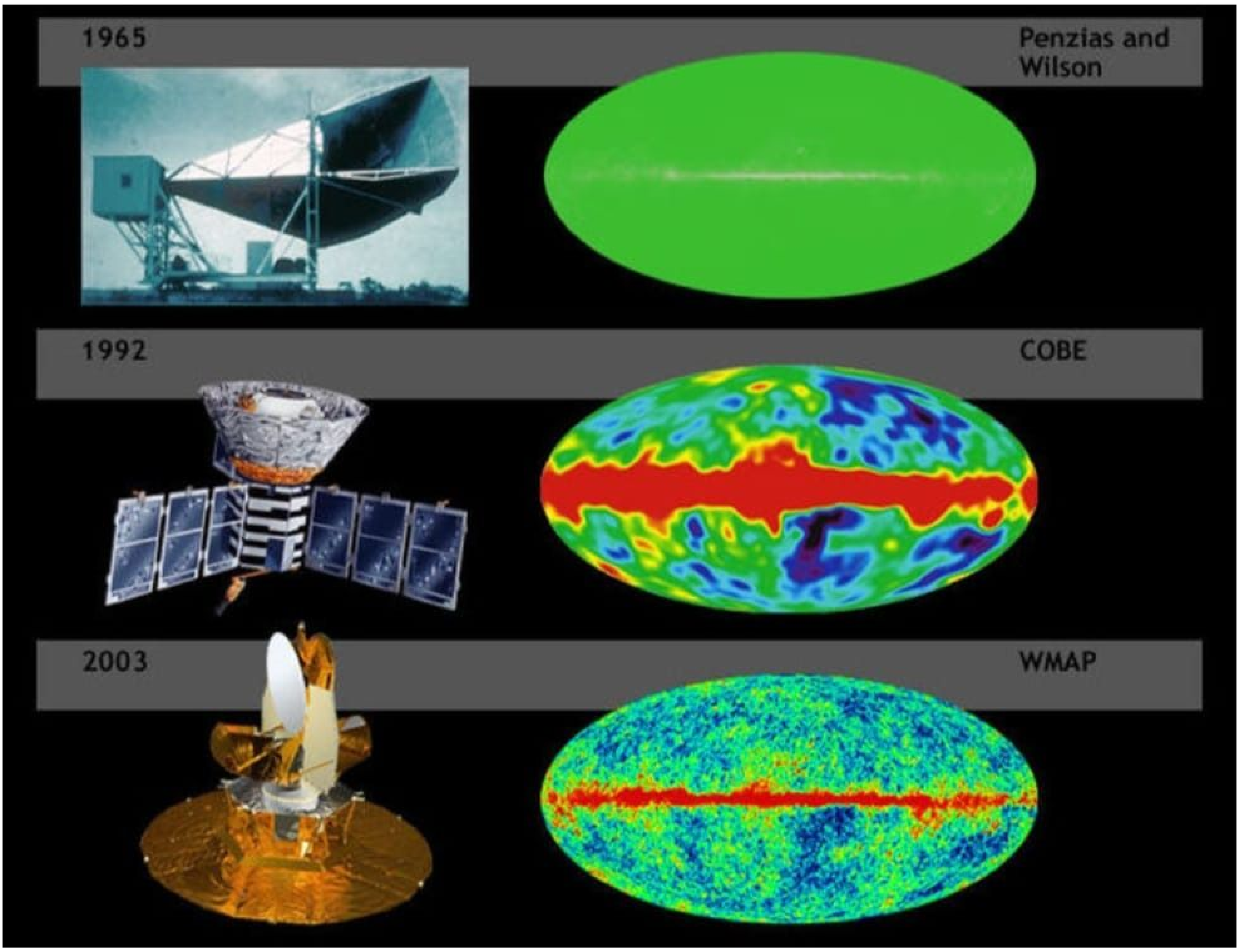
[41] Stephen W Hawking (2001). The Universe in a Nutshell. Bantam Books. Stephen W Hawking (1998). A brief history of time. Bantam Books.

[42] Alan Guth (1997). The inflationary universe: The quest for a new theory of cosmic origin. Random House.

[43] A M Ozias and M L Smith, "Elliptical solutions to standard cosmology model with realistic values of matter density".
International Journal of Theoretical Physics **45**, 925-936 (2006).
D J Schwarz and B Weinhoust, "Anisotropy of the Hubble diagram comparing hemispheres". Astronomy and Astrophysics **474**, 717-729 (2007).

[44] M. Stanley, Phys. Today **69**(7) 35 (2016)
F. Dyson, Phys. Today **63**(12) 44 (2010)

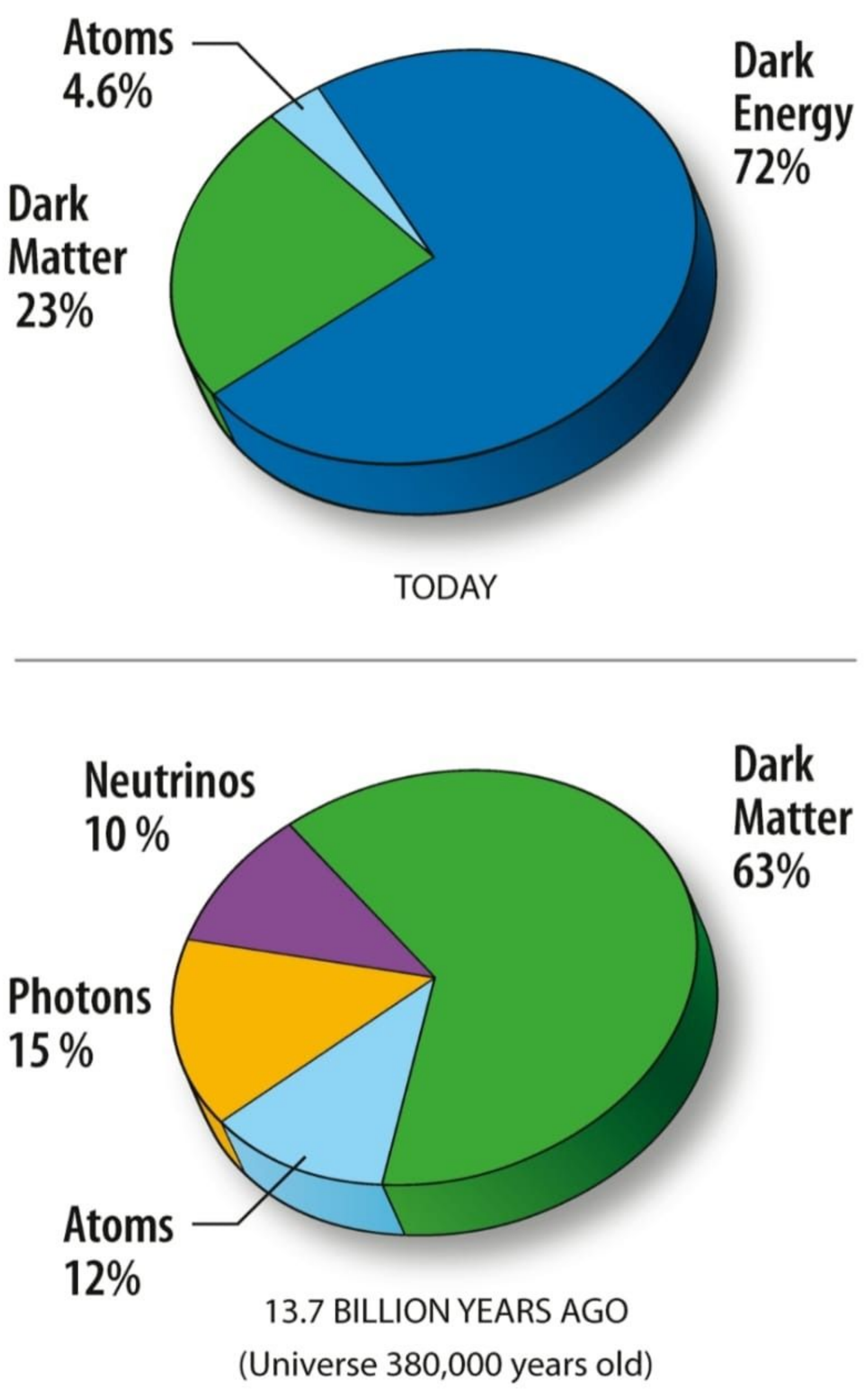
[45] Jaco de Swart, Phys. Today **77** (8) 34-43 (2024)
"Theoretical Battle: Dark energy vs modified gravity". Ars Technica 25 February 2017.Archived from the original on 28 October 2017.



A comparison of the sensitivity of WMAP with COBE and Penzias and Wilson's telescope (simulated data)

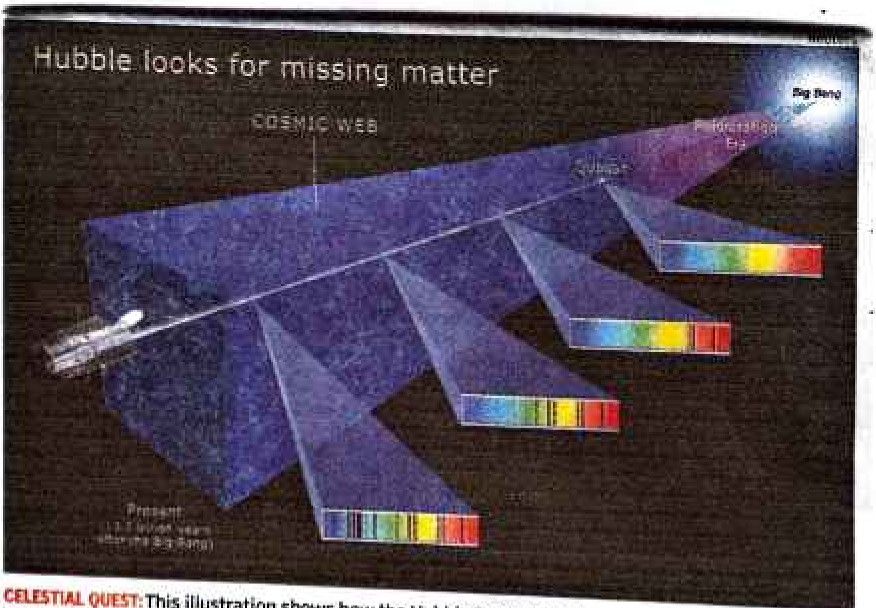
Fig. 1

Cosmic microwave background



Estimated division of total energy in the universe into matter, dark matter and dark energy based on five years of WMAP data.

Fig. 2



CELESTIAL QUEST: This illustration shows how the Hubble Space Telescope searches for missing baryons or normal matter, by looking at the light from quasars several billion light years away

Fig.3

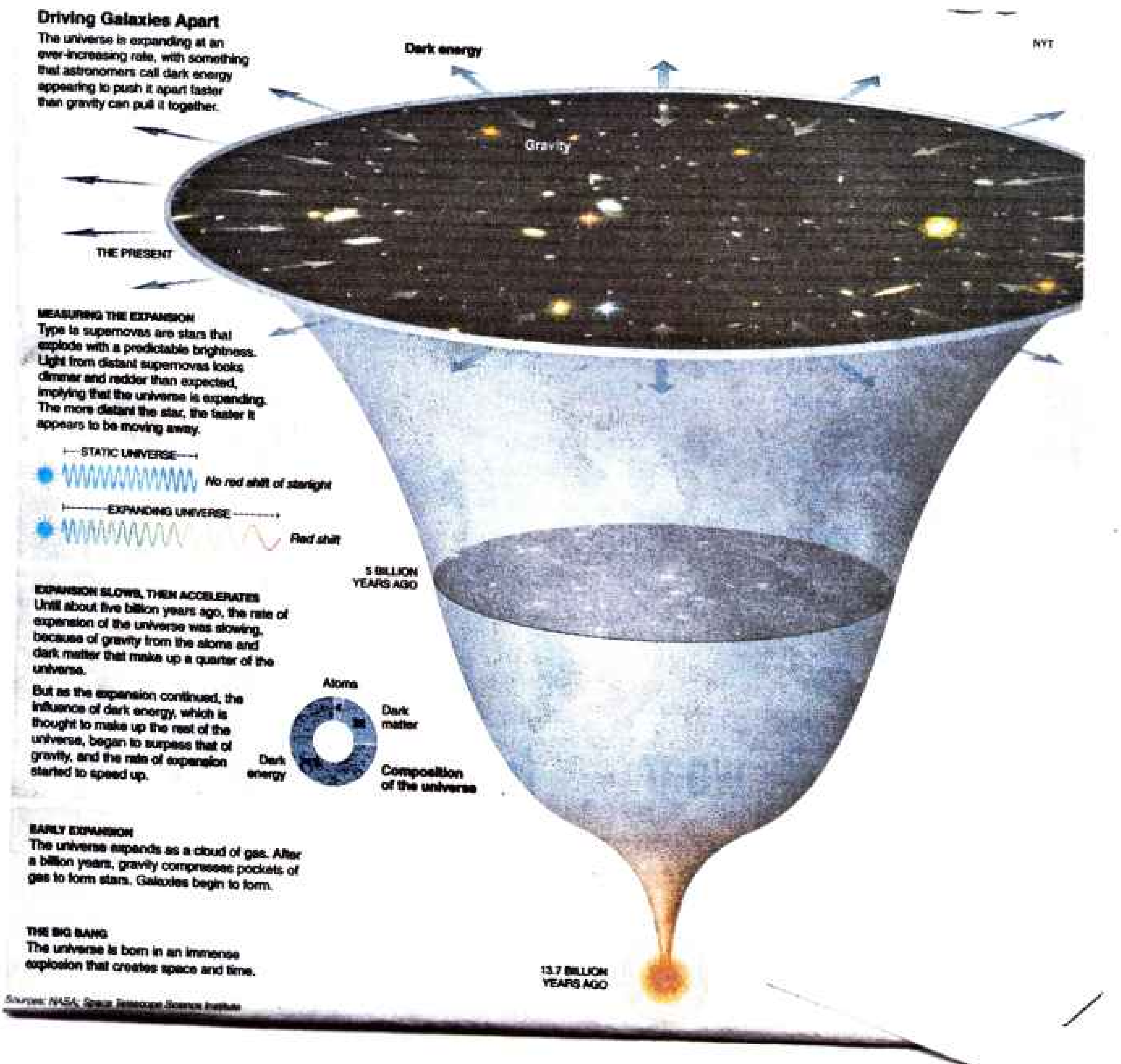

Driving Galaxies Apart
The universe is expanding at an ever-increasing rate, with something that astronomers call dark energy appearing to push it apart faster than gravity can pull it together.
Dark energy
NYT
Gravity
THE PRESENT
MEASURING THE EXPANSION
Type Ia supernovas are stars that explode with a predictable brightness. Light from distant supernovas looks dimmer and redder than expected, implying that the universe is expanding. The more distant the star, the faster it appears to be moving away.
STATIC UNIVERSE
No red shift of starlight
EXPANDING UNIVERSE
Red shift
5 BILLION YEARS AGO
EXPANSION SLOWS, THEN ACCELERATES
Until about five billion years ago, the rate of expansion of the universe was slowing, because of gravity from the atoms and dark matter that make up a quarter of the universe.
But as the expansion continued, the influence of dark energy, which is thought to make up the rest of the universe, began to surpass that of gravity, and the rate of expansion started to speed up.
Atoms
Dark matter
Dark energy
Composition of the universe
EARLY EXPANSION
The universe expands as a cloud of gas. After a billion years, gravity compresses pockets of gas to form stars. Galaxies begin to form.
THE BIG BANG
The universe is born in an immense explosion that creates space and time.
13.7 BILLION YEARS AGO
Sources: NASA; Space Telescope Science Institute

Fig. 4