

A Physico-Chemical Approach To Understanding Cosmic Evolution: Thermodynamics Of Expansion And Composition Of The Universe

Carlos A. Melendres (✉ camelendres@SHDInstitute.org)

The SHD Institute

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**A PHYSICO-CHEMICAL APPROACH TO UNDERSTANDING COSMIC
EVOLUTION: THERMODYNAMICS OF EXPANSION AND
COMPOSITION OF THE UNIVERSE**

Carlos A. Melendres
The SHD Institute
216 F Street, Davis, CA 95616, U.S.A.
Email: camelendres@SHDInstitute.org

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Carlos A. Melendres

camelendres@SHDInstitute.org

ABSTRACT

We present a physico-chemical approach towards understanding the mysteries associated with the Inflationary Big Bang model of Cosmic evolution, based on a theory that space consists of energy quanta. We use thermodynamics to elucidate the expansion of the universe, its composition, and the nature of dark energy and dark matter.

The universe started from an atomic size volume of space quanta at very high temperature. Upon expansion and cooling, phase transitions resulted in the formation of fundamental particles, and matter which grow into stars, galaxies, and clusters due to gravity. From cooling data on the universe we constructed a thermodynamic phase diagram of composition of the universe, from which we obtained a correlation between dark energy and the energy of space. Using Friedmann's equations, our Quantum Space model fitted well the WMAP data on cosmic composition with an equation of state parameter, $w = -0.7$. The expansion of the universe was adiabatic and decelerating during the first 7 billion years after the Big Bang. It accelerated due to the dominance of dark energy at 7.25×10^9 years, in good agreement with BOSS measurements. Dark Matter is identified as a plasma form of matter similar to that which existed before recombination and during reionization.

1. INTRODUCTION

The evolution of the universe is a subject of great scientific interest. It is intimately related to the composition and expansion of the universe. Our universe is 95% “dark”, consisting of 71% dark energy, 24% dark matter; it has only 5% ordinary matter, of which 0.5% is luminous. The nature of dark matter and dark energy remains unknown. Dark energy is theorized to cause the expansion of the universe, dark matter is thought to hold the galaxies together. They, along with the theory of inflation, remain rather “mysterious”.

The expansion of the universe is related to that of space. The nature of space is unknown but much debated [1]. It is generally viewed like a canvas where nature’s landscape and events are portrayed; it is then treated geometrically and mathematically as a surface in 4-dimensional spacetime in Einstein’s Theory of General Relativity. We present a more descriptive and simpler model of space based on the theory that it is a quantized dynamical entity which we will call “spaceons”. It is the “cosmic fluid” that actively participates in the evolution of the universe, along with matter and radiation. The mechanism of evolution proceeds via well known physico-chemical processes. Our Quantum Space model provides an explanation for the accelerated expansion of the universe due to dark energy, and gives an insight on the nature of dark matter.

2. A MODEL OF SPACE AND COSMIC EVOLUTION

It has been thought of that space is not really empty, that “vacuum” contains virtual particles that pop in and out of existence, and is used to explain the Casimir effect [2]. We therefore take the view that space is associated with energy and is quantized. Space consists of energy quanta that propagate as waves described by the Planck quantum energy expression:

$$E=hc/\lambda \quad (1)$$

The symbols have their usual meaning: E, is the energy; λ , the wavelength, and h, the Planck constant; we assume the velocity of spaceons to be that of light, c. In terms of equivalent volume, we could think of spaceons as spherical waves (like bubbles) such that

$$E=(4\pi/3V)^{1/3}hc \quad (2)$$

where V is the volume. The expressions above define the equivalence of space (of dimension λ or volume V), and energy, in analogy to the relation between energy and mass, given by Einstein’s equation, $E=mc^2$. Thus, energy is inherent in space and space in energy. We call the units of space “spaceons”. They can be thought of as the carrier of energy and weave the fabric of the universe. From wave-particle duality, the “wavicles” of spaceons can also be thought of as an ideal gas which obeys the equation of state [3],

$$PV=N_0K_\beta T. \quad (3)$$

P is the pressure of the gas, V the volume, T the temperature, N the Avogadro number and K_β the Boltzman constant. With this theory we can model the gross features of the evolution of the universe as follows:

The universe started (at time, $t=0$) as a very small volume of gas, the spaceons, at an extremely high pressure and temperature. For example, an Avogadro number of gas particles occupying a volume of $4.2 \times 10^{-36} \text{ m}^3$ (a spherical wave of 1 A^0 radius), at a pressure of $1.976 \times 10^{66} \text{ Pa}$ and a temperature of 10^{32} K . In this initial state of its birth, the universe consisted of “hot” spaceons and radiation in equilibrium. We shall refer to this period as the Quantum Space Epoch. The spaceons and radiation then expanded and cooled as they propagate. In the process of cooling to appropriate threshold temperatures, phase transitions occurred resulting in the formation of fundamental particles, nuclei, and atoms. From the matter formed, gravitation caused the formation of galaxies and stars; these clumped to form clusters, local groups and superclusters. The mechanisms of matter formation follow those of the Standard Model of Particle Physics; the nucleation and growth of atoms to stars and superclusters are not completely understood as yet. The universe continues to expand until the present time. The various epochs of the evolution of the universe, in our model, are similar to those of the Big Bang [4,5,6], but without the need for a theory of Inflation.

3. RESULTS AND DISCUSSION

3.1 Composition of the Universe

Several methods are used to determine the composition of the universe. Results of the Wilkinson Microwave Anisotropy Probe (WMAP) satellite studies [7] gave the composition shown in Table I soon after the Big Bang and at present:

Table I-Composition of the Universe

	At the Big Bang	At Present (13.8 billion years after)
Dark Matter	63 %	24 %
Dark Energy	–	71.4 %
Ordinary Matter	12 %	4.6 %
Neutrinos	10 %	–
Photons	15 %	–

The composition during the cosmic evolution has also been documented [4,5,6]. Table II shows this as a function of temperature (T) at various times and Cosmic Epochs, together with the cooling information (P) we have added.

Table II. Timeline of the Universe and Cooling Data During Cosmic Evolution

Time (after Big Bang)/ (Cosmic Epoch)	Temperature (K)	Pressure (Pa)	Composition
$< 10^{-12} \text{ sec/}$ (Quantum Space)	$> 10^{12}$	$> 10^{32}$	Hot spaceons, radiation, quark gluon “soup”
$10^{-12} \text{ to } 0.02 \text{ sec/}$ (Quark,Hadron,Lepton, Electrons,Protons,Neutrons)	$10^{11} - 10^9$	$10^{32} - 10^{27}$	I. Fundamental particles + radiation
$0.02 \text{ to } 300 \text{ sec/}$ (Nucleosynthesis)	$10^9 - 10^8$	$10^{27} - 10^{15}$	II. Nuclei of H, He,D,Li + radiation

300 sec to 3.8×10^5 yrs/ (Photon to Recombination)	$10^8 - 10^3$	$10^{15} - 10^{-11}$	III. Plasma of ionized H, He and e-
3.8×10^5 to 10^9 yrs/ (Dark Ages to Matter dominated)	$3 \times 10^3 - 4$	$10^{-11} - 10^{-22}$	IV. Matter in galaxies, stars , planets-gases, plasma, solid
10^9 to 13.8×10^9 yrs/ (Dark Energy dominated)	4 - 2.7	$10^{-22} \dots$	V. Dark Energy

At temperatures above 10^{12} K and time $< 10^{-12}$ sec, the universe was a primeval hot gas of spaceons and radiation. Upon expansion and cooling, fundamental particles (quarks, leptons, hadrons, protons, neutrons, electrons) were created. On further cooling to about 10^9 K, nucleosynthesis occurred to produce nuclei of H, He Li and D. At about 10^8 K a plasma phase was formed which consisted of electrons and positive ions of H and He. Radiation (photons, neutrinos) was ever present and dominated the early epoch of the universe. Further cooling of the plasma until about 3×10^3 K resulted in recombination of electrons with positive ions of H and He, converting the plasma to gases. As the universe continued to expand and cool, matter formed further through the action of gravity to become stars, galaxies, and clusters. The universe cooled

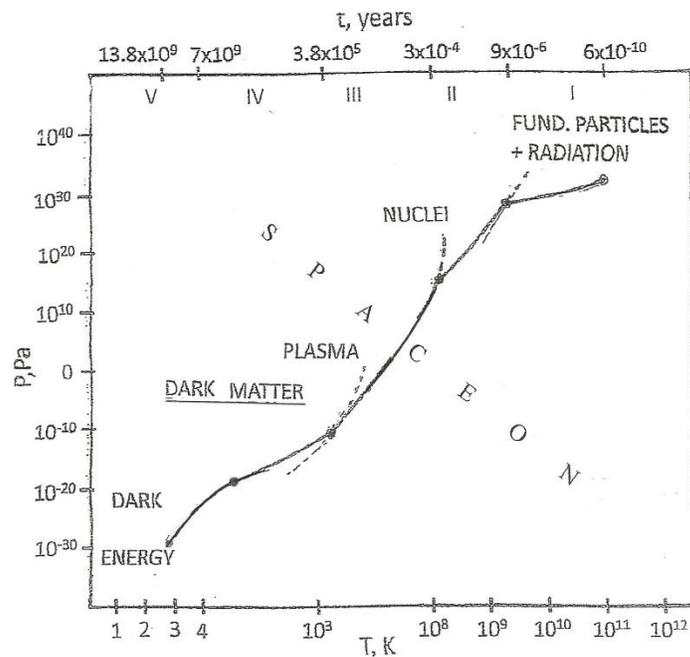


Fig. 1-Schematic Phase Diagram of the Universe with Spaceons

to 2.7 K as indicated by the Cosmic Microwave background (CMB). The primary constituents of the universe are: gases (H, He), plasma of electrons, protons, and He ions, ordinary matter (gasses, solids, dust, in stars, galaxies, clusters, intergalactic space), radiation, and spaceons (gas at all temperatures).

Thermodynamics is a very powerful method for obtaining compositional information [3,8]. The timeline of the universe is shown in Table II. We also show its cooling curve which we derived, i.e., composition as a function of temperature, pressure, and time. From the latter, and knowledge of the constituents of the universe (Table I), we constructed a thermodynamic phase diagram [3,8]. This is standard practice in chemistry and metallurgy, but are confined only to the components of matter. The equivalence of matter and energy, allows one to do the same for the universe as a whole system with matter, energy and radiation as components

The result is shown in Fig.1. Note that the figure is schematic and the temperature is not drawn to scale in order to highlight the phases formed. We only emphasized the points at which the phases are formed because the exact pressure dependence is not fully known and at best rather small. The major phases are: matter (IV, solid, gasses, plasma formed in galaxies, stars, clusters), a plasma phase (III) formed immediately after nucleosynthesis, dark energy (V) and spaceons (gas). The broken lines indicate the overlap between various phases during the process of formation. While dark energy (spaceons) were present at the beginning of the universe, its phase transition is indicated only at the time when it became the major component of the universe. Dark matter is underlined since its nature is still unknown and unassigned. All phases are in contact with spaceons at all epochs of cosmic evolution, as indicated. This is as it should be since space is in contact with all elements of the universe at all times. This results in an isotropic and homogeneous universe so that the need for an inflationary stage is unnecessary. At extremely high temperatures and pressures (right end), fundamental particles and radiation are indistinguishable from the hot spaceons. (The creation of radiation from the space field is thought to be the simplest process; this subject will be discussed in another publication). At low temperature/pressure (left end), dark energy overlaps with the cold spaceons which may further transition to another phase. These end points are critical points, where 2 phases co-exist. (For water, at the critical temperature of 647 K and pressure of 2.2064×10^7 Pa, liquid water is indistinguishable from its vapor phase.).

3.2 Dark Energy and the Expansion of the Universe

Dark energy constitutes 71% of our universe. It is hypothesized to be an unknown form of energy that permeates all of space uniformly. It is invisible and difficult to study because it does not interact with radiation, hence cannot be investigated spectroscopically. It only interacts with gravity. Its density is very low, less than ordinary and dark matter, it converts to dark matter, was less in the past than at present, and it is thought to function like an anti-gravity force which causes the accelerated expansion of the universe [9,10,11].

Based on our model, the expansion of the universe could be thought of as the expansion of spaceons into the Void (“nothingness”). It can be thought of as driven by the pressure and temperature differential of the hot high energy state (high T, short λ_s) and the cold state in the Void ($T \approx 0K$, $\lambda \approx \infty$). It is an inherent property of space that it needs to expand in order to attain a lower energy state. The expansion may be viewed from the standpoint of Quantum Field Theory [12], as arising from a force that is associated with a field. The latter is the space field from which emanate space quanta, the spaceons. It is a scalar field, dubbed “Quintessence”, that has been theorized to be the substance which comprises Dark Energy [10].

One can see from our thermodynamic phase diagram (Fig.1) that dark energy is a phase that overlaps with the new entity that we have introduced as a component of the universe, i.e., the spaceons; the two phases are indistinguishable. Hence, dark energy can be associated with spaceons, the energy of space. The amount of dark energy soon after the Big Bang was relatively

small (Table I) because most of the energy of space was converted to radiation, fundamental particles, dark matter and ordinary matter. Its density remains low as the universe expands.

The behavior of our model universe with spaceons is well suited for mathematical treatment using the Friedmann-Lemaitre-Robertson-Walker (FLRW) metric [11]. (It is worthwhile to note that in deriving his equations, Friedmann used an ideal gas as a model for his cosmic fluid.) The second Friedmann equation [10,11] delineates the contributions of the various components of the universe (matter, radiation, and spaceons) to the acceleration of expansion of the universe, i.e.,

$$d^2 a/dt^2 = -(8\pi G a/3) \{ (1/2) \rho_m + \rho_r - \Lambda/8\pi G \} \quad (4)$$

We have set the curvature term, $k=0$, normally appearing in equation 4. (This corresponds to a Euclidean universe with a flat spacetime curvature.). In the above equation, a is the scale parameter, G the gravitational constant; ρ_m is the mass-energy density of matter, ρ_r that of radiation, and Λ , the cosmological constant which represents the energy of the vacuum [10]. “Vacuum energy” is not a good term to use in our model, where the vacuum state contains “absolutely nothing”, i.e., the Void; it is preferable to use the term “energy of space”. The cosmological constant will then be replaced by the energy density of space, i.e.

$$d^2 a/dt^2 = -(8/3)\pi G a \{ (1/2) \rho_m + \rho_r + (\rho_s + 3P_s) \} \quad (5)$$

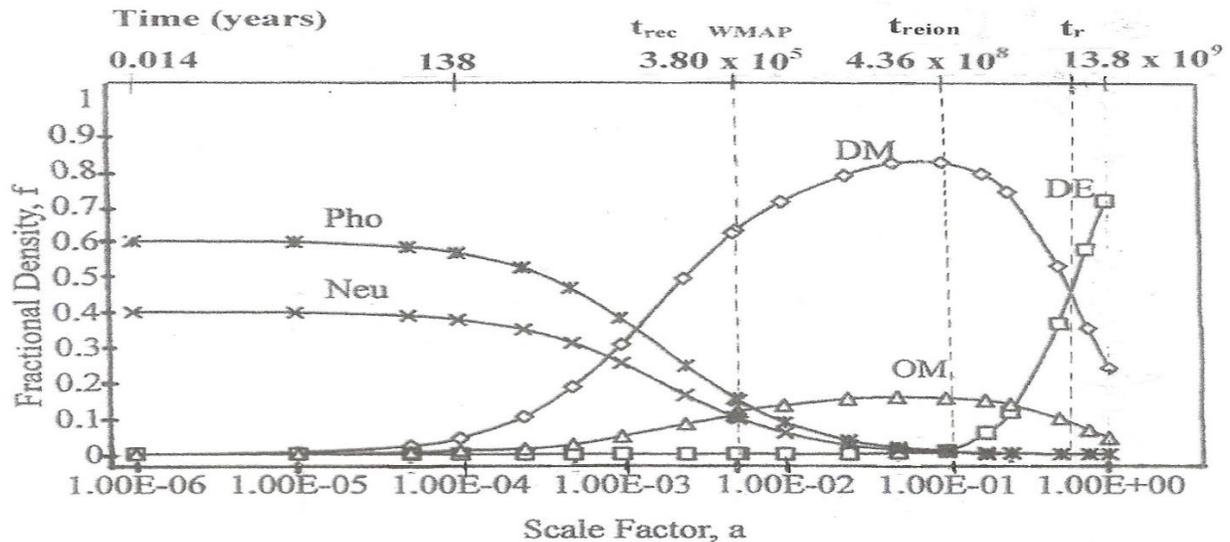


Fig.2- Fractional Energy Density (f) vs Scale Factor (a), fit with $w_s = -0.7$
 DE-Dark Energy; DM-Dark Matter; OM-Ordinary Matter; Pho-Photons;
 Neu-Neutrinos

and ρ_s is the energy density of space. It is related to the pressure P_s via the equation of state $P_s = w_s \rho_s$ where w_s is the equation of state parameter. A negative pressure would give rise to a positive ρ_s that can cause an acceleration of the expansion.

For the purpose of fitting the observed data (Table I), it is preferable to use another form of the Friedmann equation. It is common to utilize one involving the Hubble constant, H , which is measured in experiments and use velocity, da/dt , rather than acceleration [9,10,11]. Thus,

$$a H^2 = (da/dt)^2 a^2 = (H_0)^2 [\Omega_m a^{-3} + \Omega_r a^{-4} + \Omega_s a^{-3(1+w_s)}] \quad (6)$$

$H=(da/dt).a$, H_0 its value at the present time; ρ_i is the density parameter for component i , ρ_c is the critical energy density of the universe (the density of the universe at the present time) and $\Omega_i = \rho_i/\rho_c = f$, the fractional energy density.

A plot of fractional energy density as a function of of “ a ” can be constructed to fit the measured composition of the universe at about the time of the Big Bang and at the present time (see Table 1)

The plot in Fig. 2 shows the evolution of the composition of the universe. The dominance of radiation, matter, and dark energy at different times are amply illustrated. As can be seen there is good fit of the data summarized in Table I at time $t=13.8$ billion years ($a=1$) and at the time of the Big Bang, at about $t=380,000$ years ($a=5.25 \times 10^{-3}$, redshift $z=1089$), with an equation of state parameter, $w_s = -0.7$. Dark Energy is very small in the early universe as most of the energy is used

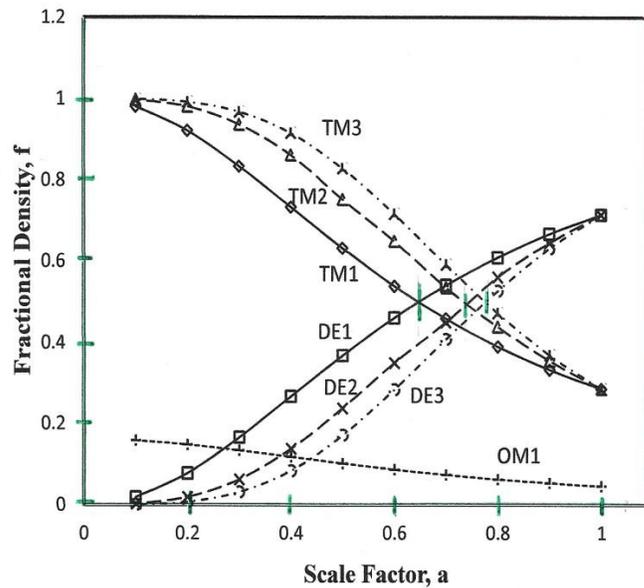


Fig.3- Fractional Energy Density (f) vs Scale Factor (a)
 DE1- Dark Energy,; DM1-Dark Matter; OM1-Ordinary Matter; TM1- Total Matter for $w_s = -0.7$; DE2, TM2 for fit with cosmological constant, $w = -1$; TM3, DE3-for fit with Phantom Energy model, $w = -1.2$

in the creation of radiation and fundamental particles. As the universe expands, however, the energy densities of radiation and matter continue to dilute and are eventually overcome by the energy density of Dark Energy. This occurs at around 7 billion years at which time the expansion of the universe starts to accelerate. We call this the transition time, t_r . This result has been established by baryon acoustic oscillation measurements in the Baryon Oscillation Spectroscopic Survey (BOSS) project [13] and supernova measurements [17]. Fig.3 lends support to these findings. One sees that the fractional energy density of Dark Energy (DE1) crosses that of total matter (TM1) at t_r with $a= 0.65$ ($t=7.25 \times 10^9$ years).

Siegel [14] has obtained a similar fit using a cosmological constant but did not give a value for the transition time. Our calculation with a cosmological constant ($w = -1$) yielded a time of 8.75×10^9 years ($a=0.74$) for the dominance of dark energy (Fig. 3, broken line, DE2, TM2). Result for the so-called Phantom Energy model [15] gives $w=-1.2$ for the transition time, t_r , and a later transition time of 9.2×10^9 years (DE3, TM3). The measurement of transition time, t_r , appears to be a good test for the suitability of models for Dark Energy.

The concept of a constant energy density for space leads to some difficulties. The cosmological constant is considered to be equal to the energy of the vacuum. Calculations give a 120 orders of magnitude for the calculated value of the density of dark energy; this is clearly catastrophically wrong. Moreover, the constancy of dark energy in the course of cosmic evolution is also thought to be unlikely [16]. It also poses difficulties in answering the question of where the energy comes from during the expansion of the universe. It is more reasonable to expect that the energy density would dilute as the universe expands for all forms of energy (Fig 4). Quintessence [16], with spaceons as the cosmic fluid that is a component of the universe, appears to be the better explanation for dark energy.

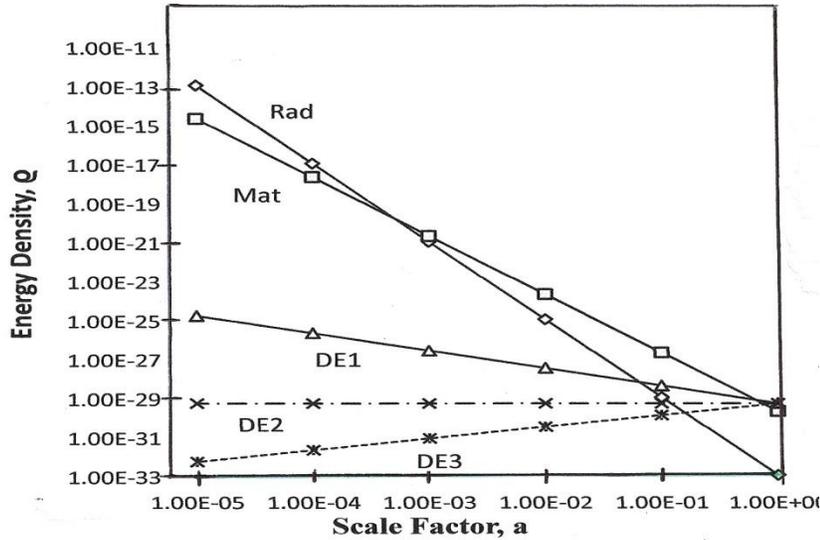


Fig 4. Energy Densities ($\rho, g/cm^3$) vs Scale Factor (a) for 3 models of Dark Energy; Rad-total radiation; Mat-total matter; DE1-Dark Energy with $w_s=-0.7$; DE2- $w = -1.0$ (Cosmological Constant); DE3- $w = -1.2$ (Phantom Energy Model)

3.3 THERMODYNAMICS OF EXPANSION AND ACCELERATION

In our model, the universe started with a finite amount of energy. It was assumed to be an isolated system and expansion was adiabatic, with no energy transfer in and out of the universe. From thermodynamics,

$$Q = dE + PdV = 0, \quad (7)$$

where Q is the energy flowing into or out of the system, dE the change in internal energy, P the pressure, and dV the change in volume during the expansion. The work to create space, PdV , is done at the expense of the internal energy, i.e. $dE = -PdV$ or

$$dE/dV = -P, \quad (8)$$

the slope of the dE/dV plot is negative. One can also derive the relation,

$$H = (1/4\pi r^3) [(dV/dE)] (dE/dt) \quad \text{or} \quad (9)$$

$$dE/dt = 4\pi r^3 H [dE/dV] \quad (10)$$

where, r , is the radius of the universe, and H is the Hubble constant, proportional to expansion velocity. To a first approximation, a decrease in H indicates a decrease in internal energy of the universe with time, t . BOSS studies of Busca et al [13, Fig 21.], show the expansion of the universe to be slowing down during the first 6 billion years after the Big Bang. A better plot is shown in Fig 5, from unpublished work [13] by a Berkeley Group who were collaborators in the Sloan Digital Sky Survey (SDSSIII) of the BOSS project. It showed that the expansion velocity reached a minimum around 7.5 billion years. This is consistent with our model universe with the expansion being adiabatic initially, i.e. $dE/dt = \text{negative}$. Turner and Riess [17] (18) have also shown that the universe changed from deceleration (during the matter dominated epoch) to acceleration at a redshift, $z=1$ or $t = 7 \times 10^9$ years. The expansion velocity increased thereafter. The slope dE/dV (and that of dE/dt) became positive at large z (longer time, Fig. 5b).

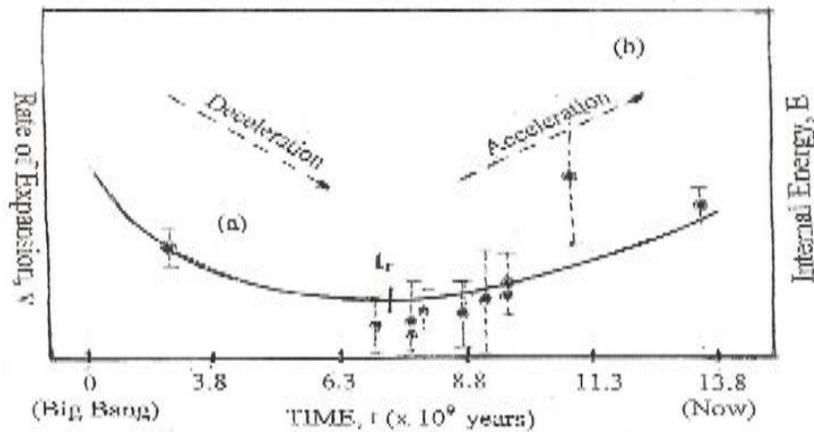


Fig 5. Rate of Expansion of the Universe as a Function of Time (t) (Left Ordinate) t_r -transition time from deceleration (a) to acceleration (b) (Right Ordinate) Schematic change in internal energy, E , with time; slope $=dE/dt$ (Fig is after P. Preuss, ref. 13, axes labels modified)

Thermodynamically,

$$dE/dV = (dQ/dV) - P = + \quad (11)$$

that is, Q is no longer zero. the expansion has become non-adiabatic. This means an ingress of energy from outside the universe. Thermodynamics leaves the possibility that the accelerated expansion of the universe could occur with an “injection” or “leak” of energy from outside the universe, if it is open. However, there is no evidence at the present time that “something” exists outside the universe to support this. Thus, we take the universe to be closed and the expansion must remain adiabatic. Thermodynamics then demands that for the accelerated expansion to continue; the Pressure, P , in equation (11) must be negative. It is interesting to note that this is just

what is required by the Theory of Relativity and Friedmann's equation (equation 4). It is also the negative pressure associated with Dark Energy. This seems like a coincidence, but it is also required by the law of Conservation of Energy on which the Friedmann's equation is based [10]. It is important to note that the negative pressure cannot be taken as due to a repulsive form of gravity, as is often theorized.

We next try to answer the question of where the energy comes from to sustain the accelerated expansion by dark energy. The negative pressure means work is done on the system and energy is added to it. A likely source is the gravitational field through the action of gravity. The gravitational force is an attractive force. It exerts this force on all matter to clump together resulting in a decrease in gravitational potential energy, i.e., the negative potential energy becomes more negative. The gravitational energy lost in turn goes to increase the energy of space and the expansion to accelerate. A simple analogy is to imagine a rubber hose filled with running water. Squeezing the hose momentarily shrinks its diameter and causes water to squirt out. Fig. 6A shows schematically the state of the universe during the period of deceleration ($5-7 \times 10^9$ yrs) in the matter dominated epoch. Consider the cosmic fluid flowing through a tube (dash lines) within the universe. The Hubble flow (HF) is slowing down. The pressure of the universe is outward ($P_s=+$) due to the inherent property of space (the spaceons) to expand into the Void; the slope dE/dV is negative (equation 7). In Fig 6B, at the transition point, the attractive force of gravity starts to dominate with a pressure inward ($P_g=-$); dE/dV becomes positive. In the process, the "cosmic fluid" contained in the tube is squeezed out much like that of the rubber hose. The fluid velocity or the Hubble flow increases, manifesting itself as an accelerated expansion of the universe.

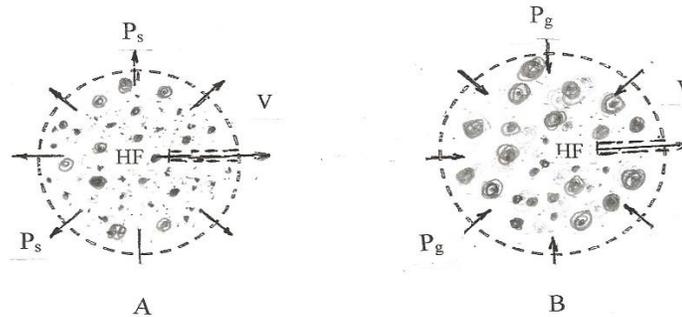


Fig 6. Schematic of the Universe during the period of deceleration (A) followed by acceleration (B); $P_s=+$, pressure due to space; $P_g=-$, pressure due to gravitational force; HF= Hubble flow; V = Void

During the expansion of the universe, following the Big Bang, matter (mostly atomic H gas) proceeded to consolidate and clump together to form stars, galaxies, clusters, and superclusters. Through the action of gravity they eventually form black holes and other massive compact objects. These grow by mergers and accretion of nearby materials (gas, dust, etc) which get compressed by gravity resulting in ever smaller volume of matter whose size approaches infinite density, i.e., a Black Hole. Chapline [18] has questioned the reality of Black Holes and proposed an alternative theory where matter infalling into the event horizon, undergoes a phase transition into dark energy [19]. The theory resolves questions associated with black holes, one of which is the loss of information when matter is swallowed by the black hole singularity. It also explains other cosmic phenomena not explained by black holes. He suggested the name "Dark Energy Stars" for Black Holes. Likewise, Mazur and Mottola [20], as well as Barcelo, et al [21], have proposed similar theories and suggested the name Gravastars and Black Stars respectively. Rovelli et al [23,24],

used Loop Quantum Gravity to show that a singularity can be prevented via a “big bounce” mechanism by which the gravitational pressure acting on matter is balanced by an opposite degeneracy-like pressure of the core. The latter eventually explodes, releasing energy and hence the information it contains; this solves the information loss paradox.

We do not really know the real state of matter in Planck stars, but we surmise that further compression by gravity should ultimately transform “particulate” matter to spaceons (dark energy), per the theories of Chapline [19] and Barcelo, et al [22]. We will adopt a hybrid model incorporating features of the models of Chapline, Barcelo et al and Rovelli and use the name “Quantum Stars”. We also propose to call the singularity as “Space Well”; they are more appropriate descriptive names and avoid confusion. In any case, Black Holes or Quantum Stars will have an “equivalent mass-energy” of M . The gravitational potential energy of the universe becomes more negative due to much greater “masses” of the clumped massive compact objects vs H atoms. One can calculate the total gravitational potential energy change between the present time t_p and that at the time of transition, t_r , at the beginning of the accelerated expansion (7.25×10^9 years), for all pairs of compact objects (“masses”) in the universe. The total energy at the present time, t_p , is

$$U_p = -G [M_i M_j / R + m_k m_l / r + M_i m_k / s + \dots], \quad (12)$$

summed over pairs of all other masses, $m_{i,j,k,l,\dots}$ (atoms, stars, etc) and Quantum Stars, other compact object, etc, $M_{i,j,k,l,\dots}$ in the universe; R, r, s, \dots are their respective distances of pair separation. Similarly, we can calculate the total potential energy just before the transition time, t_r , to give U_r . The difference in potential energy, $\Delta U = U_p - U_r$, provides the energy that feed the further expansion of the universe. The calculation is unwieldy and is best done by simulation techniques.

Our proposed mechanism is confirmed by observations on the merger of 2 black holes or neutron stars. As the two massive bodies come together, their distance of separation decreases and in the process gravitational energy is released as gravitational waves [25]. This can be thought of as the perturbation of space that increases its energy and accelerates the expansion of the universe. Both of the above are consistent with the observed increase in internal energy vs time (slope, $dE/dt = +$) shown in Fig.5.

4. ON THE NATURE OF DARK MATTER

We discuss the other component of our invisible universe, i.e., dark matter. Dark matter [25] comprises 84% of the total mass of matter in the universe. At present, it makes up 24% of the total mass-energy of the universe. It remains a mysterious, hypothetical form of matter. Its known characteristics match well those of a component present in our Phase Diagram (Fig.1). Among properties that have been reported in the literature are:

- 1). it neither emits or absorbs electromagnetic radiation, hence it is difficult to study.
- 2). it moves without friction.
- 3). it can only be detected through its gravitational effects on the motion of galaxies.
- 4). it is spread over large areas, like a cloud, and forms a “halo” around galaxies and clusters; its density decreasing as one moves away from the center [26].
- 5). it is also found in filaments between galaxies and clusters [27]. It has been observed that ordinary matter traces the path of dark matter in these filaments; this has been attributed to a strong

interaction between ordinary matter and dark matter. The search for the mediator of this interaction, thought to be the Z' boson, is being pursued actively [28].

We proceed with the premise that all components of the universe were formed during cosmic evolution and would have left their footprints in the sands of time, e.g, the CMB as a relic of the recombination or photon epoch. Table I and the phase diagram (Fig.1) show that the major phases in the formation of the universe are dark energy, baryonic or ordinary matter (gasses, solids), dark matter, and plasma. Any present-day component of the universe must have originated from one of these phases.

It can be seen from the plot in Fig. 2 that from the period of recombination (t_{rec}) until after reionization (t_{reion}), the main constituent of the universe is Dark Matter. This corresponds to the period during which plasma existed (Table II). From Fig.1, it can also be seen that the major phase present following nucleosynthesis is a plasma form of matter, i.e., H^+ , He^+ and free electrons. At this time the universe was opaque due to scattering of photons by free electrons and protons.

WMAP data (Table I), show that dark matter constitutes the major component of the universe soon after the Big Bang. During this time, the universe consisted of a hot plasma of electrons, and ionized H and He. It was opaque and cannot emit or absorb light. This state persisted until about 380,000 years after the Big Bang at which time recombination took place and the universe became transparent.

We thus see a strong correlation between Dark Matter and the plasma phase. The following additional facts on the properties of plasma [29] and those observed for Dark Matter support this:

a). Plasma, like dark matter, hangs around like a cosmic fog around galaxies and clusters, making it invisible and difficult to characterize.

b). That ordinary matter traces the path of dark matter is due to the fact that upon recombination of electrons and positive ions in the dark matter plasma, ordinary matter is formed; the plasma evaporates into H and He gasses. Thus ordinary matter follows the trail of dark matter (5 above).

c). Filamentation is a characteristic of plasmas; they move without friction, since the ions do not have attractive interaction and move collectively instead [29]. This lack of interaction also explains the origin of dark matter halos [26,30,31] that hover around galaxies for a long time.

d). The dark matter plasma scatters elastically and hence do not clump or “stick together” thus remaining diffuse, fluffy, and “halo-like”. Hence, galaxies cannot form directly from dark matter.

It appears reasonable to make the assignment that dark matter corresponds to the Plasma that existed during the photon epoch. Thus, we can replace the Dark Matter in the phase diagram by Plasma. Plasma is the major form of matter in the universe [29], most of it is invisible and dispersed throughout. Our contention could use further experimental verification. There is dearth of work along this line but it could be a fruitful avenue for further experimental work.

Energy exchange between the dark matter plasma and the surrounding hydrogen has been observed to provide a mechanism for energy exchange between the two states of matter [30]. This is consistent with (b) above. The study of the enhanced recombination processes in astrophysical plasmas [31] is yielding interesting results that lend support to our theory of the origin of Dark Matter. Dark matter being a plasma form of matter seems closer to reality than exotic particles, like WIMPS, MACHOS, etc. [32] whose existence have yet to be demonstrated.

5. CONCLUSIONS

A physico-chemical approach, using a Quantum Space model and thermodynamics, appears useful in understanding the expansion and composition of our dark universe. Dark energy is the energy of space and the cosmic fluid that is the component of the universe responsible for its expansion. It maybe thought of as a scalar space field, dubbed as Quintessence. Dark matter, on the other hand, is a plasma form of matter, similar to the state of the universe at the photon epoch, before recombination and during reionization. Dark energy and dark matter are neither “dark” nor “mysterious”, they are just invisible; one is transparent, while the other is opaque. Further work is necessary to better understand the nature and properties of the quantum space field and spaceons. The study of astrophysical plasmas would be a good way to further understand the nature of dark matter. The Theory of Inflation appears unnecessary to produce a homogeneous and isotropic universe; the continuity of space assures these. Finally, thermodynamics indicates that the acceleration in expansion of our universe is not due to a repulsive form of gravity. It requires the universe to be closed and the expansion adiabatic with a negative pressure as is necessary for energy conservation, consistent with the Theory of General Relativity and Friedmann’s equation. We provide a mechanism to explain the acceleration in Hubble Flow as due to the decrease in gravitational potential energy of the universe resulting from the clumping and consolidation of matter; this feeds back to the energy of space and accelerate the expansion. Our Quantum Space model fits well the behavior of the observable universe, from birth to death (the latter to be the subject of a future publication). It sheds light on the “mysteries” of our dark universe. It may further be amenable to the methods of Quantum Field Theory and be useful in unifying quantum behavior and gravity.

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Figures

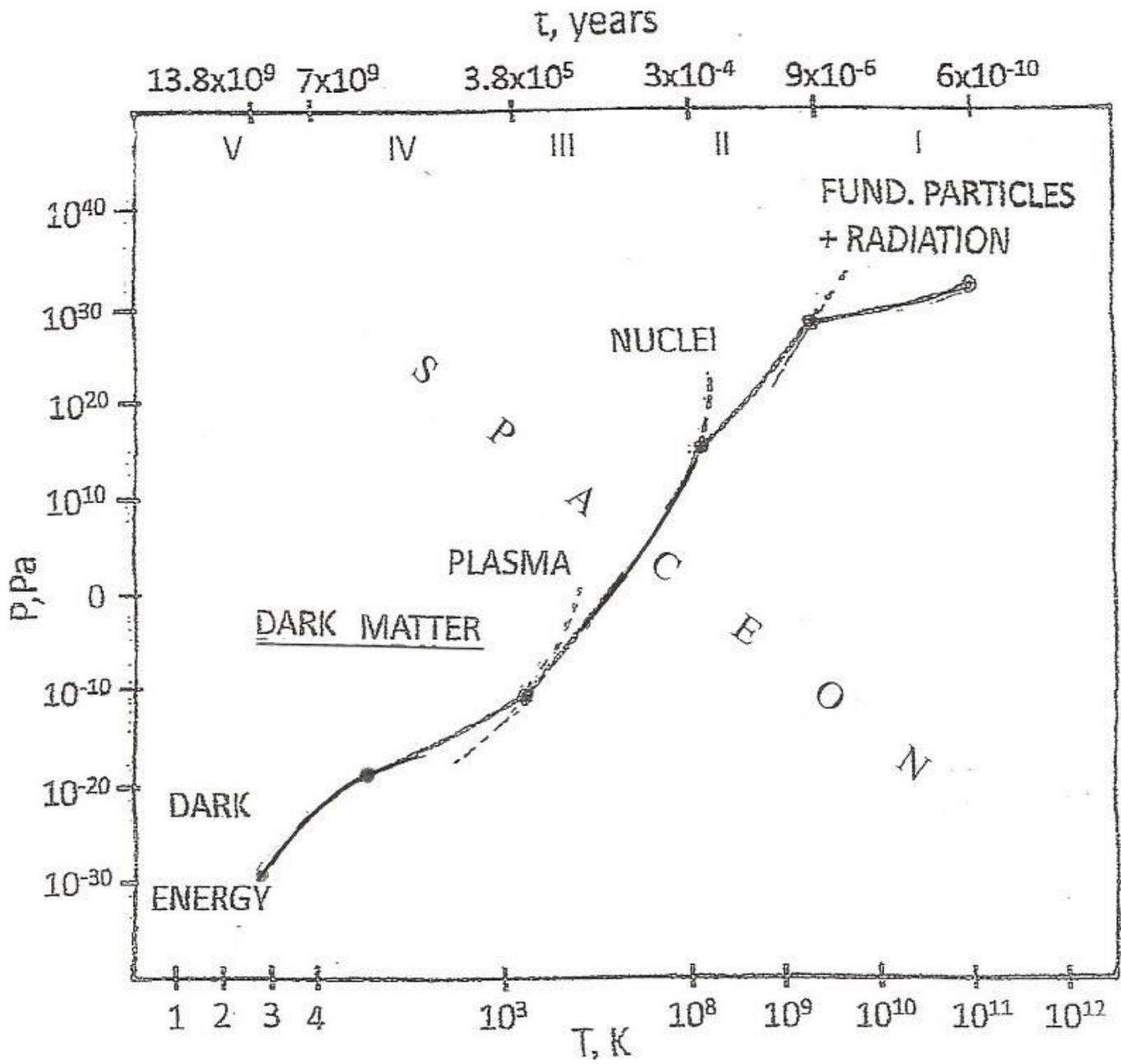


Figure 1

Schematic Phase Diagram of the Universe with Spaceons

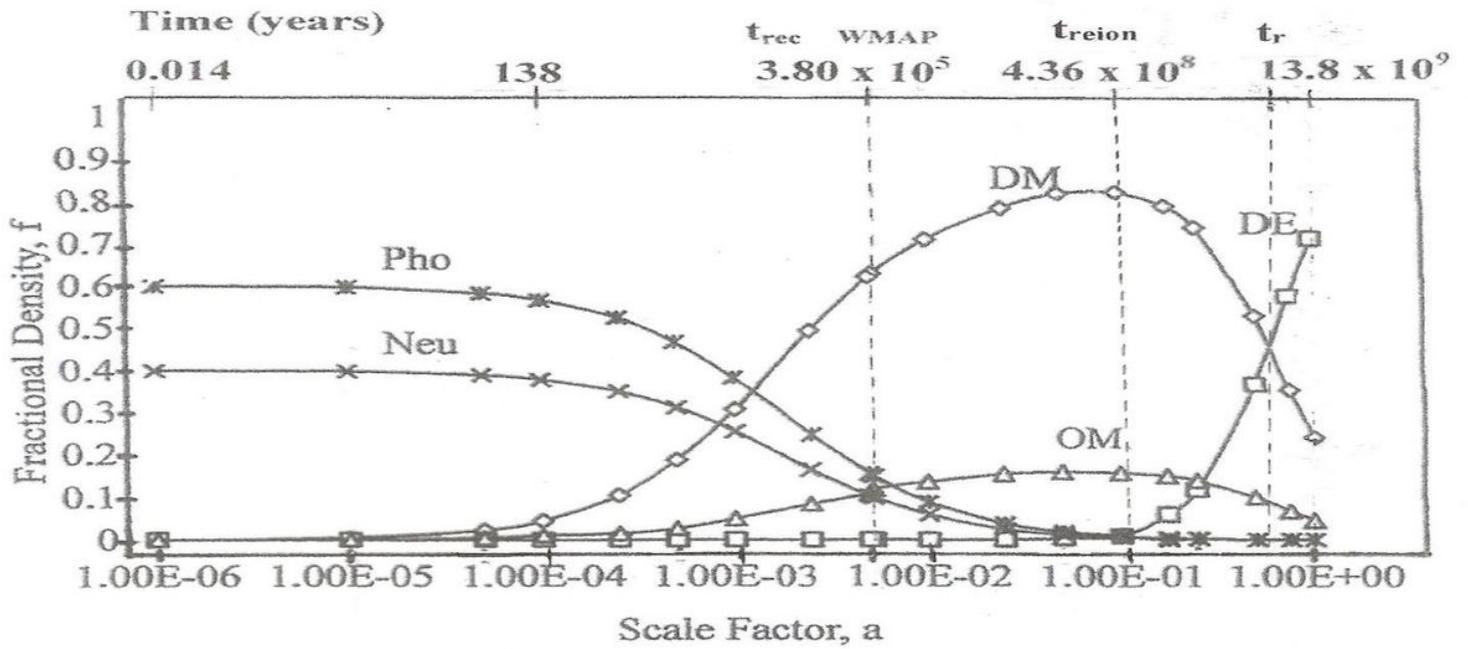


Figure 2

Fractional Energy Density (f) vs Scale Factor (a), fit with $w_s = -0.7$ DE-Dark Energy; DM-Dark Matter; OM-Ordinary Matter; Pho-Photons; Neu-Neutrinos

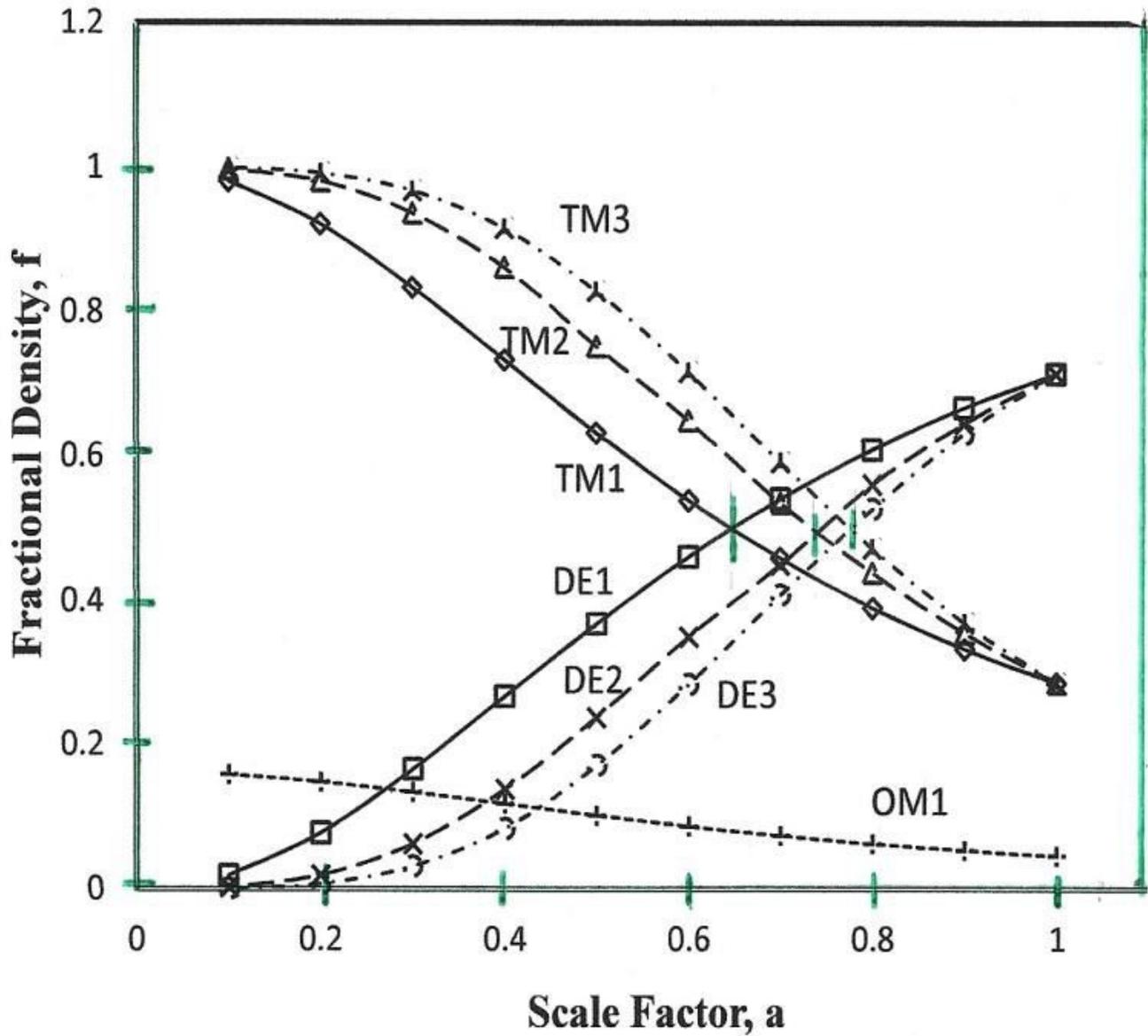


Figure 3

Fractional Energy Density (f) vs Scale Factor (a) DE1- Dark Energy;; DM1-Dark Matter; OM1-Ordinary Matter; TM1- Total Matter for $w_s = -0.7$; DE2, TM2 for fit with cosmological constant, $w = -1$; TM3, DE3-for fit with Phantom Energy model, $w = -1.2$

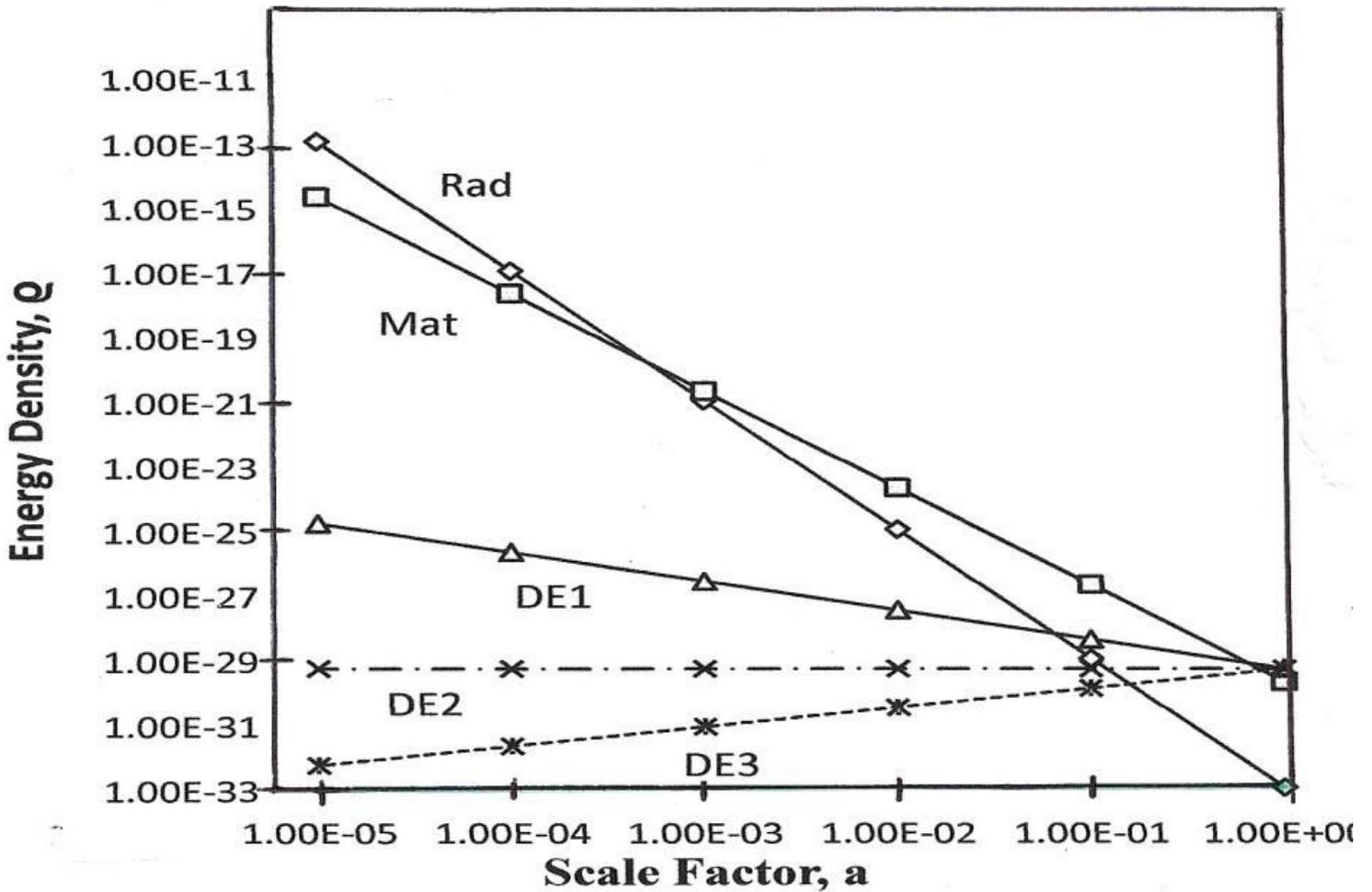


Figure 4

Energy Densities (ρ , g/cm^3) vs Scale Factor (a) for 3 models of Dark Energy; Rad-total radiation; Mat-total matter; DE1-Dark Energy with $w = -0.7$; DE2- $w = -1.0$ (Cosmological Constant); DE3- $w = -1.2$ (Phantom Energy Model)

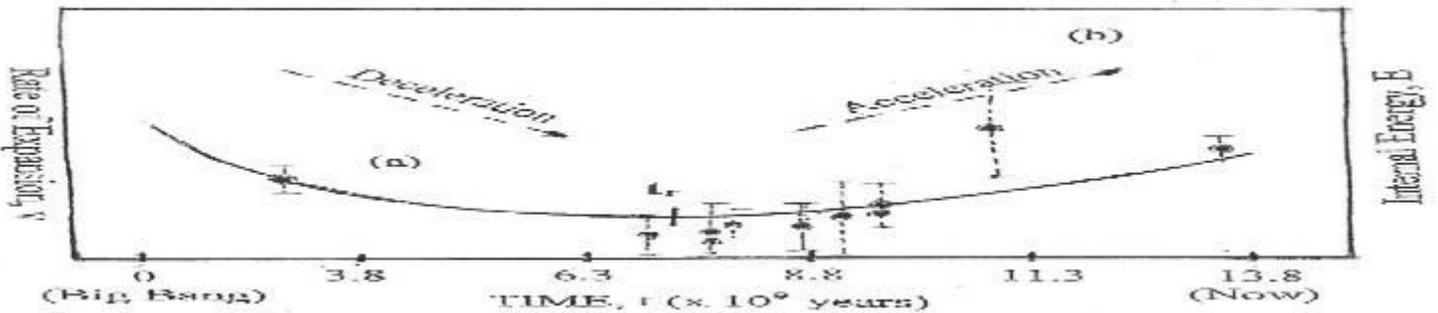


Figure 5

Rate of Expansion of the Universe as a Function of Time (t) (t_r -transition time from deceleration (a) to acceleration (b) (Right Ordinate) Schematic change in internal energy, E , with time; slope = dE/dt) (Fig is after P. Preuss, ref. 13, axes labels modified)

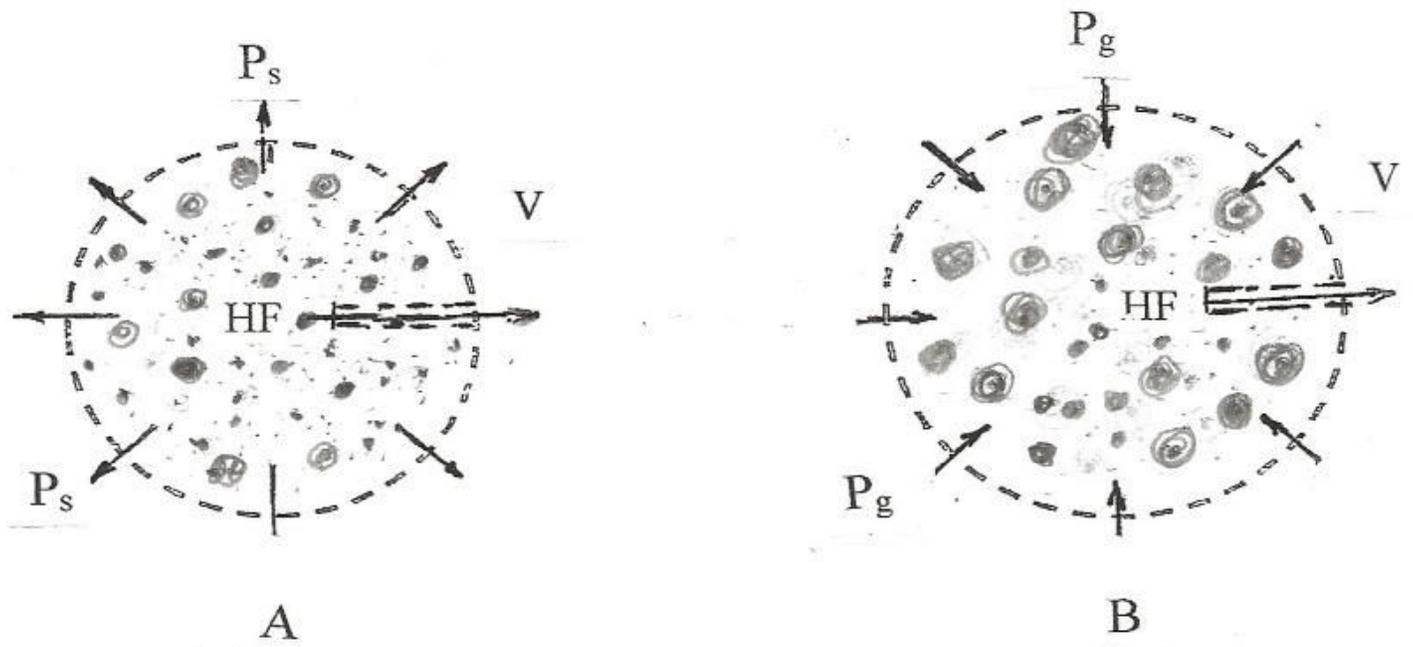


Figure 6

Schematic of the Universe during the period of deceleration (A) followed by acceleration (B); $P_s = +$, pressure due to space; $P_g = -$, pressure due to gravitational force; HF = Hubble flow; V = Void